THE ADOPTION OF SMART CHARGING IN POSITIVE ENERGY DISTRICTS

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Abstract

This doctoral thesis investigates the adoption of EV charging infrastructure equipped with smart charging technology, such as V1G or V2G, within Positive Energy District (PED) projects. In 2018, the European Union's Strategic Energy Technology Plan (SET-Plan) set a goal to develop 100 PEDs in Europe by 2025 as part of energy transition actions. PEDs refer to energy-efficient urban areas that aim to achieve an annual energy surplus production from renewable sources compared to energy consumption.

As the development of PEDs has started only relatively recently, there is a lack of understanding and empirical evidence regarding their design, decision-making processes for low-carbon technology choices, and implementation activities. This thesis addresses this gap by examining the role of EV charging infrastructure equipped with smart charging technology within PEDs, investigating the reasons for its adoption or non-adoption, and identifying the key factors that influence these decisions.

The study employs a theory-driven thematic analysis, delving into multiple data sources, including semi-structured interviews, participant observations during secondments and field study, national policy documents, and project reports. The two in-depth case studies were analysed and validated by comparing the results with an additional ten PED projects, based on project deliverables and national policy documents, to assess the generalisability and replicability of findings.

The study results in the development of the "Determinants of smart charging adoption in PEDs" framework, encompassing technological, organisational, and environmental dimensions: the perceived benefits of smart charging technology (technological context), enabling organisational capacity factors (organisational context), and supporting policy drivers (environmental context). The framework encapsulates the factors influencing the adoption of smart charging in the context of PED projects.

The results of the study reveal that the majority of PED projects (10 out of 12) have adopted EV charging infrastructure, but only half of these (5 out of 10) have adopted EV charging infrastructure equipped with smart charging technology, particularly V2G. Key drivers of the adoption of smart charging technology in PED projects include the availability of large multidisciplinary collaborations, the existence of an energy flexibility goal, EU or government funding, and supportive policy and market frameworks.

The study underscores the role of PED projects as contributors to best practice in low-carbon technologies and emphasises the importance of their impact in addressing Net Zero. Nevertheless, as only five out of twelve PED projects have adopted smart charging, there are still lessons to be learned to ensure PEDs deliver on all of their potential. The study holds implications for PED developers and policymakers, informing strategies to facilitate the adoption of smart charging within the PEDs context to enhance the role and initiatives of PEDs projects in meeting energy transition goals.

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List of Abbreviations

Abbreviation	**Meaning**
CSO	Community System Operator
DIO	Diffusion of Innovation Model
DSO	Distribution System Operator
DTPB	Decomposed Theory of Planned Behaviour
EC	European Commission
EPBD	Energy Performance of Buildings Directive
ETT	Energy Transition Tracks
EV	Electric Vehicle
ICT	Information and Communication Technology
IOS	Inter-Organisational System Model
JPI	Joint Programming Initiative
LFM	Local Flexibility Markets
NZEB	Nearly Zero Energy Building
NZEN	Net zero energy neighbourhood
PEB	Positive Energy Block
RES	Renewable Energy Sources
PED	Positive Energy District
P2P	Peer to Peer
TAM	Technology Acceptance Model
TOE	Technology-organisation-environment
TPB	Theory of Planned Behaviour
TTF	Task Technology Fit Model
V1G	Vehicle One Grid
V2G	Vehicle Two Grid
V2X	Vehicle to Everything
V2H	Vehicle to House
V2B	Vehicle to Building
V2GO	Vehicle-to-Grid Oxford
ZEC	Zero energy community
ZED	Zero energy district

Chapter 1 Introduction

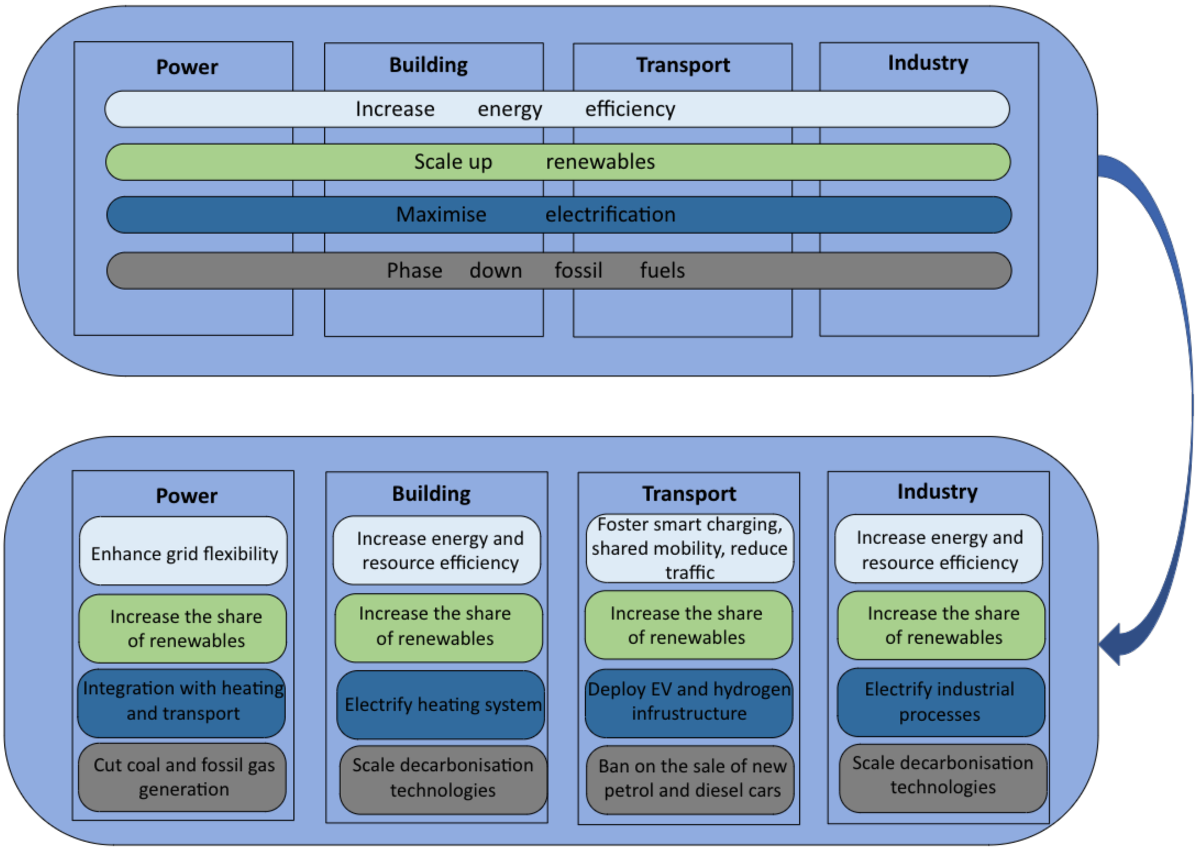
1.1 Background and Context of the Problem

In line with the Paris Agreement, over a hundred countries worldwide have committed to becoming climate-neutral and achieving “Net zero” greenhouse gas emissions by 2050 (Net Zero Tracker 2023). To progress towards a Net Zero future, countries have set out emission reduction targets and strategies to achieve them in the coming decades. The goals and strategies vary across countries, reflecting the contextual dynamics of individual regions. This thesis focuses on Europe, a frontrunner in climate action.

The agenda of the EU’s energy transition policy initiatives includes the European Green Deal, which aims for Europe to become the first climate-neutral continent by 2050, and the Fit for 55 Plan, which sets requirements to reduce emissions by 55% by 2030 compared to 1990 (European Commission 2023a). These policy initiatives focus on the development of clean technology facilitating the energy transition (Directive (EU) 2023/1791).

The EU’s energy transition policy initiatives focus on decarbonising four energy sectors: power, buildings, transport, and industry (Agora Energiewende 2019; European Commission 2023; COM(2019) 640 final; Directive (EU) 2023/17913; Directive 2010/31/EU; Regulation (EU) 2023/851). EU legislation emphasises four approaches that sectors need to follow: (1) enhancing energy efficiency, (2) scaling up renewables, (3) electrifying nearly everything, and (4) reducing the use of fossil fuels, as illustrated in Figure 1. The sectors prioritise energy efficiency and consider it a fundamental principle in all energy policy and investment decisions, with a general aim to increase it by 11.7% by 2030 compared to the projections of the 2020 EU Reference Scenario (European Commission 2023b). Furthermore, the sectors aim to increase the use of Renewable Energy Sources (RES), electrify heating and transport systems, and reduce the use of fossil fuels.

Figure 1 EU energy transition strategies for the energy sectors by 2030



Sources: Own illustration. Elaborated from Agora Energiewende 2019; Directive (EU) 2023/1791; Directive 2010/31/EU; European Commission 2023; COM(2019) 640 final; Regulation (EU) 2023/851

An implementation plan for addressing these initiatives across the EU, Iceland, Norway, Switzerland, Turkey, and the UK was established within the European Strategic Energy Technology Plan (SET Plan) (European Commission 2018; European Commission n.d.). One initiative of the SET-Plan is the introduction of the Programme on Positive Energy Districts (PEDs) and Neighbourhoods. Since 2018, this Programme has aimed to create 100 PEDs in Europe by 2025 and adopt various low-carbon technologies (JPI Urban Europe 2018). Currently, there are 20 European countries participating in the development of PEDs: Austria, Switzerland, France, Italy, the Netherlands, Sweden, Portugal, Romania, Turkey, Belgium, Denmark, Finland, Latvia, Norway, Spain, Cyprus, Czech Republic, Germany, Slovakia, and the United Kingdom (JPI Urban Europe n.d.).

Specifically, PEDs are defined as follows:

> "energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility, and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability" (JPI Urban Europe 2020, p.4).

According to the PED definition, along with buildings and the Information and Communication Technology (ICT) systems, the development of mobility is an important component of the Programme on PEDs. Mobility represents one of the largest energy-consuming and polluting sectors (International Energy Agency 2023c). Decarbonising mobility through the transition from internal combustion engines (ICE) to low emission vehicles such as electric vehicles (EVs) is one of the cornerstones of the Net Zero strategy (COM(2020) 789 final). The transition to EVs is supported by various regulatory approaches in the EU, including the ban on the sale of new petrol and diesel vehicles from 2035 (European Parliament 2022; Regulation (EU) 2023/851). The adoption of EVs in the EU is primarily framed by the Sustainable and Smart Mobility Strategy (COM(2020) 789 final) and the CO2 Emission Performance Standards for New Cars and Vans (Regulation (EU) 2023/851).

The integration of various energy systems is also underlined as part of the Programme on PEDs (JPI Urban Europe 2020a; JPI Urban Europe 2020b). An example of systems integration is the coupling of e-mobility with the power system through the adoption of smart charging technologies such as unidirectional smart charging (V1G) and bidirectional smart charging (V2G) (Ali 2023; Ilo et al. 2022; Pinto et al. 2022). In general, EV charging infrastructure is distinguished by two charging strategies: uncontrollable/uncoordinated and controllable/coordinated/smart (Nimalsiri et al. 2022; Vaidya and Mouftah 2020).

Uncontrollable EV charging refers to charging that might occur at any time, regardless of energy demand. This type of charging has a high potential to cause significant peak demands and negatively impact reliability and resilience of the electricity network (Lacey et al. 2017; Gonzalez et al. 2021). In contrast, controllable or smart charging is widely recognised for its positive impacts on the energy system (Blumberg et al. 2022). Depending on the type of embedded smart charging technology, EVs can provide demand response (both V1G and V2G) or energy storage services (V2G) to the optimisation of the grid operation. A number of studies emphasise the benefits of the use of both types of smart charging, due to their contribution to the reduction of grid congestion by alleviating the potential negative effects on power grids (Bjørndal et al. 2023; Tirunagari et al. 2022).

The acknowledgement and significance of the adoption of smart charging infrastructure in the EU is highlighted in the Report "Promotion of e-mobility through buildings policy" (COM(2023) 76 final, p.1), outlining:

> "Smart unidirectional and bidirectional charging of EVs can significantly increase the flexibility and cost-effectiveness of the electricity system and contribute to a higher level of variable renewable electricity generation within the energy mix. Moreover, smart charging contributes to the optimisation of electricity grids thanks to flexibility services provided directly by EV users or through aggregators. It will also stimulate innovation and digitalisation in the context of smart homes".

The report proposes addressing the lack of requirements for the adoption of V1G and, where appropriate V2G, by introducing the necessity of enabling EV charging infrastructure with smart charging technology as the norm for all new buildings and buildings undergoing major renovation within the Energy Performance of Buildings Directive (EPBD) (COM(2023) 76 final). The recently adopted EPBD (Directive (EU) 2024/1275, p.9) also supports the uptake of V1G and, where appropriate V2G, stating:

> "Smart recharging and bi-directional recharging enable the energy system integration of buildings. Recharging points where electric vehicles typically park for extended periods of time, such as where people park for reasons of residence or employment, are highly relevant to energy system integration, therefore smart recharging functionalities need to be ensured. In situations where bi-directional recharging would assist further penetration of renewable electricity by electric vehicle fleets in transport and the electricity system in general, such functionality should also be made available".

This underscores the importance of gaining a better understanding of the current adoption process of smart charging infrastructure and the factors influencing its spread to support policy making. The adoption of smart charging is expected to considerably enhance grid flexibility, support renewable energy integration, and improve cost-effectiveness, while also addressing key energy transition challenges associated with the electrification of heating and transport and the wider deployment of RES.

In the EU, electricity demand, due to the electrification is forecast to double from today's level by 2050, requiring time-consuming and costly grid reinforcements (Khomami et al. 2020; International Energy Agency 2023a). In addition, as the sun does not shine all the time, nor does the wind blow continuously, RESs, such as solar and wind, pose stability challenges to the grid due to their intermittent generation (Papaefthymiou et al. 2014; Jacobs 2020). The timing difference between renewable energy generation and demand peak periods may cause imbalances between energy supply and demand (Sheha et al. 2020; Nguyen et al. 2014; Gaur et al. 2019), leading to severe grid faults, such as network congestion, voltage drops, or energy outages, the resolution of which will require grid reinforcements (Khomami et al. 2020).

European Commission (2023c) estimates that capital expenditures on grid reinforcement might reach €584 billion by 2050. For example, in Germany, according to the current Network Development Plan (NDP), the investments requirements for grid enhancement are estimated to be about €62 billion over the period up to 2030 (Schreiner and Madlener 2021). To minimise grid reinforcement investments, the power sector aims to enhance grid flexibility, defined as "the capability of the energy system to absorb disturbances sufficiently fast to maintain stability" (Lechl et al. 2023, p.1). Grid flexibility is widely considered a critical alternative option to grid reinforcement through the use of energy storage and demand response mechanisms (IEA 2021; Klyapovskiy et al. 2019; Lever et al. 2021). One solution for enhancing grid flexibility is the integration of the power sector with the transport sector, through the adoption of EV charging infrastructure equipped with smart charging technology (International Energy Agency 2022).

The need in addressing a lack of knowledge on PED initiatives, including concerning the adoption of smart charging, is highlighted in a range of literature. For example, the need for data and the development of monitoring methodologies in PED experiences is emphasised in a Technical Report on "Enabling PEDs across Europe" (JRC 2020). The need to evaluate the planning and decision-making processes in relation to PEDs' outcomes are emphasised by (Krangsås et al. (2021, p.13), noting that "time and external factors, have been largely overlooked". Some literature highlights that due to the novelty and limited practical experience of PED projects, there is a lack of knowledge regarding their technology adoption processes including,in particular, smart charging adoption (Derkenbaeva et al. 2022; Hedman et al. 2021; Sassenou et al. 2024).

Considering that PEDs are a recent concept and that there are no studies analysing the adoption process of smart charging infrastructure within PED projects (Derkenbaeva et al. 2022), there is a need for research into PEDs' technological interventions, particularly regarding smart charging adoption, decision-making processes, and effects. This thesis aims to contribute to these gaps by focusing specifically on the exploration of the adoption of smart charging in emerging PED projects, which serve as a policy instrument in addressing the energy transition in Europe.

1.2 Problem Definition

Limited research into the contribution of emerging PED projects to energy transition actions, in combination with a limited understanding of the factors influencing their decisions on technological interventions, including the adoption of EV charging infrastructure equipped with smart charging technology, creates a need for studies investigating why and how PED projects can adopt smart charging technology. Additionally, the lack of research investigating the adoption of smart charging at a collective level allows this thesis to address several gaps at once.

This study investigates the experiences of PED projects in both adopting or not adopting smart charging, as well as seeking to understand the organisational and political contexts of PED projects concerning the adoption of smart charging within the energy transition pathway in various regions across Europe.

1.3 Research Aim and Objectives

This study aims to examine the role of EV charging infrastructure equipped with smart charging technology within PEDs, investigate the reasons for its adoption or non-adoption, and identify the key factors that influence these decisions. PED projects are designed to address the decentralisation of the energy system by integrating a large number of renewable technologies, whilst also promoting lower energy demand by minimising energy waste in buildings, transport, and infrastructure. The reduction of unnecessary energy consumption or inefficient use of surplus renewable energy can be achieved through the incorporation of technologies that improve energy efficiency. Since EV charging infrastructure equipped with smart charging technology is an innovative solution developed to enhance grid operations, including by supporting the deployment of renewables, this study explores how PED projects view the technology and what role it may play in decentralised energy systems. To achieve this aim, three objectives are set out:

1. Define the role of EV charging infrastructure equipped with smart charging technology within PEDs.
2. Investigate enablers and barriers of the adoption of EV charging infrastructure equipped with smart charging technology in PED projects across three dimensions: technological, organisational, and policy-related factors.
3. Develop a framework to support decision-makers in integrating EV smart charging technology into PED projects, facilitating the decentralisation of the energy system.

The key research question directing this thesis is:

1. What are the key drivers of smart charging adoption in PEDs from technological, organisational and policy perspectives?

This is then divided into three targeted sub-questions, each addressing a specific perspective:

1. *Technological:* What is the role of smart charging technology in PEDs?
2. *Organisational:* What organisational characteristics of PEDs can influence the adoption of smart charging technology?
3. *Policy:* What role does policy play in the adoption of smart charging in PEDs and how can policymakers be supported in this?

Given that the energy transition is a systems-level problem in which policy frameworks play an important role in promoting the deployment of technological infrastructures, this study examines various national visions for smart charging and their potential impacts on PEDs' decisions regarding the adoption of the technology.

1.4 Methodology

As outlined earlier, PED projects have been developing relatively recently, and there is a lack of studies evaluating their organisational characteristics and perspectives in relation to the adoption of smart charging technology. There is a range of theories and frameworks studying technology adoption, as discussed in Chapter 2 Section 2.6, which explore internal and external contexts within individuals or organisations. This research adopts the Technology-Organisation-Environment (TOE) conceptual framework, developed by Tornatzky and Fleischer (1990), to investigate the factors influencing the adoption of smart charging in PED projects.

This research employs a theory driven thematic analysis, delving into multiple data sources, including participant observations during secondments and field-study trips, semi-structured interviews, national policy documents, and project deliverables (see below). In-depth multiple case studies are conducted to explore the process of the adoption or non-adoption of EV charging infrastructure equipped with smart charging across two PED projects, namely Pocityf and Smart Energy Åland. The case studies are selected from the PED booklet (JPI Urban Europe 2020a) based on three criteria: 1) stating the aim in the PED booklet to implement smart charging; 2) illustrating diverse internal (organisational) contexts; and 3) showcasing various external (country) contexts.

A major part of the research is framed by the Smart-BEEjS project, which was part of the Marie Skłodowska-Curie Innovative Training Network programme, ending in 2022. The Smart-BEEjS project focused on studying PEDs in their goal to generate more energy than they use. Numerous activities were conducted as part of the Smart-BEEjS project framework. This research has been influenced notably by a six month secondment undertaken at the not-for-profit research technology organisation and consultancy, Cenex. During this secondment, active participation was involved in the planning and design stages of the GreenSCIES project, specifically encompassing the evaluation of energy policies concerning the barriers and drivers for the implementation of various technologies, including smart charging. The project focused on the plan to adopt 49 smart chargers (34 V1G and 15 V2G) in the London Borough of Islington to contribute to its transformation into a net-zero carbon district.

1.5 Outline of the Thesis

This thesis is organised into six chapters, each designed to contribute to an investigation of the adoption process of smart charging in PEDs in the development of energy transition actions in Europe.

Chapter 1 sets the scene by outlining the EU energy transition strategies aimed at decarbonising energy sectors and the recent Programme on PEDs developed as an instrument to address these strategies. The chapter then defines the requirements of the PED concept, which include the decarbonisation of mobility and the implementation of sector coupling. Limited knowledge on integrating e-mobility with the power system through embedding EV charging infrastructure with smart charging technology in PEDs is outlined, along with the research aim, objectives, research questions, and an overview of the methodology.

Chapter 2 explores the literature contributing to understanding the PED concept and the factors influencing the adoption of smart charging. The chapter provides an overview of the literature exploring the adoption of smart charging and the theoretical frameworks utilised to analyse technology adoption, which both informed the employment and adaptation of the TOE framework for this research. Research gaps in current knowledge are also discussed.

Chapter 3 presents the methodology employed in this thesis, explaining the research design, data collection methods, participant selection, analysis process, and the process of generalisation of findings. The chapter also discusses the ontological and epistemological foundations aligned with the TOE framework. A theory-driven reflexive thematic analysis is detailed, explaining how its logic and tools aided in developing the resulting theory.

Chapter 4 presents the findings derived from interviews, active participant observation, the two in-depth PED case studies and, in the context of the generalisation of findings, ten additional PED projects. Three overarching themes aligned with the TOE framework are presented, offering insights into the determinants of the adoption of smart charging in PEDs.

Chapter 5 offers a summary of the developed framework and a discussion of the research findings within the broader literature on the adoption of smart charging, thereby contributing to the discourse on this topic. This chapter also offers policy recommendations for PED developers and policymakers.

Chapter 6 summarises the main results, with an emphasis on how they could facilitate the development of PEDs. The chapter points out the contribution of the work, discusses research limitations, and suggests prospective avenues for future research.

1.6 Chapter Summary

This chapter presents background information explaining the need for research regarding the adoption of smart charging in PEDs. Documents discussing the development of the PED framework, including a Technical Report on "Enabling PEDs across Europe" (JRC 2020), highlight the need in studying PED experiences. The Report "Promotion of e-mobility through buildings policy" (COM(2023) 76 final) emphasises the significance of the adoption of smart charging infrastructure in the EU and the plan to introduce the technology as the norm within new or renovated buildings. There is currently a lack of evidence and research exploring the technology adoption processes in PEDs, including regarding smart charging.

A theory-driven reflexive thematic analysis was envisioned to study smart charging adoption across PED projects. The study aims to explore the experiences of PED projects to identify the determinants of smart charging adoption in PEDs. Finally, the chapter outlines the structure of the thesis.

Chapter 2 Literature Review

2.1 Introduction to the Chapter

While there is a growing body of research on emerging smart charging technology, especially examining the potential impacts of V2G on the energy grid, there is a need to understand how and why the technology is adopted, particularly in the context of PEDs. The distinct concept and functions of PEDs may impact their technology adoption strategies and the way they address climate actions. Therefore, this chapter aims to provide the context to the study by investigating what is known about PEDs, the technologies they adopt, and in particular smart charging technology adoption.

A theory-driven reflexive thematic analysis research design involves the utilisation of a conceptual framework. The approach aims to achieve a “middle-ground” by combining the advantages of a priori theorising with the opportunity for new theories to emerge (Casula et al. 2021). Hence, this literature review also investigates how smart charging has been explored in existing literature, what factors may influence its adoption, and presents existing conceptual frameworks and factors traditionally investigated in technology adoption literature. The chapter is organised into several sections.

The chapter begins with definitions of two central terms of this study: ‘positive energy districts’ and ‘smart charging’. This section defines key functions, elements, and requirements for PEDs and identifies factors that facilitate the adoption of smart charging.

The second part presents an overview of studies on smart charging adoption, discussing methods and factors studied in the existing literature.

The following section discusses what is already known about the adoption of smart charging in PEDs. This section identifies the PED projects that aim to implement EV charging infrastructure equipped with smart charging.

The literature review then delves into the theoretical frameworks on technology adoption. This section reviews factors examined in studying technology adoption, which has influenced the choice of using the TOE framework.

Finally, the chapter summarises the key points of the literature review, outlines the literature gaps, and explains the selection of the TOE framework guiding the research methodology.

2.2 Transitioning to Renewable Energy: Driving Decentralisation

In implementing decarbonisation and climate mitigation strategies, outlined in Section 1.1, low-carbon technologies and innovations are placed at the heart of net zero visions (European Commission, 2020a; UK Government, 2021). A key focus in these strategies is on the deployment of renewable and electrified technology across different sectors, including the electricity-generation and transport sectors (ibid).

In the electricity-generation sector, the transition from fossil fuel-based energy supply to renewable resources is growing rapidly and already makes up a significant share of generated electricity. In 2023, the EU's and UK's renewable electricity generation accounted for 46.4% and 45.3% respectively (Eurostat, 2024, Department for Energy Security and Net Zero 2024). However, to get on track for Net Zero 2050, further significant growth of the generating electricity rate from renewables is still required (European Environment Agency, 2021; BEIS 2022).

The large-scale adoption of renewable energy generation technologies entails a radical transformation of the energy system structure from centralised to decentralised, given the differences in energy flow between conventional fuel-based and renewable-based energy systems, and the capacity constraints of existing grid systems. In a conventional centralised energy system, energy is generated in large central fossil fuel based stations and has one-directional (top to bottom) energy flow. This structure involves, first, the transportation of energy from the power stations through transmission lines, and then energy supply to end-consumers through distribution lines (Surendra, 2018; Mittelviefhaus et al, 2022).

Historically, the centralised energy network was designed with the highest load capacity around the large generation plants that decreases with proximity to end users (Navon et al., 2020). Therefore, with peak loads or with an increase of renewable energy penetration the capacity issues generally arise in distribution lines, the solving of which requires time-consuming and costly reinforcement of energy networks (Energy Networks Association, 2019).

In a decentralised energy system, energy can be generated from one or more of numerous renewable energy sources (RESs) that have dynamic energy flow (Carbon Trust, 2013) and are located where the energy is to be used (Ueckerdt et al., 2015; Carpinelli, 2021). This location-specific feature offers technical advantages to the energy system, freeing RES from transmission line constraints that are frequently an issue of the centralised energy system (Cummins, 2021).

Nevertheless, since RES such as solar and wind fluctuate, are non-predictable, and non-dispatchable assets, a decentralised energy system faces challenges related to the mismatch between energy supply and demand, which can cause capacity issues in distribution lines (IRENA, 2018). This relates to the reason that the energy network was designed to support the centralised energy system and the existing load capacity of distribution lines is frequently insufficient to manage an increasing share of RESs.

Grid reinforcement can involve infrastructure investments for maintaining, upgrading, or building new grids, for which capital expenditures might reach hundreds of billions (bn) of pounds by 2050 (Klyapovskiy et al., 2019; Lever et al., 2021; BEIS, 2022). By some estimates, in the UK grid investments would need to be £35bn by 2031 (National Grid, 2024). In Germany, in the current Network Development Plan (NDP), grid enhancement investments are assessed to cost about €62 bn over the period to 2030 (NDP, 2019; Egenter et al. 2021). As grid investment costs will have to be paid by someone and more likely they will be spread not only between large utility companies and public funds but also with energy consumers, through the grid fee included in electricity bills, it is widely acknowledged that grid reinforcement will involve significant economic and social impacts (Toh, 2021). Therefore, alternative solutions to grid reinforcement, and the centralised generation system driving this, are required.

Matching supply and demand is called energy balancing, while "the ability to adjust supply and demand to achieve that energy balance" is called energy system flexibility (National Grid Electricity System Operator (ESO), 2020, p.1). To equilibrate the energy system, provision of additional flexibility is required to accommodate the increasing use of variable renewable energy sources. Energy system flexibility is expected to be one of the vital tools in reaching Net Zero carbon emissions around the globe (Catapult, 2020; Department for Business, Energy & Industrial Strategy (BEIS), 2022; European Commission, 2020a; European Commission, 2020b).

Definitions of flexibility are similar across countries. For example, in the UK, the energy regulator Ofgem defines flexibility as "modifying generation and/or consumption patterns in reaction to an external signal (such as a change in price) to provide a service within the energy system" (Ofgem, 2017). The European Commission, in proposing a new electricity market design that focuses specifically on demand side flexibility, defines it as “the ability of a customer (prosumer) to deviate from its normal electricity consumption (production) profile, in response to price signals or market incentives” (European Smart Grids Task Force, 2019, p.11).

Across the literature, flexibility can be categorised according to technical options and defined by types such as supply-side flexibility (e.g. building a new flexible power plant); demand-side flexibility (e.g. demand response programmes, sector coupling of power, heat and transport); flexibility from storage (battery energy storage systems (BESS), thermal storage, electrofuel storage); and grid infrastructure (e.g. transmission extension, distribution strengthening) (IRENA, 2018). Energy system flexibility measures involve the adoption of a high share of assets known as distributed energy resources (DERs), which are widely seen as a critical cost-efficient solution to grid reinforcement (Carbon Trust, 2016; BEIS, 2022). Estimates suggest that, in the UK, energy system flexibility measures have the potential to save up to £16.7 bn (Carbon Trust, 2021) or even £40-50bn (BEIS, 2022) on infrastructure investments annually.

DERs refer to small-scale modular technologies and energy efficiency and demand response mechanisms that can generate or store energy, or control energy loads and resources (IEA, 2021). They include assets such as wind turbines, PV, and combined heat and power (CHP) facilities, BESS and EVs (IEA, 2021; Pazouki et al., 2021). Nevertheless, there are many uncertainties regarding how to efficiently integrate DERs with the grid and how to incentivise energy users to invest in the right asset at the right location (Catapult, 2020; BEIS, 2022; European Commission, 2020a; European Commission, 2020b). Therefore, development strategies that enable flexibility solutions for the successful adoption of DERs are recognised across industry, academia and political institutions (ibid).

Since supplying energy to consumers involves not only energy system generation and operation functions but also the energy selling function, the adoption of DERs and flexibility solutions involve the development of strategies for electricity markets (Shammas, 2021). As mentioned above, the energy system generation and operation functions are different between centralised and decentralised energy systems, therefore, the selling function on electricity markets must also change.

This need arises because decentralised energy systems have a fundamentally different system architecture on governance and on a model of providing services compared to centralised energy systems (Adil and Ko, 2016; Ahlqvist et al. 2022). The current centralised energy system uses a cost-of-service model and is governed by monopoly utilities (Shenot et al. 2019). On the other hand, the emerging decentralised energy system uses a value-of-service procurement model that allows not only energy utility companies but also independent energy producers to provide energy and flexibility services (Shenot et al. 2019). This opens opportunities for consumers to sell electricity or provide energy system flexibility services through adopting DERs such as demand-response and storage assets (Directive (EU) 2019/944). Storage technologies play a crucial role in enhancing system flexibility by storing excess electricity, including renewable energy, and discharging it when needed to balance supply and demand (Shahzad and Jasinska, 2024). As a result, new business models and market participants are emerging in electricity markets, developing many ways of market designs (Bribois, 2020).

However, to date, emerging electricity market business models associated with the provision of flexibility by DERs are not economically viable, resulting in a low deployment of energy system flexibility solutions (Ziegler and Abdelkafi, 2022; Afentoulis et al., 2022; Cenex, 2022). In the EU and UK, electricity market reforms have been proposed to address the current lack of a regulatory framework supporting the development of energy system flexibility solutions. Hence energy regulators and public utility commissions worldwide are still seeking to understand how best to promote effective energy system flexibility solutions, particularly how to facilitate the development of innovative business models and how to better govern decentralised energy systems (Catapult, 2019; Cenex, 2022).

Meanwhile, electrified transport technologies, including charging infrastructure, are developing rapidly, allowing EV assets to contribute not only to the decarbonisation of the transportation sector but also to the electricity sector. Recent technology advancements, such as smart charging, allow EVs to benefit the energy system by delivering energy flexibility solutions (Blumberg et al, 2022).

Depending on the type of embedded smart charging technology, defined in more detail in Section 2.4, EVs can provide demand response or energy storage services, enhancing the optimisation of the grid operation (Yu et al. 2022). Smart charging infrastructure allows EVs to charge when electricity demand is lower, such as overnight or during periods of high renewable energy generation, or to discharge stored electricity back into the grid, alleviating pressure on distribution networks and reducing electricity costs for consumers. These capabilities support the integration of intermittent renewable energy sources while enhancing overall system resilience.

This thesis focuses on EV technology equipped with smart charging infrastructure and examines its potential as a type of DER within PED projects. PED projects are EU policy instruments aimed at achieving the decentralisation of the energy system to progress towards a Net Zero future, as outlined in Section 2.3. The thesis explores the role that EV technology equipped with smart charging infrastructure plays and the factors driving its adoption within the PED concept.

2.3 Defining Positive Energy Districts (PEDs)

The development of the PED concept is rooted in energy performance targets for the built environment, shaped by the EU Directive on Energy Performance of Buildings (Directive 2010/31/EC 2010; Brozovsky et al. 2021). This Directive set out the first goal to achieve "Nearly Zero Energy Buildings" (NZEBs) for all new public buildings in 2010, which drove the development of other concepts with larger geographical scales and higher energy performance ambitions, such as "Net zero energy neighbourhood", "Zero energy district", and "Positive energy district", as presented and defined in Table 1.

In general, "Nearly zero energy buildings" refer to highly efficient buildings that rely on some energy from non-renewable sources. Meanwhile, "Net zero energy neighbourhood" and "Zero energy district/community" aim to achieve an equal balance between renewable energy sources production and energy consumption. The concept of a "Positive energy block/district" is the most ambitious, aiming to produce more renewable energy than it consumes. There are no established size definitions distinguishing between blocks, neighbourhoods, and districts; rather, they are frequently described as urban areas or groups of connected buildings.

Table 1 Definitions of nearly zero, zero, and positive-energy concepts

Concept	Acronym	Definition	Reference
Nearly zero-energy building	NZEB	"a building that has very good energy performance. The nearly zero or very low amount of energy required should be supplied to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby"	Directive 2010/31/EC, 2010

Net zero energy neighbourhood	NZEN	"a neighbourhood in which the annual energy consumption for buildings and transportation of inhabitants is balanced by the production of on-site renewable energy"	Marique and Reiter 2014
Zero energy districts	ZED	"implement different cost-effective, efficient and demand-reduction strategies using renewable energy sources and technologies that are located in or outside of the district"	Aghamolaei et al. 2018
Zero energy community	ZEC	"a community with reduced energy requirements (covered by renewable resources) by increasing energy efficiency"	Koutra et al. 2023
Positive Energy Block	PEB	"several buildings that achieve an average annual positive energy balance between them"	Ahlers et al. 2019
Positive Energy District	PED	"an energy-efficient and energy-flexible district that generates more renewable energy that it consumes on an annual basis"	JPI Urban Europe, 2020b

In 2018, the Joint Programming Initiative (JPI) Urban Europe, an intergovernmental research and innovation programme developed by the European Commission, established the goal of deploying 100 PEDs by 2025 in SET-Plan (European Commission 2018). This programme highlights that the distinct feature of PED's is the ambitious objective to achieve positivity in producing local renewable energy, with the following requirements:

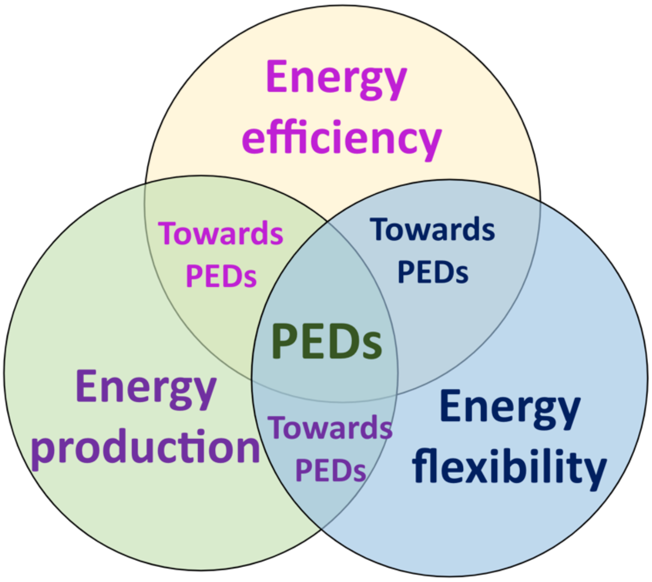
1) integration of different systems and infrastructures,
2) interaction between buildings, the users and the regional energy, mobility, and ICT systems,
3) securing the energy supply,
4) ensuring a good life for all,
5) alignment between social, economic, and environmental sustainability (JPI Urban Europe n.d; Vandevyvere 2021, p.3).

JPI Urban Europe has published two documents presenting the PED concept: (1) the PED booklet and (2) Reference framework for PEDs. The PED booklet provides brief descriptions of examples of PEDs, comprising 61 PED projects categorised into two groups (JPI Urban Europe 2020a). The first group is described as "declared a PED ambition" and consists of 28 projects. The second group is described as "not declared a PED ambition but present interesting features for the PED program", named as "toward PEDs" and encompasses 32 projects (ibid, p.96).

The reference framework for PEDs serves as a white paper, reflecting national consultations concerning PED Programme Management (JPI Urban Europe 2020b). This framework defines three key elements of PEDs: renewable energy production, energy efficiency, and energy flexibility (Figure 2). These elements encompass the following functions:

- renewable energy production, relying solely on RES;
- energy efficiency, entailing the optimal utilisation of available renewable energy; and
- energy flexibility, requiring the optimal utilisation of the energy system's resources.

Figure 2 PED Framework



Source: Adapted from JPI Urban Europe 2020a

The first element, renewable energy production, focuses on the integration of technologies that can offer production of local renewable or secondary energy sources, necessary for replacing fossil-based energy. The integration of technologies depends on local and regional conditions, economic viability, and can include photovoltaic systems (PV), wind energy, waste heat or geothermal energy (JPI Urban Europe, 2020a). The second element, energy efficiency, involves the implementation of measures focusing on both renewable energy supply and demand. The third element, energy flexibility, focuses on increasing the resilience and security of the energy system. This function involves measures designed to address the variability and uncertainty of renewable energy generation through the means of technologies and customer participation. At the same time, each PED seeks to find an optimal balance in implementing these three functions while considering the economic, legal, cultural, and climate-related diversity of European countries and cities (ibid).

In EU legislation, PEDs are characterised as “districts where several buildings optimise energy consumption across buildings as well as the wider energy system”, with common factors as follows (COM(2020) 662 final, p.18):

1) an annual positive energy balance,
2) integrated local renewable energy,
3) local storage (both electricity and heat),
4) smart energy grids,
5) demand-response,
6) cutting-edge energy management (electricity, heating, and cooling),
7) user interaction/involvement and ICT.

These characteristics suggest that PED is conceptualised around energy targets, primarily focused on the reduction of carbon emissions, employing a technology-driven approach.

Additionally, EU legislation highlights that PEDs can be achieved “through an integrated digital renovation that combines energy storage and demand-side flexibility, on-site energy generation from renewable sources, Internet of Things of the system components, appliances and recharging points for e-mobility” (COM(2020) 662 final, p.17). This implies that the adoption of energy storage, renewables, demand-side flexibility assets, and EV charging points are recommended in PEDs. Considering that smart charging technologies, as discussed below in Section 2.3, include functions such as energy storage (V2G) and demand-side flexibility (V1G), their embedding in EV charging infrastructure may address several PED requirements at once.

Given that the PED’s energy performance goal is to achieve an annual surplus of renewable energy production compared to energy consumption, and its three core energy functions, renewable energy production, energy efficiency, and energy flexibility, are at the heart of the PED concept, it implies that PEDs are primarily energy-focused, addressing their goals through the employment of a technology-driven approach. This definition of PEDs, implied in this study, supports the importance of understanding their technology adoption strategies in meeting their goals and frameworks.

2.4 Defining Smart Charging Technology

With the expected rise in the sale of EVs, increasing impacts on grid instability are forecast (Dias et al. 2018; Nour et al. 2019; Deilami and Muyeen 2020; Hussain et al. 2021). To address the expected grid issues, the EV charging market has offered smart charging technologies capable of enhancing grid flexibility (Fitzgerald et al. 2016; Pazouki et al. 2021; Ziegler and Abdelkafi 2022). There are two types of smart charging technologies, unidirectional and bidirectional (International Energy Agency 2021).

Unidirectional smart charging, also known as vehicle one grid (V1G), refers to the one-way flow of electricity energy, drawn from the grid to the EV (International Renewable Energy Agency 2019). V1G smart charging is designed to coordinate charging through automated control functionality, allowing EVs to share real-time charging data with the charging point operator (Sah and Kumar 2021). This functionality allows the charging point operator to remotely manage charging when optimisation of energy consumption is needed to maintain the balance of demand and supply, for example, shifting charging from peak hours of the day to off-peak hours (Brown et al. 2018; Blumberg et al. 2022; Hanemann and Bruckner 2018).

Bidirectional smart charging, known as vehicle-to-grid technology (V2G), refers to two-way flow of electricity energy, allowing energy to flow not only from the grid to the EV but also from the EV to the grid (IRENA 2019). This functionality allows EV users to use the EV battery as short-term energy storage when there is an abundance of renewable energy supply and to discharge it back to the grid when demand is high. A significant number of studies have assessed the impacts of both V1G and V2G smart charging on the grid, concluding that these technologies can facilitate a seamless transition to EVs by offering energy flexibility to the grid (Coignard et al. 2018; Donadee et al. 2019; IRENA 2019; Wen et al. 2020; van Triel and Lipman 2020).

In some literature, the term "smart charging" refers only to V1G, while "vehicle-to-grid" refers to V2G technology. In this thesis, the term "smart charging" refers to both V1G and V2G technologies, distinguishing between them when discussed separately. There is also another technical option of smart charging: bidirectional vehicle to everything (V2X) charging, including vehicle to house (V2H) or vehicle to building (V2B) technologies, representing "a small-scale version of V2G" that does not directly impact the grid but offers black start capability and demand charge avoidance services (DNV n.d.). Black start capability service refers to the ability of the energy system to be energised again after a power system blackout without the use of external power sources, while demand charge avoidance service refers to the ability to minimise peak demand by avoiding EV charging during peak periods (Gryning et al. 2020). As V2H and V2B do not impact the grid directly, unlike V1G and V2G technology, they are not widely considered as part of future policy considerations (House of Commons Library 2021). In this thesis, only V1G and V2G technology are considered within the scope of the research.

In today's EV charging market, V1G is a more widely adopted technology than V2G (Cenex 2020; Szinai et al. 2020; Van Triel and Lipman 2020). The main reasons are as follows: 1) the cost of V1G is significantly lower than that of V2G; 2) V1G is easier to use and implement than V2G (mainly due to concerns related to vehicle battery warranties and grid interconnection issues); and 3) V1G is more readily available on the market, whereas V2G is compatible only with car models that support the "CHAdeMO" connector (Gschwendtner et al. 2021). Nevertheless, despite the fact that V2G is not widely adopted, it is widely recognised for its significant impact on the grid by enabling better utilisation of RES, storying energy when there is an excess, and discharging energy back to the grid when needed (Barone et al. 2019; Crozier et al. 2018; IRENA 2019; 2020; Sachan et al. 2020).

A range of countries recognises and acknowledges the importance of deploying smart charging technology in their regulations. For example, in Great Britain, new domestic and workplace charging points have been mandated to incorporate smart charging functionality, including V1G technology, since 2022 (UK Government 2022). The Netherlands has developed a national programme entitled "Smart charging for all 2022-2025" with "the overall objective that by 2025, smart charging will be the standard" (National Charging Infrastructure Agenda 2022, p.12). The National Charging Infrastructure Agenda (NAL) emphasises that it views smart charging as a must-have. In the USA, the California Energy Commission is developing a Vehicle-Grid Integration Program, considering the implementation of funding solicitations and grants for the deployment of V2G chargers (California Energy Commission 2023).

The European Commission has recently emphasised in one of its Directives that "Member States should ensure a level playing field for small, decentralised electricity generation and storage systems, including through batteries and electric vehicles, so they are able to participate in the electricity markets, including congestion management and the provision of flexibility and balancing services" (Directive (EU) 2023/2413, p. 15). Thus the European Commission also recognises the importance of adopting EV charging infrastructure equipped with smart charging and its ability to contribute to grid flexibility.

To encourage the adoption of smart charging, numerous countries offer smart charging tariffs to assist EV drivers in reducing their charging costs (Burger et al. 2022; Kester et al. 2018; Philip et al. 2023). As an example, the UK offers 30 smart charging tariffs, Norway - 16, Denmark - 15, the Netherlands – 14, Germany – 13, and France – 9. Smart charging tariffs refer to “retail electricity prices that vary across the day and allow consumers to save electricity costs if they are willing to shift their consumption to periods of low prices” (Burger et al. 2022, p.15). Importantly Burger et al. (2022, p.11) emphasise that as smart charging enhances energy efficiency “EV smart charging reduces costs not only for EV users, but for all users of the system”, highlighting the significant contribution of the technology to the entire energy system.

Along with smart charging tariffs, there are demand-response programmes, referring to the shift of energy consumption in response to price signals (Burger et al. 2022). These financial incentives aim to encourage EV drivers to charge their vehicles at specific times when electricity demand is low. Some studies estimate that the use of V1G, combined with smart charging tariffs and demand-response programmes, can save approximately £225 per year on electricity bills in the UK. Further reductions in energy bills can be met through the integration of smart charging with rooftop solar (ibid). The highest reduction, potentially reaching about £414 annually, can be achieved with the incorporation of V2G with electricity markets (Cenex 2019). Such incorporation can enable more effective distribution of grid management compared to individual efforts by using wholesale markets on equal terms with energy generation assets (Geelen et al. 2019; Kotthaus et al. 2019; Lezama et al. 2020; Mystakidis et al. 2023)

Thus, the literature suggests that smart charging technology can facilitate grid flexibility and its importance is emphasised in regulations across the UK, the Netherlands, the USA, and in the EU. Additionally, the adoption of smart charging is promoted by financial incentives such as smart charging tariffs and demand-response programmes across a range of countries, including the UK, Norway, Denmark, the Netherlands, Germany, and France.

2.5 Overview of Studies on Smart Charging Adoption

The adoption of smart charging technology has primarily been investigated at an individual level, which is highlighted as a common practice in technology adoption scholarship, unlike at an organisational level (Ali et al. 2021; Meelen and Schwanen 2023). The focus on socio-economic, demographic, psychological, and behavioural factors is also frequently highlighted within the scope, as presented in Table 2, with an emphasis on user characteristics, their charging and mobility behaviour, as well as their perceptions and attitudes regarding preferences, benefits, and barriers (Baumgartner et al. 2023).

For example, Heuveln et al. (2021) investigate the perceptions of EV users about V2G and their motives behind these perceptions, assuming that V2G consumer acceptance is a prerequisite stage of V2G adoption. The study applies a qualitative approach and adopts the Theory of Planned Behaviour (TPB) to explore attitudes, perceived behavioural control, and subjective norms concerning V2G adoption. The study concludes that perceived benefits of V2G are associated with potential financial compensation gained from the usage of V2G; and its contribution to the environment by helping to balance the electricity grid. Perceived barriers include concerns regarding battery degradation, low availability of V2G chargers, and the potential presence of better alternatives.

Kubli (2022) focuses on V1G adoption and employs a different methodological approach: surveys and a choice experiment. The study reveals that all respondents, who are current or potential early EV adopters, are willing to adopt EV charger equipped with V1G technology to benefit the electricity grid and increase locally generated renewable energy. However, monetary compensation is found to be a necessary condition, especially if the level of comfort charging decreases.

Similarly, Wong et al. (2023) focus on V1G adoption by conducting surveys and a choice experiment. The study investigates the potential incentive effects on the willingness to adopt EV chargers equipped with V1G technology, focusing on users' charging behaviour, perceptions, and demographic characteristics of three types of stakeholders: EV users, EV interested buyers, and the general population. The results demonstrate that the majority of survey respondents would like to adopt EV chargers equipped with V1G technology with an incentive, particularly in the range of $300 to $400 per year.

Delmonte et al. (2020) also reveal that willingness of study participants to adopt both V1G and V2G technologies is conditional on large savings in charging costs. The study explores the following factors: demographic and socio-economic characteristics, charging behaviour, and knowledge of electricity costs, by interviewing 60 car users, 45 of whom are EV users.

Interestingly, contrasting results are found by Geske and Schumann (2018) in investigating the influential factors on the willingness to adopt EV chargers equipped with V2G technology. The study conducted a survey across 611 car users, 14 of whom are EV users, and analysed demographic and socio-economic factors of car users,, their willingness to adopt EVs and awareness about V2G. The results show that most respondents are unfamiliar with V2G technology and that remuneration schemes will not support adoption decisions unless the technology provides freedom in various mobility demands, including unforeseeable and foreseeable ones.

In exploring the acceptance of V1G and V2G among EV users in China, Wang et al. (2022) employ the Technology Acceptance Model (TAM) (Davis et al. 1989), focusing on perceived ease of use, perceived usefulness, and social influence factors. The study aims to identify acceptance differences across demographic and socio-economic characteristics, concluding that the majority (81.2%) of respondents accept the potential adoption of smart charging. It emphasises that a higher willingness to participate in smart charging is found among individuals aged 31-40 years, for whom social influence is the most influential factor.

The only study we are aware of that investigates the adoption of smart charging from a collective perspective is conducted by Meelen and Schwanen (2023), which also highlights that little attention has been given to this topic at the organisational level. To contribute to that gap, the study focuses on the investigation of the potential role of V2G in organisational fleets in the UK within the paradigm that organisations are key potential future V2G users. The study employs a case study approach by exploring the Vehicle-to-Grid Oxford (V2GO) project, operated during 2018-2020 and funded by a UK Government agency, Innovate UK. The study collects interviews from managers involved in the V2GO project and other industry professionals and investigates organisational fleet management practices, decision-making processes, managers' perceptions on potential V2G adoption, as well as expected barriers and facilitators of potential V2G adoption in their organisation's fleet management. In the study, organisational technology adoption is considered as a complex phenomenon that requires an understanding of micro and macro structures and processes influencing adoption decisions.

Thus, studies on smart charging adoption frequently analyse users' perceptions, charging behaviour, and demographic and socio-economic characteristics at an individual level. However, there is a lack of studies exploring the adoption of smart charging focusing beyond users' perceptions. For example, there is limited research encompassing policy and market dimensions at a collective level. To some extent, this thesis follows a similar methodological approach to the study outlined by Meelen and Schwanen (2023), assuming the need to learn from organisational practices in adopting technologies, including smart charging.

Table 2 Overview of studies on smart charging adoption

Type of smart charging	Unit of analysis	Theoretical frameworks	Data collection approach	Key constructs	Country	Authors
V2G	Individual	Theory of planned behaviour (Ajzen 1985)	Semi-structured interviews	-Attitudes toward V2G (perceived benefits, perceived barriers); -Perceived behavioural control; -Subjective norms	Netherlands	Heuveln et al. (2021)
V1G	Individual	Not specified	Survey with choice models	-Demographic and socio-economic characteristics (gender, ethnicity, age, education, income); -Charging frequency, charging pattern (at home, public, workplace); -A choice of various scenarios with different incentives	United States	Wong et al. 2023
V1G	Individual	Not specified	Survey with choice models	-Charging location (at home, work, public charging point); -Charging costs; -Charging duration	Swiss	Kubli 2022
V2G	Individual	Not specified	Survey with a discrete-choice experiment	-Demographic and socio-economic characteristics; -A choice of minimum numbers of day per week and hours per time restrictions for EV charging; -A choice of remuneration schemes (a fixed monthly payment and a one-time payment)	Germany	Geske and Schumann 2018
V1G and V2G	Individual	Not specified	Semi-structured interviews	-Demographic and socio-economic characteristics (gender, age, regional location, number of owned vehicles, type of vehicles, the availability of solar panels); -Charging behaviour (location); -Knowledge of electricity costs; -Perceived advantages and barriers.	United Kingdom	Delmonte et al. 2020

V1G and V2G	Individual	Technology acceptance model (Davis et al. 1989)	Survey	-Demographic and socio-economic characteristics (gender, age, marital status, educational level, occupation, monthly income, vehicle type); -Charging behaviour (daily driving time, milage); -Social influence; -Perceived usefulness; - Perceived ease of use	China	Wang et al. 2022
V2G	Organisational	Combination of social practice theory and neoinstitutional theory	One case study and interviews	-Experiences with EVs; -Perceptions on embedding V2G with current organisation's fleet; -Decision-making process, preparations, and expected barriers and enablers of the adoption of V2G within organisations	United Kingdom	Meelen and Schwanen 2023

2.6 Overview of Smart Charging Adoption across PEDs

Analysing data presented in the PED booklet (JPI Urban Europe 2020a), Zhang et al. (2021), currently over 70% of PED projects are in the planning or implementation stage. The study highlights that to address the energy transition targets, the majority of projects implement or plan to implement technologies such as district heating, solar, heat pumps, geothermal energy, and CHP, while fewer projects implement or plan to implement technologies associated with energy storage, e-mobility, and wind energy (Figure 3).

Figure 3 Implemented or planned to implement technologies across 61 PED projects

Source: Zhang et al. 2021

While a range of PED projects aim to develop e-mobility, a few projects outline the objective to adopt smart charging infrastructure (JPI Urban Europe 2020a). Nevertheless, there is a study that highlights that with the expected increase in EVs, its adoption might be critical (Derkenbaeva et al. 2022). Specifically, eight projects, including Smart Energy Åland, Pocityf, Atelier, CityxChange, ZEN research, Pietralata PED, Stardust, and MySmartLife have indicated their intention to integrate EVs into the grid, meaning that they plan to adopt EV charging infrastructure equipped with smart charging (JPI Urban Europe 2020a). The exploration of their processes in adopting smart charging might be a valuable asset for policy makers and PED developers, especially considering the limited knowledge on the smart charging adoption processes in both PEDs and the wider context, applying a collaborative approach.

2.7 Theoretical Frameworks for Analysing Technology Adoption

Technology adoption is a multidimensional phenomenon draws from various disciplines such as sociology, entrepreneurship, organisational studies, and public policy (Ashour, Al-Qirem 2021; Alford, Page 2015; Heiman et al. 2020; Mack et al. 2021). Business and consumer behaviourists analyse technology adoption from psychological (e.g. personality, openness to experience), sociocultural (e.g. ethnicity, cultural norms), and socioeconomic (e.g. income level, education level) characteristics (Daghfous et al. 1999).

Behavioural economists analyse technology adoption from the consumer willingness and acceptance perspectives (Ashour and Al-Qirem 2021), while psychologists explore consumer perceptions and attitudes (Paluch, Wunderlich 2016; Roberts et al. 2021). Business scholars focus on product fit and the role of marketing tools in influencing adoption (Alford and Page 2015; Heiman et al. 2020). Public policy scholars investigate the role of government in shaping technology adoption patterns (Mack et al. 2021).

In terms of methodological approaches, technology adoption studies employ both quantitative and qualitative methods depending on research goals. For example, to analyse interactions between various factors, some studies have employed simulation-based approaches such as agent-based modelling (Robinson and Rai 2015) or system dynamics (Chen 2011). In qualitative research, numerous studies have applied theoretical frameworks. The following subsections review factors influencing technology adoption employed across six theoretical frameworks: the diffusion of innovation model (DIO), theory of planned behaviour (TPB), decomposed theory of planned behaviour (DTPB), technology acceptance model (TAM), inter-organisational system model (IOS), task technology fit model (TTF), and technology-organisation-environment (TOE) framework (Table 3). The objective of this part of the review is to understand which factors are analysed for what research objectives in investigating technology adoption and to select the framework that best suits addressing the aim of this thesis.

Table 3 Theories and frameworks used in technology adoption literature

N	Theories and models	Acronym	Founder	Constructs	Characteristics
1	Diffusion of innovation model	DoI	Rongers 2003	1)Innovation; 2)Communication channels; 3)Time; 3.1)Innovation-decision process; 3.2)Adopter categories; 3.3)Rate of adoption; 4)Social system.	1) Relative advantage, compatibility, complexity, trialability, observability; 2) Information exchange; 3) Time period; 3.1)Knowledge, persuasion, decision, implementation, confirmation; 3.2)Innovators, early adopters, early majority, late majority, laggards; 3.3)Rate of innovation adoption over a period of time; 4) Individuals, informal groups, organisations, system norms, opinion leaders, change agents
2	Theory of planned behaviour	TPB	Ajzen 1985	Behaviour: Intention	1)Attitudes toward the behaviour; 2)Subjective norms; 3)Perceived behavioural control
3	Decomposed theory of planned behaviour	DTPB	Taylor and Todd 1995	1) Attitudes toward the behaviour; 2) Subjective norm; 3) Perceived behavioural control	1) Relative advantage, compatibility, complexity; 2) Normative influences; 3) Efficacy, facilitating conditions
4	Technology acceptance model	TAM	Davis 1987	Attitude toward using: actual system use	1)Perceived usefulness; 2)Perceived ease of use
5	Inter-organisational system model	IOS	Iacovou et al. 1995	1)Perceived benefits; 2)Organisational readiness 3)External pressures to adopt	1) Relative advantage 2) Organisational capabilities 3) Pressure/mandate from partners

6	Technology-organisation-environment	TOE	Tornatzky and Fleischer 1990	1)Technology; 2)Organisation; 3)Environment	1)Availability characteristics; 2)Formal and informal linking structures, communication processes, size, slack. 3)Industry characteristics and market structure; technology support infrastructure, government regulation;
7	Task Technology Fit model	TTF	Goodhue 1995	1)Technology; 2)Task; 3)Individual	1)Prior level of use, prior hours of use

2.7.1 Technological factors

Perceived relative advantage, compatibility, complexity, trialability, and observability

Diffusion of innovation (DOI) is a leading social science theory developed by Rogers, which explores the technological context of the adoption of new ideas and technologies by including psychological factors such as perceptions, uncertainties, and social norms (Roberts et al. 2021). Daghfous et al. (1999, p.1) explain that technology adoption "is not an essentially technological phenomenon, but rather a phenomenon of a psychologiscal and sociocultural nature because those are the keys to its success or failure". Psychological factors refer to mental and behavioural aspects that potentially influence technology adoption (Roberts et al. 2021). Rogers states that individuals' perceptions and uncertainties influence technology adoption decisions and suggest examining perceptions about five characteristics, including relative advantage, compatibility, complexity, trialability, and observability (Rogers 2003).

Relative advantage can be defined as "the degree to which an innovation is perceived as being better than the idea it supersedes" (Rogers 2003, p.15). In general, perceived benefits, defined as the pragmatic motives and advantages that individuals believe they could gain from technology adoption (Nanggong and Rahmatia 2019), fall into three groups: direct benefits, indirect benefits, and strategic benefits (Dearing 1990; Shang and Seddon 2002; Jung 2006). Direct benefits are observable and measurable, and encompass advantages related to operational activities (Dearing 1990; Jiménez-Martínez and Polo-Redondo 2004). These benefits include economic savings and other internal efficiencies, such as reduced paperwork, error reduction, and time saved on data entry (Jung 2006).

Indirect benefits are not directly observable or tangible; they encompass advantages related to managerial and organisational activities, such as improved customer service or business control (Jung 2006). Similar to indirect benefits, strategic benefits are challenging to observe and measure (Dearing 1990). They involve advantages related to strategic activities in relationships with customers, suppliers, or other stakeholders, such as improved customer loyalty or enhanced company reputation (Jung 2006).

Perceived relative advantages or benefits are considered not only in the DOI, but also in and the inter-organisational system model (IOS, developed by Iacovou et al. 1995) (Borgman et al. 2013; Curran and Meuter 2005). The IOS framework postulates that perceived benefits are instrumental in understanding intentions and usage behaviour (Agarwal and Prasad 1998; Moore and Benbasat 1991). Other theories and frameworks such as the technology acceptance model (TAM, developed by Davis 1987), the decomposed theory of planned behaviour (DTPB, developed by Taylor and Todd 1995), the theory of planned behaviour (TPB, developed by Ajzen and Fishbein 1980) examine perceived advantages through investigating individuals' attitudes determined by two factors: perceived usefulness and perceived ease of use (Agarwal and Prasad 1998; Moore and Benbasat 1991; Taylor, Shirley Todd 1995). Some studies state that perceived usefulness and perceived ease of use factors can provide a better understanding of consumer behaviour and a deeper insight into technology acceptance and usage behaviour (Aziz et al. 2017; Davis, Venkatesh 1996; Taylor and Todd 1995; Tucker et al. 2020).

Nevertheless, it is widely observed that perceived relative advantage alone does not ensure the extensive diffusion of innovation unless it aligns with the adopters" beliefs, values, needs, and past experiences (Agarwal 2000; Denis et al. 2002; E. M. Rogers 2003; Vishwanath 2009). To explore that alignment, Rogers proposes to study compatibility, defined as "the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters" (Rogers 2003, p.15).

To explore perceived disadvantages of technology, Rogers suggests investigating its complexity, defined as "the degree to which an innovation is perceived as difficult to understand and use" (Rogers 2003, p.15). Rogers emphasises that perceived complexity can act as a significant barrier to the diffusion of innovation. Examples of perceived complexity include misunderstanding the technology's function (Holak, Lehmann 1990), a lack of clarity regarding the advantages of technology use, and complex operational procedures (Min et al. 2018).

The fourth construct proposed by Rogers is trialability, defined as "the degree to which an innovation may be experimented with on a limited basis" (Rogers 2003, p.15). Rogers states that trials can reduce some degree of uncertainties, thus fostering positive influences on technology adoption. Cain and Mittman (2002) and Tan and Teo (2000) also highlight that trials provide opportunities to evaluate a technology's risks and benefits and minimise concerns about the unknown. Similarly, Kapoor et al. (2011) and Greenhalgh et al. (2004) emphasise that trialability can both accelerate technology adoption and ease its assimilation.

The last construct proposed by Rogers is observability, defined as “the degree to which the results of an innovation are visible to others” (Rogers 2003, p.15). Rogers believes that the greater the visibility of the usefulness or other benefits of a technology, the swifter its adoption. Similarly, Greenhalgh et al. (2004) and Kapoor et al. (2011) recommend demonstrations to showcase the benefits of a technology to enhance the probability of its adoption.

Therefore, numerous studies suggest that perceived relative advantage might be a critical factor influencing technology adoption, encompassing factors like economic benefits, convenience, and satisfaction. The exploration of perceived relative advantage may help understand perceptions and, most importantly, reasons for adopting technologies, prioritising this factor over others if a goal is to identify drivers.

Prior level of use and prior hours of use

The Task Technology Fit (TTF) model is based on the proposition that the adoption of technology depends on “how well technology options “fit” his or her task requirements” (Goodhue 1995, p. 1830). “Fit” is defined as “the degree to which a technology assists an individual in performing his or her portfolio of tasks”, while task refers to “the actions carried out by individuals in turning inputs into outputs” (Goodhue and Thompson 1995, p. 216). The TTF is suggested to be useful as a user evaluation tool and is measured through factors, including technology characteristics, task characteristics, and individual characteristics (Goodhue 1995). As the TTF does not provide attributes for its characteristics, studies employ various attributes depending on the technology, especially in the field of information technology (Park 2019). For example, in understanding low usage of one of the software maintenance tools for improving productivity and quality of work within organisations, Dishaw and Strong (2003) examined prior level of use, prior hours of use for technology characteristics.

Availability characteristics

Within the technology dimension, the TOE framework examines availability characteristics. This technological factor refers to technologies that are already adopted and to new technologies that organisations plan to adopt (Shukla and Shankar 2022). The developers of the TOE framework, Tornatzky and Fleischer (1990, p.163), emphasises that “decisions to adopt technology depend on what is available, as well as how the available technology fits with the firm’s current technology”, highlighting the relationship between existing technologies and decisions to adopt new ones. Other literature also supports such a relationship, explaining that the availability of technological resources in organisations may determine the scope and limit of adopting a new technology that an organisation may accept (Collins et al. 1988; Amini and Bakri 2019).

2.7.2 Social factors

A social system

A social system is one of the key constructs of the DOI theory, defined as "a set of interrelated units engaged in joint problem solving to accomplish a common goal" (Rogers 2003, p.24). In general, social systems are defined as individuals, organisations, and cultures, and in the context of technology adoption, within them awareness of a technology is generated (Bell and Ruhanen 2016). Rogers provides examples of social systems, such as villagers in a rural community, high schools in a region, or doctors in a hospital. Nevertheless, notably, Rogers' theory is frequently considered as primarily centred on the diffusion of innovation by individuals rather than organisations (Lundbland 2003; José 2020). This is due to the theory not examining constructs for understanding collective diffusion behaviours, such as institutional policies, standards, path dependence, industrial policies, and strategies (José 2020).

The DOI theory suggests examining a social system by focussing on values, norms, roles, formal hierarchies, as well as the mechanisms or communication channels for flowing messages across the social system (Cain and Mittman 2002). The theory emphasises that "the essence of the diffusion process is the information exchange by which one individual communicates a new idea to one or several others" (Rogers 2003, p.17), supporting the focus of the theory on the diffusion of innovation among individuals rather than within organisations. The theory emphasises that the behaviour of individuals involved in the diffusion process is not identical, while the structure, defined as "the patterned arrangements of the units in a system", may be determined (Rogers 2003, p.24). This implies that the identification of patterns characterising the behaviour of individuals may suggest the structure of the diffusion process, categorised within the theory into innovators, early adopters, early majority, late majority, and laggards. Thus, the DOI theory examines the behaviour of individuals and their communication mechanisms to determine the stage of a social system regarding the diffusion process.

Formal and informal linking structures

The developers of the TOE framework, Tornatzky and Fleischer (1990, p.195), emphasises that "No matter how big and complex organisation is, there will always be a relatively small number of individuals whose knowledge, interests, and beliefs will make a material difference in an innovation adoption effort". This highlights the influence of decision-makers on the adoption of technology, which identification is critical in the TOE. The importance of decision makers in organisations, often referred to as managers or leaders, is also supported in other literature on the adoption of technology (Langley et al. 1995; Sepasgozar, Davis 2018; Venkatesh 2006).

The TOE framework suggests examining a social system through an organisation construct, offering the following factors: formal and informal linking structures, communication processes, organisation size, and the number of slack resources (Tornatzky and Fleischer 1990). Formal and informal linking structures are explored to identify decision-makers (e.g. top management, idea generator) and understand communication processes that facilitate information sharing among organisational members (Tornatzky and Fleischer 1990).

The aim of examining the formal linking structure factors is to explore coordination within an organisation, involving elements of organisational governance such as management structure, power distribution, and coordination of tasks and responsibilities (Corbin and Miller 2009). Informal linking structure involves the investigation of unofficial communications and collaborations within an organisation, which are traditionally based on personal relationships and shared interests (Corbin and Miller 2009). Therefore, the TOE framework examines organisational governance and communication processes primarily to identify decision-makers within organisations.

Organisational size, resources, and capacity

Within the TOE framework, "organisational size is little more than a proxy variable for more meaningful underlying dimensions such as resources", highlighting the interchangeability of size factor with resources (Tornatzky and Fleischer 1990, p.162). Some studies link organisational resources with organisational capacity, which, in turn, is considered one of the determinants of the adoption of technology (Best et al. 2021; Gebert-Persson et al. 2014; Morgan 2006; Hoeber and Hoeber 2016; Zanello et al. 2016). Organisational capacity is defined as the ability of an organisation to manage, develop, and direct human, financial, and physical resources to achieve its goals (Morgan 2006), conceptualising it within components such as human resources, financial resources, strategy, governance, and management (Cox et al. 2020).

A range of studies consider organisation size is an important technology adoption factor (Oliveira et al. 2014; Brender and Markov 2013; Alshamaila et al. 2013). For example, Cho et al. (2007) and Zhu and Kraemer (2002) found size to be a critical factor influencing the adoption of innovation in national and local governments, with a trend for large cities to adopt more sophisticated technologies than smaller ones. Similarly, Patterson et al. (2003) and Grover and Goslar (1993) outline that larger organisations generally have more financial resources, influencing investment decisions, and a greater willingness to adopt innovations.

There is a study that argues that a large organisation's size is associated with a higher level of diversified operations, with bureaucracy sometimes negatively impacting managerial decision-making time and processes (Hitt and Hoskisson 1990). Nevertheless, although the growth in organisational size leads to increased documentation, it is viewed as a positive organisational characteristic linked to accountability (Kotey and Sheridan 2004). Accountability involves reporting regarding a statement of goals, the usage of resources, decision-making processes, relationship structures, and outcomes, aiming to clarify who is responsible for what decisions (Edward and Hulme 2013).

Thus, large organisations are frequently associated with enhanced organisational capacity, driving the adoption of technological innovations. Alongside human and financial resources, organisational capacity encompasses goals, strategies, governance, and management characteristics.

Slack resources

The TOE framework offers to examine slack resources, defined as "a disparity between the resources available to the organisation and the payment required to maintain the coalition" (Cyert and March 1963, p.35, cited in Xu et al. 2015). In other words, organisational slack is the excess resources that the organisation has compared to what it needs to sustain its operation, emphasising the role of financial resources of organisations in technology adoption.

While suggesting to examine slack resources, Tornatzky and Fleischer (1990) emphasise that the availability of slack resources does not necessarily lead to the adoption of technological innovation. Other studies also support the idea that both excess and little organisational slack can have positive and negative impacts on innovation, highlighting the inverse U-shaped relationship between slack and innovation (Nohria and Gulati 1996; Zhor 2018). Probably due to a lack of relationship between slack resources and technology adoption, slack resources seem to be rarely explored in relation to technology adoption (Zhor 2018).

Organisational readiness

The IOS model examines organisational readiness, defined as a multi-level and multi-faceted construct that reflects organisational members' commitment to adopt technology (Lokuge et al. 2019; Weiner 2009). Organisational readiness involves the analysis of financial resources and the availability of technical knowledge (Iacovou et al. 1995) or informational resources (Alsmairat 2022). Little attention is emphasised in the literature to exploring the relationship between organisational readiness and technology adoption (Alsmairat 2022), suggesting the underutilisation of this factor in analysis.

2.7.3 Environmental context

Industry characteristics and market conditions

The TOE framework suggests evaluating the industry characteristics and market conditions to examine could the motivation to enhance competitiveness across the industry, as a driving force for technology adoption (Tornatzky and Fleischer 1990). In various industry areas, however, studies show different results. For example, across fertility clinics in the United States, the adoption of technologies in competitive markets is observed earlier compared to monopolies (Hamilton and McManus 2005). The diffusion of IT technology across small organisations in the US is associated with gaining a competitive advantage (Chao and Chandra 2012). The opposite effect is found in examining the adoption of e-banking across banks in Canada, where e-banking was spread earlier in less competitive markets (Allen et al. 2008). Therefore, the influence of competitive markets on technology adoption may depend on industry area and the geographical context.

Technology support infrastructure: labour costs, skills, and access to suppliers

The TOE framework suggests examining the construct ‘technology support infrastructure’, involving three elements: labour cost, skills of the available labour force, and access to suppliers of technology-related services (Tornatzky and Fleischer 1990). Tornatzky and Fleischer (1990, p.171) believe that there is a cause and effect relationship between wage rates and technology adoption, noting that “firms paying higher wages are always more likely adopters of new technologies”. Overall, along with slack resources, this construct is rarely explored in the literature, probably as high wages are likely associated with organisations’ financial resources (Criscuolo et al. 2020), while skills and supply chains align with management activities (Amini and Jahanbakhsh 2023). In general, the latter might be explored within the organisational size/resources/capacity construct.

Government regulation

The TOE framework proposes examining government regulation characteristic, emphasising that regulation can both encourage the adoption of a new technology, referring to it as “an important stimulus to innovation”, and introduce barriers to its development (Tornatzky and Fleischer 1990, p.173). As an example, in the construction industry, the lack of government incentives and regulation has been frequently identified as a key barrier to green innovation adoption (Darko et al. 2017; Gan et al. 2015; Love et al. 2012; Raj et al. 2020). Conversely, the implementation of incentives, for example, for installing solar thermal energy technologies, demonstrates the enhancement of developing green buildings through the adoption of solar technologies (Qian et al. 2016; Shazmin et al. 2016). As smart charging aligns with green innovation goals, studying how government regulation may impact on its adoption across PEDs is essential for informing policy development.

External pressures

The IOS model suggests examining external pressure in relation to organisational decisions to adopt innovation (Iacovou et al. 1995). External pressure refers to forces that can come from other organisations, regulation, public or society expectations, influencing organisational decisions to adopt innovations to improve their performances (Jang et al. 2024; Nurdin et al. 2012). This factor is primarily analysed by studying stakeholders’ experiences and perceptions of pressure from external actors to adopt new technologies within their organisations (Jang et al. 2024). The analysis of this factor is particularly suited for studies aiming to explore how social norms, public expectations, and government incentives can influence organisational decision-making regarding their technological landscape. This can contribute to the understanding of how organisations align with public values and expectations, and their role within the broader social context.

2.8 DoI theory

Historically, diffusion research has been of interest to anthropologists, ethnologists, and cultural geographers (Kinnunen 1996; Siddiqui and Adams 2013). It was subsequently embraced by various disciplines, including the social sciences. One theory that is frequently recognised and widely used, especially concerning technological innovations, is the DoI theory, initially published in 1962 by Rogers. As technological innovation is central to this study, the DoI theory might be immediately considered. Indeed, at the outset of the research, this methodological and philosophical approach was considered.

The DoI theory, grounded in the realism paradigm, focuses on four elements: innovation, communication channels, time, and the social system, with communication being distinguished as critical to framing the diffusion problem (Raj et al. 2020; Siddiqui and Adams 2013). For this study, the DoI theory would enable an understanding of the adoption process by explaining how information is shared and which communication channels are used among energy projects at different stages, while also categorising the projects based on their adoption stage, ranging from innovators to laggards.

However, this approach would limit this study to a descriptive examination of project experiences. Although the experiences of projects are essential to answer the research questions of this study, they might not provide the strongest possible explanation of the determinants of the adoption of smart charging across various energy projects in Europe. Moreover, the DoI theory is commonly regarded as more suitable for exploring the adoption of innovation across individuals rather than within or across organisations (Siddiqui and Adams 2013). Consequently, the application of the DoI theory was reassessed, and the TOE framework was identified as the more appropriate and adaptable theoretical framework.

2.9 TOE framework

There are several arguments facilitating the usage of the TOE framework in this study, influencing the research approach. Firstly, the TOE framework is the viewpoint that maintains a data-based understanding of technology adoption processes within larger systems in which they are situated, to effectively contribute to the more efficient operation of these systems (Tornatzky and Fleischer 1990). The TOE framework is based on the idea that social, market, and political agendas are "confronting the world"; therefore, it embeds them to understand the complex processes of adopting technological innovations (Tornatzky and Fleischer (1990, p.6). Some scholars criticise the TOE framework for its broad scope and "generic" constructs, such as technology, organisation, and external task environment (Chong and Olesen 2017; Zhu et al. 2003). However, given that the energy transition is a systems-level problem, where technological infrastructure, place, energy, politics, industry, and people all interact and influence each other (Catapult 2021), the combination of the TOE framework's constructs seems appropriate in this context.

Secondly, in the applied science of technological innovation, the TOE framework is used to explore two fundamental questions: 1) why technology adoption occurs, and 2) what happened during the adoption of technology (Tornatzky and Fleischer 1990). These questions align with the questions this study aims to address, seeking to explore why smart charging has been adopted in PEDs and what the process of its adoption entails.

Furthermore, this framework is frequently combined with other theoretical frameworks and adopted in accordance with research objectives and the type of technology, which varies by purposes, settings, limits, and conditions of use. For example, some studies combined the TOE framework with the DoI theory by adding technological variables such as relative advantage, complexity, or compatibility (e.g. Chong and Olesen 2017; Jere and Ngidi 2020; Zhu et al. 2003). Matikiti et al. (2018) integrated the TOE framework with the TAM model by adding perceived usefulness and perceived ease of use variables to explore attitudes toward technological innovation. Other studies combined the TOE framework with the IOS model by adopting organisational and environmental variables, including organisations' financial resources and external competitive pressure (e.g. Gibbs, Kraemer 2004; Hsu et al. 2006; Oliveira and Martins 2011). In this study, the TOE framework is also adopted to contribute to the richness of analysis by adding and combining factors, as presented in Section 3.3, Figure

5. Additionally, Section 3.3 underscores an epistemology of the TOE framework influencing this study's research methodological design.

Lastly, the TOE framework has been applied in a several fields, including the construction industry (e.g. Mitropoulos and Tatum 1999; Pan, Pan 2019), circular economy (Chembessi et al. 2022), e-commerce (e.g. Abed 2020; Rahayu and Day 2015), and IT (e.g. Lin 2014; Ofosu-Ampong and Acheampong 2022; Neumann et al. 2022; Tomás et al. 2018; Seshadrinathan and Chandra 2021; Senyo et al. 2016; Seethamraju and Frost 2019; Yeh and Chen 2018). Zhu and Kraemer (2005) highlight that, most frequently, the TOE framework is supported empirically in the IT field. To our knowledge, there are no studies applying the TOE framework in analysing smart charging adoption.

Moreover, there is the scarcity of literature focusing on policy-oriented scholarship within technological innovation studies. Given that the energy transition in Europe has progressed thanks to the rapid expansion and evolution of energy regulatory frameworks, an approach enabling their examination in regard to the adoption of the particular technology is particularly relevant.

2.10 Chapter summary

The PED concept refers to the development of districts that produce more energy than they consume, on an annual basis, by employing a technology-driven approach. Their development is promoted in the EUs SET-Plan, confirming that they are a policy instrument toward addressing the energy transition targets in Europe. There is limited knowledge regarding PED projects due to their novelty and implementation stage of development, while contributing to this knowledge gap will provide a deeper understanding of their realisation and support evidence-based decision-making.

Studying smart charging adoption in PEDs is justified for several reasons. Firstly, there is a scarcity of studies examining smart charging adoption from a collective level, presenting a gap in the scholarly literature (Meelen and Schwanen 2023). Secondly, the chapter reveals that, in the regulatory context, the contribution of smart charging to the enhancement of grid flexibility, and the importance of adopting smart charging, is acknowledged and recognised across the EU, UK, and USA (Directive (EU) 2023/2413; UK Governmenet 2022; California Energy

Commission 2023). The countries promote smart charging adoption by offering financial incentives such as smart charging tariffs and demand-response programmes (Burger et al. 2022; Kester et al. 2018; Philip et al. 2023). This highlights the role of policy in smart charging adoptionng across countries.

The analysis of the efforts of PEDs is important for informing policy makers about their progress in implementing low carbon technologies. Research on decisions of PEDs regarding smart charging adoption is needed to understand the barriers and enablers of the technology and inform policy development. Research that addresses how and why smart charging is adopted in PEDs can inform PED developers and other decision-makers about knowledge gaps and provide evidence-based recommendations for enhancing smart charging adoption.

Finally, this chapter discusses the factors examined around technology adoption employed within different theoretical frameworks and exhibiting various objectives. Although the DoI theory is one of the most recognised and widely used theories, the TOE framework is seen as the most suitable way of studying smart charging adoption in PEDs due to its consideration of the organisational and policy perspectives. Therefore, the TOE framework has driven the research methodology to achieve a more comprehensive grasp of smart charging adoption in PEDs – as considered next.

Chapter 3 Methodology

3.1 Introduction to the chapter

This study explores smart charging adoption at the organisation level, focusing on both its determinants and process. The analysis comprises three stages. First, it investigates the factors influencing the adoption of smart charging from technological, organisational, and policy perspectives, through interviews with energy experts who have engaged with or had experience in adopting smart charging in energy projects,with the aim of addressing energy transition targets. Secondly, it examines the activities, structures, and interactions of organisational stakeholders, as well as national policy and market conditions in two PED projects that aimed to adopt smart charging, but that had contrasting outcomes in terms of adoption. Lastly, the derived findings are extrapolated to an additional ten PED projects to provide a contextualised understanding of relationships between conceptual domains and to assess the degree of similarity between contexts.

This chapter begins with Section 3.2, which outlines the overarching research question and subquestions that the thesis aims to address and how they can contribute to filling the gaps identified in the literature review. Section 3.3 introduces a theory-driven reflexive thematic analysis approach employed to analyse interviews, project documents, and policy documents. Section 3.4 presents the theoretical foundation for the research, guided by the TOE framework. This section describes the core principles and philosophical underpinnings of the TOE framework, which shaped the themes of the study.

Section 3.5 describes the methodological stages of data collection. Specifically, these stages incorporate participant observations from four study trips, active participant observations from two secondments, two-stage interviews with experts who engaged with or had experience in adopting smart charging in energy projects, interviews with stakeholders of PED projects, government policy documents, as well as Smart-BEEjS project documents.

Finally, this chapter explains how the generalisation of findings and ethical issues are addressed.

3.2 Research questions

The study aims to address the following primary research question:

1. *What are the key drivers of smart charging adoption in PEDs?*

Three subquestions guide the study. They serve to investigate the factors influencing the adoption of smart charging technology in PEDs and its detailed processes. To explore the potential prerequisites for choosing or not choosing smart charging technology, it is useful to examine the role of smart charging technology from the perspective of PED developers. This leads to the first subquestion:

1. *What is the role of smart charging technology in PEDs?*

To understand how PED projects select novel technologies and how their organisational practices influence the adoption of smart charging technology, the second subquestion explores the organisational capacity characteristics of PEDs, such as governance and financial resources, and their potential impacts on adoption. This provides insights into the resources involved in decision-making and the challenges faced by projects during adoption. A focus on organisational capacity may help shape recommendations for early-stage developer projects that aim to adopt smart charging. The second subquestion is, therefore:

2. *What organisational characteristics of PEDs can influence the adoption of smart charging technology?*

The third subquestion investigates the role of policy frameworks in the adoption of smart charging within PED projects. This involves understanding various national visions regarding smart charging and their potential impacts on the decisions of PEDs toward the adoption of the technology.

3. *What role does policy play in the adoption of smart charging in PEDs and how can policymakers be supported in this?*

Interviewing energy experts, representatives of energy projects that have implemented smart charging, and representatives of PED projects, as well as comparing the following dimensions:

technologies implemented across projects, organisational capacity characteristics, and policy and market frameworks, allow the research aims, objectives and questions to be addressed.

3.3 Theory-driven reflexive thematic analysis

The study employs the reflexive thematic analysis method developed by Braun and Clarke (2006). This method is defined as "a flexible approach that can be used across a range of epistemologies and research questions" (Braun and Clarke 2006, p.97), and encourages "a rigorous and systematic approach to coding and theme development, but is also fluid and recursive, rather than rigid and structured and requiring the use of a codebook or coding" (Braun and Clarke 2019, p.592).

The method has been chosen for several reasons, that are considered well-aligned with the research aim, objectives, and questions, and for its capacity to support a coherent research design. Firstly, it offers tools that are compatible with a deductive approach, enabling the researcher to examine pre-existing theoretical assumptions within the context of the study. Secondly, the reflexive thematic analysis approach is used to identify patterns and links within and across the data, which is key to this study exploring the factors influencing the adoption of smart charging technology in PEDs. This approach allows for a detailed examination of the research questions and objectives, in alignment with the critical realism paradigm. Tables and mind-mapping techniques, as part of thematic analysis, are employed to clearly communicate the analytic process and theme-generation structures. Lastly, the approach is well-known in qualitative research for its capacity to develop themes or 'patterns', while also contributing to analytical rigour and the robustness of findings (Braun and Clarke 2020).

The method offers "an adventure, not a recipe" (Braun and Clarke 2019, p.592), and emphasises flexibility in researchers' decisions regarding "what counts as a theme", as well as how themes are identified in data (Braun and Clarke 2006, p.83). These include choices between "inductive versus theoretical thematic analysis" and the type of analysis, such as 2a rich description of the data set, or a detailed account of one particular aspect" (Braun and Clarke 2006, p.83). Braun and Clarke (2019a) emphasise that they do not advocate generating themes based solely on frequency counts, as frequency does not necessarily correlate with importance. Instead, they encourage a clear articulation of the research design, particularly in relation to its values and philosophical assumptions.

The reflexive thematic analysis method allows for the integration of theory with data by applying a structured 6-stage framework. The six stages are as follows: 1) familiarising yourself with your data; 2) generating initial codes; 3) searching for themes; 4) reviewing themes; 5) defining and naming themes; 6) producing the report (Braun and Clarke 2006, p.86).

The first stage involves reading the collected data, understanding its content, and noting emerging patterns. The second stage includes organising the data, labelling it into groups, and developing initial codes. During this stage, Braun and Clarke (2006) emphasise the importance of giving equal attention to all data groups to avoid overlooking interesting aspects that could contribute to themes across the dataset. They also suggest generating as many potential themes as possible, explaining that "you never know what might be interesting later" (Braun and Clarke 2006, p.89).

The third stage involves combining, refining, and separating codes, as well as exploring relationships between them. To organise codes into potential main themes and sub-themes, Braun and Clarke (2006) suggest using visual representations, such as tables or mind-maps, to experiment with and refine the thematic structure. They also advise aligning themes with the research questions, emphasising that themes are soundly determined by the researcher's judgement.

The fourth stage involves refining themes across two levels (Braun and Clarke 2006). At the first level, themes are reviewed to ensure they form a meaningful pattern while remaining clearly distinct from one another. At the second level, a similar procedure is suggested but considering the entire data set. The thematic mind-map also requires refinement to ensure it accurately represents the study's theoretical and analytic approach. Overall, at this stage, a researcher typically has a clearly understanding of how themes fit together and the stories they tell in relation to the data (ibid.).

At the fifth stage, the researcher needs to think about the final titles of themes, revising working titles, keeping in mind that "names need to be concise, punchy, and immediately give the reader a sense of what the theme is about" (Braun and Clarke 2006, p.93). This stage also involves writing an analytic narrative for each theme, which refers to the story the data conveys - not in a purely descriptive manner, but as an argument that addresses the research questions.

The final stage involves writing the report, which includes analytic narratives and extracts of data, demonstrating evidence of the identified themes. This stage presents a concise account of the data, highlighting patterns both within and across themes, guided by the research questions and theoretical assumptions (ibid).

In this study, during the first stage interview transcripts were read to familiarise oneself with the data, and initial considerations of potential patterns were noted. In stage two, potential themes relevant to the research questions were generated using both deductive and inductive approaches. In the third stage, transcripts were reviewed, and a second-round of themes coding was conducted to combine or refine the themes. Additionally, mind-maps were created to visualise potential links between themes and the overall analytic structure. In stage four, themes were reviewed both within individual themes and across the entire dataset to ensure they accurately reflected the meaningfulness of the data. Stage five involved writing analytic narratives, highlighting patterns and links within and across themes. In the final stage, written analytic narratives and data extracts were reviewed to ensure they provided a concise and logical account of the data, which was reported in Chapter 4.

This study employs a theory-driven analytic approach, deductively generating three umbrella themes from the TOE framework: “technology”, “organisation”, and “environment”. The predefined themes provide a guiding structure to navigate the data effectively and frame the identified narratives within a theoretical context. Meanwhile, all other themes emerged inductively from the collected data to ensure that the analysis reflects the experiences of PED projects rather than solely adhering to the theoretical framework.

The TOE framework is founded on a critical realism perspective, as explained in Section 3.4. Braun and Clarke (2006, p.81) describe reflexive thematic analysis as a “contextualist” method, sitting between the two poles of essentialism and constructionism, and characterised by theories such as critical realism (eg, Willig, 1999), which acknowledge the ways individuals make meaning of their experience, and, in turn, the ways the broader social context impinges on those meanings, while retaining focus on the material and other limits of “reality”.

3.4 Theoretical Foundations

The TOE framework is conceptualised around the idea that “technologies should be created to serve human purposes, not vice versa”, emphasising that the process of technology adoption should be guided and managed by human purposes and human values (Tornatzky and Fleischer 1990, p.6). It emphasises that technology adoption should be guided by human values and managed within social contexts. The social context of the framework explores human behaviour patterns in relation to the use of technology, or how human behaviour can shape the use of technology. Nevertheless, in the context of epistemology, while the TOE framework acknowledges the role of human beliefs and interpretations in viewing reality, it argues that “technology is inextricably linked to scientific principles and facts” associated with the empirical observation of physical or social phenomena, assuming that “certain laws, principles, or theories can economically explain these phenomena” (Tornatzky and Fleischer 1990, p.14). It does not assume causal directionality between technology adoption and scientific principles and facts; instead, it assumes an irretrievable relationship between them, the understanding of which is part of the framework’s inquiry.

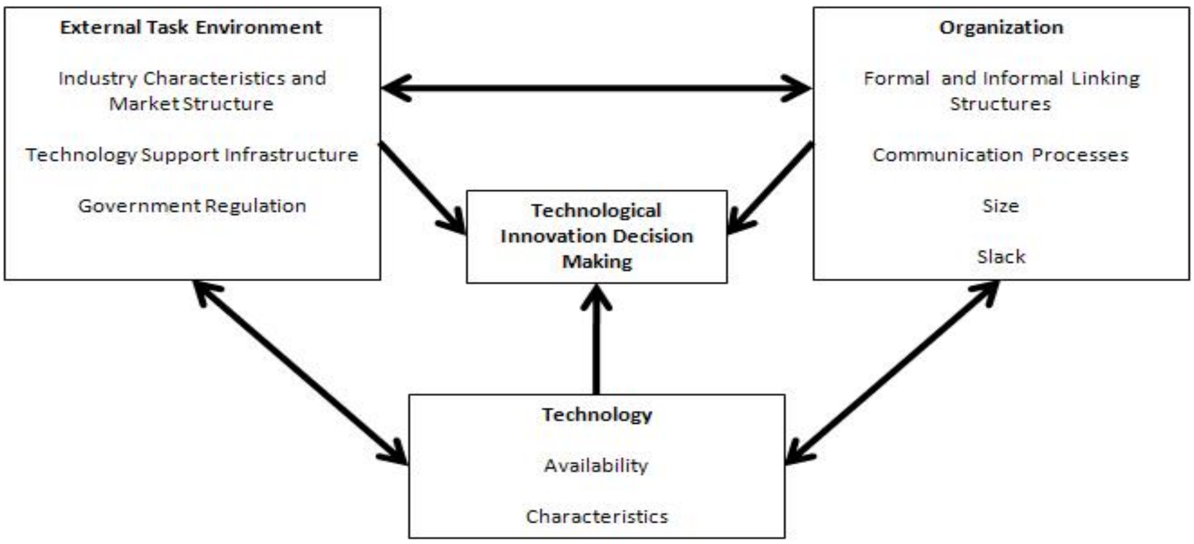
This study adopts the TOE framework to examine the adoption of smart charging among PED projects, acknowledging that a PED project is a complex social phenomenon influenced by both internal organisational factors – such as how these project members view their work, communicate with organisational stakeholders, and interpret their roles and experiences – as well as external factors, incorporating market conditions and political influences.

The TOE framework aligns with a critical realism perspective, which is significant to acknowledge, in line with my stance, as it affected the methods of collection and analysis of data (Birks and Mills 2015). Critical realists posit that “ontology (i.e. what is real, the nature of reality) is not reducible to epistemology (i.e. our knowledge of reality)” (Fletcher 2017, p.182). The tenets of critical realism suggest that human knowledge is often limited to empirical description of a context and only captures a portion of reality. Thereby, critical realists stratify reality into three levels: empirical, actual, and real (Bhaskar 1979). The empirical level is frequently measured through human experiences and interpretation. The actual level measures events without filtering them through human experience, based on the paradigm that events occur whether we experience them or not. The real level measures causal forces that for example appeared at the empirical level and explain events through those "causal mechanisms" (Fletcher 2017).

A critical realism perspective aligns with this approach, recognising that while qualitative research can identify relationships between variables, it does not seek to quantify them. Instead, the focus is on understanding mechanisms and causal influences that shape adoption behaviours.

The emphasis of the TOE framework is placed on capturing "the panorama of technological innovation, including people, organisations, and politics, and their relationships to one another" in investigating causes of adopting new technologies (Tornatzky and Fleischer 1990, p. 3). It suggests examining technology adoption with the following factors: availability characteristics, formal and informal linking structures, communication processes, size, slack, industry characteristics and market structure, technology support infrastructure, and government regulation, as presented in Figure 4.

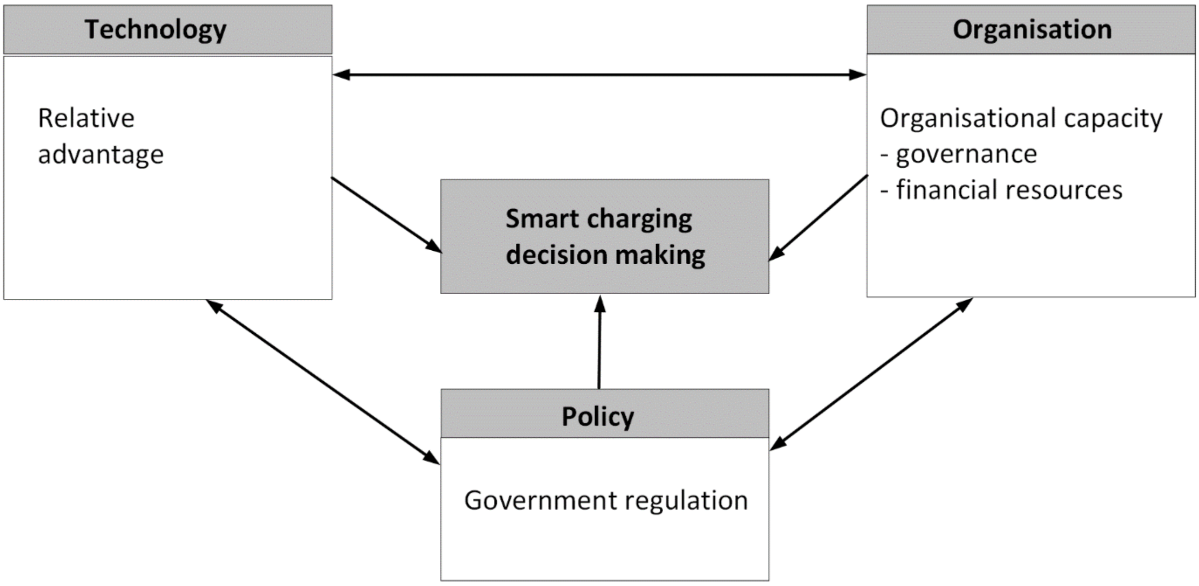
Figure 4 The TOE framework



Source: Tornatzky and Fleischer 1990

In this study, the TOE framework is adopted as presented in Figure 5, based on both the narrative literature review and participant observations. The adopted framework aims to enhance the understanding of the following aspects: 1) the reasons for adopting smart charging; 2) the relationship between organisational capacity and smart charging adoption; and 3) the role of policies in shaping adoptive behaviours related to smart charging. As a result, the adopted framework incorporates concepts such as “relative advantage” added to the technological dimension, “governance”, and “financial resources” added to the organisational dimension, and “government regulation” as part of the policy dimension.

Figure 5 The adopted TOE framework for applying a reflexive thematic analysis in the study



Source: Adapted from Tornatzky and Fleischer 1990

By applying the TOE framework, this study seeks to move beyond merely describing smart charging adoption, to exploring the underlying mechanisms influencing decision-making in PED projects, with the framework providing a structured lens for investigation. This aligns with the deductive qualitative analysis approach, which uses theoretical foundations to guide analysis and identify variables that may be related to each other - not to quantify the extent of the relationship, as in quantitative research, but to explore and refine theoretical understanding.

Deductive qualitative analysis relies on the utilisation of conceptual frameworks and *a priori* theorising which, according to Gilgun (2015), was a common approach before the publication of Glaser and Strauss’s (1967) “The Discovery of Grounded Theory”. Gilgun (2015, p. 14) states that “the purpose of deductive qualitative analysis is to come up with a better theory than researchers had constructed at the outset. Indeed, the production of new, more useful hypotheses is the goal of deductive qualitative analysis”. For instance, Henderson and Baffour (2015) purposefully applied a Socio-Ecological Framework to a reflexive thematic analysis, aiming not merely to confirm the theory but to expand it, thereby contributing to the framework and providing practical examples within the field of social justice.

Other scholars also support a deductive approach in qualitative studies. For example, Johnston et al. (2000, p.222) suggest that "when research hypotheses are not driving the research, findings can only be thought of as exploratory and/or descriptive". The originator of critical realism, Bhaskar (1979, p. 62), condones starting empirical research from existing theory: "Once a hypothesis about a generative structure has been produced in social science it can be tested quite empirically, although not necessarily quantitatively".

Patton (1991, p. 194) also supports the use of deductive processes in qualitative research, outlining that "As evaluation fieldwork begins, the evaluator may be open to whatever emerges from the data, a discovery or inductive approach. Then, as the enquiry reveals patterns and major dimensions of interest, the evaluator will begin to focus on verifying and elucidating what appears to be emerging, a more deductive approach to data collection and analysis".

Following on from these precedents, this study employs a deductive approach, using the TOE framework as a guiding structure while remaining open to emergent themes from the data. The TOE framework provides a valuable lens for examining the adoption of smart charging in PEDs, integrating technological, organisational, and environmental dimensions. Reflexive thematic analysis supports the use of deductive qualitative analysis, enabling this study to contribute both theoretical insights and practical implications for technology adoption in projects advancing toward a Net Zero future.

3.5 Multiple-case study design

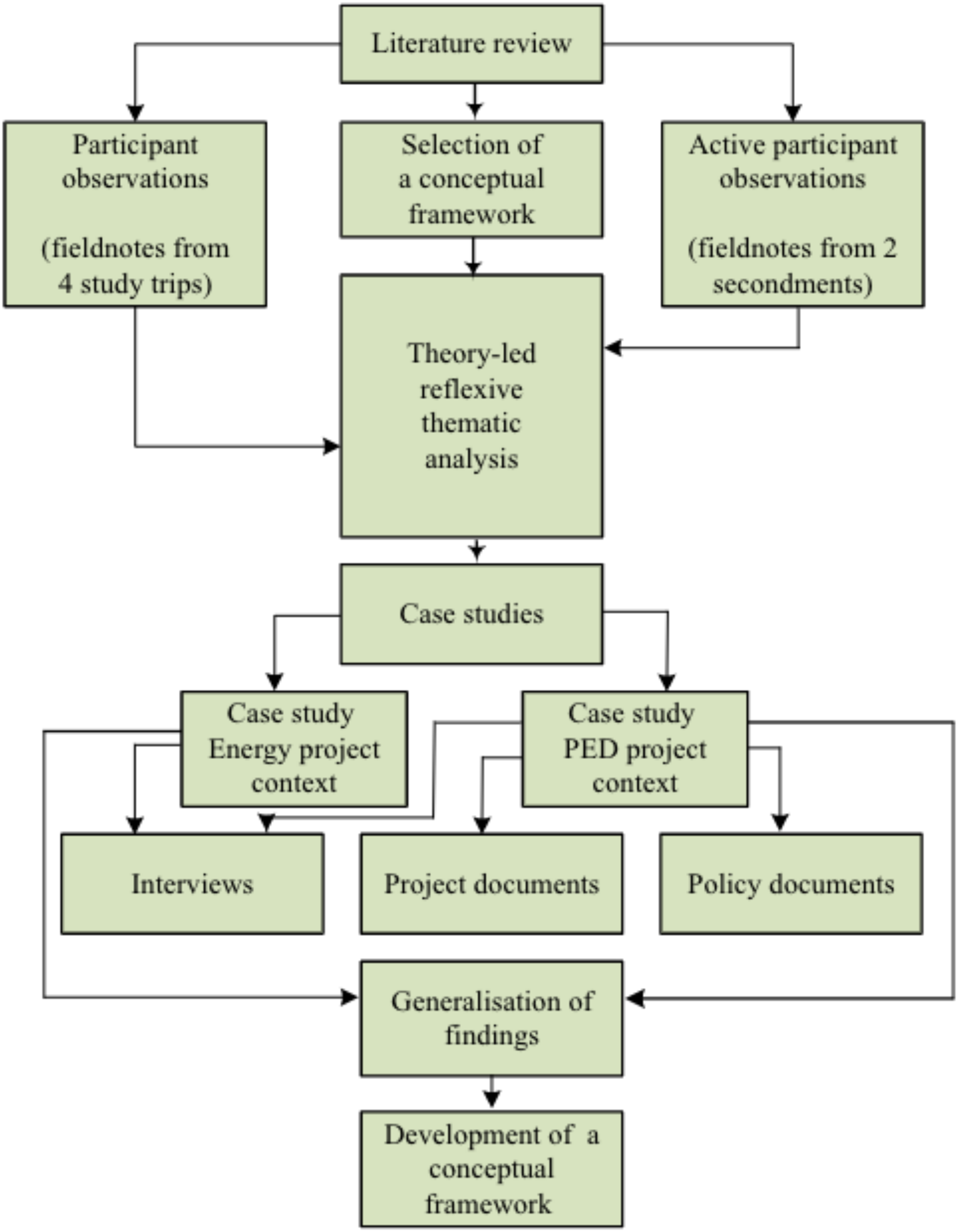
The innovative practices within organisations are frequently researched through the adoption of case studies (Brunia et al. 2016; Kaplan 1986; Otley, Berry 1994; Yin 2018). Case studies have frequently been utilised to analyse processes (George and Bennett 2005; Creswell and Creswell 2018), providing in-depth understanding of complex phenomena in a real-word context, and to answer 'how' research questions (Yin 2018). The case study approach can be distinguished by several types of design based on disciplinary orientations, including historical, psychological, ethnographic, or sociological perspective (Merriam 2002), purpose characteristics, encompassing intrinsic, instrumental, or collective (or hybrid) (Stake 1995), and function features, such as exploratory, explanatory, and descriptive (Yin 2018).

This research has a sociological orientation, focusing on the exploration of energy projects, their structures, interactions of organisational stakeholders, and the impacts on the adoption of technological innovations. It employs a collective case study design, which addresses both instrumental and intrinsic goals. An instrumental case study design aims to "better understand a theoretical question or problem" and to provide "a greater insight of the theoretical explanation that underpins the issue" (Hancock and Algozzine 2006, p.32).

An intrinsic case study design does not necessarily examine or develop theoretical concepts, nor does it generalise findings to broader populations; instead, it focuses on exploring a particular individual, event, or organisation (Hancock and Algozzine 2006). As this study aims to contribute both to the creation of general theories and to explore specific energy projects, wherein the exploration of the project is part of the investigation, a collective case study design is applied. This entails the application of functions such as exploratory and descriptive research designs.

The flow chart below summarises the methodological steps outlined in this research. The key elements of the study were analysed using a reflexive thematic analysis approach.

Figure 6 Methodology flow chart of the research



The study encompasses three stages. The first stage involves interviewing a group of people with specific knowledge and experiences, resulting in the broadening of conceptual domains and their incorporation into a conceptual framework. The selection strategy, which focuses not on a particular energy project but on interviewing a group of individuals engaged in energy projects that have implemented smart charging infrastructure or have experience in smart charging, electricity markets, or systems integration, is aimed at addressing the theoretical inquiry in identifying determinants of smart charging adoption.

The second stage involves the in-depth contextualised exploration of particular PED projects, namely Pocityf and Åland Island. This stage incorporates two case studies with different outcomes in the context of the adoption of smart charging. Schramm (1971, p.6) posits that the purpose of a case study is "to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result […] to contribute to policy and decision making". Tornatzky and Fleischer (1990) define the process of technology adoption as encompassing various activities, decisions, and behaviours of individuals and social units. Therefore, the second stage not only applies a conceptual framework to verify and test its relevance but also explores the activities undertaken by the projects and interactions among stakeholders.

Strategies for selecting case studies resemble decisions made in field experiments, where the emphasis is on cases that may best facilitate hypothesis testing (Yin 2018). Two PED projects, Pocityf and Åland Island, are selected from the PED booklet (JPI Urban Europe 2020a) and are based on three criteria:

1) setting a goal to adopt smart charging infrastructure;
2) different organisational capacity related to structure and financial resources (EU-funding/national funding);
3) diverse outcomes associated with the adoption and non-adoption of smart charging infrastructure.

The second and third criteria form part of a diverse selection strategy incorporated to enhance the robustness of the patterns emerging from the analysis of case studies (Ridder 2017) and to achieve "maximum variance along relevant dimensions" (Seawright and Gerring 2008, p. 300).

Deductive qualitative studies are frequently vulnerable to critiques associated with "the selective bias introduced by researchers" awareness of the qualitative case outcomes at the time of hypothesis formulation" (Bitektine 2008, p.161). To mitigate this bias, the study selected cases with both positive and negative outcomes in terms of the adoption of smart charging. Yin (1981, p. 108) notes that "data from a single case can be used to test a theory (i.e., a pattern), as long as contrary theories are also compared". Furthermore, Yin (2018, p.69) suggests that "Addressing such rivals becomes a criterion for interpreting your findings: the more rivals that have been addressed and rejected, the stronger will be your findings". Therefore, in this study, in-depth case study analysis explores one positive and one negative case study in terms of the adoption of smart charging.

In the Pocityf and Åland Island projects, the process of the adoption of smart charging is investigated by exploring the sequence of activities, interactions between stakeholders, as well as technological, organisational, and environmental characteristics in accordance with the adopted TOE framework. Figure 8 presents parameters explored in the case studies, wherein the process considers activities involved from setting a goal to adopt smart charging (Point A) to the outcome, adoption, or non-adoption of smart charging (Point B) within the duration of projects.

The third stage involves the generalisation and replication of findings and focuses on exploring the relationships of conceptual domains across 11 PED projects. The selection of additional projects relies on contextual conditions, distinguished under two criteria: EU-funding and non-EU funding. The projects are as follows:

1) EU-funded PED projects: CityXchange, Making-City, Atelier, Replicate, MySmartLife, SmartEnCity, Stardust, Sharing Cities projects;
2) Non-EU-funded PED projects: the ZEN research center and City District Development Graz-Reininghaus.

The outlined PED projects are selected from the PED booklet (JPI Urban Europe 2020). Notably, the ZEN research centre project is described as 7 separate PED projects in the PED booklet. Nevertheless, analysis of the project's publicly available documents revealed that these 7 projects are Norwegian pilot projects managed by one entity, the ZEN Research Centre, and funded by the Research Council of Norway. In this thesis, these 7 projects are treated as one PED project, named the ZEN research center.

3.6 Methods of data collection

To support a range of perspectives and contribute to richness of data, several methods were used to collect data, which are as follows:

1) participant observations;
2) semi-structured interviews;
3) government policy documents; and
4) Smart BEEjS project documents.

3.6.1 Participant observations

The participant observation and active participant observation initiatives were organised within the Smart BEEjS project as part of the Marie Skłodowska-Curie Innovative Training Network programme. The participant observation includes four study trips involving visits to pilot demonstration energy projects, while the active participant observation incorporates two secondments at various research organisations, as listed in Table 4.

Participant observation derived from ethnographic fieldwork refers to "establishing a place in some natural setting on a relatively long-term basis in order to investigate, experience and represent the social life and social processes that occur in that setting" (Emerson and Fretz 2011, p. 2). In this study, active participant observation refers to prolonged (4 and 6 months) observation with the active engagement of an observer in a natural setting, while participant observation refers to a short-term (1 day) observation with passive participation.

Table 4 Participant observations

Code	**Study visits/ secondment organisation**			**Location**	**Date**
ST-1	Study trip	Participant observation	Hydro-wind power plant	Gorona del Viento – El Hierro Island, Spain	29.11.2019
ST-2	Study trip	Participant observation	Smart transportation system strategy	Torres Vedras, Portugal	07.02.2020
ST-3	Study trip	Participant observation	Cooperative "Citizens"	Lisbon, Portugal	14.02.2020

			renewable energies”		
SC-1	Secondment	Active participant observation	Cenex	Loughborough, UK	April - September, 2021
SC-2	Secondment	Active participant observation	Independent transport commission (ITC)	London, UK	May-September, 2021
ST-4	Study trip	Participant observation	Eastcroft depot at Nottingham City Council	Nottingham, UK	26.05.2022

I participated in four study trips, namely ST-1, ST-2, ST-3, and ST-4, each lasting one day. The study trips demonstrated various technological innovations implemented within energy projects across European countries, including Spain, Portugal, and UK. These energy projects showcased the following technologies:

· ST-1 involved the integration of windmills with hydro storage,

· ST-2 showcased the implementation of four EV chargers without embedding smart charging technology,

· ST-3 demonstrated the “energy cooperative” project dedicated to collective investments in solar panels, resulting in the establishment of an independent electricity retailer, and

· ST-4 presented the integration of solar panels with a fleet of EV chargers embedded with V2G technologies.

I participated remotely, due to COVID-19, in two secondments, lasting 4 and 6 months respectively. These secondments were carried out simultaneously at different research organisations focusing on low emission transport infrastructure: the research charity the Independent Transport Commission and the not-for-profit research technology organisation Cenex. The aim of these secondments was to provide opportunities to experience the field of practice, engage with experts from various environments and disciplines, and collect data for the research.

The secondment at SC-1 involved participating in the GreenSCIES project, which aims to design a smart energy system integrating low-carbon electricity, heating, and mobility for one of London’s neighbourhoods, Islington. The secondment involved the active participation in internal meetings with members of the Cenex organisation, as well as meetings with stakeholders of the GreenSCIES project. As a result of the secondment, a white paper co-authored with Cenex and Energy Systems Catapult organisations was released, covering policy challenges and future changes for projects like GreenSCIES (Cenex and Catapult 2022).

The secondment at SC-2 involved participating in exploring the challenges that cities face in decarbonising road transport. This secondment included participation in meeting with the ITC Steering Committee, who guided the research, as well as primary data collection and analysis. The result of the secondment was my contribution to the research (Heinz et al. 2022). However, as the research required an extension of the secondment, which I could not continue due to personal circumstances, my participation did not meet the criteria typically required for co-authorship. Nevertheless, this secondment significantly influenced the methodological considerations of this study, particularly regarding a multiple case study approach.

Fieldnotes

A method of collecting data through participant observations incorporates fieldnotes, which are defined as "a form of representation, that is, a way of reducing just-observed events, persons, and places to written accounts" (Emerson and Fretz 2011, p. 4). Fieldnotes include descriptions of "facts", reflections embedding particular purposes, and interpretations of active processes (ibid.). My fieldnotes recorded facts from observations, discussions, and presentations, as well as my reflections and interpretations of these facts. The fieldnotes were insightful as they obtained information from the perspectives of project developers regarding project development activities, barriers, enablers, and proposals for further facilitators of the energy transition. The participant observation provided ample material for analysing and learning about project activities and development processes. Figure 7 presents an example of a summary of fieldnotes used in the study.

Figure 7 Example of fieldnotes

Fieldnotes written within study trips and secondments
The demonstration projects ST-1 and ST-4, at the time of visit, have recently implemented renewable technologies such as windmills and solar panels accordingly. Furthermore, both projects aim to implement EV charging infrastructure embedded with smart charging to benefit energy flexibility management.

The demonstration project ST-1 is an autonomous energy system integrating a wind farm with pumped-water storage. The project plans to implement V1G smart charging to manage charging when the demand is high. The project emphasises that the shift from ICE to EVs will lead to significant challenges for its local electricity demand, highlighting the importance of a strategic approach to EV charging across autonomous energy systems. The ST-4 project aims to integrate roof solar panels with the council fleet embedded with V2G smart charging. In this project, EV batteries thanks to V2G technology, will be used as an energy storage to store a surplus of solar energy when applicable.
The observations from study trips ST-1 and ST-4 have demonstrated the association between the implementation of V2G technology and renewable technologies. Meanwhile, the ST-2 project has illustrated the association between a lack of implementation of renewables and the deployment of four EV chargers without embedding smart charging technology. The ST-2 project focuses on improving the transport system, resulting in the implementation of various mobility measures, including enhancing walking, cycling, and public transport. These facts have supported the understanding of the relationship between renewables and smart charging, particularly V2G, as well as the aim to explore these themes in the context of PED projects.
Participation in the GreenSCIES project during the secondment at Cenex, SC-1, provided an opportunity to observe the project's research stage, which involved designing technical and commercial aspects. During this secondment, links between goal settings, project stakeholders, and financial resources, in relation to the decision to adopt smart charging within the GreenSCIES project were observed. During secondment SC-2, while studying the deployment of low carbon infrastructure across various cities, the importance of the roles of decision-makers and stakeholders in adopting technological innovations was also revealed. These observations supported the formulation of theoretical concepts regarding the influence of organisational characteristics on smart charging and the aim of exploring them in the context of PED projects.
During the secondment SC-1, while reviewing UK energy policy, the following aspects were revealed:

- a range of regulatory changes in energy code have been undertaken to support the provision of flexibility from small assets, including V2G;
- the UK has established the Smart System and Flexibility Plan, which supports the development of LFMs;
- the UK is the first country to mandate the incorporation of new domestic and workplace charging points with V1G smart charging functionality since 2022.

This review has facilitated my understanding of the relationships between the supportive market and policy frameworks and smart charging.

Emerson and Fretz (2011) outline that fieldnotes may incorporate not only observed activities or learning from observations, but also the researcher's own actions, questions, and reflections. Figure 8 presents an example of fieldnotes written within the SC-1 secondment, demonstrating observed activities and learning from observations. Figure 9 illustrates an example of fieldnotes written within the SC-2 secondment, showing how I was relying on them to capture my ideas and theoretical progression.

Figure 8 Example of fieldnotes, SC-1

Fieldnote (written within the Cenex secondment)
The title of the research I work on during the Cenex secondment is "Policy challenges and future changes for smart local energy systems (SLES)". I participate in a team that develops the design for the GreenSCIES project, which is a SLES that aimed to implement district heating and smart charging infrastructure. I view this project as a proxy for PEDs. This secondment has enabled the engagement with the project developers and provided an understanding of the potential impacts of organisational characteristics on technology adoption. This experience has allowed me to observe two concepts: 1) large collaboration between organisations has great human resource capacity in terms of knowledge sharing and exchange, facilitating goal achievements; 2) at the same time, multi-stakeholder organisation may face challenges in managing projects, influencing organisational progress in addressing goals or diminishing the quality of delivering results.

To some extent, this experience has facilitated to study organisational characteristics of PEDs in my thesis to gain a deeper insight into factors involved in the processes of adopting smart charging. The review of policies affecting SLES has expanded my understanding of the role of market frameworks in the adoption of smart charging and the relationship between LFMs and V2G: 1) the development of LFM is critical for SLES, as LFM can substantially increase energy efficiency and energy flexibility in SLES, which are key goals of SLES in the wider context; 2) there is a lack of regulation facilitating LFM; 3) financial rewards for using technologies that enable the enhancement of energy flexibility, including V2G, are fundamental for the development of LFM.

Figure 9 Example of fieldnotes, SC-2

Fieldnote (written within the ITC secondment)
The title of the research I work on is "Achieving low carbon infrastructure in our cities: key issues for policymakers". In the research, three case studies are selected based on the criterion of representing various archetype of cities primarily associated with the size characteristic. This approach has influenced me to reflect on criteria for case study selection as well as on factors I aim to explore within my thesis. I have asked myself a question: "The diversity of what characteristics across PED projects can better serve the exploration of decisions on technology adoption?" and made the following notes: 1) in the ITC work, the regulatory perspective demonstrates its significant influence on the adoption of EV infrastructure. This entailed my thinking toward the exploration of the role of regulation on technology adoption within the PEDs context, assuming that this perspective can significantly enrich my study. 2) in the ITC research, a lot of attention is given to the role of local authorities in the transition to low carbon transport across cities. In the evaluation stage, local policies and the managerial size of local authorities are compared, underpinning the importance of not only the regulatory context but also the organisational context.

3.6.2 Semi-structured interviews

Interviews are selected for data collection as they allow for the observation of a wider flow of information from respondents to researchers, compared to methods such as surveys (DeRosia and Christensen 2009). These wide language-based materials may facilitate the determination of new constructs or emergent phenomena (ibid). The semi-structured interview is one of the most commonly used methods in qualitative studies, defined as “a data collection strategy in which the researcher asks informants a series of predetermined but open-ended questions” (Ayres 2008, p.810). This study employs the semi-structured interview approach, as it allows interviewers to choose the wording to each question, clarify interesting or relevant points outlined by the respondents, and elicit valuable information (Barriball and While 1994). In this study, the research questions aim to elicit detailed answers rather than just ‘yes’ or ‘no’ responses.

The study includes 18 interviews, as outlined in Table 5. The respondents fall into three categories: 1) representatives of an energy project that adopted smart charging; 2) experts in smart charging, electricity markets, or systems integration; and 3) stakeholders involved in PED projects. All categories of respondents provided valuable data for understanding the complex process of smart charging adoption in a broader context, particularly regarding the integration of power and mobility systems across PED projects.

Due to the narrow and specific criteria for sampling expertise in technological innovation, it was challenging to sample respondents with relevant experience. Moreover, as the context of the study pertains to energy projects across Europe, the geographical spread of participants spans several European countries. Most contacts of respondents were recommended by members of the Cenex organisation, the AMS (Amsterdam Institute for Advanced Metropolitan Solutions) Institute’s Scientific Conference, and the Smart BEEjS consortium, and were reached by email.

Table 5 List of interview respondents

Country	**Role**	**Specialisation**	**Code**
Austria	Academia	Transport	Int 2
UK	Senior manager	Transport	Int 4
UK	Technical specialist	Transport	Int 5
UK	Senior manager	Energy policy	Int 6
UK	Consultant	Energy policy	Int 7
UK	Specialist	Renewable energy	Int 8

UK	Manager	Transport policy	Int 1
UK	Technical specialist	Energy system and infrastructure	Int 10
Switzerland	Postdoctoral researcher	Large-scale V2G project	Int 9
Netherlands	Intraday power trader	Electricity system	Int 3
Netherlands	Senior manager	Electricity system	Int 11
Netherlands	Consultant	Energy system integration	Int 12
Netherlands	Stakeholder	Transport	Int 14
Netherlands	Stakeholder	Transport	Int 16
Portugal	Stakeholder	Digital	Int 15
Portugal	Stakeholder	Digital	Int 13
Finland	Stakeholder	Academia	Int 18
Finland	Stakeholder	Renewable energy	Int 17

Below is an outline of the initial interview questions (Figure 10), which do not include probes, for representatives of PEDs, as well as for experts in smart charging, energy flexibility, or systems integration fields. As the interviews progressed, these questions were refined by adding additional or follow-up questions. Follow-up questions were employed to be receptive to new information as it can emerge and to allow a more detailed examination of specific traits under investigation (Leyens et al. 1998).

Figure 10 Interview questions

Interview questions for stakeholders involved in PEDs	Interview questions for experts in the fields of smart charging, energy flexibility, or systems integration
1. What is your role in the project, and what is the role of your organisation within the projects? 2. What is the role of managers in the project? How do stakeholders communicate with each other, and how	1. What are benefits and barriers of implementing smart charging? 2. What role can smart charging technology play in emerging energy projects? 3. Can the availability of renewables impact the adoption of smart charging across energy projects?

are organisations governed within the project? 3. What are the key objectives of your project, and what are key features of your project? 4. What are benefits of implementing smart charging? 5. Can the availability of renewables impact the adoption of smart charging across energy projects? 6. Can market and policy frameworks influence the adoption of smart charging across energy projects? If so, how? 7. If you had to identify one key barrier to smart charging adoption among technological, organisational, market, or regulatory challenges, what would it be?	4. Can organisational capacity influence the adoption of smart charging across energy projects? If so, how? 5. Can market and policy frameworks impact the adoption of smart charging across energy projects? If so, how? 6. If you had to identify one key barrier to smart charging adoption among technological, organisational, market, or regulatory challenges, what would it be?

3.6.3 Policy documents

Policy analysis is a method frequently used in qualitative approaches as a supplementary source of data collection to add rigour to a study (Cardno 2018). Data collection at this stage aims to identify statements of national and EU policies regarding the enhancement of energy flexibility and the adoption of smart charging infrastructure. This analysis would provide the environmental context of PED projects, specifically policy and market frameworks, in relation to the vision for the adoption of smart charging in the countries where they are located and the position of PEDs within this vision. Table 6 summarises the policy documents selected for detailed analysis in the case studies of Pocityf and Smart Energy Åland. Appendix D presents the policy documents considered during the generalisation of findings stage.

Table 6 Selected policy documents for analysis

Pocityf (Netherlands)	**Smart Energy Åland (Finland)**	**EU regulation**
Dutch National Charging Agenda	Finland's Integrated Energy and Climate Plan	Directive (EU) 2023/1791: Energy Efficiency
Smart charging for all 2022-2025. Action Plan	Government report on National Energy and Climate Strategy for 2030	Directive (EU) 2019/944: Common Rules for the Internal Market for Electricity
Smart Charging Requirements	Roadmap to Fossil-Free Transport	Directive (EU) 2023/2413: Promotion of Energy from Renewable Sources
National Grid Congestion Action Programme	Carbon Neutral Finland 2035 – National Climate and Energy Strategy	Promotion of e-mobility through buildings policy COM (2023) 76 final
	National Battery Strategy	REPowerEU Plan

3.6.4 Project documents

Along with policy documents, the study utilises project documents as a supplementary research technique involving the collection of data from project deliverables, research reports, and media publications, including project websites and broadcast webinars. Most energy projects provide publicly available project deliverables to inform the alignment between their goals and outputs created (Too and Weaver 2014). This study utilises project deliverables as documentary evidence to supplement participant observations, interviews, and policy documents and contribute to a multi-method form of triangulation (Cardno 2018), where they are available and relevant.

These project deliverables frequently disseminate the project's management strategies, goal-settings, milestones, progress, lessons learned, and outcomes (Jaber et al. 2018), which might be useful source in determining cause and effects between different factors, such as knowledge creation and innovation outcomes (Richtnér, Åhlström 2010). Table 7 summarises project documents selected for analysis in the case studies of Pocityf and Smart Energy Åland. Appendix E sets out the policy documents considered during the generalisation of findings stage.

Table 7 Selected project documents for analysis

Pocityf	Time points	Smart Energy Åland	Time points
D4.1: Pocityf citizen engagement plan	2020	Final joint report of the Smart Energy Åland project	2019
D9.1: Pocityf Clustering action plan	2020	Presentation, Flexens: Vision, target and future challenges of Smart Energy Åland	2019
D1.7: City Vision and Master Plan for ETT#2 solutions	2020	Presentation, Flexens: Business plan overview	2020
D11.2: Project Management Roadmap	2020	Presentation, municipality: Roadmap of Smart Energy Åland	2020
D11.1: Project Management Roadmap	2021	Presentation, Flexens: Smart Energy Åland – a demonstration platform of a 100% renewable energy system	2021
D11.7: Technical and Innovation Management Plans	2020	Report: Determining the technical potential of demand response on the Åland Islands	2021
D8.5 Granada replication plans and city vision for 2050	2022	Presentation, Flexens: Project status and future	2022
Factsheets: ETT#1, ETT#2, ETT#3	2023		

3.7 Analysis

The analysis of the study involves breaking down the data into themes and codes, identifying patterns, interpreting the presence or absence of causes, and establishing a conceptual framework in response to the research questions.

The study employed the six stages of the reflexive thematic analysis method (Braun and Clarke 2006), as described in Section 3.3. The first stage involved the transcription of interviews and familiarisation with the data. The second stage involved tentative and provisional coding, aiming to examine and reflect on the content of the data. This stage of coding attempted to utilise a more open and broad approach. Open coding aims to remain open to all possible theoretical directions (Charmaz 2014), to reduce selection bias, and ensure that all the possible types of responses, defined with different wording, are considered (Saldana 2013).

The third stage involved comparing codes for similarities and differences and categorising themes within the TOE framework. One advantage of using the TOE framework is that it not only directs the research process but also helps to organise and shape data collection (Anfara and Mertz 2015). The goal of using the conceptual framework and empirical research is "to see where the overlaps, contradictions, refinements, or qualifications are", as highlighted by Miles et al. (1994, p.22). This stage involved revising the codes, which included restructuring, sub-structuring, refining, or deleting irrelevant codes.

NVIVO software was used as an instrument for data management. Figure 11 illustrates a snapshot of NVIVO coding representing a refined stage of coding of the first 12 interviews. Codes were categorised into three themes: technology, organisation, and environment, in line with the TOE framework. I acknowledged the potential risk of this simplification that may constrain my analytical perspectives. However, it ultimately aided to structure and allowed me to visualise the numerous themes that emerged in a manageable format.

The fourth stage involved reviewing themes and codes, both within themselves and across the entire data set. During this stage, four mind-maps, shown in Figure 13, 14, 15, and 16 were created to represent visually the themes and sub-themes. Mind maps were used as an additional research tool to define potential interrelationships between themes and codes. Mind maps are widely employed "to visualise the "mental model" of concepts that individuals use to interpret the world around them" (Meier 2007, p.4). The following figures present examples of my mind maps developed from the analysis of interviews and case studies. Figure 13 is derived from the first cycle of interviews, while Figures 14 and 15 are developed from interviews, policy documents, and project documents. Figure 16 is developed from project and policy documents.

In the fifth stage, an analytic narrative of the data was developed, including the selection of data extracts to support the identified themes and sub-themes. The sixth stage focused on producing the report, which is presented in Chapter 4.

Policy documents were carefully read with the aim of defining the vision of national policies associated with energy flexibility, the adoption of EVs and smart charging infrastructure, especially in the context of energy communities. Therefore, policy documents were analysed according to four codes: smart charging, EVs, energy flexibility, and energy communities. Figure 12 presents an example of domains identified in relation to codes.

Figure 11 Snippet of NVIVO coding use of the first cycle of interviews

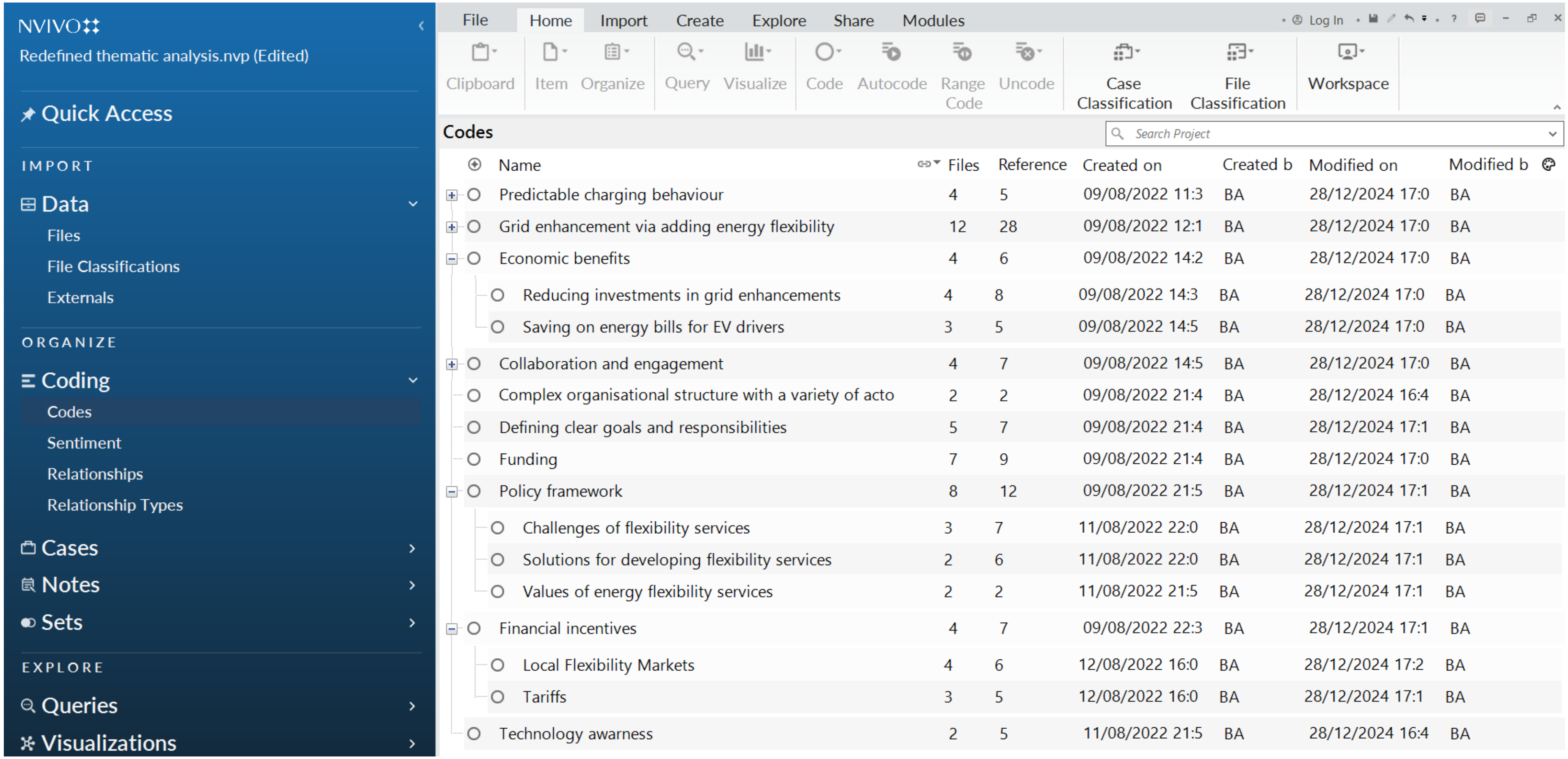


Figure 12 Example of coding of policy documents (text retrieved from NVIVO)

Codes	Domains outlined from policy text
Smart charging	Vehicle to grid Unidirectional and/or bidirectional charging Intellectual charging Recharging points
Electric vehicles	Electric transportation e-transportation e-mobility
Energy flexibility	Grid and/or integration to the grid Demand-respond program Energy optimisation Grid management Energy efficiency Grid congestion
Energy community	Joint self-consumption Collective generation and consumption Positive energy district (PED) Positive energy block (PEB) Positive energy neighbourhood (PEN) Smart local energy system (SLES) Zero energy neighbourhood (ZEN)

Figure 13 A thematic map for analysis of the first cycle of interviews within the TOE framework

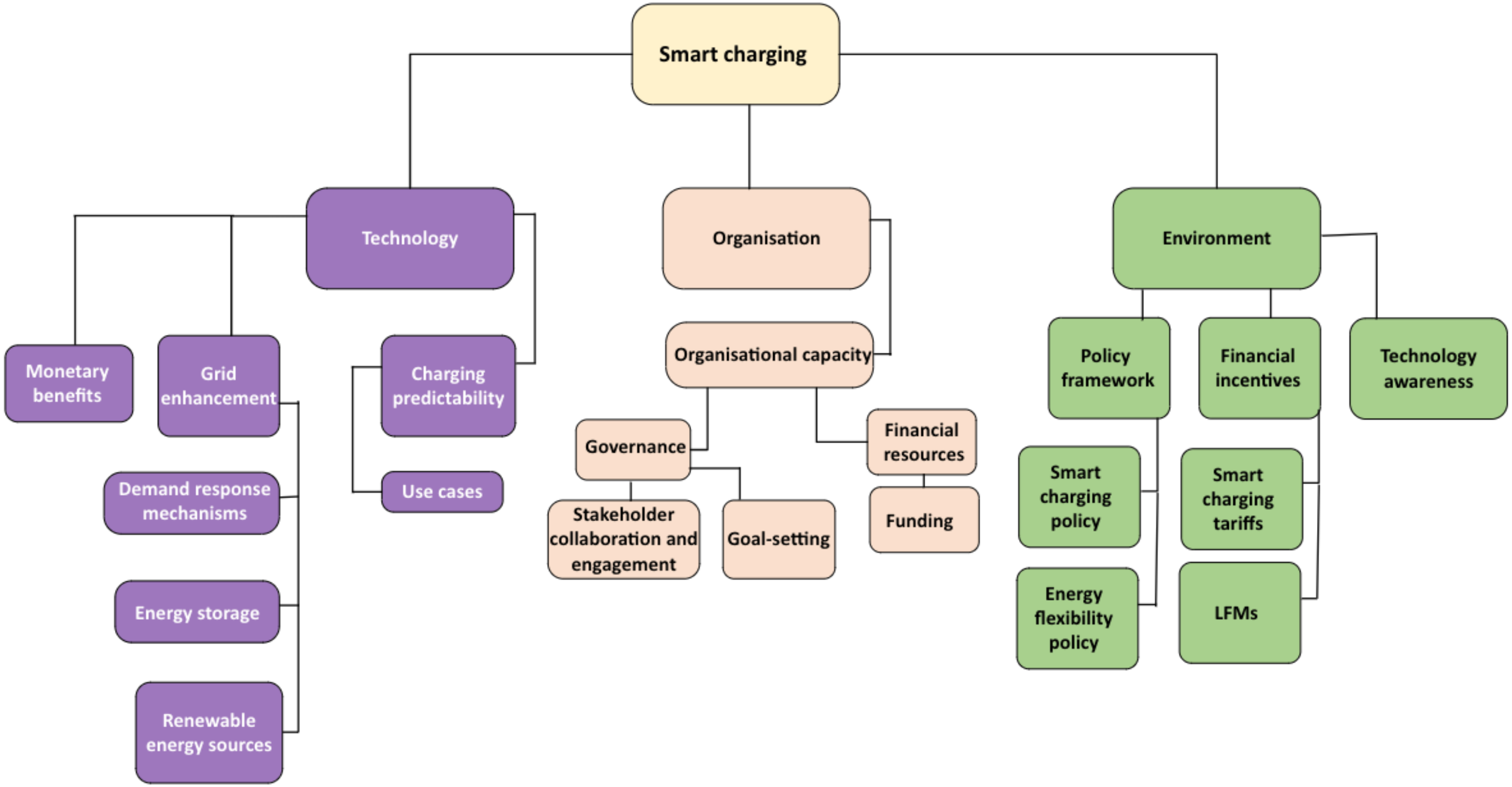


Figure 14 A thematic map for analysis of the Pocityf project within the TOE framework

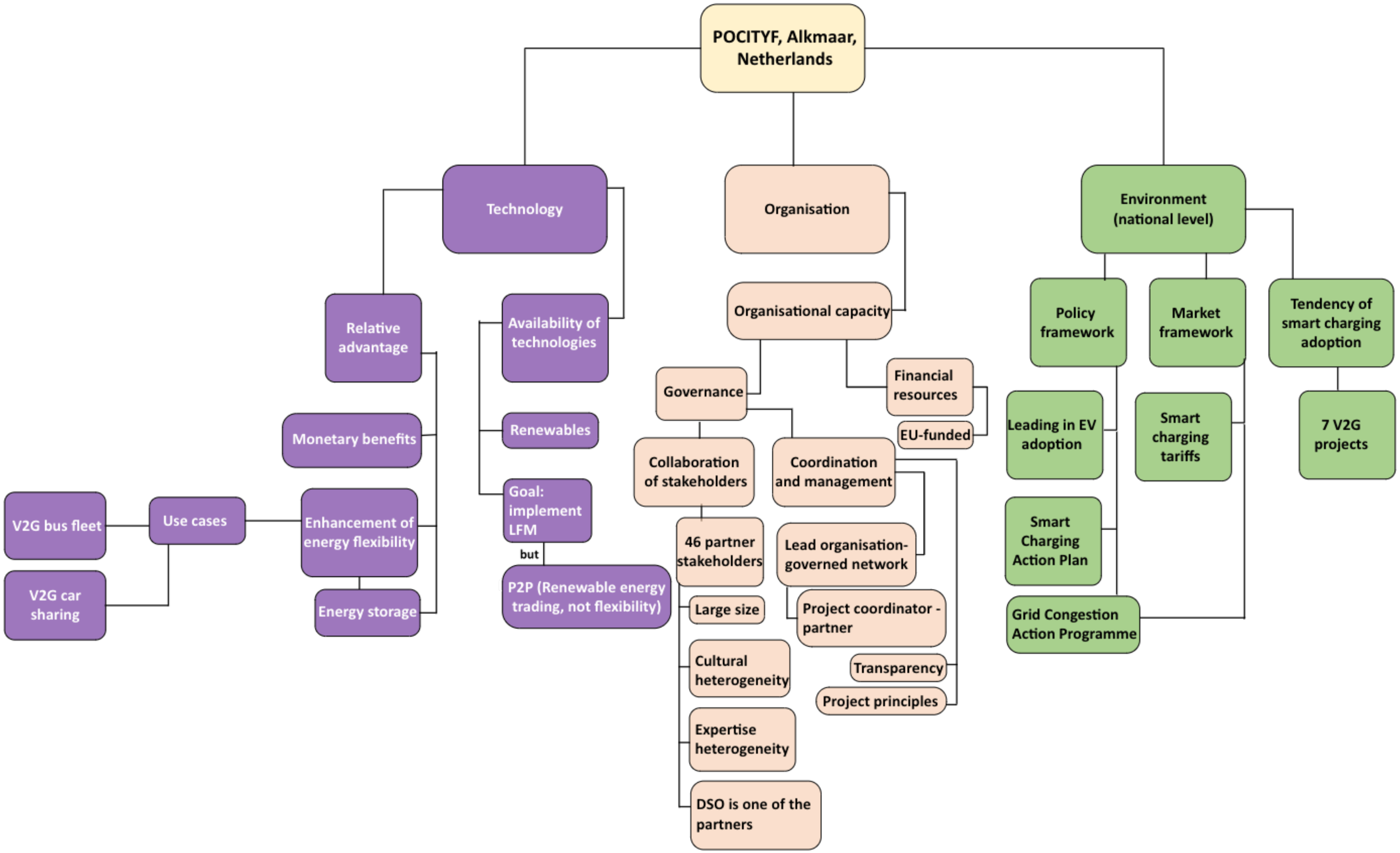


Figure 15 A thematic map for analysis of the Åland Island project within the TOE framework

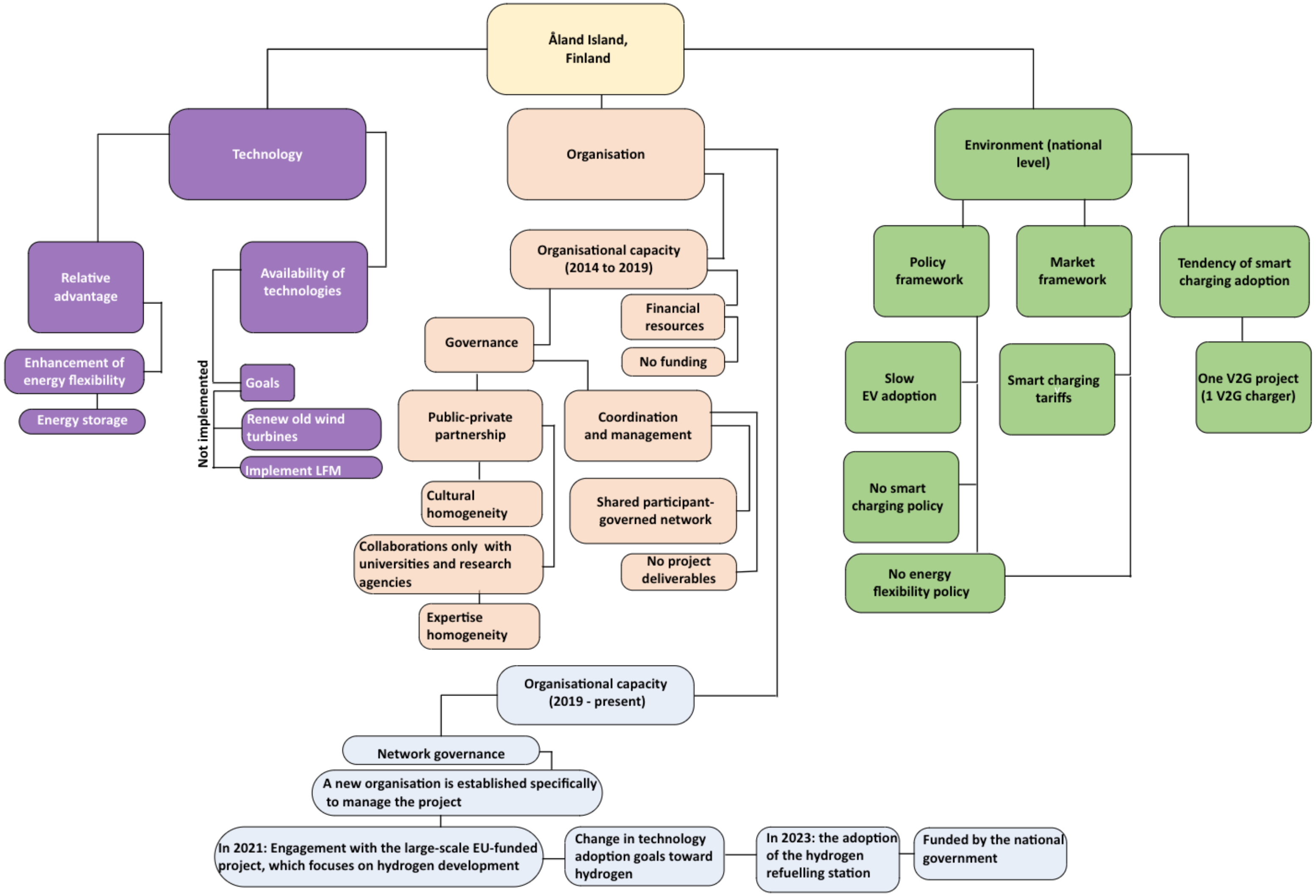
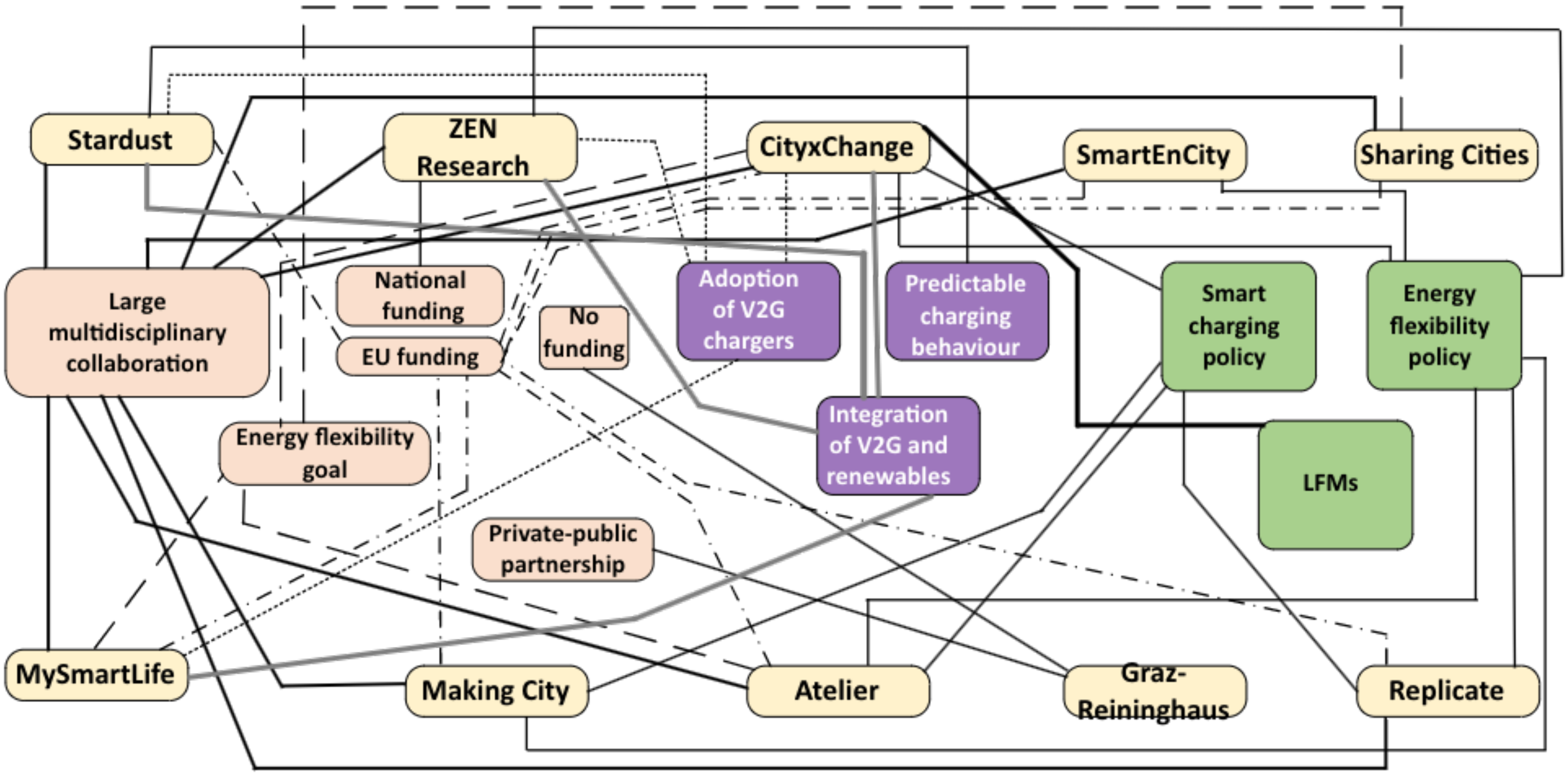


Figure 16 A thematic map for analysis of additional 10 PED projects within the TOE framework



Before developing a conceptual framework for the determinants of smart charging, I ensured meticulous analysis of the themes in NVIVO, along with reviewing my fieldnotes, and with mind maps aiding the establishment of relationships among themes. The following chapter presents the detailed results of the reflexive thematic analysis method. Overall, this method facilitated insights into the adoption of smart charging among energy projects and helped identify determinants, links, and relationships between themes.

3.8 Generalisation of findings

Among qualitative scholars, there are still debates regarding whether qualitative studies can be externally validated, which in turn refers to "the degree to which inferences from a study can be generalized" (Polit, Beck 2010, p. 1452). While in quantitative study one key criterion of study quality is generalisability, in qualitative studies not all researchers agree about the significance or attainability of generalisation of findings. Frequently, the primary purpose of qualitative studies is simply to provide an in-depth, comprehensive, and contextualised understanding of the phenomenon through the intensive examination of specific cases (ibid).

Nevertheless, validity remains a much-discussed topic (Lincoln et al. 2011), referred to as a criterion that strengthens qualitative studies, as it determines the accuracy of the researcher, as well as authenticity, trustworthiness, and credibility of the study (Creswell and Miller 2000). Specifically, in case study research, Yin (2018, p.108) compares the terms: case studies and experiments, and suggests "generalising" rather than "particularising" the analysis by employing analytic generalisation strategies, rather than aiming to extrapolate probabilities through statistical generalisation methods.

Generalisation frequently refers to the development of conceptualisations involving the following steps:

1) distinguishing information between what can be replicated in other contexts,
2) determining what is exclusive to a particular context,
3) identifying evidence supporting those conceptualisations (Ayres et al. 2003).

Findings of particular analytical generalisation reflect valid descriptions with a level of detail sufficient to justify a degree of generalisation within a field of understanding (Polit and Beck 2010). Analytical generalisation might be challenging, as noted by Polit and Beck (2010, p.

1453): “as is true for statistical generalisability, the analytic generalisation model is an ideal that is not always realised”. However, problematic patterns frequently occur in qualitative studies that do not generalise findings (Thorne and Darbyshire 2005). For example, researchers may conclude their study prematurely (“stopping at the “aha”), be eager to force coherence onto data (“fitness addiction”), and stop before reaching saturation (“the wet diaper”) (ibid, p. 1108).

To minimise these issues, this study assesses the generalisability of findings, specifically, derived patterns across ten additional energy projects that offer varying contexts, regarding the technology, organisation, and policy framework. To assess the generalisation of findings, this study aims to compare as many PED projects as possible within the available timeframe and utilises a record of hits and misses, as suggested by Pearse (2019), to increase the visibility of the pattern comparison process across studied projects. The record of hits and misses presents a table that visually represents the availability or non-availability of various themes among energy projects and their outputs regarding the adoption or non-adoption of smart charging. This record allows us to compare the themes and their potential relationships with the adoption of smart charging among different energy projects. Table 8 presents themes and patterns analysed for assessing generalisation of findings.

Table 8 The record of hits and misses for generalisation of findings

N	**Themes**	**Patterns of relationships**	
		Sub-themes	**Outputs**
1	Technology	Energy flexibility goal	Smart charging adoption
		Renewables implementation/ availability	
		Renewables availability	Adoption of EV chargers without smart charging
2	Organisation	Large multidisciplinary collaboration	Smart charging adoption
		Smart charging adoption goal	
		LFM implementation goal	
		EU-funding	
3	Policy framework	LFM implementation goal	
		Smart charging policy	

		Energy flexibility policy	

3.9 Research ethics

Data collection and management procedures involved in this study are addressed in accordance with the requirements of ethics committee at NTU and the Smart-BEEjS Horizon2020 Marie Skłowdowska-Curie ITN Project. Data from interviews were collected with the prior informed consent of the participants. The consent form, provided along with the information sheet, explained that participation is voluntary and can be withdrawn at any point, including after the interview. Participants were informed that they were free to skip any questions without needing to provide a reason. The researcher was committed to ensuring transparency with the participants. Data collection and management procedures ensured the anonymity of the participants by omitting names or organisations in the stored data.

Data from participant observations involved information regarding the technology and the potential technological, organisational, and environmental impacts on its adoption. I frequently asked clarification or follow up questions with the participants individually. In such discussions, I explained that these observations would be directly utilised in my thesis. Particularly in active participant observations, in addition to a written agreement indicating that I can collect data for my thesis, I received verbal consent to write fieldnotes reflecting my observations and interpretations. All these considerations are consistent with the ethical guidelines for educational research outlined in the British Educational Research Association (2018).

3.10 Chapter summary

A theory-driven reflexive thematic analysis was employed to explore the complex and dynamic process of adopting smart charging technology in PED projects. The research utilised various data sources, including participant observations, interviews, policy documents, and project deliverables. Focused on Europe, where the PED concept is developed by European Commission, the study offers a lens through which to examine strategies in technology adoption to address climate change in Europe.

Firstly, the TOE framework was selected based on insights from the literature and fieldnotes generated from both passive and active participant observations. Secondly, interviews were conducted with energy experts, representatives of energy projects that have implemented smart charging, and representatives of PED projects. Thirdly, two in-depth case studies were utilised to understand how smart charging was adopted in the Pocityf project and why it was not adopted in the Smart Energy Åland project, despite being planned. Finally, an additional ten PED projects were analysed to validate the generalisation of findings.

Chapter 4 Research Findings

4.1 Chapter introduction

Chapter 4 presents the research findings on the adoption of smart charging across energy projects like PEDs, drawn from various data resources. To help visualise the findings and guide the reader through the volume of text, the chapter opens with a table summarising the themes that emerged as a result of the analysis of the collected data.

Section 4.2 begins with findings derived from the first cycle of semi-structured interviews and active participant observation, showcasing the opinions of respondents regarding three themes: technology, organisation, and environment, and their potential relationships with the adoption of smart charging in energy projects like PEDs.

Section 4.3 provides an in-depth case study analysis of two PED projects, which explores the structures of the projects and their key activities undertaken toward the adoption of smart charging, within the adapted TOE framework. The section concludes by discussing the relationships between themes found across the projects.

Section 4.4 focuses on the replication of findings derived from ten additional case studies, providing a broader perspective on the outcomes.

Table 9 Results – Themes

Data source		
Interviews and active participant observation	**In-depth two case studies: interviews, project documents, policy documents**	**Additional ten case studies: project documents and policy documents**
Technology	Pocityf	Organisation
-Grid enhancement	-Role of smart chargers	-Stakeholders
--Demand response mechanism	--Energy flexibility	-Funding
--Energy storage	--Smart charging use cases	-Challenges
--Renewable energy sources	--Renewable energy sources	Technology
-Charging predictability	--Local flexibility market	-Technology implementation framework
-Monetary benefits	-Organisational governance	Policy framework
Organisation	--Managerial structure	-Smart charging policy
-PED's governance	--Responsibilities	-Energy flexibility policy
--Goal-setting	--Communication channels	-Trend in adopting smart chargers
-Financial resources	-Policy framework	
--PEDs Funding	--Smart charging policy	
Environment	--Energy flexibility policy	
-Policy framework	--Trend in adopting smart chargers	
-Financial incentives	Smart Energy Åland	
--Local flexibility markets	-Role of smart chargers	
-Technology awareness	--Energy flexibility	
	-Organisational governance	
	--Project activities (2014-2019)	
	--Decision tree	
	--Financial resources	
	--Governance (2019-present)	
	-Policy framework	
	--Energy flexibility policy	
	-Trend in adopting smart chargers	

4.2 Findings from the first cycle of interviews and active participant observations

Technology

All participants recognised the environmental benefits of the adoption of smart charging technology. EVs equipped with smart charging were frequently described as more environmentally-friendly compared to those without such infrastructure. This was frequently linked to the capabilities of smart charging infrastructure to enhance the grid by functioning as both a demand response mechanism (in the case of V1G and V2G) and an energy storage solution (specific to V2G). More specifically, these two functions enable EVs to contribute to grid flexibility, a feature emphasised as crucial for supporting the electrification of the transportation and heating systems. Grid flexibility facilitates the integration of renewable energy sources, addressing the challenges of managing the grid as the deployment of low-carbon technologies continues to expand. Thus, EVs can provide environmental benefits on their own. With the integration of appropriate technology that extends beyond their core function as vehicles, however, their environmental performance can be further enhanced.

Another highlighted advantage of smart charging was monetary benefits for stakeholders such as DSOs and EV drivers. It was explained that the use of smart chargers can reduce costs for grid enhancement, benefiting DSOs; and lower energy bills, benefiting EV drivers.

Grid enhancement. The analysis reveals that many respondents believe smart charging can play a crucial role in enhancing the grid, both within the broader energy transition and particularly in the adoption of EVs. With the growing number of EVs posing significant challenges to grid capacity, smart charging is seen as an important strategic approach to provide the energy flexibility necessary for maintaining grid stability.

> I'd say the answer is definitely yes, they could do. Smart charging adds a layer of flexibility to energy systems and helps the whole system work smarter and more efficiently (Int 1).
>
> Instead of relying on costly grid upgrades, DSOs could look at encouraging EV drivers to charge their cars when it's cheaper, like during off-peak hours. That way, you're easing the pressure on the grid and also saving money for DSOs and EV users (Int 7).

Some respondents highlighted an increase in the value of flexibility at a national level, for example, in the Netherlands as well as in the UK, and linked it with smart charging by noting that it plays a crucial role as its enabler.

> What we're seeing here is that development of local flexibility is really lagging behind. We have, we only see proper markets in two countries in the UK, and in the Netherlands… I think flexibility plays an incredibly important role because we’re seeing such rapid growth in renewables, and we absolutely want that growth to continue. As you know, renewables are highly variable, we can’t always predict when they’ll produce energy and when they won’t. Right now, we cannot really predict when they produce when not, so we have situations right now in which we have very high generation of flexibility of renewables and periods in which we don't have any production or very low production of renewables (Int 3).

> I think the UK has been ahead in some areas, like having a relatively liquid balancing market. Part of the reason for this is that the UK faced the challenges earlier than others, partly because it’s an island and doesn't rely much on hydro. But as renewables grow in other markets, they’ll start facing challenges too (Int 6).

> But what we expect to see is greater requirements for general flexibility. So not for response or the very fast reacting stability services, but for slightly longer reserves. In the UK, we have the balancing mechanism and that's expected to increase in value and all sorts of others and for things like V2G to get involved. So, we're seeing potentially more value in flexibility, but not necessarily in very short-term, fast reacting flexibility (Int 4).

Demand response mechanism. Both V1G and V2G chargers can help reduce grid demand during peak periods, contributing to grid stability. Respondents highlighted that this capability is an important part of demand response mechanisms, helping in grid optimisation.

Int 4 outlined that an increasing number of EVs can add significant demand to the grid, but it could be “completely avoidable” by embedding an EV with V1G smart charging, specifying as follows:

> The benefit of that is that you can at least take an electric vehicle and use it to firstly stop it from creating additional demand when there's already peak demand on the grid, which is really important. If you're adding extra demand during peak hours, then that's going to cause big problems for the distribution network and for National Grid. Those problems are completely avoidable. What smart charging lets you do is take the demand from electric vehicles and move it to a time when it's not contributing to a peak, it's just adding to a baseload of demand (Int 4).

Int 6 emphasised the positive impact of V1G smart charging technology on the grid, particularly in its ability to optimise charging efficiency and reduce strain during peak demand periods. It is explained that:

> V1G charging facilitates the efficient charging of EVs. EVs are usually charged for several hours at a time, but the vehicles are only actively charging for the first one or two hours. If those initial one or two hours fall during the peak hours, for example, at five or six o'clock in the evening, when grid demand is frequently high, such charging would be inefficient in relation to the grid. However, the use of V1G smart charging allows automatic shifting of charging to a time when it will not negatively impact the grid (Int 6).

Energy storage. Another widely discussed capability is the provision of energy storage, which only V2G chargers can offer. The deployment of energy storage systems is a part of decarbonisation strategies that facilitate electrification by storing renewable energy when supply is abundant. In discussing the benefits of V2G smart charging, almost all respondents emphasised its potential for small-scale energy storage and the support it can offer to the grid. One respondent referred to V2G as "energy storage on wheels" (Int 8). This respondent explained that with the continuously increasing number of EVs on the roads, the positive impact on the grid of using EV batteries as storage, which is possible when equipped with V2G, would be substantial in the future. Other respondents also outlined the significance of the collective effect that both V1G or V2G can have to the grid, specifying that in the case of V2G, the impact is on storage capacity (Int 9, 12).

In discussing the role of smart charging in relation to energy flexibility, which is interconnected with the relative advantages of the technology, respondents frequently emphasised the significance of its integration with renewables. Specifically, respondents explained that the greatest value of V2G or the full potential of V2G can be achieved through its integration with renewables. In general, this is attributed to the whole principle of V2G, which is maximised through its integration with renewables and its role as energy storage. Examples are below:

> The whole principle of vehicle to grid is that you could use an electric vehicle effectively as a storage device which then means that you could generate renewable energy in one time of the day or one point in time and then release it back to the grid in another point in time (Int 6).

> If you have an electric vehicle and you're using it through vehicle to grid, it's a bit like a battery or a storage device, the main use of that is storing renewable energy surplus and reducing the amount of electricity that you import (Int 4).

> The combination of renewables like wind and solar plus battery storage is a necessary combination. So, there is a clear synergy where you can't really do one without the other. So, that's a necessary synergy of things. And I suspect, we'll go see a few more of those sorts of things, where to keep decarbonise electricity, we're gonna have to bring in all the other elements as well, such as flexibility with electric vehicle charging, and some flexibility with heat pumps, and things like that (Int 10)

Renewable energy sources. The positive effects of integrating V2G with renewables were highlighted, emphasising the rationale behind implementing V2G in combination with renewable energy sources. That said, several respondents were not decisive about whether the availability of renewables may influence the decision to adopt smart charging in energy projects. Reflecting on personal experience in working on a range of V2G projects, one respondent (Int 5) emphasised that large-scale projects with sufficient financial investments tend to integrate V2G with renewables. Nevertheless, there are small-scale V2G projects that integrated the technology into the grid even when renewables were not available. The respondent explained that the purpose of those projects was to explore the potential of V2G under different contexts and business models.

Two respondents highlighted that decisions regarding the integration of V2G and renewables depend on the project's scope and objectives. This suggests that the adoption of these technologies is strategically driven by specific aims, such as enhancing systems integration or improving grid flexibility. Recognising this decision-making process is important, as ensuring these elements are on the decision-making agenda might influence the extent to which V2G and renewables will be incorporated, to contribute to grid stability, decarbonisation, and the broader energy transition.

> If a project focuses on achieving systems integration, they're more likely to adopt technologies like V2G and renewables. The decision to adopt a technology depends on the specific set of goals the project aims to pursue (Int 4).

> Local flexibility procurement is at the pilot level. And, V2G together with the development of local flexibility markets are often being tested to kind of explore how these pieces can work together (Int 11).

One respondent (Int 11) mentioned another example of the integration of V2G with renewables, emphasising a potential link between the development of new local flexibility markets (LFMs) and V2G adoption. The respondent outlined that their organisation aims to trial LFMs while also adopting V2G as a flexibility enabler. This is an interesting finding, suggesting that projects differentiate goals between systems integration and the development of LFMs, albeit with both focusing on enhancing energy flexibility.

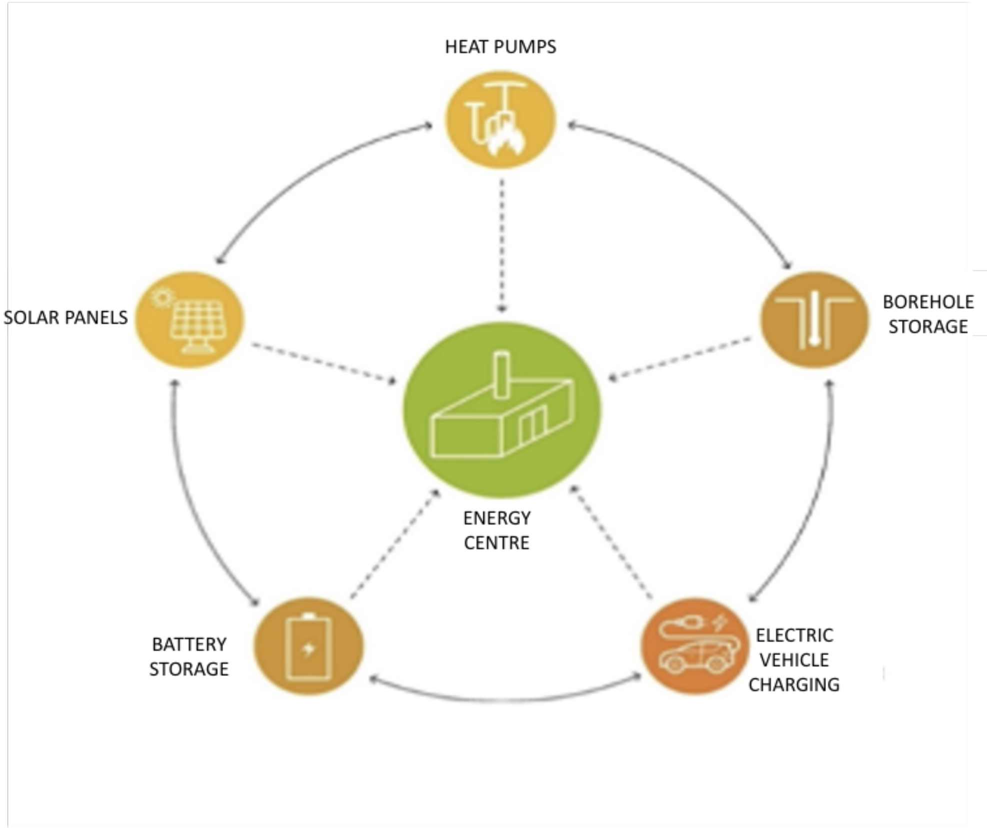
Nevertheless, the goals are indeed different, as they require different approaches and varying levels of stakeholder involvement. When aiming for systems integration, projects focus on incorporating renewable energy generation, supply, and demand respond technologies. In contrast, when the goal is the development of LFMs, projects not only adopt renewable and demand respond technologies but also work on the development of new electricity markets for trading flexible energy resources, which requires substantial engagement from ICT and DSO stakeholders.

> The project our organisation is participating in is testing market trials for what is called peer to peer services. … It is looking at bolt technologies kits, including solar panels, heat pumps, and V2G technologies (Int 11).

> The project trialled new designs of electricity markets and added electric vehicle charging to test with new market concepts (Int 12).

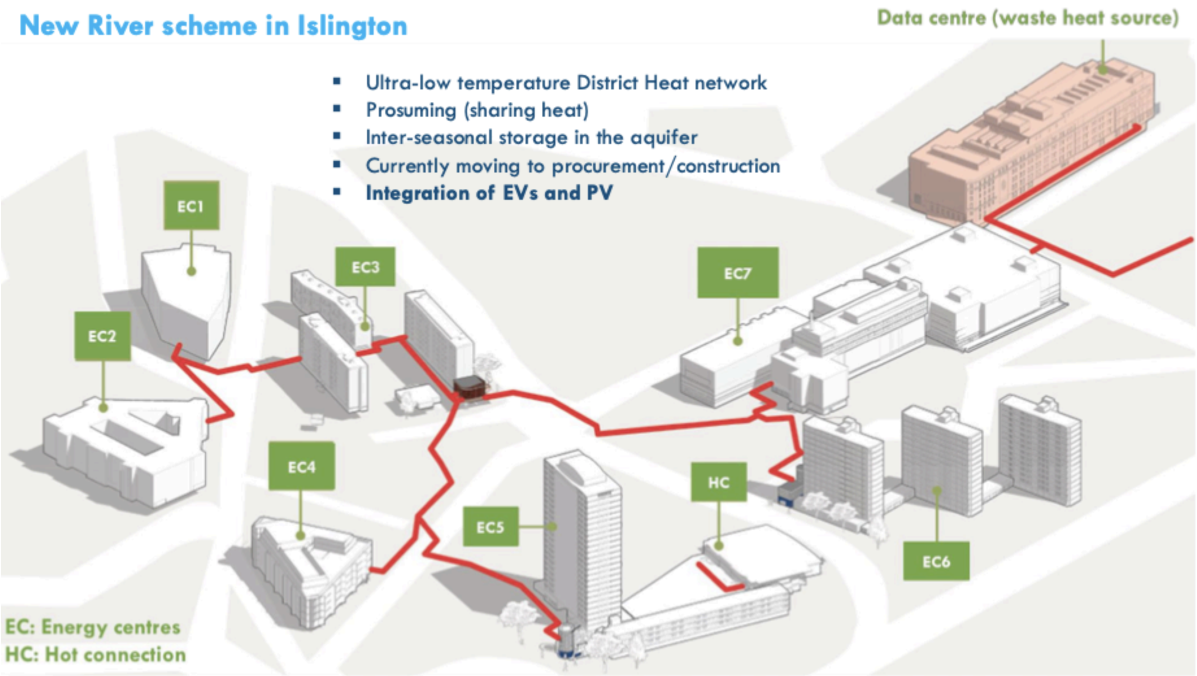
Similarly, the goal of energy system integration was observed within the GreenSCIES project (SC-1). Figures 17 and 18 present graphs from the project, highlighting the focus of the project on energy system integration and the specific integration between solar and EVs equipped with V2G. Therefore, the GreenSCIES project demonstrates that energy projects might choose to adopt smart charging when aiming to integrate energy systems through the integration of V2G and renewables.

Figure 17 Energy system integration goal - the GreenSCIES project



Source: GreenSCIES, 2022

Figure 18 The integration of EV and PV is a key objective of the GreenSCIES project



Source: GreenSCIES, 2022

Charging predictability. The findings suggest that factors such as use cases and predictable charging behaviour influence the impact of smart charging on energy efficiency. To maximise the benefits of the technologies, the adoption of V1G is suggested for public charging infrastructure due to its traditionally unpredictable charging behaviour. In contrast, V2G is proposed for charging infrastructure with typical predictable charging behaviour, such as fleet depots, workplaces, and domestic chargers.

> To really unlock the full potential of V2G, it needs to be used in situations where the charging patterns are predictable. That way, grid operators can better anticipate and manage the loads (Int 5).

> Predicting charging patterns is important for optimising the system's efficiency but it's difficult to predict them unless they are typical home or workplace chargers (Int 6).

Additionally, Int 9 explained that this collective effect is one reason why fleets with a large number of vehicles, especially those that have predictable charging behaviour, are "perfect" for utilising V2G technology. As an example, a case about an American school bus fleet, which comprises 50 buses equipped with V2G and integrates solar panels, was provided, mentioning that it has proven the efficiency of V2G as an energy storage solution.

The typical characteristics of the usage of school buses were underlined as ideal for employing V2G, which involves driving twice a day at predictable times and long summer breaks. This example again confirms the importance of use cases and predictable behaviour in relation to smart charging. Moreover, this example outlines the availability of both technologies: renewables, such as solar panels, and V2G.

> Like the case with the school buses. This vehicle use types are not used for a long period of time, obviously. And they have a long summer breaks. So that's quite good for vehicle to grid, and also car parks at airports, for example, where cars are parked for several weeks (Int 9).

Similar links between the importance of use cases and charging predictability in relation to smart charging and its efficiency for energy flexibility were observed within the SC-1 active participant observation. In one of the largest UK energy projects, GreenSCIES, that aims to implement V2G smart charging infrastructure in the London Borough of Islington, thorough attention was given to selecting the types of smart charging. In the project's development phase, a decision-tree was created to determine whether to install V1G or V2G.

The decision process begins with the question "Where is it located?" to define a use case, whether it is public, fleet depot, or at an energy centre, followed by determining if charging is predictable or not. Thus, V1G is suggested for cases when charging is not predictable, especially for public charging infrastructure. V2G charging is proposed for cases when charging is predictable and located off-street, specifically for fleet depots, workplaces, and domestic charging infrastructure.

Monetary benefits. Along with the grid flexibility benefits, which denote the environmental advantages that smart charging may offer, economic benefits were also frequently outlined. Respondents emphasised that smart charging could help to "defer", "reduce", or "avoid" substantial the required grid infrastructure investments, due to the increasing electrification of heating and transportation. The following response highlighted that issues with grid capacity are already occurring in Europe. Additionally, due to differences in expenses, the preference toward the enhancement of flexibility solutions over the extension of the grid is emphasised.

> I think the biggest problem we're facing in Europe is now the hosting capacity of the grid. The most expensive solution and maybe the most trivial solution is to extend and enhance the grid. But on the other hand, we can exploit flexibility of the end users or built energy communities controlled with signals by distribution system operation (Int 2).
>
> Grid expansion costs can be passed on to end users. If the grid operator needs to expand the grid, it means that in the coming years, the grid costs for end users will increase (Int 7).

Another respondent emphasised the value of "deferring" in the context of grid infrastructure reinforcement, noting that it is a slow process, as follows:

> V2G could defer required reinforcement and that's actually very valuable because we cannot reinforce all distribution grids at the same time. But it's not clear whether those reinforcements can also be avoided, or will be required anyways, just at a later stage (Int 5).

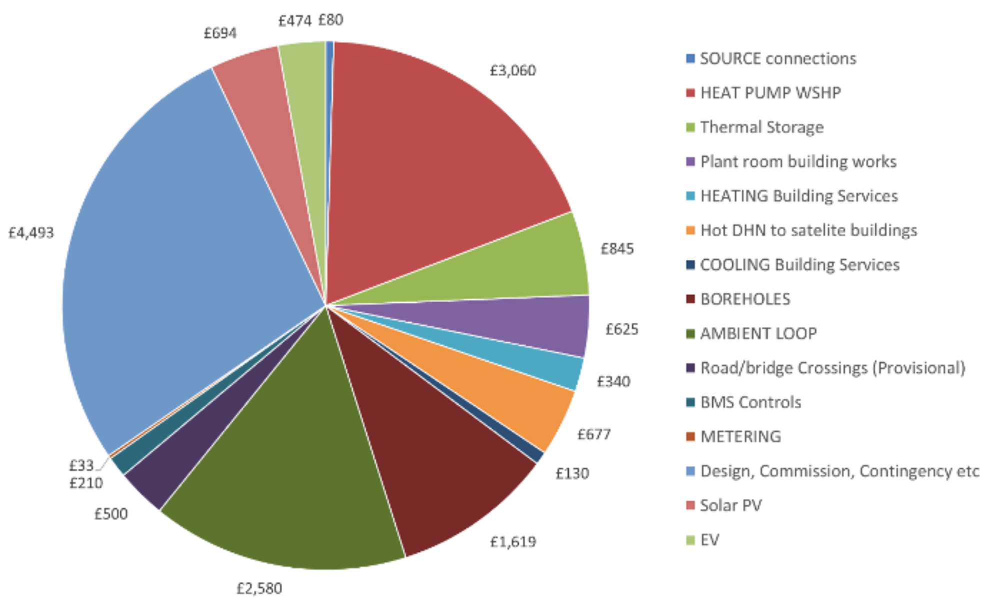
Currently, there are tariffs incentivising EV users to adopt smart charging, including V2G. However, respondents stated that these tariffs are too low from a monetary perspective to effectively promote technology adoption:

> I've analysed smart charging from an economical point of view, considering the benefits that managed charging and V2G can bring. And from a monetary perspective, I can say that the benefits are really low (Int 9).
>
> As much as I can buy an electric vehicle and I can get a V2G charger, I pay loads of money for that, I'll be paying thousands of pounds more for the electric vehicle for starters, and then thousands of pounds more for the V2G charger and I'll get some money back but the actual cost saving from V2G, we've done quite a lot of work on this, it very rarely stacks up (Int 5).

Notably, in the GreenSCIES project (SC-1), one key factor influencing the decision to adopt smart charging infrastructure is its higher internal rate of return compared to stationary batteries. The project conducted a techno-economic analysis of four technology scenarios: 1) heat pumps only, 2) heat pumps and solar PV, 3) heat pumps, solar PV, and EVs with both V1G and V2G capabilities, and 4) heat pumps, solar PV, and stationary batteries. The results revealed that the adoption of heating and cooling and PV with smart charging infrastructure would be more economically beneficial than the same systems with stationary batteries.

Thus, the design of the GreenSCIES project, which is currently under review by local authorities, suggests installing 49 smart chargers (34 V1G and 15 V2G) in the London Borough of Islington, leaving out the fourth scenario with stationary batteries. Figure 19 presents the total investment costs for integrating a 5th Generation District Heating and Cooling (5DHC) network, PV, and EVs smart charging infrastructure, as estimated within the GreenSCIES project (Revesz et al. 2022). The figure demonstrates that within the project's technological scale, the implementation of 49 smart chargers will cost about £474k, which is 3% of the total cost (£16,4 M), excluding the adoption of static stationary batteries (£3.4M).

Figure 19 Investment costs of technologies - the GreenSCIES project



Source:(Revesz et al. 2022)

Organisation

Along with technical aspects, technology adoption in energy projects also involves social processes. Energy projects like PEDs are frequently EU- or nationally funded collaborations among various organisations working to deliver energy transition initiatives, including the adoption of low-carbon technologies. Organisational factors in PEDs, such as governance structure and financial capacity, can influence decision-making processes related to technology adoption. Thus, this section examines key factors including active stakeholder collaboration and engagement, clear goal-setting, and the availability of funding as being important to ensure a smooth and efficient adoption of technologies.

PED governance. Reflecting on the potential impacts of governance characteristics on the adoption of smart charging, a few respondents discussed the challenges their organisations faced during the implementation stage of V2G technology, emphasising the importance of effective engagement and communication among stakeholders. For example, two respondents outlined low engagement of a DSO in the projects they worked on, which led to various challenges, including delays in technology adoption. Notably, in cases when small-scale assets are integrated to the grid, including V2G, a DSO is highlighted as "a key player" (Int 12). Therefore, in the context of V2G adoption, low engagement of a DSO might considerably impact its implementation.

> From personal experience, we had difficulty with a network company in a previous project that was not very engaged. So, gaining buy-in from infrastructure stakeholders was challenging, as we found in that project (Int 4).

> And dealing with DSOs is also a bit of a challenge with these sorts of projects, because firstly, the DSO seem to vary in terms of their level of engagement. And then the level of how much they're sort of leaning into this challenge of smart, innovative networks and smart energy systems. So, there's a challenge there, depending on which DSO happens to be the one in the geographical area that you're looking at (Int 5).

One respondent (Int 5) emphasised the complexity of any structural changes in projects. The respondent explained that their organisation had encountered a situation where key partners withdrew from the project. Such a situation was difficult to predict and required the redefinition of action plans and timeframes.

> It's really complex when key partners unexpectedly withdrew from the project. It was something we couldn't predict, and it forced us to completely redefine our action plans (int 5).

Another respondent (Int 10) highlighted challenges associated with undefined communications among stakeholders. The respondent explained that their organisation participated in a V2G trial where there was a lack of monthly scheduled management meetings with partners. This sometimes caused delays in addressing emerging problems occurring in the trial due to a lack of full understanding of the issues across partners, resulting in inefficiencies in problem-solving.

Other respondents discussed organisational governance in the context of technology adoption, highlighting the importance of coordination and management aspects for achieving better outcomes. These aspects involve project components such as goals and responsibilities. Regarding project goals, their influence on the adoption of smart charging was outlined within two project stages. As mentioned earlier, two respondents (Int 4,11), discussed the role of project goals in the initial project design and development stage, emphasising them as an essential factor influencing the decision toward the technology adoption.

Goal-setting. Other respondents discussed the importance of goals within the project implementation stage. Specifically, respondents outlined the role of clarity in project goals and responsibilities across partners to ensure the progression of the adoption process. Additionally, the importance of clarity in responsibilities was emphasised, especially in projects involving a wide range of objectives and numerous stakeholders. A few examples are presented below:

> Sometimes there isn’t a perfect alignment between what the project aims and how to work towards common goals… The implementation of V2G chargers requires effective communication among partners, such as transport providers, energy utilities, and network companies (Int 5).

> I suspect that the clearly defined responsibilities among stakeholders are closely connected with organisational outcomes. To make progress, everyone needs to be on the same page (Int 10).

The GreenSCIES project (SC-1) involves 10 key stakeholders from various fields of expertise, including academia, architectural design, innovation labs, heat network, EV charging infrastructure, etc. The primary goal of the project is to establish an innovative, smart local energy system within a local community by integrating mobility, heat and power. During meetings and workshops, I observed three overarching principles guiding the project: innovation, smartness, and the integration of mobility, heat, and power. Notably, the project emphasises the integration of these three energy systems to underscore their importance within the project, aiming not only to decarbonise them but also to enhance and optimise the grid.

Regarding technology-related principles, three key considerations were observed at different decision-making stages, namely “innovate, optimise, replicate”. This suggests that technology selection and related options in the project are evaluated based on the following criteria:

1) beyond typical business models and common practice;
2) reduce costs;
3) can be replicated at other local communities.

In some cases, decision-making stages, alongside costs and replicability, involve criteria such as the capability to benefit grid flexibility, policy compliance, and ease of deployment.

During the research and development stage, the project conducted the following activities: publication of internal project deliverables (currently not publicly available), publication of academic journal and conference papers, provision of stakeholder optimisation workshops and meetings, hosting online consultation events with the local community, and the release of a professional film about the project for a wider audience. Academic papers present various types of analysis conducted within the project, such as techno-economic modelling, carbon emission analysis, capital expenditure, etc. Internal project deliverables involve information regarding the development of architectural design concepts, engineering options, mapping of social infrastructure regarding technology-related installation works, and other topics that might be important for project consideration.

Overall, elements of organisational governance, such as collaboration, engagement, and communication among stakeholders, are important in technology adoption. Additionally, project goals may shape criteria for decision-making stages related to technology. In particular, having system integration goals aimed at enhancing e-mobility and energy flexibility can encourage energy projects to adopt smart charging.

Financial resources. As V2G technology incurs high costs and its utilisation does not yet guarantee monetised benefits, securing financial incentives or funding for its deployment was highlighted as crucial. In general, financial resources of projects are emphasised as a leading factor influencing their adoption of technological innovations.

> If businesses are not getting back their investments, they need very strong incentives from their values and moral to do that, because otherwise, financially, it's not beneficial. So, I think, currently, funding is crucial to ensure that individuals and business owners, and investors are participating in these business models, we need to make sure they have both that first level of values and morals which you motivate them (Int 6).

> Why would one business owner go against his budget, you know, and his profits and margins and invest into their green? Sort of image? Yeah. Unless it's marketing and pays off. So that one is very important. But then, of course, we need to back it up with some financial resources (Int 8).

PEDs Funding. The respondents emphasised that currently, energy projects that have adopted V2G charging infrastructure are funded either by government or EU funds. Funding for energy projects deploying environmentally friendly technological innovations is seen as essential due to their high costs, which limit their promotion across businesses. Funding enables projects to implement and test environmentally friendly business models, examine their impacts, and raise awareness about them.

Environment. Respondents believe that a supportive policy framework is critical for the adoption of low-carbon technologies, including smart chargers. This is because these technologies are expensive for energy users, including EV owners, and without incentives and funding, their adoption is likely to be slow or limited. Therefore, government regulations with a clear vision to support the adoption of smart charging, including economic considerations, are recommended. Monetary incentives, such as special energy tariffs like smart charging tariffs and the development of local flexibility markets encouraging the use of smart chargers were emphasised as essential.

Policy framework. Respondents supported the view that the policy framework influences the adoption of technological innovation, highlighting that nowadays, regulations are evolving rapidly and becoming more supportive of deploying technologies that drive the energy transition.

> The challenge is really in harmonizing the technology to work together so that we can control all of these assets and create the energy architecture and market framework and policy frameworks that enable these things to be able to control in a holistic way that works together for the system (Int 10).

> There's a lot of uncertainty because it's all shifting at the moment. So, having greater certainty as to what was changing when, I think would help a lot of projects out (Int 12).

Some respondents specified that regulatory uncertainties may pose challenges to the business models of innovation. As mentioned earlier, respondents provided examples of the current lack of a regulatory framework concerning LFMs. For example, one respondent explained that this issue is addressed through regulatory sandboxes, allowing pilot projects to test the impacts of LFMs on energy flexibility (Int 11). Furthermore, the need for a clear regulatory framework for the wider deployment of LFMs, as well as flexibility providers such as V2G, to empower the energy transition, is emphasised.

Nevertheless, one respondent emphasised that currently there are no policy barriers, but rather only market-related ones, to the adoption of smart charging in the UK.

> I'm not sure there are any specific policy barriers preventing that now. I'd say the main problem is that there's not enough incentive for it. So, it's not that anything is preventing it from happening, it's that there's no mechanism that makes it worth doing, because if there was, we'd probably have already done it (Int 1).

Another respondent highlighted that smart charging would definitely become law in the UK.

> There was a consultation two years ago now that concluded about a year ago, although the actual output of that consultation hasn't been put into law yet, but the principle is that all new domestic charge points will have to be smart enabled. It will happen, how it happens and when it happens it slightly up in the air, but it will happen (Int 5).

Indeed, since 2022, new domestic and workplace charging points are required to include V1G smart charging functionality (UK Government 2022). Additionally, in 2023, the "Electric Vehicle Smart Charging Action Plan" was released, setting out the programme for accelerating the commercialisation of the "vehicle to everything" (V2X) technology, which includes the integration of vehicles to home, buildings, and grid (V2G). The programme aims to deliver small-scale demonstrations from 2022 to 2025 to increase the adoption of V2X as part of the Net Zero Innovation Portfolio Funding (UK Government 2023). As the GreenSCIES project (SC-1) is also part of the government funding, this might suggest a relationship between the availability of smart charging policy at a national level and the decision to adopt smart charging within the project.

Additionally, Figure 20 showcases the importance of the policy's role in the GreenSCIES" various technology-related decisions. The figure presents an appraisal of electrical connection options for EVs equipped with V2G, PV, and heat pumps, conducted in the GreenSCIES project (SC-1). Alongside factors like costs, grid flexibility, replicability, and ease of deployment, policy compliance was one of the selection criteria for one of the decision stages. These criteria are aligned with the project's goals and assessed on a scale of good (green tick), moderate (amber alert), and bad (red cross). For example, the "virtual private network" connection currently requires a policy change. As it could pose challenges for replication due to uncertainty regarding potential future policy adjustments, that connection was omitted. Thus, this suggests that the GreenSCIES project incorporates policy considerations at various stages of technology adoption.

Figure 20 Qualitative appraisal of electrical connection options for the GreenSCIES project

Approach	Cost	Optimisation	Policy	Deployable	Replicability
Behind the Meter	✓	⚠	✓	✓	✓
Private Network	✗	✓	✓	⚠	⚠
Virtual Private Network	⚠	✓	✗	✗	✗

Source: Revesz et al. 2022

Financial incentives. As mentioned above, respondents frequently emphasised the current commercial unviability of V2G technology, considerably constraining its wider adoption. As currently, there is a lack of market and policy frameworks promoting smart charging, particularly V2G, given the significant environmental benefits of V2G, respondents suggest that financial incentives - with tariffs being the principal form mentioned - are necessary to compensate the costs and enhance the attractiveness of the technology.

> The technology can create some lovely flexibility, but you may not be attached to monetise them because of the way that the markets work at the moment (Int 4).

The tariff, namely the time-of-use tariff, was mentioned as an effective incentive widely used in Europe. This tariff applies to all appliances, aiming to encourage households to use electricity at cheaper rates. However, there is concern that the tariff alone might not be sufficient to enhance smart charging and benefit grid flexibility. For example, one respondent emphasised that the implementation of this tariff might be effective only in educating EV users to charge vehicles at certain times of the day when demand is low (Int 1). To increase the adoption of smart charging overall, respondents suggested enhancing monetised benefits for EV users, for example, by introducing tariffs specific to smart charging. Additionally, market mechanisms such as local flexibility markets enhancing monetised benefits for V2G were also suggested.

> I think it would be better to incentivise with higher tariffs. We need to change the tariffs to reflect the higher power related costs to motivate to reduce peaks, which are very harmful to the grid. This is a really crucial point for creating flexibility markets and developing the provisions of flexibility by electric vehicles cost efficient. It will play a key role in the future (Int 2).

> I think we need that sort of mechanism and some kind of probably Ofgem regulated system where the electricity networks contribute to making these things happen. I think if they did that, all of a sudden V2G might actually become quite viable electric vehicles as part of a local energy system (Int 10).

Local flexibility markets. Currently, various electricity market models are in an experimentation phase, testing different approaches, including LFMs, to market arrangements.

The respondents explained that currently, only large energy players provide flexibility in electricity markets, while the development of LFMs may enable small businesses and households owning small-scale assets, including V2G, to also provide flexibility to the grid. The challenge lies in designing them in a way that ensures all participants cooperate effectively and benefit monetarily.

The role of aggregators in LFMs, which is helping to control and manage small-scale assets, was emphasised as crucial. That said, the uncertainty surrounding their roles and functions from a regulatory perspective was outlined as a challenge that needs to be addressed in standardising the design of LFMs.

> Now EVs can participate in a continuous market, unless you're an aggregator with a lot of batteries, then they can participate in capacity markets… A local flexibility market is pretty much like an intraday market, I think in a continuous market. So instead of beating, volume and price, I'm also saying where my asset is. And then the grid operator can look at my location and see if I can solve a problem or not (Int 12).

> Local flexibility markets as a part of solution for sure, but we need to completely automate them (Int 2).

During the SC-1 active participant observation, I engaged in research activities that examined potential revenue streams generated by various small-scale assets, including V2G, in projects like GreenSCIES (Cenex 2022). We explored the potential of three power values streams, site optimisation, aggregation services, and electricity market, within the existing market and policy frameworks in the UK. Given that the GreenSCIES project was in the research and development stage at that time, this underscores the importance of both market and policy frameworks being incorporated into decisions related to the adoption of small-scale assets, including V2G.

Technology awareness. In addition to policy and market suggestions, some respondents emphasised the significance of raising awareness about technological innovations. In this regard, energy projects were emphasised as instrumental in promoting sustainable behaviour as well as trends in technologies that encourage the energy transition. This highlights one of the roles of energy projects as explorers, evaluators, and contributors to best practices in sustainable technologies, potentially forming trends in technology adoption.

> These projects are to kind of coldly and scientifically point out the benefits of sustainable behaviour (Int 5).

> What we observed in the project is that most people aren't aware of what local flexibility is… I think it highlights a sort of third value of our project by showcasing its potential (Int 8).

> By implementing sustainable technologies, we certainly aim to create awareness and support residents and commerce to make green choices (Int 9).

Overall, in the context of the policy framework, participants frequently discussed the importance of network tariffs and market mechanisms - including the development of LFMs - in both individual use and energy project contexts, highlighting their inevitable influence on the adoption of smart chargers.

4.3 Findings from the Pocityf project case study

The Pocityf project (project), which stands for Positive Energy CITY Transformation Framework, aims to facilitate the development of positive energy districts. The project focuses on the implementation, testing, and monitoring technolog y- and innovation-driven initiatives that support the energy transition in historical cities with diverse cultural heritage (Pocityf n.d.). The project focuses on 2 lighthouse pilot cities, Alkmaar in the Netherlands and Évora in Portugal, with plans to replicate the initiatives in 6 fellow cities: Hvidovre in Denmark, Ioannina in Greece, Ujpest in Hungary, Bari in Italy, Celje in Slovenia, and Granada in Spain (Figure 21). The project was carried out from 2019 through 2024 (EDP n.d.).

Figure 21 Map of city participants - 2 lighthouse and 6 fellow cities

Source: European Commission 2022

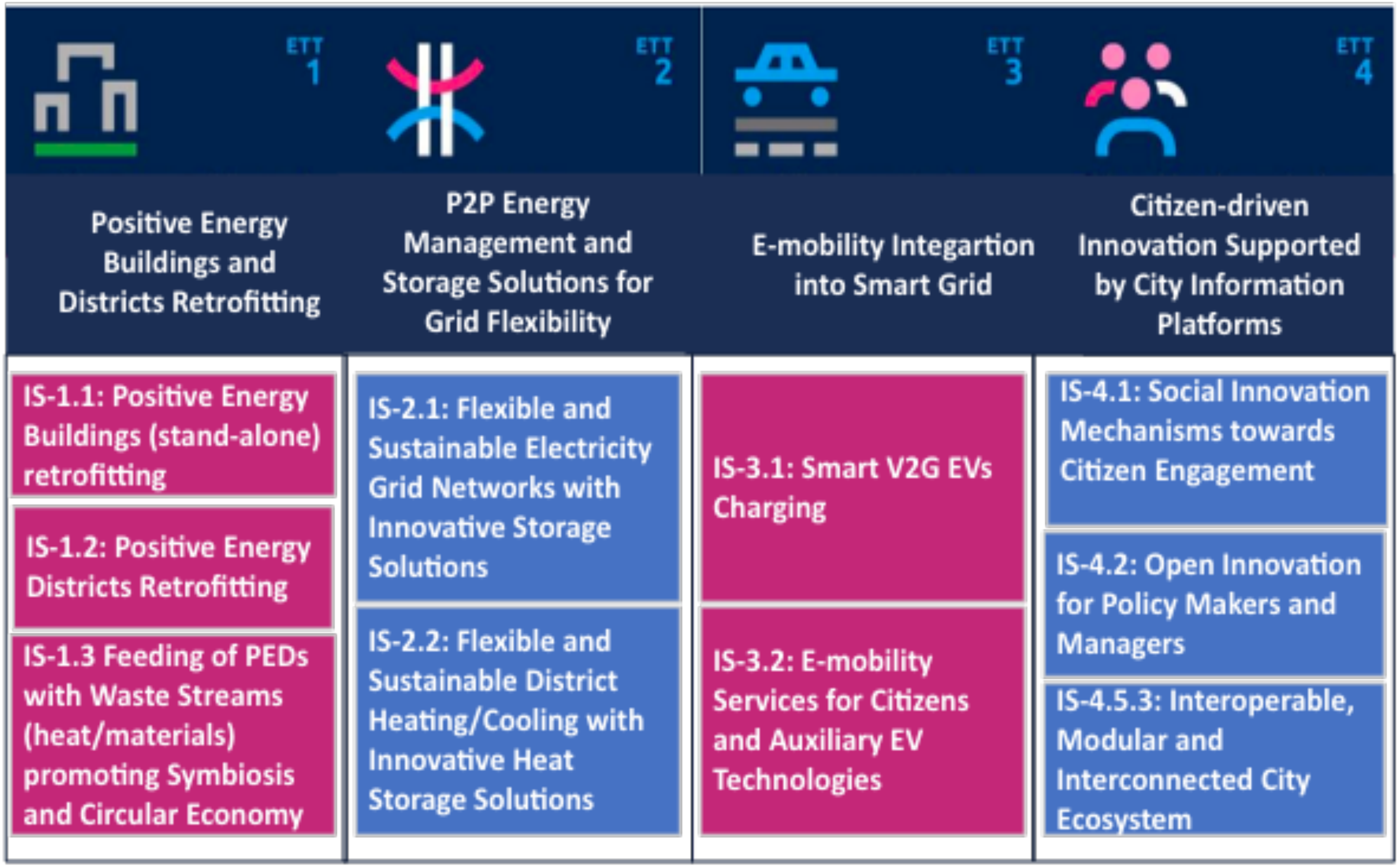
4.3.1 The role of smart chargers in the project

In the Pocityf project, the implementation of technology and innovation-based initiatives is built around four energy transition tracks (ETTs) (Figure 22):

- Retrofitting of positive energy blocks and districts (ETT#1),
- Management of grid flexibility (ETT#2),
- E-mobility integration into the grid (ETT#3) and
- Citizen-driven innovation supported by city information platforms (ETT#4).

These ETTs are key pillars in the project's strategy and described as "a universal yet versatile framework" for promoting the energy transition as a whole (Gonçalves et al. 2020, p. 65). Each ETT is divided into so-called integrated solutions (IS) that guide the actions and outcomes planned to be undertaken in the two lighthouse cities and replicated in six fellow cities within the project. These ETTs and ISs, as illustrated in Figure 22 below, are seen as key solutions for achieving PEDs on a small scale, as well as facilitating the broader energy transition (Int 13).

Figure 22 Framework of four ETTs and ten ISs for two lighthouse cities and their fellow cities



Source: Adapted from Pocityf n.d; Gonçalves et al. 2020

Energy flexibility. The Pocityf project considers smart charging as an important approach to promoting EV uptake, enhancing grid flexibility, and reducing grid investment costs (Int 13,14,15,16). In the project, V2G smart charging infrastructure is implemented in Alkmaar, the Netherlands. Respondents emphasised that the increasing number of EVs, particularly in the Netherlands, where uptake is among the fastest in Europe, could present challenges to the energy grid. Therefore, the implementation of measures that can help to avoid the simultaneous charging of a large number of EVs, which could lead to high energy demands, and incentivise charging during low demand periods, such as overnight, is vital. Furthermore, respondents emphasised that since EVs are frequently parked most of the time, EV batteries can offer valuable opportunities to the energy system by serving as an energy storage option through the use of V2G (Int 13, 15). Specifically, within the project, smart charging, particularly V2G, is seen as a flexibility provider and a contributor to innovation deployment (Int 14).

Smart charging use cases. The project adopts V2G charging infrastructure within the public bus depot and car-sharing scheme use cases (Int 14). The V2G public bus depot use case is led by the public bus company within the project. The respondent emphasised that by implementing this use case, the project aims to decarbonise public buses. Additionally, as the depot is equipped with PV panels, enhancing the energy efficiency of renewable energy use is pursued. The respondent specified that since the existing electric buses were found to be outdated for V2G software embedding, new electric buses with embedded V2G software were purchased.

The V2G e-carsharing scheme is led by the Housing Cooperation (Int 14). The scheme is implemented in a newly built residential building block with rental apartments. The new building block ensures the implementation of energy efficiency measures, including integrating PV panels. Interestingly, the project aims to develop the business model based on a parking restriction policy that is currently under consideration in the Netherlands. As a result, the project does not provide parking spaces within the new building block except for those dedicated to the e-carsharing scheme.

The respondent highlights that this approach aligns with the national mobility strategy, which seeks to reduce car ownership and encourage the shift towards more sustainable means of travel, such as e-carsharing. The respondent explained that the practice of implementing car-free neighbourhoods in the Netherlands is increasing, aiming to encourage residents to walk, cycle, use public transport, or use car sharing clubs. Nevertheless, its implementation is challenging. The respondent outlined that if a parking restriction policy is implemented, widely the adoption of such business models might become less challenging, at least in the context of behaviour change. This underscores the impact of policy on the various stages of technology implementation within the project.

Renewable energy sources. Respondents (Int 14, 16) explained that the project includes a large number of PV panels on the roof, particularly within ETT#1. The enhancement of the use of renewables is a key objective of the project, hence they are integrated in combination with stationary batteries, second-life EV batteries, or V2G charging infrastructure. In cases where PV panels can align with e-mobility goals, such as at the bus depot and in new residential areas requiring the update or implementation of EV charging infrastructure, V2G solutions were considered.

Alongside the enhancement of the e-mobility goal, the alignment of use cases with the predictability of charging behaviour was also considered, due to its effects on the efficiency of V2G use on the grid. In the case of the bus depot, charging behaviour is quite definite, while in the car-sharing scheme, it is less predictable. However, the assumption relies on the location of the charging infrastructure, which is in the residential area. Therefore, it is assumed that the use of cars would be similar to domestic driving behaviour with vehicles charging overnight.

Local flexibility market. The project is developing the P2P energy trading platform within ETT#2 activities. Initially, the project planned to implement a P2P energy trading platform, which would enable the operation of LFM in both Alkmaar and Évora cities (Kourtzanidis et al. 2020). In Évora, the platform aimed to reward market participants for trading PV energy. In Alkmaar, along with PV energy trading, the platform aimed to trial flexibility trading provided by V2G technologies (ibid). However, according to project factsheets for implemented solutions and Int 13, 15, the P2P platform is implemented only in Évora, Portugal.

This P2P energy trading platform aims to allow PV users to monetise or donate their surplus of energy to neighbours (Int 13, 15). This entails flexibility from V2G not being trialled within LFM in the project. Respondents explained that the development of LFM is still nascent, uncertain, and challenging, requiring specific skills and expertise. Respondents emphasised that although the platform in Évora does not support the trading of flexibility, it will provide users with information about the savings they have achieved if they own energy flexibility providers, specifically with 2nd life EV batteries installed in homes.

One respondent (Int 15) explained that the P2P energy trading platform in Évora is a transactive platform that integrates similar to “a virtual wallet like Paypal”. The platform does not involve the complex elements that LFM does, specifically location and forecasting, pointing out that “we are not controlling where the energy is flowing”. The platform aims to test the impact of PV fluctuations on grid congestions and trade PV energy in the context of an energy community (Int 13).

This means that the trial of the platform will be conducted in accordance with Portuguese regulations, which apply the concept of “collective self-consumption” (also known as energy sharing in EU documents), enabling prosumers to trade self-generated energy or flexibility within a radius of 2km on low-voltage and 4km on medium voltage with neighbouring areas (Int 13). The trading process will involve allocating energy generated by one prosumer to another prosumer and sharing the relevant information with the DSO at the end of each month to be reflected on the energy bill. Overall, the implementation of the P2P platform expects to increase efficiency of the use of renewable energy, contribute to the reduction of the use of fossil-fuel-generated electricity, and decrease energy bills for end-users.

4.3.2 Organisational Governance

The project comprises 46 partners from 13 countries, namely Portugal, Italy, Spain, Germany, the Netherlands, Greece, Slovenia, Denmark, Hungary, Finland, Belgium, Austria, and Switzerland (Pocityf n.d.). This extensive partnership characterises the project with a large size, cultural heterogeneity, and its interorganisational network nature. The project’s partners are organisations, specialising in different fields such as academia, energy consultancy, housing association, and public transport. This implies the presence of a mix of skills and competences within a dynamic environment. The Pocityf project conceptualises itself as a network of smart cities and highlights collaboration and knowledge sharing as one of its key project principles, along with citizen engagement and innovativeness in addressing common environmental challenges and achieving sustainable urban ecosystems (Gonçalves et al. 2020; Pocityf 2019).

The project is funded by the European Commission (EC) under the Horizon 2020 programme, with a budget of €22.5 million and an EC contribution of about €20 million (Pocityf n.d.; Cordis 2024). Similar to all EU funded projects, the authority processes and managerial initiatives of the project are documented in the Grant Agreement, the Consortium Agreement, and Project Management Plan (Costa and David 2020). Authority processes define the roles and responsibilities within the project, while managerial initiatives are described through a sequence of stages required for planning and controlling project activities. Four times during the project, reports on technical and financial information are submitted to the European Commission (Costa and Leitão 2020). Additionally, the project participates in European Commission review meetings, where progress and possible corrections are discussed. This indicates that the project's governance involves EU coordination, combining both multi-level and cross-sector decision-making processes.

Nevertheless, while the project underscores a combination of both top-down and bottom-up approaches, a certain degree of operational autonomy across local actors is also highlighted (Int 16). The top-down approach involves the European Commission monitoring the implementation of actions, deadlines, costs, and other aspects, defined in the grant agreement. The utilisation of these mixed approaches refers to the complex institutional nature of the project and the utilisation of the EU financial support.

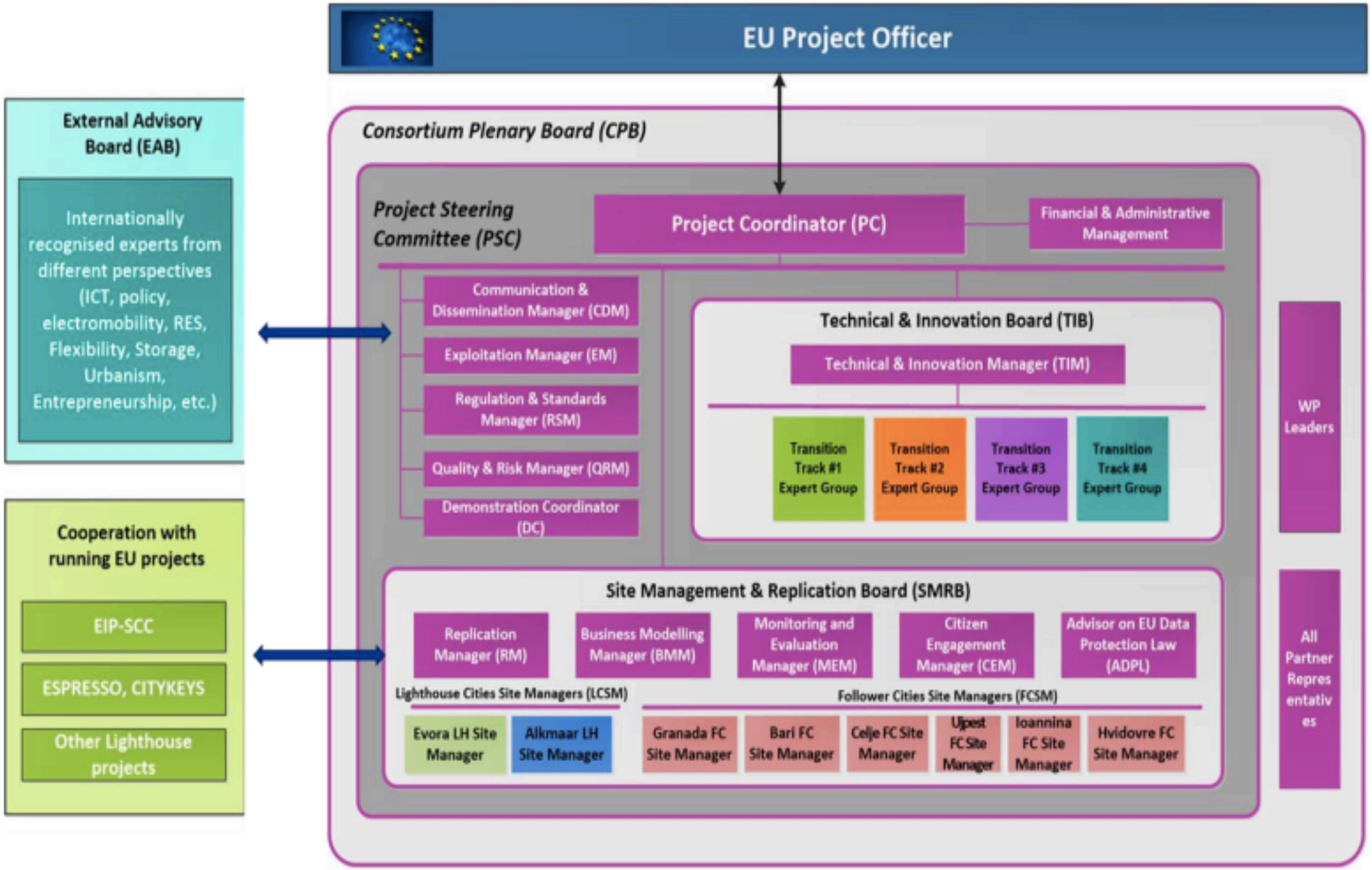
Within the consortium, however, the project operates as a lead organisation-governed network, coordinated by one of the project partners, EDP Labelec. Alongside coordinating the project, EDP Labelec offers services ranging from energy generation to consumption (Int 13). Within the project, EDP Labelec coordinates the following activities: 1) grid and local electricity market-related initiatives in the city of Évora; 2) delivering reports regarding clustering and communication with ongoing European Smart Cities and Communities projects; 3) shaping the strategic plans and development frameworks (EDP n.d).

Managerial structure. The managerial structure of the project is illustrated in Figure 23, outlining the distribution of responsibilities among consortium members and their collaboration with external experts and projects. The managerial structure consists of three boards: the project steering committee, technical and innovation board, and site management and replication board (Costa and Leitão 2020). The first project steering committee board is responsible for financial, administrative and knowledge distribution tasks.

The second, technical and innovation, board is responsible for coordination, implementation, and monitoring of the progress of technology-based initiatives within the cities of Évora and Alkmaar (Costa and Leitão 2020). There are four technical and innovation managers responsible for the implementation of innovations in ETTs. These ETTs address solutions around building retrofitting, grid flexibility, e-mobility integration into the grid, and city information platforms.

The third board, site management and replication, is responsible for managing replication activities in both the lighthouse and fellow cities. This board includes managers who are responsible for replicating the implementation of innovations in each of the eight cities. The project also facilitates external networking and cooperation with internationally recognised experts and ongoing EU projects, such as EIP-SCC, ESPRESSO, and CITYKEYS, to support knowledge sharing and distribution among organisations that are beyond the Pocityf project.

Figure 23 Pocityf governance structure



Source: Costa and Leitão, 2020

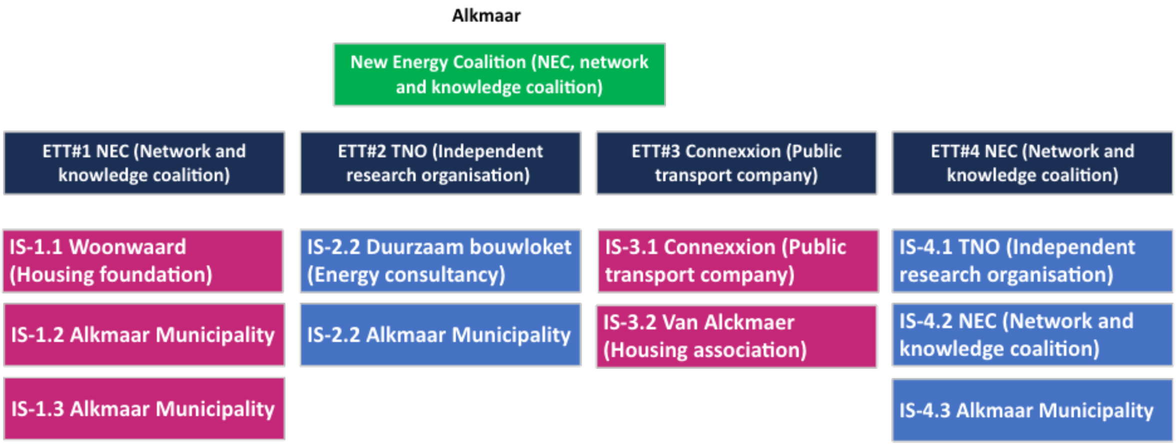
Responsibilities. The coordination of activities is overseen by managers based on their expertise in designated relevant areas from project partners (Int 13). The interview participant emphasised that one of the roles of managers in the Pocityf project is to encourage cross-organisational interaction to ensure the support to knowledge exchange and cooperation. One of the project's key means of exchanging and sharing knowledge is publishing report deliverables. The project encompasses 18 publicly available deliverables informing about the project's management strategies, milestones, progress, and outcomes (Pocityf n.d.).

The coordination of tasks related to the enhancement of grid flexibility and the implementation of EV smart charging technology is led by local authorities and other local organisations, including research institutes, energy consultancy firms, public transport companies, housing associations, and engineering companies. The coordination and management of activities is accordingly assigned to expert groups from the lighthouse cities. The lead organisations are assigned to task activities according to their actuation and expertise in the relevant areas (Costa and Leitão 2020, p.21). The lead organisations responsible for the implementation of activities within the cities of Évora and Alkmaar, are mapped in Figures 24 and 25, respectively.

Specifically, in Alkmaar, the lead organisations that coordinate initiatives related to the enhancement of grid flexibility are TNO (Independent research organisation), Duurzaam bouwloket (Energy consultancy) and Alkmaar Municipality, respectively. As for the implementation of EV smart charging initiatives, the lead organisations are Connexxion (public transport company) and Van Alkmaar (housing association).

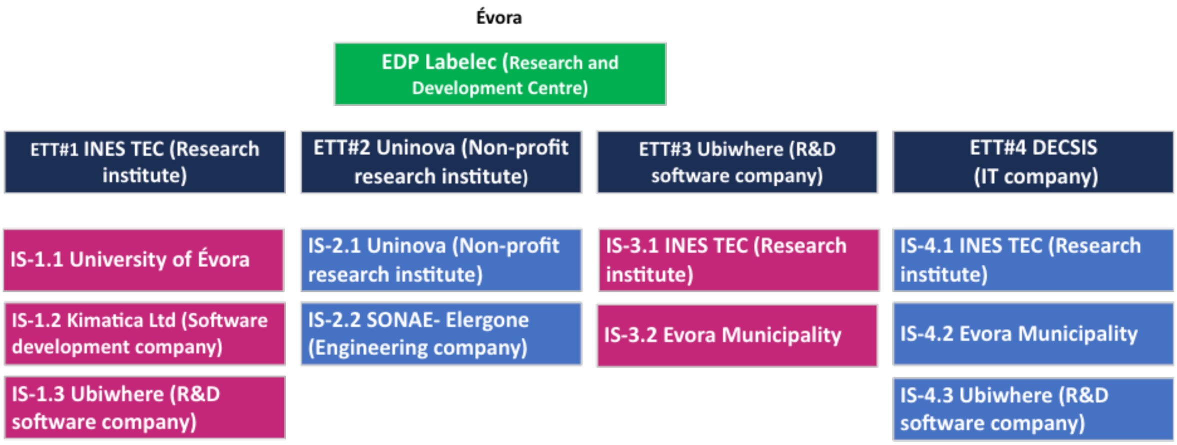
In Évora, the lead organisations that coordinate initiatives related to the enhancement of grid flexibility are Uninova (a non-profit research institute) and SONAE- Elergone (an engineering company). The lead organisations coordinating the implementation of EV smart charging initiatives are Ubiwhere (an R&D software company), INES TEC (a research institute), and Évora Municipality, respectively.

Figure 24 Leading organisations in delivering ETTs and ISs in Alkmaar



Source: Adapted from Costa and Leitão, 2020)

Figure 25 Leading organisations involved in delivering ETTs and ISs in Évora



Source: Adapted from Costa and Leitão, 2020

Communication channels. The project's one key objective is knowledge sharing and distribution, which involves various organisational activities, such as capacity building through stakeholder cooperation and engagement (Int 16). Within the project, internal communication is established through scheduled face to face meetings, virtual meetings, emails, and the online collaborative tool Teams for an information and document library. External communication channels for dissemination purposes include social media platforms such as LinkedIn, newsletters, workshops, and conferences.

4.3.3 Policy framework

Smart charging policy in the Netherlands. As V2G charging infrastructure is adopted in Alkmaar, the policy and market framework of the Netherlands is explored here. The Netherlands is a frontrunner in installing EV charging infrastructure within the EU (ACEA 2020). The increasing number of EVs, coupled with other technologies like heat pumps, impacting extensive electrification, has already caused grid congestion and subsequent power cuts (RAP 2024; Thormann and Kienberger 2020). Anticipating further challenges in the Netherlands over the upcoming years, the Dutch government has set out the programme "Smart charging for all 2022-2025. Action Plan".

This Action Plan describes smart charging as "a must have" technology for preventing local peaks in demand (NAL 2020, p.3). The Action Plan emphasises that "smart charging is rapidly becoming proven technology and a logical next step is to transform this technology into customer propositions. Given the accelerated uptake of electric vehicles and the capacity boundaries of the power grid, smart charging is essential" (NAL 2022, p.7). The policy emphasises that smart charging offers an opportunity to provide "a fairer distribution of the available grid capacity" among energy consumers, highlighting the necessity for enabling charging in a socially responsible manner (NAL 2020, p.29).

The Netherlands government aims to incentivise 70% of EV drivers to charge smartly by 2025 and plans to establish smart charging as the standard from 2025 (NAL, 2022). The policy recognises that the current lack of financial stimulus is an absolute precondition to the non-adoption of smart charging among domestic users. Therefore, in upcoming policies, two national charging regulations, the National Charging Infrastructure Agenda and the Roadmap for Smart Charging 2030, expected in 2025, will introduce new domestic usage rates, rendering smart charging, particularly V2G, more financially appealing.

The National Charging Infrastructure Agenda (NAL) working group reports that "smart charging with the standard setting will be significantly cheaper than conventional charging" (NAL 2020, p.3). Other approaches, such as interventions to promote behaviour change through communication, the development of ease of use, and the provision of opportunities to become familiar with the technology, are also planned as part of policy development (ibid).

Energy flexibility policy in the Netherlands

Currently, the Netherlands faces a serious grid capacity shortage due to increased electrification and the expansion of renewables (RAP 2024). To accelerate the enhancement of grid capacity, in 2022, the Netherlands government initiated the National Grid Congestion Action Program (the 'Program'). The Program defines goals and actions toward incentivising efficient grid use through various means, including network tariff reform, amendments to the network code on congestion management, and support for smart charging initiatives. This entails that, in the Netherlands, the enhancement of energy flexibility is a high priority and the support of smart charging is recognised as a significant part of the solution.

In terms of tariff optimisation, there is currently an agile tariff supporting the adoption of V2G in the Netherlands (Int 16). The agile tariff contract offers lower energy prices during off-peak periods, incentivising EV drivers to charge their vehicles when electricity demand is lower. This leads to a reduction in electricity costs that is reflected in the energy bills of V2G users. One participant (Int 16) noted that users have reported savings on their energy bills and have found V2G chargers easy to use, especially with the use of the integrated app. Nevertheless, the development of additional financial incentives to accelerate the adoption of V2G charging is suggested.

Trend in adopting smart charging in the Netherlands

The Netherlands is one of the leading countries in EV adoption across Europe (Paradies et al. 2023). To incentivise EV uptake, the Netherlands has offered tax exemptions, purchase subsidies, company lease incentives, and the dynamic distribution of public EV chargers since 2020 (Fier Sustainable Mobility 2023). Tax exemptions include road taxes, which range from €500 to €1500, and registration taxes, ranging from €1000 to €15,000 (Paradies et al. 2023). The number of public EV charging points across the country numbered about 70,000, which is one of the largest figures in Europe (Statista 2023).

In implementing V2G technologies, the Netherlands is also a frontrunner in Europe. There are seven V2G projects, including the world's largest V2G carsharing schemes within the SMART Solar Charging project. Additionally, there are large-scale V1G charging initiatives under the INVADE project, as presented in Table 10.

Table 10 V2G projects in the Netherlands

N	Projects	Scale	Location	Year of the implementation
1	City-Zen Smart City	9 V2G chargers	Amsterdam	2017
2	NewMotion of V2G project	10 V2G chargers	Amsterdam	2017
3	Amsterdam Vehicle2Grid	2 V2G chargers	Lochem	2017
4	SEEV4-City	2 V2G chargers	Amsterdam	2016-2020
5	SMART Solar Charging (as part of IRIS Smart Cities project)	500 V2G chargers	Utrecht	2018 - 2023
6	INVADE	1 V2G charger and 199 V1G chargers	Arnhem	2017 – 2020
7	Pocityf	V2G sharing scheme (2 units) V2G bus depot	Alkmaar	2019-2024

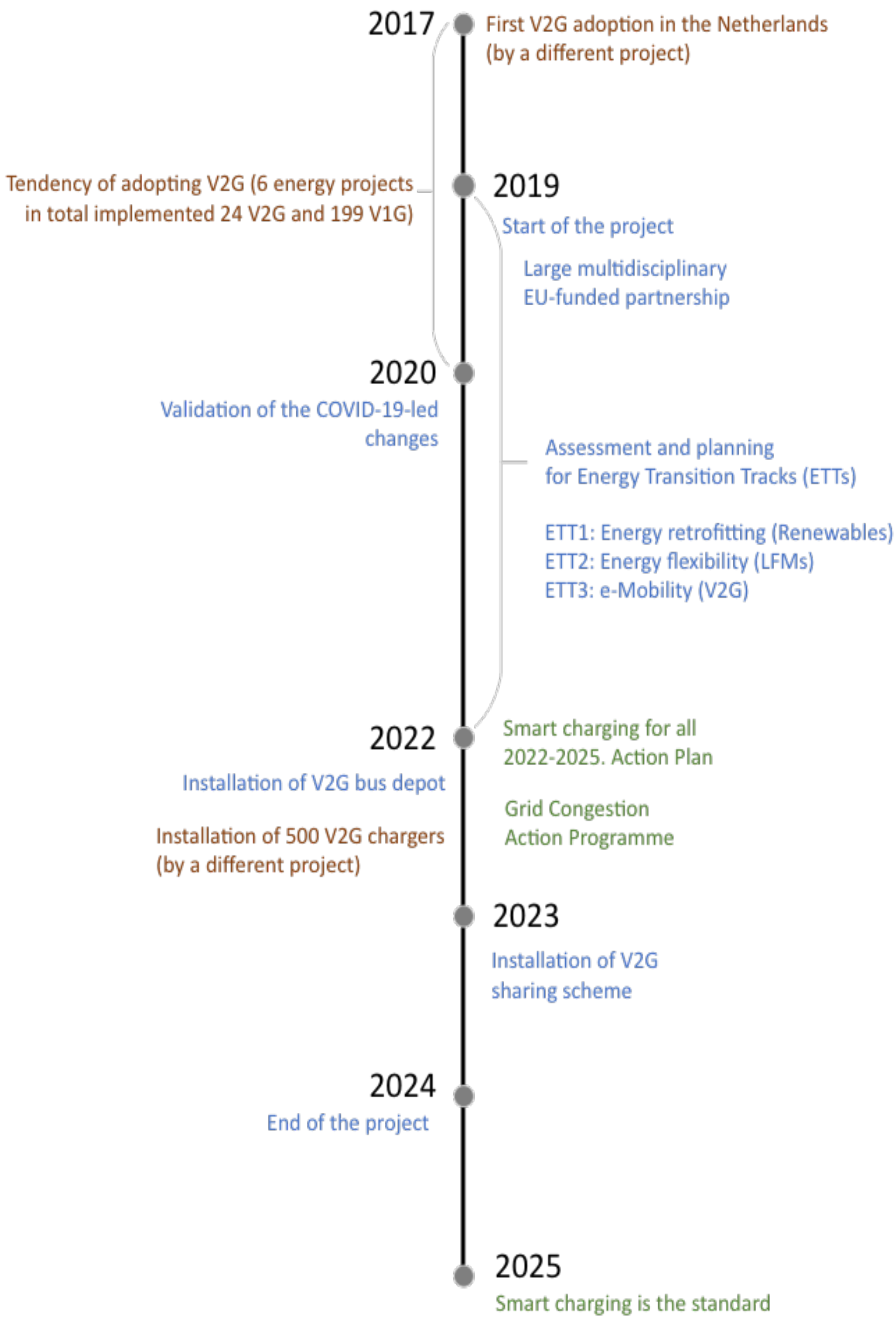
In summary, the Pocityf project is a large multidisciplinary EU-funded partnership with the goals of deploying the energy transition solutions, including renewables, energy flexibility, and e-mobility. The project underscores the significance of collaboration and active engagement among various organisational stakeholders, as well as the availability of funding, which influences the adoption of smart charging. Additionally, the project supports the influence of the availability of renewables, the goal to integrate power and mobility systems, and the goal to address energy flexibility on the adoption of smart charging.

The project has installed numerous PV panels, developed a P2P platform for energy trading within the local community, and adopted V2G technology in both a bus depot and a car sharing scheme. The project aimed to deliver a LFM, supporting the relationship between the availability of LFMs and the adoption of V2G chargers. These V2G initiatives are implemented in Alkmaar city, the Netherlands, a leading country in V2G implementations, proactively supporting both smart charging and energy flexibility initiatives at a regulatory level. These findings showcase potential relationships between the availability of smart charging policy, energy flexibility policy, trends in adopting V2G chargers at a national level, and the adoption of smart charging within the Pocityf project. Figure 26 presents a visual representation of the key findings revealed from the case study.

Overall, in the project, the adoption of V2G smart charging is positively associated with the following factors:

- a large multidisciplinary EU-funded partnership;
- the goal to enhance energy flexibility;
- the goal to develop LFMs;
- integration with renewables;
- availability of smart charging policy;
- availability of energy flexibility policy;
- trend in adopting smart charging at a national level.

Figure 26 Timeline of developments in the Pocityf project



Source: Own elaboration

4.4 Findings from the Smart Energy Åland project case study

The Smart Energy Åland project aims to achieve a 100% renewable energy system on the *Åland* Islands by 2030 (JPI Urban Europe, 2020a). The project's duration was from 2014 until 2019; however, there are still ongoing energy initiatives in the Åland Islands developing on behalf of the project (Flexens 2022; JPI Urban Europe 2020a). The project was established in 2014 by the government and managed by the project development organisation, CLIC Innovation. Since 2019 and up to the present, the project has been managed by the Flexens organisation, which was specifically established for the development of the Smart Energy Åland project.

Figure 27 Image of the Åland Islands

Source: European Commission 2023

4.4.1 The role of smart chargers in the project

From 2014 to 2021, the Smart Energy Åland project (henceforth the 'project') aimed to develop the integration of the power, heating and transportation sectors (Leichthammer 2016). This aim was reflected in the project's roadmap, which was developed by the VTT Institute in 2015 (Int 17; Leichthammer 2016). The project roadmap was developed based on a feasibility study conducted by the VTT Institute (Int 17), estimated potential cost-efficient energy system solutions for achieving 100% renewable energy in Åland by 2030 and proposed two scenarios, presented in Figure 28 (Leichthammer 2016).

The first scenario proposed the expansion of wind energy from 20% to 70%, solar energy from 0% to 15%, and biomass CHP plants from 0% to 15%. The proposal included the conversion of fuel-based CHP plants to biomass CHP plants. The second scenario excluded the development of biomass CHP plants and focused solely on the extension of wind and solar energy, from 20% to 90%, and 0% to 10%, respectively. The first scenario was considered as the most cost-efficient, as transitioning to biomass CHP plants would potentially require fewer infrastructure changes compared to the second scenario (Thomasson et al. 2018, cited in CLIC Innovation 2019; Thomasson et al. 2021). However, both scenarios highlighted the need to enhance energy system flexibility to accommodate the fluctuating supply of wind and solar energy.

Figure 28 Åland's renewable energy system scenarios

Current situation:

- Wind capacity 21 MW
- Heat 20 MWe
- Peak 75 MW
- Total consumption 318 GWh
- Min load 16 MW
- Capacity mix
  - Import 80 %
  - Wind 20 %

Future 1:

- Wind capacity 85 MW
- Heat CHP 20 MWe
- Solar 15 MW
- Peak 85 MW
- Total consumption 400 GWh
- Min load 16 MW
- Capacity mix
  - Wind 70 %
  - Solar 15 %
  - CHP 15 %

Future 2:

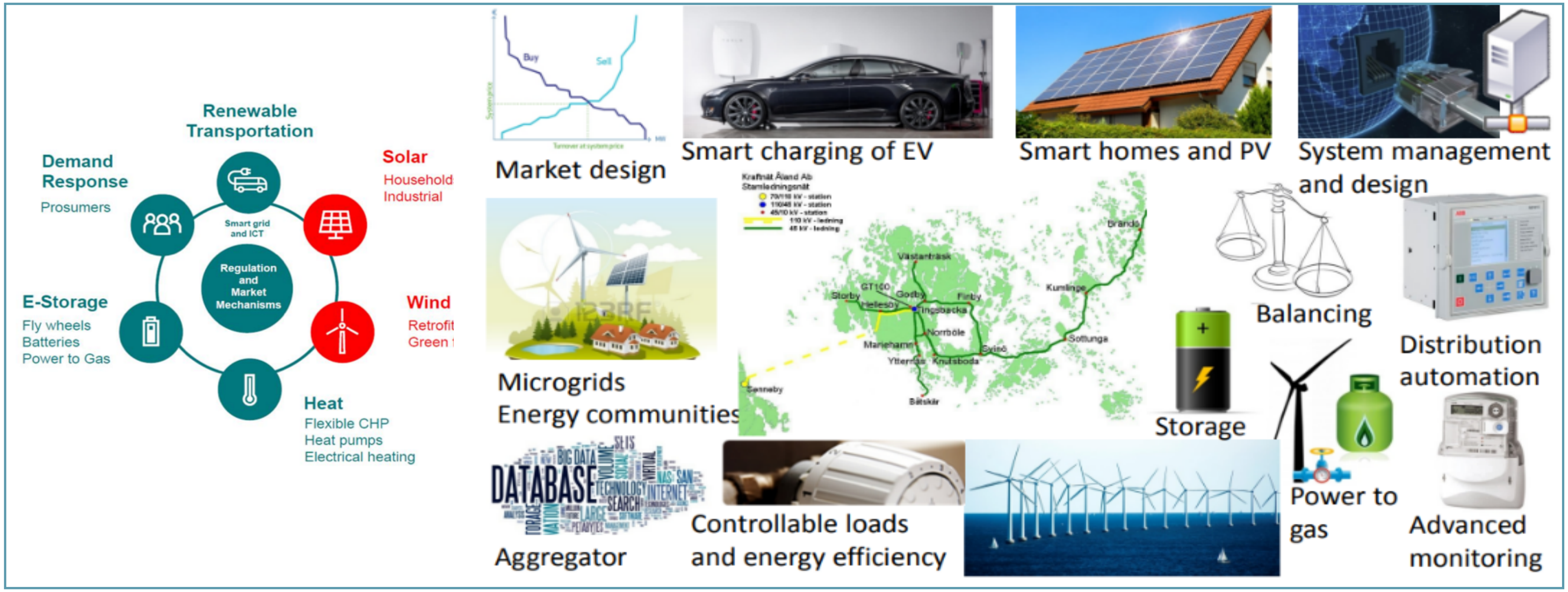
- Wind capacity 170 MW
- Heat CHP 0 MWe
- Solar 20 MW
- Peak 85 MW
- Total consumption 400 GWh
- Min load 16 MW
- Capacity mix
  - Wind 90 %
  - Solar 10 %
  - CHP 0 %

Source: Leichthammer 2016

Thus, the project aimed to install new wind turbines (four times more than currently existed), a shift to biomass CHP plants, as well as implement smart charging, particularly V2G, energy storage (e.g. stationary batteries), and energy management systems, as illustrated in Figure 29 (Flexens 2019; ATEC 2015). The integration of these technologies was intended to increase the efficiency and reliability of the energy system in Åland (ATEC 2015).

The project's feasibility study identifies characteristics such as the manageable size of the Åland Islands and its location between Finland and Sweden create "good conditions to combine electricity with heat and even transport" (Leichthammer 2016, p.21). This implies that Åland's geographical location and its electricity interconnections between Sweden and Finland were envisioned as significant opportunities for developing the integration of electricity, heating/cooling and transportation systems (Flexens 2019). This integration was planned to be achieved through the development of "novel technology, management, and design principles" (ATEC 2015, p.5).

Figure 29 The smart energy system Åland project's envisioned solutions



Source: ATEC 2015 and Flexens 2019

Energy flexibility. Respondents (Int 17,18) outlined their view that V2G is a technology that can contribute to the enhancement of energy flexibility, which is an essential consideration with the increasing renewable generation. Within the project, flexibility enhancement was intended to be achieved through the development of a flexibility market and the deployment of flexibility providers, including V2G (Int17). However, due to financial constraints, the project has not implemented targeted technologies, including V2G (Int 17,18).

One of the project's research documents recommends the implementation of V2G in the Åland Islands, noting that "V2G services seem to offer a key flexibility for future energy systems in the Åland islands" (Child et al. 2018, p. 14). The document explains that V2G technology can offer significant benefits to the Åland's energy system by supporting the management of high shares of fluctuating renewable energy generation. Furthermore, the document highlights that the integration of V2G charging can reduce the necessity for expensive battery energy storage investments, as it contributes to the more cost-efficient management of offshore wind power capacity.

Local flexibility market. To date smart charging, particularly V2G, along with flexibility markets, has not been implemented within the project. The major reason mentioned for their non-implementation is a lack of financing (Int 17,18; Soderholm 2020). Additionally, one of the participants outlines that the project aimed to implement V2G due to the initial plan to implement flexibility markets (Int 17). The aim was to trial V2G as one of the flexibility assets within flexibility markets.

Nevertheless, the respondent (Int 17) emphasised that that apart from financial challenges, there was a lack of knowledge and experience in implementing new flexibility markets. Even today, these markets are in a nascent stage, accompanied by a plethora of uncertainties regarding the design of flexibility markets and the engagement of customers to participate in them.

4.4.2 Organisational governance from 2014 to 2019

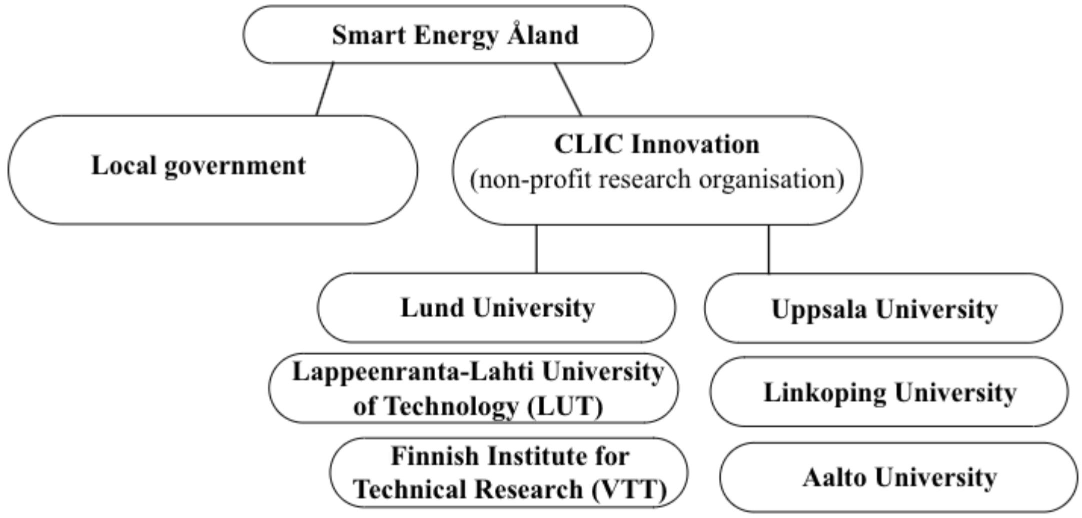
In 2014, the project was initiated by the governmental organisation Åland Technology and Energy Centre (ATEC). During 2014-2019, the project encompassed the local government and the non-profit research organisation CLIC Innovation, representing a public-private partnership (Flexens 2019). This indicates that both the local government and CLIC Innovation jointly established the strategic direction and made decisions equally in coordinating tasks (Int 17). This reflects a shared participant-governed network, also known as a horizontal or decentralised arrangement. During this period, the project solely focused on research activities, including thesis projects conducted within local universities.

Project activities (2014 - 2019). From 2014 to 2019, the project's activities involved "eight individual project sub-groups to evaluate opportunities from different perspectives, where each sub-group was responsible for their own timetables and work packages" (CLIC Innovation 2019, p.8). Research topics were divided among the eight groups as follows: energy production (2 groups), potential providers of energy system flexibility (4 groups), the future grid's technical requirements (1 group), and potential information and communication technology (ICT) solution needs (1 group) (CLIC Innovation, 2019).

The research activities were led by various universities and research agencies, including Uppsala University, Aalto University, Lund University, Linkoping University, Lappeenranta-Lahti University of Technology, and the Finnish Institute for Technical Research (VTT) (Flexenss 2021). The research activities were coordinated independently and monitored only by universities (Int 17,18). The research outputs are available at the CLIC Innovation media resource, demonstrating a homogeneous disciplinary engagement with academia and a lack of engagement with industry. The organisational structure of the project is demonstrated in Figure 30.

The majority of research initiatives have contributed to the energy production topic, with limited contributions to other research areas. This suggests that the research initiatives were conducted with a low level of collaboration between research groups. The synthesis of research activities is presented within the document "Final joint report of the project" (CLIC Innovation 2019), which describes the current energy system of Åland and discusses its 2050 vison.

Figure 30 The smart energy Åland project's stakeholders

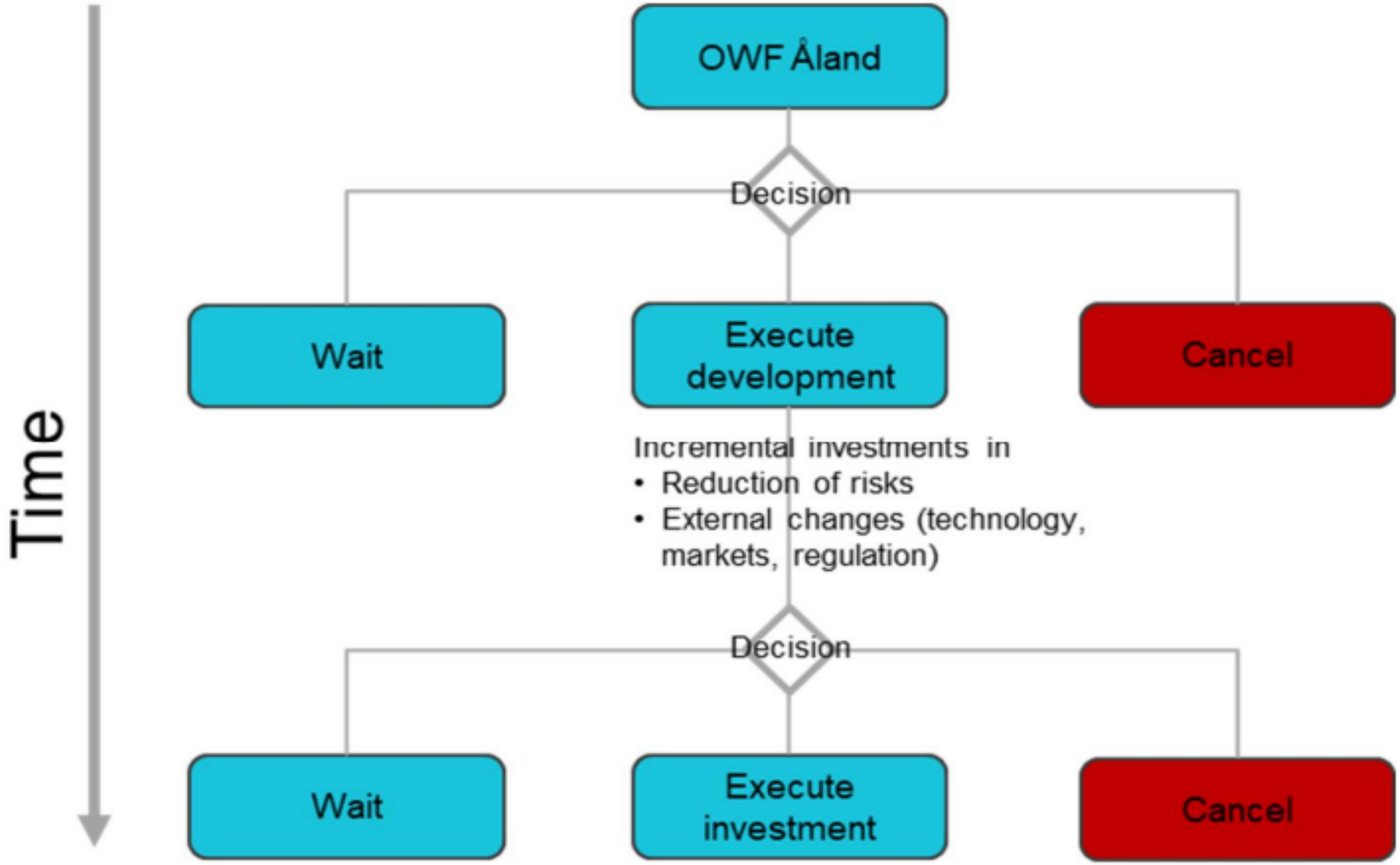


Source: Own elaboration

The project's decision tree. One of the project's research resources, "The Carbon negative Åland strategic roadmap" (LUT University 2021), outlines a decision tree for offshore wind technology development (Figure 31). The decision-tree, also referred to as the development scheme, consists of three options: "wait", "cancel" or "proceed" decisions. The criteria suggested for use in technology decisions, particularly for wind technology, are outlined as "incremental investments in reduction of risks and external changes (*regulation, technology, and markets)"*, as presented in the middle of the diagram. This might illustrate that the project considered regulation and market frameworks in decisions related to the selection of technologies.

Additionally, the project document emphasised factors such as "opportunities, political will in the EU, technology and market development, and time", as influential in the decision-making processes within the project (LUT University 2021, p.42). This not only reiterates the importance of the market in the project's decisions, but also highlights the role of the EU and the opportunities that might be opened for the project. The importance of the latter was confirmed by interview respondents, as discussed below.

Figure 31 Decision tree for technology development in Åland



Source: LUT University 2021

Financial resources. One interview participant (Int 17) explained that the project planned to obtain investments from EU funding, noting that "it is difficult to obtain investments for large technologies". The respondent explained that EU funding was seen as one of the realistic opportunities for investments for all types of technology developments in the project. The participant noted that the project applied for investments to deploy energy technologies multiple times to the EU Innovation Fund, but applications were not approved. That is why the respondent believes in the strong link between a lack of investments, particularly from EU funding, and the non-implementation of technologies, whether wind, solar, or V2G, within the project.

One of the project's research documents also highlights that a lack of financial investments is a primary challenge to technology implementation in the project (Leichthammer 2016). The project's document reports that although 70% of wind turbines are already very old and need updating, "due to lacking funding, all winds intend to maintain and keep them in operation as long as possible but has no plans on updating them. And as long as the funding situation stays the way it is today there are no updates reasonable" (Leichthammer 2016, p.64). This highlights that the project relies on funding even to update old wind turbines.

Governance from 2019 to the present. In 2019, the Flexens organisation was specifically established to develop and manage the project, transforming its governance into a network administrative organisation. (Flexens 2019; Flexens 2021). This maintained a horizontal approach where the project's partners collectively made strategic-level decisions (Int 17). The difference is that Flexens, an organisation established specifically for the task , now handles operational decisions.

There were no significant changes in technology adoption during 2019-2021. However, since 2021, an increased level of proactiveness has been observed within the project, possibly associated with the change in the project's governance mode. In 2021, the project conducted a webinar announcing a shift in its technology adoption goals towards hydrogen development (Flexens 2021). The project mentioned plans to focus on the implementation of hydrogen technology for heavy vehicles, including maritime transport. In the same year, the project's partner, CLIC Innovation, became the project coordinator of a large-scale EU funded project, BalticSeaH2, the change in technology adoption goals might be associated with such project collaboration.

Currently, Flexens is conducting a feasibility study for potential hydrogen-powered ferry routes and supply within the BalticSeaH2 project. Since 2023, Flexens has started constructing the hydrogen refuelling station for both light and heavy vehicles, funded by the national government (Flexens 2023). At the beginning of 2023, the project received an €800,000 investment grant from the Finnish Energy Authority to build the first hydrogen refuelling station for light and heavy vehicles in Finland. Currently, the hydrogen refuelling station is in the construction phase, during which a 100 MW electrolyser is being prepared for construction nearby in Naantali (ibid). The construction of the hydrogen refuelling station is expected to be operational in 2025 (Lhyfe 2023).

Thus, from 2014 to 2019, within a public-private partnership, the project focused primarily on research activities. Since 2019, changes in governance, including the establishment of a specific organisation to coordinate the project, have shown results in technology adoption. The project has collaborated with a large multidisciplinary EU-funded project, which may have influenced the Finnish Government' decision to invest in a technology, specifically a hydrogen refuelling station.

4.4.3 Policy framework in Finland

The Finish government has begun supporting EV adoption since 2019, aiming to increase it to at least 250,000 by 2030, (Ministry of Economic Affairs and Employment of Finland 2019). Policy incentives for promoting EV adoption involve the reduction of import and annual taxes for EVs (International Energy Agency 2021), a purchase subsidy for EVs equal to €2000 (Finnish Government 2021), and the deployment of public EV charging points in Finland, which in 2021 totalled 1,392 (Statista 2021). As of 2021, the proportion of EVs on the road in Finland accounted for less than 1%, equivalent to approximately 22,892 cars (Statista 2022; Geostreams 2021). One interview respondent (Int 18) explained that such slow EV adoption in Finland might relate to the relatively late introduction of incentives and their limited scope, suggesting that offering more incentives such as free or reduced-cost parking benefits and e-carsharing programmes is more likely to facilitate EV uptake.

Energy flexibility and smart charging policies. There is also a lack of policies and incentives promoting energy flexibility and smart charging adoption. The terms “intelligence” and “flexibility” are briefly outlined in the “Integrated Energy and Climate Plan”, noting that “the intelligence and flexibility of new and decentralised systems will be promoted, for example in electric transportation” (Ministry of Economic Affairs and Employment of Finland 2019, p.41). On the one hand, the Plan states that the development of smartness and flexibility in Finland are in the plan, but on the other hand, the language suggests uncertainties or indecisiveness regarding their promotion.

The “Government report on the National Energy and Climate Strategy for 2030” recognises the significance of smart charging adoption, noting that “in the future, smart recharging will make it possible to control the recharging times of batteries, thus creating significant potential for demand response in the electricity market” (Ministry of Economic Affairs and Employment Energy 2017, p.59). Nevertheless, taking into consideration that there are no other references to smart charging or energy flexibility, it might be concluded that their promotion is not a priority within Finish energy policies.

Trend of adopting smart charging in Finland. There is only one project that implemented a V2G charger, in Helsinki in 2017, which was part of the EU-funded MySmartLife project (Kulmala et al. 2019). By 2023, no additional V2G projects had been implemented in Finland (V2G-hub 2024).

Table 11 V2G projects in Finland

N	Projects	Scale	Location	Year of the implementation
1	Suvilahti pilot (as part of MySmartLife project)	1 V2G charger	Helsinki	2017

In summary, the Smart Energy Åland project was established in 2014 as a public-private partnership with the goal of significantly scaling-up the adoption of renewable energy sources on the Åland Islands to achieve a 100% renewable energy system. To enhance renewables and support energy flexibility, the project planned to adopt stationary batteries as well as V2G charging infrastructure. However, from 2014 to 2019, the project did not implement any technologies, offering the lack of financial resources as the primary reason. This highlights the importance of funding for PED projects that aim to address climate change. During this period, the main project activities were limited to collaborations with universities with minimal engagement among project stakeholders. This emphasises the significance of collaborations and active engagement with various stakeholders, including along with universities, local authorities, and businesses, to foster activities supporting technological interventions.

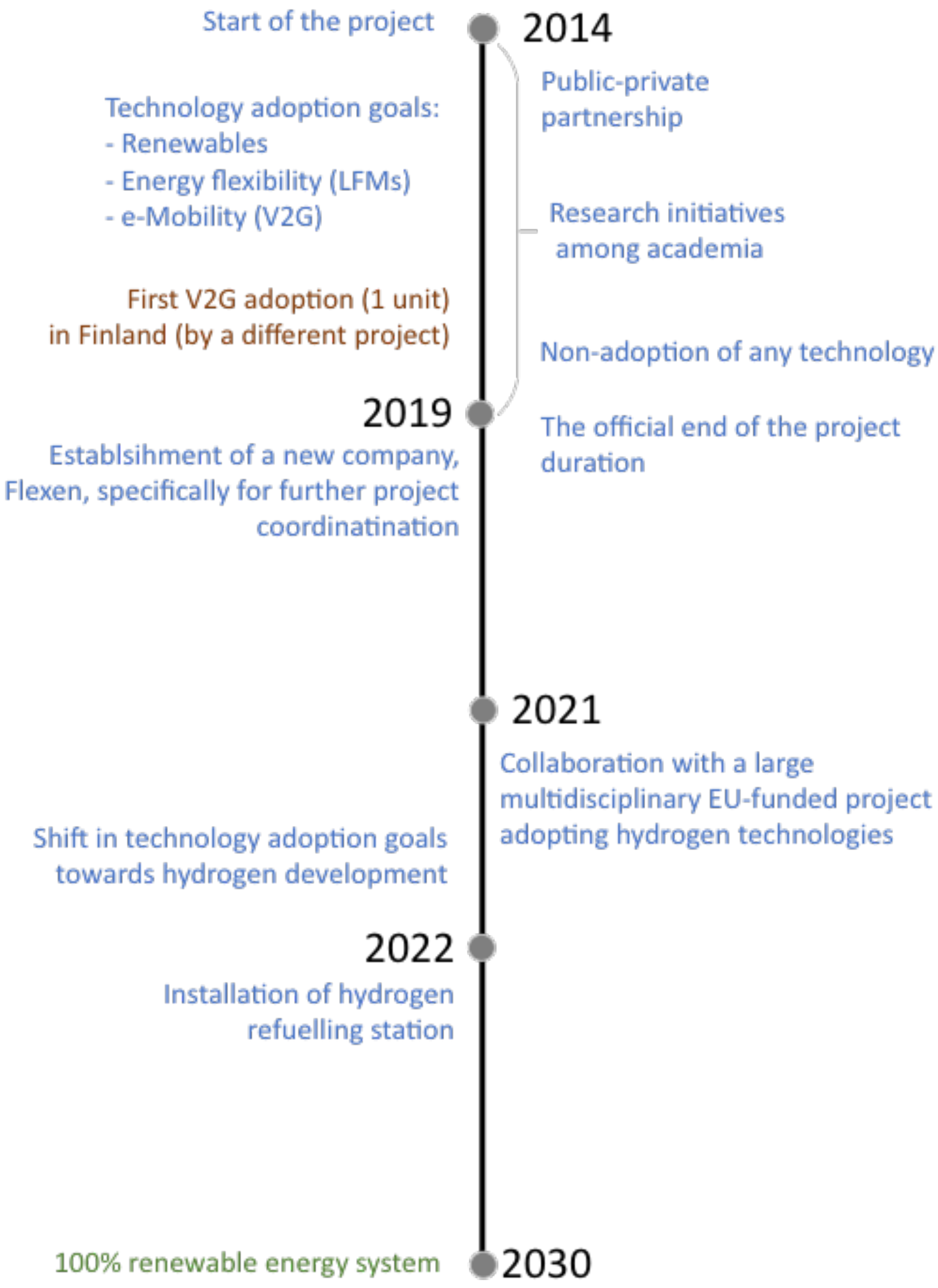
Since 2019, the project has undergone the change in governance by establishing an organisation specifically for project management and coordination. Within two years, the project had established a partnership with a large multidisciplinary EU-funded project, which focuses on the development of hydrogen technologies. This again supports the importance of collaborations in projects that aim to address complex climate change strategies. Such collaboration supported the implementation of the first hydrogen refuelling station for light and heavy vehicles in Finland, financed by the Finnish government. Therefore, after the official end of the project duration, the Smart Energy Åland project has recently demonstrated features such as collaboration with a large multidisciplinary EU-funded project and technology adoption, specifically in the hydrogen refuelling station.

In the national context, there is a lack of strategies specifically focusing on the development of smart charging and energy flexibility, as seen in the cases of the Netherlands (Pocityf) and the UK (GreenSCIES). In general, there is a slow trend in the adoption of smart charging among other energy projects in Finland. This supports the potential influence of policy and market characteristics, including trends in smart charging adoption at a national level, on the adoption of smart charging within the Smart Energy Åland project. Figure 32 presents a visual representation of the key findings revealed from the case study.

Overall, in the Smart Energy Åland project, the non-adoption of smart charging, specifically V2G, is associated with the following factors:

- a relatively small partnership with a homogeneous disciplinary environment;
- a lack of financial resources;
- a lack of smart charging policy;
- a lack of energy flexibility policy;
- a slow trend in adopting smart charging at a national level.

Figure 32 Timeline of developments in the Smart Energy Åland project



Source: Own elaboration

4.5 Generalisation of findings

In order to gain an understanding of the replicability of the data and to validate it, the identified themes were explored within an additional ten PED projects. To support the emerging themes and provide examples, selected quotes from project deliverables and policy documents are included. The selection of quotations is based on their relevance, showcasing the importance of the data.

Stardust

Organisation *(Stakeholders, funding, challenges).* Stardust is a large multidisciplinary EU-funded project comprising 30 partner organisations from the government, business, and research fields (Ntavos et al. 2020). The duration of the project spans from 2017 to 2024. The project activities are aligned with the following four criteria: collaboration, citizen engagement, knowledge sharing, and innovativeness (Corradino and Heidenreich 2019; Tomasi et al. 2019). These criteria are established within the EU agenda to ensure the effectiveness and accountability of project interventions to complex development challenges (ibid). This highlights that the EU agenda is critical in supporting the design and implementing of energy transition actions across PED projects, providing the resources and requirements for them to follow.

The project highlights organisational challenges in coordinating large, multi- stakeholder and multidisciplinary collaboration. It specifies unforeseen circumstances the project had to cope with, associated with restructuring and redefining roles among partners, as presented below.

> "While the final project of Alzania St building was being developed, JOFEMAR left STARDUST and BEEPLANET (BEE) took over its role… One of the biggest challenges of this project is the management and coordination of the different teams of multidisciplinary experts who must work together to carry out such an innovative project" (Costero et al. 2020, p.12).

Similar patterns emerged during interviews conducted within this study with energy experts and representatives of energy projects that have implemented smart charging. This underscores the impact of organisational factors, particularly stakeholder collaboration, on technology adoption.

Technology *(Technology implementation framework)* **.** The project outlines that its technology implementation framework involves three domains: "energy/building, mobility, and ICT" (Zacco et al. 2020, p.11). Within the energy/building domain, the project has installed PV panels, heat pumps, 2nd life-batteries from EVs, and LED lighting. Within the ICT domain, the project has developed the City Platform, which involves engagement with citizens (Costero et al. 2020).

Within the mobility domain, the project has implemented a significant number of charging stations in Pamplona city, Spain (Costero et al. 2020). These charging stations are dedicated to vehicle modes, such as e-buses, taxis, and public EV charging points, but are not equipped with smart charging technology, except for two V2G chargers implemented in the Pamplona City Council fleet. All charging stations, including the two V2G smart chargers, are integrated with PV panels (ibid), which helps to address two of the project's goals: to increase the efficiency of renewable energy use and enhance the grid. Such integration can address the latter goal by discharging the EV battery during periods of peak demand, to help manage the grid. Thus, the PV energy source may be a prerequisite for V2G chargers to be adopted in the Stardust project.

> "A 108 kWp-PV facility will be installed in the roof of Pamplona Bus Station to supply enough energy for the daily charge of at least two vehicles (around 40 kWh) every day. The goal of this installation is the promotion of local renewable energy and the reduction of the impact of fast charging in the grid by lowering by 80% the maximum power demanded" (Costero et al. 2020, p. 23).

Policy framework *(Smart charging, energy flexibility).* "Spain's National Integrated Energy and Climate Plan 2023-2030" (the 'Plan') outlines national strategies toward the energy transition. Specifically regarding charging infrastructure, the Plan highlights the aim to develop a promotion plan to increase its deployment to enhance EV adoption (MITERD 2020). Nevertheless, the Plan rarely emphasises smart charging adoption, mentioning it only in the context of required amendments in regulations on the construction of new buildings, outlining the need "to establish the conditions for developing the minimum infrastructure necessary for the smart charging of electric vehicles in building car parks" (ibid, p.139). Overall, there are no national strategies or action plans specifically promoting smart charging and energy flexibility in Spain (Fernández et al. 2023).

In the context of the trend towards adopting smart chargers, particularly V2G, in Spain, there is one V2G charger in Barcelona funded by the local municipality and 16 V2G chargers in the Balearic Islands funded by the EU programme, NextGenerationEU, supporting a greener future (Acciona 2022; Nuvve 2019; V2G-Hub 2024). These 16 V2G chargers have been installed as part of Spain's Recovery and Resilience Plan under REPowerEU Plan (European Commission n.d.). This Plan aims to deliver "sustainable, safe and connected mobility in urban and metropolitan environments" but does not particularly promote the deployment of V1G and V2G smart charging infrastructure (SWD(2021) 147 final, p.1). Instead, it establishes general requirements to address smart mobility without specifying particular actions, only mentioning the need to implement "mobility innovation" and "intelligent infrastructure". Thus, the majority of V2G chargers in Spain are implemented within a single project, NextGenerationEU, promoted and funded under EU support.

To sum up, in the Stardust project, the adoption of V2G smart charging is associated with the following factors:

- large multidisciplinary EU-funded project;
- importance of stakeholder collaboration;
- availability of the energy flexibility goal;
- integration of renewables and e-mobility;
- council fleet with relatively predictable behaviour;
- lack of particular strategy promoting smart charging and energy flexibility at the national level.

ZEN research center

Organisation. The ZEN research centre is a large multidisciplinary partnership, funded by the Research Council of Norway, comprising 34 partner organisations from the government, business, and research fields (Sørensen et al. 2018). The budget of the project is NOK 380 million, with a duration spanning from 2017 to 2024 (Lien et al. 2020). The project consists of seven sub-projects spread across Norway: Furuset, Fornebu, Sluppen and Campus NTNU, Ydalir, Campus Evenstad, NyBy, and Zero Village Bergen (Urban Europe 2020a). The project highlights the following "ZEN criteria": energy, GHG emission, power, spatial qualities, mobility, economy, and innovation (Wiik et al. 2022).

Technology. The project interventions involve the installation of various technologies. In particular, the project has adopted two public V2G chargers, PV panels, CHP, heat storage, district heating, and a stationary battery within Campus Evenstad (PED-EU-NET n.d.). The ZEN research centre project's fields of applications lie around the following domains: energy production, energy efficiency, energy flexibility, digital technologies, e-mobility, and construction materials (ibid). This showcases that the project distinguishes between energy efficiency and energy flexibility domains and highlights the goal of fostering e-mobility, suggesting that a combination of addressing energy flexibility and e-mobility is a necessary condition to adopt V2G chargers within the project.

During the design stage, the Campus Evenstad project conducted a techno-economic analysis of the energy system, assessing investment costs, emission reductions, value creation, operational control, and the regulatory framework (Backe et al. 2019a; Backe et al. 2019b). The analysis assessed the potential monetary value from flexibility provision to the grid from technologies such as PV, stational battery, and EV equipped with V2G, as well as potential changes in grid tariffs, expected due to the revision of market regulation (Backe et al. 2019; Stai et al. 2023). This is similar to the GreenSCIES project that also conducted such analysis to contribute to policy development. Undertaking research for the expected monetary value from a policy change not only confirms the consideration of policy and market frameworks in analysing smart charging technologies across some PED projects, but also showcases their involvement in creating knowledge and evidence for policy development. This may imply that specifically the ZEN research centre project positions its role and functions beyond just implementers that manage practical activities for the energy transition but also as contributors to policy decisions facilitating the generation of further, future, evidence-based change.

Policy framework. Reviewing the Norwegian strategies, particularly Norway's Climate Action Plan for 2021–2030 (Norwegian Ministry of Climate and Environment 2021) and national charging strategy (Norwegian Ministry of Transport 2023), the only point outlined regarding smart charging is as follows:

> Energy efficiency is still important in all sectors, and it often pays for individual people to improve their energy efficiency. Smart meters provide better information on electricity consumption and are important as a tool for facilitating other technological solutions, for example smart charging of electric cars. (Norwegian Ministry of Climate and Environment 2021, p.217).

This implies that in Norway, smart charging is considered equally as important as smart meters, which facilitate energy-efficient consumption, and is not considered as a potential demand response or energy storage technology. This contrasts with the regulations in the Netherlands and the UK which, similarly to Norway, are ambitious in terms of adopting renewables and EV but view smart charging not only as an energy-efficient technology but also as an important flexibility provider technology capable of aiding in managing supply and demand. This different approach might relate to Norway's reliable power grid, which is competitive with variable renewables (McKinsey&Company 2023). Therefore, in regulation, Norway arguably does not need to consider smart charging technology as an asset supporting energy flexibility.

Despite Norway's subsidy structure leading to a relatively large EV fleet, there is a relatively low trend in adopting smart charging, with only five V2G chargers implemented within the NeX2G project, funded by the Norwegian government (Grøtan et al. 2022; V2G-hub 2024). Nevertheless, given the flexibility advantages of V2G, it is questionable why Norway is not exploiting this to benefit its grid even more.

To summarise, in the ZEN research project, the adoption of smart charging is associated with the following factors:

- large multidisciplinary project funded by the national government;
- availability of the energy flexibility goal;
- integration of renewables and e-mobility goals;
- consideration of policy and market frameworks in decision-making;
- lack of strategies promoting smart charging at the national level;
- low trend in adopting V2G chargers at the national level.

CityxChange

Organisation. CityxChange is a large multidisciplinary EU-funded project comprising 33 partner organisations from the government, business, and research fields (CityxChange n.d.)(CityxChange n.d.). The duration of the project spanned from 2018 to 2023. Similarly to the Stardust project, which is also EU-funded project, the CityxChange project has aligned its activities with the following four criteria: collaboration, citizen engagement, knowledge sharing, and innovativeness, established within the EU agenda (Grabinsky et al. 2021).

In developing interventions, the project emphasises policy as an important element, as shown below.

> "Policies are an important element in the storyline to communicate the project to stakeholders. This can get shaped into a message with the format , <policy> <project> <intervention>" (Gall and Haxhija 2019, p.10).

> "For EU level the policies have been explored and listed below... These form the background of the overall project ambition and also show relevant areas… The national and local policy context were further analysed for the different +CityxChange cities in D3.1: Support Framework for Bold City Vision, Guidelines, and Incentive Schemes" (Gall and Haxhija 2019, p.11).

The project highlights the barriers faced during the implementation of interventions, categorising them into technological, financial, market, regulatory, political, social, and organisational governance dimensions (Berthelsen et al. 2023). The barriers involve challenges associated with the non-maturity of LFM: (technological), "lack of incentives and funding, lack of private investment, lack of monetisation of energy and flexibility services" (financial, market), lack of policy on local energy trading (regulatory), and gaps in driving and facilitating a green energy shift across local and regional public authorities (organisational governance) (ibid., p.89). This underscores the significance of technological, organisational, and regulatory dimensions considered within the project, confirming the relevance of the TOE framework in this thesis.

Technology. The project's technology implementation framework involves four domains: energy retrofitting, grid flexibility, e-mobility, and citizen engagement by ICT (Limerick City and County Council 2019, p.30). In the energy retrofitting domain, the project aimed to reduce demand and create renewable energy supply. In the grid flexibility and e-mobility domains, the project aimed to test new designs of LFMs and trade flexibility provided by V2G assets in two cities: Limerick (Ireland) and Trondheim (Norway) (Stephens et al. 2023). This suggests that the project distinguishes between energy efficiency and energy flexibility functions and considers the integration of V2G with emerging LFMs as part of the latter function.

The initial design of LFMs within the project involved the introduction of a new entity, the Community System Operator (CSO), to oversee a community grid system. In Limerick, the CSO was planned to be a community-owned franchise, while in Trondheim, the CSO aimed to be part of the DSO. Subsequently, a CSO was not established in either city. In Trondheim, the LFM was implemented under the roles and responsibilities of the DSO, while in Limerick the DSO withdrew from the project due to conflicts of interest between a new CSO and existing DSO roles and responsibilities (ibid).

> "… this Regulatory Sandbox was not developed and ultimately this process came to an end when the Irish Distributed System Operator (ESB Networks) withdrew its support for the formation of a CSO/Community Grid" (Stephens et al. 2023, p.6).

> "Indeed, it was felt that the precedent of defining a role, such as the CSO, based on theoretical rather than practical implementation would leave high potential for conflict with existing DSO roles and licenced responsibilities" (Stephens et al. 2023, p.36).

The project emphasises that the non-implementation of a LFM entailed the adoption an e-carsharing sharing scheme without V2G, highlighting the relationship between a LFM and the adoption of V2G chargers.

> "Since that [LFM] did not materialise in Limerick due to a number of reasons, the V2G became less relevant without the PEB (Positive energy block) around it… While there is no V2G charger installed as part of this project, the shared EV will utilise an existing ESB public charging infrastructure at University Limerick" (Bastable et al. 202), p.13).

This relationship is explained by the fact that a lack of LFM entails a lack of financial compensation for using V2G, resulting in a non-viable financial business case. The non-adoption of V2G is also linked with the absence of tariffs supporting its use in Ireland, fully eliminating the monetary benefits of integrating the technology. This highlights the importance of a framework that delivers a sufficiently strong business case for the adoption of V2G, involving tariffs and LFM development.

> "The current lack of a functioning flexibility market, at the scale of an EV battery, means the potential rewards for interacting with the Grid are unknown" (Bastable et al. 2023, p.39).

> "V2G is an important component of the flexibility markets, both as provider and customer of flexibility" (Sørum et al. 2022, p.15)

> "With no current support scheme offering a tariff for electricity export generated by a V2G, there is no benefit to connect a V2G directly to the grid. For these reasons the Garden International location was deemed impractical" (Bastable et al. 2023, p.27).

Additionally, the project highlights that the implementation of V2G in e-car sharing use cases might not be suitable, due to the unpredictability of charging behaviour, emphasising the importance of considering use cases in the adoption of smart charging, as outlined below. This is similar to patterns found within the GreenSCIES project, which also suggests installing V2G for domestic or fleet chargers due to their relatively predictable charging behaviour.

> "Using V2G charging for car sharing purposes is debatable as the challenge for EV car sharing is to maintain the battery at a practical state of charge at all times. V2G would be more applicable for predictable charging usage such as domestic chargers or commercial fleet scenarios" (Bastable et al. 2023, p.39).

Nevertheless, the project implemented 7 public V2G chargers in Trondheim (Berthelsen et al. 2023). The frequency and distinctiveness of outlining V2G adoption in combination with PV, stationary battery, and LFM, confirms the consideration of the relationship between renewables, LFM, and the adoption of V2G technology in the project, as presented in some examples below.

> "The demonstrations at Sluppen and Brattøra are a combination of renewables, energy storage (stationary and batteries through V2G chargers), other innovative interventions like sector coupling, and a developed and implemented Local Energy Market" (Berthelsen et al. 2023, p.13).

> "The main inputs for developing the DP11 concepts and models emerge from the PEB (DP06), EV sharing/EV batteries w/V2G, and Local Energy Market (DP10) provide the most crucial frameworks and inputs to establishing viable investment and business models" (Berthelsen et al. 2023, p. 20).

> “V2G chargers used in Trondheim, the total simultaneous capacity of 110 kW becomes a viable contributor in a local flexibility market/local energy system” (Berthelsen et al. 2023, p. 74).

Policy framework. As mentioned earlier, in the ZEN project, there is no particular strategy promoting smart charging, and there is also a low trend in its adoption in Norway. However, in Ireland, smart charging has been promoted at a regulatory level since 2022 within the “Electric Vehicle Charging Infrastructure Strategy 2022-2025” (Ireland Government 2023). This strategy introduces requirements for V1G on new domestic chargers from 2023 and discusses V2G as a future-thinking initiative that can help manage demand and supply (ibid). This indicates that the Irish government views both V1G and V2G chargers as flexibility assets capable of enhancing the grid. Ireland is also developing the “Phased Flexibility Market Development Plan”, currently under consultation (Ireland Government 2024), suggesting a consideration for promoting flexibility solutions in the country and the absence of an energy flexibility policy during the duration of the CityxChange project.

To our knowledge, there are currently five V2G chargers adopted in Ireland within a single project, Dingle, funded by the National Research Funding (Ireland Government 2023), indicating a relatively low trend in adopting V2G chargers in the country, at the time of writing. The Dingle project explored the impacts on the grid of several technologies, including V2G, selecting the location, the Dingle Peninsula, to investigate the usage of EVs in rural communities with longer journey distances (ibid). Thus, in Ireland, V2G chargers have been funded and adopted for research and development initiatives, supporting the argument that funding, in this case national funding, is currently a necessary condition for adopting V2G chargers.

To summarise, the project has the following patterns:

- large multidisciplinary EU-funded project;
- importance of stakeholder collaboration;
- importance of policy and market frameworks;
- importance of use cases and the predictability of charging;
- availability of the energy flexibility goal;
- integration of renewables and e-mobility;
- integration of LFMs and V2G;

Specifically, in Limerick, the non-adoption of V2G chargers within the project is associated with the following patterns:

- lack of market mechanisms, particularly supportive tariffs and a functional LFM stimulating V2G usage;
- low trend in adopting V2G chargers at the national level;
- energy flexibility policy is under consultation;
- availability of smart charging policy since 2022.

In Trondheim, the adoption of V2G chargers within the project is associated with the following patterns:

- availability of LFM and renewables;
- importance of a market framework, including the availability of LFM and supportive tariffs;
- lack of strategies promoting smart charging at the national level;
- low trend in adopting V2G chargers at the national level.

SmartEnCity

Organisation. SmartEnCity is a large multidisciplinary EU-funded project comprising 37 partner organisations from government, business, and research fields (SmartEnCity n.d.). The duration of the project spanned from 2016 to 2022. The project's overarching concept relies on four pillars: collaboration, knowledge sharing, citizen engagement, and innovativeness (Urrutia et al. 2021), aiming to deliver interventions using a holistic approach:

> "SmartEnCity research and its interventions understand the city from a multisystemic urban planning perspective and not the energy system as an isolated silo, where all city systems interact with each other and contribute to this transition, thus pushing planners to look at the decarbonisation challenge from an integrated approach, getting all city sectors on board" (Urrutia et al. 2019, p.8).

Collaboration and engagement are outlined as crucial for successful delivering project interventions:

> "The success of planned interventions will depend very much on the level of agreement achieved among all parts at stake in the city (and district). That's why it is important to

> carefully engage all key stakeholders to ensure their alignment during and after the project" (Urrutia et al. 2019, p.35).

Additionally, the project emphasises that factors such as the city's needs and the context of policies, best practices, plans, and regulations play an important role in designing interventions (Urrutia et al. 2019). In particular, it highlights the impact of differences in locational characteristics and city goals on the design of technological intervention strategies across cities within the project (ibid). This suggests that the project underscores the importance of contextual factors, including locational characteristics, policy dynamics, and the role of goals on the decision-making process regrading technological interventions.

Technology. The project highlights that its interventions aim to address three elements of the energy system: energy supply, energy demand, and energy management, using a collaborative and technology-supported approach (Urrutia et al. 2019). The project's interventions are conceptualised around three domains: energy/building, mobility, and ICT platform, and implemented across three cities: Tartu (Estonia), Vitoria-Gasteiz (Spain), and Sonderborg (Denmark) (Urrutia et al. 2019). Energy/building and ICT interventions are similar across all three cities. Energy/building solutions are associated with building retrofitting involving the installation of PV panels, various energy control sensors, district cooling network, insulation measures (e.g. window replacement, roof and façade reconstruction), and LED lighting system (Urrutia et al. 2021).

ICT solutions involve the development of an open information platform, also called a city platform, that aims to monitor energy use across the retrofitted buildings within the project and engage with residents to encourage them towards energy efficiency behaviour (ibid). Mobility interventions vary across cities (Urrutia et al. 2021). In Tartu, an e-bike sharing system and 64 biogas buses with fuel stations have been adopted. In Vitoria-Gasteiz, 4 ultra-fast inverted charging pantographs for 13 electric public buses, an e-bike sharing system, and 2 EV charging points for the VitoriaGasteiz city council's electric vans have been implemented (Albaina et al. 2021). In Sonderborg, 44 biogas buses and 31 public EV chargers have been installed (Nielsen et al. 2020).

Importantly, in Sonderborg, the project had planned to adopt public EV chargers equipped with V1G technology as part of "the smart mobility demo actions" (Nielsen et al. 2020, p.7). However, the project reports that due to technical issues, public EV chargers were adopted without V1G technology (ibid). The project explains that an EV charging infrastructure supplier failed to provide chargers with the agreed software and generally delivered chargers that often encountered errors, as presented below. Thus, this project demonstrates a case where V1G smart charging was not adopted due to technology-related issues.

> "The Evergreen EV charger's hardware was supposed to be combined with intelligent software to make the chargers intelligent. The software was never properly developed, and the developer of the software (VikingeGaarden) encountered problems when "Evergreen" stopped supplying chargers. The seven intelligent EV chargers purchased at the beginning as a test showed several problems:
>
> 1. Firstly, the chargers never turned intelligent since the supplier was unable to deliver on the agreed software.
> 2. Secondly, the chargers often had errors that had to be corrected manually, which turned out to be a burden some tasks both resource, time and cost wise" (Nielsen et al. 2020, p.12).

Policy framework. Denmark has set strategies promoting the enhancement of grid flexibility, such as "Development and Role of Flexibility in the Danish Power System" (Danish Energy Agency 2021), "Nordic Power Market Design and Thermal Power Plant Flexibility" (Danish Energy Agency 2018), and "Smart Grid Strategy" (Danish Ministry of Climate Energy and Building 2013). These strategies aim to continue improving the management of variable renewable energy sources through incentivising "new investments in specific technologies, grid investments or increasing accessibility of electricity that need to be taken into consideration, when developing a market design" (Danish Energy Agency 2018, p.13). This suggests the high importance of energy flexibility measures across the country.

Nevertheless, these strategies, along with "A Green and Sustainable World" (Danish Government 2020), "Denmark's Integrated National Energy and Climate Plan" (Danish Ministry of Climate Energy and Utilities 2019), and "Infrastructure plan 2035" (International Energy Agency 2023b; Danish Government 2021), do not mention any plans regarding the promotion of smart charging. This suggests that currently Denmark does not promote smart charging as an important flexibility provider.

In terms of the trend in adopting smart chargers in Denmark, it is found that during the project's period, there was a trend in adopting V2G chargers, as presented in the table below.

Table 12 Trend in adopting V2G in Denmark

Country	Number of V2G chargers	Project	Timespan
Denmark	10	Denmark V2G	2016-2018
	50	Parker	2016-2018
	15	Parker Denmark	2016-2019

Source: V2G-hub 2024

Thus, the non-adoption of smart charging in the SmartEnCity project is associated with the following factors:

- large multidisciplinary EU-funded project;
- importance of stakeholder collaboration;
- importance of policy framework;
- non-availability of the energy flexibility goal;
- adoption of renewables;
- lack of strategies promoting smart charging at the national level;
- trend in adopting V2G chargers at the national level.

Sharing Cities

Organisation. Sharing Cities is a large multidisciplinary EU-funded project that ran from 2016 to 2021 and comprised 35 partner organisations from government, business, and research fields (Gibbons 2018).

Technology. The project implemented three types of technology-related activities across energy/building, e-mobility, and ICT platform domains across the cities of Lisbon, London, and Milan (Manca et al. 2021). Within the energy/building domain, the project retrofitted buildings (e.g. window replacement), improved lighting systems (LED lamps), adopted renewable energy sources (PV panels), and installed a sustainable energy management system (SEMS) for monitoring and managing energy consumption in public service buildings (e.g. the City Hall in Lisbon) (Zavitas et al. 2019). The ICT domain involved the creation of an urban sharing platform aiming to function as “a citizen engagement element” as well as to “enable a

Smart City” by providing information to citizens about a city from various devices and sensors (ibid).

The e-mobility domain was addressed through the adoption of EVs, e-bike sharing schemes, and charging facilities (Zavitas et al. 2019). Specifically, Lisbon adopted 22 EVs and charging points for municipal use, 2 public EV charging points, 1000 sharing e-bikes, and 125 smart parking sensors, also referred to as smart lampposts, integrated with cameras and surface-mounted sensors. London adopted 32 sharing e-bikes, EV charging points with smart parking sensors, and lampposts integrated with EV charging. Milan adopted 60 sharing EVs with charging facilities, 150 sharing e-bikes with 7 bike stations, and 164 smart parking sensors (ibid). Thus, in the project, mobility is addressed through the adoption of e-bike sharing, EVs, and charging facilities, but without smart charging technologies.

Policy framework. Given that the European Climate Law was established in 2021, requiring climate action across the EU and the Member States (Regulation (EU) 2021/1119), and considering that the project was implemented before that year, there were no strategies promoting the adoption of smart charging and grid flexibility measures at that time.

During the project’s lifetime, there was a trend in adopting V2G chargers across countries, including Italy, Portugal, and the UK, as presented in the table below.

Table 13 Trend in adopting V2G in Italy, UK, and Portugal

Country	Number of V2G chargers	Project	Timespan
Italy	2	Genoa pilot	2017-unknown
	32	Fiat-Chrysler V2G	2019-2021
	1	BloRin	2019-2022
UK	1	Cenex EFES	2013-2013
	1	ITHECA	2015 - 2017
	6	SEEV4City	2016 - 2020
	2	SaMDES	2017 - 2021
	320	Sciurus	2018 - 2021
	16	Northern Power Grid	2018 - 2021
	35	EV-elocity	2018 - 2022
	28	Bus2Grid	2018-ongoing
	135	Powerloop	2018-ongoing
	2	V2Street	2018-2020
Portugal	1	Renault: the mobility house	2018 - 2020
	10	V2G Azores	2020 - 2021

Source: V2G-hub 2024

Thus, the non-adoption of smart charging in the Sharing cities project is associated with the following factors:

- large multidisciplinary EU-funded project;
- non-availability of the energy flexibility goal;
- adoption of renewables;
- lack of strategies promoting smart charging and energy flexibility at the national level (at the time of project duration);
- trend in adopting V2G chargers at the national level.

City District Development Graz-Reininghaus

Organisation. City District Development Graz-Reininghaus is a private-public partnership that aims to build a CO2-neutral city district in Graz, Austria (Urban Europe 2020a). The project runs from 2012 to 2025. The project is primarily focused on the construction of residential buildings financed by private stakeholders (80%), while the construction of public spaces, such as squares, parks, and a School Campus, is financed by public resources (20%) (ibid). The project collaborates with local government, businesses, and academia and aims to set out strategies for achieving energy self-sufficiency in the Graz-Reininghaus district (Austria Governement n.d.).

Technology. The project has built 162 flats and commercial premises, installed PV panels, geothermal energy, heat pumps, and uses low-temperature waste heat sources (Austria Government n.d.). The project intentionally provided a low number of parking facilities to encourage residents to use public transport (PED-EU-NET n.d.). Currently, there is no implementation of any EV charging infrastructure within the project (Reininghaus n.d.).

Policy framework. The needs towards enhancing energy flexibility are outlined in the national strategy “Integrated National Energy and Climate Plan for Austria” (Plan) (Federal Ministry of Sustainability and Tourism 2019). The Plan does not promote specific technologies for enhancing energy flexibility, rather in general noting that “increasing the flexibility of the national energy system, in particular by means of deploying domestic energy sources, demand response and energy storage” (ibid., p.89). Consequently, there are no specific references to smart charging as a mean of energy flexibility. Nevertheless, the Plan highlights the aims to enhance energy flexibility through market mechanisms; and to integrate various energy sectors, including mobility:

> “National objectives related to other aspects of the internal energy market such as increasing system flexibility, in particular related to the promotion of competitively determined electricity prices in line with relevant sectoral law, market integration and coupling” (Federal Ministry of Sustainability and Tourism 2019, p.94).
>
> “Development of integrated system solutions for coupling infrastructure, technologies and services for power, gas, heat and mobility” (ibid., p.100).
>
> “Sector coupling is a vital part of developing a decarbonised energy system. This means linking together previously separate systems” (electricity, heating, mobility, industry) (ibid.p.183).

In Austria’s 2030 Mobility Master Plan, there is also no emphasis on smart charging (Federal Ministry Republic of Austria 2021). The Plan discusses the need to continue the expansion of EV charging infrastructure, without specifying any objectives for promoting a specific type of EV charging to benefit the grid. There is also a low level of smart charging adoption in Austria, as shown in the table below, with only one V2G charger implemented under the I-GReta project (V2G-hub 2024).

Table 14 Trend in adopting V2G in Austria

Country	**Number of V2G chargers**	**Project**	**Timespan**
Austria	1	I-GReta	2021 - 2023

Source: V2G-hub 2024

To sum up, the non-adoption of smart charging in the City District Development Graz-Reininghaus project is associated with the following factors:

- primarily privately funded project;
- adoption of renewables;
- a low level of smart charging adoption at the national level;
- lack of smart charging policy at the national level
- lack of a particular strategy or plan regarding energy flexibility at the national level.

MySmartLife

Organisation. MySmartLife is a large multidisciplinary EU-funded project comprising 27 partner organisations from government, business, and research fields (MySmartLife n.d.). The duration of the project spanned from 2016 to 2022 (Cordis 2024b). The project activities were aligned with the following four criteria: collaboration, citizen engagement, knowledge sharing, and innovativeness (Revilla and Usobiaga 2019).

Technology. The project's technology implementation framework involves three domains: energy/retrofitting building, ICT, and e-mobility (Arrizabalaga et al. 2019). The energy and building retrofitting domain involves the implementation of PV panels, LED lamps, 5G telecommunication networks integrated with lamppost infrastructure, a smart home system (e.g. intelligent light control, detection of water damage), and smart metering for improving and managing energy consumption (Arrizabalaga et al. 2019; Willmer et al. 2019). The ICT domain involves the development of the Urban Platform that integrates the data from the PV system and CHP plants (Willmer et al. 2019).

The e-mobility domain involves the adoption of e-buses and public EV charging facilities across all three cities (Arrizabalaga et al. 2019), but with only one V2G charger, outlined as the first in Finland, installed in Helsinki within the project (Kulmala et al. 2019). The project highlights that the V2G charger is integrated with a stationary battery and a PV plant and aims to explore the impacts of this business model on grid flexibility (ibid). This suggests that the investigation of energy flexibility solutions was part of the project's goals.

> "In two-way charging, vehicle battery can be used as an electricity storage unit, and it can be charged and discharged to maintain electricity network frequency. Charging and discharging capacity of the V2G charger is 10 kW and during its installation, it was the first V2G charger in Finland" (Kulmala et al. 2019, p.65).

Within such investigation, the capability of the dynamic power response of V2G was tested, identifying delays of 4-10 seconds (Kulmala et al. 2019). Nevertheless, it was noted that "the technology of V2G chargers has improved already in a few years period and it is expected that the V2G chargers will be a part of future systems" (ibid., p.69), highlighting that the project results were already outdated as the technology is improving.

Policy framework. As found in the Smart Energy Åland project discussed above, there is a slow trend in adopting smart charging, as well as a lack of strategies promoting smart charging adoption and energy flexibility measures in Finland.

To summarise, in the MySmartLife project, the adoption of V2G smart charging is associated with the following factors:

- large multidisciplinary EU-funded project;
- importance of stakeholder collaboration;
- availability of the energy flexibility goal;
- integration of renewables and e-mobility;
- a lack of strategies promoting smart charging and energy flexibility at the national level;
- a low trend in adopting V2G chargers at the national level.

Making-City

Organisation. Making-City is a large multidisciplinary EU-funded project comprising 34 partner organisations from government, business, and research fields (Vélez et al. 2019). The duration of the project spans from 2018 to 2024 (Cordis 2023). The project interventions are implemented in Groningen (Netherlands) and Oulu (Finland) and are aligned with four criteria: collaboration, citizen engagement, knowledge sharing, and innovativeness (Vélez et al. 2019). Similar to other EU-funded projects discussed above, these criteria, along with the project's technology implementation framework involving energy retrofitting, e-mobility, and citizen engagement by ICT domains, are highlighted in a project document (ibid).

Technology. In the design stage, the project developed a "PED solution catalogue" outlining interventions considered in the project (Alpagut et al. 2020). This catalogue includes the intervention of adopting EV charging infrastructure embedded with smart charging technology. The process of selecting solutions involved several steps, including the evaluation of political, social, economic, environmental, technical, and legal barriers and enablers, as well as the techno-economic analysis of each solution. The results of the evaluation of barriers to the adoption of smart charging are presented in the Appendix B. The results suggest that the project have viewed the adoption of smart charging as challenging from all dimensions, including political, social, economic, environmental, technical, and legal aspects (ibid).

The project conducted a techno-economic analysis of EV charging interventions in both Oulu and Groningen cities. Both analyses assessed three types of charging: unmanageable charging, V1G, and V2G charging. The results of the analysis do not deny the potential benefits of smart charging to the grid. Nevertheless, they suggest that in Oulu, smart (coordinated) charging is not necessary, while in Groningen, its benefits are uncertain. Conclusions are presented below:

> Oulu: "If charging is not coordinated in any way, there may be electricity network congestion problems in the evening when the consumption in apartment buildings is at highest. If the already then peaking consumption is added with EV charging when people get home after working day, there may be problems. The simplest and likely an effective enough solution is to time the charging in the night-time. It is feasible from points of view of transmission network, electricity production and car use comfort" (Rinne 2021), p.37)
>
> Groningen: "The different scenarios present different strategies to reduce grid impact. Coordinated charging was highly effective at reducing peak loads at a local level (i.e., at an individual cable or transformer), but less effective when considering a city-wide level (due to the expected decrease in charging simultaneity as the number of charging stations increases). Bi-directional charging provides a significant amount of potential energy storage, but how effectively this storage can be utilized is highly situational" (Someren and Tjahja 2021, p.35).

Thus, the project planned to implement smart charging within the project (Leeuwen et al. 2021). However, a range of project documents suggest that EV charging stations are implemented without smart charging in either Oulu and Groningen (Alpagut et al. 2020; Konsman et al. 2021; Someren and Tjahja 2021; Rinne 2021).

Policy framework. Again, as found in the Smart Energy Åland project, there is a slow trend in adopting smart charging, as well as a lack of strategies promoting smart charging adoption and energy flexibility measures in Finland. This is different in the Netherlands, which is a leading country in V2G implementation, proactively supporting both smart charging and energy flexibility initiatives at a regulatory level, despite the fact that V2G was not implemented within the Making-City project, with no clear explanation provided for this omission.

To sum up, in the Making-City project, the non-adoption of V2G smart charging is associated with the following factors:

- a large multidisciplinary EU-funded project;
- importance of stakeholder collaboration;
- availability of the energy flexibility goal;
- integration of renewables and e-mobility;

In Oulu:

- a lack of strategies promoting smart charging and energy flexibility at the national level;
- a low trend in adopting V2G chargers at the national level.

In Groningen:

- trend in adopting V2G chargers at the national level;
- availability of strategies promoting smart charging and energy flexibility at the national level.

Atelier

Organisation. Atelier is a large multidisciplinary EU-funded project comprising 30 partner organisations from various fields, including government, business, and research (Atelier n.d.). The duration of the project spans from 2019 to 2024, aligning its activities with four criteria: collaboration, citizen engagement, knowledge sharing, and innovativeness (WAAG 2021). The project implements various technologies across two cities: Amsterdam (Netherlands) and Bilbao (Spain). Notably, the project highlights that before 2018, large EU-funded projects focused on domains such as energy, buildings, ICT platforms, transport, and e-mobility. However, this focus has since changed due to the shift from a smart city perspective to a PED one:

> "There has been a shift of focus topic for the call from general 'integration of smart city solutions' (e.g. energy, transport, ICT and digital platforms, buildings, E-mobility) to 'positive energy blocks/districts' since 2018" (University of Deusto et al. 2020, p.45).

As a result, the project has developed a technology implementation framework that incorporates different domains: energy efficiency, renewable energy sources, energy system flexibility, e-mobility (University of Deusto 2020).

Technology. The energy efficiency domain involves building retrofitting measures, including low energy demand (e.g. façade, roof, glazing) and energy management solutions (e.g monitoring systems, LED lamps) (Vallejo et al. 2022). The renewable energy sources domain involves the installation of solar PV. The energy system flexibility domain includes the implementation of stationary storage, thermal storage, district heating-geothermal rings, and heat pumps (ibid).

> "They are basic elements for the co-design and co-implementation of the PED demo site in Amsterdam (WP4) and PED demo site in Bilbao (WP5), where specific solutions such as the adoption of an increased share of renewables, integration of different energy sources and storage methods, deployment of e-mobility solutions, development of new energy markets and, the promotion of smart and active collaboration with citizens among others are to be validated" (Andonegui et al. 2020, p.11).

The e-mobility domain involves the adoption of EV chargers (Andonegui et al. 2020). Currently, the adoption of smart charging in Amsterdam is under consideration, as presented below. The state of the adoption of EV chargers in Bilbao is not presented yet, likely because the project is still in the implementation stage. This doctoral thesis considers the non-adoption of smart charging within this project.

> "The city of Amsterdam is planning an electromobility sharing hub in the PED. Discussions with operators are taking place. Expansion of the facility to include smart charging and/or vehicle to grid pilots are under consideration" (Rooth 2023, p.8).

Similar to Making-City, the Atelier project evaluated political, social, economic, environmental, technical, and legal barriers and enablers of each technology solution. The results of the evaluation of the adoption of EV chargers are presented in Appendix C, indicating a lack of obstacles for implementing EV chargers within the project (Vallejo et al. 2022).

Policy framework. As outlined in the Pocityf project, the Netherlands is a leading country in V2G implementation, proactively supporting both smart charging and energy flexibility initiatives at a regulatory level. However, it is unclear why the Atelier project did not implement smart chargers. This is in contrast to Spain, as discussed above with the Stardust project, where there are no national strategies or action plans specifically promoting smart charging and energy flexibility in Spain (Fernández et al. 2022). Nevertheless, there is still a trend in adopting smart chargers, particularly V2G, in Spain (Acciona 2022; Nuvve 2019; V2G-Hub 2024), probably driven by the openness of projects to innovative technologies.

Thus, in the Atelier project, the non-adoption of V2G smart charging is associated with the following factors:

- importance of stakeholder collaboration;
- availability of the energy flexibility goal;
- integration of renewables and e-mobility;
- trend in adopting V2G chargers at the national level;

In Amsterdam:

- availability of strategies promoting smart charging and energy flexibility at the national level.

In Bilbao:

- lack of strategies promoting smart charging and energy flexibility at the national level.

Replicate

Organisation. Replicate is a large multidisciplinary EU-funded project, that ran from 2016 to 2021, comprising 36 partner organisations from the government, business, and research fields (Sebastián 2018). The project interventions are implemented in San Sebastián (Spain), Florence (Italy), and Bristol (UK), and aligned with the following four criteria: collaboration, citizen engagement, knowledge sharing, and innovativeness (ibid).

Technology. The project's technology implementation framework involves three domains: "energy efficiency, sustainable mobility and ICT" (Fundación ESADE 2018, p.11). The energy efficiency domain involves retrofitting, district heating, and demand side platform measures. The sustainable mobility domain incorporates the installation of public EV charging stations without smart charging, while the ICT domain includes the implementation of smart public lighting (ibid).

The project describes that the decision-making process involved a PESTEL analysis (political, economic, social, technological, legal, and environmental) of those three domains (Fundación ESADE 2018). The consideration of the PESTEL analysis highlights the relevance and importance of technological, organisational, and environmental dimensions in decision-making when selecting interventions.

For example, in evaluating political factors within the analysis, the project highlighted the role of National Energy Efficiency Action Plans established across all three countries, which influenced the project's focus and the selection of interventions toward energy efficiency (Fundación ESADE 2018). This underscores the importance of policy in project decision-making processes, suggesting that national strategies promoting particular technologies have influenced decisions regarding technology adoption within the project. This implies that the absence of strategies viewing smart charging technology as an important flexibility provider and promoting the adoption of the technology at the time of project implementation may have influenced the decision not to adopt smart chargers within the project.

In assessing economic factors, the project evaluated trends on technology adoption across national funding, as exemplified below.

> "As in the energy sector all three countries are setting up funds to encourage investment in improving mobility, and in particular, in encouraging the use of electric vehicles and the deployment of electric stations in cities… In Italy, there were provisions for incentives for buying vehicles with overall low emissions worth a total of EUR 108 million in the three-year period 2013-2015, and the plan is being renewed" (Fundación ESADE 2018, p.19).

In evaluating technological factors, the project investigated technological trends that existed across pilot projects. Particularly in the mobility sector, alongside autonomous cars and battery technology for e-vehicles, the project determined trends in the adoption of EVs and EV charging stations, while not considering their embedding with smart charging technology (ESADE and FSS 2018). These findings support the consideration of technological trends in technology adoption in the project's decision-making process and emphasise that the project has not studied trends regarding the adoption of smart EV charging infrastructure embedded with smart charging technology across pilot projects.

Policy framework. Nevertheless, as outlined in the Sharing City project, there was a trend to adopt smart charging across Italy and the UK before 2021. The fact that the Replicate project did not consider those trends and particularly emphasised technological trends observed across pilot projects demonstrates that the focus of trends might not necessarily be at a national level, while it suggests that decisions considered across projects might be influential.

> We can identify several technological trends that are currently influencing developments in the mobility sector. These technological trends can be seen directly in the choice of pilot projects that the consortium has chosen to pursue in Donostia/San Sebastian, Florence, and Bristol (Fundación ESADE 2018, p.20).

Thus, in the Replicate project, the non-adoption of V2G smart charging is associated with the following factors:

- a large multidisciplinary EU-funded project;
- importance of stakeholder collaboration;
- importance of policy and funding elements;
- importance of trends in technology adoption;
- non-availability of the energy flexibility goal;
- adoption of renewables;
- a lack of strategies promoting smart charging and energy flexibility at the national level;
- trend in adopting V2G chargers at the national level.

Table 15 below summarises the main findings from the projects discussed above. This is followed by reflections across the projects in the Section 4.6. The table shows vertically in the left-hand column patterns identified across PED projects studied within Section 4.5, listed horizontally. The green colour illustrates the adoption of smart charging technology, particularly V2G, across projects, while the red colour represents the non-adoption of the technology. The symbol 'Y' indicates the availability of the pattern within the project, while the symbol 'N' denotes the opposite. As it is typical for each PED project to implement technological interventions across two cities in different countries, the combination of both symbols, 'YN', 'NY', 'YY', represents the difference in identified patterns across involved countries, taking into account the order of countries followed within each project.

Table 15 Results - A record of hits and misses

	Energy projects	**Star dust**	**ZEN research**	**CityxChange**	**SmartE nCity**	**Sharing Cities**	**Graz-Reininghaus**	**MySmart Life**	**Making City**	**Atelier**	**Replicate**
Themes	Energy flexibility goal	Y	Y	Y	N	Y	N	Y	N	Y	N
	Renewables implementation/avail ability	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	LFM implementation goal	N	N	Y	N	N	N	N	N	N	N
	Large multidisciplinary collaboration	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	EU or national funding	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	Smart charging Policies (e.g., Action Plans or Programs)	N	N	N/Y	N	N	N	N	N/Y	Y/N	N/Y
	Energy flexibility policy framework	N	Y	Y/Y	Y	N	N	N	N/Y	Y/N	N/Y
	Trends in V2G adoption at the national scale	Y	N	N	Y	Y	N	N	N/Y	Y	Y
	Adoption of EV chargers without smart charging	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	Smart charging adoption (or decision to adopt)	Y (V2G)	Y (V2G)	Y (V2G)	N	N	N	Y (V2G)	N	N	N

4.6 Chapter Summary

This chapter presents the research findings on the adoption of smart charging across PED projects in Europe. The research aimed to investigate factors influencing the adoption of smart charging in PEDs within the technology, organisation, and environment framework. To draw relevant results, the study utilised various data resources, including interviews, fieldnotes from participant observations, project deliverables and policy documents.

The interviews, participant observations, and the two in-depth case studies shed light on the perceived advantages and challenges of smart charging, as well as organisational, policy, and market barriers and drivers to adopting the technology across PED projects. The results highlight the relevance of the TOE framework in understanding the context of PED projects, suggesting that decisions to adopt smart charging in PEDs were closely associated with technology advantages, organisational capacity, and policy factors.

In particular, the findings indicate that the PED projects studied adopted smart charging because of its potential monetary benefits, grid enhancement capabilities, availability of PED funding, and the goal of addressing energy flexibility - specifically through the integration of smart charging with PV panels or energy markets like LFM, and a supportive policy framework that promotes the technology through smart charging programmes and incentives. These factors are recognised as key enablers of smart charging adoption in PEDs, collectively creating a favourable environment for their deployment and enabling them to contribute to energy transitions and enhance grid efficiency.

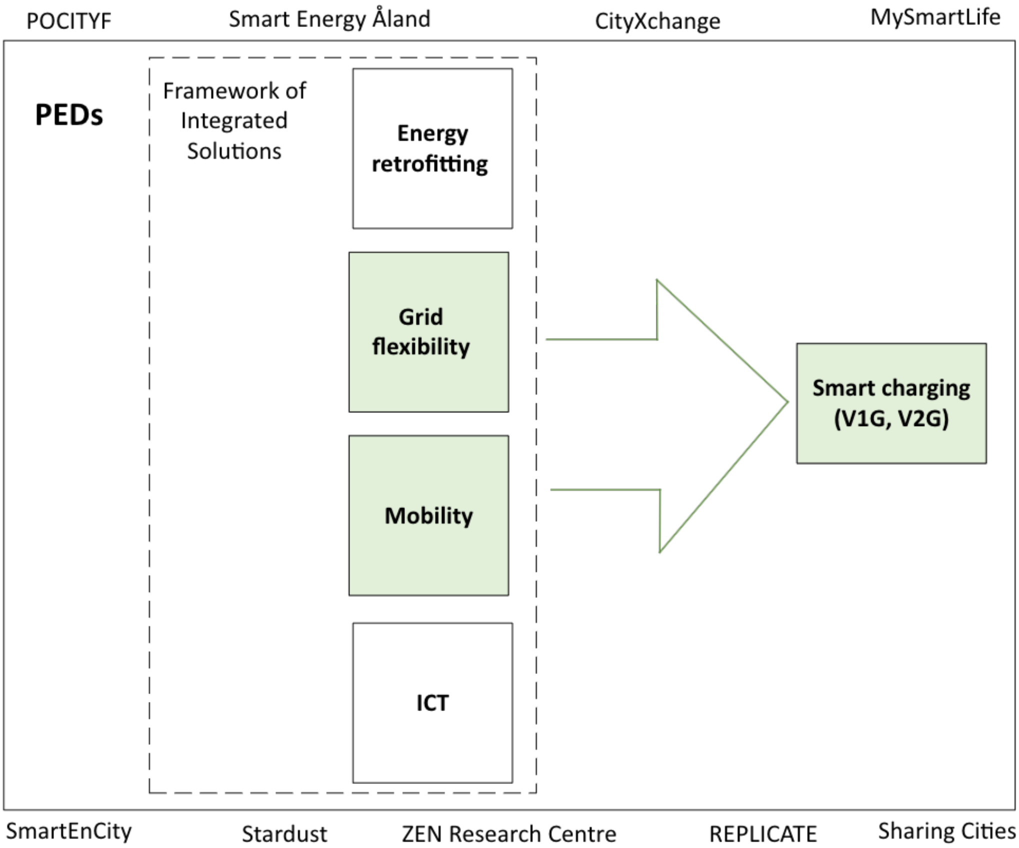
The availability of PED funding is found to be a crucial factor for projects, as the implementation of public charging infrastructure equipped with smart charging, especially V2G technology, is still not a commercially viable business model without financial incentives. As an example, in one of the PED projects, Smart Energy Åland, despite aiming to enhance energy flexibility, it failed to adopt any technology, including V2G, due to a lack of financial resources for the project.

In an effort to comprehend the factors influencing the adoption of smart charging and examine the generalisation and replicability of findings, an additional ten PED projects were analysed based on policy documents and project deliverables. The analysis of the ten PED projects supports the idea that PED projects need to consider technological, organisational, and environmental contexts in decision-making when selecting technological interventions. The findings support a relationship between the adoption of smart charging and the following factors: the energy flexibility goal, adoption of renewables, collaboration of multidisciplinary partners, availability of funding, market mechanisms, and policy frameworks. These results are synthesised in the framework of “Determinants of smart charging adoption in PEDs”, which is presented and discussed in the following chapter.

The factor of trends in adopting smart charging, suggested by several interview respondents and supported by the two in-depth case studies, was the only factor not supported within the generalisation of findings. Consequently, this is the only factor not included in the developed framework. There are two reasons for this. First, the 10 PED projects do not show a relationship between the trend in adopting smart charging at a national level and the adoption of smart charging. Secondly, within the generalisation of findings, only one project highlighted in the project deliverable included the analysis of trends in technology adoption in decision-making, and that analysis was across PED projects, not at the national level. To some extent, this emphasises the interrelationship between PED projects but may not prove the role of trend in technology adoption in the decision-making of PEDs.

The findings from the ten PED projects demonstrated that almost all projects, except City District Development Graz-Reininghaus, contributed to the e-mobility sector by adopting public EV charging infrastructure. However, not all projects have adopted charging infrastructure equipped with smart charging technology. The findings support the idea that while not all projects have aimed to enhance energy flexibility, those that set that goal have adopted smart charging, highlighting its impact on the adoption of the technology (Figure 33).

Figure 33 Relationship between project goals and the adoption of smart charging across PED projects



The findings from the ten PED projects highlighted that while not all large multidisciplinary EU or government-funded projects adopt smart charging, all projects that did adopt smart charging were large multidisciplinary EU or government-funded projects. This supports the relationship between collaborations, funding, and smart charging adoption found within interviews and two in-depth case studies. Thus, the findings regarding the significance of project capacity, incorporating human and financial resources, are found to be relevant in the PED context, influencing their decisions toward the adoption of smart charging.

Furthermore, the findings suggested that the projects such as Pocityf, CityXchange, MySmartLife, Stardust, and ZEN research centre have adopted EV charging infrastructure equipped with V2G technology. These projects integrated V2G charging infrastructure with PV panels, highlighting the objective of increasing the efficiency of renewable energy use. Alongside the integration of PV with V2G, the Pocityf and CityxChange projects implemented energy markets, such as P2P or LFM, aiming to test the impacts of trading flexibility provided by V2G across these markets. Both projects highlighted difficulties in implementing energy markets associated with a lack of policy and market frameworks to encourage their development.

Nevertheless, they emphasised the aim of integrating V2G with energy markets. One project, CityxChange, specifically highlighted that due to the failure to implement LFM and the lack of tariffs supporting monetary benefits from the use of V2G in one of the participating cities (Limerick, Ireland), V2G chargers were not deployed there, as the business model was deemed unviable without incentives. However, the CityxChange project successfully implemented seven public V2G chargers in another city, Trondheim, Norway, alongside the development of LFM within the project, supporting the importance of the relationship between the availability of LFM and the adoption of V2G chargers across PEDs. A similar pattern is observed in the Posityf project, where both the P2P platform and V2G chargers are intended to facilitate the deployment of a flexible, decentralised energy system.

Moreover, this supports the need for a framework that delivers a sufficiently strong business case for adopting V2G chargers, encouraged by the implementation of smart charging tariffs and the development of energy markets supporting flexibility trading from small-scale assets, including V2G. Thus, the results of interviews and the two in-depth case studies align with the findings of the ten PED projects, supporting the importance of viability of V2G business models and the environmental benefits from integrating V2G with renewables.

Finally, the analysis of various policies, such as National Energy and Climate Plans, Charging Infrastructure strategies, Grid Congestion Plans across European countries, including Ireland, Norway, Denmark, Spain, UK, Italy, Netherlands, and Austria, revealed that currently only the UK, and the Netherlands view smart charging technology as an important flexibility provider at a regulatory level and have established smart charging strategies promoting the adoption of the technology. Energy Flexibility Plans are set across Norway, the UK, and the Netherlands. The findings did not show a relationship between the availability of smart charging strategy or energy flexibility plan and the adoption of smart charging across projects. However, the consideration of policy and market frameworks in decision-making processes was emphasised by a range of projects, including Replicate, SmartEnCity, and CityxChange, highlighting their impacts on the adoption of technologies, including V2G.

Chapter 5 Discussion

5.1 Chapter Introduction

The overarching research question of this thesis is:

What are the key drivers of smart charging adoption in PEDs?

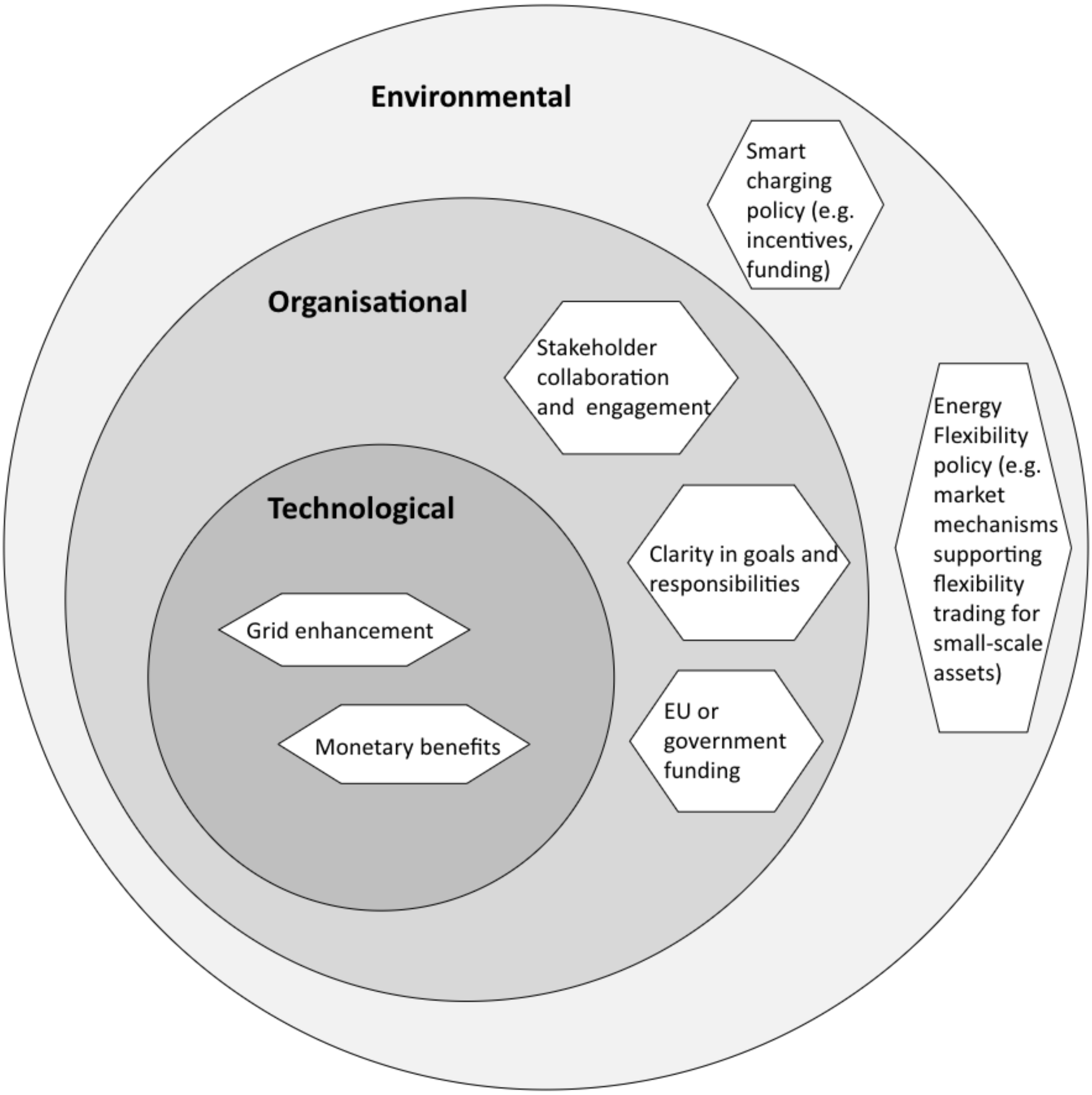
The key output of this study is the development of a framework for the adoption of smart charging in PEDs, presented in Section 5.2. This framework addresses the overarching research question and represents a synthesis of the key identified drivers of the adoption of smart charging across energy projects like PEDs. To study the process of adopting smart charging across PEDs, the framework was applied at two in-depth case studies: Pocityf and Smart Energy Åland. This part of the analysis helped to explain why some PEDs succeed in adopting smart charging while some may fail. To assess the generalisability of findings, the framework was further applied to ten other PED projects: CityXchange, MySmartLife, Stardust, ZEN research center, Making-City, Atelier, Replicate, SmartEnCity, Sharing Cities, and City District Development Graz-Reininghaus. This part of the analysis investigated the relevance of the factors in technology decision-making, particularly smart charging, and established the robustness of the wider applicability and generalisability of the framework.

This chapter is structured with reference to the developed framework, categorised into the technological, organisational, and environmental contexts. The chapter also discusses the links between the findings and the existing literature. While the results align with the existing knowledge on the role and relationship of factors influencing the adoption of smart charging, they introduce a novel framework providing a deeper understanding of the process. These findings establish insights into the complexity of the adoption of smart charging across PEDs, extending understanding of technology adoption at a collective level. Finally, this study provides evidence-based recommendations for PEDs and policy makers in Europe to leverage the expertise and capacity of PEDs to address challenges of adopting smart charging.

5.2 Framework of Determinants of Smart Charging Adoption in PEDs

Figure 34 below presents the framework consolidating factors influencing the adoption of smart charging across PED projects. Since comprehending the adoption of smart charging in PEDs is an evolving and dynamic process, the developed framework should not be considered as the definitive blueprint but rather as a starting point for ongoing improvements for energy projects like PEDs. The framework is a representation of the current perspectives and realities shared by representatives of energy projects like PEDs and other relevant stakeholders involved in the research, as well as the information presented in PED project deliverables.

Figure 34 Conceptual framework of "Determinants of smart charging adoption in PEDs" adopted from the TOE framework



The adoption of both types of smart charging, particularly V1G and V2G, was seen as a necessary strategic approach towards the decarbonisation of both the transport and electricity sectors. Nevertheless, the findings were predominantly focused on the adoption of V2G technology for two main reasons. Firstly, interview respondents more frequently and widely, especially with technology-related questions, discussed V2G technology, probably due to its innovativeness and the uncertainties surrounding its viability in terms of a monetary business model. Secondly, case studies, including those discussed in the generalisation section, also only demonstrated the adoption of V2G charging infrastructure across PED projects. There was a case where one project aimed to adopt EV charging infrastructure equipped with V1G technology, but ultimately, due to technical issues, smart charging was not adopted at all. Nevertheless, it is important to note that the developed framework is applicable to both types of smart charging technologies.

5.3 Technological determinants

The technological context of the developed theoretical framework encompasses two key factors driving the adoption of smart charging across PED projects: grid enhancement and monetary benefits. These factors highlight the primary advantages that smart chargers offer, particularly for the grid and energy users. Smart chargers could benefit the grid by enabling EVs to function as energy storage or demand response mechanisms, thereby contributing to energy flexibility. Additionally, as these smart charging functions add value to the energy system, they can result in monetary rewards for EV drivers through tariffs and other incentives.

These findings align with the literature, which indicates that EV charging infrastructure equipped with smart charging can be classified as DERs or as ‘behind-the-meter’ resources, which refer to small-scale modular technologies and energy efficiency and demand response mechanisms that can generate or store energy, or control energy loads and resources (International Energy Agency (IEA) 2021). One of the significant characteristics of DERs is that they are usually located close to customers and owned and operated by individual users - such as households or businesses managing their own solar panels or battery storage systems - or managed through aggregated models, where DER units are owned collectively, often through the establishment of a cooperative (Xu et al., 2021). DERs are known for offering capabilities such as increasing the integration of renewable energy (IRENA, 2020), reducing infrastructure investments (Lever et al. 2021), improving grid resilience (Immerman 2021), and reducing electricity bills (Shenot et al. 2019).

According to Blackhall et al. (2020), the continuous growth of DER adoption, including EV charging infrastructure equipped with smart charging, will transform the energy system from the following perspectives:

- From a technical perspective, the global energy system will transition from a traditional centralised energy system to a decentralised energy system, shifting from historical one-way energy flows to bidirectional, dynamic energy flows.
- From an economic perspective, the global energy system will move from the traditional role of energy consumers who have little involvement to prosumers who, through purchasing DER assets and software, are able to both produce and consume energy and become active energy market participants.
- From a social perspective, DER adoption can reduce energy costs for prosumers and utilities and increase energy equity for energy consumers, including those who might not be able to host or directly invest in DERs.

The findings of the present study emphasise that the integration of V2G technology with PV is one of the most efficient technology synergies in both energy and monetary terms. Following Blackhall et al.'s (2020) predictions, the integration of V2G technology with PV has been shown to contribute to the energy system from all three perspectives: technical, economic, and social. Technically, V2G facilitates a decentralised energy system by improving the efficiency of solar PV use and optimising self-consumption, while simultaneously limiting the impact of EV adoption on the grid, by sourcing energy from RES.

From an economic standpoint, V2G integration helps EV owners reduce charging costs while potentially generating income through energy exports. Furthermore, it provides economic benefits by reducing grid infrastructure strain, especially during peak times. Socially, integrating V2G with PV can offer more accessible energy solutions, promoting energy equity by allowing a broader range of consumers to participate in energy production, while also enhancing grid stability and reducing reliance on non-renewable energy sources.

This, further, aligns with the wider literature, which supports the integration of renewables with EVs equipped with smart charging (Dik et al. 2022; Shi et al. 2020). For example, Franco et al. (2020) state that V2G charging can provide intelligent coordination of the use of renewable sources, emphasising the importance of such integration. Sadeghian et al. (2022, p.3) define the integration of EV chargers with renewables as "smart green charging" as well as "an effective action to enhance the positive environmental impact of EVs". Similarly, Spencer et al. (2021, p.1) highlight such integration as "a viable method of reducing transportation emissions and meeting GHG reduction targets".

Findings highlight that grid capacity issues already affect some countries in Europe. The reduction of fossil-fuel usage, the increased share of renewable sources, and the rapid uptake of EVs, pose challenges in managing supply and demand, impacting grid stability and reliability. Whilst EVs create a challenge, they also offer a solution as well, with the right connectivity, playing the role of "an energy storage on wheels". As the adoption of energy storage serves as a traditional solution for addressing variability of renewables, some PED projects, such as Pocityf, Stardust, ZEN research, CityxChange, and MySmartLife, have adopted V2G smart chargers to enhance the use of PV assets and provide significant grid capacity.

These findings are in line with the wider literature, which discusses V2G smart charging as "flexibility enablers", "flexibility providers", or "quasi-stationary" energy storage system in defining the role EV chargers in the energy system (Ilieva and Bremdal 2020; Franco et al. 2020; Sevdari et al. 2022; Sørensen et al. 2024; Gonzalez et al. 2021). Some literature compares smart charging with uncontrolled, unguided, and disorganised EV charging, concluding that the latter strategy leads to chaotic charging behaviour that "can cause a huge adverse impact on distribution systems", emphasising the need to adopt smart charging to contribute to the operational stability of energy grids (Liu and Qin 2023; Zhou et al. 2021).

The findings suggest that the efficiency of energy flexibility provided by smart charging technology depends on use-cases and the predictability of charging behaviour. V2G is suggested as better suited for domestic or commercial fleet chargers characterised by consistent charging patterns, while the implementation of V1G is recommended for public charging points. Bibak and Tekiner-Mogulkoc (2022), Kester et al. (2018) and Gschwendtner et al. (2021) also highlighted that pre-defined driving schedules are the most suitable for adopting V2G technology, while V1G is considered more efficient for unpredictable driving behaviour, similar to that observed at public charging points. Similarly, Lee et al. (2021) suggests installing smart charging points in locations where driving patterns are more established, such as apartment complexes, workplaces, airports, and fleet charging facilities. The importance of predictable charging behaviour is associated with minimising the risk of discharging the EV battery before the EV user's departure, thus avoiding an insufficient state of charge to reach the destination (Huber et al. 2020).

Most PED projects implemented V2G across commercial fleets, where charging behaviour is quite predictable. However, some PED projects adopted V2G chargers in a public car-sharing scheme. The rationale behind the latter choice of use case lies in the adoption of V2G chargers within a residential area, assuming that their charging behaviour would resemble domestic charging behaviour, with vehicles frequently plugged in overnight. However, this finding is not very generalisable concerning the adoption of V2G across public charging facilities. The literature on car sharing use case varies; some supports the idea that V2G carsharing services in residential areas might adopt a charging pattern based on home-work-sport trips, potentially aiding in peak shaving (Kahlen et al. 2018; Novatlantis 2019; Nespoli et al. 2023; Zhang et al. 2021). However, other literature argues that carsharing schemes generally exhibit unpredictable driving behaviour, suggesting the implementation of V1G in such use cases (Gschwendtner et al. 2021; IRENA 2019). Nevertheless, the findings of these studies align with broader research on the impact of smart charging use cases on energy flexibility. Understanding the influence of smart charging use cases on energy flexibility can help PED projects make more informed choices in different settings.

The findings suggest that the adoption of smart charging technology can provide economic benefits to the whole energy system through the reduction of investments in grid expansion, which is necessitated by increased electrification measures supporting the energy transition. This is in line with the literature, suggesting that without smart charging, the grid is likely to require costly infrastructure upgrades, especially with the growth in EV penetration (Borozan et al. 2022; Sadeghian et al. 2022; Spencer et al. 2021). Some studies emphasise that even if the adoption of smart charging does not entirely eliminate the need for grid upgrades, which are not only costly but also time-consuming, taking traditionally about 3-5 years (Nielsen et al. 2023), the technology could defer upgrades, which is also recognised as advantageous (Adegbohun et al. 2024; Karduri and Ananth 2023; Valentine 2023).

Additionally, the results of techno-economic analysis from the active participation observations showed that the adoption of a large number of smart charging outlets, both V1G and V2G, can eliminate the need to purchase costly stationary batteries. The economic benefits associated with the substitution of a stationary battery with a significant number of smart chargers are supported by studies such as Englberger et al. (2021), Gamil et al. (2022) and Qin et al. (2023). Nevertheless, some studies suggest the adoption of both stationary battery and V2G smart charging, whilst acknowledging the challenge of the high costs of implementing both technologies together (Kelm et al. 2021; Fouladi et al. 2021). They explain that EVs might not be available when storage is needed, posing risks of grid congestion impacts (ibid).

5.4 Organisational determinants

The findings indicate that all of the large multidisciplinary EU-funded PED projects studied herein categorise their interventions into three domains: energy/building, mobility, and ICT, while distinguishing between energy efficiency and energy flexibility goals. These domains and goals align with the definition of the PED concept outlined in the Reference framework for PEDs (JPI Urban Europe 2020b), as cited in Section 1.1, suggesting that they are a fundamental part of requirements for the development of PED projects.

Particularly within the mobility domain, the results indicate that PED projects address interventions through the adoption of low or zero carbon vehicles and their infrastructure. This technology-driven approach to addressing mobility in PEDs may be related to the overall technology-oriented approach of PEDs in overcoming the energy transition. Interestingly, all nine large multidisciplinary EU-funded PED projects (Pocityf, CityXchange, Making-City, Atelier, Replicate, MySmartLife, SmartEnCity, Stardust, Sharing Cities), as well as one large multidisciplinary national government-funded project (ZEN research centre), have adopted EV charging infrastructure. This infrastructure varies from public EV chargers to council fleets and public e-bus charging infrastructure. However, only about half of the projects, particularly Pocityf, CityXchange, MySmartLife, Stardust, and ZEN research centre, have adopted EV charging infrastructure equipped with V2G technology. This highlights the important role that the adoption of EV charging infrastructure needs to play across the technological interventions that PED projects deploy.

The findings indicate that when PED projects aim to address energy efficiency, they tend to focus significantly on implementing measures related to buildings, such as insulation or LED lighting. However, when PED projects, in addition to the energy efficiency goal, incorporate a grid flexibility goal, they focus on integrating energy systems and implementing energy storage solutions, leading to the adoption of EV charging infrastructure equipped with smart charging technology. This emphasises the relationship between energy flexibility goal and smart charging technology as a key goal motivating PED project to adopt smart charging.

Technology adoption in PEDs involves a process that comprises interconnected and interacting functional components, as well as social actors, namely project stakeholders. These stakeholders establish goals, develop catalogues of potential technological interventions, conduct techno-economic analyses of interventions, make decisions on technology selection, allocate human and financial resources, and provide project deliverables. The findings underscore the importance of stakeholder collaboration, clarity in goal setting and responsibilities, and availability of funding resources in the adoption of smart charging in PEDs. Therefore, the organisational context of the developed theoretical framework encompasses these three factors that facilitate the adoption of smart charging in PED projects. The findings are consistent with broader research that supports factors such as stakeholder collaboration and engagement, goal setting and responsibilities, and funding, impacting technology adoption, including smart charging adoption.

Most PED projects, preliminary large multidisciplinary EU-funded projects, highlighted that they align their activities with the following components: stakeholder collaboration, engagement, knowledge sharing, and innovativeness. The majority of EU-funded projects studied underscored these components as important aspects of their collaborative approach to climate action efforts, indicating their integral role in PED project activities. This aligns with requirements for PEDs established by the JPI Urban Europe programme developed by the European Commission (European Commission 2018), which encourages PED projects to support various collaboration and communication activities, involving project partners, policy makers, other projects and stakeholders (JPI Urban Europe 2021).

During interviews with experts from relevant fields, respondents also emphasised that these components, particularly stakeholder collaboration and engagement, are interrelated and important prerequisites for successful outcomes in many project initiatives, including the adoption of smart charging. In the organisation and diffusion of innovation literature, knowledge sharing and innovativeness are frequently stated as outcomes of effective stakeholder collaboration and engagement. The literature emphasises that stakeholder collaboration and engagement offer opportunities to incorporate diverse skills, knowledge perspectives, competences, best practices, and experiences, thereby fostering innovative behaviour and interventions (Campbell 2012; Crescenzi, Gagliardi 2018; Oerlemans et al. 1998; Pérez-Luño et al. 2014).

Furthermore, the literature supports the argument that collaboration between stakeholders is one of the necessary elements for successful technological advancements across smart cities (Clement et al. 2022; Galati et al. 2021). Anthony (2021) and Apata et al. (2023) highlight that for the successful deployment of EV chargers, a collaborative approach among stakeholders is also essential. Some studies highlight that multi-stakeholder partnerships are emerging as a policy trend for building capacity to address complex development issues (Fowle and Biekart 2017; Clarke and MacDonald 2019) and consider them instrumental or as "a catalyst" in achieving sustainable development goals (Eweje et al. 2020, p.186). This supports the role of PEDs in policy development and highlights the importance of effectively managing their capacity for better performance, particularly with technological interventions.

The findings enhance understanding of stakeholders involved in PEDs in adopting smart charging technology. There are four key stakeholders that adopted EV charging infrastructure equipped with smart charging in PEDs: local governments, public transport companies, housing associations, and DSOs. Some local governments have adopted electric council fleets equipped with V2G chargers to facilitate the EV adoption and promote and provide an example of energy transition measures. Others have encouraged the adoption of public V2G chargers in residential areas to promote innovative sustainable solutions for the public. Public transport companies have facilitated the adoption of e-buses equipped with V2G chargers, while housing associations have supported the adoption of V2G chargers in residential parking areas. DSOs play a significant role in connecting EV chargers to the grid, impacting the maintenance of the infrastructure.

Another organisational factor highlights the importance of clearly defined goals and responsibilities within projects. The findings suggest that unclear goals and responsibilities do impact the performance and effectiveness of PEDs in adopting technologies, including smart charging, especially considering the scale of PEDs. The findings emphasise that PEDs are large projects that implement a wide range of complex innovative interventions involving numerous stakeholders playing different roles, such as capacity-builders, advisors, or implementers.-The findings suggest that ensuring understanding of mutual goals and benefits among stakeholders and promoting transparency and clarity in action plans could be an effective strategy for improving the adoption processes of technologies, including smart charging. This is consistent with the literature that supports setting goals aligned with multi-stakeholder partnerships' values and missions, as well as the alignment of responsibilities for achieving set goals (Fowler and Biekart 2017; Gray and Purdy 2020). Such alignment, frequently referred to as 'orchestration', is emphasised as vital for the effectiveness of multi-stakeholder partnerships (Fowler and Biekart 2017).

Lastly, funding is highlighted as one of the most important organisational factors influencing the adoption of smart charging in PEDs. This relates to the current non-commercial viability of adopting sustainability-related technologies, including V2G, which limits the engagement of business investments. Thus, most PED projects have relied on EU funding supported through Horizon research and innovation programmes, given the considerable scale of technological interventions and their capital and operational costs. These grants provide support for various expenses, including research, capacity-building initiatives, implementation of technology and infrastructure, and monitoring, thereby creating opportunities for PEDs to access both human and financial resources.

Notably, one PED project that has not adopted any technologies within the project duration emphasised that the primary reason for not implementing technologies, including V2G chargers, was a lack of funding. The project applied several times for EU grants, which were unsuccessful, but considered this type of funding as the only realistic solution for addressing their development goals. Nevertheless, there are a few PED projects funded by national governments, showcasing the capability of implementing V2G chargers that have relied on local funds, while still supporting the need for funding from somewhere. This is consistent with the literature that highlights the importance of funding for smart charging technologies, especially V2G (Malya 2020; Pardo-Bosch et al. 2021; Jones et al. 2022). For example, Mojumder et al. (2022, p.1) emphasise that "the promise of V2G could be colossal, but the scheme first requires tremendous collaboration, funding, and technology maturation". In general, Ali and Qadir et al. (2021) highlight that financial investments are undoubtedly one of the major hurdles in implementing green technological innovations.

5.5 Environmental determinants

Findings from this study indicate that the availability of smart charging tariffs and LFM increases the financial rewards received from the use of smart charging, encouraging its adoption among EV users. Smart charging tariffs are implemented in the UK and Ireland, while similar mechanisms, such as dynamic pricing, provide opportunities for cost-effective EV charging in other European countries, including the Netherlands. However, LFM remains relatively uncommon and is still in the testing phase, being trialled across various European projects. This is supported by Venegas et al. (2021) and Couraud (2023), who state that while a framework exists for the procurement of flexibility services by transmission system operators (TSOs) through balancing markets, a framework for the procurement of flexibility by distribution system operators (DSOs) is still under development and remains at a trial stage.

LFM is considered as a potential market solution that could fully incorporate the benefits DERs provide to local energy systems, including PEDs, if it reflects the range of values DERs contribute within electricity markets and compensation mechanisms. Nevertheless, the implementation of LFM has been shown to face challenges due to a lack of policy and market frameworks to support its development. As a result, only two out of the 12 studied PED projects, CityxChange and Posityf, have implemented a P2P platform to integrate DERs within a LFM structure.

Zinaman et al (2020) also note that most electricity markets, including LFMs, fail to capture the full range of values that DERs can provide, leading to lost opportunities in DER deployment decisions. A widely recognised solution for expanding DER adoption, including V2G, is transitioning to more reflective and responsive market approaches with accurate valuation mechanisms that fully reflect all variance of values that DERs can provide (O'Shaughnessey and Shah 2021).

Two PED projects, Posityf and CityxChange, have deliberately aimed to develop LFMs and integrate V2G with them to interconnect electricity and transport systems to enhance energy optimisation. In one of the cities, CityxChange even highlighted that a lack of LFM was one of the reasons for not implementing V2G, while in another, their integration demonstrated the relationship between LFM and V2G. This aligns with Hashemipour et al. (2021) describing LFM as a new mechanism for encouraging the adoption of small-scale assets, including EVs equipped with smart charging. Ilieva and Bremdal (2020, p.1047) also support the synergy of EVs and LFM, highlighting that “EVs and local flexibility markets can be seen as a co-joint instrument for sustainability transition and their interrelation as a topic of high research interest”. Thus, the development of energy markets that facilitate flexibility trading, such as LFM, can encourage the adoption of flexibility assets, including V2G, thereby helping to mitigate the impact of EV adoption on the grid by balancing energy supply and demand when needed.

The findings suggest that certain countries, such as the UK, the Netherlands, and recently Ireland, recognise smart charging as a valuable source of energy flexibility from a regulatory perspective, by establishing smart charging policies and action plans to promote the deployment of the technology. Although no direct relationship was found between the adoption of smart charging and the presence or absence of smart charging policy across geographical locations of PED projects, interviewed representatives from energy and PED projects, as well as project deliverables, frequently highlighted the importance of policy in decision-making processes.

PED projects evaluated the techno-economic benefits of technologies to determine and justify technological choices, which involved the consideration of policy aspects. For example, some projects utilised a PESTEL analysis that includes the evaluation of political, economic, social, technological, legal, and environmental aspects of technologies. Other projects evaluated policy aspects regarding potential economic benefits that may emerge if incentives such as supportive tariffs for V2G are implemented. The significance of policy support for the adoption of V2G is discussed in a large number of studies exploring the value of V2G as a flexibility provider, as well as the value of energy flexibility as a whole (Anaya and Pollitt 2021; Dudjak et al. 2021; Pressmair et al. 2021; Teotia and Bhakar 2017; Valarezo et al. 2023; Zabaleta et al. 2020). These studies suggest that incentives can unlock the potential of flexibility solutions, including V2G, and considerably facilitate their deployment.

Similarly to policy, market frameworks were also emphasised as an important factor to consider in decision-making processes. Representatives from energy and PED projects, as well as project deliverables, highlighted a lack of electricity market mechanisms as a market barrier limiting business models of V2G. The findings suggest that the emerging local flexibility markets, which are currently in the experimental phase, could play a key role in facilitating the adoption of flexibility technologies including V2G, by increasing their monetised benefits and fostering business opportunities. This is consistent with the literature supporting a lack of market mechanisms that limit the understanding of V2G business models (Bray et al. 2020; Pressmair et al. 2021; Zabaleta et al. 2020). The studies also suggest that transparent and clearly defined flexibility markets can illuminate the feasibility and value within flexibility markets, fostering business opportunities that will facilitate the adoption of flexibility assets, including V2G (Anaya 2020; Zabaleta et al. 2020).

5.6 Chapter summary

This chapter discusses the developed framework of determinants for smart charging adoption in PEDs, based on a study conducted on European PED projects. The framework comprises three dimensions, technological, organisational, and environmental, - each encompassing factors that influence the adoption of smart chargers across PED projects.

The technological dimension focuses on the perceived relative advantages influencing the adoption of smart charging in PEDs. The perceived relative advantages include environmental and economic benefits, namely the enhancement of grid flexibility, the reduction of grid reinforcement costs, and lower energy bills for EV drivers.

The organisational dimension explores stakeholder collaborations, project goals, and financial resources. PED projects encompass a large number of various stakeholders, including universities, government and local authorities, and businesses. These collaborations provide resources and expertise supporting PEDs to progress in addressing energy transition strategies. A lack of funding in projects, which are not funded by the EU, is emphasised as a major factor behind not adopting technologies, including smart charging infrastructure.

The environmental dimension explores the role of policy and market frameworks in adopting smart charging technology in PEDs. The findings emphasise the importance of policy incentives and market mechanisms in encouraging the adoption of smart chargers due to the invalidity of its business model. The findings reveal that only the UK, the Netherlands, and recently Ireland have recognised the role of smart charging technology in promoting energy flexibility, thus necessitating more efforts to promote its adoption for enhancing the energy system.

The implications of the study for PED projects underscore the importance of shifting from implementing uncontrollable public EV chargers to V1G smart charging infrastructure at public locations and V2G for commercial fleets. The implications for policy makers emphasise the critical role of PEDs in promoting the adoption of smart charging and the need to learn from best practise. Overall, this chapter provides valuable insights into the factors influencing the adoption of smart charging in PEDs, highlighting the role of PEDs as contributors to the development of efficient practices addressing the energy transition in regions.

Chapter 6 Conclusions and recommendations

6.1 Summary of results

Since 2018, the EU has committed to a climate and energy framework up to 2030, aiming to decarbonise four energy sectors: power, buildings, transport, and industry (Agora Energiewende 2019). This framework has involved a significant policy shift, transitioning from the traditional separation of these energy sectors to their coupling. A key prerequisite for this transition is prioritising energy efficiency and minimising energy waste. This research explores smart charging technologies, such as V1G and V2G, which are developed to integrate power and transport systems and to contribute to their digitalisation.

In the same year, the Strategic Energy Technology Plan (SET-Plan) introduced an ambition to create 100 PEDs in Europe by 2025 (SET-Plan 2018), highlighting their role as a policy instrument for achieving decentralised energy systems across regions. The transition from centralised to decentralised energy systems is emphasised in the European Commission's Clean Energy for All Package as a vital pathway towards a Net Zero future. Since centralised energy systems rely on large, fossil-based power plants, the shift to decentralised energy systems - supplying energy from numerous renewable sources typically owned by consumers - is seen as essential. Therefore, the role of energy users is redefined from just consumers to prosumers, those who both consume and produce energy.

However, this transition involves challenges related to fluctuations in renewable energy supply, which can pose risks of energy disruption. Additionally, the electrification of transportation, which is part of the transport decarbonisation agenda, also adds risks to energy disruption from growth in grid demand. This research focuses on PED projects as case studies to understand what technologies PED projects adopt to address the EU decentralisation agenda and whether they couple energy and transport sectors by adopting EV infrastructure equipped with smart charging technology.

Smart charging technologies, particularly vehicle-to-grid (V2G) and unidirectional managed charging (V1G), provide controllable charging enabled by digitalisation. This includes the visibility of charging data and the ability for operators to, for example, pause charging during periods of high grid demand. V2G adds additional value to the grid by using EV batteries for temporary energy storage, when there is a surplus of energy supply. This research shows that the adoption of EV infrastructure equipped with smart charging technology is part of the agenda in several PED projects, although its implementation largely depends on funding - whether through grants, subsidies, or incentives.

While interest in PEDs as a research topic is increasing, there is still a lack of empirical evidence and a comprehensive understanding of their effects. For example, a Technical Report on "Enabling PEDs across Europe" (JRC 2020) highlights scarcity in data and monitoring methodologies in current PED experiences. The SET Plan progress report (JRC 2023) emphasises the importance and need to understand the barriers and enablers of PED projects. Academic papers highlight limited knowledge on PEDs due to their novelty and a lack of practical experience (Derkenbaeva et al. 2022; Hedman et al. 2021; Sassenou et al. 2024). In particular, Krangsås et al. (2021) underscore the need to investigate the planning and decision-making processes and the outcomes of PEDs.

In response to these gaps, this thesis has investigated the factors influencing the decision-making processes of PED projects in technology adoption, specifically smart charging, by providing evidence from analysing data on multiple PED projects. With the rapid increase in renewables and electrification of transportation, the need to enhance energy flexibility has become evident in European countries, prompting the use of flexibility providers, including smart charging. The integration of EV charging infrastructure with smart charging technologies, such as V1G and V2G, supports sector coupling between transport and power, offering grid management opportunities.

The results suggest that decisions to adopt smart charging in PEDs are closely linked to technology advantages, organisational capacity, and policy factors. Specifically, the findings indicate that the PED projects studied adopted smart charging given its potential monetary benefits, grid enhancement capabilities, availability of funding, and a supportive policy framework promoting the technology. The application of the TOE framework has enabled the development of a framework for "Determinants of smart charging adoption in PEDs", highlighting not only the verification of theories in practice but also providing a holistic perspective on the factors and dynamics between them that influence decisions regarding the adoption of EV charging infrastructure equipped with smart charging in PED projects.

This framework attempted to capture the system-level inter-relationships between technologies, organisation, and policy environment within PED initiatives. The framework describes the perceived benefits of smart charging technology, including enhancing energy flexibility and economic benefits, within the technological context. The framework emphasises enabling organisational capacity factors such as stakeholder collaboration and engagement, clarity in goals and responsibilities, and funding for enhancing the adoption of the technology within the organisational context. The framework underscores the importance of policies and markets promoting the adoption of smart charging and considering it as an energy flexibility technology within the environmental context.

The results highlight that PED projects distinguish energy efficiency and energy flexibility goals. PED projects address energy efficiency goals by implementing building retrofitting measures, such as insulation and LED lighting. Addressing energy flexibility goals, meanwhile, is typically associated with grid management measures through the implementation of sector coupling and enhancement of the efficiency of renewables. Specifically, some PED projects have addressed energy flexibility by integrating mobility and power through the implementation of EV charging infrastructure equipped with smart charging, in combination with PV panels. Moreover, the energy flexibility goal, along with the availability of funding, is found to be the most influential factor in the decision-making process for adopting smart charging. Lack of funding is identified as the primary reason for not implementing smart charging, despite being planned, in one of the PED projects, Smart Energy Åland.

The results underscore the key stakeholders involved in the adoption of smart charging in PED projects: local governments, public transport companies, housing associations, and DSOs. Local governments tend to adopt public V2G chargers in residential areas and for V2G equipped electric council fleets, while public transport companies have adopted e-buses equipped with V2G chargers. Housing associations adopted V2G sharing schemes in residential parking areas. DSOs were frequently involved in partnerships across PED projects; specifically in smart charging adoption, they were involved in the maintenance of the infrastructure, impacting the connection of EV chargers to the grid. Overall, the findings support the implementation of V2G on chargers with predictable charging behaviour patterns, and recommend the adoption of V1G on chargers with unpredictable charging behaviour. The importance of predictable charging behaviour within the V2G use case is associated with its capability to discharge energy and the minimisation of the risk of discharging the EV battery before the EV user's departure, thereby avoiding an insufficient state of charge before reaching the destination (Huber et al. 2020).

The results suggest that the process of technology adoption involves activities such as establishing goals and aligning them with responsibilities among stakeholders, developing catalogues of potential technological interventions, conducting techno-economic or PESTEL (political, economic, social, technological, environmental, and legal) analyses of potential technological interventions, making decisions on technology selection, allocating human and financial resources for implementing technologies, and providing project deliverables.

Some projects additionally evaluate potential economic benefits that may emerge if governments establish supportive incentives to address policy implications and contribute to policy making. This highlights a lack of standardised cost-benefit methodology for PED projects supporting efficient decision-making processes. Additionally, this underscores the notion that some PED projects perceive themselves not only as implementers but also as contributors to policy decisions. Clarity in defining the role of PED projects at the regulatory level may enhance their effectiveness in achieving set goals and the long-term impacts of their initiatives – especially where lessons can be learned by policymakers from the experiences of PED project teams.

The significance of adopting smart charging and its potential role as an energy flexibility provider has already been recognised at the regulatory level in some countries, such as the UK, the Netherlands, and recently Ireland, establishing smart charging policies and action plans to promote the deployment of the technology. Other European countries also may consider the development of smart charging policy to promote the technology. Overall, the implications of this study for policy makers highlight the important role of PED projects in addressing climate change and the need to learn and scale up their best practices.

The findings also have implications for PED projects themselves, emphasising that since not all PEDs have adopted smart charging, there are still lessons to be learned to ensure PEDs deliver on all of their potential. PED projects should shift from implementing uncontrollable EV chargers to chargers equipped with smart charging and lead transformative change by navigating government commitments toward grid-management and sector integration solutions. This chapter provides insights into the processes, stakeholders, and use cases of the adoption of smart charging in PED projects, emphasising the potential role of PED projects to contribute to the more proactive and efficient adoption of smart charging in Europe.

6.2 Methodology

A theory-driven reflexive thematic analysis approach laid the foundation of this study's research design. The study applies the TOE framework as a structured lens to explore factors influencing smart charging adoption, deductively identifying three key themes: technology, organisation, and environment. Meanwhile, other themes emerged inductively, uncovering patterns and relationships that reflect the experiences of PED projects**.** The primary aim in employing this approach was to develop a conceptual framework that would provide insights into the determinants of smart charging in energy projects like PEDs and to elucidate how and why smart charging is adopted or not adopted among PED projects.

The data were collected from energy projects located in Europe, which aimed to adopt or had already adopted smart charging at a collective level. Firstly, fieldnotes from both passive and active participant observations were analysed. Secondly, two stages of semi-structured interviews with energy experts, representatives of energy projects that have implemented smart charging, and representatives of PED projects, were conducted. The interviews aimed to gain information about their experiences and viewpoints regarding enablers and barriers to the adoption of smart charging.

Thirdly, in-depth multiple case studies were utilised to explore the process of smart charging adoption across two PED projects, namely Pocityf and Åland Island. These case studies were selected based on the criteria of having similar goals but rival outcomes in terms of the adoption of smart charging, aiming to strengthen derived findings. The case studies ascertained the activities undertaken by the projects, their structures, and interactions among organisational stakeholders. This stage involved the analysis of six interviews, national policy documents on smart charging and energy flexibility, as well as project documents. Policy documents were analysed to ascertain the external factors that might impact the decisions regarding the adoption of smart charging among energy projects. Project documents were utilised as documentary evidence to supplement other sources used in this study.

Finally, a comparative case study analysis with an additional ten PED projects was conducted to assess the generalisation of findings derived from interviews and in-depth multiple case studies. This stage involved the analysis of project deliverables and policy documents. The generalisation of findings allowed for the exploration of multiple technological, organisational, and environmental contexts of additional PED projects and validating the developed conceptual framework.

6.3 Limitations

While this research offers significant insights into the determinants of smart charging technology in PED projects, there are several limitations that might impact the validity, scope, and generalisability of the results. Firstly, the number of interview participants and their expertise in electricity markets, transport, and policy fields may not fully represent the diverse perspectives within the PED projects. Inclusion of a wider spectrum of stakeholders, particularly those directly involved in PED projects, could enhance the comprehensiveness of the insights and the validity of the study. Additionally, the findings of interviews might be subject to biases and limitations inherent in this method's data collection and interpretation.

Second, the generalisation of results relied on project deliverables and policy documents. Despite the employment of strict inclusion criteria and careful reading of each project deliverables and policy documents, the analysis of documents could have selection bias. This highlights the potential of context-specificity of the results of this study, embedded with socio-political contexts of these PED projects. Therefore, caution is advised when applying the results to contexts outside of the PED projects examined in the current research.

Thirdly, the socio-political landscapes in which PED projects adopted or did not adopt smart charging technology are subject to continual change. The study captured a specific timeframe, and the results may not entirely portray the impacts of future policy changes or societal dynamics that may impact the adoption of smart charging in PED projects.

Finally, despite efforts to conduct thorough and rigorous analysis and generalisation of findings, the data interpretations could be influenced by my preconceived notions and experiences. It is essential to recognise and minimise these biases to uphold the validity of the research.

6.4 Research Contribution

This thesis has made significant contributions to the study of technological innovation in multidisciplinary partnerships addressing climate change targets, particularly in European countries. By employing the TOE framework, a reflexive thematic analysis approach and examining the intricate dynamics of the adoption of smart charging technology in emerging PED projects, this study has broadened scholarly comprehension in several respects:

- It has provided a holistic framework of determinants: The development of the "Determinants of smart charging adoption in PEDs" framework offers a holistic perspective on the factors influencing the adoption of EV charging infrastructure equipped with smart charging in PED projects. This framework is applicable not only to PED projects but also to energy projects that employ a collaborative approach to address complex climate change goals. The framework captures technology advantages, organisational capacity building, goals, and policy factors that encourage projects to adopt EV charging infrastructure equipped with smart charging capabilities.
- It has deepened understanding of barriers and enablers: The identification of barriers and enablers of the adoption of smart charging in PEDs within technological, organisational, and environmental contexts adds depth to the existing body of knowledge. Acknowledgment of the influence of the socio-political landscape on technology adoption decision-making can enhance the understanding of the challenges faced by PED projects and help in formulating effective strategies or interventions to overcome them.
- It has identified significant implications for policymaking: Through the exploration of the adoption of smart charging in PED projects, this research offers insights for multidisciplinary partnerships addressing climate change targets that have the potential to inform and shape policymaking. The proposed recommendations offer practical guidelines for PED developers, policymakers, and charging infrastructure providers seeking to maximise the contribution of PED projects in addressing climate change.
- It has contributed to a theory-driven reflexive thematic analysis approach: The utilisation of a theoretical framework, specifically the TOE framework, contributes to the growing body of work on theory-driven reflexive thematic analysis. This methodological application demonstrates a structured and theoretically grounded strategy that can serve as valuable guidance for empirical investigations across various fields of applications.
- It has contributed to technological innovation scholarship: This research enriches technological innovation scholarship by offering a practical application of the TOE framework and a conceptualisation of determinants and dynamics of the adoption of smart charging.
- It has contributed to the adoption of smart charging scholarship: The adoption of smart charging has primarily been examined from an individual perspective. This research

provides empirical evidence and a comprehensive understanding of smart charging adoption from a collective standpoint.

- It has contributed to tracing the process underlying the adoption of PV panels, P2P and LFMs platforms: As this study explores the potential relationships between the adoption of smart charging and the availability of other innovations, it offers a perspective allowing for the tracing of the adoption of particularly PV panels and digital platforms such as P2P and LFMs across PED projects. Thus, the study offers important lessons for other PED projects, either in the development or planning stages.
- It has contributed to PED concept scholarship: The concept of PEDs is emerging and requires knowledge for better planning, designing, and implementation. This research contributes to a better understanding of the decision-making processes, technological interventions, and challenges faced by PED projects. The results of this study can be practically applied to enhance the role and initiatives of PEDs.

6.5 Recommendations for Policy Makers

The study results demonstrate how current national regulations treat smart charging technology in Europe. The findings show that only the UK, the Netherlands, and recently Ireland promote the adoption of smart charging through strategic action plans and policy documents. This information may inform policy makers from other European countries to recognise the valuable role smart charging technology can play in grid management and potentially collaborate more effectively with PED projects to achieve energy flexibility and systems integration goals.

The findings of this research have several implications for smart charging policy and practice in Europe, categorised into three policy types: regulation, incentives, and information.

- **Regulation: Treating smart charging as a provider of energy energy flexibility and energy system digitalisation:** Policy makers should recognise the important role of smart charging in enhancing energy flexibility and sector-coupling enabled by digitalisation. Smart charging facilitates the visibility of charging data, allows operators to pause or shift charging during periods of high grid demand, and enables the use of EV batteries as small-scale energy storage. It should be supported through initiatives that promote - or even require - the incorporation of sustainable charging technologies in new developments.

- **Incentives (economic): Supporting market mechanisms**: To enhance the adoption of smart charging technology, policy makers need to address the current lack of economic incentives, for example, by offering smart charging tariffs, and market mechanisms, such as LFMs, supporting monetised benefits from the use of V2G assets. Overall, policies providing access to revenue for the use of technologies that can facilitate grid management are critical. Similar to other low-emission technologies, such as solar panels - which were not widely adopted until they provided clear financial benefits - smart charging is also unlikely to be widely deployed until it offers significant cost savings or enables free charging.
- **Incentives (financial): Replicating successful practices**: Scaling up successful smart charging practices from PED projects can serve as a blueprint for policy makers. Learning from the initiatives and best practices of PED projects can accelerate progress in the adoption of sustainable technologies, including smart charging, and create positive social and environmental impacts.
- **Information: Encouraging collaboration**: Policy makers could actively collaborate with PED projects that successfully adopted smart charging in decision-making processes related to further EV charging adoption. Consulting and engaging with PED projects can lead to more effective and relevant policies and practices being developed from these technology adoption leaders.

In conclusion, the results of the study underscore the crucial role of smart charging technology in advancing grid management and highlight the significant role of PEDs in deploying them effectively to the public. The commitment at the policy level to promote smart charging can encourage more PED projects to shift from implementing unmanageable public EV chargers to V1G smart charging infrastructure at public locations and V2G for commercial fleets and domestic chargers. By acknowledging and tackling the challenges PEDs may face, policy makers can more effectively utilise their capacity, thereby accelerating the energy transition progress in Europe.

6.6 Recommendations for PEDs

The future energy grid needs to be more resilient, decentralised, and capable of adapting to fluctuations in renewable energy demand and supply. To address this, PED projects are implementing sector coupling by integrating the power and transport sectors to enhance system flexibility. Prosumers, who both produce and consume energy, have the potential to play a transformative role in the future energy grid, advancing the PED agenda. This research highlights that engaging prosumers, particularly solar panel and EV owners, and encouraging them to adopt smart charging, can significantly benefit the grid by offering energy flexibility and digitalisation solutions.

The study results underscore the important role of the adoption of smart charging technology in PED projects. This aligns with European efforts to decarbonise and improve the energy system within the energy transition pathway. The adoption of smart charging technology enhances energy flexibility by integrating power and e-mobility systems through digitalisation, helping to reduce the cost of grid reinforcement. Therefore, directing the efforts of PEDs to adopt smart charging technologies, whether V1G or V2G depending on use cases, is instrumental in supporting the digitalisation of the energy system, enabling better grid management, and promoting awareness of sustainable charging behaviour.

Currently, while nearly all PED projects implement solar panels and EV charging infrastructure, not all adopt charging infrastructure equipped with smart charging. To ensure that PED projects effectively address energy transition goals and enhance the long-term impacts of their initiatives, this research recommends the following for PED developers:

Adoption of Smart Charging: PEDs need to consider the implementation of V1G smart charging for public chargers with unpredictable charging behaviour, and V2G smart charging for commercial fleets and domestic EV charging with pre-defined charging behaviour in all projects aiming to implement EV charging infrastructure. As PED projects view themselves as contributors to best practices and trends in technology adoption, they have the opportunity to influence policy decisions in promoting EV charging infrastructure equipped with smart charging technology to unlock their full potential and achieve more significant impacts within a project.

Strategic Collaboration and Clear Planning for Effective Stakeholder Engagement: PED projects address complex energy transition goals through extensive multi-stakeholder and multidisciplinary collaborative actions. These collaborations offer substantial human resource capacity with diverse field expertise. Nevertheless, PED projects may face challenges in aligning goals and responsibilities, low stakeholder engagement, or turnover among project stakeholders, creating uncertainties and disruptions in implementing technological interventions. To address these challenges, PED projects must establish clarity and transparency in action plans to enhance project capacity and form partnerships with receptive organisations that leverage their expertise. Investing in strategic collaborations can strengthen PED projects' capacities and manage challenges more efficiently.

Standardised Methodologies for Decision-Making: PED projects employ various approaches to evaluate and select technologies for adoption. Determining the most appropriate technologies for adoption in PED projects is not the choice or preference for one technology to another, but rather a decision based on a scientific approach aimed most efficiently at reducing emissions in the region. Developing a standardised cost-benefit methodology for PED projects could foster more supportive and efficient decision-making processes, ensuring clarity and understanding of business models that encourage energy flexibility and strengthen their long-terms impacts.

Some PED projects evaluate policy and market frameworks and utilise the results as a driving factor in selecting technologies for adoption. A lack of supportive policies toward the adoption of smart charging might hinder their implementation within projects. To maximise projects' efforts toward not only decarbonisation of the transport sector but also enhancing the power sector, PED projects need to shift from implementing unmanageable EV chargers to chargers equipped with smart charging to navigate governmental commitments towards grid-management, sector integration, and digitalisation solutions.

Through a collaborative approach and continuous growth, PED projects can lead transformative change, fostering the adoption of smart charging behaviour among EV users that benefit all energy users by improving grid management. Scaling up the lessons learned from the PED projects can provide a pathway for achieving a more integrated, sustainable, and efficient energy system across Europe.

6.7 Future Research

This study reveals potential avenues that may further enrich the understanding of the adoption of smart charging in PEDs:

- While this thesis has investigated the perspectives and decisions of PED partners, mainly from the energy, transport, and policy spheres of expertise, future research can delve deeper by exploring the perspectives of EU project officers, local governments, businesses, residents, and from other PED projects. The investigation of a wider range of stakeholder perspectives would be beneficial and provide a better understanding of the decision-making processes of PED projects.

- This study focuses on the investigation of the adoption of smart charging technology. Future research could explore other technologies adopted in PED projects to facilitate the energy transition, such as heat pumps, stationary batteries, or PV plants. This investigation would offer a comprehensive understanding of PED strategies in technology adoption and their performance, enabling the provision of more targeted recommendations for PED projects.
- The emphasis on stakeholder interactions could inform more impactful strategies for technology adoption, including smart charging. For example, the investigation of power dynamics, negotiation processes, or engagement strategies within PEDs could provide insights into how the stakeholder interactions influence decisions regarding technology adoption.
- Conducting longitudinal research would provide an evolving perspective on the adoption of smart charging in PED projects over time. Such research can help assess the effectiveness of the adoption of smart charging in PEDs and track the evolution of policy and strategies applied by PED projects. This would further aid in identifying factors that influence smart charging adoption in PED projects.

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Appendix A: Overview of PED projects

N	Project	Partnership	Governance	Financial resources	Project principles	Technology framework	Smart charging adoption	Project duration
1	CityXchange	6 countries; 7 cities; 33 partners	Lead organisation-governed network (coordinated by a university)	Horizon 2020 EU contribution: €19,999,996	Collaboration Citizen engagement Knowledge sharing Innovativeness	Energy retrofitting Grid flexibility (flexibility trading) e-Mobility Citizen engagement by ICT	V2G chargers	2018-2023
2	Making-City	8 countries; 8 cities; 34 partners	Lead organisation-governed network (coordinated by a research institute)	Horizon 2020 EU contribution: €18,089,582	Collaboration Citizen engagement Knowledge sharing Innovativeness	Energy retrofitting, e-mobility, Citizen engagement by ICT	Not implemented	2018-2024
3	Atelier	11 countries; 8 cities; 30 partners	Lead organisation-governed network (coordinated by a city council)	Horizon 2020 EU contribution: €19,607,835	Collaboration Citizen engagement Knowledge sharing Innovativeness	Energy efficiency, Renewable energy sources, Energy system flexibility, e-Mobility	Not implemented	2019-2024
4	Replicate	8 countries; 6 cities; 39 partners	Lead organisation-governed network	Horizon 2020	Collaboration Citizen engagement	Energy efficiency, Sustainable mobility,	Not implemented	2016-2021

			(coordinated by a city council)	EU contribution:€ 24,965,263	Knowledge sharing	ICT		
5	MySmartLife	8 countries; 6 cities; 27 partners	Lead organisation-governed network (coordinated by a research centre)	Horizon 2020 EU contribution:€ 18,656,102	Collaboration Citizen engagement Knowledge sharing Innovativeness	Energy/retrofitting building, ICT, and e-mobility	Up to 2023, the only V2G project in Finland	2016-2022
6	SmartEnCity	5 countries; 5 cities; 37 partners	Lead organisation-governed network (coordinated by a research organisation)	Horizon 2020 EU contribution:€ 27,890,138	Collaboration Citizen engagement Knowledge sharing Innovativeness	Energy supply, Energy demand, Energy management	Not implemented	2016-2022
7	Stardust	9 countries; 7 cities; 30 partners	Lead organisation-governed network (coordinated by a renewable Energy Centre)	Horizon 2020 EU contribution: €17,939,998	Collaboration Citizen engagement Knowledge sharing Innovativeness	Energy/building Mobility ICT	2 V2G	2017-2024
8	Sharing Cities	6 countries; 6 cities; 35 partners	Lead organisation-governed network (coordinated by a	Horizon 2020 EU contribution: €24,753,944	Collaboration Citizen engagement Knowledge sharing Innovativeness	Energy/building e-mobility, and ICT platform	Not implemented	2016-2021

			renewable Energy Centre)					
9	ZEN Research Centre	1 country (Norway); 8 cities; 34 partners	Lead organisation-governed network (coordinated by a university and a research organisation)	Budget: NOK 380 million, Private and public funding	-	Energy, GHG emission, power, spatial qualities, mobility, economy, and innovation	2 V2G chargers	2017-2024
10	City District Developm ent Graz-Reiningha us	1 country (Austria); 1 city	Private-public partnership	private (80%), public resources (20%)	-	-	Not implemented	2012-2025

Appendix B: Evaluation of barriers for adopting smart charging in the Making-City project

Integration with other smart solutions	BARRIERS / ENABLERS _ PESTEL STUDIES
the combination with the electrification of transport is highly appealing. (the combination with smart charging for instance).	Political: What is the value of integration? (this solution is non0-invasive). The market is a governmental market. A steady market growth is crucial for investors to further develop this concept. Economic: investment cost must, and will decrease when volume grows. Social: the fact that is is perfectly integrated (instead of other renewables) makes that there is a high social acceptance. Technical: durability is still under research. the concept itself is proven. Environmental: The product is under development, amongst others to increase the EOL scenario of the solution Legal: for (very) large scale applications the energy production by road authorities might become an issue.
Potential for Replication	**Expected Impacts - Benefits**
System is installed in 2014 in Krommenie, since then multiple projects in the Netherlands and France are realized.	

Source: Alpagut et al. 2020

Appendix C: Evaluation of barriers for adopting EV chargers in the Atelier project

Business model patterns			
Sell electricity at an attractive price to the users. Determined by the Republica energy community and Poppies inhabitants			
BARRIERS / ENABLERS _ PESTEL STUDIES			
Political	No major barriers	**Technical**	No major barriers
Economic	No major barriers	**Environmental**	No major barriers
Social	No major barriers	**Legal**	No major barriers
POTENTIAL FOR REPLICATION		**EXPECTED IMPACTS**	
Adaptation needs		**Benefits**	**Co-benefits**
Is it the solution very site-specific?	NO		Enhance stability of the urban infrastructure
Does the developer export the solution to other locations?	YES		Financial savings for citizens
Are there other developers in other locations/countries?	YES		Energy management optimization
Does its implementation depend on a specific business model (such as the creation of an ESE)?	NO		Provide users with energy management capabilities
Does its implementation depend on existing specific regulation (such as Energy Communities legislation)?	NO	But the fact that the chargers are in a microgrid makes it possible that prices are determined by the users (of course the total bill needs to be paid	
Do you think that the solution is highly replicable?	YES	But without the smart grid special circumstance.	**Other:**
Relevant Publications / Presentations / Services / Products to this Solution			

Source: Vallejo et al. 2022

Appendix D: List of project deliverables used in the analysis of PED projects in Section 4.5

Project title	Project document	Reference
Stardust	D 2.3 Midterm report on implemented actions	Costero et al. 2020
	D 5.2 Stakeholder mapping	Ntavos et al. 2018
	D 5.3 Capacity building and knowledge sharing	Corradino and Heidenreich 2019
	D 6.3 Monitoring protocol	Zacco et al. 2019
	D 7.1 Living Labs activities report in each Lighthouse	Tomasi et al. 2019
	D 8.1 Dissemination and communication plan	Lusuan and Moreschi 2018
	D 9.1 Project management plan	Stardust 2017
Sharing Cities	D 3.5 Sustainable energy management systems (SEMS)	Gibbons et al.2018
	D 8.3 Local monitoring programme design	Zavitas et al. 2019
	D 8.4 Monitoring programme data report	Daina et al. 2020
	D 8.9 Final report on model toolbox	Manca et al. 2021
Zen Research Center	ZEN report No. 17: Consequences of local energy supply in Norway: A case study on the ZEN pilot project Campus Evenstad.	Sørensen 2019
SmartEnCity	D 2.8 Integrated and systemic SmartEnCity urban regeneration strategy	Urrutia et al. 2019
	D 8.7 Report on widening the scope of replication knowledge through Smart Cities Network and several European platforms	Urrutia et al. 2021
CityxChange	D 4.5 eMobility in Limerick DPEB implementation guide	Bastable et al. 2023
	D 4.9 White Paper "Regulations Unlocking Innovation Potential"	Stephens et al. 2023
	D 5.10 Trondheim innovation lab solutions catalogue	Grabinsky et al. 2021
	D 5.14 Trondheim project documentation repository including project status report 4	Stephens et al. 2023
	D5.16: Trondheim sustainable investment and business concepts and models	Berthelsen et al. 2023
	D 10.6 Plan for dissemination and exploitation of CityxChange project results	Gall and Haxhija 2019
MySmartLife	D 1.17 Techno-economic analysis of each intervention per pilot (final)	Arrizabalaga et al. 2019
	D 1.4 Delivery of workshops for citizen engagement	Revilla et al. 2019
	D 3.4 Smart Energy Supply and Demand, Integration of RES, storage, management and Control	Willmer et al. 2019
	D 4.8 Report on grid to vehicles strategies and performance	Kulmala et al. 2019
Making-City	D 2.7 Electric vehicles and charging stations roll-out strategy and analysis in Oulu	Rinne 2021
	D 3.5 Smart energy systems in Groningen	Leeuwen et al. 2021
	D 3.7 Electric vehicles and charging stations roll-out strategy and analysis in Groningen	Someren and Tjahja 2021

	D 4.1 Methodology and guidelines for PED design	Alpagut et al. 2020
	D 5.8 Groningen monitoring programme	Konsman et al. 2021
Atelier	D 1.3 Data Management Plan	Andonegui et al. 2020
	D 4.6 Shared cars platforms evaluation	Rooth 2023
	D 6.2 Replication and Upscaling strategy	Vallego et al. 2022
	D 7.1 Citizen and stakeholder engagement plans	WAAG 2021
	D 9.1 Repository of definitions of terms, key characteristics archetypes, and a set of KPIs	University of Deusto et al. 2020
Replicate	D 1.2 Project Management Plan	Sebastián 2018
	D 9.3 Sectorial Business analysis / Exploitation Sectorial Business analysis / Exploitation potential in the field of energy, ICT, sustainable potential in the field of energy	Fundación ESADE 2018

Appendix E: List of policy documents used in the analysis of PED projects in Section 4.5

Project title	**Project document**	**Reference**
Stardust	Spain's National Integrated Energy and Climate Plan 2023-2030	MITERD 2020
	Spain's Recovery and Resilience Plan	SWD (2021) 147 final
Sharing Cities	European Climate Law	Regulation (EU) 2021/1119
Zen Research Center	Norway's Climate Action Plan for 2021–2030	Norwegian Ministry of Climate and Environment 2021
	National charging strategy	Norwegian Ministry of Transport 2023
SmartEnCity	Development and Role of Flexibility in the Danish Power System	Danish Energy Agency 2021
	Nordic Power Market Design and Thermal Power Plant Flexibility	Danish Energy Agency 2018
	Smart Grid Strategy	Danish Ministry of Climate Energy and Building 2013
	A Green and Sustainable World	Danish Government 2020
	Denmark's Integrated National Energy and Climate Plan	Danish Ministry of Climate Energy and Utilities 2019
	Infrastructure plan 2035	(International Energy Agency 2023b; Danish Government 2021
CityxChange	Electric Vehicle Charging Infrastructure Strategy 2022-2025	Ireland Government 2023
City District Development Graz-Reininghaus	Integrated National Energy and Climate Plan for Austria	Federal Ministry of Sustainability and Tourism 2019
	Austria's 2030 Mobility Master Plan	Federal Ministry Republic of Austria 2021