Introduction Strategies for Vehicle to Grid Technology in the United Kingdom

A comprehensive approach to understand and introduce the technology prior to large-scale diffusion

Marisú Mangino Rivas

TU Delft

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by

Marisú Mangino Rivas

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Supervisors: Dr. L. M. Kamp
Prof. Dr. J. R. Ortt

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TU Delft

Preface

I have always firmly believed that everything happens for a reason. I was convinced I wanted to work in finance after graduating with my Bachelor's Degree, and it was through a series of coincidences that I ended up working in the renewable energy sector instead. I instantly fell in love with it and knew what I wanted to do with my professional career: help make the world a more sustainable place through the energy transition. This Master's Degree and my time at TU Delft have been a significant step in this journey towards striving for a more sustainable world. I have learned more than I signed up for within classroom walls and more than I ever imagined outside of them; my experience here has been truly extraordinary.

As these months of work come to a close, I can't help but reflect on the many, many people without whom this work would not have been possible. First, I would like to thank my main advisor, Dr. Linda Kamp. It was in one of her classes that I discovered what focus I wanted to give my thesis, and her guidance these past several months has been invaluable. Always attentive, always willing to have a call or a meeting if I needed help, and always encouraging me to put forward my best work.

I would also like to thank my second supervisor, Prof. Dr. Roland Ortt. When I started my thesis, he said that as a scientist, he would always find something that needed fixing in my work; however, he also mentioned that having someone take the time to actually read your work and find those details is the highest form of respect they can show your work. I am thankful for every single detail that he brought up, which exemplified all the time he put into revising my work and which made it all the better.

I want to extend my gratitude to all the experts who agreed to participate in an interview; your insights were immensely helpful while conducting my research. Additionally, I'd like to thank the team at DNV for allowing me the opportunity to participate in the V2X project that sparked the idea for this thesis. My family has always been dedicated to the transport sector, and it was serendipitous that I found a thesis project combining a sector I've been familiar with my whole life with my passion for sustainable energy technology.

I'd like to thank my friends back home who have supported and believed in me my entire life, and my new friends in the Netherlands who made this experience a lot more enjoyable. I also want to thank everyone in my family. I am aware of the luck and privilege I have to have them all in my life. Everything I have achieved so far has resulted from the encouragement and support they have given me. All the work, effort and love they put into raising me has led me here. This degree is a culmination of all the things they have done for me, and although I will never be able to repay them, I can sincerely express my gratitude for helping me get to where I am today.

Finally, I'd especially like to thank my fiancé, Rodrigo, for being my best friend and biggest supporter for so many years. For simply letting me be myself, accepting and supporting every version of me, and encouraging me to always follow my dreams, no matter what those are or how crazy they may be. I would have given up on several occasions if it weren't for him. Thank you for being with me every step of the way in this journey.

Marisú Mangino Rivas
Delft, August 2024

Summary

The world's energy supply is becoming increasingly driven by renewables and is expected to become even more so as the race towards climate neutrality intensifies. Coupled with the rapid uptake of electric vehicles (EVs) driven by policies to decarbonise the transport sector, the challenges on electricity grids worldwide are becoming more evident every day. The United Kingdom (UK) has made significant strides in these fields and now faces the choice of investing millions to reinforce its energy grid, building large storage facilities, or investing in technologies that will allow flexibility.

EVs have a unique ability to provide vehicle-to-grid (V2G) services, charging when there is a surplus in renewable energy generation and discharging when demand surpasses renewable generation. This enables EVs to act as storage units, provide ancillary services to the grid, assist in peak shaving, increase grid reliability and provide voltage and frequency regulation. Through these services, V2G can relieve several of the pressures brought on by the sustainable energy transition and save the UK millions of pounds in cumulative distribution network reinforcements.

V2G technology is an incredibly important innovation, gaining popularity with record speed; however, current research on V2G in the UK talks mostly about the optimisation of V2G from a technological perspective and has failed to study the sociotechnical development and adoption of the technology itself. In addition, a framework to study technological innovations from a joint company and policymaking perspective is noticeably absent from literature, with companies and policymakers having different approaches. Therefore, this thesis aims to determine the state of the Technological Innovation System (TIS) for V2G in the UK and derive niche introduction and policy strategies that are suitable for combating barriers within this TIS.

Two main research approaches are used in this work: theoretical development followed by a case study. The first consists of building upon a TIS framework developed by Ortt and Kamp to obtain a Shared framework that both policymakers and companies can use to derive policy strategies and niche introduction strategies for radically new innovations. This framework allows both actors to combine strategies and create a more coordinated approach towards technological adoption.

The Shared framework developed comprises eight building blocks (BBs) and eight influencing conditions (ICs) used to evaluate a TIS. These eight BBs portray the necessary conditions for technological innovation to exist from a company and policymaker perspective, and the ICs show which conditions in the TIS may be driving or hindering the innovation process.

The framework also categorises niche introduction strategies and TIS build-up strategies according to which BB and IC combinations they are applicable for. The strategy categories group strategies with similar purposes to facilitate the strategy derivation process. The proposed Shared framework is illustrated in Figure 1

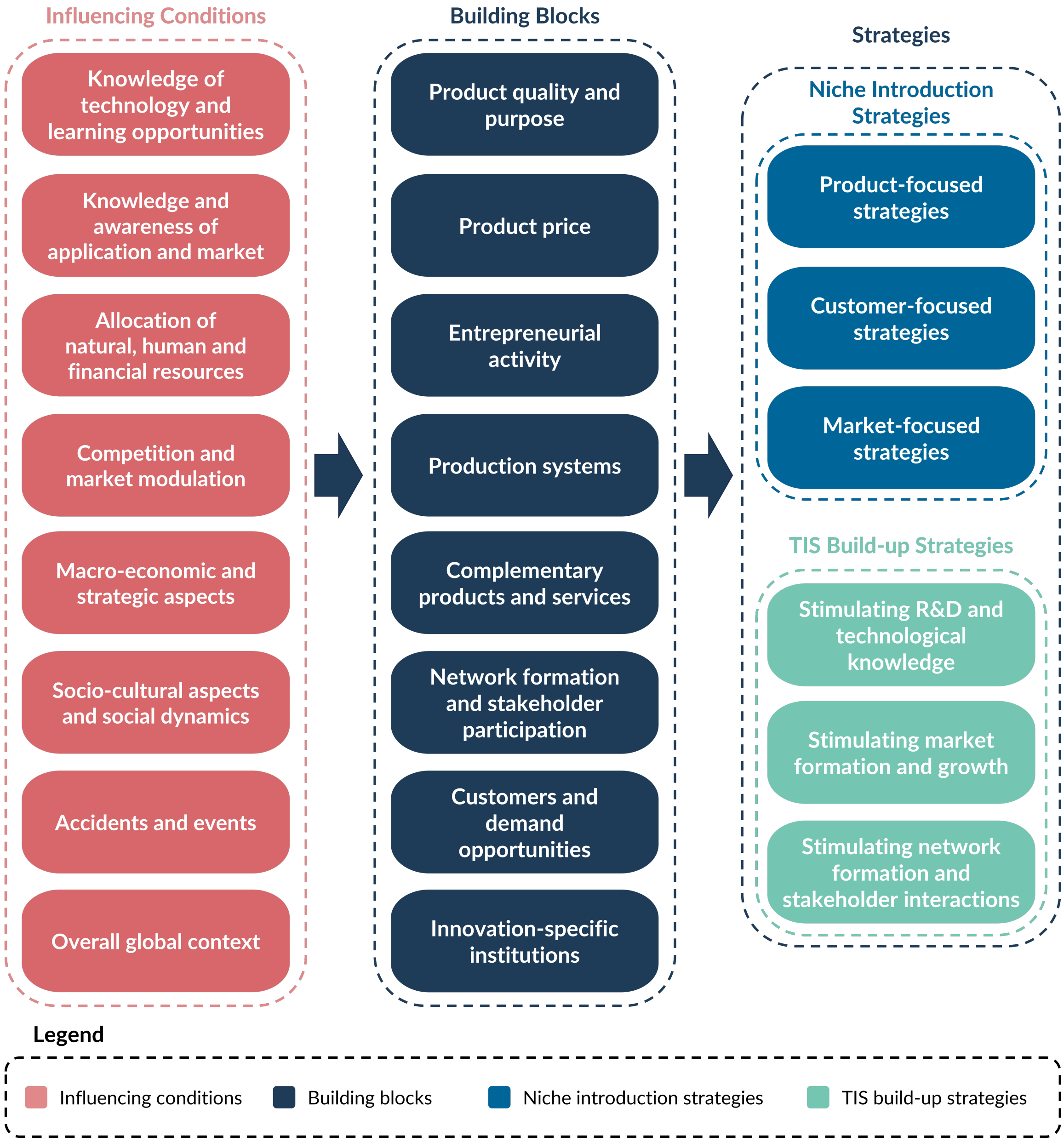

Figure 1: Shared framework influencing conditions, building blocks and categorisation of strategies

The second research approach is a case study in which the Shared framework is applied to V2G in the UK. Such a study is relevant because it helps understand the technology's context and derives niche introduction strategies and policy strategies to aid in its roll-out. Additionally, this study is useful as a starting point to test the adapted framework in a practical setting.

The richness of the in-depth case study shows that the TIS for V2G in the UK is still partially complete, with several barriers blocking the technology from being ready for large-scale diffusion. However, both niche introduction strategies and TIS build-up strategies can aid in combating these barriers within the TIS. The main identified barriers, along with their recommended strategies, are summarised in the following table with the name of each strategy showcased in *italics*.

Table 1: Main identified barriers for V2G in the UK with the recommended strategies to combat them

Main barrier	**Recommended strategies**	**Applicable by**
Low vehicle availability due to a lack of confidence in the business model and uncertainty of where charging architecture is heading (alternating current vs direct current).	*Provide standards and regulations* that require all EVs to have V2G capabilities by a certain date and provide clarity on which charging architecture should be employed.	Policymakers
	Provide guaranteed markets for V2G in which the benefit for each stakeholder involved with the technology is clearly delineated.	Policymakers
	Provide *incentives* to companies involved with V2G to make vehicle models and V2G-capable chargers available faster.	Policymakers
	Hire capable *human resources* with deep knowledge and understanding of the technology who may help build up the business case for V2G.	Companies
Interoperability issues between existing standards (CHAdeMO vs CCS) and across different devices and platforms.	*Provide standards and regulations* that appoint a ‘dominant’ charging standard and communication protocol and mandate open standards such as the OCPP to ensure interoperability across devices and platforms.	Policymakers
	Build networks and create *partnerships* to collaborate in the creation of high-quality standards that will solve relevant issues.	Companies
High prices of EVs in general and V2G-capable chargers.	Provide *incentives*, such as discounts, dynamic tariffs, tax breaks or subsidies to make the technology more financially accessible to customers.	Companies and policymakers
	Cross sell the product with home management systems or rooftop photovoltaic systems, which will make it more appealing and will likely see higher returns on investment when bundled.	Companies
	Provide *result-oriented contracting* that will reassure the customer of the expected payback period of their investment and will show them the expected benefits.	Companies
	Provide policies to incorporate externalities which will stimulate price parity between EVs and internal combustion engine vehicles.	Policymakers
	Have the option to *lease* V2G-capable EVs and chargers to eliminate high up-front costs.	Companies
	Market the technology to *top niche* customers who are willing to pay a premium to obtain the technology.	Companies
Complex and onerous requirements for V2G connection and market participation.	Provide simple and coherent *standards and regulations* that will enable V2G to access different revenue streams in a simple manner and eliminate double taxation.	Policymakers
	Lobby for V2G to be accepted in different markets and obtain standards and regulations that will benefit its adoption.	Companies
	Form *partnerships* to share knowledge and work together on the best ways to create useful rules, laws and regulations that will boost the technology.	Companies and policymakers

User concerns related to the complexity of interaction with the technology, battery degradation and range issues.	Have battery *leasing* or battery subscription services to allow customers to have their range needs met without unnecessary costs.	Companies
	Provide extended warranties on the EV's battery life that cover V2G application as an *incentive* to customers.	Companies
	Allow *trial runs* or simulations for customers to experience the technology first-hand.	Companies
	Provide demonstrations and information campaigns to *educate* customers on the benefits of the technology, the ways in which it may be used and reassure some of their concerns.	Companies and policymakers
	Market the technology to *lead users* who already know the advantages of V2G, are aware of how it works and how to use it, and are willing to accept its downsides.	Companies

While this work explores some important aspects for technological development and V2G in the UK, a lot of research may still be done in these areas. A few recommendations for further research are as follows:

- Analysing and refining the proposed set of indicators to evaluate the completeness of building blocks and influencing conditions, as well as research literature to support each indicator.
- Conducting an in-depth exploration of the dynamics and interactions between policy strategies and company strategies, describing how they may support or counteract each other.
- Studying multi-system interactions for technologies within sustainability transitions, such as V2G, which does not exist within a single sector but rather in the overlap of the energy and transport sectors.
- Analysing V2G's technological development with different technological boundaries than those given in this work to determine which barriers and drivers remain the same and which differ depending on system boundaries.

Along with providing relevant insights and recommendations for the introduction of V2G technology in the UK, this thesis contributes to academic literature by expanding on a relevant framework to study and drive technological development. While Ortt and Kamp developed a framework to formulate niche introduction strategies for companies, this work reconsiders BBs and ICs, adding more dimensions by including a policy-making perspective and different types of strategies. This contribution is portrayed in blue in Table 2

Table 2: Contributions made to academic literature in this work

Stakeholders	**Strategies**	
	Niche introduction strategies	TIS build-up strategies
Company perspective	Included in Ortt & Kamp's framework	**Contribution made in this work**
Policymaker perspective	**Contribution made in this work**	**Contribution made in this work**

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List of abbreviations

The next list contains the description of abbreviations used throughout this report.

Abbreviations

AC	Alternating current
BB	Building block
BEV	Battery electric vehicle
CCC	Climate Change Committee
CCS	Combined charging system
CO_2	Carbon dioxide
DC	Direct current
DER	Distributed energy resources
$DESNZ$	Department for Energy Security and Net Zero
DfT	Department for Transport
DNO	Distribution Network Operator
ESC	Electricity Settlements Company
ESO	Energy System Operator
EV	Electric vehicle
$EVSE$	Electric vehicle supply equipment
FIS	Functions of Innovations Systems
GHG	Greenhouse gas
$HREC$	Human Research Ethics Committee
IC	Influencing condition
ICE	Internal combustion engine
$LCCC$	Low Carbon Contracts Company
$OCPP$	Open Charge Point Protocol
OEM	Original equipment manufacturer
$Ofgem$	Office of Gas and Electricity Markets

$OZEV$ Office for Zero Emission Vehicles

$PHEV$ Plug-in hybrid electric vehicle

PV Photovoltaic

$R\&D$ Research and development

REA Renewable Energy Association

SET Sustainable Energy Technology

SNM Strategic Niche Management

SoC State of charge

$SSLR$ Semi-systematic literature review

TIP Transformative Innovation Policy

TIS Technological Innovation System

TSO Transmission System Operator

UK United Kingdom

$UKRI$ UK Research and Innovation

US United States

$V2B$ Vehicle-to-building

$V2G$ Vehicle-to-grid

$V2H$ Vehicle-to-home

$V2X$ Vehicle-to-everything

ZEV Zero emission vehicle

1 Introduction

In light of the current global climate crisis, many countries are racing towards a more sustainable future, particularly in the energy sector. For this purpose, several nations have been transitioning towards renewable energy sources such as photovoltaic (PV) systems and wind power. However, the main downside of these technologies is that their variability poses a barrier to continuous energy flow. This translates into an immense challenge for grid reliability (Lucas-Healey, Sturmberg, Ransan-Cooper, & Jones, 2022).

As a way to address grid reliability concerns, several different solutions have been proposed and are currently under development or investigation. Some solutions include energy storage, demand side response and grid interconnection throughout large expanses of land (Thomas et al., 2023). Nonetheless, these potential solutions have several intrinsic challenges such as high costs, technical difficulties and prohibitive requirements (European Environmental Agency, 2022).

A second critical issue to address for the energy transition is the decarbonisation of the transport sector since it is one of Europe's largest greenhouse gas (GHG) emitting sectors. Transport accounts for more than a quarter of Europe's GHG emissions (European Environment Agency, 2023). Particularly in the United Kingdom (UK), it was responsible for 26% of its total GHG emissions in 2021, according to the Government of the United Kingdom (2023). A shift towards electric vehicles (EVs) has become increasingly important to achieve climate goals in this sector.

Over the past five years, EVs have had a tremendous boom worldwide. Specifically, in the European market, they went from having less than 1% market share of new vehicle sales in 2018 to over 15% as of June 2023, according to the European Automobile Manufacturers' Association (ACEA, 2023a). A similar report by the same authority (ACEA, 2023b) shows that more than five million battery electric vehicles (BEVs) operate in Europe. Contributing to this growth are the policies introduced by the European Parliament (2023) and the UK Government (2021b), which state that starting in 2035, all new vehicles that come on the market should be emission-free. Although these policies were introduced to aid in reaching carbon neutrality in the transport sector by 2050, they will also succeed in accelerating EV adoption in the following decades.

With the rapid growth of the EV market, a new question presented itself: are current electricity distribution networks prepared to meet the energetic needs of charging all these vehicles? In several countries, the answer was found to be a resounding no (Ray, Kasturi, Patnaik, & Nayak, 2023). The question then turned to: how can EVs be assets instead of liabilities for the electricity grid?

These challenges stemming from both EV uptake and renewable intermittency have one common solution: vehicle-to-grid (V2G) bidirectional charging. V2G involves charging EVs when there is a surplus in energy and discharging them to assist the grid when there is congestion or when energy generation is scarce. Several benefits regarding V2G exist, among the most prominent are increased grid reliability, load balancing, peak shaving (Gschwendtner, Sinsel, & Stephan, 2021), voltage support, frequency regulation (Blair, Moran, & Fitzgerald, 2023), and integration of renewable energy (Lund & Kempton, 2008). This last benefit, in particular, is crucial to bolster the transition towards a more sustainable world.

This thesis aims to shed some light on the development and implementation of vehicle-to-grid in the UK and formulate strategies for both companies and policymakers to support its technological adoption. Utilising the Technological Innovation Systems (TIS) framework by Ortt and Kamp (2022), and aided by innovation policy literature, it analyses what drives and hinders the roll-out of this technology and what strategies could boost its uptake. This approach provides details on the dynamics of the UK's V2G market and sheds some light on possible explanations for the way it is developing to devise niche introduction strategies for companies and policy recommendations using a common framework.

1.1. Research gap

When looking for mentions of V2G within the specific context of the UK, few references were found to be related to the sociotechnical development, roll-out and adoption of the technology. Most of the existing literature about the UK pertains to the optimisation of V2G from the technological perspective, and only a few articles look into what drives and hinders the technology or how it is developing within a sociotechnical system. Furthermore, only one article (Meelen, Doody, & Schwanen, 2021) looks into possible avenues for up-scaling V2G technology in the UK, and even then, only focuses on the fleet market. As it stands, an important **knowledge gap exists in studying and formulating niche introduction strategies for V2G technology prior to large-scale diffusion and other strategies to accelerate its adoption.**

In addition, several studied papers highlight academic knowledge gaps regarding the implementation and adoption of V2G. Particularly, Earl and Fell (2019) conclude that while manufacturers recognise they play a role in the sociotechnical development of V2G technology and demand-side flexibility, more research is needed to understand how to achieve large-scale adoption. Furthermore, Sovacool, Axsen, and Kempton (2017) and Sovacool, Noel, Axsen, and Kempton (2018) mention that most studies regarding this technology to date focus on technical aspects of V2G and their potential to provide grid services; however, not on how the technology itself is developing, citing that *"These gaps create promising opportunities for future research [... another] substantial gap in the literature is how a large-scale transition to [V2G] can be achieved"*.

On a similar note, within the reviewed literature **policy recommendations for V2G adoption are noticeably absent**. Several papers applying a technological innovation system framework view a country's political situation as a factor to be studied employing the framework (Hacking, Pearson, & Eames, 2019). However, no paper was found in which policy strategy recommendations were derived from using the framework itself.

Papers using Technical Innovation System or Strategic Niche Management (SNM) frameworks tend to derive conclusions on how a market is forming and usually do not provide introduction strategies for the technology. However, in the rare cases in which they do, they are mostly issued towards innovation firms and not policymakers. Such is the case of the Ortt and Kamp TIS framework (Ortt & Kamp, 2022). This framework is conceptualised from a company perspective; while it includes aspects that are highly important for companies and will aid them in creating strategies, it may overlook aspects crucial for policymakers to derive their strategies. Additionally, the framework focuses mainly on niche introduction strategies, a sub-category of niche strategies, which by definition are company-focused (Ortt & Kamp, 2022).

Conversely, there is plenty of literature focused on innovation policy, and several approaches towards policy analysis exist, such as Transformative Innovation Policy (TIP) (Haddad & Bergek, 2023) and Mission-oriented Policy (Haddad et al., 2022). Nonetheless, these often fail to study the sociotechnical development of a technological innovation from a company perspective.

These two gaps highlight that companies and policymakers have different approaches while strategising or studying technological development and tend to navigate on separate maps. Innovation Management is employed by companies, and Innovation Systems is most commonly employed by policymakers. The lack of coordination and alignment between these crucial actors can directly impact the adoption of a technological innovation. Therefore, **this thesis contributes to the existing literature by creating a common framework to derive company strategies and policy recommendations parting from the application of the Ortt and Kamp TIS framework, adapted with input from innovation policy literature.**

A final gap encountered is the discussion of the overlap between the energy and transport sectors; Kanger et al. (2021) highlights the need to study multi-system interactions for innovations that are part of more than one system. EVs fall within this category, being a part of both the energy and transport systems and creating an entirely new technological system that is V2G. While this is a critical aspect to consider in further research, this work will not explore the dynamics between the systems but rather treat V2G as a single independent technological system.

After conducting an extensive literature review, presented in detail in chapter 3, it has been made clear that existing academic literature has focused on the technical feasibility of V2G technology and the development of the broader vehicle-to-everything (V2X) category. Nevertheless, there is an evident **academic knowledge gap regarding the sociotechnical development of V2G technology in the UK**. In particular regarding strategies for introducing and up-scaling V2G within the country and having a common framework for both policymakers and companies to derive strategies from.

1.2. Research questions

This work aims to complement the existing knowledge of the technology and the academic gap with the following research question:

What is the state of the Technological Innovation System for V2G in the UK, and which niche introduction strategies and policy strategies may be suitable for combating barriers within this TIS?

In order to answer it, the following sub-questions were formulated:

1. Who are the relevant stakeholders for V2G within the UK, and how are they connected?
2. How can the Ortt and Kamp framework be adapted to derive niche strategies for both companies and policymakers?
3. What is the status of each TIS building block for V2G in the UK?
4. Which influencing conditions are most predominant for each block, and do they act as drivers or barriers?
5. What type of niche introduction strategies may be suitable for companies?
6. What type of niche or TIS build-up strategies may be suitable for policymakers?

All of these questions are directly related to one of the introduced knowledge gaps, as observed in Table 1.1 below, and may be addressed by using one of the research approaches mentioned in chapter 2.

Table 1.1: Link between knowledge gaps and research questions

Knowledge gap	Related research questions
Limited research on V2G technological development in the UK	Who are the relevant stakeholders for V2G within the UK and how are they connected? What is the status of each TIS building block for V2G in the UK? Which influencing conditions are most predominant for each block, and do they act as drivers or barriers?
Different approaches to studying technological development between companies and policymakers	How can the Ortt and Kamp framework be adapted to derive policy strategies?
Missing framework that allows policymakers and companies to align strategies and combat an issue in a collaborative manner	How can the Ortt and Kamp framework be adapted to derive policy strategies? What type of niche introduction strategies may be suitable for companies? What type of niche or TIS build-up strategies may be suitable for policymakers?
No existing studies of strategies for introducing and upscaling V2G	What type of niche introduction strategies may be suitable for companies?
Absent policy recommendations for V2G adoption	What type of niche or TIS build-up strategies may be suitable for policymakers?

1.3. Relevance

Policymakers and companies are usually two of the most relevant stakeholders in the development of any technological innovation. However, they tend to have different ways of studying the innovation context and creating strategies to boost technological adoption. The **theoretical relevance of this thesis lies in the adaptation of the Ortt and Kamp TIS framework to derive policy recommendations and company strategies with the same framework** to create a more coordinated approach for technological roll-out.

On a **practical** level, this work provides **insight into the sociotechnical development of V2G technology in the UK**, as well as strategies for both companies and policymakers that may lead to a smoother introduction of V2G. This is relevant because **V2G technology remains under-explored from a sociotechnical perspective** and its wide-spread adoption (similar to that of the automobile in its time) is dependent on cooperation from several actors and integration of factors ranging from the economic to the technological and environmental.

This thesis also has **specific relevance for the Sustainable Energy Technology (SET)** curriculum. As one of its primary objectives is to bolster the transition towards sustainable energy, it is imperative to understand the progress of key technologies and the strategies required to encourage their adoption. This work is relevant for SET in three particular aspects.

First, **EVs are a sustainable energy technology crucial in decarbonising the transport sector** within the energy transition. However, the rapid growth in EV adoption could have severe negative impacts on grid stability if they only serve as loads and do not implement charge management. V2G is the key technology that may help to turn EVs from a potential risk to the grid into a valuable asset by managing charging schedules to times with high generation and low demand, and allowing discharge to the grid when generation is low and demand is high.

Second, **using V2G technology, EVs can provide energy storage services, with storage being one of the critical needs in a renewable-driven world**. One of the main barriers to renewable adoption worldwide is the downsides associated with the intermittency of renewable energy. V2G technology enables EVs to charge from the grid when renewable generation is high and would otherwise be 'wasted', and to feed energy into the grid when renewable generation is low, covering for demand. These functionalities help mitigate the intermittency of renewables.

Third, and most importantly, **V2G can significantly aid in the energy transition by providing flexibility and grid stabilisation services**, assisting in integrating renewable energy sources and decarbonising the electricity matrix. Apart from integrating renewables via storage, V2G can provide grid services currently supplied by peaking power plants, which are currently very carbon-intensive.

1.4. Thesis outline

The thesis will be presented in the following structure. First, chapter 2 introduces the research approach and methods employed to answer each research question. Next, chapter 3 presents the performed literature review and introduces the theoretical basis of the TIS framework and innovation policy elements. Subsequently, chapter 4 introduces the context of V2G in the UK to better understand the development of the technology. Next, in chapter 5, the TIS framework is adapted to include elements from innovation policy and to be able to derive policy strategies from its application. Chapter 6 then applies the adapted framework to the case of V2G in the UK while chapter 7 presents the derivation of strategies for both companies and policymakers. The results are then analysed and discussed in chapter 8. Finally, chapter 9 states the conclusions from the findings in all previous chapters, along with the recommendations derived from those conclusions.

2

Research approach and research methods

This chapter presents the research approach and methods followed throughout the work. Each research question is re-introduced with a brief explanation of the method followed to answer it. The overall research approach and its relevance are introduced in section 2.1, followed by the detailed research methods employed in section 2.2.

2.1. Research approach

The development of radically new technological innovations may be studied from a sociotechnical perspective through the use of well-developed and structured methods such as the Multi-Level Perspective developed by Geels (2002) or Hekkert's Functions of Innovation Systems (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). Two research approaches were taken to study this particular topic. The first consisted of theory development, parting from the conceptual TIS framework coined by Ortt and Kamp (2022), and the second consisted of a case study. A literature review and an extensive data-collection strategy supported both.

The literature review proved its significance in obtaining important conceptual information for the adaptation of the TIS framework in the theory development approach, and the evaluation of V2G for the case study. Data collection was also relevant for this work to assess the status of the building blocks and influencing conditions. For this purpose, a combination of desk research and interviews with experts were employed. Desk research involved studying academic literature and company reports, newsletters, etc. (so-called 'grey literature') to obtain the required background knowledge and a general sense of what the innovation system for V2G looks like in the UK. Semi-structured interviews with relevant experts were then conducted to validate the information obtained from the research and gain new insights to generate strategies.

The theoretical development approach consisted of expanding upon Ortt and Kamp's TIS framework by adapting it and including strategies for policymakers as well, drawing on concepts from innovation policy. This step proved relevant for this work since it provided a comprehensive approach to understanding and addressing barriers within the V2G TIS in the UK. Ortt and Kamp's framework analyses the state of the TIS from a company perspective by evaluating the status of seven fundamental building blocks (BBs) and seven influencing conditions (ICs) that may affect the building blocks, which were expanded to eight BBs and eight ICs in this work. Once the status of these two factors was clear, niche strategies were formulated to introduce the technology in a way that could circumvent or lower identified barriers (Ortt & Kamp, 2022). Both the TIS framework and core innovation policy concepts are introduced in further detail in chapter 3.

As a final approach, a case study was conducted. The relevance of such a consists of understanding the type of niche introduction strategies that could be suitable for V2G in the UK and exploring what policy strategies could be employed to aid in the roll-out of the technology. Additionally, this study proves useful as a starting point to test the adapted framework in a practical setting and formulate strategy suggestions for both companies and policymakers.

2.2. Research methods

Each one of the research sub-questions posed in chapter 1 requires different steps to be answered; however since most are exploratory questions, desk research is a good starting point for each of them.

The first sub-question, **who are the relevant stakeholders for V2G within the UK and how are they connected?**, explores the most important actors that may influence V2G adoption within the context of the UK. Understanding who these actors are and how they interact with each other is crucial for several of the following steps, namely identifying the role they play within BBs and ICs and for the derivation of policy and company strategies.

To best answer this sub-question, extensive desk research in both academic and grey literature proved sufficient. A semi-systematic literature review (SSLR) was conducted to explore the context of V2G in the UK aided by grey literature. A SSLR is a structured research approach focused on obtaining a comprehensive overview of a particular study field but does not contain all available studies, only a relevant selection (Snyder, 2019). The answer found during the research stage was also corroborated indirectly through the answers to interviews conducted in the following stages and contributed to the case study.

The second sub-question, **how can the Ortt and Kamp framework be adapted to derive policy strategies?**, aims to explore how the current framework needs to be modified to derive policy strategies. Since the Ortt and Kamp framework was designed from a company perspective to derive niche strategies, essential concepts for policymakers may be overlooked. Therefore, concepts of innovation policy needed to be integrated to derive policy strategies.

This sub-question was answered in two stages. The first stage consisted of gathering relevant concepts for innovation policy strategies which were missing from the current framework. These concepts were obtained by conducting a SSLR on innovation policy and analysing the information on barriers obtained from the SSLR on V2G in the UK.

The second stage incorporated these concepts into the framework through conceptual thinking. The original building blocks and influencing conditions were adapted to support a policymaker perspective as opposed to a company one, which was critical in the theory development approach. The adapted BBs and ICs were then used in the case study for V2G in the UK.

The third and fourth sub-questions, **what is the status of each TIS building block for V2G in the UK?** and **which influencing conditions are most predominant for each block and do they act as drivers or barriers?**, are focused on exploring the context that V2G is developing in and understanding how each of the influencing conditions drives or hinders the adoption of V2G. These were answered in two steps: desk research and interviews with industry experts.

The first step links to the SSLR conducted for sub-question one, which was also relevant for this sub-question. This literature review was complemented with research from grey literature and was fundamental to understanding the background and development of the building blocks and influencing conditions. Furthermore, good background information was required to come up with relevant questions and topics to discuss in the interviews.

The second step consisted of conducting interviews with industry experts who provided up-to-date details and insights from within the industry that were difficult to come across through other methods. The interviews were semi-structured and supported two main objectives. The first was to make sure that relevant topics within the field (and for the research) were addressed without creating biases. The second was to maintain enough flexibility to allow interviewees to talk about topics they consider the most relevant to the technology. Once concluded, the interviews were transcribed and coded to find patterns. The detailed interview questions and codes may be found in Appendix A.

Finally, the last two sub-questions are **what type of niche introduction strategies may be suitable for companies?** and **what type of niche or TIS build-up strategies may be suitable for policymakers?**. These two are the same questions posed with different stakeholders in mind; thus, they employ the same method, although each question was evaluated separately since the strategies recommended differ.

The answers to these questions required knowledge previously obtained about the relevant stakeholders, the adaptation of the TIS framework, the status of each building block, and the influencing condition related to that status. The connection between them determined the type of strategy that best worked for each barrier, for both companies and policymakers. Once there was a full understanding of the context in which V2G is developing, niche introduction strategies were explored in three stages.

First, all previously collected data was evaluated to determine which strategies were applicable by employing the adapted TIS framework. Second, existing strategies employed by companies and/or policymakers were identified from the desk research and interviews conducted. Third, using the previous knowledge, new potential strategies were conceptualised by applying the adapted TIS framework.

The answer to these six sub-questions provided the answer to the main research question: **what is the state of the Technical Innovation System (TIS) for V2G in the UK and which Niche Introduction Strategies may be suitable for combating barriers within this TIS?**

2.2.1. Interview protocol

General followed protocol

As part of conducting responsible research, TU Delft requires all studies involving Human Research Subjects to follow a specific procedure needing approval from the Human Research Ethics Committee (HREC). First, a project risk assessment was performed, identifying possible risks and vulnerabilities for participants with a mitigation plan for each identified risk. Next, a Data Management Plan and Informed Consent Form were drafted and submitted for approval before participants were approached.

Once the procedure was approved by the HREC, thorough research was conducted to assemble a list of experts in V2G in the UK. These experts were approached via LinkedIn or email if it was publicly available through their company web page. Once a participant agreed to be interviewed, the Informed Consent Form was shared with them to be reviewed and approved prior to the interview.

The interviews were conducted via Teams or Google Meet, according to participant preferences, recorded and transcribed. The transcript was shared with participants after the interviews to correct any factual errors and ensure they were comfortable with the level of anonymity provided. Finally, transcripts were coded and insights gained from them were incorporated into the work.

Profile of interviewed experts

The selection of participants was made after researching the technology's main stakeholders in the UK, trying to interview at least one person from each stakeholder group (presented in chapter 4) to gain different perspectives. When looking at companies and policymakers, a balance was required between people understanding the technology and its commercial landscape, as well as enough expertise and availability to participate. The profile for each participant is briefly summed up in Table 2.1.

Table 2.1: Profile of interviewed experts

Participant	**Stakeholder**	**Relevant expertise**
P1	Technology provider	Participant 1 has a directive job at a dedicated V2G solution provider. They are also doing work on the policy side to influence European policy to be able to support the technology and its economics.
P2	Technology provider	Participant 2 is the founder of an EV and commercial real estate company with more than ten years of experience in the EV sector and several years of working with V2G.
P3	Association	Participant 3 is an energy consultant in the UK, specialising in electricity distribution and transmission. They have conducted several relevant studies on vehicle-to-grid.
P4	End user	Participant 4 does advisory work related to EVs and V2G in the UK. They led an important V2G pilot project and have V2G technology at home.
P5	Energy service provider	Participant 5 works at an energy service providing company looking after market strategy for flexibility and how to generate value for flexibility assets, including V2G.
P6	Government	Participant 6 works at the ESO looking to strategically enable more flexibility, including V2G.
P7	Policymaker	Participant 7 is a sector lead at a government-funded innovation agency, currently working on V2X programmes under the DfT and DESNZ.

2.2.2. Digital tools used during research

To conduct desk research, no specific tools were used other than search engines such as *Scopus* and *Google Sholar* for academic literature and *Google* for grey literature. To present results, however, some diagrams and flow charts were useful to illustrate the findings better.

The interviews were carried out through *Microsoft Teams* and *Google Meet* and, after obtaining consent, recorded and transcribed using the integrated tools within the same app. Subsequently, interview transcripts were thoroughly checked and edited when needed to maintain clarity and anonymity. These transcripts were sent to the interviewees to ensure neutrality and correctness. Finally, they were coded using *Delve* coding software.

2.2.3. Research flow diagram

Figure 2.1 below shows the flow diagram followed for the research. Each step of the work is shown, along with its relevant inputs, corresponding research method and the chapter it relates to. The relevant research question(s) addressed in each step are also shown.

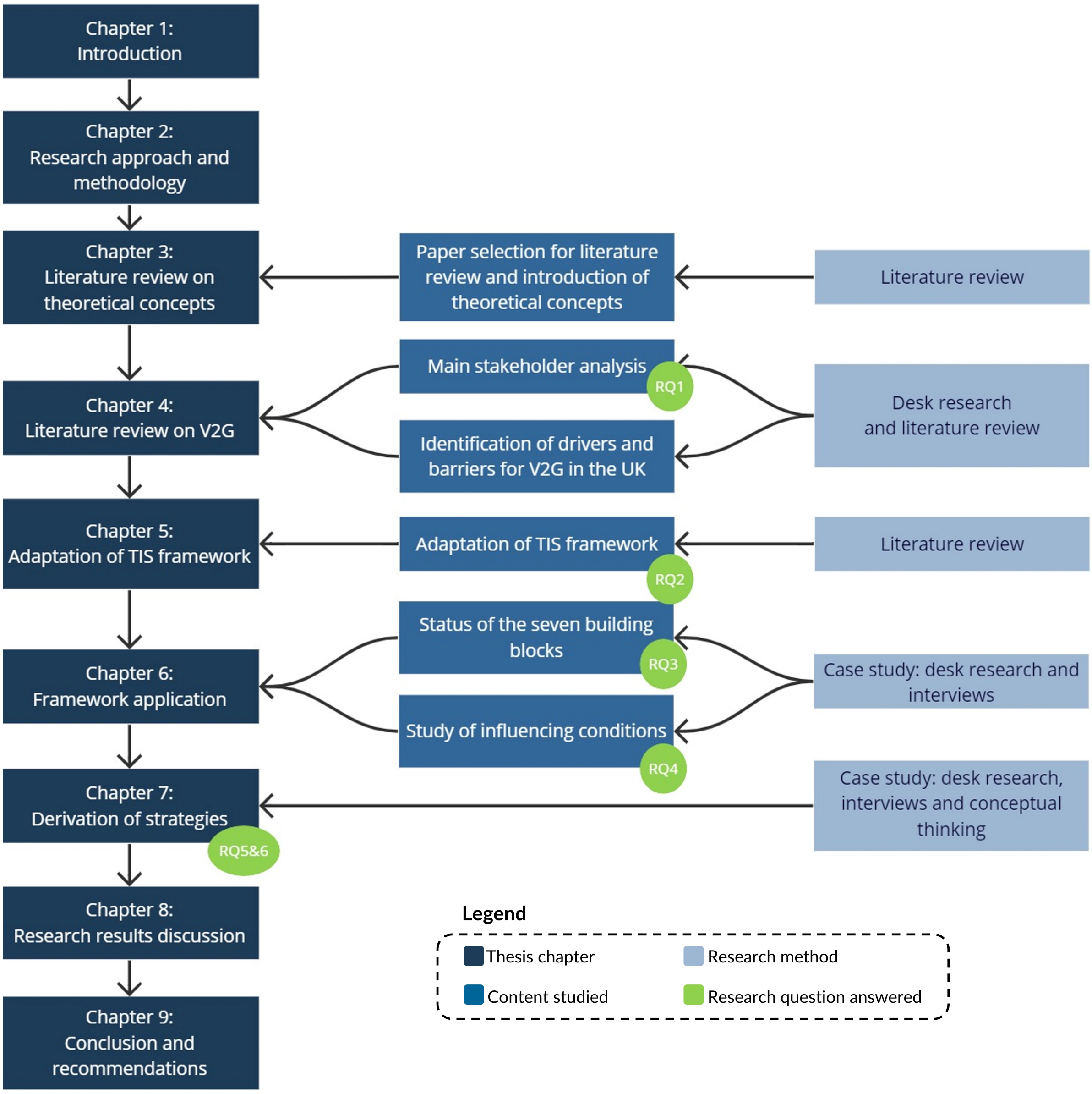

Figure 2.1: Thesis research flow diagram

3
Literature review

This chapter consists of a literature review conducted to gain knowledge on critical theoretical aspects for the development of the revised TIS framework and to understand the context of V2G technology to use during the case study. Furthermore, the literature review serves to gather information that will be relevant to interview questions and to establish the basis from which the second sub-question (**how can the Ortt and Kamp framework be adapted to derive policy strategies?**) will be answered.

The first section (3.1) briefly introduces how the search for relevant articles was made, followed by the explanation of the selection criteria and selected articles in section 3.2. Next, theoretical background concepts stemming from the literature review are presented in three sections. The Ortt and Kamp (2022) TIS framework and niche introduction strategies are introduced in section 3.3 and section 3.4, and relevant concepts for innovation policy and policy strategy are presented in section 3.5.

3.1. Article search process

To conduct a thorough but efficient literature review, several different combinations of the following keywords were used while searching for appropriate papers to study: "V2G", "vehicle to grid", "UK", "United Kingdom", "Britain", "sociotechnical", "niche", "niche strategies", "niche introduction strategies", "drivers", "barriers", "Technological Innovation System", "policy", "strategies" and "innovation policy".

The first eleven keywords were used to find a knowledge gap within the V2G technological context in the UK. In contrast, the last three were used to find a knowledge gap regarding the theoretical framework to be employed. The terms "Technological Innovation System" and "niche strategies" were used in both searches.

The review was conducted mainly using *Scopus*, while other sites such as *World of Science, Google Scholar* and *TU Delft's Library* were used for additional support. Some of the searches made include the following combinations:

- ("vehicle to grid" OR "V2G") AND ("United Kingdom" OR "UK") yielded 84 results, excluding those focused on mathematics and computer science; only 26 papers were left. However, several were focused on predicting and optimising grid management via V2G, and only seven were related to the sociotechnical development of V2G and its effects in different sectors.
- ("V2G" OR "vehicle to grid") AND ("United Kingdom" OR "UK" OR "Britain") AND ("drivers" OR "barriers" OR "drives" OR "hinders" OR "Technological Innovation System" OR "TIS") yielded nine

results, six of which overlapped with the previous 26.

- ("V2G" OR "vehicle to grid") AND ("niche") yielded 16 results, though none were related to the UK.
- "policy strateg*" AND ("V2G" OR "vehicle to grid") yielded 2 results.
- ("Technological Innovation Systems" OR "TIS") AND "policy strateg*" yielded 5 results.

Several of the topics included in the search overlap with each other in different ways. Figure 3.1 portrays the overlap of the main topics included during the literature search. The image on the left shows the number of papers resulting from the combination of the abovementioned terms. As may be observed, numbers for individual terms are not shown for this step since no individual terms were researched through a top-down approach.

The image on the right shows the number of articles selected for each topic with individual terms exhibiting a figure if articles related to it were selected. In this case, a search was made for specific relevant articles within some individual topics (bottom-up approach). The purpose was to find papers that reflect V2G development in countries with a similar context to the UK to gain some background on drivers and barriers for the technology and papers related to the theoretical aspect of the thesis, whether for innovation policy or TIS.

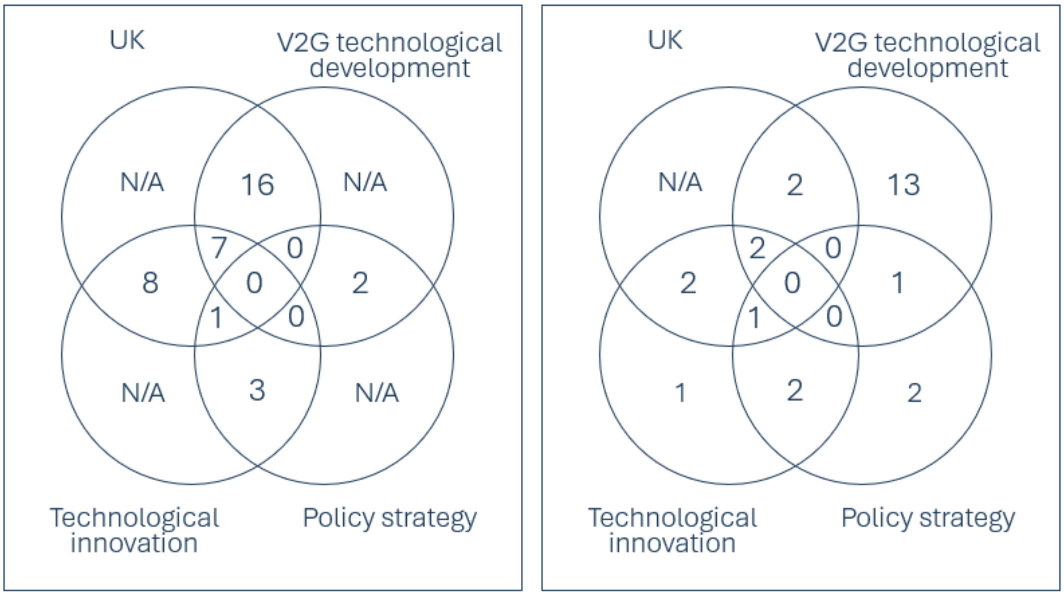

Figure 3.1: Overlap of topics within researched papers (left) and chosen papers for the literature review (right)

3.2. Article selection criteria

All the selected articles present some background knowledge or groundwork related to a topic within the scope of the proposed thesis. The main criteria are mentioned below, and the selected papers may be found in Table 3.1.

First and foremost, four articles were selected because they discussed the central studied technology and context: V2G in the UK, for instance, Meelen et al. (2021). To dive further into the technology, 14 other papers were selected. Most of them relate to V2G and its development or implementation, whether in a specific country or a general sense, as is the case for Noel, de Rubens, Kester, and Sovacool (2021), Lucas-Healey et al. (2022) and Adnan, Md Nordin, and Althawadi (2018), among others. One particular paper was found that serves a dual purpose since it studies V2G from a policy strategy perspective (Yannick, Marc, & Willett, 2014).

Meanwhile, three other papers were selected to explore related technologies in the UK: Foxon, Hammond, and Pearson (2010); Hacking et al. (2019); Weiller, Shang, and Mullen (2020). Even if these works are not explicitly related to V2G, they are essential to understand the context in which the technology is developing and relevant stakeholders in the energy and transport sectors in the UK.

Finally, five other works, among which are Haddad and Bergek (2023); Haddad et al. (2022); Ortt and Kamp (2022) were chosen from the theoretical point of view to study the TIS framework and literature related to innovation policy. These form the basis of developing an adapted framework to study the technology.

After the search was conducted, 26 papers were selected to be read and analysed. Table 3.1 summarises the most important information for each selected paper.

Table 3.1: Overview of selected papers

Year of Publication	**Author(s)**	**Title**	**Related Topic(s)**				
			V2G	UK	Tech innovation	Policy and transitions	Company strategies
2010	Foxon, T.J., Hammond, G.P. and Pearson, P.J.G.	Developing transition pathways for a low carbon electricity system in the UK	No	Yes	No	Yes	No
2013	Meelen, T. and Farla, J.	Towards an integrated framework for analysing sustainable innovation policy	No	No	Yes	Yes	No
2014	Yannick, P., Marc, P. and Willett, K.	A public policy strategies for electric vehicles and for vehicle to grid power	Yes	No	Yes	Yes	No
2017	Noel, L., Zarazu de Rubens, G., Kester, J. and Sovacool, B.	Leveraging user-based innovation in vehicle-to-X and vehicle-to-grid adoption: A Nordic case study	Yes	No	Yes	Yes	Yes

2017	Sovacool, B.K.; Axsen, J. and Kempton, W.	The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda	Yes	No	Yes	No	Yes
2018	Sovacool, B.K.; Noel, L.; Axsen, J. and Kempton, W.	The neglected social dimensions to a vehicle-to-grid (V2G) transition: a critical and systematic review	Yes	No	No	Yes	No
2018	Adnan, N.; Nordin, S. M. and Althawadi, O. M.	Barriers Towards Widespread Adoption of V2G Technology in Smart Grid Environment: From Laboratories to Commercialization	Yes	No	Yes	Yes	No
2018	Høj , J. C. M. L.; Juhl, L. T. and Lindegaard, S. B.	V2G—An Economic Gamechanger in E-Mobility?	Yes	No	No	Yes	No
2019	Earl, J. and Fell, M. J.	Electric vehicle manufacturers' perceptions of the market potential for demand-side flexibility using electric vehicles in the United Kingdom	Yes	Yes	No	No	Yes
2019	Hacking, N.; Pearson, P. and Eames, M.	Mapping innovation and diffusion of hydrogen fuel cell technologies: Evidence from the UK's hydrogen fuel cell technological innovation system, 1954-2012	No	Yes	Yes	Yes	No

2019	Roberts, M. and Geels, F.W.	Conditions and intervention strategies for the deliberate acceleration of sociotechnical transitions: lessons from a comparative multi-level analysis of two historical case studies in Dutch and Danish heating	No	No	Yes	Yes	No
2020	Thompson, A.W. and Perez, Y.	Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications	Yes	No	Yes	Yes	No
2020	Weiller, C.; Shang, A.T. and Mullen, P.	Market Design for Electric Vehicles	No	Yes	Yes	No	Yes
2020	Aunedi, M. and Strbac, G.	Whole-system Benefits of Vehicle-to-Grid Services from Electric Vehicle Fleets	Yes	Yes	No	No	No
2021	Gschwendtner, C.; Sinsel, S.R. and Stephan, A.	Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges	Yes	No	Yes	No	No
2021	Meelen, T.; Doody, B. and Schwanen, T.	Vehicle-to-Grid in the UK fleet market: An analysis of upscaling potential in a changing environment	Yes	Yes	Yes	Yes	Yes
2021	Zagrajek, K., Paska, J., Sosnowski, Ł., Gobosz, K., Wróblewski, K.	Framework for the introduction of vehicle-to-grid technology into the Polish electricity market	Yes	No	Yes	No	Yes

2021	van Heuveln, K.; Ghotge, R.; Annema, J. A.; van Bergen, E.; van Wee, B. and Pesch, U.	Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands	Yes	No	Yes	Yes	No
2022	Lucas-Healy, K.; Sturmberg, B. C. P.; Ransan-Cooper, H. and Jones, L.	Examining the vehicle-to-grid niche in Australia through the lens of a trial project	Yes	No	Yes	No	Yes
2022	Haddad, C. R.; Nakic, V.; and Bergek, A. and Hellsmark, H.	Transformative innovation policy: A systematic review	No	No	Yes	Yes	No
2022	Ortt, J. R. and Kamp, L. M.	A technological innovation system framework to formulate niche introduction strategies for companies prior to large-scale diffusion	No	No	Yes	Yes	Yes
2023	Li, S., Zhao, P., Gu, C., Li, J. and Cheng, S.	Integrating Incentive Factors in the Optimization for Bidirectional Charging of Electric Vehicles	Yes	Yes	No	Yes	No
2023	Haddad, C. R. and Bergek, A.	Towards an integrated framework for evaluating transformative innovation policy	No	No	No	Yes	No
2023	Bondalapati, S.R., Bhukya, B.N., Anjaneyulu, G.V.P., Ravindra, M. and Chandra, B.S.	Bidirectional Power Flow Between Solar-Integrated Grid To Vehicle, Vehicle To Grid, And Vehicle To Home	Yes	No	Yes	No	No

2023	Rehman, M.A., Numan, M., Tahir, H., Khan, M.W. and Iftikhar, M.Z.	A comprehensive overview of vehicle to everything (V2X) technology for sustainable EV adoption	Yes	No	No	Yes	No
2023	Saxena, S.; Farag, H. E. Z.; St. Hilarie, L. and Brookson, A.	A Techno-Social Approach to Unlocking Vehicle to Everything (V2X) Integration: A Real-World Demonstration	Yes	No	Yes	Yes	Yes

While several of the selected papers touch on the subject of sociotechnical analysis of V2G, only a few explore it in relation to niche applications (Lucas-Healey et al., 2022; Noel et al., 2021). Furthermore, when looking for "niche introduction strategies", only one paper by (Ortt & Kamp, 2022) exists, and it is not applied to the case of V2G. This lack of literature on the subject points to a significant knowledge **gap in regards to studying and formulating niche introduction strategies for V2G technology** prior to large-scale diffusion.

Moreover, when looking for V2G within the specific context of the UK, only a few papers were found to be related to the development of the technology. Most of the existing literature for the context of the UK talks about the optimisation of V2G from the technological perspective; only a small selection delves into barriers and drivers for the technology and its sociotechnical development, with only one paper (Meelen et al., 2021) touching on the up-scaling of V2G in the UK, and only focuses on the fleet market. This highlights a **gap in studying the sociotechnical development of V2G in the UK**.

Within the reviewed literature, **policy recommendations for V2G adoption in the UK are also noticeably absent**. While some papers have applied a TIS framework to study V2G and other technologies in the UK (Hacking et al., 2019), none have derived policy recommendations from its application.

Further, the Ortt and Kamp TIS framework (Ortt & Kamp, 2022) is conceptualised from a company perspective; while it includes aspects that are highly important for companies in creating strategies, it overlooks aspects that are crucial for policymakers to derive their strategies. Conversely, plenty of literature focuses on innovation policy, and several approaches towards policy analysis exist, such as those in Haddad and Bergek (2023) and Kivimaa and Kern (2016). Nonetheless, these do not study the development of a technological innovation from a company perspective.

While there is plenty of literature that studies strategies for both companies (Ortt & Kamp, 2022; Ortt, Kamp, Bruinsma, & Vintila, 2015; Ortt, Langely, & Pals, 2013) and policymakers (Haddad et al., 2022; Kivimaa & Kern, 2016; Rogge & Reichardt, 2016) separately, there is a **lack of literature that coordinates and aligns these two crucial actors** for technological development. Therefore, a knowledge **gap is also found in a missing common framework to study technological development and derive company strategies and policy recommendations.**

3.3. Theoretical introduction of TIS framework

Many authors mention Innovation Systems throughout literature with several different definitions for the concept. However, most of them agree that Innovations Systems include a collection of actors, social and economic structures and learning processes surrounding an innovation (Kamp, 2002). This concept was then adapted for cases consisting of *technological innovations*. The difference between an Innovation System and a Technological Innovation System (TIS) is that a TIS is bound by a technology rather than a geographical location or institution (Negro, Kamp, & Vasseur, 2009).

Throughout the years, a number of frameworks for studying innovations using a TIS perspective have been developed. Each framework has a particular objective in mind, such as the Functions of Innovation Systems framework, which is an analytical approach used to examine an innovation in a certain niche within a designated geographical area, first introduced by Jacobsson and Johnson (2000). This thesis will first study and then expand upon the TIS framework developed by Ortt and Kamp (2022), introduced in subsection 3.3.1.

3.3.1. Ortt and Kamp Framework

Ortt and Kamp (2022) introduce *"a technological innovation system framework to formulate niche introduction strategies for companies prior to large-scale diffusion"*. This framework is designed to identify the most relevant actors and factors within a sociotechnical system, study their influence on technological development of an innovation and formulate niche strategies to introduce the technology, all from a company perspective.

The aim is to help formulate strategies for the so-called 'adaptation stage'. The adaptation stage is the period between the moment when an innovation is first introduced and the moment when it reaches large-scale diffusion. This adaptation period can span years to decades and relies on several actors and conditions to drive the technological development (Ortt & Kamp, 2022).

The framework consists of seven building blocks that make up the TIS and seven influencing conditions that affect the building blocks. The identified BBs and ICs from the framework are enlisted and further explained below:

Building blocks

1. Product performance and quality
2. Product price
3. Production system
4. Complementary products and services
5. Network formation and coordination
6. Customers
7. Innovation-specific institutions

Influencing conditions

1. Knowledge and awareness of technology
2. Knowledge and awareness of application and market
3. Natural, human and financial resources
4. Competition
5. Macro-economic and strategic aspects
6. Socio-cultural aspects
7. Accidents and events

BBs are the primary units that make up the TIS and must be evaluated before deciding which niche introduction strategies to implement. The BBs represent social, economic, technological and institutional factors that may become barriers or drivers to the diffusion of the innovation. The definition of each BB as introduced by Ortt and Kamp (2022) is presented below.

Building blocks

1. ***Product performance and quality*** refers to the technology itself. An innovation must have sufficiently good performance and quality compared to competing products to foster its adoption. A barrier is formed if it is not viewed as a viable alternative due to poor quality or performance.
2. ***Product price*** refers to the cost, time and effort of acquisition of the innovation. Generally speaking, innovations tend to have very high prices compared to alternatives when they are first introduced, which may become a barrier for their diffusion.
3. ***Production systems*** are essential to be able to manufacture and distribute large quantities of an innovation with high quality. Initially, production systems signify a large investment of resources (time and money) and may have several inefficiencies that hamper the large-scale diffusion of the technology. However, as companies progress through the learning curve, production systems become more efficient and thus more competitive, fostering technological adoption.
4. ***Complementary products and services*** should be in place and well-coordinated to support the diffusion of the innovation in several aspects. Development, distribution, maintenance and disposal services are just a few examples of complementary services needed in the large-scale diffusion of an innovation. In this regard, companies providing complementary products and services should have aligned strategies to bolster technological adoption.
5. ***Network formation and coordination*** refers to the interaction and alignment between all the actors involved in the supply chain (suppliers, producers, distributors, complementary service providers). All these actors must be active and coordinated (i.e., willing to collaborate and share a vision). Missing actors within the network and/or a lack of coordination between actors form barriers to the diffusion of the innovation.
6. ***Customers*** are essential for a TIS since they are the ones that carry out the actual diffusion of the technology. Customers are first identified as 'potential customers' because the innovation will solve some of their problems or because they will largely benefit from its use. Potential customers need to be aware of the innovation and its benefits over other products and have the means and willingness to acquire and use it to become actual customers. If one or several of these characteristics are unmet, a barrier to technological diffusion is formed.
7. ***Innovation-specific institutions*** refer to *"formal and informal rules such as government policies, laws, standards and regulations"* (Ortt & Kamp, 2022) that surround the innovation. These institutions have the power to drive diffusion by providing a stable and supportive environment or hampering it if there is a lack of consistency that leads to distrust from relevant actors.

In their paper, Ortt and Kamp (2022) argue that an innovation cannot surpass the adaptation stage and go into large-scale diffusion if one or more of the BBs are missing, incomplete or incompatible with each other. These BBs provide information on the technological niche and the barriers and drivers that exist for large-scale diffusion of the technological innovation.

However, knowing what barriers are causing a BB to be incomplete is often not enough to address them. An understanding of the root causes of these barriers needs to exist in order to combat them. This is where the ICs come in. ICs provide information on the source of the barriers, which is crucial when devising the type and timing of niche introduction strategies. The definition for each IC and the way in which it influences the formation of BBs is presented below.

Influencing conditions

1. ***Knowledge and awareness of technology*** involves understanding the technological principles of TIS components (fundamental knowledge) and the requirements to carry out the innovation throughout its stages of development, production, maintenance and repair (applied knowledge). This knowledge may be obtained through learning by searching, learning by doing and learning by using (Kamp, 2002). Learning by searching is done in research and development facilities, while learning by doing takes place when companies produce the technology. Finally, learning by using happens when the technology is tested. Incorrect or incomplete knowledge from actors may negatively influence several of the BBs within the TIS.
2. ***Knowledge and awareness of application and market*** refers to the understanding of the general conditions of the target market and the application of the technological innovation. Some of these conditions include the market structure, relevant actors and the way in which the technology may be applied. This knowledge, too, may be obtained through the ways of learning mentioned above with the addition of learning by interacting. This last way of learning refers to how information exchanges are sustained between the relevant actors (Kamp, 2002). Lack of knowledge regarding market conditions or lack of awareness of its possible applications may result in TIS BB formation being hampered.
3. ***Natural, human and financial resources*** are necessary for successful technological implementation. First, natural resources are the main input in creating the product itself and related complementary products. Next, human capital is required to partake throughout the entire innovation process; human resources need to have sufficient knowledge, competences, and mobilisation capacity to be supportive of technological diffusion. Finally, financial resources are of utmost importance to drive technological development and may come from different actors within the network. If natural, financial or human resources are missing, several BBs may result incomplete or missing altogether.
4. ***Competition*** refers to all other existing products or innovations that may substitute or replace the innovation. Competition may be found amongst new products based on different technologies or a product based on different versions of the same technology. If competing alternatives have different production systems (with different components, complementary products and services), then parallel networks of actors may develop, creating a chaotic environment that is not conducive to TIS formation. However, if competing alternatives have similar components, complementary products and production systems, one option may prevent the other from meeting its requirements and thus also block the BBs from properly forming.
5. ***Macro-economic and strategic aspects*** are relevant to consider when studying the formation of a TIS. They include market formation and structure, general economic conditions within the context and the current way of conducting business. When macro-economic conditions are positive (i.e., economic growth), then this condition acts as an enabler for technological diffusion. On the other hand, if these conditions are adverse (i.e., an economic recession), then this condition may act as a barrier to TIS formation.
6. ***Socio-cultural aspects*** include all the norms and values that the network of actors, as a society, have. Most of them are unwritten and tend to fluctuate as cultural change occurs over time. Though less formal than laws or regulations, these aspects may sometimes have an even more

significant impact on the formation of building blocks since they stem from ingrained values and behaviours in the actors.

7. ***Accidents and events*** refer to unplanned incidents that occur within the TIS or outside of it but which may have a direct impact on the formation of its BBs and how an innovation diffuses. Some examples include wars, natural disasters or even new inventions. The nature of an event (negative or positive) does not directly dictate the way in which it will influence the innovation. Negative events, such as wars, may actually drive the formation of one or several BBs. In contrast, positive events, such as the creation of a new product, may render the innovation obsolete and thus block its development.

Different influencing conditions might influence different building blocks; often, several conditions may affect a single block at once. For this reason, Ortt and Kamp (2022) portray the relationship of ICs to BBs with a single arrow, as may be observed in Figure 3.2 below.

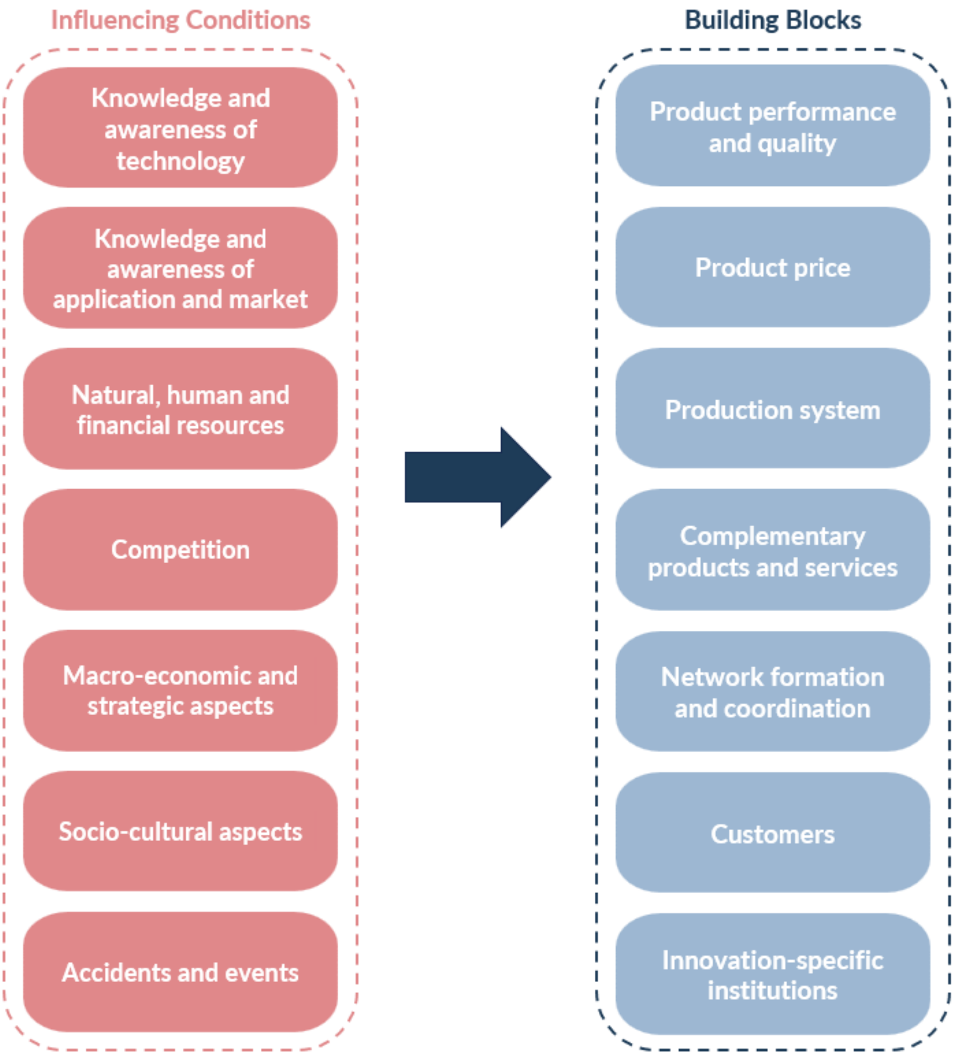

Figure 3.2: Graphic overview of the TIS framework adapted from Ortt and Kamp (2022)

3.4. Introduction of niche strategies

A different approach to studying technological development comes from Strategic Niche Management (SNM). Its focus is mainly on technological niches, where radical innovations take place. SNM's main assumption is that the creation of protected spaces for specific applications (or niches) can leverage the development of sustainable technology innovations Schot and Geels (2008).

In the initial stages of technological development, there are no established markets for the technology to diffuse across, nor are there defined user preferences. Niches are therefore essential for transitions (Geels, 2002, 2011) since the selection criteria, rules, and problems for radical innovations strongly differ from those for existing markets (Geels, 2011).

Ortt (2012) defines niche strategies as *"a deliberate choice to introduce a radically new high-tech product in particular types of market niches"*. These strategies focus on catering to the unique needs, preferences, and characteristics of the specific niche. Throughout literature, two broad categories of niche strategies are identified: niche accumulation strategies and niche hybridisation strategies (Ortt, 2012). Niche hybridisation refers to combining existing technology with the radically new innovation into a single product, while niche accumulation refers to introducing the innovation in several niches outside of the primary market (Ortt, 2012). Both of these strategies are used to circumvent competition from the mature market.

In later works, Ortt et al. (2013) introduce ten different types of niche strategies for radically new innovations:

1. ***Demo, experiment and develop niche strategy*** is employed when the technology does not have sufficient quality yet and, therefore, is used to demonstrate to the public in an experimental or controlled environment to enable further research.
2. ***Top niche strategy*** may be employed when the price of the technology is still too high due to a lack of knowledge. In this strategy, the innovation is marketed to top-end customers and made to order in small quantities.
3. ***Subsidised niche strategy*** is employed in cases similar to the previous one, where the price is affected by lack of knowledge or resources. In this case, the government may subsidise the product if its use by a specific set of users is considered 'societally relevant or important' (Ortt et al., 2015).
4. ***Redesign niche strategy*** also applies for price barriers influenced by lack of knowledge or resources or by diffusion being hampered due to socio-cultural aspects. The redesign niche strategy suggests introducing the product as a simpler version to lower the price or exploring a different application to the original one, where socio-cultural aspects are less likely to be a barrier.
5. ***Dedicated system or stand-alone niche strategy*** refers to cases when the technology is introduced as a 'stand-alone' because a lack of knowledge affects complementary products and services.
6. ***Hybridisation or adaptor niche strategy*** refers to the previously mentioned strategy where new technology is used alongside old technology in a hybrid product. This enables the re-utilisation of complementary products and services and thus is employed when a lack of knowledge affects their availability.
7. ***Educate niche strategy*** may also be employed when a lack of knowledge of the technology

affects its availability. This strategy consists of introducing pilot projects as a means to educate suppliers or customers on the technology and its benefits.

8. ***Geographic niche strategy*** consists of adopting the technological innovation in a different geographical area to the intended one due to a lack of resources, knowledge of the technology or socio-cultural aspects that impede its adoption.
9. ***Lead user niche strategy*** refers to marketing the innovation to early adopters of a technology, which may then collaborate in the development and diffusion of the product. This strategy may be employed when knowledge of the application of the innovation is lacking or when socio-cultural or macro-economic aspects block technological development.
10. ***Explore multiple markets niche strategy*** can be adopted when knowledge of the application of the technology is missing. It consists of exploring various possible applications for the product stemming from the visibility of its first application.

Schulz (2019), Dwisatyawati (2022) and Nandigam (2023) later expanded on these ten strategies and, based on works from several other authors, created a more comprehensive list of strategies. Dwisatyawati went as far as categorising them into niche introduction strategies and TIS build-up strategies.

TIS build-up strategies differ from niche introduction strategies in the sense that their main goal is not necessarily to introduce or market the technology but rather to build the system around it, as their name suggests. These strategies aim to improve the TIS so that it will be ready for large-scale diffusion (Dwisatyawati, 2022).

Additionally, in 't Veld (2020) compiled a list of strategies to be employed by governments from several different works in literature. While mainly focused on strategies for developing countries, some of the strategies in in 't Veld's work may also be applicable to the UK. The following table shows a compilation of all the strategies by the above-mentioned authors that are considered relevant to this work. The full description for these strategies is found in Appendix B.

Table 3.2: TIS build up and niche introduction strategies for innovations

Strategy	**Stakeholder**	**Source**	**Niche introduction**	**TIS build-up**
Technological R&D strategy	Companies and policymakers	Dwisatyawati (2022); in 't Veld (2020); Schulz (2019)		x
Human resource management strategy	Companies	Dwisatyawati (2022); Schulz (2019)		x
Internal knowledge sharing strategy	Companies	Dwisatyawati (2022); Schulz (2019)		x
Partnership strategy	Companies and policymakers	Dwisatyawati (2022); Schulz (2019)		x

Finance sourcing strategy	Companies	Dwisatyawati (2022); Schulz (2019)		x
Lobbying strategy	Companies and policymakers	Dwisatyawati (2022); Schulz (2019)		x
Changing behaviour strategy	Companies	Dwisatyawati (2022); Schulz (2019)		x
Crowd-sourcing strategy	Companies and policymakers	Dwisatyawati (2022); Schulz (2019)		x
Leasing strategy	Companies	Dwisatyawati (2022); Schulz (2019)	x	
Campaign funding strategy	Companies and policymakers	Dwisatyawati (2022); Schulz (2019)		x
Network building strategy	Companies	Dwisatyawati (2022)		x
Get specified strategy	Companies	Dwisatyawati (2022)		x
Complementary products and services strategy	Companies	Dwisatyawati (2022)		x
Cross-selling strategy	Companies	Dwisatyawati (2022)		x
Existing social network strategy	Companies	Dwisatyawati (2022)	x	x
Result-oriented contracting strategy	Companies	Dwisatyawati (2022)	x	
Turnkey product strategy	Companies	Dwisatyawati (2022)	x	
Incentives strategy	Companies and policymakers	Dwisatyawati (2022); in 't Veld (2020)	x	x
Local implementation strategy	Companies	Dwisatyawati (2022)	x	
Market positioning strategy	Companies	Dwisatyawati (2022)	x	
In-house network strategy	Companies	Dwisatyawati (2022)	x	x
Preannouncing strategy	Companies	Dwisatyawati (2022)	x	x
Pilot project strategy	Companies and policymakers	in 't Veld (2020); Schulz (2019)	x	x
Provide guaranteed markets strategy	policymakers	in 't Veld (2020)		x
Investments strategy	policymakers	in 't Veld (2020)		x

Provide standards and regulations strategy	policymakers	in ’t Veld (2020)		x
Provide policies to incorporate externalities strategy	policymakers	in ’t Veld (2020)		x
Public sector participation strategy	Companies and policymakers	in ’t Veld (2020)	x	x

As may be observed in the previous table, some strategies may be considered as both niche introduction strategies or TIS build-up strategies. This depends on who is using the strategy and the purpose that the strategy is being used for. For instance, when companies use the *incentives strategy* by providing gifts or free samples to get customers to buy the product, then it may be considered a niche strategy. Conversely, when policymakers use the same strategy via subsidies or tax breaks to get companies to invest in research and development (R&D) for specific technologies, then it may be considered a TIS build-up strategy.

3.4.1. Strategy clean-up

All the strategies mentioned in the work by Table 3.2, as well as Ortt et al., can be condensed by integrating some strategies with similar descriptions or purposes. The consolidations proposed in this work are as follows.

1. *Local implementation strategy* may be consolidated into the *geographic niche strategy* since it consists of making a product’s specifications suitable to a specific geographical area (i.e. local markets) in which a product may be launched.
2. Market research is an important part of the *explore multiple markets strategy*; therefore, the *market research strategy* may be integrated into it.
3. The *pilot project strategy* is already included in the definition of the *educate niche strategy*; therefore, having a specific pilot project strategy would be redundant.
4. The *subsidised niche strategy* may be incorporated into the *incentives strategy*. A subsidy is a type of incentive that is included in the description of the broader strategy.
5. The aim of the *complementary products and services strategy* is already accounted for in other strategies such as the *investment strategy* and the *cross-selling strategy*. Therefore, this strategy may be omitted.
6. Both the *in-house network strategy* and *existing social networks strategy* make use of a company’s network to market and sell a product. Therefore, an overall ***‘existing networks strategy’*** is proposed to encompass them with the following definition: ***optimising in-house resources such as sales channels, marketing and sales departments, the current customer base and relationships with relevant actors to promote the sale and diffusion of the technology, rather than resorting to a third party to do so.***
7. The *get specified niche strategy* talks about mentioning a product in specification sheets; however, it may also be talked about by influencing people as described in the *changing behaviour* strategy

and, therefore, is consolidated into it.

The complete list of strategies after clean-up is then:

1. *Demo, experiment and develop niche strategy*
2. *Top niche strategy*
3. *Redesign niche strategy*
4. *Dedicated system or stand-alone niche strategy*
5. *Hybridisation or adaptor niche strategy*
6. *Educate niche strategy*
7. *Geographic niche strategy*
8. *Lead user niche strategy*
9. *Explore multiple markets niche strategy*
10. *Public sector participation strategy*
11. *Incentives strategy*
12. *Leasing strategy*
13. *Result-oriented contracting strategy*
14. *Turnkey product strategy*
15. *Technological R&D strategy*
16. *Human resource management strategy*
17. *Internal knowledge sharing strategy*
18. *Partnership strategy*
19. *Finance sourcing strategy*
20. *Lobbying strategy*
21. *Changing behaviour strategy*
22. *Crowd-sourcing strategy*
23. *Campaign funding strategy*
24. *Network building strategy*
25. *Cross-selling strategy*
26. *Existing networks strategy*
27. *Preannouncing strategy*
28. *Provide guaranteed markets strategy*
29. *Investments strategy*
30. *Provide standards and regulations strategy*
31. *Provide policies to incorporate externalities strategy*

3.5. Innovation Policy concepts

Formulating innovation policy strategies involves various key concepts derived from academic research and practical insights. Some of these concepts include the stages of the policy-making process, policy instruments and their purpose, policy instrument design features, and challenges for policy-making. All of these concepts are enlisted below.

3.5.1. Stages of the policy-making process

The policy-making process consists of six main stages, which are considered to be cyclical: agenda setting, policy formulation, legitimation, implementation, monitoring and evaluation, and policy learning (Haddad et al., 2022; Rogge & Reichardt, 2016). Although the focus of this work is largely on the three first stages, it is important to consider all of them together since the later stages (from a previous cycle) will have an impact on the early stages. These stages are presented as a policy cycle, illustrated in Figure 3.3.

In the first stage, the problems that need attention from policymakers are identified. Subsequently, policymakers gather information on these issues and prioritise them. This stage also involves the definition of the policy aim, domain and logic and is called **agenda setting** (Haddad et al., 2022).

The second stage is **policy formulation**. Once an agenda has been set, solutions to the problem need to be explored. Policy instruments come into play in this stage since they are tools that policymakers may turn to in order to formulate policies (Rogge & Reichardt, 2016). When selecting which policy instruments to implement, several factors play a role, such as the maturity of the technology, the context in which it is developing and how many resources are available (Haddad et al., 2022).

The third stage is not included in several models of the policy-making process, however, it is believed to be a crucial one in this work since it is also an important function in TIS literature (Hekkert et al., 2007). Creation of legitimacy or **legitimation** consists in choosing a course of action that will be accepted and supported by the relevant actors (Haddad et al., 2022). The creation of legitimacy usually occurs through stakeholder interaction, which is why stakeholder interaction and involvement are critical for the policy-making process.

In the fourth stage, the policy instruments are put into effect and enforced; this is usually referred to as the **policy implementation** stage (Rogge & Reichardt, 2016). For a policy to be successfully implemented, it requires active involvement of all relevant stakeholders, active dialogue to smooth over any conflicting interests and an implementation style that is consistent with the policy goals (Haddad et al., 2022; Rogge & Reichardt, 2016). Furthermore, this stage also includes another important TIS function: resource mobilisation. Policy implementation requires large amounts of human and financial resources to be mobilised (Frank, Jacob, & Quitzow, 2020).

Finally, the fifth and sixth stages go hand in hand. The **monitoring and evaluation** stage studies the perceived success that a certain policy or policy mix has, and it feeds directly into the **policy learning** stage. This last stage refers to synthesising the information obtained in the previous stage and, in turn, feeding it again into the first stage, which is why the policy-making process is considered a cycle (Haddad et al., 2022). The lessons obtained from the last two stages may lead to a modification in the policy objective itself or on elements of the process, such as policy instruments or implementation style.

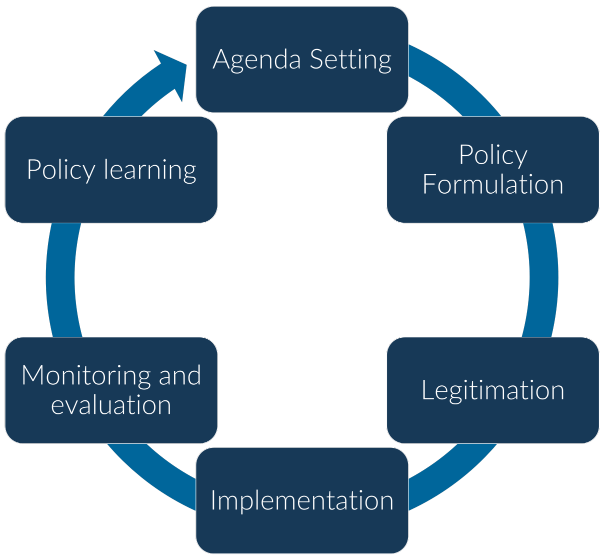

Figure 3.3: The Policy Cycle, adapted from Haddad et al. (2022)

3.5.2. Approaches to policy-making

Policy-making approaches have evolved throughout time as problems plaguing society have changed. Some of the most relevant policy approaches studied in literature include 'innovation policy', 'environmental policy' and 'mission-oriented policy', among others (Haddad et al., 2022).

As its name suggests, innovation policy focuses on creating favourable conditions for innovation to thrive. Depending on the type of innovation, this policy approach has been adapted to better suit sustainability transitions (sustainable innovation policy) or technological innovations (technological innovation policy). In the past, innovation policy tended to focus on neutral or moderate levels of intervention (Foray, 2018). However, as so-called 'grand challenges' (such as climate change) started to emerge, the need for different approaches to policy-making arose.

Some of these approaches include transformative innovation policy (TIP) (Haddad et al., 2022), non-neutral innovation policy (Foray, 2018) and a notion of creative destruction (Kivimaa & Kern, 2016). All of these approaches have in common a more strategic and radical kind of intervention focused on targeting a certain grand challenge or overarching objective, usually by supporting radically new or 'disruptive' technologies. These technologies are those that *"bring to the market a very different value proposition than previously available"* (Johnstone & Kivimaa, 2018).

Foray (2018) highlights the need for targeted (non-neutral) policy approaches when one sector needs to change radically in order to address a grand challenge. An example of this approach would be to set certain budgets for specific types of innovation (e.g., sustainable innovations) rather than innovation in general. Underscoring this importance, Haddad et al. (2022) stress that *"innovation should not be pursued for the sake of innovation or economic growth"*. Instead, it should have a purpose or direction aligned with overarching objectives, such as a sustainable energy transition.

For their part, Kivimaa and Kern (2016) mention that in order to favour sustainability transitions, it is not enough to implement policies that favour niche creation (creative term) but also policies that destabilise the existing context (destructive term) and create windows of opportunity for the innovation to grow.

Since the main focus of this work is a radically new innovation (V2G), which will develop in the context of combating a grand challenge (climate change), it will draw on concepts from all three policy approaches. These concepts form the basis for designing effective innovation policy strategies that foster technological advancement and economic growth.

Policy-making concepts

Transformative innovation policies have five broad characteristics in common (Haddad et al., 2022). These characteristics are:

1. A focus on solving grand challenges characterised by complex inter-dependencies.
2. A clear direction of where the transition is heading, also referred to as directionality.
3. A need for multi-faceted policy intervention, including policy mixes.
4. Involvement from a broad set of actors and global networks.
5. Multi-level governance and coordination between different policy domains.

Policy instruments are *"concrete tools [used] to achieve overarching objectives"* (Rogge & Reichardt, 2016) and may be translated into plans of action which can aid policies with the above-mentioned characteristics. They may be categorised by type into economic, such as grants and loans; regulatory, such as patent laws; or informative, such as training or qualification workshops (Rogge & Reichardt, 2016). They may also be categorised by purpose, having a focus on demand pull, technology push or addressing systemic concerns (Haddad & Bergek, 2023; Rogge & Reichardt, 2016). This categorisation is shown in the Rogge and Reichardt matrix below.

Table 3.3: Policy instrument type and purpose matrix

Primary type	**Primary Purpose**		
	Technology push	**Demand pull**	**Systemic concerns**
Economic	R&D grants, tax incentives	Subsidies, feed-in tariffs, taxes, levies, trading systems, public procurement	Tax and subsidy reforms, infrastructure provision, cooperative R&D grants
Regulation	Patent law, intellectual property rights	Technology/performance standards, prohibition of products/practices, application constraints	Market design, grid access guarantee, priority feed-in, environmental liability law
Information	Professional training and qualification, entrepreneurship training, scientific workshops	Training on new technologies, rating and labelling programmes, public information campaigns	Education system, thematic meetings, public debates, cooperative R&D programmes

Source: Rogge and Reichardt (2016)

There are too many policy instruments to list, and more are created or modified as time goes by when none of the existing instruments are suitable for addressing a problem. However, some policy instruments are used often and may apply to any type of innovation. A few of these as mentioned by Kivimaa and Kern (2016) and Rogge and Reichardt (2016) are:

- **Subsidies**, which provide an incentive for technological adoption by lowering the amount of investment required to produce or acquire it.
- **Taxing instruments**, which may create positive reinforcement, such as tax deduction schemes or consequences, such as taxing externalities.
- **Grants and loans** with low interests that provide firms with resources to develop their products.
- **R&D funding schemes** and innovation platforms, which, similarly to the previous instruments, provide financial aid to firms to bolster research and foster innovation.
- **Training schemes** and workshops providing qualifications in order to overcome a lack of knowledge that may impede technological development.
- **Project incubators** that give support and guidance to promising innovations and help them grow over time.
- **Patent laws**, which provide firms with a sense of security that they will recover the investment made on their innovations.

In order for policies to be successful, instruments must be carefully selected to address all relevant issues and be implemented in a coordinated way. Foray (2018) suggests that the number of instruments in a policy mix should match the number of externalities or market failures that need to be addressed.

Kivimaa and Kern (2016) identify measures for creative destruction that can guide the selection of policy instruments based on where the needs are identified. Their measures are inspired by SNM literature and Hekkert et al.'s Functions of Innovation and comprise seven creative and four destructive measures, mentioned below.

Creative measures

1. Knowledge creation, development and diffusion
2. Establishing market niches/market formation
3. Price-performance improvements
4. Entrepreneurial experimentation
5. Resource mobilisation
6. Legitimation
7. Influence on the direction of the search

Destructive measures

1. Control policies
2. Significant change in existing market rules
3. Reduced support for dominant market technologies
4. Changes in social networks, replacement of key actors

3.5.3. Policy-making challenges

As with any process surrounding technological development, the policy-making process faces several challenges, some of which are introduced here. The first challenge is that the process, in general, is a complex activity. policymakers must be strategic in the decisions they make and deal with a myriad of different actors and conflicting interests. This complexity may pose a significant challenge encountered by policymakers (Frank et al., 2020).

Another significant challenge is establishing credibility. This challenge goes hand in hand with the legitimation stage of the policy process (and the creative measure with the same name) and may be significantly more relevant in contexts where macro-economic challenges are severe (Rogge & Reichardt, 2016). It may also be directly influenced by a third challenge which is maintaining consistency and coherence across a policy mix.

While in some cases finding inconsistencies in current policy mixes is desirable for new policies to be born (Frank et al., 2020), a systematic lack of consistency or coherence between policies can have a negative effect on the credibility of policymakers and lead to a policy coordination failure (Sovacool et al., 2017). Consistency and coordination, however, are challenging to achieve since policies evolve with time and the broader the system boundaries (e.g., national policies vs regional policies), the more inconsistencies present (Rogge & Reichardt, 2016).

A final broadly identified challenge is managing stakeholders (Haddad et al., 2022). This poses a challenge because all stakeholders have a role in the policy-making process, and a lack of stakeholder participation can result in policies not reflecting the true needs of stakeholders. On the flip side, over-involvement may also not be desirable since it may cause delays in the process of having too many different opinions.

As can be seen throughout this section, several different concepts (such as directionality, legitimation, and resource mobilisation) are repeated throughout innovation policy literature and highlighted in different contexts related to policy-making. These concepts are, therefore, deemed relevant and will be incorporated into the revision of Ortt and Kamp's TIS framework to provide a policy-making perspective.

4

V2G in the UK

This chapter delineates the context for V2G in the UK, the aim is to identify the main drivers and barriers behind V2G adoption in the UK and the most relevant stakeholders related to it, thus answering sub-question 1 of the research: **what are the relevant stakeholders for V2G within the UK and how are they connected?**.

A brief history of the development of EVs and V2G within the UK is showcased in section 4.1, followed by an introduction of the technology and its main functionalities in section 4.2. The most relevant actors involved with V2G technology in the UK are then presented in section 4.3.

4.1. V2G history

The concept of electric vehicles was born in the UK in the early 1800's with Faraday's invention of the electric motor and Barlow's application of this motor (Hosseinpour, Chen, & Tang, 2015). Throughout the century, the concept was further explored in other countries and in the early 1900s EVs had a golden age where their market share was above that of internal combustion engine (ICE) vehicles (Hosseinpour et al., 2015). An important factor that contributed to its adoption was it being marketed towards women due to its ease of use (Sovacool et al., 2018).

However, in 1908, Ford introduced a mass-produced and widely available gasoline-powered car which cost less than half of an EV. This, along with several crude oil discoveries in the following decades, put a damper on the development and use of EVs for almost half a century (United States Department of Energy, 2014). During this time several companies kept trying and failing to re-introduce EVs, but it wasn't until 1997 with Toyota's release of the hybrid Prius that electric vehicles started gaining traction again (United States Department of Energy, 2014).

At the same time, environmental concerns in the 1990s were growing significantly, and in the following decades, several countries around the world started passing legislative instruments that would require a de-carbonisation of their energy systems (Hosseinpour et al., 2015). This new mindset, along with Toyota's previous success with the Prius, led to the development of the 100% electric Nissan Leaf, which was the first mass-produced fully electric vehicle in modern times (UK Energy Saving Trust, 2021). Since then, EVs have slowly been gaining traction, and with the rapidly decreasing cost of batteries and increasingly ambitious environmental goals, the past few years have seen a boom in the sale of electric vehicles (UK Energy Saving Trust, 2021).

Specifically in the UK, Prime Minister (at the time) Boris Johnson announced in 2020 the UK's plan to have an emission-free vehicle fleet by 2035 and published a full delivery plan outlining its main strategies in 2021 (UK Government, 2021b). At present, the UK is ranked the 5th best-prepared country in the world for the EV transition and EV sales are expected to grow 36% year-on-year for the next few years (Ernst & Young Global Limited, 2023).

The concept of V2G is generally attributed to Kempton and Letendre (1997), who first stated that electric vehicles would have value for electric utilities and power resources, observing that vehicles tend to be idle 95% of the time. Since then, the potential of EVs to serve as intermediate storage for electricity and provide several services to the grid has been entertained and widely studied (Høj, Juhl, & Lindegaard, 2018; Lucas-Healey et al., 2022).

Since its conception, V2G technology has been regarded as a valuable asset throughout the world and energy and automotive companies alike have been working on the development of this technology. Particularly within the UK, the beginnings of V2G are traced back a decade to 2013 when the first trial of the technology in the country took place. The project consisted of determining the feasibility of systems which integrate V2G by installing a V2G unit at a particular residence (V2G Hub, 2023). Though this project was done at a very small scale, soon after, other projects followed. At present the UK has conducted over 28 pilot projects for V2G, some of which are still ongoing (V2G Hub, 2023).

One of the largest projects was *Powerloop*, led by Octopus Energy in partnership with Nissan, which concluded in 2022. Its aim was to validate the feasibility of residential V2G technology and it involved an impressive 135 participants leasing a Nissan Leaf (V2G Hub, 2023). The project went forward to prove that V2G is feasible to support system balancing (Octopus Energy, 2023b). Further research demonstrated that over 80% of the users were keen to use V2G technology in the future (Energy Saving Trust, 2022).

Other relevant projects include the *Sciurus* project led by OVO Energy, the *V2GO* project led by EDF and the *EV-elocity* project led by Cenex. All of these projects provided valuable insights for V2G in the UK, among which were insights into customers' experiences and relevant barriers to the technology.

Although V2G technology has made important strides in the UK in recent years, several barriers remain before the technology is ready for large-scale diffusion. The following chapters will explore these barriers and relevant drivers for the technology's adoption.

4.2. V2G technology

V2G was coined as a way to shorten the term vehicle-to-grid, which refers to the integration of EVs with the electricity grid (Sovacool et al., 2017). The concept of V2G describes the intelligent linkage of EVs with the electric power grid (Sovacool et al., 2017) via a bidirectional flow that enables the vehicle to charge electricity from the grid or discharge electricity to the grid (Meelen et al., 2021). This exchange is controlled using communication software combined with a smart grid system (Høj et al., 2018).

V2G technology integrates several different types of technologies from different sectors. Some of these include electric vehicles, communication technologies, and electric vehicle supply equipment (EVSE, most often referred to as chargers), which includes several power conditioners. Furthermore, since V2G directly interacts with the grid, elements such as network operation, discharge capacity, metering, and grid regulations need to be taken into account as well.

Additionally, there is a need to consider existing complementary and competing technologies to V2G, along with those that may emerge once V2G becomes widely adopted (Lucas-Healey et al., 2022). To better illustrate this technological interaction, Figure 4.1 presents the main technologies included in and interacting with V2G, along with its competing and complementary technologies; these are also elaborated upon below.

Electric vehicles

Electric vehicles refer to means of transport that use electric motors to function, this term is more commonly used to refer to cars, buses and light-duty vehicles. Depending on whether the vehicle requires a grid connection to charge, they are divided into plug-in EVs and hybrid EVs. Hybrid EVs include a battery and electric motor in an internal combustion engine vehicle to make it operate more efficiently, reducing fuel consumption and GHG emissions (Sovacool et al., 2017). However, these vehicles do not have the capability of being plugged in and providing V2G services.

Plug-in EVs are also split into two types of vehicles: plug-in hybrids (PHEVs) and fully electric battery vehicles (BEVs) (Blair et al., 2023). PHEVs work similarly to hybrid EVs, but they have the capability of connecting to the grid, therefore having the potential to provide V2G services. BEVs are fully electric vehicles that do not have an ICE and rely completely on the battery to power them. Being fully electric, BEVs have the highest potential to provide V2G services, however, PHEVs do not have some of the perceived drawbacks for V2G that BEVs encounter (van Heuveln et al., 2021). For clarity throughout this work, when talking about EVs in the context of V2G, it is referring to PHEVs and BEVs, including cars, motorcycles, buses and light-duty vehicles.

Currently, in the UK, more than 16% of all new vehicle registrations are BEVs, and over 7% are PHEVs (Society of Motor Manufacturers and Traders, 2024). These numbers only provide an indication of the likelihood that V2G-capable EV models and chargers will be adopted since most EVs are not V2G-capable yet. Nonetheless, EV adoption is fundamental for the uptake of V2G-capable vehicles once they inevitably start flooding the market. A list of some vehicles that are V2G ready in the European market is provided below (Høj et al., 2018; Thomas et al., 2023).

- Mitsubishi iMiev
- Mitsubishi Outlander
- Nissan Leaf 2.0
- Nissan eNV200/Evalia
- Kia Soul Electric
- Hyundai Ioniq 5 and Ioniq 6

Electric vehicle service supply equipment

Chargers is the most common term used to refer to EVSE. EVSEs are complex systems consisting of all the necessary power electronics that allow for the charging and discharging of EVs to occur (Sovacool et al., 2017). Through this work, the term chargers will also be used to refer to EVSE.

EVSEs are regulated by charging and communication protocols, which differ in varying regions of the world. These protocols regulate the types of plugs used in vehicles and EVSEs, the charging architecture (alternating current or direct current), and communications between charging station and vehicle, among other factors (European Commission, 2023).

Alternating current (AC) charge points offer lower power levels and are commonly used for home charging. Two main connector types exist for AC charging: Type 1 (used mainly in Japan and the US) and Type 2 (used in the rest of the world) (Sovacool et al., 2017). When AC charging is used, an inverter is needed in the vehicle (onboard inverter) since batteries have to be charged using direct current.

In contrast, direct current (DC) charge points are capable of high-kilowatt charging and are more frequently found in public locations for quicker charging and for heavy-duty vehicles. However, DC chargers are very difficult to install and maintain since they need to have an inverter as well, transforming the current received from the grid in AC into DC (Sovacool et al., 2017). As a result, some companies such as Renault are looking into enlarging AC chargers to make them suitable for fast charging (Høj et al., 2018). Three main charging types for DC exist nowadays: Tesla superchargers (used by Tesla automobiles), CHAdeMO and the Combined Charging System (CCS) (Blair et al., 2023).

The CHAdeMO was the worldwide standard for DC charging until recently (Høj et al., 2018), with its own communication protocol which was already able to provide V2G. However, a few years ago, it started being phased out in Europe due to most European EV manufacturers opting for the CCS that enables them to have one joint AC and DC charging port rather than two separate ones, thus increasing its interoperability (European Commission, 2023). At present, only CHAdeMO supports V2G (Meelen et al., 2021), with CCS expected to follow suit in 2025 (Miller, 2023b).

Communication technologies

Due to its complex functioning, V2G requires state-of-the-art communication between several actors including the vehicle itself, the charger, a remote controlling software to establish important parameters (such as minimum state of charge, desired battery at certain times, etc.), and aggregators and grid operators to receive signals for service provision (Thompson & Perez, 2020).

These communication processes make use of information and communication technologies, and communication protocols that should be regulated through uniform standards in order to ensure interoperability and data safety (Blair et al., 2023; Thomas et al., 2023). Some important communication standards include the IEC 61851-1, ISO 15118-20 and the Open Charge Point Protocol (OCPP).

The IEC 61851-1 contains the basic principles for communication and controlling charging processes in EVs (Blair et al., 2023). The ISO 15118-20 specifies all the communication protocols between EVs and EVSE; it laid the groundwork for V2G in CCS by introducing Transport Layer Security for data security and a “dynamic” control mode to more easily provide ancillary services (Thomas et al., 2023). Finally, the OCPP is an open-source communication protocol for EV charging points that facilitates the transmission of data in a standardised manner, which increases interoperability (Blair et al., 2023).

Complementary and competing technologies

As with any new technology, several products and services may be considered complementary or competing with V2G. Some technologies may even be considered both complementary and competing products at the same time.

Some examples of complementary products and services include trip planning and charge optimising platforms (Meelen et al., 2021), EV charging stations (Lucas-Healey et al., 2022), and battery swapping services. In the last case, a depleted EV battery may be exchanged for a fully charged one at a swapping station (Rehman et al., 2023).

Products that directly compete with V2G are smart charging (Rehman et al., 2023), different types of storage technologies, and distributed energy resources (DERs) (Lucas-Healey et al., 2022). Smart charging may lower incentives for V2G by lowering the charging costs of EVs while lacking some barriers, such as range anxiety and battery degradation concerns associated with V2G. Energy storage technologies include battery banks, compressed air energy storage systems, pumped hydro energy storage systems, and storage in hydrogen, among others. Storage technologies may also provide the flexibility services of DERs along with behind-the-meter generation, which is why they are direct competition for V2G (Lucas-Healey et al., 2022).

What is interesting about DERs is that they may also be considered complementary technologies for V2G (Lucas-Healey et al., 2022). The integration for rooftop PV, for instance, is considered a very good incentive for V2G and is usually promoted alongside it. However, rooftop PV provides de-centralisation services that compete with V2G.

Another example of technologies that may be competing or complementary to V2G are other types of bidirectional charging (Rehman et al., 2023). Vehicle to home or building (V2H and V2B) are applications that could complement V2G to provide a stand-alone power supply or compete with it from a flexibility service provision perspective (Lucas-Healey et al., 2022).

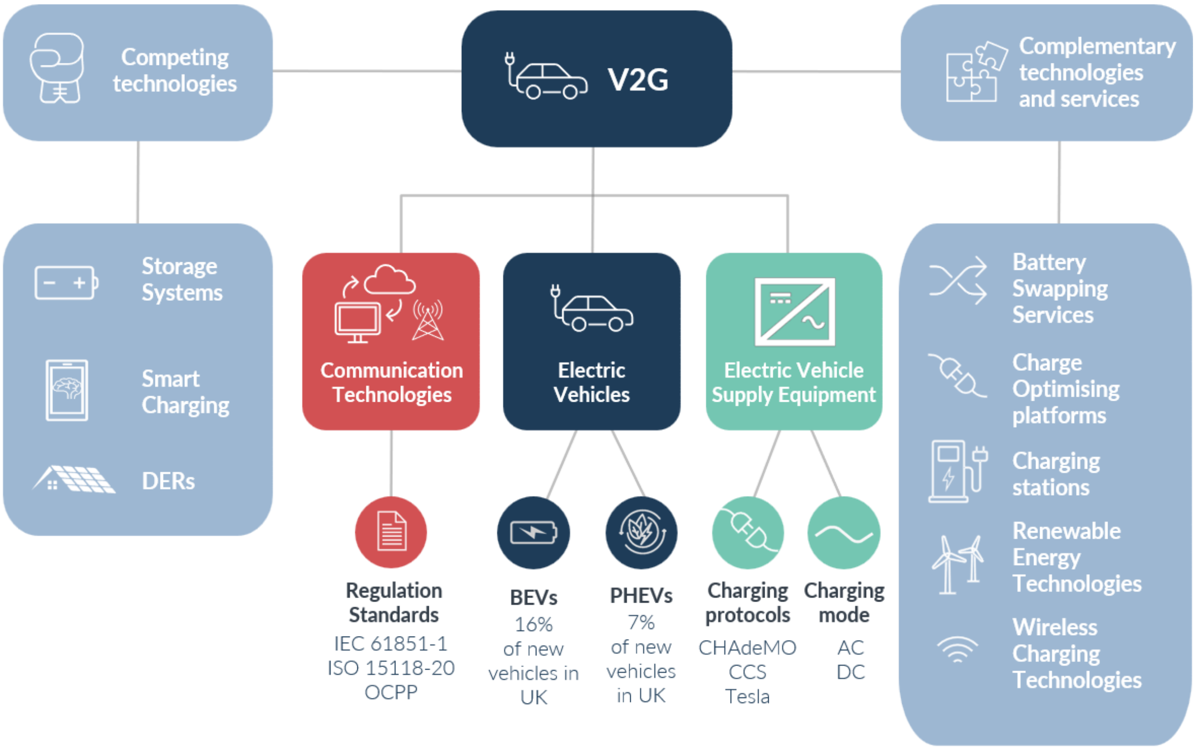

Figure 4.1: V2G technology map

4.3. Stakeholder analysis

The context of V2G stakeholders in the UK is very particular. Several stakeholders come into play both from the energy system and the transport system perspective, which creates an interesting mix of objectives and interaction between stakeholders. It is also important to distinguish stakeholders that are currently involved in the innovation process from those that could potentially hold a role in the future, once the technology has been more widely adopted.

Stakeholders may be broadly classified into four main categories. First are government organisations, which include those with direct interaction, such as system operators, and non-direct interaction, such as ministries. Second, technology distributors, which include EV manufacturers, EVSE manufacturers, energy suppliers, charge-point operators, and load aggregators, with some functions usually carried out by the same entities. Third are end users, including those with direct interaction with V2G and those that benefit from it without interacting. The fourth category is outside organisations and associations that do not directly interact with the technology but provide support and advocate for it. The main classification of stakeholders and the relationships between them are portrayed in Figure 4.2 and explained below.

4.3.1. Government organisations

Within the UK, the government oversees policy-making, technology regulation, and competition in energy market functionality and electricity system operation. Most of the stakeholders mentioned in this section are active in the current stage of development of V2G in the UK, albeit at different levels of involvement.

Regardless of involvement level, V2G could bring government organisations several benefits, mainly by providing grid services such as peak-load management, congestion mitigation, voltage control and ancillary services (Rehman et al., 2023; Sovacool et al., 2018; Thomas et al., 2023), and mitigating the intermittency effects of renewables to better integrate them into the grid (Rehman et al., 2023). A study conducted by SmartEn and DNV (2022) estimates that V2G could provide 26 GW of upward and downward flexibility in Europe by 2030, which could greatly benefit the grid. The main stakeholders within this group, along with their participation in V2G, are as follows.

The Department for Energy Security and Net Zero (DESNZ) and the Department for Transport (DfT) have the highest hierarchy within the government. Each of them is the highest regulating body within its sector. The DfT is in charge of developing policies that support the transport network and plan and invest in transport infrastructure (DfT, 2023). They interact with several other agencies and public bodies in this task, however none of them are directly related to V2G. A joint organisation between the DfT and DESNZ is Office for Zero Emission Vehicles (OZEV) which is the main entity in charge of EV infrastructure in the UK and V2G development programmes (UK Government, 2023d), thus other transport related agencies are not further examined within this work.

The DESNZ is in charge of making the policies that regulate the energy sector in their broadest sense. Their main interest is to secure long-term energy supply for the UK, bringing down energy bills and achieving emission targets (DESNZ, 2023). The DESNZ interacts with 14 other agencies and public organisations, among which (and relevant to this thesis) are the five mentioned below.

At the top of the hierarchical chain, the DESNZ and DfT are very relevant stakeholders for V2G at the moment since they are the ones establishing the main policy objectives and thus guiding the direction of innovation. Their involvement, however, stays mostly within the confines of policy-making and regulation.

The next body down the hierarchy chain is the Office of Gas and Electricity Markets (Ofgem). Ofgem oversees the regulation of the energy market itself, including companies that run electricity and gas networks. It makes sure that all participants in the energy sector are abiding by the set regulations and has the authority to make specific regulations for the energy sector; however, these regulations cannot go against anything stated by parliament. Its primary interest is to *"protect energy consumers, especially vulnerable people, by ensuring they are treated fairly and benefit from a cleaner, greener environment"* while enabling competition and innovation (Ofgem, 2023).

Ofgem is the stakeholder with the highest involvement with V2G within government organisations. It plays a role in both the regulatory and policy-making aspects of the development and the technical trials taking place. Ofgem is the link between the high-level policymakers and the market where V2G is developing.

The National Energy System Operator (ESO) manages the grid and operates the electricity market. They ensure that supply meets demand at every instant and work directly with Distribution Network Operators (DNOs) and Transmission System Operators (TSOs). Furthermore, the ESO administers relevant standards and codes such as the Connection and Use of System Code, the Grid Code, and the Security & Quality of Supply Standard. Their main interest is to make sure there is always a reliable and safe supply of electricity in the country (National ESO, 2023).

The ESO's interaction with other actors outside of the governmental unit is mainly through the UK's TSOs and DNOs. In the UK the transmission network ownership and system operation have been split since 2019 (National Grid, 2023b). The transmission network is owned by National Grid Electricity Transmission, and operation is split among several companies depending on the region. Similarly, the operation of the distribution network is carried out by fourteen licensed DNOs in the UK. While these TSOs and DNOs are individual companies, they are all ruled by the ESO and thus have been engulfed in the same 'entity' in the stakeholder map shown in Figure 4.2. A full list of electricity transmission and distribution operators may be found in Appendix C.

All system operators (ESOs, TSOs, DNOs) have a much lower level of involvement in the development of V2G within the UK. These stakeholders are limited to some pilot projects where the project falls within their geographical service area, however, if they participate in a project their involvement is highly important to ensure the benefits of V2G are properly assessed. As V2G technology becomes more widespread, system operators will become one of the most relevant stakeholders in this context since they provide the signals for EVs to charge/discharge as needed.

The Low Carbon Contracts Company (LCCC) and Electricity Settlements Company (ESC) are public companies responsible for financial transactions related to the electricity market. They are in charge of managing contracts with generators, operating the Capacity Market, and managing auction bids. In this context, they interact directly with technology providers and End Users. Their main interest is to accelerate the delivery of net zero by enabling investment into low carbon technologies (Energy Settlement Company, 2023).

The LCCC and ESC are not involved in V2G development at this time, since only pilot projects of V2G are being carried out. However, being the operators of the capacity market, which can be one of the most important revenue streams for V2G, their participation will be critical once the technology starts becoming more wide-spread.

4.3.2. Technology distributors

V2G is an interesting innovation regarding technological distribution. It requires cooperation from two different entities: one with the know-how in the transport sector, usually referred to as vehicle Original Equipment Manufacturers (OEMs), and one with knowledge in the energy sector, usually providing help with software development for vehicle control and communication protocols with charge points and the grid. These two entities have been teaming up together to explore several pilot projects for V2G currently operating within the UK (V2G Hub, 2023), the latter generally serving the role of system aggregator as well. Some of the main companies for both entities are mentioned below, however a full list of companies involved with V2G technology in the UK is presented in Appendix C.

Some vehicle OEMs active in V2G development in the UK are Nissan, Mitsubishi and BMW. All three big automotive companies have expressed an interest in the development of V2G technology and have V2G-capable cars coming into the market soon. Moreover, both Nissan and Mitsubishi have participated in V2G pilot projects in the UK (V2G Hub, 2023) and are, therefore, actively involved stakeholders at present.

Nissan's main objective as a company is to contribute with the goal of a zero-emission future by helping secure necessary infrastructure and to make the entire life cycle of EVs sustainable (Nissan, 2023).

Mitsubishi's interest in V2G development is also in line with its company mission and values which include realising the potential of mobility while making positive contributions to sustainable development (Mitsubishi, 2023).

EVSE manufacturers also play a current role in the roll-out of V2G, since V2G-capable chargers are crucial to its adoption. Wallbox is one EVSE manufacturer that has already designed a V2G-capable charger, the Quasar 2. Wallbox's main objective as a company is to change the way the world uses energy and *"push the boundaries of what EV charging can do"* (Wallbox, 2024), which is why it is invested in V2G.

Companies that specialise in the energy sector are the other big players in this collaboration. They provide technology that enables the control and interaction of EVs with the grid, provide tariffs to incentivise the use of V2G and some serve the critical role of energy system aggregators. Some of the most prominent companies participating in pilot projects for V2G in the UK are Nuvve, OVO Energy, Octopus Energy, Enel, and Eon.

Eon and Enel are companies whose main company objectives are pretty similar, they all seek to contribute to the global energy transition towards net-zero through environmentally friendly solutions (Enel, 2023; Eon, 2023) and V2G is one one such solution. Nuvve, OVO Energy and Octopus Energy are companies that focus more on wholesome energy solutions with a strong area for EVs. Their mission is similar as all three companies are focused on supporting the acceleration of EV uptake to combat climate change and being pioneers in the technological development of V2G (Nuvve, 2023; Octopus Energy, 2023a; OVO Energy, 2024).

For vehicle manufacturers, charge point operators, and software service providers, V2G brings value streams in the form of product differentiation and revenue from playing a part in energy management systems. In addition, V2G may bring additional revenue streams from participating in different market mechanisms to entities serving as load aggregators.

4.3.3. End users

In relation to V2G technology two main user categories have been identified. The first are EV owners whose vehicles have V2G technology, and the second are indirect users who benefit from it but do not interact with it directly.

Direct users may benefit from the technology through several means. First, it gives them the opportunity to optimise self-consumption if they have on-site renewable generation (such as rooftop PV). Second, they save money from their vehicle smart charging at times when the cost of electricity is lowest, and third, they may generate additional income by selling surplus energy into the grid in times of shortage and potentially from providing balancing services as well (SmartEn and DNV, 2022). Though most of them do not have V2G capabilities yet, currently there are 920,000 EVs on the road in the UK. In the coming years, this number is expected to grow exponentially, and new EVs are expected to include V2G capabilities (Zapmap, 2023). In this sense, only a few users who have participated in V2G pilots are current stakeholders for V2G.

The second type of users is indirect users. This category includes all the individuals and entities that benefit indirectly from V2G technology, through lower electricity prices procured by a more stable demand on the grid and energy security provided by V2G balancing capabilities. These beneficiaries include but are not limited to, renewable energy generators, utility companies, and electricity users with big demand peaks that experience lower energy prices. However, since V2G has not been largely adopted yet, these users are only potential stakeholders at the moment.

4.3.4. Associations and non-governmental organisations

There are several associations that play a role in the V2G context in the UK. Some of them are conformed by a series of relevant market actors, such as the Renewable Energy Association (REA) and Energy UK. These associations have the main purpose of uniting important stakeholders with the shared purpose of driving a sustainable energy transition (Energy UK, 2023; REA, 2023).

In addition to these associations, other organisations exist, such as the Climate Change Committee (CCC) and Cenex. The CCC is an independent statutory body that provides advice on policy and regulation matters. The CCC interacts directly with the DESNZ, its main purpose being advising the government on emission targets and reporting to parliament on GHG reduction efforts to parliament. Since the transition to EVs and adoption of V2G is highly relevant for GHG emission reduction in the UK, the CCC plays an important role within stakeholders (Climate Change Committee, 2023).

Cenex is an independent organisation that conducts not-for-profit technological research mainly focused on low-emission transport and associated energy infrastructure. They continuously interact with other stakeholders of the technology, such as the government at different levels to provide advice, companies to test and develop new technologies and end users to obtain insights (Cenex, 2024).

Both associations and organisations are actively involved in advocating for V2G technology and pushing for its adoption in the UK as soon as possible. Therefore, they are considered current stakeholders.

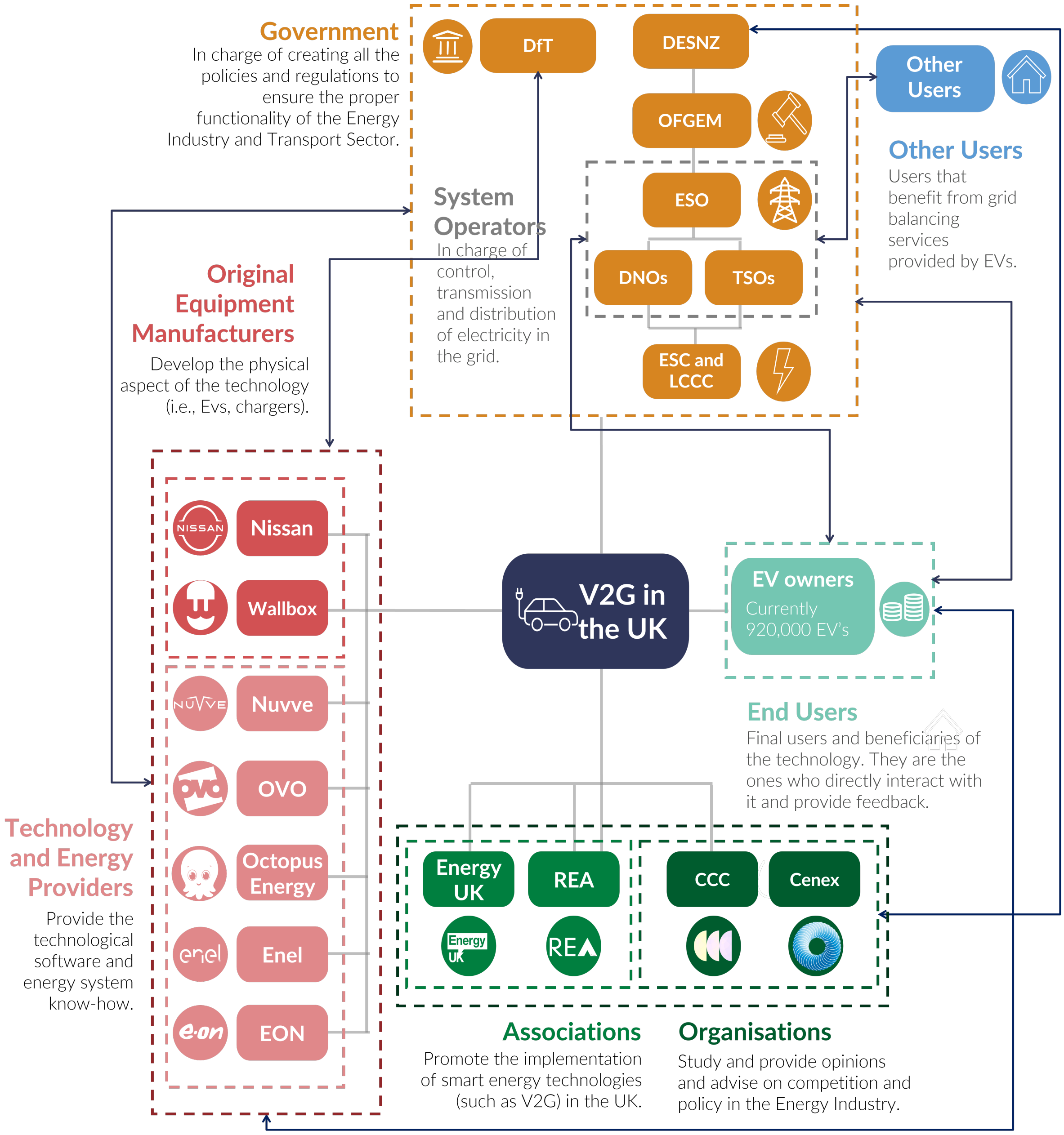

Figure 4.2: Stakeholder's map

5

Adaptation of TIS framework

Chapter 3 introduced the necessary basis to expand upon and adapt Ortt and Kamp's TIS framework to include policymakers and chapter 4 provided an overview of V2G in the UK. This chapter makes use of the knowledge obtained to present revised building blocks and influencing conditions to create a Shared framework for companies and policymakers. The application of this framework is intended to aid in deriving niche introduction strategies for companies and innovation policy strategies for governments, therefore creating a single shared framework for both entities to use, as its name suggests.

While companies are the ones that effectively create and develop new technologies, governments generally establish visions of the future and expectations that motivate companies to innovate (Sovacool et al., 2018). Further, sustainability transformations are driven mainly by policy interventions that steer the direction of change (Frank et al., 2020).

These arguments support the need to create a framework that accounts for both a policymaker's perspective and a company's perspective. A joint framework was chosen instead of two separate ones since technological innovation requires collaboration between a multitude of actors to succeed (Haddad et al., 2022). As will be observed in the following sections, the BBs and ICs are relevant to both companies and policymakers and highlight the need for them to work together.

The proposed Shared framework consists of eight building blocks explained in detail in section 5.1, with a set of proposed indicators to evaluate their completeness (section 5.2) and eight influencing conditions, which are further explained in section 5.3 with their indicators in section 5.4. These adapted BBs and ICs are followed by a categorisation and analysis of niche introduction strategies in section 5.5 and TIS build-up strategies in section 5.6 to see which combinations of BBs and ICs they are applicable for.

The list of adapted BBs and ICs is presented here with text in black representing the original framework by Ortt and Kamp (2022), while the text in blue are modifications made in this work.

Building blocks

1. Product quality and purpose
2. Product price
3. Entrepreneurial activity
4. Production systems
5. Complementary products and services
6. Network formation and stakeholder participation
7. Customers and demand opportunities
8. Innovation-specific institutions

Influencing conditions

1. Knowledge of technology and learning opportunities
2. Knowledge and awareness of application and market, and learning opportunities
3. Allocation of natural, human and financial resources
4. Competition and market modulation
5. Macro-economic and strategic aspects
6. Socio-cultural aspects and social dynamics
7. Accidents and events
8. Overall global context

5.1. Adapted building blocks

Product quality and purpose

Originally, this building block refers to how the product performs compared to competing products in the market (Ortt & Kamp, 2022). As long as the product is perceived to be of good quality or a viable alternative to existing products, then this block should be complete. In conjunction with policy-making, however, it is not enough that the product is of good quality and has good performance; its directionality or overall purpose also matters. The overarching objectives or goals that the product may aid in achieving must be considered by policymakers and companies as well. Therefore, this building block has been expanded to account for the fact that the product not only needs to be seen as a viable alternative to existing products but as an alternative better aligned with specific strategic goals.

If a product has poor quality or performs poorly when compared to its alternatives, then a barrier to its adoption from a company perspective is formed (Ortt & Kamp, 2022). Additionally, existing policies all have a strategic purpose (Foray, 2018; Haddad et al., 2022); if an innovation is not better aligned with their strategic goals than its competition, then a policy barrier for the innovation may also be formed.

Product price

As stated in the original framework, a product must have a competitive price to achieve large-scale diffusion. In the case of radically new innovations, however, the price is usually much higher than that of incumbent technologies (Kivimaa & Kern, 2016; Ortt & Kamp, 2022). This building block directly affects companies since they need to devise strategies to lower their prices. However, it also involves policymakers since they should aid in devising and implementing price-performance improvements (Kivimaa & Kern, 2016).

Entrepreneurial Activity

Ortt and Kamp (2022) devised their framework purely from a company perspective, therefore, entrepreneurial activity was taken as a given. Since this shared framework also includes a view from policymakers, an additional block was considered necessary to evaluate the state that entrepreneurial activity is in.

Entrepreneurial activity is one of the main functions in TIS literature (Hekkert et al., 2007); it describes how certain actors turn potential knowledge, networks, and markets into concrete actions which drive the innovations and is therefore highly relevant to consider. The number of existing actors interested in developing the technology, the amount of interest they exhibit and the amount of support they are able to access directly impact technological development.

Different stakeholders may carry out entrepreneurial activity, including incumbent actors, government organisations or start-up companies; all of these can take distinct actions to bring the technology to market. In order for technological development to occur, there should be a large number of entrepreneurial activities with enough support provided through several policy instruments (Kivimaa & Kern, 2016).

Production systems

Production systems not only need to be in place for technological adoption to occur, but they also need to be efficient and competitive (Ortt & Kamp, 2022). Nonetheless, to become efficient and competitive, they must undergo a lengthy process of learning by doing (Kamp, 2002), which can be costly and complicated.

For companies, it is relevant to analyse the state of the production system to generate strategies for their innovation. For policymakers, it is essential to assess whether these production systems are in place and working efficiently or if there is a need for intervention or support, which can aid in abating some of the costs (Kivimaa & Kern, 2016). If production systems are not in place and insufficient entrepreneurial support is provided, then diffusion of the technology may be hampered.

Complementary products and services

Every innovation requires complementary products and services for diffusion to occur (Lucas-Healey et al., 2022). This block is relevant for companies and policymakers alike and thus is kept without modification; only relevance for both parties is highlighted. It is important for companies since their development and production strategies must be aligned to generate complementary products and services. For policymakers, the significance of this block stems from the fact that while policy measures that support the innovation are important, the policy mixes must also include instruments that foster the growth and uptake of the innovation's complementary services and products.

Network formation and stakeholder participation

Ortt and Kamp (2022) refer to the interaction, alignment, and coordination between all the actors involved in the supply chain as an integral part of network formation. In order to include a policy-making perspective, however, this block has been expanded to include stakeholder involvement as well, at all levels of the TIS. As mentioned before, stakeholder interaction and participation are what help the creation of legitimacy, making this a crucial block for the policy-making process (Haddad & Bergek, 2023). On a similar note, Rogge and Reichardt (2016) highlight the necessity of coordinating structures and communication networks to create coherence in the policy-making process.

Both network formation and stakeholder participation go hand in hand and need to occur in a coordinated manner in order for technological diffusion to occur. Lack of participation and involvement of actors or coordination within networks has been identified to be a barrier in both policy-making processes (Haddad et al., 2022) and company success (Ortt & Kamp, 2022) with product development and diffusion.

Customers and demand opportunities

In Ortt and Kamp's TIS framework, the importance of the 'Customers' block relies on the need to identify a potential customer segment and develop the innovation with them in mind to avoid customer-related issues that may hamper its diffusion (Ortt & Kamp, 2022). Additionally, these customers must possess awareness of the innovation and its benefits, and the means and willingness to acquire and use it.

To adapt this block for the inclusion of policymakers, its scope has been broadened from assessing customers to assessing demand opportunities as well. Policymakers can make market conditions more favourable for an innovation by developing niche markets or providing competitive advantages through policy instruments such as tax incentives or subsidies (Hekkert et al., 2007; Kivimaa & Kern, 2016); in turn, these open the possibility of acquiring the technology to a broader public, therefore creating demand and thus potential customers.

Innovation-specific institutions

This block is relevant in both Ortt and Kamp's framework and the Shared framework. The difference lies in the reasoning behind the significance of assessing innovation-specific institutions. While Ortt and Kamp (2022) highlight the importance of existing stable and supportive rules that increase certainty for companies, the shared framework argues that for policymakers their existence is not enough.

When analysing innovation-specific institutions from a policy-making perspective, a thorough assessment of the regulatory framework (directly or indirectly linked to the innovation) is necessary. Assessing the current policy mix is key since identifying inconsistencies is a relevant part of developing policy strategies (Frank et al., 2020) and coherence between policy mixes is crucial for technological diffusion (Rogge & Reichardt, 2016). Furthermore, all policies, laws, standards and regulations need to be legitimised in order to work. This legitimation occurs through interaction with relevant stakeholders, including companies.

Table 5.1 provides a contrast between the building block definitions in the TIS framework by Ortt and Kamp (2022) and the Shared framework with contributions made in this work shown in blue.

Table 5.1: Comparison of Ortt and Kamp TIS building blocks and Shared framework building blocks

BB	**Ortt and Kamp framework**	**Shared framework**
1	An innovation must have sufficiently good performance and quality in comparison to competing products in order to foster its adoption. The product needs to be seen as a viable alternative to existing ones.	The product must exhibit good quality and performance in regard to its competition while aligning with an overarching objective. The innovation should be seen as a viable alternative to existing products that better aligns with strategic goals designed to tackle grand challenges.
2	Product price should be competitive in comparison to other products for technological diffusion. This includes financial and non-financial (time and effort of acquisition) costs.	Product price (including financial costs, time and effort of acquisition) should be competitive and price-performance improvements should be assisted by policy instruments in order to facilitate technological diffusion.
3	N/A	Entrepreneurial activity describes how different stakeholders turn potential knowledge, networks, and markets into innovations. In order for technological development to occur, there should be a large number of entrepreneurial activities from companies with enough support provided through several policy instruments.
4	Production systems must be efficient in order to be competitive and foster technological adoption. They are essential to be able to manufacture and distribute large quantities of an innovation at high quality.	Production systems must be efficient in order to be competitive and foster technological adoption. They are essential to be able to manufacture and distribute large quantities of an innovation at high quality and should be supported by different policy instruments to support technological diffusion.
5	Complementary products and services should be in place and well-coordinated to support the diffusion of the innovation. Companies providing them should have aligned strategies.	Complementary products and services should be in place and well-coordinated to support diffusion of the innovation. Companies providing them should have aligned strategies and policies surrounding them must be supportive and coherent.
6	Actors in the supply chain should interact and align to form coordinated networks that can help the diffusion of the innovation.	All stakeholders involved in the TIS should be involved in the formation of coordinated networks by communicating, interacting and aligning objectives that can help the diffusion of the innovation.

7	Customers need to be aware of the innovation and its benefits regarding other products and have the means and willingness to acquire and use it. They are a primary block since they are the ones that carry out the actual diffusion of the technology.	Customers need to be aware of the innovation and its benefits regarding other products and have the means and willingness to acquire and use it. Furthermore, new customer demand opportunities need to be created through different means since they are the ones that carry out technological diffusion.
8	Formal and informal rules need to be in place and provide a stable and supportive environment in order to drive diffusion. These include policies, laws, standards and regulations.	Formal and informal rules (including policies, laws, standards and regulations) need to be in place and provide a stable and supportive environment in order to drive diffusion. These rules also need to be coherent with each other and have the support of relevant stakeholders to encourage the diffusion of the innovation.

5.2. Indicators to evaluate building blocks

In order to evaluate the completeness of each building block a series of indicators are proposed stemming mainly from the literature sources consulted to write section 3.5 in this work. These indicators intend to provide clarity and guidance when gauging the status of each BB. The list of indicators is presented below in Table 5.2.

Table 5.2: Evaluated indicators for each building block

BB	Indicators	Source in literature
Product quality and purpose	What is the overall quality of the product?	Ortt and Kamp (2022)
	Is the product reliable?	
	Is the product easy to use?	
	What are the product's benefits over its competition?	
	Does the product serve a purpose aligned with strategic goals?	Foray (2018); Haddad et al. (2022)
	What is the public opinion of the technology?	Hekkert et al. (2007)
	How has the product's technological performance increased over time?	Hekkert et al. (2007)

Product price	How attainable is the product price?	Ortt and Kamp (2022)
	What are the main costs of installation?	
	How complicated is it to learn to use the product?	Ortt and Kamp (2022)
	What are the main transaction costs?	Ortt and Kamp (2022); Verdegaal (2023)
	Are there subsidies available to offset the price?	
Entrepreneurial activity	To what extent is there entrepreneurial activity?	Ortt and Kamp (2022)
	How many entrepreneurs are interested in technology?	Hekkert et al. (2007); van Alphen, Hekkert, and van Sarkb (2006)
	Is it economically feasible to adopt the technology?	van Alphen et al. (2006)
	How many pilot projects and experiments exist for the project?	Hekkert et al. (2007)
	Are there enough entrepreneurial support instruments (grants, loans, etc.)?	Kivimaa and Kern (2016)
Production system	To what extent is a production system in place?	Ortt and Kamp (2022)
	Are there enough physical resources?	Hekkert et al. (2007)
	Is there enough trained manpower to satisfy the growing demand of the product?	Hekkert et al. (2007)
	Are there enough existing production facilities to cover demand?	Ortt and Kamp (2022)
	Are there manufacturing systems in place?	
	Are there distribution systems in place?	
Complementary products and services	To what extent do complementary products and services exist?	Ortt and Kamp (2022)
	Are there enough high-quality maintenance and repair services?	Ortt and Kamp (2022)
	Are there collaborations and partnerships across complementary industries?	
	Do strategies across industries align?	Ortt and Kamp (2022)

Network formation and stakeholder participation	To what extent are networks present?	Ortt and Kamp (2022)
	To what extent do stakeholders participate?	Haddad et al. (2022)
	Is there high-quality contact between actors?	Hekkert et al. (2007)
	Are there workshops and conferences where knowledge is exchanged?	Hekkert et al. (2007)
	Are there research projects and collaborations between actors?	Hekkert et al. (2007)
	Is there a strategic vision and alignment of goals between stakeholders?	Haddad and Bergek (2023)
	Do actors come together in lobbying activities for financial and political support?	Hekkert et al. (2007)
Customers and demand opportunities	To what extent are customers and demand opportunities present?	Ortt and Kamp (2022)
	How easy is it for potential users to access information?	
	What is the motivation for customers to adopt the technology?	van Alphen et al. (2006)
	To what extent are different types of incentives present?	Hekkert et al. (2007); Kivimaa and Kern (2016); van Alphen et al. (2006)
	Are there campaigns and forums for potential customers to get to know the technology?	
Innovation-specific institutions	To what extent are there supporting rules, regulations and laws present?	Ortt and Kamp (2022)
	Are there regulations or standards blocking the technology?	Ortt and Kamp (2022)
	Are there enough regulating bodies?	van Alphen et al. (2006)
	What actions are regulating bodies taking to promote the technology?	van Alphen et al. (2006)
	What are strategic targets set by regulating bodies?	Haddad and Bergek (2023); Hekkert et al. (2007)
	Is there coherence between different regulating instruments?	Frank et al. (2020); Rogge and Reichardt (2016)

5.3. Adapted influencing conditions

Knowledge of technology and learning opportunities

The adaptation for this influencing condition comes in two instances. The first is highlighting the need for knowledge for both companies and policymakers alike, and the second is identifying the role that policymakers play in knowledge creation. In their framework, Ortt and Kamp (2022) talk about the need for companies to develop fundamental and applied knowledge through searching, doing, using and interacting (Kamp, 2002). Policymakers also require a deep knowledge of the technology for the policy formulation stage (Haddad et al., 2022; Rogge & Reichardt, 2016), this knowledge can be acquired through collaboration with companies.

Additionally, Hekkert et al. (2007) express the need for knowledge development in TIS formation, which is portrayed as a policy responsibility by Kivimaa and Kern (2016). Thus, it is also important to evaluate whether learning opportunities for all stakeholders are provided and supported by existing policies in order to develop the knowledge required to encourage TIS formation.

Knowledge and awareness of application and market, and learning opportunities

Ortt and Kamp already mention that all TIS actors can suffer from a lack of knowledge and awareness of the application and market within their original framework. However, they only mention how a lack of knowledge from customers or firms may hinder TIS formation. Therefore, it is important to expand this IC and include learning opportunities that companies provide, such as webinars or other campaigns, to help customers learn about the product and its possible applications.

On the policy-making side, when governments lack awareness of possible applications for the technology, it may be entirely overlooked when creating policies. For instance, when a policy agenda is being set to tackle a grand challenge such as climate change, policymakers will likely implement instruments that favour technological innovations whose applications mitigate or reduce its effects (Haddad et al., 2022). However, if this application of the technology is not known to policymakers, then they may bypass it completely and instead create policy strategies that favour its competition. Similarly, if they do not know which actors are involved with this technology or what the market conditions are for it, they may not provide enough support or the right supporting instruments for TIS formation.

Allocation of natural, human and financial resources

In the original TIS framework, Ortt and Kamp (2022) stress the need for natural, financial and human resources to be present and available for product development and diffusion, as well as a need for their mobilisation. In this adaptation, it is expanded to account for financial and human resources that are needed in the policy-making process as well. Rogge and Reichardt (2016) explain that *"appropriate crafting of policy instruments [...] includ(e) sufficient funding and staff for implementation"*.

Moreover, the importance of resource mobilisation is highlighted since it is not enough for resources to be sufficient; they need to be efficiently allocated to where they may bring the most benefit. For instance, financial resources are needed by companies to sponsor their technological development and by governments to carry out administrative tasks in the policy-making and implementation processes. These financial resources may then be distributed between grants and loans for innovators and human resource budgets for governments.

However, if these resources are not efficiently allocated (e.g., too little or too much financial support is given to companies), then the innovation process or the policy implementation process could be hampered. Therefore, it is up to companies to express their needs for resources accurately so policymakers can make the most efficient allocation.

It is also relevant to mention that sometimes the allocation or mobilisation of resources to a certain TIS is not enough to drive its development. There are cases in which these resources must also be withdrawn from existing competing technologies (Kivimaa & Kern, 2016) in order to encourage TIS formation.

Competition and market modulation

Competition represents an important aspect to consider both for companies and policymakers, therefore this IC is slightly modified and broadened to include the relevance for policymakers as well. As mentioned by Ortt and Kamp (2022), new technologies compete with existing technologies for customers, services and resources. It is important for firms to know the quantity and state of competing products in order to formulate strategies for the introduction of their innovation. Likewise, policymakers need to be aware of competition since they are the ones in charge of regulating the market (Sovacool et al., 2017).

In addition, policymakers act as mediators between stakeholders (Haddad et al., 2022) and ensure that there is a 'level playing field' in the market for all products (Thomas et al., 2023). The government can modulate the degree of competition in different ways, such as limiting competition through anti-merger laws. Even though it may be controversial, this level playing field may sometimes come from disrupting market equilibrium to provide additional support to certain innovations that align with strategic goals and which would not be competitive otherwise (Foray, 2018; Hekkert et al., 2007), thus stalling their TIS formation.

Macro-economic and strategic aspects

Macro-economic conditions have a strong impact in the formation of the TIS and need to be analysed both from a company and policy-making perspective. From a company standpoint, economic conditions determine the amount of funding they can get and whether market conditions will be favourable for their innovation (Ortt & Kamp, 2022). From a policymaker's standpoint, economic aspects directly dictate the budget that they can allocate to specific tasks, which is why this influencing condition is highly relevant.

If macro-economic conditions are not favourable, then fewer resources may be allocated to R&D or for subsidies, for instance, effectively hindering TIS formation. Particularly regarding sustainability transitions, a change to a 'greener' economic framework, driven by policymakers, is necessary in order for the innovation to succeed (Geels, 2002). Conversely, the formation of new TISs in key sectors such as energy and transport can improve macro-economic development (Geels, 2011), which can create a positive cycle of more innovations being developed.

Socio-cultural aspects and social dynamics

This influencing condition is very relevant to companies and requires some expansion when policymakers are included as well. Ortt and Kamp (2022) include in this condition all the unwritten norms and values held by society and which may directly influence the TIS. The shared framework includes, within socio-cultural aspects, the evaluation of existing social dynamics which refer to general social behaviour and the relationships that exist in society between government entities, companies, customers, etc. In some cases, long-standing relationships, particularly between governments and incumbent actors, may impede technological development, and therefore Kivimaa and Kern (2016) argue that for technological development to occur, changes concerning social dynamics need to happen.

Socio-cultural conditions are also relevant for policymakers since they shape policy-making processes and institutions (Rogge & Reichardt, 2016); policymakers need to be aware of the intrinsic values that exist within a society in order to set their entire policy agenda, determine what the best policy strategy may be and be able to create legitimacy. If policy strategies to drive the innovation do not align with socio-cultural aspects, then the formation of several TIS building blocks may be curbed.

The state of social dynamics is made even more relevant in light of today's digitalisation and social media use. Social media can dictate several different socio-cultural aspects and has the potential to influence relationships between government entities, companies, customers and other social dynamics in a powerful and almost immediate way. Therefore, it is an important influencing condition to account for when analysing TIS building blocks since a technological innovation's success can be considerably driven or hindered by the social dynamics that surround it.

Accidents and events

This influencing condition is found to be equally important for both companies and policymakers alike. Therefore, the only addition to it is to clarify that, often, policymakers have to react to these accidents or events taking into account the greater good for the country, regardless of whether such an event (or their political actions) could potentially drive or hinder TIS formation.

Overall global context

This additional influencing condition is particularly relevant in an increasingly globalised world. policymakers' decisions are directly influenced by the global environment (Thomas et al., 2023) and multilevel governance is highly relevant in policy-making for sustainable transitions (Haddad & Bergek, 2023; Haddad et al., 2022), which means that local, regional, national and global policies all need to be coherent and coordinated in order for change to truly occur. If policymakers are facing pressures against the technology from other political entities, they are less likely to take favourable actions towards a radically new innovation, therefore blocking TIS formation.

On a separate note, while companies developing an innovation need only be concerned with political conditions being beneficial within their country or region (at least initially), the global agenda and scientific context has a big impact on companies' decision-making. The global context may shape the types of innovation a company chooses to invest in or where to best allocate its resources, therefore potentially driving or hindering TIS formation for a specific innovation.

Another important factor to consider within this influencing condition is the existence of Big Tech. Nowadays, most innovations involve Big Tech in one way or another, and these, in turn, are part of the overall global context. Due to increased data sharing, the difference in privacy laws around the world, and the sensitive nature of some innovations, the way in which actors function may differ. If, for instance, an innovation requires secrecy or deals with sensitive data, then the way information is shared and the people that can be involved in specific activities change, which has a direct impact on TIS formation.

A summary comparing the influencing conditions in the TIS framework by Ortt and Kamp (2022) and the Shared framework is portrayed in Table 5.3 below.

Table 5.3: Comparison of Ortt and Kamp TIS influencing conditions and Shared framework influencing conditions

IC	Ortt and Kamp framework	Shared framework
1	Understanding the technological principles of TIS components (fundamental knowledge) and the requirements to carry out the innovation throughout its stages of development, production, maintenance and repair (applied knowledge) is crucial for the development of the TIS.	Understanding the technological principles of TIS components (fundamental knowledge) and the requirements to carry out the innovation throughout its stages of development, production, maintenance and repair (applied knowledge) is crucial for the development of the TIS. Furthermore, learning opportunities to develop this knowledge should be supported.
2	Knowledge of the target market structure, relevant actors in the market and awareness of possible applications for the technology are necessary to drive innovation diffusion.	Knowledge of the target market structure, relevant actors in the market and awareness of possible applications for the technology are necessary (for firms, customers and policymakers alike) to drive innovation diffusion.
3	Natural, human and financial resources are necessary for a successful technological implementation. Natural resources being the main input to create the product itself, human capital with sufficient knowledge and competencies to partake throughout the entire innovation process, and financial to drive technological development.	Natural, human and financial resources are necessary for a successful technological implementation. Natural resources being the main input to create the product itself, human capital with sufficient knowledge and competencies to partake throughout the entire innovation process, and financial to drive technological development. These resources must also be properly allocated and mobilised, which sometimes implies the withdrawal of resources from incumbent technologies.
4	Innovations compete with other products in the market for customers, resources and services. If competing alternatives have production systems that are too similar, then one option may prevent the other from meeting its requirements. However, if they are too different a chaotic environment may be created which is not conducive to TIS formation.	Innovations compete with other products in the market for customers, resources and services. If competing alternatives have production systems that are too similar, then one option may prevent the other from meeting its requirements. However, if they are too different a chaotic environment may be created which is not conducive to TIS formation. Market modulation must exist with supporting conditions that allow radically new innovations to be competitive with existing technologies, even if a disruption in market equilibrium is caused.

5	Macro-economic and strategic aspects are relevant to consider when studying the formation of a TIS since positive conditions (i.e., economic growth), act as enablers for technological diffusion. On the other hand, negative conditions (i.e., an economic recession), may act as barriers for TIS formation.	Macro-economic and strategic aspects are relevant to consider when studying the formation of a TIS since positive conditions (i.e., economic growth), act as enablers for technological diffusion. On the other hand, negative conditions (i.e., an economic recession), may act as barriers for TIS formation. For sustainability transitions in particular, a "green" economic framework needs to exist in order for the innovation to succeed.
6	Socio-cultural aspects have a big impact on the formation of the TIS since they stem from ingrained values and behaviours in society. They include all the norms and values held by society and are usually unwritten and fluctuating as cultural change occurs over time.	Socio-cultural aspects have a big impact on the formation of the TIS since they stem from ingrained values and behaviours in society. They include all the norms and values held by society and are usually unwritten and fluctuating as cultural change occurs over time. Social dynamics between governments and incumbent actors are also relevant since close relationships between them may prevent the formation of several TIS building blocks. Social media should also be accounted for since it is a direct reflection of socio-cultural aspects and can influence social dynamics in a way which may considerably impact technological development and diffusion.
7	Unplanned incidents that may occur within the TIS or outside of it and which have a direct impact on its formation. Some examples of accidents or events include wars, natural disasters or even new inventions.	Unplanned incidents may occur within the TIS or outside of it but have a direct impact on its formation, reactions from policymakers to these events may also have an impact on the formation of the TIS. Some examples of accidents or events include wars, natural disasters or even new inventions.
8	N/A	External political pressures, such as those from global organisations or other political entities, may influence politicians to take action for or against a certain innovation. Moreover, the global agenda and scientific and technological advances in the world influence companies' decisions on investment and innovation. In addition, the existence of Big Tech may dictate how stakeholders behave and how information is exchanged within a system. All of these global phenomena can directly bolster or block TIS formation.

5.4. Evaluation of influencing conditions

In order to evaluate if certain influencing conditions are creating barriers or working as driving forces for the innovations, a series of aspects were taken into account. These aspects were derived from the definition of each one of the ICs in the TIS framework by Ortt and Kamp and the literature used to adapt them for the Shared framework. They are portrayed in Table 5.4

Table 5.4: Evaluated aspects for influencing conditions

IC	Evaluated aspects
Knowledge of the technology and learning opportunities	Do companies know enough about the technology to develop it? What does the learning curve for the product look like? Is there enough knowledge about its complementary products? Do customers know and understand how the product works? Do policymakers know and understand how the product works? Are policymakers encouraging learning opportunities for companies (e.g. R&D grants)?
Knowledge and awareness of application and market	Do companies know what applications exist for their product? Are companies aware of customer needs and profiles? Are companies and policymakers aware of the relevant actors for the innovation? Are customers aware of the technology's possible applications? Are stakeholders aware of the value the technology may bring? Are there proven markets or revenue streams for the technology?
Allocation of natural, human and financial resources	Are there enough resources (natural, human and financial) to develop the technology? Are there enough resources to market, distribute and provide service to the technology? Are government resources allocated in a position to bolster the technology?
Competition and market modulation	How many competitors exist for the technology in the market? Who are the main competitors for the technology? Are incumbent technologies difficult to compete with? Are there significant benefits from the technology over its competition? Is there competition for production systems? Does the market allow entrance for the new technology?
Macro-economic and strategic aspects	Are economic conditions favourable for the technology? Are market conditions favourable for the innovation? Is there certainty in the business model for the new technology? Are policies driving a greener economic framework?

Socio-cultural aspects and social dynamics	Are there cultural norms that directly interfere with technological adoption? Are stakeholders willing to adopt the new technology? Is the social media discourse in favour of the technology? Is the policy agenda aligned with society's intrinsic values? Are there government relationships with incumbent actors that may block the technology from entering the market?
Accidents and events	Are there important events (such as wars, a pandemic, etc.) that are directly affecting/have affected technological development? Have the government's actions towards these events influenced technological development? Have these events influenced customers' perception of the technology and willingness to adopt it?
Overall global context	What is the overall global opinion of the technology? Are there regulations or laws in other countries that may influence policymakers' standings on the innovation? Are there big research projects related to the innovation going on worldwide? Is the global technological context pushing for the innovation? What are the views of the scientific community on the technology? Is Big Tech involved in some way with the innovation? Are there data protection issues or secrecy required that may slow down the innovation process?

The evaluation of these BBs and ICs can help policymakers to determine where the market failures and externalities for the innovation may stem from, and use the knowledge to select the number and type of policy instruments that will best drive its diffusion (Foray, 2018; Kivimaa & Kern, 2016).

Figure 5.1 shows the revised ICs and BBs that make up the Shared framework.

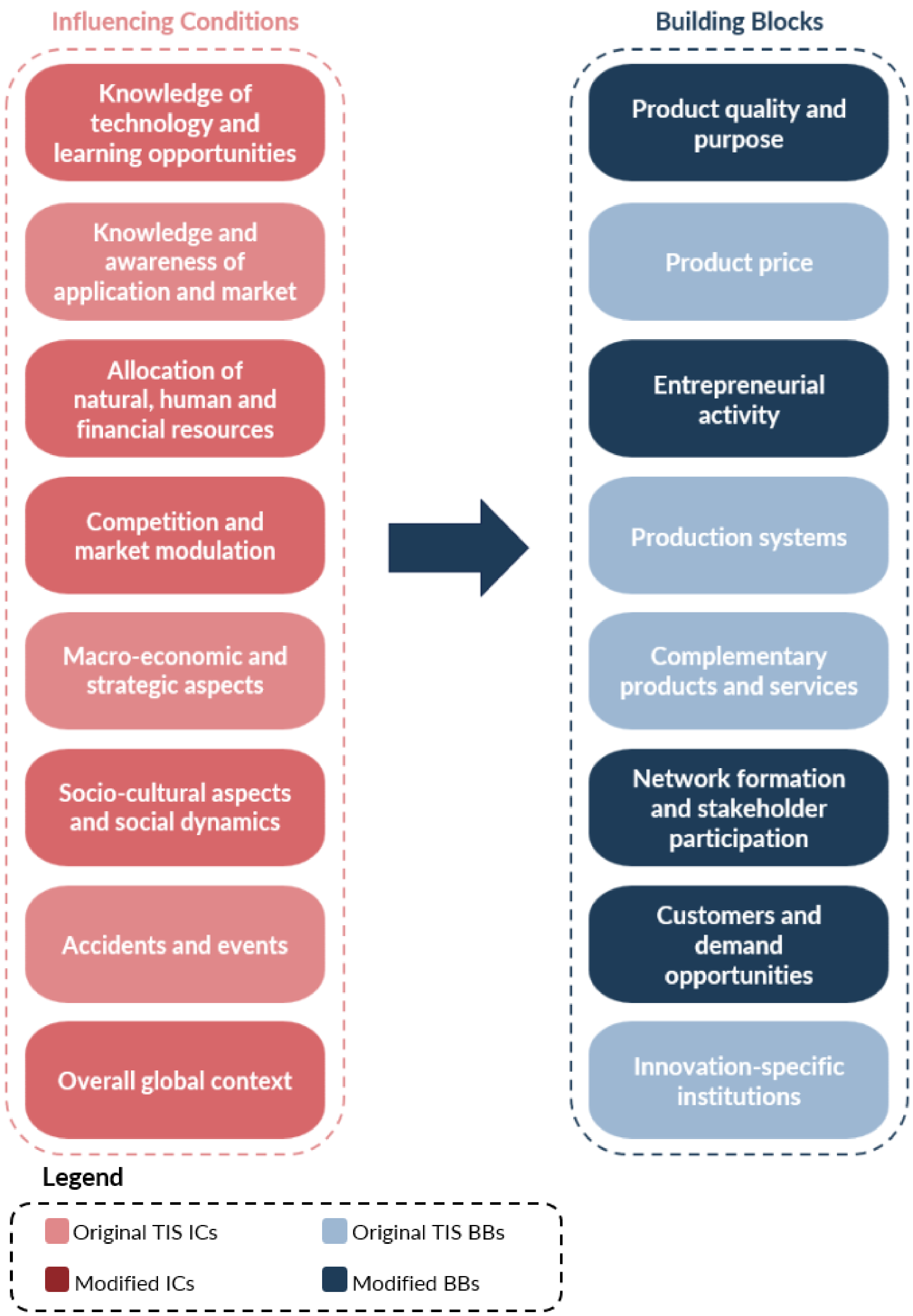

Figure 5.1: Shared framework diagram

5.5. Niche introduction strategies

Niche introduction strategies are mainly relevant for companies since their main goal is to be able to commercialise the product (Ortt et al., 2013), though policymakers also have a role in the implementation of some of these strategies. They may be broadly classified into product-focused strategies, customer-focused strategies and market-focused strategies. An important distinction is found between customer and market, where customers are the individuals who acquire and/or use the technology, while the market is the set of conditions, rules, procedures and practices that surround the sale of the product.

Product-focused strategies

Product-focused strategies are those in which the product itself is modified, altered, or complemented in some way to circumvent or eliminate barriers and to aid in its commercialisation by making it more attractive. These strategies focus on barriers that may help with product quality and purpose (BB1), price (BB2), production systems (BB4), complementary products and services (BB5) or customers and demand opportunities (BB7); mainly when they are caused by ICs 1, 2, 3, 6, and 7 as shown in Figure 5.2.

Product-focused strategies can address quality issues (BB1) by redesigning or modifying the product itself or by providing experimental settings in which the product's benefits are showcased, even if its quality is not good enough to market yet. Modifying a product also impacts its production systems (BB4). If a product is modified to make it simpler, its production system is likely to change to become simpler and will need fewer complementary products and services (BB5).

Regarding BB2, product-focused strategies may help circumvent barriers within it by increasing its ease of adoption or by making it simpler, therefore driving down its costs. If the product's convenience is improved or its price is lowered, then it is also likely that it will appeal to more customers, building BB7.

Strategies that may be included within this category are:

1. Demo, experiment and develop niche strategy
2. Redesign niche strategy
3. Hybridisation or adaptor niche strategy
4. Educate niche strategy
5. Dedicated system or stand-alone niche strategy
6. Turnkey product strategy

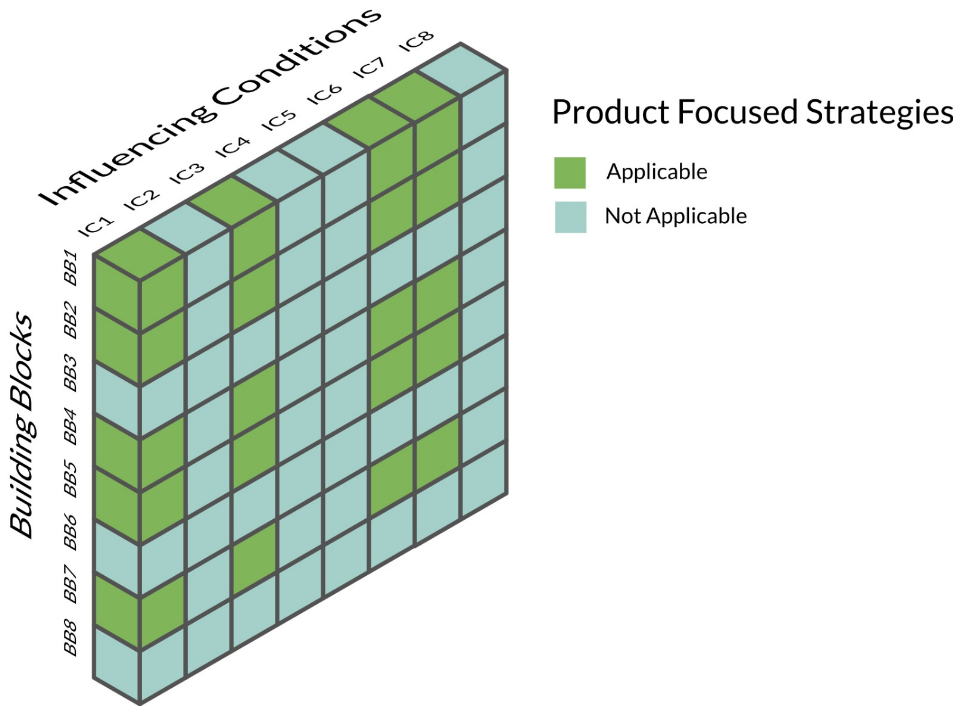

Figure 5.2: Combinations of BBs and ICs for which product-focused strategies are applicable

Customer-focused strategies

Customer-focused strategies consider customers' needs or interests when commercialising a product. These strategies may be employed when the product cannot be directly modified but clients can be persuaded or incentivised to adopt the technology.

Customer-focused strategies can directly help with barriers arising from product quality and purpose (BB1), product price (BB2), and customer and demand opportunities (BB7), mainly when caused by ICs 1, 2, 5, 6, 7, and 8 as shown in Figure 5.3.

The three blocks affected by these strategies are very closely linked since quality, purpose and price all have a big influence on customers and demand opportunities. Customer-focused strategies may target specific customers that are less likely to care about high prices (BB2) or quality issues (BB1), or provide instruments that expand potential demand opportunities (BB7). Similarly, these strategies circumvent pain points for customers like high upfront costs by providing incentives, measures to break down costs, or provide reassurance of return on investment.

Strategies that may be included within this category include:

1. Top niche strategy
2. Educate niche strategy
3. Lead user niche strategy
4. Incentives strategy
5. Preannouncing strategy
6. Crowd-sourcing strategy

7. Leasing strategy
8. Result-oriented contracting strategy

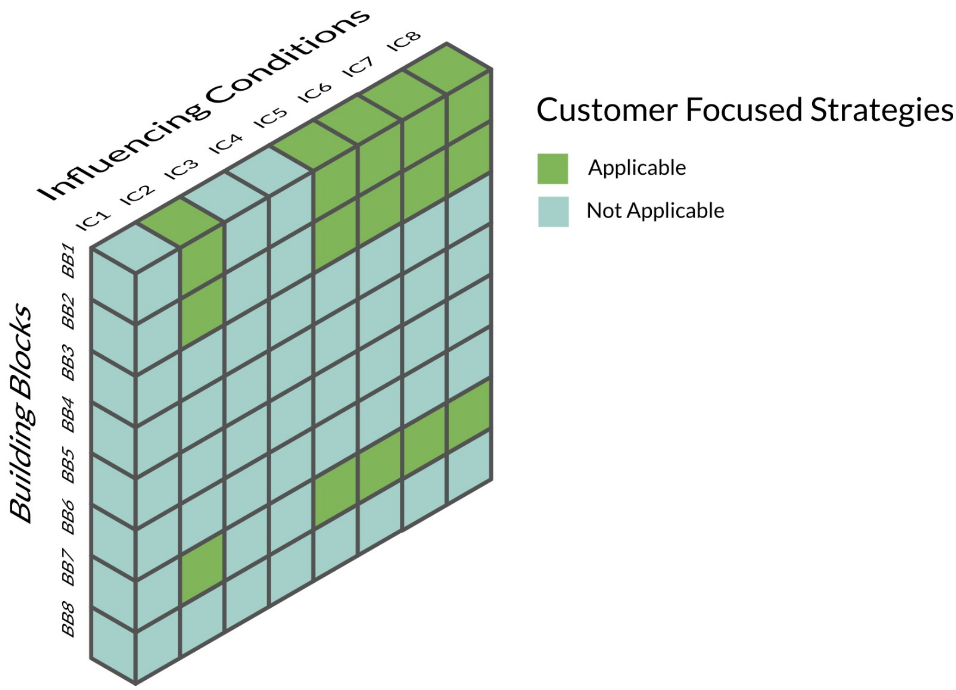

Figure 5.3: Combinations of BBs and ICs for which customer-focused strategies are applicable

Market-focused strategies

Market-focused strategies help address barriers that arise directly from market practices, a lack of market rules or an immature market where the product can be commercialised. Particularly, market-focused strategies aim at removing or bypassing barriers in entrepreneurial activity (BB3), production systems (BB4), complementary products and services (BB5), network formation and stakeholder interaction (BB6), customers and demand opportunities (BB7), and innovation-specific institutions (BB8). These are particularly effective when the cause of these barriers stems from any IC other than a lack of knowledge of the technology (IC 1), as portrayed in Figure 5.4.

Market-focused strategies make it easier for companies to find favourable conditions in which to commercialise their product. This instills confidence in stakeholders and promotes entrepreneurial activity (BB3). Similarly, when there are issues with complementary products and services (BB5) or customers and demand opportunities (BB7), market-focused strategies can help find different applications whose complementary products exist or markets in which there is higher demand for the technology or more favourable rules and regulations (BB8).

Additionally, participating in a market will involve stakeholders interacting with each other and forming networks by nature, which helps build up block 6.

Strategies within this category include:

1. Geographic niche strategy

2. Market positioning niche strategy
3. Preannouncing strategy
4. Public sector participation strategy
5. Leasing strategy
6. Explore multiple markets strategy

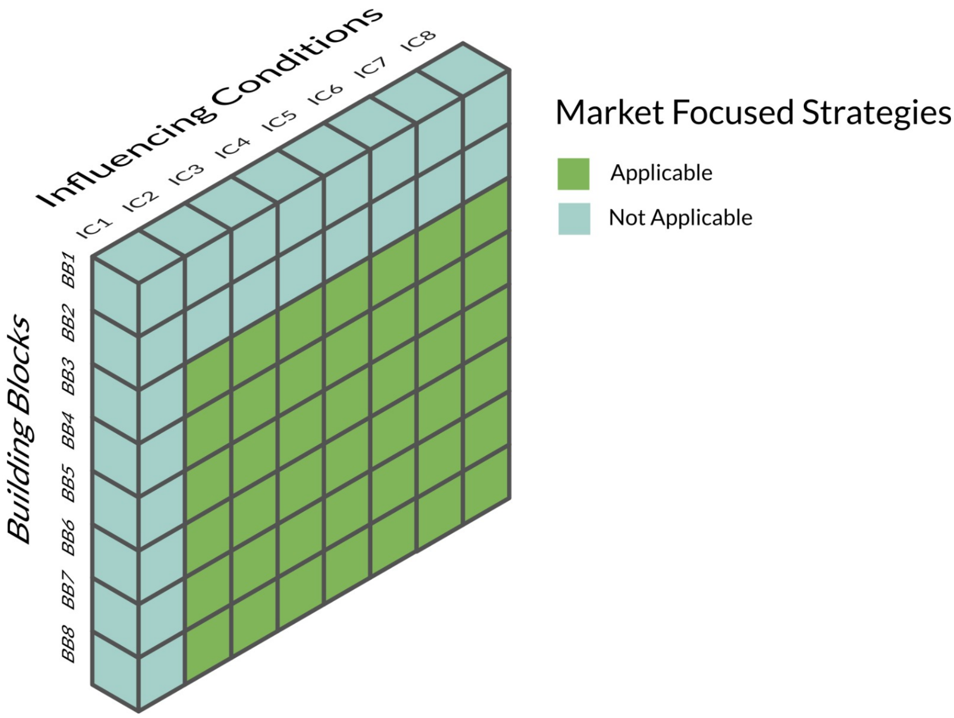

Figure 5.4: Combinations of BBs and ICs for which market-focused strategies are applicable

Table 5.5 shows a summary of the combination of building blocks and influencing conditions that each type of strategy may aid in lowering barriers with.

Table 5.5: Niche introduction strategies applicable for different combinations of BBs and ICs

<table>
<tr><th>Influencing conditions</th><th>Building blocks affected</th><th>Niche introduction category</th></tr>
<tr><td>IC1 Knowledge of technology and learning opportunities
IC3 Allocation of natural, human and financial resources
IC6 Socio-cultural aspects and social dynamics
IC7 Accidents and events</td><td>BB1 Product quality and purpose BB2 Product price
BB4 Production systems
BB5 Complementary products and services
BB7 Customers and demand opportunities</td><td>Product-focused strategies</td></tr>
<tr><td>IC1 Knowledge of technology and learning opportunities
IC2 Knowledge and awareness of application and market
IC5 Socio-cultural aspects and social dynamics
IC6 Socio-cultural aspects and social dynamics
IC7 Accidents and events
IC8 Overall global context</td><td>BB1 Product quality and purpose
BB2 Product price
BB7 Customers and demand opportunities</td><td>Customer-focused strategies</td></tr>
<tr><td>IC2 Knowledge and awareness of application and market
IC3 Allocation of natural, financial and human
IC4 Competition and market modulation
IC5 macro-economic and strategic aspects
IC6 socio-cultural aspects and social dynamics
IC7 Accidents and events
IC8 Overall global context</td><td>BB3 Entrepreneurial activity
BB4 Production systems
BB5 Complementary products and services
BB6 Network formation and stakeholder participation
BB7 Customers and demand opportunities
BB8 Innovation specific institutions</td><td>Market-focused strategies</td></tr>
</table>

5.6. TIS build-up strategies

While niche introduction strategies are important for companies to be able to sell their technological innovation, TIS build-up strategies are more relevant for policymakers since their aim should be to complete the building blocks for the innovation. TIS build-up strategies may be broadly classified into: stimulating R&D and technological knowledge, stimulating market formation and stimulating network formation and growth and stakeholder interaction.

Stimulating R&D and technological knowledge

This category encompasses all strategies that may be adopted by both companies or policymakers and that address barriers related to a lack of knowledge. In particular, strategies that stimulate R&D may directly contribute to complete BBs 1, 2, 3 and 8 when their barriers are caused by influencing conditions 1, 2 or 7, as shown in Figure 5.5.

Stimulating R&D helps build up BB1 by providing instruments that directly address a lack of knowledge of the technology and/or awareness of its application. Building technological knowledge helps firms improve the quality of their product, and align its application and purpose to solve contemporary grand challenges. Similarly for BB2, the more research that is carried out in regards to a technology, the more likely its price will be driven down. As the process along the learning curve advances, the product price will get better.

Regarding BB3, actions and strategies that stimulate R&D are also likely to stimulate entrepreneurial activity. In particular, stakeholders may be hesitant to partake in entrepreneurial activity if there is little knowledge of the technology or its applications. Higher levels of R&D mean more knowledge of the technology, leading to more certainty for stakeholders to partake in entrepreneurial activity surrounding the innovation.

With respect to BB8, a symbiotic relationship between R&D strategies and innovation-specific institutions exists. On one hand, technological knowledge about the product and its possible applications needs to be taken into account when creating policies or laws. If its benefits and applications in a certain category are not known, then it may not be included in policies, laws or regulations within that category. A large part of this knowledge stems from R&D work, thus the strategies in this category could help build up this TIS block. On the other hand, the more laws and policies that exist, the more likely support for R&D in the area will exist.

Strategies that may be included within this category are:

1. Demo, experiment and develop niche strategy
2. Educate niche strategy
3. Technological R&D strategy
4. Finance sourcing strategy
5. Incentives strategy
6. Investments strategy
7. Crowd-sourcing strategy
8. Internal knowledge sharing strategy
9. Human resource management strategy

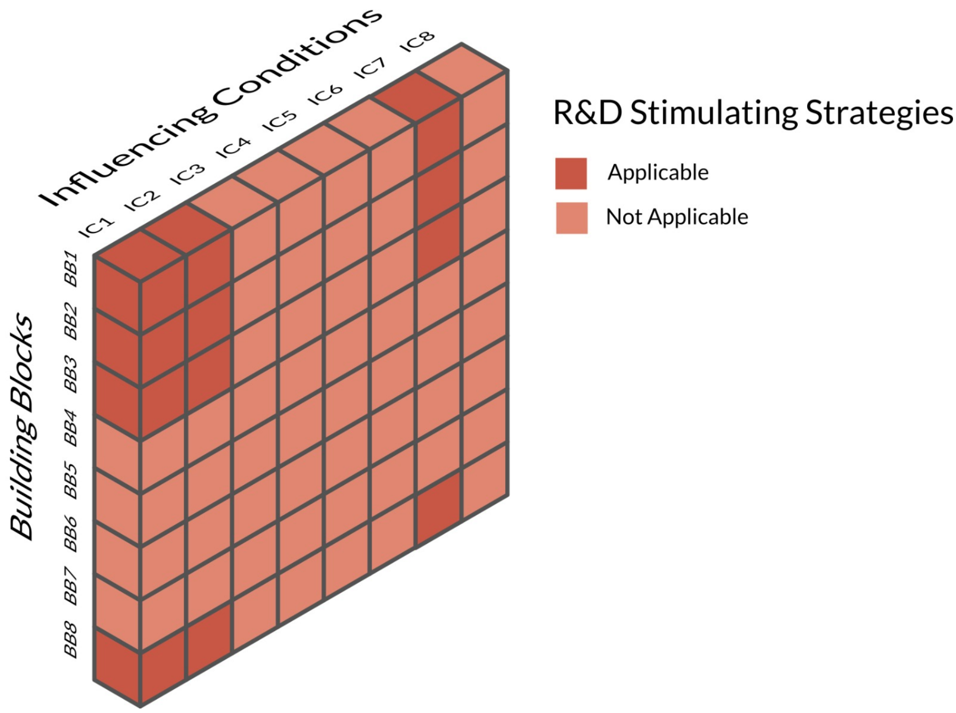

Figure 5.5: Combinations of BBs and ICs where strategies that stimulate R&D and technological knowledge are applicable

Stimulating market formation and growth

Strategies that stimulate market growth help build up blocks that are related to market conditions for the product or circumvent barriers whose root causes may be found in any one of the influencing conditions, though some strategies are more effective in targeting certain ICs. These include barriers in BB2, BB3, BB4, BB5, BB6, BB7 and BB8, as may be observed in Figure 5.6.

Entrepreneurial activity is a fundamental block in the TIS (BB3). It may be built up using several different market formation strategies, regardless of the ICs that cause barriers in it. When a market for an innovation exists and its signals for investment are favourable, entrepreneurial activity will develop naturally.

A more developed market with increased entrepreneurial activity will also contribute to its price being driven down. Likewise, the more developed a market is and the more adapted it is to a specific technology, the more likely production systems and entrepreneurial support for the product will be in place. Thus, blocks 2, 3, and 4 are built up by this type of strategy.

With respect to BB5, a well-developed and mature market contributes to the development of markets for complementary products and services, which in turn strengthens the original market. A mature market with established complementary products then attracts customers and creates demand, hence building up BB7.

As in the previous category, BB8 is bi-directionally related to market formation strategies. A growing market requires standards, rules, and regulations to govern it, thus stimulating their creation. Alternatively, the existence of policies of a certain type will also stimulate market growth, which is why their relationship is reciprocal. Stimulating market growth entails stimulating innovation-specific institutions.

The following strategies may be included within this category:

1. Educate niche strategy
2. Human resource management strategy
3. Finance sourcing strategy
4. Lobbying strategy
5. Changing behaviour strategy
6. Cross-selling strategy
7. Provide guaranteed markets strategy
8. Provide standards and regulations strategy
9. Provide policies to incorporate externalities strategy
10. Existing networks strategy

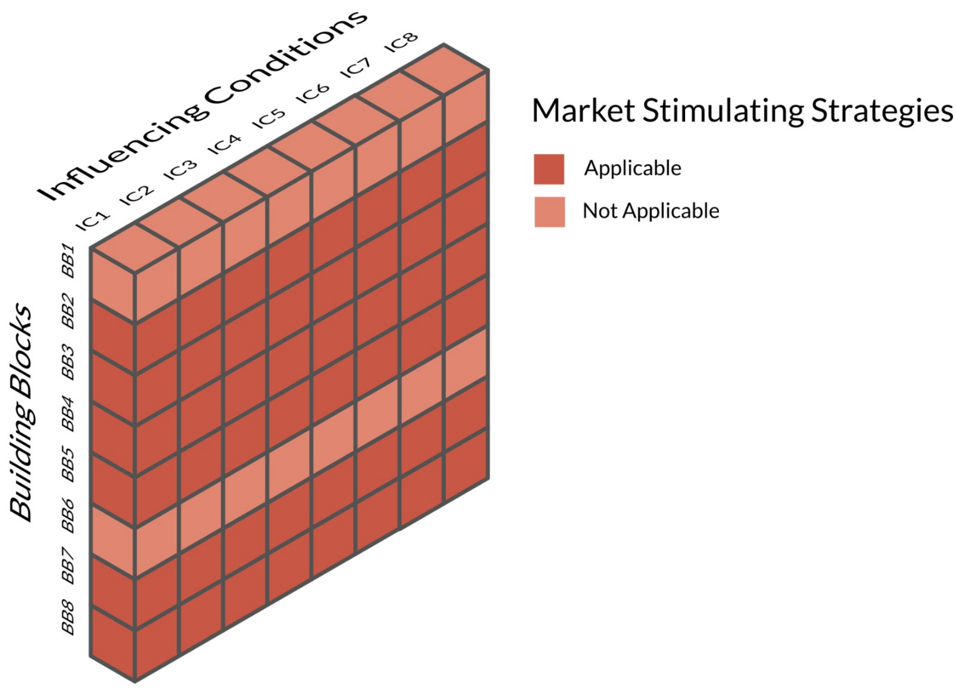

Figure 5.6: Combinations of BBs and ICs where strategies that stimulate market formation and growth are applicable

Stimulating network formation and stakeholder interaction

The last category includes strategies that relate to knowledge diffusion. It includes network formation and any interaction between stakeholders that may help information to travel and spread. These types of strategies may help build up blocks 3, 4, 5, 6, 7, and 8, specifically when their barriers are caused by ICs 1, 3, 4, 6, 7 or 8. These combinations are shown in Figure 5.7

A key aspect within the entrepreneurial activity block (BB3) is using networks to innovate and grow innovation. Therefore, stimulating network formation and stakeholder interaction which is significant in driving entrepreneurial activity.

Every product needs an effective production system and distribution network. When interaction between different actors surrounding said production system is stimulated, a more efficient communication of needs and capabilities will lead to more efficient production systems, addressing barriers in BB4.

A well-formed network of actors is also quite useful in producing complementary products and services, which make up block 5. Since the relationship between an innovation and its complementary products is interdependent, a well-established interaction between stakeholders fosters knowledge diffusion, which in turn makes products complement each other flawlessly.

Regarding BB6, these strategies directly help to build network formation and stakeholder participation. Additionally, increased stakeholder interaction also leads to a better understanding of customers' wants and needs, thus helping to build up block 7.

Finally, with respect to block 8, a well-established network and good interaction between stakeholders can help create policies, laws, and regulations that favour the technology. If several different stakeholders get together to pursue the same goal, regulation in favour of this goal is more likely to be created. Furthermore, if a good relationship between companies and policymakers exists, then the creation of laws and policies is more likely to be effective and address real issues.

Some strategies that fall under this category are:

1. Human resource management strategy
2. Internal knowledge sharing strategy
3. Partnership strategy
4. Lobbying strategy
5. Campaign funding strategy
6. Network building strategy
7. Public sector participation strategy
8. Existing networks strategy

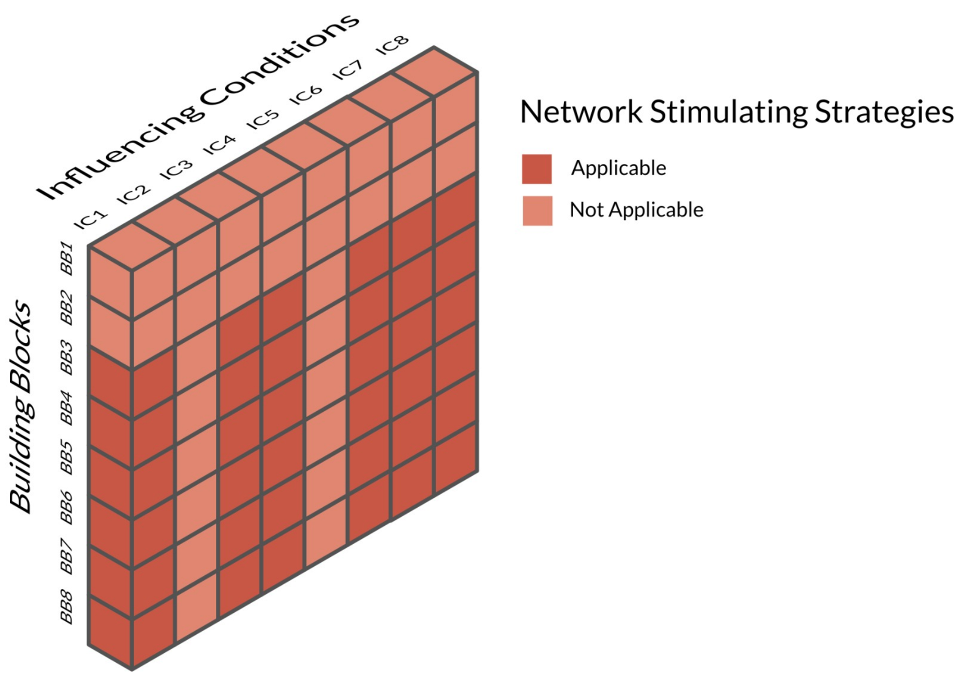

Figure 5.7: Combinations of BBs and ICs where strategies that stimulate network formation and stakeholder interaction are applicable

Table 5.6 shows the building blocks that may be built with each type of strategy and the related influencing conditions which they help address within each block.

Table 5.6: TIS build-up strategies best suited for different combinations of BBs and ICs

Influencing Conditions	Building Blocks affected	TIS Building Category
IC1 Knowledge of technology and learning opportunities IC2 Knowledge and awareness of market and application IC7 Accidents and events	BB1 Product quality and purpose BB2 Product price BB3 Entrepreneurial activity BB8 Innovation-specific institutions	Stimulating R&D and technological knowledge
All influencing conditions	BB2 Product price BB3 Entrepreneurial activity BB4 Production systems BB5 Complementary products and services BB7 Customers and demand opportunities BB8 Innovation-specific institutions	Stimulating market formation and growth
IC1 Knowledge of technology and learning opportunities IC3 Allocation of natural, financial and human resources IC4 Competition and market modulation IC6 socio-cultural aspects and social dynamics IC7 Accidents and events IC8 Overall global context	BB3 Entrepreneurial activity BB4 Production systems BB5 Complementary products and services BB6 Network formation and stakeholder participation BB7 Customers and demand opportunities BB8 Innovation specific institutions	Stimulating network formation and stakeholder interaction

Each block category makes up a piece of a whole block where ICs, BBs and strategies interact, as portrayed in Figure 5.8.

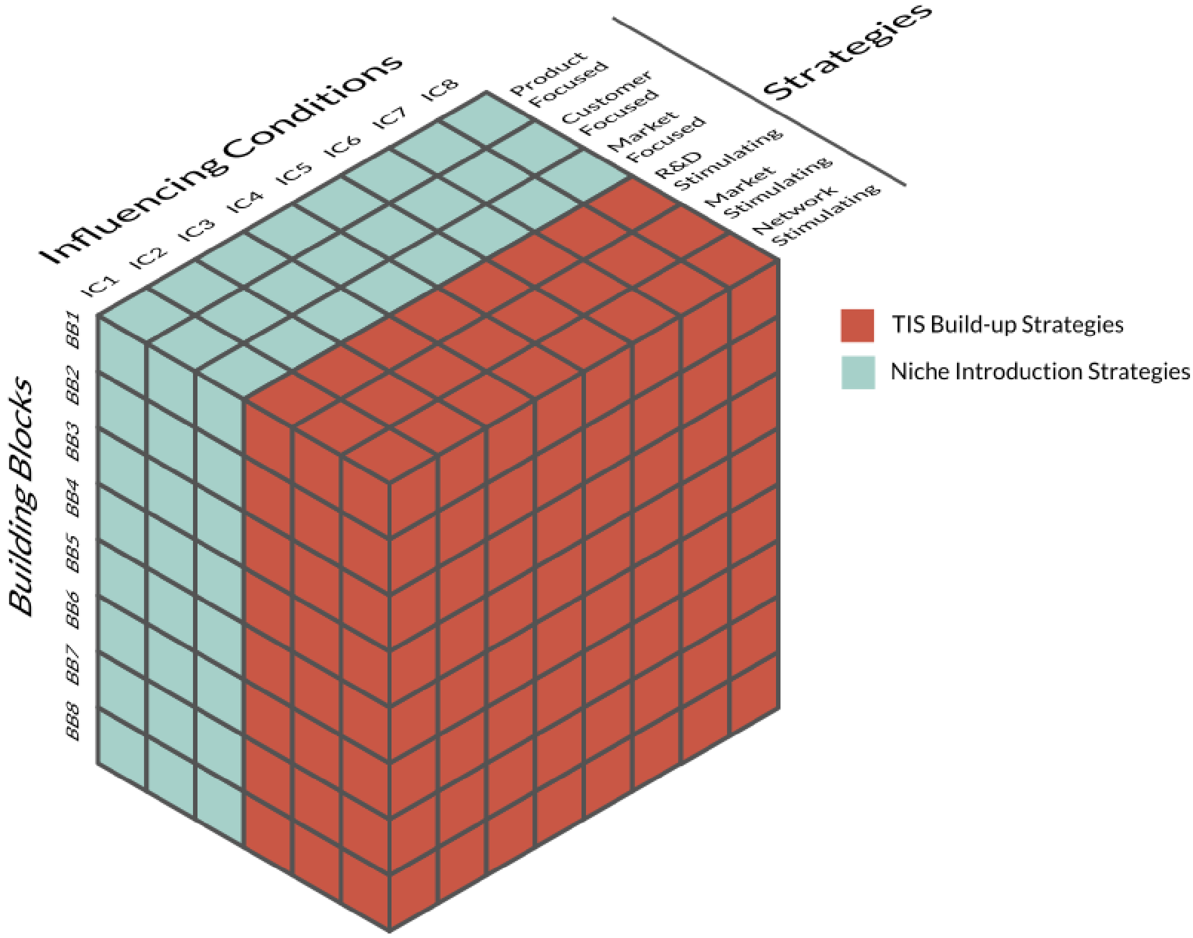

Figure 5.8: Shared framework diagram of BBs, ICs and strategies

5.7. Use of Shared framework

In order to employ the framework in practice, a few steps need to be followed. Ortt and Kamp established a methodology to apply the framework, consisting of four steps. Nevertheless, since this work addresses a knowledge gap pertaining to the inclusion of policymakers and the alignment of strategies between stakeholders, some modifications are required.

The first step is conducting an analysis of the status of each building block in order to determine if it is complete and compatible with other blocks (Ortt & Kamp, 2022). If a block is incomplete or incompatible, then the barriers that make it so must be identified.

The next step consists of evaluating all influencing conditions. First, to pinpoint which conditions are causing each of the identified barriers (Ortt & Kamp, 2022). Even when barriers exist within the same building block, these may be caused by completely different influencing conditions and thus need different strategies to be addressed. Second, to determine if certain conditions are acting as drivers for the innovation rather than causing barriers.

After identifying barriers and their ICs, strategies to confront or circumvent these barriers can be derived (Ortt & Kamp, 2022). When looking for the type of strategies to address each barrier, figures 5.2 to 5.8

may be used as a quick guide. Once the type(s) of strategies that suit the combination of BB and IC are known, the strategies within those categories may be analysed to see which is the best fit for each specific barrier.

When selecting applicable strategies, several options may become available for both companies and policymakers to combat a single barrier. During this process, a crucial action is to analyse the interaction between strategies. Some combinations of strategies from policymakers and companies interfere in a negative way with each other or become redundant, while other combinations complement each other. Therefore, checking the alignment of strategies between both actors is highly relevant.

The final step consists of revising the status of the BBs and ICs periodically (Ortt & Kamp, 2022). As strategies are implemented and the conditions around the TIS change, it is likely that existing barriers will be lowered or eliminated and that new barriers will arise, requiring different strategies to be used. The following table summarises these five steps.

Table 5.7: Steps to use the framework in practice

1.	Evaluate the status of the seven TIS building blocks
2.	Analyse which influencing conditions are causing barriers and which are acting as drivers
3.	Explore possible applicable strategies for each combination of BBs and ICs
4.	Check for alignment of strategies between policymakers and companies
5.	Periodically revise the status of each BB and IC

5.8. Main takeaways from the Shared framework

Innovation is a process that requires collaboration between several different actors to take place. It is so important that most papers talking about innovation include collaboration between stakeholders as a relevant part of their analysis (Geels, 2002; Haddad et al., 2022; Hekkert et al., 2007; Negro et al., 2009; Ortt & Kamp, 2022). Companies are in charge of conducting all the research and actually developing an innovation, while policymakers should create a context conducive for the innovation to thrive. Both stakeholders may benefit from the implementation of strategies to help the innovation while it is still in its adaptation phase.

Ortt and Kamp (2022) created a framework to derive strategies from a company perspective, however, a similar framework for policymakers was missing from literature. What is more, an integrated framework for both companies and policymakers to use was also noticeably absent and, due to the relevance of collaboration highlighted above, this adaptation was made.

A relevant piece of information when applying the framework is that some strategy categories only work when both the affected building block and influencing condition responsible for the barrier are known. This is always true for niche introduction strategies, it is not enough to know the nature of the barrier, but rather its related IC is necessary to determine the type and timing of the strategy (Ortt & Kamp, 2022). However, for TIS build-up strategies this is not always the case. For instance, all the strategies contemplated within the stimulating market formation and growth category apply to blocks 2, 3, 4, 5 and 7 regardless of the IC.

It is also important to remember that the basic structure of the framework is a simplified representation. There is not a single trajectory of 'cause and effect' between ICs, BBs and strategies. Though the typical order is that ICs influence BBs, which together help determine the best strategies to be used, there are feedback loops through all stages. Some BBs or ICs may have influence between themselves, such as an increase in entrepreneurial activity (BB3) may be related to a decrease in price (BB2). The use of certain strategies will likely have a feedback loop on ICs and BBs and vice versa, such as the symbiotic relationship between R&D strategies and innovation-specific institutions (BB8); and the relationship between ICs and BBs may be reversed at times, such as an increase in complementary products and services (BB5) which may use many of the same resources than the innovation itself, which in turn affects the allocation of natural, financial or human resources (IC3).

6

Case study: V2G in the UK

The status of V2G technology in the UK was evaluated through academic literature, company reports, government reports, news articles and seven interviews conducted with experts in the sector. All the consulted sources coincide in it being a relatively new market. Interview participants described it as *'nascent', 'emerging'* and one participant described it as being at the *"Innovation project stage, without large-scale commercial adoption"* (Interview 3).

EV technology and V2G are policy-led technologies due to several circumstances. First, from an economics perspective, the current market under-supplies EVs regarding the socially optimal number; therefore, policy instruments are needed to encourage its adoption (Yannick et al., 2014). Second, according to Sovacool et al. (2018) and Frank et al. (2020), governments are generally the ones that drive sustainable transitions through policy objectives that motivate companies to innovate and establish the direction of change.

Moreover, being a collaborative technology by nature (Høj et al., 2018), V2G needs policies to help coordinate its uptake. Earl and Fell (2019) note that strong leadership from policymakers, along with clear and consistent policies that support the market development, are required in order to see the adoption of EVs for flexibility and *"enable electrification and decarbonisation that the UK requires"*.

In other words, V2G may be considered in the adaptation phase of its technological development and requires significant collaboration between policymakers and companies to diffuse. As such, the Shared framework is appropriate for evaluating the TIS status, which will be presented in this chapter. Section 6.1 evaluates the status of each individual building block and the existence of barriers within them; when barriers are identified, the main influencing conditions behind them are also presented. Particular cases in which influencing conditions are found to be drivers rather than barriers may be found in section 6.2.

6.1. Status of building blocks

Each building block is individually evaluated in this section, providing information on its current status and the existence of barriers preventing it from being complete. The evaluation of building blocks was carried out by analysing the set of indicators provided in the previous chapter, as well as through inductive reasoning from the conducted interviews.

A technological delineation is relevant to mention here, since V2G is a technology comprised of several different components. In this analysis V2G comprehends the electric vehicle, the charging equipment and the communication technology used to control charging cycles and exchange data with the grid and other servers.

It is important to include, as well, the fact that the identified status of the building blocks and their associated barriers is for V2G technology in general in the UK. Specific applications of V2G (fleets, passenger vehicles, etc.) may bypass some of the general barriers and/or have some specific barriers of their own. For instance, refuse collection trucks have a very predictable schedule and route, so range anxiety is not likely to be an issue, but bigger batteries for heavy-duty transport are much more expensive, which will be a case-specific barrier (Veolia, 2024). Another example is observed in the case of retired professionals who can obtain great value from V2G; cost and range issues are not likely to be barriers, but a reluctance to learn how to use new technologies could be (Cenex, 2021).

6.1.1. Product quality and purpose

Product quality and purpose is a divergent block with strong driving elements but important barriers as well. The identified drivers and barriers are presented in the analysis of each of the indicators below.

What is the overall quality of the product?

At the moment, quality for V2G in the UK is promising, with several different trials that have demonstrated that the technology works (Octopus Energy, 2023b; V2G Hub, 2023) and can provide the same (or higher) level of service as competing technologies, such as smart charging or static energy storage. What is more, its ability to aid in the decarbonisation of the transport sector and the integration of renewable sources renders it increasingly appealing over incumbent short-term grid balancing technologies, such as natural gas plants (Interview 5) (Cenex, 2022a; Energy Saving Trust, 2022). Despite its proven functionality, several barriers still exist within this block that cause it to be incomplete.

One of the barriers most often mentioned in literature are range issues, which encompass low vehicle ranges and what is commonly referred to as 'range anxiety' (Energy Saving Trust, 2022; Lucas-Healey et al., 2022; van Heuveln et al., 2021). This term refers to users being unsure the vehicle will be ready for use at the moment that it is needed and/or its state of charge (SoC) will not be enough to cover the intended distance. These issues, though, are already being overcome. A few years ago, when trial projects started, the mainly available vehicles were Nissan Leafs with 40kWh batteries (Miller, 2023a; Octopus Energy, 2023b); however, the average EV battery range in 2023 surpassed 60kWh (Bloomberg NEF, 2023; European Commission, 2024), and new V2G-capable vehicles coming onto the market in 2024 have on average 77 kWh batteries, providing a much broader driving range (around 350 km) to customers.

Range issues stem mainly from a lack of knowledge of the technology from a customer or company perspective (IC1). When users have a difficult time understanding a technology they tend to be 'overly cautious'. An example of this arose in a pilot project where customers tended to accept a lower charging threshold when it was expressed as minimum distance rather than minimum SoC (Energy Saving Trust, 2022). On the other hand, for users who need to travel long distances frequently using a large percentage of their battery power or users who have uncertain schedules, the barrier changes to a lack of availability of models with larger ranges, which is caused by a lack of knowledge on the company side (IC1). Nevertheless, new vehicles with larger batteries are already solving these issues.

Another commonly found concern among customers relates to battery degradation (Earl & Fell, 2019; van Heuveln et al., 2021). This refers to worries that a constant cycling of the EV battery will result in faster degradation than through regular use, and therefore significantly diminish its lifespan.

As with the previous barrier, battery degradation is also rooted in a lack of knowledge, however, both on the customer and company side (IC1). Several different studies have proven that the 'gentle cycling' of frequency regulation services provided by V2G can actually be better for the battery than the more common practice of using the vehicle until the battery is running low and charging it to full again once this happens (Cenex, 2022a). This is due to the shallow depth of discharge that occurs when the vehicle is providing V2G services where the battery's SoC oscillates between 30% to 80% (Miller, 2023a).

Nonetheless, other applications of V2G may result in higher levels of battery degradation than regular use (Høj et al., 2018), and therefore user hesitancy is justified. A workaround, in this case, could be extended warranties that cover V2G applications from the EV that some vehicle OEMs are already offering. However, the barrier remains since most OEMs *"still don't have much data from out in the field, and therefore they find it difficult to really well define what warranty they're prepared to put on, given [that] they don't know how expected usage profiles will actually impact the battery"* (Interview 5).

Is the product reliable?

An often-mentioned issue in V2G trial projects is the lack of reliability that the technology exhibited in pilot projects. From miss-communication between the controlling application, vehicle and charger (Energy Saving Trust, 2022) to the reliability of the charging hardware itself (Cenex, 2022a). Issues with reliability left users with a lower SoC in their vehicles than was needed, therefore interfering with their plans and routines (Cenex, 2022a; Energy Saving Trust, 2022). Other issues with reliability included: vehicles that didn't charge/discharge to the desired threshold, frequent disconnection from the internet and incorrect energy exchange information displayed on reports (Octopus Energy, 2023b).

After analysing the influencing conditions, it is clear that this particular barrier is mainly rooted in IC1, a lack of knowledge of the technology. Being a radically new innovation, it is normal that issues arise during the first rounds of trials since developers don't know whether an innovation will work until they test it. In this case, issues in reliability stemmed mainly from a lack of knowledge on the best way to coordinate the vehicle, control application and charger, and a lack of knowledge of what unreliable internet conditions could cause.

Nonetheless, reliability issues faced within the trials served as a guidepost for companies, and several of them worked on correcting the errors that arose during the pilot projects to make the technology more reliable overall (Interview 4).

Is the product easy to use?

Another found objection relating to quality is the complexity of the user interface when interacting with the technology (Energy Saving Trust, 2022; van Heuveln et al., 2021). When using the technology customers want an easy and intuitive way to control it, without several parameters to control or change. Users tend to prefer a 'set-and-forget' type of interface (Miller, 2023b).

In the studied pilot projects, some trials did not even have applications or simple user interfaces that could help control the charging and dis-charging in a simple way (Cenex, 2022a). In others where applications were available, there were issues with the interfaces where not enough options to set preferences existed, but other set-ups had too many complicated steps (Energy Saving Trust, 2022). In general, a difficulty in installation and initial set-up of the technology was perceived, with the user interface ranking as the highest downside perceived by users in the Powerloop pilot project (Energy Saving Trust, 2022; van Heuveln et al., 2021).

Three different influencing conditions are at play to cause a barrier for ease of adoption. First, a lack of knowledge and understanding of the technology from consumers (IC1). Second, a lack of awareness of the market from technology providers in the form of not recognising the customer's wants and needs (IC2). And third, socio-cultural aspects and social dynamics (IC6), since there is a tendency in present-day society to want all things to be effortless and simple.

These barriers, however, have also been identified by technology providers and several different companies are making an effort to create simpler value propositions and ways of interacting with the technology (Interviews 1, 2, 4, 5).

What are the product's benefits over its competition?

V2G technology poses a couple of important benefits over competing technologies, which makes this indicator a positive point in the building block. One important advantage that V2G has over other forms of demand-side flexibility, such as peak-load shifting, is the benefit it provides to the environment. By helping with EV adoption (E-Flex, 2020) and integration of renewable energy into the grid (Sovacool et al., 2018), V2G serves an important purpose for sustainability.

Particularly over stationary storage systems, V2G poses the benefit of serving multiple purposes. While an electric vehicle's main purpose is mobility, their idle time gives them great storage capabilities. According to Meelen et al. (2021) cars in the UK sit idle for 96% of the time, meaning that people with EVs are already in possession of a storage system that could power more than one home. *"A lot of people were realising that [they] already have cars, they don't need to have another battery on top of that"* (Interview 6).

Another benefit over competing technologies is the integration with self-consumption and renewable systems (Interview 7) and the potential to earn higher revenue than other similar technologies, such as smart charging. *"It allows you to continue providing flexibility, even after your battery is fully charged [...] It's earning revenue potential [is] greater than unidirectional smart charging, which makes sense"* (Interview 3).

Does the product serve a purpose aligned with strategic goals?

V2G is a technology that aligns very well with relevant societal goals such as the energy transition towards renewables (Sovacool et al., 2018) by aiding in the integration of EVs (E-Flex, 2020), providing grid stability services (Rehman et al., 2023) and contributing to demand-side flexibility (Earl & Fell, 2019). Its environmental benefits are one of the main reasons users join pilot projects (Energy Saving Trust, 2022; van Heuveln et al., 2021) since early adopters of the technology tend to be more environmentally aware (Earl & Fell, 2019).

What is the public opinion of the technology?

Although, in general, public opinion of the technology is good in the sense that people are excited about V2G, especially for the social contribution that they can make through it (van Heuveln et al., 2021), there is still some wariness of the technology.

Has the product's technological performance increased through time?

This indicator is evaluated in a very positive way for V2G since its increase in performance through time has been impressive. Several of the interview participants mentioned that significant barriers that existed for V2G in the UK back in 2018 when pilot projects were first starting, were no longer a relevant concern at present since technological performance has greatly improved in the past six years (Interviews 1, 2, 3, 4, 5).

BB status

Evaluating all the indicators that make up this block, it can be concluded that it still incomplete. There are important quality elements missing such as higher reliability and more user-friendliness, but the industry is already working to address these concerns. Nonetheless, in terms of purpose and public opinion of the technology, V2G has a positive standing.

The status of the block is depicted in Figure 6.1.

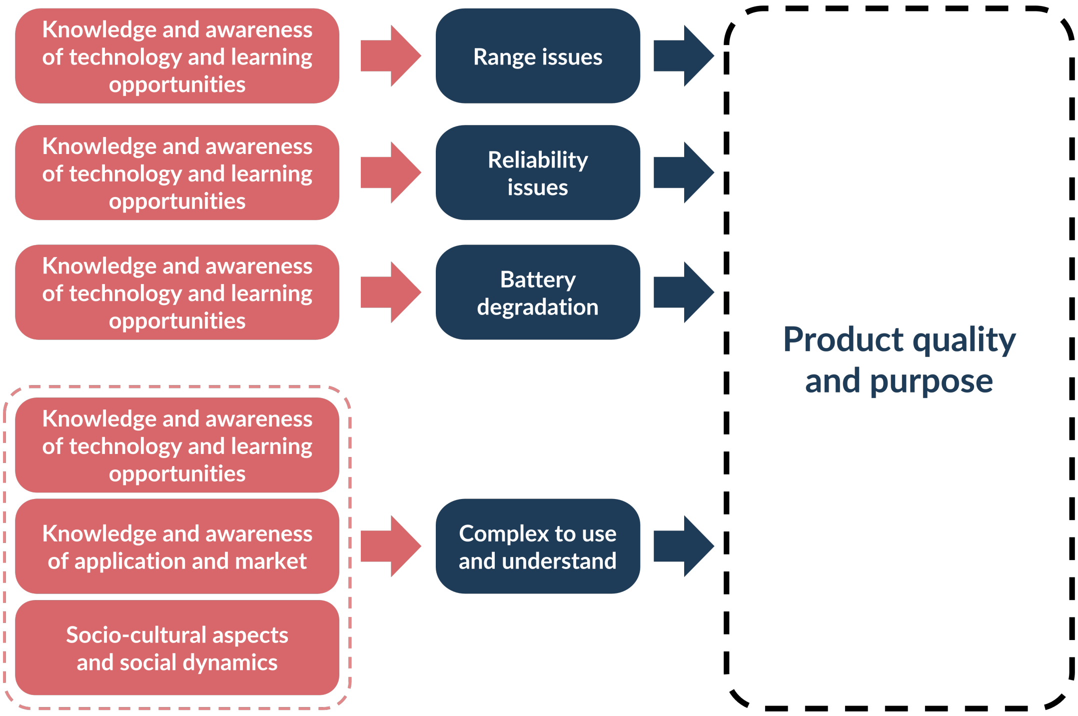

Figure 6.1: BB1: Product quality and purpose with identified barriers and ICs

6.1.2. Product price

Product price is one of the most barrier-laden blocks for V2G technology, according to consulted sources. Even with EV prices going down dramatically over the past decade, price-parity with ICE vehicles has not been achieved yet (Bloomberg NEF, 2023). What is more, bi-directional capable chargers are still more expensive than regular uni-directional ones (Thomas et al., 2023). The analysis of each of the indicators within this block provides further insights into its overall price.

How attainable is the product price?

As mentioned before, V2G technology in this work comprises the EV, charger and communication technologies, which means that the cost of these three elements must be taken into account.

Although EVs have a significantly higher up-front cost than ICE vehicles (Bloomberg NEF, 2023), a study conducted by the Nickel Institute (2021) running different scenarios shows that EVs in the UK have an average Total Cost of Ownership 20% lower than ICE vehicles, mainly due to much lower maintenance and fuel costs (Banks, 2021). Although an EV is less expensive over time, few customers are willing to pay the higher up-front costs, which portrays a relevant issue (Interviews 1, 3, 5).

The high costs of EVs is mainly rooted in a lack of knowledge of the technology (IC1) and availability of resources (IC3). The learning curve of EVs (and its components) is still developing since the technology has not yet reached a point of mass market. Furthermore, batteries in EVs use rare and expensive materials such as lithium which drives up the price (Rehman et al., 2023).

While this barrier mentions EVs in general, currently there is no price distinction between V2G-capable EVs and regular EVs (Banks, 2021) and is therefore considered applicable in both cases. However, an important note to add here is that whether the dominating charging architecture will become AC charging or DC charging is still undefined. If it becomes AC charging, then significant cost increments may be seen in EVs due to the need for an onboard inverter in the vehicle. If DC charging becomes the main standard, then the high costs will be translated to charging equipment (Van Eijk, 2024).

Chargers also present a price barrier, since the cost of uni-directional chargers is £900 - £1,000, while bi-directional chargers can cost around £4,000 (Weiss, 2022). In addition to this, bi-directional chargers are not widely available yet, so the cost of acquisition is very steep as well. A study conducted by (Cenex, 2022b) states that the V2G premium over smart uni-directional chargers needs to be lower than £2,000 for the technology to be accepted to the mass market. Despite these numbers, one of the interview participants said that cost and availability of chargers are not likely to be an issue for long since *"charger manufacturers are struggling to find differentiation factors for themselves and V2G is definitely one"* (Interview 1), and the same study by Cenex expects this premium to be under £1,200 before 2030.

These high technological costs for bidirectional chargers come from macro-economic and strategic aspects (IC5). Companies do not have certainty of whether market conditions will be favourable for them and some uncertainty is rooted in the current transition of CHAdeMO standard towards CCS and the debate of AC vs DC charging (Interviews 2, 4, 5). Manufacturers are hesitant to commit efforts towards one type of V2G and have the market move in a different direction.

The last element is communication technologies. These, however, are not likely to be available at an extra cost but rather come as a part of a contract with an energy supplier such as Octopus (Octopus Energy, 2023b) or as an independent application from software developers such as Crowd Charge and Enode (Crowd Charge, 2022; Enode, 2022). Moreover, the rise of telematics worldwide has made these technologies widely available and may serve as a driver rather than a barrier for V2G (Meelen et al., 2021).

What are the main costs of installation?

The high cost of installation for V2G also poses an important barrier noted by both consumers and EV manufacturers (Earl & Fell, 2019; Energy Saving Trust, 2022), although in this case only the charging equipment requires installation and therefore is the only cost that needs to be considered. Installation of a charger may cost about £350 on average; however, several charge equipment manufacturers and retailers tend to bundle cost of installation with the purchase of hardware which can lower the cost of installation (Ogden, 2023).

A lack of skilled human resources (IC3) may be behind the high costs of installation for chargers. Installation requires technical knowledge of electricity connections, among other things, and one mistake could potentially interfere with energy supply or damage the charger itself, which is very expensive. Therefore, a trained specialist is required for the job and therefore increases costs of installation.

How complicated is it to learn to use the product?

Day to day use of V2G technology is not complicated and requires little effort and time from end-users, apart from setting charging thresholds and time of use preferences, there is no need for much interaction (Interview 4). However, the knowledge required to understand the technology itself, how it works and what benefits it may bring is an entirely different matter. Understanding V2G technology at present is not simple for people with little knowledge of the energy sector and as one Powerloop pilot project user stated *"As an early adopter, I could never recommend this to my less technical friends"* (Energy Saving Trust, 2022).

A barrier in this regard is formed from a lack of knowledge of the technology (IC1) and a lack of knowledge of possible applications (IC2), both conditions on the user side. In general customers have a lack of understanding of how the technology works, the benefits it has, and the possible applications which may bring them revenue (Interviews 2, 4, 5, 7).

What are the main transaction costs?

The case for transaction costs for V2G is a particular one. Since it is made up of three main elements, costs for each one must be taken into account; however, since the elements that conform it are already existing and part of purchasing an EV, there are no new transaction costs specific for V2G technology. Rather, transaction costs for V2G are likely to be the same as for regular EVs and standard uni-directional chargers, therefore these costs do not pose a significant barrier to V2G technology.

Are there subsidies available to offset the price?

The UK government is very committed to innovation and technological development, as well as diffusion of new, sustainable technologies (Meelen et al., 2021). As part of this commitment, different subsidy schemes have been in place for several years to support customers in the acquisition of electric vehicles, charging equipment and charging installation.

A few examples of available subsidies are the “Electric vehicle chargepoint grant for renters or flat owners”, which provides a grant to install a charger at home covering 75% of the purchase and installation costs up to £350 (UK Government, 2023a); the “Electric vehicle infrastructure grant for staff and fleets” (UK Government, 2023b), which is destined to small and medium-sized businesses looking to electrify their fleet; and the “Plug-in Grant”, which helps with the acquisition of low-emission vehicles such as EVs (UK Government, 2023c).

Although subsidies for components of V2G technology are in place, subsidies for the technology as a whole do not exist yet in the UK (Interview 7). Moreover, the existing subsidies for chargers cover a very small amount compared to the total cost of bi-directional chargers. This means that although some financial aid is provided for V2G in the UK to help build up the price block, the existing subsidies are not enough to counteract high technological costs.

BB status

The price building block can also be classified as partially complete. Although the financial and non-financial costs of acquiring the technology are still steep, efforts are being made by different stakeholders to bring those costs down and there are some subsidies to help cover some of the costs. In addition, experts expect that V2G technology prices will have an important decline in the coming years.

The status of the block is depicted in Figure 6.2.

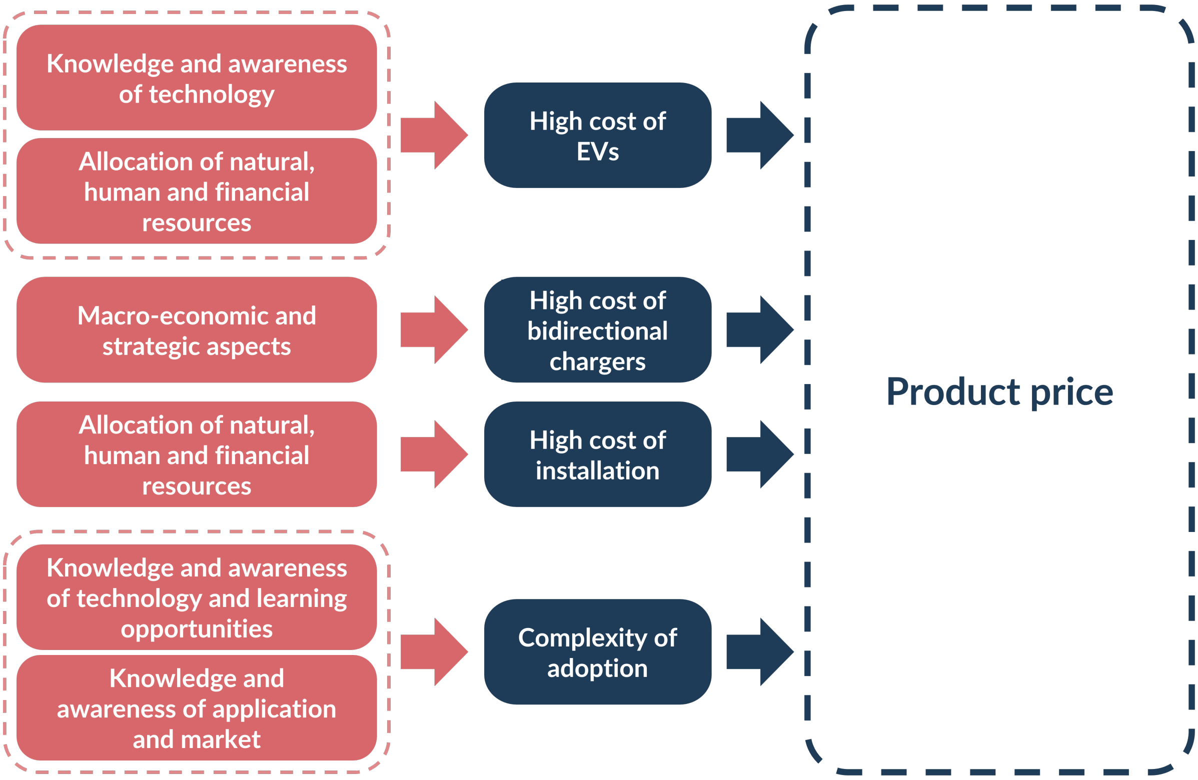

Figure 6.2: BB2: Product price with identified barriers and ICs

6.1.3. Entrepreneurial activity

The level of activity for V2G in the UK was described as *"the most activity in vehicle-to-grid probably in just about any country"* (Interview 2). This is good news for the technology since this block is the first that needs to be complete, if there are no entrepreneurs interested in a technological innovation, then it is not likely to survive. The level of completeness of the block is evaluated through the following indicators.

To what extent is there entrepreneurial activity present?

V2G has an important amount of entrepreneurial activity in the UK, with more than 28 pilot projects conducted, one of the highest in the world (V2G Hub, 2023). These projects have gathered a large number of stakeholders interested in the technology. From small start-up enterprises to incumbent actors to policymakers, the level of interest in the technology within the UK is significant (V2G Hub, 2023), which in turn drives up entrepreneurial activity.

How many entrepreneurs are interested in the technology?

As demonstrated by the amount of companies that partook in the V2G pilot projects, there is a lot of interest in V2G within the UK. Energy suppliers that serve the role of aggregators are starting to create, or already have in place, energy tariffs to encourage V2G technology and applications to control communication between charger, vehicle and grid (Octopus Energy, 2023b; OVO Energy, 2023).

A barrier within this indicator was the limited choice of vehicles that was expressed as a downside in most trial projects, since only the Nissan Leaf was V2G-capable at the time (Energy Saving Trust, 2022; Meelen et al., 2021). At present, there are over 130 EV models available in the UK (Lucas-Healey et al., 2022) and over the past two years several automobile manufacturers have expressed plans to introduce V2G-capable cars in the near future or are already participating in V2G trials in other countries. Some of the commercially available vehicles (existing and announced) may be observed in Table 6.1.

Table 6.1: List of commercially available V2G-capable vehicles, adapted from Thomas et al. (2023)

OEM	Model	Year	Charging standard
Nissan	Leaf	2013	CHAdeMO
Mitsubishi	Outlander	2018	CHAdeMO
Volkswagen	ID.5	2022	CCS
Volkswagen	ID.Buzz, ID.3, ID.7	2023	CCS
Cupra	Born	2023	CCS
Volvo	EX90	2024	CCS
Kia	EV9	2024	CCS
Hyundai	Ioniq 5	2024	CCS
Hyundai	Ioniq 6	2024	CCS

However, even with these announcements a major barrier is still perceived by all interviewees in regards to vehicle availability. Similarly to high charger costs, this barrier stems from macro-economic and strategic aspects (IC5). The uncertainty of the future charging standards and the AC/DC debate have made manufacturers hesitant towards committing efforts towards one type of V2G (Van Eijk, 2024).

Is it economically feasible to adopt the technology?

Lack of trust in the business model for V2G is still an important barrier to overcome in the UK (Miller, 2023a). Relevant stakeholders still have some uncertainty in the business plan for the technology (Meelen et al., 2021) or a lack of confidence in creating their own value proposition (Interview 1, 2, 4, 5, 6).

This nervousness around the V2G business model has its cause in two different influencing conditions. First, a lack of awareness of application and market (IC2), since there is still not enough data from out in the field to solidly support whether there is enough value in V2G for all stakeholders involved and if the cost/benefit is worth it (Interview 1, 6). Second, macro-economic aspects (IC5), since there is still uncertainty of whether market conditions will be favourable for their innovation (Miller, 2023b), (Interview 1, 2, 4, 6).

Even so, V2G technology has been proven to be *"technically feasible and economically viable"* (Earl & Fell, 2019) in several different studies and trial projects around the world. A study conducted by SmartEn and DNV (2022) shows that smart charging along with V2G can lead to a cost reduction of 48% per year in consumer's energy bills. Further studies also show that V2G could save the UK up to

£40 billion by 2050 (Octopus Energy, 2023c).

How many pilot projects and experiments exist for the project?

Regarding pilot projects for V2G, *"the UK has been at the forefront with a lot of V2G projects that came out of the UKRI Competition in 2017"* (Interview 1). Some of these projects were delayed, and their results were affected due to the COVID-19 lockdown, causing a barrier at the time stemming from the worldwide event (IC7) (Cenex, 2022a). However, with more than 28 trial projects complete at the moment (V2G Hub, 2023) spanning the residential sector, light-duty vehicle fleets and even heavy-duty fleets such as refuse trucks (Veolia, 2024), this indicator can be deemed fully complete.

Are there enough entrepreneurial support instruments (grants, loans, etc.)?

The UK government has provided several research grants and created different initiatives to support the development of the technology. The main instrument being the "Innovation in vehicle-to-grid (V2G) systems: real-world demonstrators", which ran in 2017 and provided £20 million to companies with innovative projects that developed V2G products, services and knowledge (UK Government, 2017a). This competition is where several important V2G pilot projects stemmed from and has been crucial for entrepreneurial activity: *"New businesses have been formed around that [competition], and you've seen companies that really have launched full products off the back of that innovation funding"* (Interview 2).

More recently, the UK government established the "V2X Innovation programme: bi-directional charging demonstrations" which will provide up to £9.4 million in grants to small-scale demonstration projects of V2X (including V2G) (UK Government, 2023f).

BB status

The entrepreneurial activity building block can be rendered virtually complete since the the UK is one of the countries with highest number of V2G pilot projects in the world, and its government has provided different measures to support its technological development. As a result, several different companies have sought to establish themselves within the country to further develop the technology and have obtained the knowledge to keep improving it. Moreover, several car manufacturers, energy suppliers, and other important stakeholders have announced short-term releases of V2G-capable products. Only one important issue remains which is that of hesitancy from companies to engage in further production while charging standard issues remain unclear.

The status of the block is depicted in Figure 6.3.

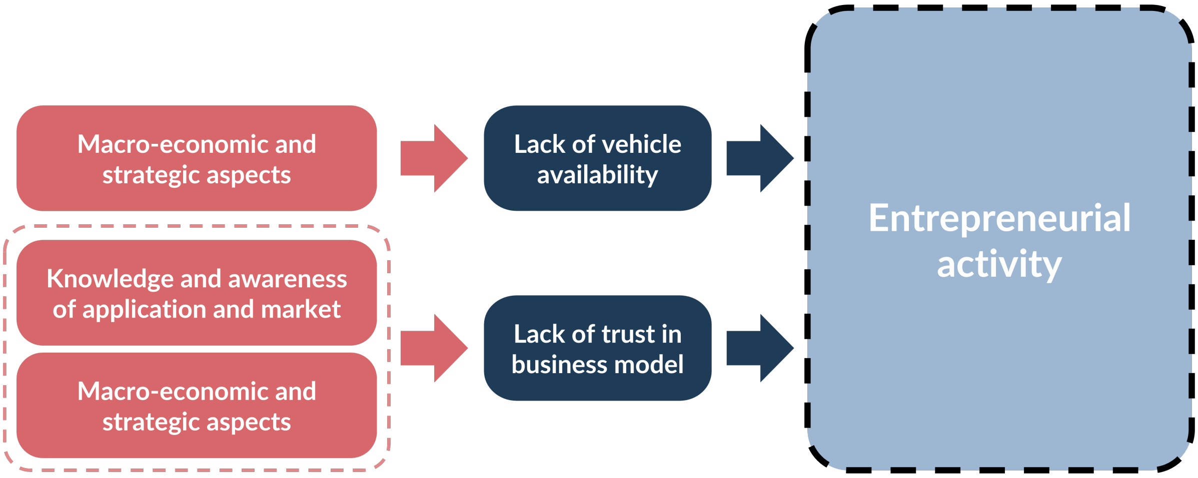

Figure 6.3: BB3: Entrepreneurial activity with identified barriers and ICs

6.1.4. Production systems

V2G technology makes use of the pre-existing production systems belonging to EVs, EVSE and energy suppliers' software development, although with the added complexity of having to adapt certain elements. Since all of these production systems are already in place, there is already an element of completeness for this block. However, all the relevant barriers that exist in any of these elements' production systems is also a barrier that exists for V2G. The following indicators provide an overview of the status of production systems for V2G in the UK.

To what extent are production systems in place?

Production systems for all the technological components that conform V2G are already in place and work efficiently (Ernst & Young Global Limited, 2023). This knowledge is likely to permeate to production systems for V2G-capable components as well, although a barrier may be formed when V2G-capable production systems start competing for resources with non-V2G-capable production systems. This barrier would then be influenced by competition (IC4) and allocation of resources (IC3).

Are there enough physical resources?

Physical resources for V2G technology in the UK exist and are ever growing. Since the resources necessary to produce V2G technology are the same as those for producing EVs, EVSEs, these are the resources analysed. Communication technologies also form a part of V2G, however there are no physical resources directly necessary for their development.

Regarding EVs, there is a conflict in the availability of resources (IC3). The most hard to come by resources for EVs tend to be batteries, but the owners of Jaguar Land Rover have announced the development of a factory with the ability to produce 40GWh of battery cells for EVs annually (Roberts, 2023). However, important minerals required for the elaboration of batteries (such as lithium, cobalt, etc.) are finite resources and as their demand increases rapidly, they will likely become more difficult to obtain in the coming decades (Steckelberg, Dormido, Mellen, Rich, & Brown, 2023). Even so, their availability is not a barrier that currently plagues V2G. Furthermore, several EV manufacturers are already making recyclable batteries, which will mitigate resource shortages.

With respect to chargers, the materials used are more common and less likely to be in short supply in the future. These materials include copper and plastic for wiring and aluminium or steel for structures and other elements (Rocky Mountain Institute, 2023).

Is there enough trained manpower to satisfy the growing demand of the product?

The adoption of V2G technology requires a skilled, specialised workforce. Since the technology involves several different components, people who work with it need to have knowledge in several different fields and an excellent understanding of its function, purpose, and functionality.

Among the skills required in the workforce are knowledge of the electricity grid, how it works and regulations such as grid codes; knowledge and understanding of the services V2G can provide and market mechanisms available to them; and knowledge of different charging protocols and communication standards. At the moment there are not enough people who possess all of these knowledge and skills (Interview 4), reflecting a lack of resources (IC3). However, 'skill development' is one of the recommended action steps stemming from some V2G pilot projects (Meelen, Budnitz, & Schwanen, 2020).

In addition to workers with these skills, human resources with the ability to maintain and repair electric vehicles, human resources with data science background to develop, maintain and de-bug user applications, and human resources with technical knowledge to service and maintain charging equipment are also necessary. In this respect, a report published by the Social Market Foundation (2022) has found that there is currently a surplus of well-trained technicians to service EVs and EVSEs. There is also a wide pool of app developers available to maintain user applications (Interview 4), so no barrier exists in this regard.

Are there enough existing production facilities to cover demand?

As with physical resources, V2G technology does not have specific facilities dedicated to the production of the technology but rather combines those facilities used for its technological components. In this aspect, only a few chargers available in the market have V2G capabilities, such as the Wallbox Quasar 2, OVO's V2G charger and Blink Charging's EQ 200 (European Commission, 2023). Of these, none have production facilities in the UK but rather in other places in Europe where they ship to the UK. Indra has also developed a V2G domestic charger that is currently in beta trials and its manufacturing facilities are based in the UK (Indra, 2023).

Regarding EVs, several vehicle manufacturing plants exist within the UK, with many of them already producing V2G-capable vehicles. Nissan, the leading V2G-capable vehicle OEM, has the largest vehicle manufacturing plant in the UK (Nissan, 2023) which has produced more than a quarter million Nissan Leafs capable of V2G. In addition to this, the first EV-exclusive manufacturing plant in the UK was just announced by Stellantis (2023).

Are there manufacturing systems in place?

Efficient manufacturing systems are unlikely to be an issue for V2G in the UK. The knowledge behind the production of each of its components already exists and their manufacturing time is not substantial.

The most complex part of the manufacturing process, however, is dealing with the inverters to allow vehicles and chargers to return energy to the grid.

Nonetheless, Nissan has been successfully manufacturing V2G models in an efficient manner for several years, utilising the CHAdeMO charging protocol (Nissan, 2023; Thomas et al., 2023), and other OEMs have begun to do so as well. With the publication of the ISO 15118-20 detailing communication procedures, the adaptation of manufacturing processes for hardware using the CCS protocol should not take too long.

Are there distribution systems in place?

As with the previous indicator, distribution networks for electric vehicles and charging equipment are already in place and highly functional. In this case no relevant adaptations need to happen since EV or EVSE distributors do not have different needs to sell a V2G-capable EV or charger from those of regular EVs.

BB status

Production systems for V2G in the UK are nearly complete, with the advantage of already existing production systems for EVs and EVSEs. Some small adaptations, however, are still in process, and as a result, the roll-out of V2G technology has been slow. Skilled labour is also likely to pose a barrier for V2G production systems in the near future.

The status of the block is depicted in Figure 6.4.

Figure 6.4: BB4: Production systems with identified barriers and ICs

6.1.5. Complementary products and services

V2G has a wide range of complementary products and services. Some of them are already in place and contribute to the motivation for V2G adoption, while others are still under development. The completeness of this block is analysed through the following indicators.

To what extent do complementary products and services exist?

Though some complementary products and services seem to be completely developed and widely available, such as telematics for communication and communication standards (Meelen et al., 2021) and ever-growing renewable energy sources (Rehman et al., 2023); others, namely charging point infrastructure, are still lacking, hindering technological adoption of V2G (Meelen et al., 2021).

While EV charging stations have been growing significantly in the UK over the past year (European Commission, 2023), the number of charging stations compared to EVs is still small. Of those, only about 500 were V2G-capable charge points as of January 2023 (UK Government, 2023e). The UK government has stated goals to increase the number of EV charge-points in the coming years, however, there are still no specific goals for V2G-capable chargers (Department for Transport, 2022; Meelen et al., 2021). Without V2G-specific goals, there is a risk that a technological lock-in for unidirectional chargers may happen at relevant places where V2G could provide high value (such as overnight car-parks, airports and offices) (Thomas et al., 2023).

This barrier is mainly caused by a lack of awareness of applications and market (IC2) and macro-economic and strategic aspects (IC5). The former is because if governments are not aware of the possible applications of V2G, then they may not know where it can provide most value. The latter is because uncertainty still exists on what V2G's value is for all parties involved, which in turn makes it hard for policymakers to justify actions to support it over other technologies (Banks, 2021), (Interview 6).

An additional IC working on this barrier is competition and market modulation (IC4). Within V2G technology competition exists between CHAdeMO vs CCS standards, as well as with AC vs DC charging. The uncertainty of which will be widely adopted in the future makes stakeholders wary of installing too many charging points with one standard and having to switch to a different one in the future.

Conversely, the growth in solar PV installation numbers could really highlight the benefits of V2G adoption and provide more incentives for its adoption. Solar PV installations in the UK are a highly relevant complementary product for V2G (Interviews 2, 3, 6, 7) and they averaged 16,000 installations per month in the UK in 2023, with over one gigawatt of newly installed capacity in the year (UK Government, 2024). Additional complementary technologies for V2G, such as battery swapping services, battery subscription services, and wireless charging, are already under development and could significantly increase V2G adoption as well (Interview 2).

Are there enough high-quality maintenance and repair services?

With the technology still being in the 'innovation' stage, and the existence of little trained manpower (IC3), there is still not a high number of maintenance and repair services for V2G. However, during the pilot projects, services provided were noted to be of good quality, quickly fixing issues that arose (Energy Saving Trust, 2022). In addition, a surplus of well-trained technicians to service EVs and EVSEs exists (Norman, 2022) and there is also a wide number of app developers, both of which hold the potential to develop V2G-specific maintenance and repair services.

Are there collaboration and partnerships across complementary industries?

There is a high number of collaborations across industries when it comes to V2G. The biggest one is the link usually provided through energy suppliers. These stakeholders have partnerships with vehicle OEMs, charger OEMs, solar PV suppliers, and charge point operators (Octopus Energy, 2023a, 2023c). They then provide bundles to customers with the best prices and tariffs to encourage technological adoption, like a *"one-stop shop energy supply"* (Interview 3), which facilitates technological adoption.

Do strategies across industries align?

Companies across complementary industries surrounding V2G seem to have aligned goals and strategies focused on encouraging sustainability and the energy transition. Though different companies have different specific tactics, they all have partnership and collaboration strategies at their core (Interview 1, 2, 3).

BB status

Complementary technologies and services for V2G are well underway to become a complete building block. Company strategies across different complementary industries are well aligned and the number of complementary services and products keeps increasing in both number and quality. The only barrier identified for this building block is the lack of infrastructure for V2G charging points and specific repair and maintenance services.

The status of the block is depicted in Figure 6.5.

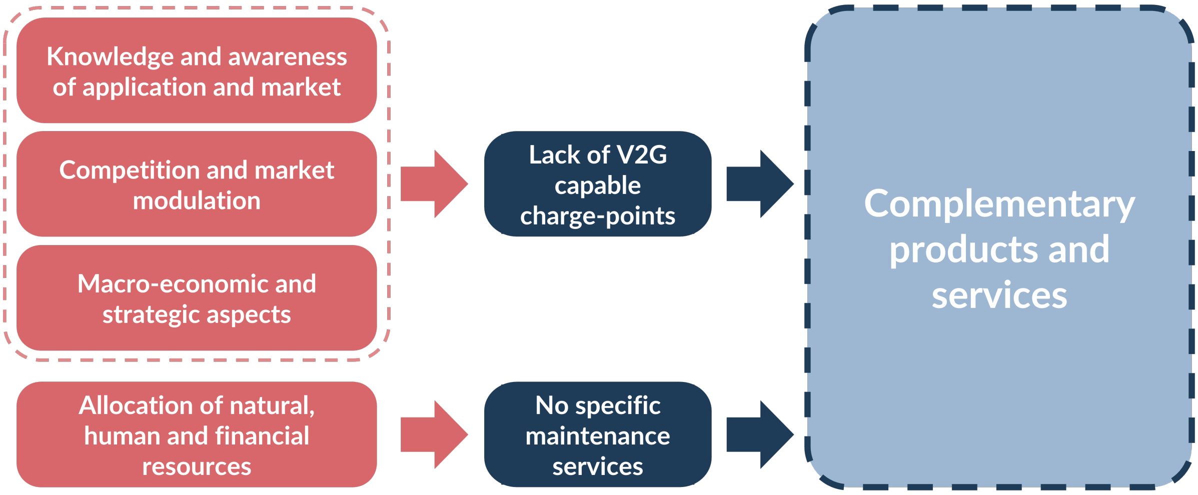

Figure 6.5: BB5: Complementary technologies and services with identified barriers and ICs

6.1.6. Network formation and stakeholder participation

Due to its multi-sector nature, network formation and stakeholder participation are crucial to V2G technology. Thankfully, the UK exhibits many networks and enthusiastic stakeholder involvement, making this the only complete block. Below is a review of the status of each indicator for the block, along with the conditions that make it complete.

To what extent are networks present?

Strong networks and a high degree of actor cooperation are prerequisites for V2G technology, both of which exist in the UK. To begin with, a high number of large consortia participated in V2G trial projects (V2G Hub, 2023), (Interview 4). Moreover, interest in the technology exists from an extensive number of actors, all of which tend to seek cooperation between them (Interview 6, 7).

To what extent do stakeholders participate?

There is a high level of stakeholder participation in the UK regarding V2G, which can be seen in the number of companies involved in trial projects, as well the numerous webinars, conferences and events that take place. These events are organised by different actors and involve the participation of individuals from all stakeholder groups.

The government of the UK also plays a role in encouraging stakeholders to participate with their call for action through different instruments like the Innovate UK funding competition for vehicle-to-grid demonstrations of 2017 (UK Government, 2017b) and the call for evidence for the role of vehicle-to-X energy technologies in a net zero energy system (Department for Business, Energy and Industrial Strategy, 2023).

In addition, the 'Zero Emission Vehicle (ZEV) Mandate', which came into effect in January 2024, was elaborated in consultation with industry and manufacturers. An important suggestion that resulted from the mandate consultation was that *" Several respondents suggested additional minimum requirements, related to bi-directional charging"* (UK Government, 2023g). Even though the mandate does not contemplate requirements for V2G at the moment, the outcome of the consultation reflects stakeholder involvement.

Is there high-quality contact between actors?

All the different means through which stakeholders come together around V2G in the UK support high quality of interactions between them. There are several formal channels in the form of consultations from the government to gain insights on the technology itself and public opinion about it (UK Government, 2023g). Additionally, less formal channels also exist and allow discussion between different levels of actors, such as panels and meetings organised by associations like the REA (REA, 2023), where concerns can be voiced and lobbying can take place. Informal gatherings at events also allow the exchange of more technical information or the formation of potential partnerships, such as the Everything Electric Event (Fully Charged Ltd., 2024).

Are there workshops and conferences where knowledge is exchanged?

The UK has several big events where knowledge on new technologies is exchanged. In the particular case of V2G, events on both the transport sector and the energy sector work to exchange knowledge on the technology since it is a multi-sector innovation (Van Eijk, 2024). Over the past few years different digital conferences and webinars (Innovate UK, 2022; Newcastle University, 2021) have taken place to encourage knowledge exchange, as well as big live events.

One example was the EV Charging Infrastructure Focus Day, in June 2023, where public and private end users and buyers were brought together to discuss EV related technologies, including V2G. The event included an exhibition space for stakeholders to show their latest technological developments (EV Charging and Infrastructure, 2023).

Several other events in which V2G knowledge exchange took or will take place this year are the Everything Electric event (2024), the UK Charging Infrastructure Symposium (2024), and the Everything EV event (2024), some of which occur periodically. Moreover, associations such as the REA also hold periodic events in which the technology may be discussed (REA, 2023).

Are there research projects and collaborations between actors?

All 28 V2G pilot projects in the UK stemmed from collaborations between different actors (V2G Hub, 2023). Moreover, other ongoing collaborations between stakeholders exist in the UK to keep researching possible V2G applications, such as Veolia's refuse truck V2G trial partnered with several different companies (Veolia, 2024).

Is there a strategic vision and alignment of goals between stakeholders?

All of the stakeholders involved with V2G technology share a common goal: supporting the energy transition towards a more sustainable future. In the first place, customers participating in pilot projects have stated that the environmental component is one of the main reasons they were attracted to the technology (Energy Saving Trust, 2022). For their part, vehicle OEM's and V2G technology providers have statements about their commitment towards a more sustainable future (Indra, 2023; Nissan, 2023; Octopus Energy, 2023a). Finally, policymakers have also stated goals to take the UK through the energy transition (UK Government, 2021b).

Do actors come together in lobbying activities for financial and political support?

Several lobbying activities for V2G have been undertaken by large groups of stakeholders, among which was a round of lobbying to recognise the importance and possible benefits of V2G in the ZEV Mandate (Interview 4). The REA also hosts periodic events and consultations (sometimes in partnership with the government) in which different interest groups are brought together to voice their concerns (REA, 2023).

BB status

The network formation and stakeholder participation block can be rendered fully complete. With high levels of interaction between actors, growing numbers of conferences, webinars and events talking about the technology and high levels of support and coordination between actors, the UK has a strong collaborative environment for V2G. What is more, several different organisations continue bringing stakeholders together to keep pushing for the technology and interest in it keeps growing.

The status of the block is depicted in Figure 6.6.

Figure 6.6: BB6: Network formation and stakeholder participation, fully complete

6.1.7. Customers and demand opportunities

Customers for V2G technology range in type of customer and size of operation. The most common market tends to be passenger vehicles (Interview 2), however there seems to be a popular opinion that vehicle fleets can be the best target customers for V2G technology (Interview 1, 2, 3), (Aunedi & Strbac, 2020; Meelen et al., 2021).

To what extent are customers and demand opportunities present?

V2G is still a relatively new and complicated technology, which is why not many people are aware of it or its possible applications and benefits (IC2). Even most EV drivers are still not aware of the value of V2G and its applications to provide flexibility (Earl & Fell, 2019; Evbenata & Jakeman, 2023). The technology can still be considered to be at the very beginning of the early adopter phase (Interview 2, 4, 5).

Nonetheless, early adopters who have had contact with the technology, particularly in domestic pilot projects, have shown eagerness and willingness to adopt V2G. An 85% of domestic users in the Powerloop trial were willing to use V2G again (Energy Saving Trust, 2022) and more than 70% of users from Project Sciurus trial said it was important that their next EV was V2G-capable (Cenex, 2021). One of the key reasons being that early adopters tend to be more environmentally aware (Earl & Fell, 2019), and the environmental benefits of V2G are widely broadcast. However, it is important to consider that early adopters may have other demand characteristics than later adopters.

Even so, barriers in other blocks, such as quality (BB1) and price (BB2), also interfere with customer availability and demand opportunities. Particularly in the case of vehicle fleets, which are one of the most promising potential customers for V2G, the business case for V2G needs to be clear before they turn from potential customers into actual customers (Aunedi & Strbac, 2020), (Interviews 1, 2, 4, 5, 7).

How easy is it for potential users to access information?

While conducting pilot projects one of the main barriers encountered was that people did not have access to information on V2G and were unaware of its existence and benefits: *"Those were really early days, so no one had really heard of V2G"* (Interview 1).

Things have changed since then, and now several different stakeholders such as energy companies, car manufacturers and even government institutions have created blogs, videos, webinars and even podcasts to inform people about V2G; explaining everything from its most basic principles to its most advanced concepts for those who are interested (Innovate UK, 2022).

"People now at least have had some exposure to it, particularly because the OEMs have started talking about [it] and [are] using it as part of their advertising or promotional material" (Interview 3).

"[...] now there's actually market demand for V2G as the consumers of the tech are getting more educated, [...] you will see people proactively reaching out when they buy an EV saying 'Oh, can I do V2G with this EV?'" (Interview 1).

However, a lack of knowledge (IC1) on available grants, available V2G-capable EV models, and charging infrastructure are still found to cause a barrier for customers with respect to the adoption of V2G (Meelen et al., 2021).

What is the motivation for customers to adopt the technology?

At present the main motivation for buyers seems to be the environmental benefits it may bring (Energy Saving Trust, 2022) and the 'trendy' factor (Interview 2, 3, 4). An additional source of motivation is potential revenues that they may obtain from participating in V2G, which can range from a few hundred pounds per year for domestic customers (Evbenata & Jakeman, 2023) to £3,000-£9,000 per bus per year for bus fleets (Southernwood, 2023).

Notwithstanding, there is still a lack of public awareness of all the ways in which V2G may provide value (IC2) since it is a complicated technology to understand. Furthermore, companies are still struggling to have a clear value proposition statement to effectively communicate to customers what is their selling point and the benefit they are offering (Interviews 1-6), which is a struggle rooted in macro-economic and strategic aspects (IC5).

To what extent are different types of incentives present?

At the moment there are no specific incentives put out by the government or firms for customers to adopt V2G technology (Interview 1, 2, 3, 7). However, there have been several incentives put in place to accelerate the roll-out of EVs which could, in turn, drive V2G adoption in the future (UK Government, 2023a, 2023c).

"Nothing specific on vehicle to grid, but there's quite a few on just getting people into EVs, [for instance] lowering the fuel tax or the parking in a certain City Council" (Interview 2).

Are there campaigns and forums for potential customers to get to know the technology?

Similarly to the previous block, there is a lot of readily available information on the technology for potential customers to get to know it. Webinars are offered by government institutions and universities, such as those by Innovate UK (2022) and Newcastle University (2021); several different trending energy podcasts talk about the technology like the Fully Charged Podcast and the Insider's Guide to Energy Podcast; and some of the biggest energy service providers in the nation have blogs and videos that talk about it, such as Octopus Energy (2023a), Eon (2023) and OVO Energy (2023). In addition to these, public events like the EV Charging Infrastructure Focus Day, which occur periodically, usually have panels and Q&A sessions with experts to better explain the technology.

BB status

This block remains incomplete due to different barriers, namely the lack of a clear value proposition and the incompleteness of other blocks. Potential customers exist and have the means to learn more about the technology every day; there is a lot of buzz and expectation around it. However, whether these potential customers will be turned into actual ones is still to be seen. A big leap into completing this block will likely be made once prices for the technology become lower, reliability issues are fixed and more V2G-capable EVs and chargers become available in the market.

The status of the block is depicted in Figure 6.7.

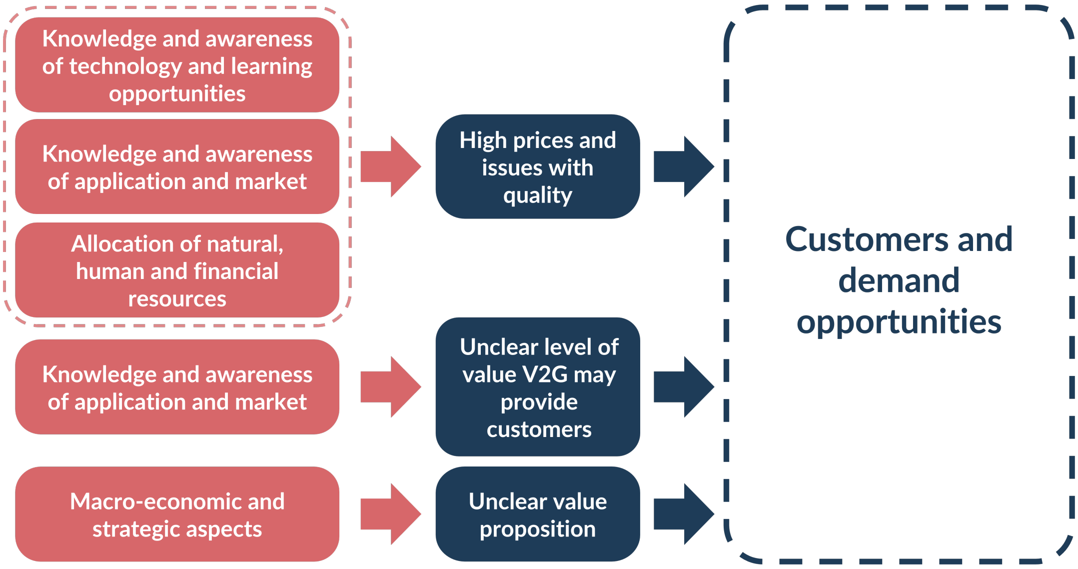

Figure 6.7: BB7: Customers and demand opportunities with identified barriers and ICs

6.1.8. Innovation-specific institutions

V2G is a technology that exists in two different sectors, namely transport and energy. Therefore, several rules, regulations, standards, etc. surround it and setting regulations has proven to be a complex task: *"How can we actually legislate [V2G]? How can we mandate it into UK law [...]? It's very complicated, because you've got the car industry, big industry, and then because it's part of the built environment, you've got to think about things like infrastructure planning, industries, local authorities, regional authorities, etc."*(Interview 7).

Due to these issues, there is some incoherence in the status of this block; despite great strides being made to further V2G in some regards, others still hinder its roll-out.

To what extent are there supporting rules, regulations and laws present?

The importance of V2G has been recognised by the UK government in several different instances and significant strides have been made to construct a supporting regulatory environment for V2G. First, the UK has one of the most well-developed and detailed EV smart charging regulations with detailed security requirements (UK Government, 2021a). While V2G is not explicitly contemplated in these regulations, important groundwork for its adoption, such as security standards, has been laid down and *"[including V2G in the ZEV Mandate] is on the radar of the Department of Transport and of the Cabinet, Treasury, etc."* (Interview 7).

Moreover, the UK has well-developed electrical safety standards that apply to bidirectional charging, and a clear application process for connection of V2G is outlined in the Energy Network's Association through the G98 and G99 connection procedures (Thomas et al., 2023). *" It's one of the few countries where you actually have it approved in the grid codes, so you can actually check a box that says vehicle-to-grid when you're submitting a generation application"* (Interview 2).

Communication standards are another relevant aspect in which V2G finds support. The ISO 15118-20 communication standard contemplates V2G and allows for more complex communication between the vehicle and the charging infrastructure, which is key for V2G adoption (Thomas et al., 2023), (Interview 1, 4).

In addition, the UK has energy market regulations and standards which are favourable to V2G, the key ones being that load aggregation is permitted so users can access several different revenue streams such as the capacity market, balancing markets, the wholesale energy market and local flexibility tenders (Cenex, 2022a; Thomas et al., 2023), (Interview 1, 2, 5). An important caveat here is that, though several different supporting instruments for V2G exist, the process that it must follow to access these revenue streams is often complex and time-consuming, which may be a deterrent for its uptake.

Finally, V2G is contemplated in the ESO's Future Energy Scenarios as a relevant 'low regret' technology to provide flexibility and drive the energy transition. They expect that including V2G as Demand Side Response early on has the *"potential for demand at peak times to be reduced by almost 15 GW in 2030 and 40 GW by 2050 compared to the counterfactual demand with no Demand Side Response"* (National Grid, 2023a).

Are there regulations or standards blocking the technology?

While several laws and regulations in the UK support V2G technology, there are still some in place which are blocking it as well. The first one is mentioned in the previous indicator and pertains to the complexity of requirements and processes to access markets. Current markets were not designed with smaller assets such as V2G in mind, therefore connection requirements such as providing line diagrams is a *"very onerous thing to do if you're doing tens of thousands of individual domestic properties"* (Interview 5).

Another barrier is the financial responsibility of a network reinforcement or substation upgrade falling on a single individual when looking to connect V2G (Banks, 2021). For example, when a G99 procedure is taking place, and a user is requesting permission to connect with a licence to export, they may be met with a negative from network operators citing too much installed capacity in the area (due to a lot of PV installed, for instance). In this case, a user may upgrade the substation or reinforce the grid to connect, but this is a very expensive process that most likely will not be undertaken by individual users (Miller, 2023a), (Interviews 2, 4, 5).

A third issue is related to metering. Metering arrangement or requirements for different types of sites may be complicated (Thomas et al., 2023) (Interviews 2, 3), and metering requirements to access certain markets ask for more accuracy than current meters have: *"the metering requirements are more than what you'd naturally get from smart meter data, for example. They ask for 1% accuracy, whereas the smart meter data only needs to be 2.5% accurate. That mismatch becomes very, very painful"* (Interview 5).

These three barriers come from a lack of knowledge and understanding of the technology from the policy-making side (IC1), and from a lack of awareness of the technology and its applications (IC2) when these instruments were first created. Even if the second IC is not an active condition anymore, its influence remains (Cenex, 2022b). A lack of skilled human resources (IC3) may also be at play for these barriers. Skilled professionals who have a full understanding of the technology are needed in the policy-making stage to develop well-thought-out regulations, however, there may not have been enough trained people available to provide insights when these regulations were first created. Competition and market modulation (IC4) can also be identified as an IC since current market practices are tailored to other technologies that compete in certain aspects with V2G.

One final regulatory barrier is presented by double taxation of the energy that passes through the battery. When the EV charges and consumes energy from the grid, taxes accrue. That energy is taxed again when the vehicle discharges, leading to a double taxation of that energy, which is perceived as a significantly large barrier (Thomas et al., 2023) (Interviews 2, 3, 5).

This last barrier may stem from a mix of the same conditions mentioned above, with the inclusion of competition macro-economic and aspects (IC5). Taxes are charged to generate revenue for the government and to maintain and improve strategic aspects of national life which directly impact a country's economy.

Are there enough regulating bodies?

The UK has several different regulating bodies related to V2G with enough granularity to ensure easier communication and make processes more efficient. The high-level policies are supervised by the DfT and DESNZ, with a closer interest in V2G by the OZEV (DESNZ, 2023; DfT, 2023; UK Government, 2023d). Further down the chain, Ofgem works with the government, industry and consumers to make sure appropriate regulations are in place (Ofgem, 2023). They provide an important link between the government and other stakeholders and have been relevant for V2G since they *"are very progressive in terms of really looking ahead to the flexibility and V2G plays a big part in that"* (Interview 4).

In addition to these regulating bodies, energy operators at different levels (National Grid ESO, DNOs, TSOs) ensure that the network works properly and that potential issues that may arise by the uptake of V2G and other distributed flexibility sources are addressed (Interview 6).

What actions are regulating bodies taking to promote the technology?

The UK government has issued different calls for evidence and competition grants to demonstrate V2G, which has been an important first step towards its uptake (UK Government, 2017a). Nevertheless, at present, there are no further specific actions that regulating bodies have taken to promote V2G, but other measures that promote distributed flexibility and the uptake of EVs can also boost V2G.

Some measures include the implementation of low-emission zones in cities, where only certain vehicles may circulate and go as far as a zero-emission zone in Oxford (Meelen et al., 2021), and the Demand Flexibility Service, which incentivises customers to shift their energy demand to off-peak times (National Grid, 2023a).

What are strategic targets set by regulating bodies?

At the moment, no specific targets have been set by the UK government regarding V2G, however several goals related to EV uptake and charging points have been issued (UK Government, 2021b). Moreover, the government has pledged to deliver the Vehicle-to-X Innovation Programme by 2025 to *"address barriers to wide-scale deployment specific to this technology"* (UK Government, 2023e).

Is there coherence between different regulatory instruments?

A lack of coherence in regulatory instruments has been identified by several interviewees. Mainly between high-level policy instruments being very forward and supportive of EVs and demand-side flexibility, while specific regulations are still complex to navigate and don't encourage the entry of V2G into the market (Interviews 1, 2, 3, 5, 6).

"A lot of the regulations aren't actually built to support the directives that the industry is putting forward" (Interview 2).

"It's a main challenge we have now, with a lot of emergent demand-side technologies, they struggle sometimes with the requirements because some of the markets were designed without the technologies in mind when they were first set up" (Interview 6).

This lack of coherence between regulatory instruments may be rooted in four different influencing conditions. The first and second one being a lack of knowledge of the technology (IC1) or its market and applications (IC2) by the regulating authorities. If those in charge of regulation are not aware of the actual requirements to drive V2G adoption, then the regulatory instruments they set may turn out to be to the detriment of the technology (Interviews 2, 3, 5).

The third and fourth ones are competition and market modulation (IC4) and socio-cultural aspects and social dynamics (IC6). Authorities are likely hesitant about emitting strong regulatory measures that may boost V2G for fear of being perceived as giving an unfair advantage to the technology (Interview 2), or wanting to preserve their existing relationship with incumbent actors that may be affected by its uptake, such as big oil and gas companies. Furthermore, authorities need to safeguard their credibility and be able to justify why they are opening up certain markets or changing some parameters in existing markets before they do so (Cenex, 2022b) (Interview 6).

An important lack of coherence is also found in the lack of standardisation of charging protocols and architectures. There is, at present, no uniform charging standard (both CHAdeMO and CCS still exist), though the UK and Europe are now moving towards CCS; likewise, charging architectures are also split between AC and DC charging, depending on vehicle models, charge points and even regions (Cenex, 2022b). This lack of uniformity across charging technologies is a significant barrier that has also influenced other blocks, such as entrepreneurial activity.

This last barrier stems from macro-economic and strategic aspects (IC5) and the overall global context (IC8). The former is due to uncertainty existing in which technology is 'better' suited for V2G and EVs in general. The latter, due to technological development going on in different parts of the world that may push one charging technology over another, for instance, the CHAdeMO standard being the main one in Asia stalls Asian car manufacturers (such as Nissan) from adopting the CCS which is the main standard being employed in the UK. Additionally, the delay in the publication of the ISO 15118-20 has also stalled CCS V2G for a while.

BB status

This is a controversial block for V2G technology. On one hand, the UK is one of the leading countries in the world in terms of designing an energy market that supports V2G, and has made good progress towards making regulations that support its adoption. There are several different regulating bodies that mark clear responsibilities and make regulatory processes simpler, and the technology is aligned with the country's overarching objectives regarding energy and the environment.
On the other hand, several regulatory impediments remain for the technology. The main ones are the complexity of processes and requirements to access market revenue streams, issues with double taxation of energy, and metering requirements. In addition, there is still a lack of coherence among different regulatory instruments, which must be overcome for the technology to advance.

The status of the block is depicted in Figure 6.8.

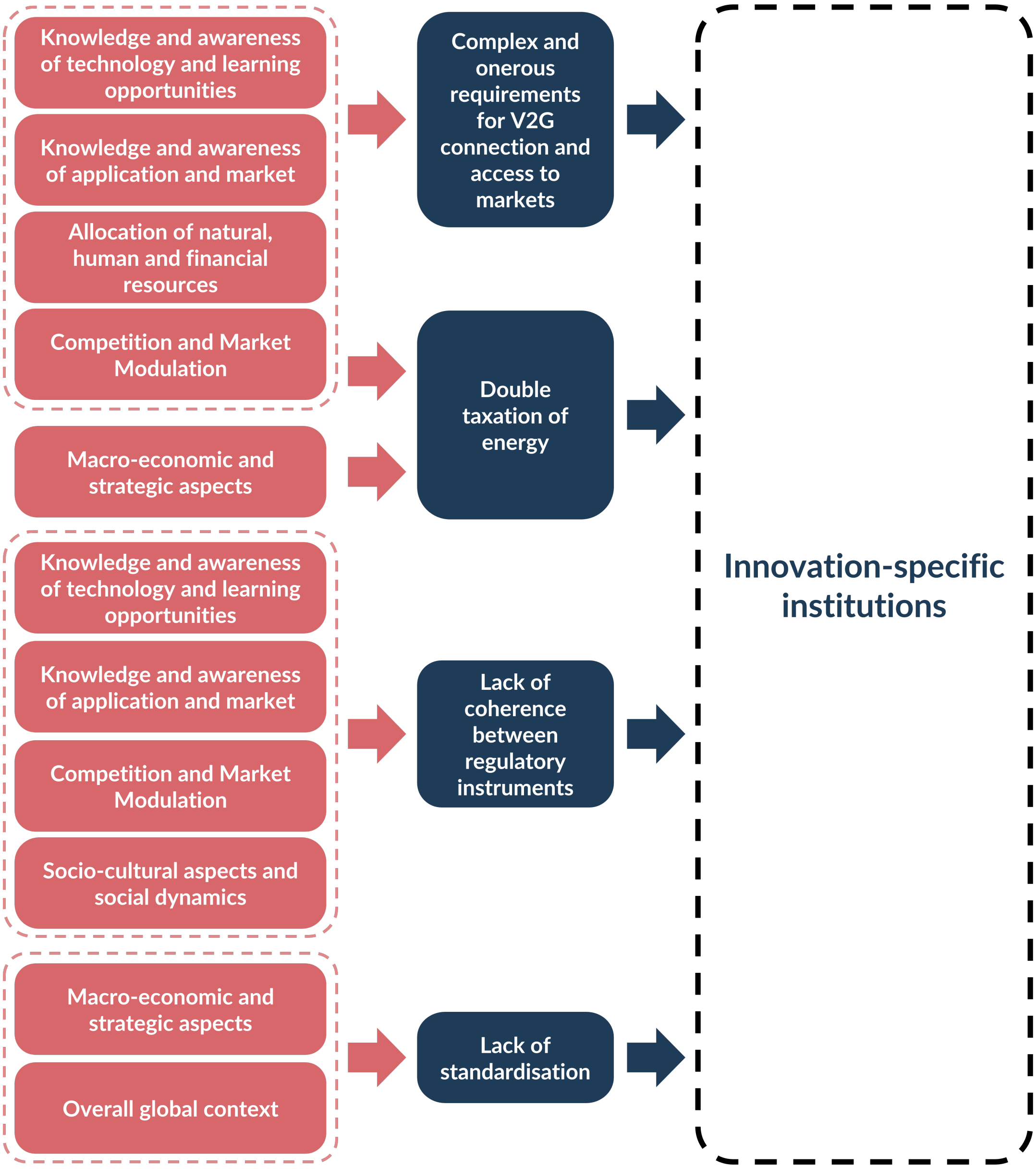

Figure 6.8: BB8: Innovation-specific institutions with identified barriers and ICs

A summary of the status of the TIS for V2G in the UK with all the identified barriers and influencing conditions for each building block may be observed in Figure 6.9.

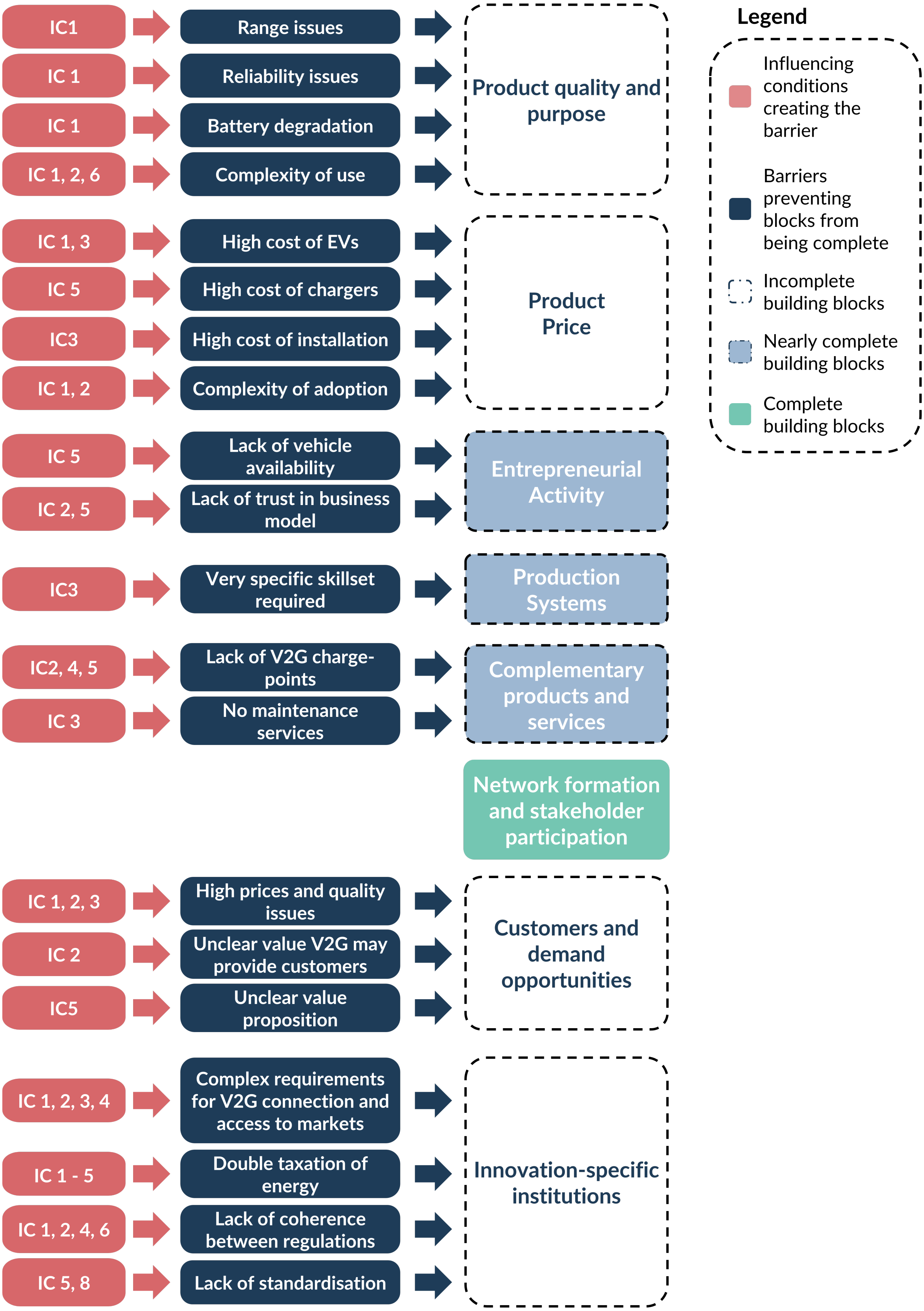

Figure 6.9: TIS status for V2G in the UK

6.2. Influencing conditions as driving factors

Influencing conditions can act as origins for barriers for the different BBs, as was shown in section 6.1. However, in some cases, ICs are driving factors that bolster technological adoption rather than hinder it. This section presents those cases in which influencing conditions have been found to be aiding TIS formation for V2G in the UK rather than creating barriers within building blocks.

6.2.1. Competition and market modulation

Being a complex technology, V2G has little to no direct competition in the UK. Some of its main competitors include other sources that provide flexibility (such as stationary storage). However, there is a huge requirement for flexibility services that is ever-growing with the integration of renewables (Cenex, 2022b) and competing technologies of V2G are not likely to pose a threat (Interview 6, 7). Moreover, V2G has several benefits over its competitors, as mentioned in the previous chapter. This lack of direct competition leaves an important market gap to be filled, which helps build the entrepreneurial activity block (BB3).

In addition, V2G does not need to compete with other technologies for resources or production systems since those are already in place for its essential components. This makes the technology's production and distribution easier and supports its uptake, which in turn builds the production systems block (BB4).

6.2.2. Macro-economic and strategic aspects

Several different aspects exist within this category that help build up the TIS for V2G. One of them is the rising cost of fossil fuels (Meelen et al., 2021; Sovacool et al., 2018). As fuels become more expensive, ICE vehicles will become more and more costly to maintain, and thus, EV prices will be more reasonable. This, in combination with decreasing battery prices (Meelen et al., 2021), aids in building the price block (BB2) and, as a result, the customer block (BB7).

Another highly relevant strategic aspect is the growth of renewable energy (Cenex, 2022b; Earl & Fell, 2019). With the rise of renewable energy in the grid, the need for flexibility is exacerbated, and V2G provides a fitting solution to this problem. Based on the avoidance of renewable curtailment alone, V2G could help save six megatonnes of CO_2 per year (Cenex, 2022b) and provide £200 million of cumulative savings in distribution network reinforcements between 2020 and 2030 (Element Energy, 2021). Both of these benefits serve a greater purpose (BB1) can help build up the TIS.

6.2.3. Socio-cultural aspects and social dynamics

Socio-cultural aspects and social dynamics are among the main influencing conditions driving V2G in the UK. In today's world, the public's perception of a product can make or break its success; social media and influencing figures have a strong bearing on people's perception of technological innovation.

Fortunately, there is a socio-cultural trend currently focused on solving environmental issues. Societal contribution and feeling like there is something to be done for the environment is one of the highest reasons for V2G adoption among existing customers of the technology (Cenex, 2021; Energy Saving

Trust, 2022) and potential customers (van Heuveln et al., 2021).

Moreover, a shift in social dynamics within the energy sector is occurring due to socio-cultural pressures. This shift pertains to an overall breaking of fossil fuel companies' preferential positions with governments. With this shift, more public resources are being destined to innovation projects that are helping build up the TIS for V2G in the UK, such as the UKRI V2G demonstration of 2017 and the V2X Innovation Programme (UK Government, 2023f).

Additionally, peer effects and a sense of 'good standing' in society have also worked as a driver for EV adoption and could potentially extend to V2G as well. *"Anything we can do to accelerate the proliferation of the technology, anything we can do to make it simple to be talking about, to get it in the public discourse means we will get through that process faster to a tipping point where people are saying: 'I'm not gonna buy a car without V2G, [that's] crazy. Bob up the road, he saved £500 last year so, if I'm gonna buy a car, I want one with V2G'"* (Interview 4).

6.2.4. Accidents and events

Two relevant events were identified in this IC which have positively affected the status of the TIS for V2G in the UK: climate change (E-Flex, 2020; Van Eijk, 2024) and the the Ukraine-Russian War (Southernwood, 2023; van Dijk, 2023). Both events have had a bearing on the rapid growth of renewable energy in the UK, highlighting its importance in guaranteeing energy security in a sustainable future. The growth of renewables stemming from them has, in turn, brought on a set of network challenges (Earl & Fell, 2019), which V2G can help alleviate, thus aiding in the formation of different TIS blocks.

6.2.5. Overall global context

The overall global context has also played a favourable role for V2G in the UK. In general, the world has an agenda of moving towards renewables and e-mobility (ENTSO-E, 2021) and V2G has a significant role to play in helping these causes. The value of V2G has been recognised all over the world (Blair et al., 2023), and many countries are actively promoting actions that will help with its uptake. An example is the discussion happening in the state of California in the US to create a mandate for all new EVs to have bi-directional capabilities in the near future (Thomas et al., 2023) (Interview 7).

These actions restate the technology's potential and can pressure the UK to take similar steps to promote V2G. Conversely, being at the forefront of V2G markets in the world (Cenex, 2022b) puts the UK in a favourable light worldwide. Both of these reasons can influence the formation of several TIS building blocks, such as entrepreneurial activity (BB3) and innovation-specific institutions (BB8).

6.3. Main takeaways

V2G is a complex technology that requires the involvement of several different actors and factors to advance and become widely adopted. Though its potential is highly recognised, and important strides have been made in the UK to drive this technology, relevant barriers are still blocking it from becoming widely adopted.

The richness of the in-depth case study shows that a number of barriers and driving factors exist with respect to the technology, and the complex relationship and influence that they have on each other. However, there are some key factors that are considered to be predominant and that were found in most of the studied sources (academic literature, grey literature, and interviews with experts). Among the most critical factors blocking the technology are the following.

1. Low vehicle availability due to a lack of confidence in the business model and uncertainty of where charging architecture is heading (AC vs DC).
2. Interoperability issues between existing standards (CHAdeMO vs CCS).
3. High prices of EVs in general and V2G-capable EVSEs.
4. User concerns related to the complexity of interaction with the technology, battery degradation and range issues.
5. Complex and onerous requirements for V2G connection and market participation, as well as penalties such as double taxation.

These issues call for cooperation between stakeholders and high levels of engagement to be solved.

"Through this combination of policy, public awareness and a deepening understanding of the market opportunity, it's only with all of those factors progressing that we'll see this technology become mainstream" (Interview 4).

The following chapter (chapter 7) talks about the strategies currently employed to introduce V2G in the UK and a derivation of new strategies using the TIS status presented above.

7

Derivation of strategies

The previous chapter provided a clear picture of the status of the TIS for V2G in the UK at the moment. This chapter presents an overview of niche introduction strategies and TIS build-up strategies that could be employed for each identified barrier. The general overview of the chapter is presented in Figure 7.1.

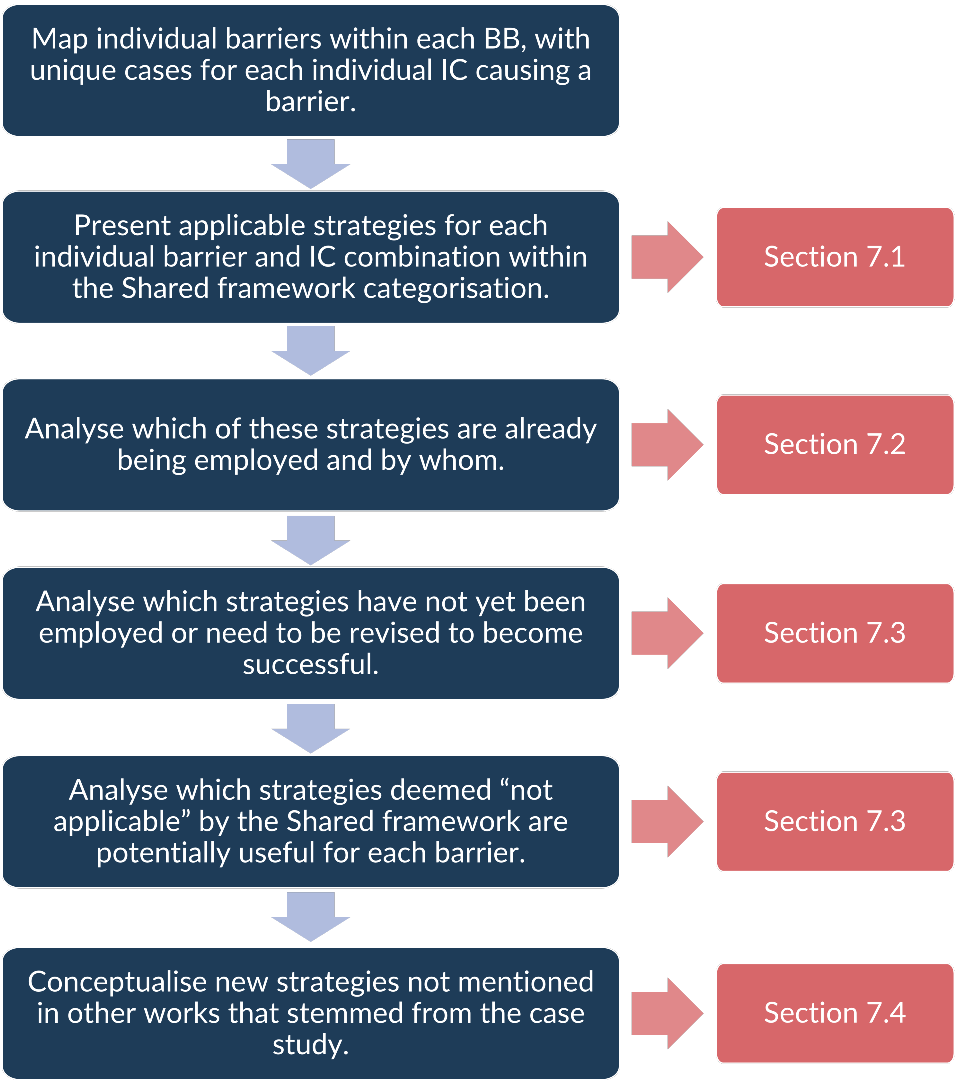

Figure 7.1: Strategy derivation flowchart

First, the Shared framework was employed to obtain an initial overview of applicable strategies for each barrier, which is shown in section 7.1. Next, an analysis of all the strategies currently employed (or used in the past) to promote V2G adoption in the UK was conducted and is presented in section 7.2. Following this, section 7.3 presents examples of all the potential strategies that have not been employed or have been unsuccessful, including strategies that were deemed ‘not applicable’ by the Shared framework but were found to be relevant nonetheless. Section 7.3.1 introduces potential TIS build-up strategies, while subsection 7.3.2 presents potential niche introduction strategies for companies to employ in their journey to commercialising V2G.

Finally, each combination of barrier and IC was individually analysed, looking at possible solutions for the barrier and whether these solutions fit into one of the existing strategies or whether additional strategies had to be created. Two new strategies were conceptualised in this manner while conducting the case study and are shown in section 7.4.

7.1. Applicable strategies from Shared framework

The purpose of the Shared framework is to derive potential strategies for both companies and policymakers in order to encourage the diffusion of an innovation. This section uses the framework to derive applicable strategies for each of the barriers that exist for V2G in the UK.

First, each block was mapped with its barriers and the ICs causing each barrier. Next, following the Shared framework, applicable strategy categories for each combination of BB and IC were identified for each barrier. Subsequently, all strategies within these categories were evaluated to see whether they fit that particular barrier since not all applicable strategies within a category necessarily apply to all barriers stemming from that particular combination. At least one example of the strategy that served to circumvent or eliminate the barrier was thought of before it was included, so all the generic strategies presented are plausible for that specific barrier.

As a result, the following table (Table 7.1) was obtained. In it, a list of all barriers identified in chapter 6 are shown, along with the influencing condition causing them and the BB to which they belong. A series of strategies that were found to help lower or circumvent these barriers is shown for each IC causing a barrier. Examples of why these strategies are applicable for the specific barrier and IC combinations are shown in section 7.2 and 7.3.

Table 7.1: Strategies proposed for each combination of BBs and ICs identified for V2G in the UK

IC	**Barrier (BB)**	**Niche introduction strategies**	**TIS build-up strategies**
Knowledge of technology and learning opportunities	Range issues (BB1)	*Demo experiment and develop niche strategy, educate niche strategy, leasing strategy*	*Technological R&D strategy, demo experiment and develop niche strategy, investments strategy, educate niche strategy*

Knowledge of technology and learning opportunities	Reliability issues (BB1)	*Demo experiment and develop niche strategy, educate niche strategy*	*Technological R&D strategy, demo experiment and develop niche strategy, human resource management strategy, educate niche strategy, internal knowledge sharing strategy, crowd-sourcing strategy*
Knowledge of technology and learning opportunities	Battery degradation concerns (BB1)	*Demo experiment and develop niche strategy, educate niche strategy, incentives strategy, leasing strategy*	*Technological R&D strategy, demo experiment and develop niche strategy, educate niche strategy, human resource management strategy, incentives strategy*
Knowledge of technology and learning opportunities	Complexity of use and understanding (BB1)	*Demo, experiment and develop niche strategy, educate niche strategy*	*Technological R&D strategy, demo experiment and develop niche strategy, educate niche strategy*
Knowledge and awareness of application and market		*Educate niche strategy, leasing strategy, lead user niche strategy, incentives strategy, preannouncing strategy*	*Educate niche strategy, incentives strategy, preannouncing strategy*
Socio-cultural aspects and dynamics		*Leasing strategy, lead user niche strategy, incentives strategy, turnkey product strategy*	*Incentives strategy*
Knowledge of technology and learning opportunities	High cost of EVs (BB2)	*Top niche strategy, incentives strategy, educate niche strategy, lead user niche strategy, leasing strategy, result-oriented contracting strategy*	*Incentives strategy, educate niche strategy, investments strategy, technological R&D strategy, human resource management strategy, provide guaranteed markets strategy, provide policies to incorporate externalities strategy*
Allocation of natural, human and financial resources		None	*Finance sourcing strategy, provide policies to incorporate externalities strategy*

Macro-economic and strategic aspects	High cost of bidirectional chargers (BB2)	*Top niche strategy, incentives strategy, lead user niche strategy, leasing strategy, result-oriented contracting strategy*	*Incentives strategy, finance sourcing strategy, provide guaranteed markets strategy*
Allocation of natural, human and financial resources	High cost of installation (BB2)	None	*Investments strategy, human resource management strategy, finance sourcing strategy*
Knowledge of technology and learning opportunities	Complexity of adoption (BB2)	*Educate niche strategy, lead user niche strategy, turnkey product strategy, cross-selling strategy*	*Educate niche strategy, human resource management strategy*
Knowledge and awareness of application and market		*Educate niche strategy, lead user niche strategy, existing networks strategy, preannouncing strategy*	*Educate niche strategy, changing behaviour strategy, existing networks strategy, preannouncing strategy*
Macro-economic and strategic aspects	Lack of vehicle availability (BB3)	None	*Partnership strategy, provide standards and regulations strategy*
Knowledge and awareness of application and market	Lack of trust in business model (BB3)	*Demo, experiment and develop niche strategy, educate niche strategy, public sector participation strategy*	*Demo experiment and develop niche strategy, educate niche strategy, public sector participation strategy, technological R&D strategy, human resource management strategy*
Macro-economic and strategic aspects		None	*Partnership strategy, provide guaranteed markets strategy, provide standards and regulations strategy*
Allocation of natural, human and financial resources	Very specific skill-set required (BB4)	None	*Network building strategy, human resource management strategy*

Knowledge and awareness of application and market	Lack of V2G-capable charge-points (BB5)	*Educate niche strategy*	*Educate niche strategy, public sector participation strategy*
Competition and market modulation		*Public sector participation strategy*	*Network building strategy, investments strategy, public sector participation strategy, provide standards and regulations strategy*
Macro-economic and strategic aspects		*Public sector participation strategy*	*Partnership strategy, network building strategy, public sector participation strategy, provide standards and regulations strategy*
Allocation of natural, human and financial resources	No specific maintenance services (BB5)	None	*Finance sourcing strategy, human resource management strategy*
Knowledge of technology and learning opportunities	High prices and issues with quality (BB7)	*Top niche strategy, educate niche strategy, incentives strategy, leasing strategy*	*Educate niche strategy, incentives strategy, human resource management strategy*
Knowledge and awareness of application and market		*Lead user niche strategy, educate niche strategy, public sector participation strategy, result-oriented contracting strategy*	*Educate niche strategy, public sector participation strategy*
Allocation of natural, human and financial resources		*Incentives strategy, public sector participation strategy*	*Incentives strategy, public sector participation strategy*
Knowledge and awareness of application and market	Unclear value V2G may provide customers(BB7)	*Educate niche strategy, preannouncing strategy, existing networks strategy*	*Educate niche strategy, preannouncing strategy, existing networks strategy, human resource management strategy*
Macro-economic and strategic aspects	Unclear value proposition (BB7)	*Explore multiple markets strategy*	*Human resource management strategy*
Macro-economic and strategic aspects	Lack of standardisation (BB8)	*Educate niche strategy, explore multiple markets niche strategy*	*Educate niche strategy*
Overall global context		None	*Network building strategy, provide standards and regulations strategy*

<table>
<tr><td>Knowledge of technology and learning opportunities</td><td rowspan="4">Complex and onerous requirements for V2G connection and access to markets (BB8)</td><td>Educate niche strategy</td><td>Educate niche strategy, human resource management strategy, partnership strategy, network building strategy</td></tr>
<tr><td>Knowledge and awareness of application and market</td><td>Demo, experiment and develop niche strategy, educate niche strategy</td><td>Demo experiment and develop niche strategy, educate niche strategy, partnership strategy</td></tr>
<tr><td>Allocation of natural, human and financial resources</td><td>None</td><td>Campaign funding strategy, network building strategy, lobbying strategy</td></tr>
<tr><td>Competition and market modulation</td><td>None</td><td>Campaign funding strategy, network building strategy, lobbying strategy, provide guaranteed markets strategy, provide standards and regulations strategy</td></tr>
<tr><td>Knowledge of technology and learning opportunities</td><td rowspan="5">Double taxation of energy (BB8)</td><td>Educate niche strategy</td><td>Educate niche strategy, partnership strategy, network building strategy</td></tr>
<tr><td>Knowledge and awareness of application and market</td><td>Demo, experiment and develop strategy, educate niche strategy</td><td>Demo, experiment and develop strategy, educate niche strategy</td></tr>
<tr><td>Allocation of natural, human and financial resources</td><td>None</td><td>Campaign funding strategy, network building strategy, lobbying strategy</td></tr>
<tr><td>Competition and market modulation</td><td>None</td><td>Campaign funding strategy, network building strategy, lobbying strategy</td></tr>
<tr><td>Macro-economic and strategic aspects</td><td>None</td><td>Changing behaviour strategy, provide standards and regulations strategy</td></tr>
<tr><td>Knowledge of technology and learning opportunities</td><td rowspan="4">Lack of coherence between regulatory instruments (BB8)</td><td>Educate niche strategy</td><td>Educate niche strategy, network building strategy, human resource management strategy, partnership strategy</td></tr>
<tr><td>Knowledge and awareness of application and market</td><td>Educate niche strategy, explore multiple markets strategy</td><td>Educate niche strategy</td></tr>
<tr><td>Competition and market modulation</td><td>None</td><td>Campaign funding strategy, network building strategy, lobbying strategy, provide standards and regulations</td></tr>
<tr><td>Socio-cultural aspects and social dynamics</td><td>None</td><td>Campaign funding strategy, network building strategy, lobbying strategy</td></tr>
</table>

Many of the presented strategies have already been used or are still in use to promote V2G adoption in the UK. By keeping these strategies in use or enhancing them if necessary, the technology will overcome several barriers. However, other strategies remain unused but could potentially further aid in combating barriers for V2G in the UK.

7.2. Existing strategies

While the previous section provided an overview of all available strategies for each of the identified barriers, this section presents the strategies that are already being used for V2G in the UK. This application of several strategies over the past decade has made the UK one of the most promising markets for V2G in the world (Cenex, 2022b). Some of these strategies have served their purpose and are being phased out, while others need revising. All the identified strategies and their specific application(s) are shown in Table 7.2, as well as their classification as niche introduction strategy, TIS build-up strategy or both, and who they are employed by.

Table 7.2: Strategies employed to promote technological adoption of V2G in the UK

Strategy	**Application**	**Type of strategy**	**In use by**
Demo, experiment, and develop niche strategy	Both companies and policymakers have used this strategy. Several different demonstrations for V2G emerged in the UK as a result of the UKRI competition in 2017 (UK Government, 2017b), which allowed companies to identify issues with the technology and further improve it. Some of the issues identified were the reliability of the technology and its complexity of use. Nowadays, a call for evidence of the role of V2X technologies in a net-zero energy system has been issued by the government (UK Government, 2023f), which also falls under this strategy. The fact that it is still being used today may help combat barriers stemming from a lack of knowledge (ICs 1 and 2), mainly in BB1, BB3 and BB8.	Both	Companies and policymakers
Incentives strategy	An attempt has been made by the government at applying this strategy via subsidies for EVs (UK Government, 2023c) and chargers (UK Government, 2023a). Nonetheless, these subsidies have not been technology-specific for V2G, and several of these instruments are already being phased out. No other incentives have been identified, which has made applying this strategy very unsuccessful on the government side, which is why it is further expanded in the next section. However, some companies have recently started using this strategy, such as Octopus Energy's V2G tariff. Released in February, this tariff offers free EV charging as an incentive to customers to provide V2G services (Octopus Energy, 2024).	Both	Companies and policymakers

Educate niche strategy	The application of this strategy by companies and policymakers alike has been consistent and successful in the UK and is still ongoing. Spearheaded by 28 pilot projects (V2G Hub, 2023), educating relevant stakeholders on V2G and its benefits has been a priority in the UK. Different institutions (companies, government, universities) have been and currently are involved in spreading knowledge on V2G (Innovate UK, 2022; Newcastle University, 2021). The continuous application of this strategy will also help in lowering barriers stemming from ICs 1 and 2 in most blocks.	Both	Companies and policymakers
Public sector participation strategy	This strategy has been employed at a 'limited' scale, with the participation of local authorities and some public institutions in V2G pilot projects, for instance, Transport for London fleet and facilities being used in the E-Flex project (E-Flex, 2020). Nonetheless, additional participation from the public sector could greatly benefit V2G, which will be further analysed in the next section.	Both	Policymakers
Technological R&D strategy	The government and several companies have invested a large amount of effort and financial resources over the past several years in V2G technological R&D in the UK. However, with the advances the technology has made and several pilot projects concluded with important insights, the technology has surpassed the R&D stage, and this strategy has become obsolete. Nonetheless, the findings from the application of this strategy are lowering barriers that still exist like reliability issues. Additionally, R&D in technologies related to V2G (such as batteries) is also helping to combat battery degradation concerns (BB1), range issues (BB1) and high costs of EVs (BB2).	TIS build-up	Companies and policymakers
Partnership strategy	The partnership strategy has been one of the most commonly employed and successful strategies for V2G in the UK. Being a collaborative technology (Høj et al., 2018), V2G requires the coordination and participation of several different stakeholders. For this reason, various actors have formed partnerships. As an example, some energy providers have partnered with vehicle OEMs or EVSE OEMs to exchange knowledge on the technology and offer bundled products. Continuous use of this strategy can help combat barriers surrounding entrepreneurial activity (BB3), production systems (BB4) and innovation-specific institutions (BB8). The nature of these partnerships may be strengthened in ways discussed in the following section.	TIS build-up	Companies and policymakers

Internal knowledge sharing strategy	Internal knowledge sharing with respect to V2G is something already occurring within companies. After conducting research, several companies looked within their organisations for people to lead V2G pilot projects (Miller, 2023a) and once these projects were over, the information was internally shared through different levels in the company to make use of its full advantage and address issues related to quality of the technology (BB1). Additionally, internal knowledge sharing is also taking place within government organisations, for instance, National Grid ESO shares its findings with different government officials to help them make the best decisions and policies with respect to V2G and other technologies (Interview 6).	TIS build-up	Companies and policy-makers
Crowd-sourcing strategy	While not addressing the general public, different pilot projects (Cenex, 2021; Energy Saving Trust, 2022) asked users for their opinion on the technology and their ideas to improve it. This, in turn, is helping companies overcome vehicle reliability issues (BB1) and issues related to the complexity of use (Cenex, 2021).	TIS build-up	Companies and policy-makers
Finance sourcing strategy	Most companies involved with V2G in the UK have used this strategy, taking advantage of the high number of competitions and grants made available by the government (UK Government, 2017a, 2023f). The use of this strategy has been successful in eliminating barriers to entrepreneurial activity (BB3) and lowering barriers in the price block (BB2) and complementary products and services block (BB5), especially those caused by a lack of resources (IC3).	TIS build-up	Companies and policy-makers
Lobbying strategy	Lobbying is also a strategy that companies in the UK have employed to encourage V2G, particularly to build up innovation-specific institutions (BB8). The entrepreneurial community has made important efforts to get V2G recognised in the ZEV Mandate (UK Government, 2023g), promote symmetric grid tariffs that encourage export to the grid (Interview 1), and try to remove double taxation for energy that passes through the battery. Some of these lobbying activities have been more successful than others; however, this is an ongoing strategy.	TIS build-up	Companies

Network building strategy	The UK hosts several events and conferences on sustainability, electric mobility and other relevant topics related to V2G, such as the UK Charging Infrastructure Symposium (2024). Different stakeholders attend these events and have the opportunity to network, putting this strategy to use. Network building has eliminated all barriers within the network formation block (BB6) and lowered barriers in the production systems block (BB4), complementary products and services block (BB5), and the innovation-specific institutions block (BB8). Nevertheless, its application is still valuable and can help in further lowering or removing barriers stemming from a lack of knowledge (IC1), a lack of resources (IC3), and competition and market modulation (IC4); specifically in block 8.	TIS build-up	Companies and policy-makers
Changing behaviour strategy	Rather than putting V2G on a specification sheet or getting influential people to promote it, the UK government has implemented this strategy by making it a part of the ESO's Future Energy Scenarios (National Grid, 2023a). Having the technology mentioned and highlighting the benefits it may bring in the future will likely get more actors interested in it and influence them to invest in its development or become early adopters. These factors can lower barriers like the complexity of adoption (BB2) due to lack of awareness of the technology (IC2), encourage entrepreneurial activity (BB3) and help remove regulatory barriers (BB8).	TIS build-up	Policymakers
Existing networks strategy	Companies are already using their sales channels, web pages and blogs to promote the technology and using existing contacts to build their networks and form partnerships. This application of the strategy has helped lower barriers in the customer and demand opportunities block (BB7). Nonetheless, further advantages can be achieved from different ways of applying this strategy which are mentioned in the following section.	Both	Companies
Preannouncing strategy	This strategy is employed by several companies, mainly vehicle OEMs, to build expectations on their soon-to-be-released V2G-capable vehicles (Thomas et al., 2023). The use of this strategy is combating barriers related to a lack of awareness of the technology and market (IC2), mainly in BB1, BB2 and BB7.	Niche introduction	Companies

Provide guaranteed markets strategy	This strategy is employed by the UK government, leading to one of the most conducive energy markets for V2G at the moment (Cenex, 2022b). Several different revenue streams may be accessed by V2G, such as the capacity market, ancillary service markets, and even the wholesale electricity market (Interview 5, 6). However, many of the requirements for these markets are open in theory but practically very difficult for V2G to access. This means this strategy needs to be adjusted or strengthened to work properly, as explored in the following section.	TIS build-up	Policymakers
Investments strategy	This strategy is already widely employed by companies in the UK. Investments in complementary technology for V2G, such as rooftop PV systems and wireless charging, keep growing in the country (UK Government, 2024). Nonetheless, investment for V2G-capable EVSE is still noticeably lacking from the UK's government charging goals for 2030 (Department for Transport, 2022) which means this strategy could be strengthened to remove further barriers and is expanded in the next section.	TIS build-up	Companies
Provide standards and regulations strategy	Several standards and regulations favourable to V2G have already been implemented in the UK, such as those allowing flexibility assets to obtain revenues from different markets (Thomas et al., 2023). Nevertheless, a lack of coherence exists among them, and many regulatory barriers still exist, so this strategy must be tailored to remove barriers effectively and build up the TIS.	TIS build-up	Policymakers

More of these strategies fall under the TIS build-up category than the niche introduction category, which is to be expected since it is essential to build up the TIS as much as possible before introducing the product. This is reflected in the high number of network-stimulating and market-stimulating strategies, which have led to the blocks centred around the market and network interactions being complete or almost complete (network formation, production systems, complementary products and services, entrepreneurial activity).

Nonetheless, companies have already started using some niche introduction strategies to sell their products at a niche level, as exemplified in Table 7.2. Cooperation between policymakers and companies has been crucial in making these strategies work successfully.

Strategies already in use address several different barriers across all blocks rooted in various influencing conditions. However, many of these strategies can be expanded and complemented by additional strategies to remove or circumvent persisting barriers.

7.3. Potential strategies

Even with several strategies already being applied successfully in the UK, there are still several strategies that hold a lot of untapped potential for V2G. This section presents several strategies that have not yet been employed or were unsuccessful and are presented in a way in which they could be improved. Wherever ICs work as driving factors for strategies, these are also mentioned in this section. Potential strategies are shown in two sub-sections, subsection 7.3.1 presents potential TIS build-up strategies and subsection 7.3.2 presents potential niche introduction strategies.

7.3.1. Potential TIS build-up strategies

Many different TIS build-up strategies are applicable to V2G in the UK. Some are not in use yet, while others are already being used by companies and policymakers but their application could be strengthened. This section explores these applicable TIS build-up strategies and the barriers they seek to overcome.

R&D stimulating strategies

The first group of strategies in this category is R&D stimulating strategies. Both companies and policymakers have already used many of these strategies to successfully combat barriers and build up the TIS. Nonetheless, there are still a few R&D stimulating strategies that could help in the roll-out of V2G.

The first is the *incentives strategy*, which has not been employed specifically for V2G yet. However, incentives are relevant economic policy-making instruments that help with technology push, and aid in solving systemic concerns. As such, this strategy has a solid potential to combat vehicle availability (BB3), which is one of the main barriers for V2G at the moment. If policymakers provide an important incentive, companies could overlook some uncertainties in the market (IC5), and the barrier would be circumvented. Even if R&D strategies are not generally applicable for IC5, this strategy proves relevant to stimulating R&D since it could get vehicle OEMs to bring vehicles to the market faster. Companies may also apply this strategy, but it then falls under the customer-focused category, explained in the next section.

A second strategy falling under more than one category is the *human resource management* strategy. It combats a lack of knowledge of the technology (IC1) and of its market and applications (IC2) and can be considered an R&D strategy when it is focused on solving issues with the product itself. Such is the case when hiring relevant scientists or engineers to improve the quality of their products (BB1), and lower costs (BB2). For different applications, it falls under the market-stimulating strategies mentioned below.

The *investments strategy* is already employed by companies in the UK, but its application by policymakers could be improved. A big improvement would be to invest in V2G-capable EVSEs in public places where V2G could be of value (like airports, train stations, etc.), which could completely eliminate the lack of V2G charge point barrier in BB5. As a result, this strategy also indirectly helps reduce range issues (BB1) since the more available charge points there are, the less likely users will be worried about plugging their vehicles on time. This application is supported by influencing conditions acting as drivers, such as the rising cost of fossil fuels (IC5), which will drive EV adoption and highlight the need for more EVSE and flexibility for the grid; and the general public's desire for a more sustainable world (IC6), which makes it easier for policymakers to allocate resources to sustainable technologies. This last IC, in particular, makes use of three important policy-making concepts: creative destruction, non-neutral policy and solving grand challenges. The former two since current industries, like the fossil fuel industry, will suffer the effects of fund reallocation; the latter since investing in clean technology helps combat climate change.

Another way to apply the strategy is by *investing* in specialised institutes, which uses the strategy as an informative policy instrument to address systemic concerns and help with technology push. Specialised institutes can help train skilled manpower and eliminate barriers related to a lack of human resources (IC3) across all blocks. Although R&D strategies are not generally applicable for IC3, this strategy, in particular, is found to be useful in combating barriers that stem from it.

Market stimulating strategies

The second group of strategies stimulates market formation and growth. Only a few of these strategies are employed at present or have been used in the UK, with some still only halfway successful. However, these strategies are essential since they can address barriers in most blocks regardless of their influencing conditions.

Two strategies already used within this category are the *provide guaranteed markets strategy* and the *provide standards and regulations strategy*. Both of these are important regulatory policy instruments focusing on addressing systemic concerns. Nonetheless, the application of both strategies could be improved. Currently, markets have stringent requirements, so even if V2G can access them theoretically, it is still challenging in practice. In addition, some existing standards are incoherent with one another, which creates further difficulties for V2G. These standards should be restructured to become more coherent, and access to markets should be simplified for V2G to prosper.

Providing guaranteed markets that are well thought-out helps circumvent and lower barriers in different blocks. For instance, guaranteed markets for V2G that provide an income to customers help offset the high initial costs of EVs and charging equipment, therefore circumventing these barriers in BB2, regardless of their cause. Furthermore, these markets also help build up entrepreneurial activity (BB3) by lowering the lack of trust in the business model stemming from macro-economic and strategic aspects (IC5).

These markets need to be backed by *providing coherent standards and regulations* to give a sense of security to entrepreneurs. For instance, setting specific regulations or laws that back up high-level goals and objectives. Additionally, if a single charging standard and architecture are encouraged (AC vs DC and CHAdeMO vs CCS), several barriers in different blocks stemming from competition and market modulation (IC4) and macro-economic and strategic aspects (IC5) may be combated, as well as the lack of standardisation (BB8) coming from IC8. Lastly, if proper regulation is set in place regarding taxation, the issue of double taxation of energy (BB8) could be avoided, regardless of the influencing conditions.

Human resource management is another strategy that falls into this category when it is focused on market barriers related to a lack of knowledge of the technology (IC1) and of its market and applications

(IC2). Hiring people with a deep understanding of V2G and its benefits can help companies improve trust in their business case (BB3), create or ask for useful complementary products and services (BB5) and create clear and simple value propositions tailored to customers (BB7), all of which encourage market formation. Policymakers can also benefit from it by hiring experts in the sector to help create regulatory instruments, thus also combating barriers in BB8.

Another strategy is the *existing networks strategy*, which companies already use to promote the technology and build partnerships. However, the benefits of this strategy as a market-stimulating strategy could be enhanced by strengthening the relationship with specific relevant customers, particularly those who could potentially be early adopters of the technology. By going through existing networks, customers are more likely to trust in the value that a company is offering them and better understand the benefits of the technology than if an unknown company approached them. This application of the strategy could help circumvent several barriers in different blocks (BB1, BB2, BB7) caused by a lack of awareness of the market and application (IC2) or by socio-cultural aspects (IC6) and broaden the market for V2G. It is worth noting that, in general, market-stimulating strategies do not apply for BB1; nonetheless, in this case, an existing relationship between a user and company could help overcome the barrier related to the complexity of use.

The *cross-selling strategy* could be implemented for V2G by selling complementary products, like rooftop PV, with V2G and providing the whole package to make an energy-intelligent home. This cross-selling, in turn, could encourage customers to get V2G since it could bring higher benefits from an intelligent PV system. This strategy is likely to work for minor inconveniences, such as the complexity of adoption in BB2, but not for more significant issues like steep prices or quality issues. However, socio-cultural aspects and social dynamics (IC6) provide excellent support for this strategy's success since climate consciousness is a big part of today's society and integrated PV - V2G systems could greatly aid in the energy transition.

A final strategy to stimulate market formation is the *provision of policies to incorporate externalities*. While some taxes are already imposed on emissions and fossil fuels (Office for National Statistics, 2023), further policies incorporating externalities from ICE vehicles and electricity obtained from polluting sources could greatly benefit V2G. These policies would bridge the price gap between EVs and ICE vehicles, circumventing the price barriers (BB2) and driving the roll-out of renewable technologies, making the case for V2G stronger and building its market. This strategy is based on the policy notion of creative destruction by 'destroying' some revenue in the incumbent ICE vehicle sector and polluting energy systems, and 'creating' opportunities and demand for EVs and renewables.

Network stimulating strategies

While network formation is the only complete block at the moment, some strategies to keep stimulating network formation and stakeholder interaction are still relevant. These include the *campaign funding strategy* and the reinforcement of the *partnership strategy*.

Campaign funding is a relevant strategy for companies to remember, especially since the UK should hold its next general election no later than January 2025 (UK Parliament, 2024). By donating to campaigns for the next elections, companies can build their networks with certain policymakers, which could help remove regulatory barriers (BB8). Specifically, those barriers related to competition and market modulation (IC4) by creating more opportunities for V2G over its competition, those pertaining to allocation of resources (IC3) by designating more resources for V2G, and those caused by socio-cultural aspects and social dynamics (IC6) by challenging government relationships with incumbent actors. This strategy can also take advantage of IC6 working as an influencing condition since sustainable innovations like V2G are trending in the socio-cultural sphere.

In addition, it is also important to change the approach to the *partnership strategy* currently employed by companies. Several companies currently rely on their partners to *"tell them the answer"*; however, this proves counterproductive to technological development. A different approach in which companies invest in their own capabilities and then form partnerships is more likely to be effective (Interview 4). For instance, vehicle OEMs should focus on getting the best V2G-capable vehicle possible, and flexibility providers should focus on making reliable, responsive systems that are able to extract the most value across most markets and then form a partnership. Partnerships like these can circumvent barriers in BBs 3 and 5 related to a lack of knowledge of the technology (IC1) by increasing information exchange and those from macro-economic and strategic aspects (IC5) by reducing uncertainty for actors.

From a policy-making side, the *partnership strategy* can also help circumvent several barriers, especially those related to innovation-specific institutions (BB8). By creating partnerships with companies that have knowledge of the technology, policymakers can overcome their own lack of it (IC1) and create effective and coherent regulatory measures to drive its roll-out (Interviews 2, 3, 4, 5, 6).

7.3.2. Potential niche introduction strategies

Though Ortt's ten niche introduction strategies were originally conceptualised for companies, policymakers may also employ some; for instance, education may be used as information and awareness campaigns to educate citizens on new technologies and promote their benefits (in 't Veld, 2020). This section describes niche introduction strategies that may be used by companies, policymakers, or both to introduce V2G in the UK.

Product-focused strategies

The first set of strategies within this category are product-focused strategies. These strategies centre around the product itself and change/enhance it to make it more appealing and more accessible to sell. Of these strategies, only the *turnkey product strategy* is not currently used and has high potential for the case of V2G in the UK.

V2G is a complex technology that involves several different components and *"it's pretty hard for [customers] at the moment to have to coordinate all of those things individually themselves"*(Interview 5), which is why the *turnkey product strategy* is applicable. Setting up a 'one-stop-shop' system where the EV, the charger and the tariff are bundled can simplify things for customers and make the product more appealing (Interviews 3, 5). This strategy can also extend to complementary products or services, such as battery swapping or rooftop PV installations to make an 'energy-intelligent home' via the *cross-selling strategy* previously mentioned. Barriers like the complexity of use (BB1), complexity of adoption (BB2) or even high costs of the technology (BB2) may be circumvented with this strategy.

Customer-focused strategies

The second set of niche introduction strategies are customer-focused strategies. These strategies aim to address barriers by catering to the customer and creating demand for the product itself. Five strategies are applicable within this category.

Being an expensive technology, V2G could benefit from the *top niche strategy*. Marketing the technology to top-end customers willing to pay a premium could help circumvent the price barriers in BB2 stemming from a lack of knowledge of the technology (IC1) or macro-economic and strategic aspects (IC5). Furthermore, the *top niche strategy* is already a strategy used by companies to sell EVs; therefore, adapting it for V2G should not prove too complicated. This strategy is enhanced by socio-cultural aspects and social dynamics (IC6) since peer effects are an important driver for technological adoption and 'status' has significant appeal to top niche customers.

The *lead user strategy* has a similar application except that the product is marketed towards early adopters of the technology, as opposed to top-end customers. Early adopters of a technology are usually more well-versed in the technology's benefits and its possible applications and are more likely to accept its issues (Interview 4). In general, early adopters tend to be more environmentally conscious as well (Earl & Fell, 2019), which also makes use of IC6 as a driving condition, and is good for V2G since some of its main contributions concern the environment. By marketing the technology to lead users, barriers stemming from a lack of knowledge of the technology, lack of awareness of the technology's application (IC2) and socio-cultural aspects and social dynamics (IC6) can be circumvented. This strategy is particularly useful in combating barriers such as complexity of use (BB1), complexity of adoption (BB2), and a lack of customers due to high prices (BB7); especially when they are rooted in the previously mentioned ICs.

A third customer-focused strategy applicable to V2G in the UK is the *incentives strategy*. This strategy was previously mentioned in the R&D stimulating category as well since how it is applied determines where it belongs. In this case, the *incentives strategy* could be used as an economic policy instrument to push the technology in the form of subsidies or other financial benefits; or as a non-financial benefit provided to customers by policymakers since V2G is a technology that can be considered societally relevant. One such incentive may be credits for charging EVs with renewable energy.

Companies may also employ the *incentives strategy* by providing additional benefits or discounts to customers acquiring V2G. In both cases, this strategy can aid in circumventing the complexity of adoption (BB1) and price barriers in BB2 stemming from different ICs, as well as barriers in the customer block (BB7). When these incentives are given in the way of extended warranties for the battery, then they also circumvent the battery degradation barrier in BB1.

On a similar note, the *result-oriented contracting strategy* may also be employed by companies to combat these price-related barriers (BB2) and the uncertainty over the value that V2G may bring customers (BB7), stemming from a lack of knowledge and awareness of the technology (IC1 and IC2) or macro-economic and strategic aspects (IC5). By providing information on estimated benefits from the acquisition, such as the projected return on investment, companies can offer a sense of security to customers.

Another relevant strategy tailored to customers is the *leasing strategy*. At the moment, this strategy is not being employed, but it could circumvent barriers related to battery degradation concerns (BB1), range issues (BB1), and steep prices (BB2), mainly stemming from a lack of knowledge of the technology (IC1) or a lack of awareness of its application (IC2). Leasing a V2G-capable EV allows customers to spread the high initial costs of acquiring the vehicle over time. Additionally, it alleviates battery degradation concerns since vehicle ownership stays with the dealership and worries over 'ruining' the battery lessen. This strategy can also be applied to batteries, for instance, leasing a smaller battery for day-to-day use and having the option of upgrading to a larger battery when necessary (Interview 2). This helps mitigate range issues and degradation concerns as well.

Market-focused strategies

Public sector participation is another strategy already employed on the policymaker side. However, this strategy has been limited mainly to some roles in pilot projects. In order to help promote V2G adoption, the public sector could participate in more ways. For instance, integrating V2G in public buildings and fleets could significantly broaden the market for the technology. Using this strategy as a demand-pull instrument, policymakers can create demand and circumvent barriers that still cause the customer block (BB7) to be incomplete. Additionally, if the public sector is seen investing in the technology, it could help bring visibility to its application and build trust in the business model, eliminating this barrier in BB3. Finally, having V2G-capable charge points in government-owned sites could also lower the barrier related to their low numbers in BB5.

Applying the*public sector participation strategy* is also beneficial for policymakers since it is backed by several ICs acting as drivers. For instance, it aligns with the environmental concerns in socio-cultural aspects (IC6) by focusing on solving a grand challenge; it stays on-trend with the overall global context (IC8), which is moving in the direction of renewable energy, EV adoption and overall energy transition; and it circumvents the high prices of fossil fuels brought on by different world events (IC7).

A final applicable strategy is the *explore multiple markets niche strategy*, along with its market research element. Lack of coherence and lack of standardisation in BB8 are two barriers that could benefit from its application. On one hand, a lack of knowledge of the technology's benefits and applications (IC2) has created unclear and incoherent regulations, which could be solved by conducting proper market research, looking at all the possible revenue streams for V2G and then making regulations that will benefit rather than counteract each other. On the other hand, uncertainty revolving around charging standards and architecture (IC5) has affected standardisation for V2G; however, conducting proper market research and exploring the different options thoroughly may help bring clarity on which option should be chosen and standards can be issued. This strategy may also combat barriers in the customer and demand opportunities block (BB7) by providing information on the market to create a clearer value proposition.

7.4. Additional strategies

While interviewing participants and conducting research on V2G in the UK, two more potential strategies to encourage technological adoption were derived: the ***targeted value proposition strategy*** and the ***trial run or sampling strategy***.

The first strategy consists of properly identifying the profile of each target customer and adjusting the value proposition accordingly (Interview 1). An example of this strategy in the V2G context is the value proposition given to a fleet manager vs a driver who has owned a lower-cost EV for years due to its environmental value vs a driver who owns the newest, top-of-the-line EV.

For the first customer, the fleet manager, the value proposition needs to be adjusted to economic terms. The main focus should be on how much financial benefit V2G can provide their fleet since they are unlikely to adopt the technology without the economic incentive. In this instance, companies can make use of IC5 as a driving condition since rising fuel prices can encourage fleet managers to make a move towards EVs.

For the second customer, a low-cost EV driver, the value proposition should focus mainly on the environmental benefits that V2G can provide, aiding in the integration of renewables. As an early adopter of EVs, this customer is likely to be more environmentally conscious and, therefore, more likely to respond to this type of marketing. In this case, IC6 is working as a driver due to the social importance of sustainable technology. These benefits can also be complemented with potential savings; even if they are small, the driver will likely be interested in them.

The final customer is a driver with the newest top-of-the-line EV, who is more likely concerned with the status or 'look' that V2G can give them. *"They're not going to care about saving £10 a month; that's just not going to be a driving factor for them, but they might have solar, they might have batteries, and they might want to do a whole house optimisation, and that's something that's really cool and that they can see"* (Interview 2). Therefore, the value proposition should be focused on the innovative, sleek integration that V2G can provide. IC6 also plays as a driver in implementing this strategy since the 'look' that these customers are trying to achieve is related to social dynamics and standing.

The *targeted value proposition strategy* may be used in the case of V2G in the UK to clear up the value proposition for customers (BB7). It would also aid in creating more specific business cases with lower levels of uncertainty to encourage entrepreneurial activity (BB3).

The *trial run or sampling strategy* consists of letting the customer try out the technology during a certain period. This provides reassurance that their needs will still be met and gives them the opportunity to experience first-hand the benefits that the technology may bring them. This strategy may work better with certain types of innovation than others though, and it may be completely impractical for some innovations. Nonetheless, experiencing the technology directly provides reassurance and alleviates customer concerns, as was found in the Sciurus pilot project (Cenex, 2021).

For the specific case of V2G, it may be too difficult to allow a sampling or trial period of the technology. However, a simulator may serve the purpose. Companies could create an interface that simulates a customer's driving patterns, energy bills, etc. and gives them the chance to set different parameters such as the desired SoC and time at which they usually use their car. Then, the simulator could calculate how much benefit V2G could provide them with while showing them that their transportation needs are met.

The simulator could eliminate different barriers in different blocks. First, by allowing users to familiarise themselves with the company's V2G interface, the complexity of use (BB1) and complexity of adoption (BB2) barriers could be overcome. Building up these blocks would also circumvent the barrier in BB7 related to quality issues and high prices. Additionally, a trial run in a simulator could provide users with more certainty on the value that V2G could bring them, eliminating this barrier in BB7, as well.

7.5. Main takeaways

There are numerous strategies to introduce V2G technology in the UK and foster its adoption, and companies and policymakers are already employing them. Most strategies already in use fall under the TIS build-up category. However, certain niche introduction strategies are also being employed, mainly by companies.

Consistently throughout strategy formulation, several important policy-making concepts come into play. Non-neutral policy is found in strategies where clean technology is given an advantage over other technologies. For instance, if a mandate were to be made regarding V2G-capable technology, or if more funds were allocated to V2G R&D over other technologies. Creative destruction is found in certain strategies that focus on penalising or breaking away from incumbent technologies, such as the provision of policies to incorporate externalities. Transformative innovation policy is found in all strategies that focus on highlighting the environmental benefits of V2G or that integrate it with other sustainable technologies to address the grand challenge of climate change. Additionally, it is worth noting that most strategies to be employed by policymakers relate to one or more policy-making instruments as suggested by Rogge and Reichardt (2016).

Influencing conditions serving as driving factors also play an important role in the application of several strategies. In a number of instances, the effectiveness of a strategy may be greatly enhanced by an IC that acts as a driver, for example, socio-cultural aspects enhancing the top niche or lead user strategies. In other cases the decision to use a strategy may be supported or rationalised through driving ICs, for instance, the overall global context supporting the provision of standards and regulations or public participation in V2G. In either case, keeping ICs that serve as driving factors when deciding which strategies to apply is relevant.

Due to several different types of constraints (economic, time, personnel, etc.), not all strategies can be implemented, especially not simultaneously. This being the case, some strategies become more relevant than others when it comes to V2G in the UK. The critical strategies for the technology are those that address the main issues identified in previous chapters, which are shown below in Table 7.3.

Table 7.3: Recommended strategies for the most relevant barriers identified

Main barrier	Recommended strategies	Applicable by
Low vehicle availability due to a lack of confidence in the business model and uncertainty of where charging architecture is heading (AC vs DC).	*Provide standards and regulations* that require all EVs to have V2G capabilities by a certain date and provide clarity on which charging architecture should be employed.	Policymakers
	Provide guaranteed markets for V2G in which the benefit for each stakeholder involved with the technology is clearly delineated.	Policymakers
	Provide *incentives* to companies involved with V2G to make vehicle models and V2G-capable chargers available faster.	Policymakers
	Hire capable *human resources* with deep knowledge and understanding of the technology who may help build up the business case for V2G.	Companies
Interoperability issues between existing standards (CHAdeMO vs CCS) and across different devices and platforms.	*Provide standards and regulations* that appoint a 'dominant' charging standard and communication protocol and mandate open standards such as the OCPP to ensure interoperability across devices and platforms.	Policymakers
	Build networks and create *partnerships* to collaborate in the creation of high-quality standards that will solve relevant issues.	Companies
High prices of EVs in general and V2G-capable EVSEs.	Provide *incentives*, such as discounts, dynamic tariffs, tax breaks or subsidies to make the technology more financially accessible to customers.	Companies and policymakers
	Cross sell the product with home management systems or rooftop PV, which will make it more appealing and will likely see higher returns on investment when bundled.	Companies
	Provide *result-oriented contracting* that will reassure the customer of the expected payback period of their investment and will show them the expected benefits.	Companies
	Provide policies to incorporate externalities which will stimulate price parity between EVs and ICE vehicles.	Policymakers
	Have the option to *lease* V2G-capable EVs and chargers to eliminate high up-front costs.	Companies
	Market the technology to *top niche* customers who are willing to pay a premium to obtain the technology.	Companies
User concerns related to the complexity of interaction with the technology, battery degradation and range issues.	Have battery *leasing* or battery subscription services to allow customers to have their range needs met without unnecessary costs.	Companies
	Provide extended warranties on EV's battery life that cover V2G application as an *incentive* to customers.	Companies
	Allow *trial runs* or simulations for customers to experience the technology first-hand.	Companies
	Provide demonstrations and information campaigns to *educate* customers on the benefits of the technology, the ways in which it may be used and reassure some of their concerns.	Companies and policymakers
	Market the technology to *lead users* who already know the advantages of V2G, are aware of how it works and how to use it, and are willing to accept its downsides.	Companies

Complex and onerous requirements for V2G connection and market participation.	Provide simple and coherent *standards and regulations* that will enable V2G to access different revenue streams in a simple manner and eliminate double taxation.	Policymakers
	Lobby for V2G to be accepted in different markets and to obtain standards and regulations that will be beneficial for its adoption.	Companies
	Form *partnerships* to share knowledge and work together on the best ways to create useful rules, laws and regulations that will boost the technology.	Companies and policymakers

All of the strategies mentioned above may be used as stand-alone or in combination with other strategies. However, when being used in combination it is important to analyse whether certain combinations of strategies could interfere with each other rather than being harmonious.

As was expected, TIS build-up strategies tend to be more applicable for policymakers, while niche introduction strategies tend to be more applicable for companies. Nevertheless, certain strategies in both categories were applicable for companies and policymakers alike.

8
Discussion

Initially, this work was conceptualised with a central focus on studying V2G in the UK, along with potential niche introduction strategies for companies and policymakers to employ regarding this technology. Nevertheless, the work evolved to comprise two equally important contributions. The first is the adaptation of a framework to derive niche introduction and TIS build-up strategies for both companies and policymakers, creating a new framework. This Shared framework can be used in several technological innovation cases and allows both actors to study the combination of different sets of strategies while pursuing a common goal. The second contribution is the case study of V2G in the UK using the Shared framework. By conducting the case study, the functionality of the Shared framework was tested, and relevant strategies that can aid in V2G's technological adoption were derived.

Several important insights were obtained by applying the Shared framework to V2G in the UK. Some of these insights relate to the technology and the context in which it is developing, shown in section 8.1, while others relate to the framework itself, which are presented in section 8.2. Limitations to the framework, areas of opportunity, and recommendations for further work are presented in section 8.3.

8.1. V2G case analysis insights

One of the first things to consider while conducting the case study is the identification of barriers from different viewpoints. While working to identify barriers and drivers for V2G in the UK, it was evident that barriers perceived differ between users, companies, and government entities. Users tend to perceive barriers related to their experience with the technology, such as ease of adoption of V2G, quality issues, and prices, as stronger deterrents for technological uptake. Contrarily, technology and energy service providers perceive barriers related to the product and regulatory issues, such as vehicle availability, technological risks, differences in charging standards, and unclear rules and regulations as the most relevant barriers. Government entities, however, present a mix of both viewpoints but are most concerned with proving the benefits that V2G can provide to the energy system in order to support their decision-making.

Similarly to barriers varying depending on the stakeholder at hand, drivers and motivation for the adoption of V2G may vary and biases may be found depending on different sources consulted. A general consensus seems to exist that environmental and social aspects are the main motivation behind the policy push for V2G since its benefits are mainly for a greener electricity grid and society as a whole. However, some academic papers and most interviewees also believe that an economic incentive could provide strong motivation for customers to adopt the technology, particularly for fleets since they tend to be more financially oriented. While V2G's financial benefits have been studied in several pilot projects and are expected to be a strong motivator for certain types of users, more evidence is needed to determine whether this will be a decisive factor in acquiring V2G.

Another relevant consideration to discuss is the difficulty of establishing system boundaries. V2G is a complex product that combines several different technological components and has no clear boundaries that delineate it. Defining 'V2G technology' brought on several questions to answer during the process. What components does V2G encompass? Does it only include the bidirectional capabilities of the charger regarding communication with the grid? Does it include the EV as well? What about the batteries themselves? Are AC V2G and DC V2G considered two different technologies? Some of these questions have different answers depending on the source at hand or the consulted expert.

After much deliberation, the V2G system was delineated as a combination of the EV, charger, and communication technology used to connect the components for the purpose of this work. Furthermore, AC and DC V2G were considered sub-categories of V2G technology as a whole. However, it would be interesting to conduct an exploration of the TIS with different technological boundaries to determine which barriers and drivers remain the same and which differ.

8.2. Framework adaptation insights

The application of the framework to the case of V2G in the UK led to several theoretical insights. The first, pertaining to the usefulness of the framework adaptation is discussed in subsection 8.2.1. The second relates to important considerations to keep in mind regarding the two main stakeholders in this framework and is presented in subsection 8.2.2. The third subsection (8.2.3), talks about important aspects regarding the derivation and use of strategies. Finally, the framework's strategy completeness is evaluated in subsection 8.2.4.

8.2.1. Framework adaptation

Modifications to the original TIS framework were found to be relevant for the case of V2G in different ways. First, V2G is a collaborative technology by nature. Bringing together two different systems (energy and transport), V2G requires the involvement of several different actors and cooperation between them. In particular, alignment needs to exist between policy instruments to coordinate its uptake.

A coordinated approach requires collaboration between companies and policymakers, which is hard to achieve if each stakeholder is analysing the TIS in a different manner. The Shared framework allowed barriers to be identified from both perspectives, looking for potential barriers (or drivers) that may have been irrelevant to one stakeholder but are important to another. For instance, V2G's potential in stabilising the grid and helping to integrate renewables is a driver that may not have been identified as relevant for companies but is significant for policymakers.

A second way in which framework additions were found relevant was the classification of strategies. After analysing the barriers in each BB and identifying their root causes in different ICs, categorising the strategies made their derivation less daunting. Understanding which strategies were applicable to different cases helped form connections and consider strategies within the same category that had previously not been considered. However, a few areas of opportunity were found in the categorisation, which are mentioned in subsection 8.3.1.

Finally, the nuance of product quality **and purpose** in BB1 was found to be particularly relevant in this work, since V2G is a technology whose adoption is highly motivated by purpose at the moment. As previously mentioned, there is a general belief that economic incentives will also attract customers such as fleets in the future. However, at the moment, this innovation is mainly being driven by policy push due to its environmental and societal purpose and by early adopters who tend to be more environmentally conscious.

All framework adaptations were initially made to accommodate a policymaker's perspective. Nevertheless, most of these modifications proved relevant for companies as well and should be incorporated into the original TIS framework by Ortt and Kamp. One of the most relevant modifications is the inclusion of the eighth IC: overall global context. In today's world, the global context is extremely important to consider when launching a technological innovation and companies should be aware of how it may affect the TIS surrounding their product.

8.2.2. Stakeholder considerations

Another important aspect to discuss regarding the framework is how it may be employed depending on the stakeholder using it. The framework was adapted to work for both companies and policymakers; nonetheless, the entrepreneurial activity and innovation-specific institutions blocks have a duality in which the stakeholder's use determines whether they are necessary blocks or outputs.

From a company perspective, the innovation-specific institutions block is a necessary condition for innovation to occur. Without regulations, rules and standards, it will be difficult for an innovation to enter the market. However, entrepreneurial activity does not need to be present. Through a company's eyes, this framework aims to evaluate the status of the TIS and devise strategies to introduce the technology to the market. In this case, entrepreneurial activity is the result or output of the framework application.

On the other hand, from a policymaker's perspective, entrepreneurial activity is a necessary building block. Without it, there would be no innovation or TIS. The goal for policymakers when applying the framework is to evaluate the status of the TIS and develop a mix of innovation policy strategies that will help build up the TIS for innovation and accelerate its diffusion. These policy strategies are usually translated into rules, regulations, and standards that make up the innovation-specific institutions block, making it the output of the framework application.

With one stakeholder's output being a necessary building block in the other's framework, company strategies and innovation policy strategies have a mutually dependent relationship. One cannot be fully efficient without the other, and there is an important need for alignment and collaboration between stakeholders.

The Shared framework was originally conceptualised for policymakers and companies who are developing and introducing the technology. Nevertheless, it may also be employed by other actors in the network to derive their own strategies. A few examples of other actors with different roles include suppliers, complementary product developers, external service providers and different government entities. In further works, this application by other actors may be studied in detail, with an analysis of which strategies work for them and whether more strategies need to be created.

8.2.3. Application of strategies

Several issues pertaining to the application of strategies are also relevant to discuss. The first arises when implementing strategies as stand-alone or by themselves. In this case, caution is required during the process since they may have undesired secondary effects. For instance, providing standards and regulations to promote charge point roll-out could remove some barriers for V2G since a higher number of charge points would lessen range issues. On the other hand, it could inadvertently create a technological lock-in of unidirectional EVSE if the strategy is implemented too quickly and is not well-defined.

A second issue appears when strategies are employed in combination with each other. Occasionally, strategies do not affect each other in any way. In this case, completely different strategies are employed by different stakeholders to address barriers in different blocks, stemming from different influencing conditions. Strategies do not interact or interfere with each other and may be used independently without much consequence. This is the case, for instance, of the *network building strategy* and the *leasing strategy*. The *network building strategy*, in general, does not apply to BB1 or BB2 where the *leasing strategy* is most effective. Moreover, these strategies are unrelated and, even when employed by the same stakeholder, are unlikely to affect each other.

However, in most cases, strategies will influence each other somehow, and these interactions should be considered before implementing them. Sometimes, strategies are used in combination and have a positive effect on each other. This can be because the same stakeholder employs them, they address the same barrier or influencing condition or simply address a barrier in a block that indirectly influences a separate block. Some strategies may even enable the use of different strategies.

One example of a pair of strategies reinforcing each other is the *cross-selling strategy* and *turnkey product strategy*. When selling a product ready to use, it may reinforce the business case when paired up with complementary products or services and vice versa. These strategies help build each other up and combat barriers more effectively.

A different example is found with the *investments strategy* and the *human resource management strategy*. In this case, policymakers investing in technological institutes to form capable manpower enables companies to hire skilled human resources, which will help lower barriers in several blocks. If there are not enough skilled human resources to hire, then the human resource management strategy cannot be employed. This also serves as an example to illustrate how coordinating strategies between policymakers and companies can help with TIS formation.

One final example occurs with the application of the *incentives strategy* and the *result-oriented contracting strategy* in separate blocks. Incentives will most likely lower or circumvent barriers within product price (BB2), which makes the product accessible to a wider demand base, building up block 7. If the investment customers need to make on the product is smaller, then providing a well-supported, result-oriented contract is easier. The *result-oriented contracting strategy*, in turn, provides customers with a sense of security over their investment and is also likely to increase demand (BB7).

Conversely, there are times when a combination of strategies may negatively interfere with each other, and it is important to be observant of this. In this case, a strategy employed by one stakeholder could neutralise or deter a strategy employed by a different stakeholder. Or two strategies within the same BB or IC could negatively influence one another.

A specific example of this case could be policymakers implementing the *investments strategy* and *incentives strategy* at once. As a result, a certain budget would have to be split into two different strategies, which could be counterproductive and result in incentives that are not attractive enough to overcome price barriers or investments where the sum is too small to make a significant difference. In this case, it would be better if only one of the two strategies were selected and the funds completely allocated to it.

Another example of this is found in both policymakers and companies employing the *human resource management strategy* simultaneously. In this case, since there is still limited skilled human capital, both stakeholders may compete to hire the same people, thus hindering each other's progress. For situations such as this, it would be better if companies employed the *human resource management strategy* and policymakers employed the *partnership strategy* to be advised on certain matters by companies.

It is clear that strategies within a TIS will most likely interact with each other in some way or another and need to be considered when formulating a business or innovation policy plan. The importance of alignment between policy strategies and company strategies is also evident in these examples, since they may help or interfere with one another. Although a few specific instances are mentioned above, further research could be done where strategy interaction is studied in more detail, and a recommendation on the best types of strategies to pair together is made.

Finally, looking at drivers stemming from influencing conditions, as opposed to barriers, was also found useful while deriving strategies. Certain strategies can piggyback on or strengthen driving factors, further boosting technological adoption in both cases. Therefore, analysing which influencing conditions are working as driving factors and keeping them in mind is crucial when deriving strategies and deciding which to implement.

8.2.4. Evaluation of strategy completeness

One of the main contributions of this work is the classification of niche introduction strategies and TIS build-up strategies. The set of strategies included here and their classification was conceptualised to cover a broad range of BB and IC combinations. To achieve this, all possible logical combinations of BBs and ICs that form a barrier were analysed and checked to have at least one applicable strategy within the provided list.

Nevertheless, even when a strategy is applicable for a combination of a particular BB and IC, it may not be applicable for a specific barrier stemming from that combination. A relevant example for V2G in the UK is the lack of trust in the business model barrier present in BB3, which stems from macro-economic and strategic aspects (IC5). Several niche introduction strategies work for this specific combination of BB and IC (such as the *explore multiple markets strategy* and *geographic niche strategy*), depending on the nature of the macro-economic aspect. For V2G, the nature of the IC comes from the uncertainty of whether market conditions will be favourable for their innovation and none of the niche introduction strategies studied were suitable to combat the barrier.

Since each technological innovation is different and will bring its own unique barriers, there is an infinite number of barriers that could emerge within a specific TIS. This argues that the framework cannot ever be fully complete since there is no way of accounting for all of the barriers that will exist for all technological innovations.

8.3. Framework limitations and suggestions for further research

The Shared framework served the important purpose of analysing the case of a radically new innovation through the lens of companies and policymakers using a single framework. This framework enabled the joint study of V2G and the derivation of strategies for both stakeholders to employ, highlighting the importance of their cooperation. However, the framework has some limitations which are discussed in this section.

First, this work made a first approach to establish a list of indicators used to study the completeness of building blocks and the influencing conditions causing barriers, using some concepts found in literature and critical thinking. Nonetheless, in further works, the list of indicators could be refined with more research to support each element.

Additionally, the exploration of the dynamics and interactions between policy strategies and company strategies stays at a surface level with some case-specific examples. Nonetheless, the importance of policymakers and companies working together to encourage innovation has been made evident in several different works (Earl & Fell, 2019; Frank et al., 2020; Sovacool et al., 2018). Therefore, a more in-depth analysis of how their strategies may support or counteract each other is needed in future works.

The application of the framework is also limited since it analyses the relationship between ICs and BBs in a unidirectional way and takes a snapshot of the TIS status at this moment time. However, TISs have a dynamic nature which requires a constant re-evaluation of their conditions since several barriers and drivers evolve over time and with the implementation of strategies. Moreover, the influence that BBs and ICs have on each other is not linear and requires further study and analysis. For instance, an increase in entrepreneurial activity has significantly driven down EV prices in the past few years (economies of scale), and issues with quality and price have, in turn, affected the customer block for V2G in the UK. This influence that BBs and ICs have on each other exists with other innovations as well. A suggestion for further work in relation to this issue may be to conduct an analysis of V2G in the UK at different moments in time to see how the technology has evolved, which barriers have been eliminated and which have surfaced through time to have a good overview of the evolution of the TIS.

One final limitation to this work is the analysis of V2G as if it were a single TIS when, in reality, it exists in the overlap of two different sectors: energy and transport. While most innovations in the sustainability field are studied from a single sector perspective, Kanger et al. expresses the importance of studying multi-system interactions for sustainability transitions. First, a multi-system interaction study calls for attention to inter-system intermediaries, which are actors that fluctuate between systems and can serve as links between stakeholders in different sectors who would otherwise have difficulty interacting. Second, it focuses on links or connections that need to be created or broken between sectors to encourage the innovation to thrive. Third, it examines how relevant stakeholders, institutions and events in one sector may influence the other and what impact this may have on the innovation.

Residing at the intersection of the energy and transport systems, V2G is an interesting example where such a study would be beneficial. Each sector has its own set of rules, regulations and actors that influence the way in which the technology is developing and barriers or strategies applicable to one sector may not necessarily be applicable to both. Furthermore, events in both the energy and transport sectors can impact the technology and have a ripple effect on the other sector, so this dynamism is also relevant to study in future works.

8.3.1. Suggested framework improvements

Three main improvements should be made to the framework based on this work. The first improvement is to include the two newly conceptualised strategies, the *test run or sampling strategy* and the *targeted value proposition strategy*. Both of these strategies may be considered niche introduction strategies, mainly to be used by companies, and they can both be considered customer-focused strategies.

The second improvement suggested is to add a sub-category within TIS build-up strategies that focuses on innovation-specific institutions. A highly important element within a TIS are institutions. Sometimes, institutions or regulations exist that directly form a barrier for the technology. Other times, the barrier stems from these institutions being absent. At the moment, strategies to stimulate innovation-specific institutions are considered within the network-stimulating and market-stimulating strategies. However, their importance warrants a specific category focused on strategies that create, adjust or remove institutions and regulations.

The third improvement is to re-classify certain strategy categories to include additional BB and IC combinations. There were four instances where certain strategies were applicable to situations where the framework did not contemplate them (i.e., for a combination of BBs and ICs that were not contemplated under a certain category). Three of these instances are believed to be specific exceptions for certain particular barriers, while the fourth begs to consider re-classifying the applicability of the category.

The first instance occurs where *existing networks strategy* was found to be applicable in combating the complexity of use barrier in BB1. This strategy falls under network-stimulating and market-stimulating strategies, and neither category is usually applicable to BB1. Nevertheless, for the specific case of the complexity of use barrier (in BB1) stemming from a lack of knowledge or awareness of the technology (IC1, IC2) or socio-cultural aspects (IC6), the *existing networks strategy* works well. When companies approach customers who already know and trust them, they are more likely to be receptive to their value proposals and test the new technology, thus circumventing the barrier. However, the same does not happen for other strategies within these categories or for the *existing networks strategy* in other cases stemming from the same BB and IC combination (BB1 + IC1, IC2, IC6). Therefore, it may be said that this is case-specific.

The second instance occurred with the *incentives strategy* being applicable for IC5 in the entrepreneurial activity building block (BB3). In this case, certain incentives extended by the government could help vehicle OEMs overcome uncertainties in the market and increase vehicle availability. Nonetheless, other R&D strategies are not applicable for IC5, and the incentives strategy may not be applicable for other barriers caused by IC5, which is why this is deemed as a case-specific situation.

In the third instance, the *investment strategy* demonstrated that investing in specialised institutes may lower barriers related to a lack of skilled human resources (IC3) in different blocks. However, since not the same can be said for natural or financial resources and other R&D stimulating strategies may not apply in the same way, IC3 cannot be included in the list of conditions for which R&D stimulating strategies are applicable.

The final instance involves the same strategy; however, in this situation, the *investment strategy* provided insight into an error in the R&D strategy category. Initially, this category was not found to be applicable to the complementary products and services block (BB5). Nonetheless, by investing in R&D of complementary technologies, it is more likely that a central innovation will be adopted. This argument may be extended to other strategies within the category, and the following generalisation may be made: R&D strategies may help to combat barriers in BB5 since complementary products and services also need research and development. Therefore, a revision to the original categorisation should be made.

8.4. Main takeaways

The adaptation of the Ortt and Kamp TIS framework to create a new Shared framework that adds value in various ways:

- A policymaker perspective was included to have one single roadmap that different actors can use to derivate strategies that will drive technological innovation and development.
- The framework allows for combinations between company strategies and policy strategies to create a more aligned approach towards technological development.
- The categorisation of strategies provides an easier overview of their applicability and facilitates their selection process after evaluating the status of the TIS.
- Most adaptations made in this work also work for a company perspective on its own, making the Ortt and Kamp framework more complete.

The framework was successfully applied to the case of V2G in the UK, providing several relevant insights into its sociotechnical development. In future research, it would be interesting to explore the technology with a different system delineation or from a combined TIS perspective.

The application of the framework also allowed to discover several opportunities for further research. These include the in-depth exploration of the dynamics between policy-making strategies and company strategies, the re-evaluation of indicators used to assess the BBs and ICs, and the analysis of cyclical/non-linear interactions between BBs and ICs.

9
Conclusions & recommendations

The world's energy supply is becoming increasingly driven by renewables and is expected to become even more so as the race towards climate neutrality intensifies. Coupled with the rapid uptake of electric vehicles driven by policies to decarbonise the transport sector, the challenges on electricity grids all over the world are becoming more evident every day. Several countries now face the choice of investing millions to reinforce their energy grids, building large storage facilities, or investing in technologies that will allow flexibility.

V2G technology will relieve several of the pressures brought on by the sustainable energy transition. It can increase grid reliability, provide load-balancing and peak-shaving services, and provide voltage and frequency regulation. All while using assets that are a big part of today's world and are manufactured and sold by the millions worldwide: EVs. In addition, millions of cumulative savings in distribution network reinforcements could be obtained from its use.

V2G has become one of the hottest technologies in the field of sustainable energy at the moment, with much research being carried out worldwide around it, all the benefits it could bring, and its potential to transform energy systems. Therefore, **the main purpose of this thesis was to explore the state of the TIS for V2G in the UK and devise niche introduction strategies and innovation policy strategies suitable for combating barriers within this TIS**. This purpose was achieved by answering six sub-questions presented in section 9.1. Finally, a list of recommendations for companies and policymakers is provided in section 9.2.

9.1. Answers to research questions

Who are the relevant stakeholders for V2G in the UK and how are they connected?

Six main categories of relevant stakeholders exist for V2G in the UK at the moment, all of which are crucial to bolster its technological adoption. These are policymakers, OEMs, energy providers, technology providers, associations and organisations, and end users. In the future, when V2G becomes more widely adopted, system operators will also start playing a big role in the uptake of the technology.

Policy-making and regulating roles surrounding V2G in the UK are carried out by the DfT, the DESNZ, and Ofgem. The DfT and DESNZ set the overarching objectives to achieve through technological innovations such as V2G, and Ofgem regulates the markets where V2G can derive benefit from; together, they set the standards that the technology must follow. Furthermore, they can aid the R&D process, incentivise companies to accelerate technological roll-out and provide incentives to create demand for the technology. These roles mean that policymakers are connected to all major stakeholders involved with V2G in the UK at the moment.

Vehicle OEMs and EVSE OEMs are in charge of making the physical components of the technology affordable, high quality and available. Their part in the adoption of V2G in the UK is fundamental since an important barrier that still plagues it is the lack of vehicle availability. Some OEMs that are active with this technology in the UK are Nissan, Hyundai and Mitsubishi for vehicles and Wallbox and Indra for chargers. OEMs interact with customers by providing them with the product itself, and with policymakers, associations, and organisations by expressing what they need to develop the technology faster at more affordable prices.

Energy service providers are in charge of providing users with tariffs that increase their V2G benefits and managing energy requirements in the grid. At times, they also work as load aggregators and may manage the V2G services that each user can provide. Energy service providers should communicate well with policymakers to help them create rules and regulations conducive to V2G. Most of the time, energy service providers serve as technology providers as well, and they have the crucial role of linking vehicle capabilities to grid requirements. A few examples of these actors in the UK include Octopus Energy, Eon Energy, and OVO Energy.

Technology providers are the ones who develop the interfaces through which information is shared between the vehicle and charging points, as well as with charge point operators and load aggregators. They are also responsible for creating a trustworthy and user-friendly interface so customers can set their vehicle preferences without worries. They should be in close contact with end-users to receive feedback often on their software and, when they are not a single actor, with energy service providers to tailor the software appropriately according to energy needs. Additionally, they need to be aware of the latest vehicle and charger models, and all current standards and regulations to include in their software.

These companies are often linked through organisations, such as Cenex, which conduct research to explore the benefits of V2G, and associations, such as the REA, which bring companies together in forums and lobbying activities to accelerate its roll-out. Associations and organisations are also connected to policymakers since they often provide communication channels between them and companies to help advance a technology.

Finally, end users are those who use the technology and without whom adoption would not happen. At the moment, in the UK, there are very few V2G users, mainly limited to those who participated in V2G pilot projects. However, there is a lot of buzz and expectation around the technology, and a niche market for it is beginning to develop. End users interact with OEMs, energy service providers and technology providers by acquiring their products and services and providing feedback. They also interact with policymakers by asking or applying for subsidies or other incentives that will help them acquire the technology.

When V2G's roll-out is accelerated, two new sets of stakeholders will come into play. The first is system operators who will need to plan and manage the services that V2G will provide to the grid. They will need to interact directly with energy service providers and policymakers to allow for good integration of V2G services into the energy grid. The second is indirect users who will benefit from these services and can range from energy companies to grid operators to individuals who do not have V2G but benefit from lower energy prices.

How can the Ortt and Kamp TIS framework be adapted to derive niche strategies for both companies and policymakers?

The Ortt and Kamp framework was initially conceptualised from a company viewpoint; therefore, some modifications were needed to include a policy-making viewpoint as well. These modifications consisted of studying literature on innovation policy to include relevant concepts, expanding definitions of certain building blocks and influencing conditions and exploring different types of strategies to be employed.

The first step was reviewing literature to determine important policy-making concepts to include when modifying the framework. Some of the most important ones identified were the policy-making stages, different approaches to policy-making, such as Transformative Innovation Policy, Non-neutral policy and Creative Destruction policy, and different types of relevant policy instruments along with their classification depending on their type and purpose.

For the second step, each individual BB and IC were analysed, and all of their definitions were slightly expanded to reflect the relevance they hold for policymakers in addition to companies. However, some BBs and ICs included major modifications and one extra building block and influencing condition were added to obtain the following BBs and ICs:

Building blocks

1. Product quality and purpose
2. Product price
3. Entrepreneurial activity
4. Production systems
5. Complementary products and services
6. Network formation and stakeholder participation
7. Customers and demand opportunities
8. Innovation-specific institutions

Influencing conditions

1. Knowledge of technology and learning opportunities
2. Knowledge and awareness of application and market
3. Allocation of natural, human and financial resources
4. Competition and market modulation
5. Macro-economic and strategic aspects
6. Socio-cultural aspects and social dynamics
7. Accidents and events
8. Overall global context

The last step consisted of categorising niche introduction strategies and TIS build-up strategies found in literature to identify which applied for different combinations of influencing conditions causing barriers in each building block. The categorisation allowed for a simpler application of the adapted framework to derive strategies.

What is the status of each TIS building block for V2G in the UK?

An extensive analysis of the context for V2G in the UK led to the conclusion that most TIS building blocks are incomplete or partially complete, with varying numbers of barriers. The network formation and stakeholder participation block, on the other hand, was found to be complete. Table 9.1 shows the status of each block.

Table 9.1: Status of each building block for V2G in the UK

Building block	Status
Product quality and purpose	Incomplete
Product price	Incomplete
Entrepreneurial activity	Partially complete
Production systems	Partially complete
Complementary products and services	Partially complete
Network formation and stakeholder participation	Complete
Customers and demand opportunities	Incomplete
Innovation-specific institutions	Incomplete

Which influencing conditions are most predominant for each block and do they act as drivers or barriers?

While studying the status of the TIS for V2G in the UK, several different ICs were found to affect each block differently. While most influencing conditions were creating barriers in several blocks, there were a few instances in which they served as drivers. It is worth noting that in some instances, an influencing condition served as both a barrier and a driver for the same block, depending on the specific situation. However, one of its influences has a bigger effect on the block, which is the one depicted in **bold** in the middle column.

Table 9.2: Main influencing conditions affecting each building block with their predominant effect in **bold**

<table>
<tr><th>IC</th><th>Acting as</th><th>Affected BB</th></tr>
<tr><td>Knowledge of technology and learning opportunities</td><td>Barrier</td><td rowspan="6">Product quality and purpose</td></tr>
<tr><td>Knowledge and awareness of application and market</td><td>Barrier</td></tr>
<tr><td>Macro-economic and strategic aspects</td><td>Driver</td></tr>
<tr><td>Socio-cultural aspects and social dynamics</td><td>Barrier/ Driver</td></tr>
<tr><td>Accidents and events</td><td>Driver</td></tr>
<tr><td>Overall global context</td><td>Driver</td></tr>
<tr><td>Knowledge of technology and learning opportunities</td><td>Barrier</td><td rowspan="2">Product price</td></tr>
<tr><td>Knowledge and awareness of application and market</td><td>Barrier</td></tr>
</table>

Allocation of natural, human and financial resources	Barrier	Product price
Macro-economic and strategic aspects	**Barrier**/ Driver	
Accidents and events	Driver	
Knowledge and awareness of application and market	Barrier	Entrepreneurial activity
Competition and market modulation	Driver	
Macro-economic and strategic aspects	Barrier	
Overall global context	Driver	
Allocation of natural, human and financial resources	Barrier	Production systems
Competition and market modulation	Driver	
Knowledge and awareness of application and market	Barrier	Complementary products and services
Allocation of natural, human and financial resources	Barrier	
Competition and market modulation	Barrier	
Macro-economic and strategic aspects	Barrier	
Knowledge of technology and learning opportunities	Barrier	Customers and demand opportunities
Knowledge and awareness of application and market	Barrier	
Allocation of natural, human and financial resources	Barrier	
Macro-economic and strategic aspects	**Barrier**/ Driver	
Socio-cultural aspects and social dynamics	Driver	
Accidents and events	Driver	
Overall global context	Driver	
Knowledge of technology and learning opportunities	Barrier	Innovation-specific institutions
Knowledge and awareness of application and market	Barrier	

Allocation of natural, human and financial resources	Barrier	Innovation-specific institutions
Competition and market modulation	Barrier	
Macro-economic and strategic aspects	Barrier	
Socio-cultural aspects and social dynamics	**Barrier**/ Driver	
Accidents and events	Driver	
Overall global context	**Barrier**/Driver	

What type of niche introduction strategies are most suitable for companies in this TIS?

Generally speaking, niche introduction strategies are all suitable for companies. However, for this TIS, it is crucial that companies employ certain strategies to introduce V2G. Strategies within the customer-focused category were found to be particularly important in addressing the main barriers currently affecting V2G in the UK. Some of the most relevant are the *leasing strategy, cross-selling strategy, incentives strategy, top niche strategy* and *lead user strategy* since they all combat or circumvent barriers related to product price, which is one of the main obstacles for V2G at the moment.

In addition to this, some TIS build-up strategies were also found to be relevant to companies, such as the *network building* and *partnership* strategies. These strategies are relevant since they can help companies acquire knowledge and skills and gain trust to form strong partnerships. This, in turn, can help companies overcome uncertainties in the V2G business case which was identified as a significant barrier for V2G in the UK.

What type of niche and TIS build-up strategies are most suitable for policymakers in this TIS?

For policymakers, TIS build-up strategies were found to be more useful than niche introduction strategies in general. This is also true for the specific case of V2G in the UK. The most relevant strategies for policymakers to combat barriers within this TIS were those focused on stimulating market formation, mainly *providing guaranteed markets*, *providing standards and regulations* and *providing policies to incorporate externalities*. These strategies can appease companies' concerns over the technology and motivate them to roll out their products faster.

However, all of these strategies should be backed by the *partnership strategy*, which was singled out as important across all sources. It is highly relevant since uninformed policy-making may lead to potentially unhelpful standards or an inability to provide the right incentives for its technological adoption. At the moment, incoherent or complicated regulations form some of the main barriers for V2G, which is why it is crucial that going forward legislation is done in collaboration with experts on the technology.

9.2. Recommendations

The answers to the previous questions provided the context to extend the following recommendations for companies and policymakers looking to drive the technological adoption of V2G in the UK. These recommendations summarise the most relevant strategies identified for each stakeholder while analysing the case. Each recommendation relates to certain specific strategies which are mentioned in parentheses below.

Recommendations for policymakers:

1. Continue gathering information on V2G and its benefits through large-scale demonstrations if necessary, to prove the benefits it can provide and mitigate any concerns related to its functionality (*educate niche strategy; demo, experiment and develop niche strategy*).
2. Establish high-quality partnerships with relevant actors in the sector that can provide information on V2G and express what is needed from the regulatory side to drive its roll-out (*partnership strategy and network building strategy*).
3. Provide clear regulations and standards that enable V2G to participate in markets where it can derive value, removing onerous and complex requirements that hinder its entrance (*provide standards and regulations strategy*).
4. Evaluate existing standards, rules and regulations to create coherence across different regulatory levels and policy mixes (*provide standards and regulations strategy*).
5. Create relevant incentives for companies to accelerate the development of V2G-capable vehicles and chargers and for customers to be able to access the technology (*incentives strategy)*.
6. Employ a mix of TIS build-up and niche introduction strategies that make use of differing policy instruments to address barriers from different angles.
7. Set specific targets to be achieved by the technology regarding the number of V2G-capable charge points, number of bidirectional vehicles, etc. *(provide guaranteed markets strategy).*
8. Explore different public use cases for V2G, such as refuse collection trucks or vessels in the Thames (*explore multiple markets strategy*).

Recommendations for companies:

1. Form relevant, high-quality partnerships with other stakeholders where each actor focuses on delivering the best working component possible (V2G-capable EVs, chargers, communicating software) to create a high-quality technological innovation (*partnership strategy, network building strategy*).
2. Clearly communicate to relevant authorities what regulatory barriers exist for the technology and ask/lobby for important incentives and measures that will increase technological development (*lobbying strategy*).
3. Provide reassurance to customers on the quality of the product and the availability of their vehicle for the main purpose for which it was purchased: transport (*educate niche strategy, trial run strategy*).
4. Choose a clear customer segment to market the technology to, such as top niche, lead users, etc. and form clear value propositions for each of the intended segments, keeping their needs and pain points in mind (*top niche strategy, lead user strategy, targeted value proposition strategy*).

5. Provide clarity to customers on what value V2G can bring them, having a clear proposition for each customer profile they approach (*targeted value proposition strategy, result-oriented contracting strategy*).
6. Provide different incentives or schemes to make it easier for customers to acquire and use the technology (*incentives strategy*).

9.3. Final conclusion

What is the state of the Technological Innovation System for V2G in the UK, and which niche introduction strategies and policy trategies may be suitable for combating barriers within this TIS?

The TIS for V2G in the UK is still partially complete, with several barriers blocking the technology from being ready for large-scale diffusion. Both niche introduction strategies and TIS build-up strategies can aid in combating these barriers within the TIS.

The Shared framework provided a joint guideline for companies and policymakers to analyse the TIS and derive strategies from. Niche introduction strategies that are customer-focused were found to be the most useful for companies to employ at the moment, while TIS build-up strategies with a focus on market stimulation were found to best for policymakers to use.

In general, several different sets of strategies resulted helpful in combating barriers for V2G in the UK, with various recommendations being provided to both stakeholders.

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A

Interview protocol

A.1. Interview guide and structured questions

A brief introduction to the thesis topic and research objective is provided, as well as the goal for the interview, the expected amount of time and the initial number of questions. Following this, any doubts or concerns arising from previously shared informed consent form are addressed and consent to record the interview is asked for again, accounting for participant's preference of having video and audio or only audio recorded. After obtaining verbal consent, recording begins.

1. Wold you please tell me what you currently do in your role, and what is your area of expertise?
2. How would you describe the current market for V2G in the UK?
3. Could you briefly mention a few of the main stakeholders that exist and their relation to the technology?
4. What role are UK policymakers playing in regards to this innovation?
5. Have you worked on or observed any V2G pilot projects that you could briefly describe?
6. What would you say are the main barriers that V2G has encountered in the UK?
7. What are some relevant strategies that companies can implement to sell this technology?
8. What can policymakers do to foster V2G adoption?
9. What are the main drivers you see for someone to adopt V2G?
10. What are some incentives you see for this in the UK?
11. Could you mention some competing and complementary services or products for V2G?
12. Is there any other topic we have not touched on that you find particularly relevant for V2G in the UK?

Closing statement and recap of key points from interview is delivered, after which recording stops. Participant is thanked for agreeing to partake in this research and next steps, including when the transcript is expected to be shared for approval, as well as expected publication of thesis are mentioned.

A.2. Code book

After conducting and transcribing the interviews, they were coded to obtain relevant insights for this work. A mixture of inductive and deductive coding was employed. Inductive coding was used with premeditated codes related to each BB and IC, while deductive coding was employed to form insights from relevant issues mentioned in interviews.

A.2.1. Inductive codes

Inductive codes correspond to each building block and influencing condition within the framework. The following table shows the number of times participants talked about each specific topic.

Table A.1: Inductive codes with number of mentions in interviews

Code	# of times mentioned	# of unique interviews
IC1	24	7
IC2	26	7
IC3	18	6
IC4	23	6
IC5	7	4
IC6	9	4
IC7	2	2
IC8	7	5
BB1	23	7
BB2	25	6
BB3	19	6
BB4	9	4
BB5	30	7
BB6	28	7
BB7	38	6
BB8	40	7

A.2.2. Deductive codes

Table A.2: Deductive codes with number of mentions in interviews

Code	# of times mentioned	# of unique interviews
Simplifying value propositions	14	7
Collaboration	13	6
Targeted customer proposition	13	6

Importance of policy-makers providing clarity for OEMs	10	6
Issues with different charging standards (CHAdeMO vs CCS)	10	6
Uncertainty in business model	9	6
Economic aspects are a driver to adopt V2G	9	6
Opportunities of V2G in fleets	9	6
Need for a mandate regarding bidirectionality	8	6
Call for V2G-specific incentives	7	6
Domestic use case of V2G	7	6
Value-generating opportunities of V2G	9	5
Call for simplifying market design and access	9	5
Lack of available V2G-capable vehicles	9	5
UK has a lot of opportunities for V2G	8	5
Integration of renewables	8	5
Need for dynamic tariffs	8	5
V2G providing flexibility to grids	7	5
Lack of V2G-capable chargers	5	5
Lack of incentives for V2G adoption	5	5
Peer-effects are a driver for V2G adoption	7	4
Double taxation	7	4
AC vs DC charging	7	4
High levels of expectation and excitement around V2G	7	4
High levels of innovation funding for V2G	6	4
Emerging market	6	4
Existing incentives for EVs	6	4
Importance of early adopters	6	4
Importance of proper market signals	6	4
Refuse collection truck use case of V2G	6	4
Other use cases of V2G	6	4

Complex regulations causing barriers	5	4
Uncertainty in value for customers	5	4
Importance of hiring specialists in V2G	4	4
Relevance of network planning	4	4
Complicated grid connection process	7	3
Complexity of the technology	6	3
Importance of revenues from market participation	5	3
Necessary grid upgrades	5	3
Charging as a service (battery swapping, subscriptions, etc.)	5	3
Policymakers should provide standards	4	3
Importance of developing internal capabilities	4	3
Environmental concerns are a driver for V2G adoption	4	3
Interoperability across platforms, vehicles and equipment	3	3
Metering complexities	3	3
Importance of reassuring customers of vehicle availability	3	3
Difficult technology to legislate/regulate	4	2
Parity with competition	3	2
Aggregation	3	2
Battery degradation concerns	3	2
Pilot projects affected by COVID-19	3	2
Range concerns	2	2
Data-sharing complexities	2	2
Cybersecurity concerns	1	1

B

Niche strategies

B.1. Full description of mentioned niche strategies

Niche introduction strategies

1. ***Demo, experiment and develop niche strategy*** is employed when the technology does not have sufficient quality yet and therefore is used as a demonstration to the public in an experimental or controlled environment to enable further research (Ortt et al., 2013).
2. ***Top niche strategy*** may be employed when the price of the technology is still too high due to a lack of knowledge. In this strategy the innovation is marketed to top-end customers and made to order in small quantities (Ortt et al., 2013).
3. ***Subsidised niche strategy*** is employed in cases similar as the previous one, where the price is affected by lack of knowledge or resources. In this case, the product may be subsidised by the government if its use by a specific set of users is considered "societally relevant or important" (Ortt et al., 2015, 2013).
4. ***Redesign niche strategy*** also applies for price barriers influenced by lack of knowledge or resources, or by diffusion being hampered due to socio-cultural aspects. The redesign niche strategy suggests to introduce the product as a simpler version to lower the price, or explore a different application to the original one, where socio-cultural aspects are less likely to be a barrier (Ortt et al., 2013).
5. ***Dedicated system or stand-alone niche strategy*** refers to cases when the technology is introduced as a "stand-alone" because a lack of knowledge affects complementary products and services (Ortt et al., 2013).
6. ***Hybridisation or adaptor niche strategy*** refers to the previously mentioned strategy where new technology is used alongside old technology in a hybrid product. This enables the re-utilisation of complementary products and services and thus is employed when lack of knowledge affects their availability (Ortt et al., 2013).
7. ***Educate niche strategy*** may also be employed when a lack of knowledge of the technology affects its availability. This strategy consists of introducing pilot projects as a mean to educate suppliers or customers on the technology and its benefits (in 't Veld, 2020; Ortt et al., 2013; Schulz, 2019).
8. ***Geographic niche strategy*** consists in adopting the technological innovation in a different geographical area to the intended one, due to a lack in resources, knowledge of the technology or socio-cultural aspects that impede its adoption (Ortt et al., 2013).

9. ***Lead user niche strategy*** refers to marketing the innovation to early adopters of a technology, which may then collaborate in the development and diffusion of the product. This strategy may be employed when knowledge of the application of the innovation is lacking, or when socio-cultural or macroeconomic aspects are blocking technological development (Ortt et al., 2013).
10. ***Explore multiple markets niche strategy*** can be adopted when knowledge of the application of the technology is missing. It consists on exploring multiple possible applications for the product, stemming from visibility of its first application (Ortt et al., 2013).
11. ***Local implementation strategy*** means introducing the technology in local markets by making its design and specifications suitable for them by addressing local needs and matching local context (Dwisatyawati, 2022).
12. ***Market research strategy*** refers to properly exploring and selecting the market that the product will be launched into. It includes looking into competitor's best practices, main performance, price and quality differences with other products, etc. (Dwisatyawati, 2022; Schulz, 2019).
13. ***Pilot project strategy*** also referred to as supportive demonstration, consists of performing small-scale product implementations when barriers such as costs impede large-scale diffusion. It allows companies to show how their product works and reveal potential technological issues that arise in practice, while the government can test if the technology can provide significant public benefits (in 't Veld, 2020; Schulz, 2019).
14. ***Public sector participation strategy*** refers to allowing the public sector to participate in technological uptake and diffusion, such as implementing the technology on public buildings and fleets to increase sales and promote awareness (in 't Veld, 2020).
15. ***Incentives strategy*** may be used by both governments and companies as a niche introduction or TIS building strategy. For companies it consists in providing customers and relevant partners with incentives to make product acquisition more attractive (Dwisatyawati, 2022). For governments this strategy consists in giving incentives (mainly financial), such as subsidies or tax breaks to companies that develop certain technologies or to customers that will adopt them (in 't Veld, 2020).
16. ***Leasing strategy*** consists in providing the product through a leasing contract with different subscription options which spreads its high initial cost over a specific period of time (Dwisatyawati, 2022; Schulz, 2019).
17. ***Result-oriented contracting strategy*** aims to provide customers with a sense of security regarding their investment by providing information on estimated benefits from the acquisition such as the projected return on investment (Dwisatyawati, 2022).
18. ***Turnkey product strategy*** consists in selling the product ready to use by customers (providing design, building, installation and complementary technologies and services) so that their convenience is increased (Dwisatyawati, 2022).

TIS build-up strategies

1. ***Technological R&D strategy*** refers to investing effort and financial resources into research and development in order to expand technological knowledge and reduce costs (Dwisatyawati, 2022; in 't Veld, 2020). Both policy makers and companies may adopt and benefit from this strategy.
2. ***Human resource management strategy*** aims to improve product performance and quality by hiring new employees or interns with specific knowledge and competences (Dwisatyawati, 2022; Schulz, 2019).

3. ***Internal knowledge sharing strategy*** consists in providing internal training, courses and other resources to promote knowledge sharing within the company. In turn, this increases the company's capacity to solve problems (Dwisatyawati, 2022; Schulz, 2019).
4. ***Partnership strategy*** refers to different stakeholders partnering to combine resources and knowledge, as well as address competence or knowledge gaps that any of them may have to increase product performance and quality (Dwisatyawati, 2022; Schulz, 2019).
5. ***Finance sourcing strategy*** aims to circumvent a lack of financial resources by participating in competitions, applying for grants and loans or taking similar actions to increase financial assets (Dwisatyawati, 2022; Schulz, 2019).
6. ***Lobbying strategy*** consists in approaching relevant and strategic stakeholders to gain their support and help to achieve a certain goal or raising awareness of existing norms and values that are blocking technological diffusion. Companies resort to lobbying the government for financial or normative support and the government may lobby other parties or offices for political support (Dwisatyawati, 2022; Schulz, 2019).
7. ***Changing behaviour strategy*** refers to changing actors' habits, norms or values through methods such as getting an influencing person or company to raise product awareness (Dwisatyawati, 2022; Schulz, 2019).
8. ***Crowd-sourcing strategy*** aims to generate ideas for the product or additional revenue by addressing and involving the general public (Dwisatyawati, 2022; Schulz, 2019).
9. ***Campaign funding strategy*** refers to providing resources to fund campaigns for strategic policy makers that design institutional rules, or institutions themselves in order to gain influence with them (Dwisatyawati, 2022; Schulz, 2019).
10. ***Network building strategy*** consists in attending formal and informal events to broaden the actor's network. The aim is to strengthen relationships that may serve for other strategies such as the partnership or lobbying strategies (Dwisatyawati, 2022).
11. ***Get specified strategy*** aims to have the new technology mentioned in specification sheets derived from big projects such as consultancy projects (Dwisatyawati, 2022).
12. ***Complementary products and services strategy*** means providing or having in place the services and products associated with the technology that users require to maintain their level of convenience when the technology has higher costs or lower quality and performance (Dwisatyawati, 2022).
13. ***Cross-selling strategy*** refers to coupling the new product or technology with the sale of existing products to create an easier transaction, increase customer convenience and reduce costs (Dwisatyawati, 2022).
14. ***Existing social network strategy*** means employing the current customer base and relationship with relevant actors to promote the sale and diffusion of the technology, benefiting from the existing loyalty and trust in the company (Dwisatyawati, 2022).
15. ***In-house network strategy*** refers to optimising in-house resources such as sales channels, marketing and sales departments, etc. to promote technological diffusion rather than resorting to a third party to do so, thus avoiding additional costs (Dwisatyawati, 2022).
16. ***Preannouncing strategy*** means publishing information about the technology previous to its launch in order to create hype and expectations in potential customers, therefore raising awareness and willingness to pay and reducing uncertainty and misinformation (Dwisatyawati, 2022).
17. ***Provide guaranteed markets strategy*** consists in the government creating instruments such as contests, tenders or specific requirements that ensure the technology will have a market. This increases company competitiveness and reduces uncertainty (in 't Veld, 2020).

18. ***Investments strategy*** aims to have governments invest in complementary technologies and services for the technology or in specialised institutes that may bolster technological adoption (in 't Veld, 2020).
19. ***Provide standards and regulations strategy*** refers to issuing certain regulatory instruments that include use of the new technology in certain standards, therefore increasing its uptake (in 't Veld, 2020).
20. ***Provide policies to incorporate externalities strategy*** is a strategy that only applies to sustainable energy technologies (as is V2G) and consists in providing measures that dictate companies to include externalities in their prices, for instance, which can give a competitive advantage to sustainable technologies (in 't Veld, 2020).

C

Stakeholders

C.1. Full list of Transmission Network Operators

Tranmission Network infrastructure in the UK is owned by 3 transmission companies: National Grid Electricity Transmission, Scottish Hydro Electric Transmission Ltd. and Scottish Power (SP) Energy Networks.

C.2. Full list of Distribution Network Operators

The UK is comprised of one distribution region in Northern Island operated by Northern Ireland Electricity Networks, and eight distribution regions in GB operated by six companies, which are:

1. Scottish and Southern Electricity Networks
2. Scottish Power Energy Networks
3. Electricity North West
4. Northern Powergrid
5. UK Power Networks
6. National Grid

C.3. Full list of energy service providers

The following is a list of load aggregators and energy providers in the UK.

- Enel
- OVO Energy
- Nuvve
- Flexitricity
- The Mobility House
- Virta
- Upside Energy
- Moixa
- SSE services
- EON Energy
- Octopus Energy
- Engie
- CrowdCharge
- EV Energy
- Q Energy
- Element Energy

- EDF Energy
- E Energy
- SSE
- Haven Power
- British Gas
- Scottish Power
- Affect Energy
- Cardiff Energy
- Utility Warehouse
- Breeze Energy
- Boost Power
- Ecotricity
- 100 Green
- Bluegreen energy
- Centrica
- National Grid
- Opus Energy
- Bulb Energy
- Npower
- Shell Energy
- Spark Energy
- Avid Energy
- Corona Energy
- Sainsbury's Energy
- Smartest Energy
- Valda Energy
- YGP
- Green Energy
- Rebel Energy
- Utilita
- Good Energy

C.4. Full list of technology distributors

This section contains a list of vehicle OEMs and EVSE OEMs that have V2G-capable products ready, have participated in V2G trials in the UK or have announced V2G-capable products to be released in the near future. A list of companies that serve as technology providers and have products related with V2G is also shown.

Vehicle and charger OEMs

- Indra Technologies
- Powerstar
- Nichicon
- EVTech
- MagnumCap
- Wallbox
- Hitachi
- EO Charging
- Nissan
- Mitsubishi
- BMW
- Hyundai
- Ford
- Volkswagen
- Cupra
- Kia
- Volvo

Technology providers

- Fermata Energy
- EA Technology
- Grid Edge
- Octopus Energy
- SmartestEnergy Limited
- Open Energi
- Nuvve
- OVO (Kaluza platform)
- Piclo
- E-Car Club