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The implications of technological neutrality for innovation policy design

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Abstract

In an ideal scenario, innovation policy leads to optimal societal outcomes by allowing the market forces to determine technology choices according to the principle of technological neutrality. However, criticism of technological neutrality has increased since 2000s as the market-oriented innovation policies have failed to address major societal challenges. This study contributes to this debate by examining the implications of the principle of technological neutrality for the effective design of transformative innovation policy mixes.

The general research design of this study emphasises the approach of theory elaboration and abduction while including some traits of theory generation and induction. The empirical part of this study is conducted as an embedded single case study to analyse the role of technological neutrality in the Finnish innovation system. The final sample is a unique combination of 32 interviews, including a broad range of actors in the Finnish innovation system, and all 55 Finnish parliamentary discussions in 2014 – 2023 where technological neutrality was discussed. The data was analysed by following the principles of reflexive thematic analysis to identify and develop themes from the data. Finally, the empirical results were integrated into the theory-based models which were developed as part of the literature review.

The main findings of this study are twofold. First, this study suggests that technological neutrality impacts innovation policy outcomes through three intermediate policy goals: (1) fairness, (2) technological goals, and (3) policy sustainability. The policy makers should pursue the desired goals by customising the policy design related to technological neutrality with different governance arrangements, policy goal boundary setting, and five different techniques to operationalise technological neutrality. Both technology neutral and specific policies can be justified depending on the desired goal and various contextual factors. Second, this study proposes a process for designing policy mixes from the perspective of technological neutrality by connecting the implications of technological neutrality into broader policy mix context. In conclusion, this study recommends taking a pragmatic approach to applying technological neutrality in policy design.

Keywords technological neutrality, technological specificity, transformative innovation policy, technology policy, policy design, innovation policy mix

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Tiivistelmä

Ideaalissa tilanteessa innovaatiopolitiikka johtaa optimaalisiin yhteiskunnallisiin lopputuloksiin antamalla markkinoiden määritellä teknologiavalinnat teknologianeutraliteettiperiaatteen mukaisesti. Kuitenkin kritiikki teknologianeutraliteettia kohtaan on kasvanut 2000-luvulta lähtien, koska markkinalähtöiset innovaatiopolitiikat ovat epäonnistuneet suurten yhteiskunnallisten haasteiden ratkaisemisessa. Tämä työ edistää tätä keskustelua tarkastelemalla teknologianeutraliteetin vaikutuksia tehokkaan innovaatiopolitiikan suunnitteluun.

Tämän työn yleinen tutkimustapa korostaa abduktiivista lähestymistapaa sisältäen myös joitain induktiivisia piirteitä. Työn empiirinen osuus toteutettiin laadullisena yksittäistapaustutkimuksena, joka analysoi teknologianeutraliteetin roolia Suomen innovaatiojärjestelmässä. Tutkimusaineisto sisältää 32 haastattelua Suomen innovaatiojärjestelmän eri toimijoilta sekä kaikki 55 Suomen eduskunnan keskustelua vuosilta 2014–2023, joissa teknologianeutraliteettia käsiteltiin. Aineisto analysoitiin noudattaen refleksiivisen temaattisen analyysin periaatteita teemojen tunnistamiseksi ja kehittämiseksi aineistosta. Lopuksi empiirisiä tuloksia verrattiin ja yhdistettiin kirjallisuuskatsauksessa kehitettyihin teoreettisiin viitekehyksiin.

Tämän työn päätulokset ovat seuraavat. Ensinnäkin työ argumentoi, että teknologianeutraliteetti vaikuttaa innovaatiopolitiikan tuloksiin kolmen välitavoitteen kautta, jotka ovat oikeudenmukaisuus, teknologiset tavoitteet ja politiikan pysyvyys. Päättäjien tulisi tavoitella haluttuja päämääriä räätälöimällä teknologianeutraliteettiin liittyvää politiikan suunnittelua erilaisilla hallintojärjestelyillä, politiikan tavoitteilla sekä viidellä eri tekniikalla teknologianeutraliteetin soveltamiseen. Sekä teknologianeutraalien että -spesifien politiikkojen käytölle löytyy perusteluita riippuen politiikan tavoitteista ja kontekstista. Toiseksi tämän tutkimuksen kuvaama suunnitteluprosessi auttaa innovaatiopolitiikkayhdistelmien suunnittelemisessa teknologianeutraliteetin näkökulmasta yhdistämällä teknologianeutraliteetin vaikutukset laajempaan innovaatiopolitiikan kontekstiin. Yhteenvetona tämä tutkimus suosittelee käytännöllistä lähestymistapaa teknologianeutraliteetin soveltamiseen innovaatiopolitiikan suunnittelussa.

Avainsanat teknologianeutraliteetti, transformatiivinen innovaatiopolitiikka, teknologiapolitiikka, innovaatiopolitiikka.

Table of contents

Preface and acknowledgements

This thesis marks the end of my long journey to pursue a master's degree. When I started my studies in 2013 at Aalto University, I could not have imagined that it would take over 10 years to finalise my studies due to various detours. However, these important and insightful endeavours during the studies, such as my time as a startup co-founder, have helped me to gain most of the studies. Even though the process has been lengthy and sometimes consuming, it has provided me with joy and helped me develop as an individual. Now, it is time for me to move towards the next adventures of life. Before that, it is time for me to show my deepest gratitude for the people who have helped me in this long process.

First, thank you for the organisers, project partners and participants of the two research projects for collaboration that has made this study possible: TYSTI project organised by the Prime Minister's office and PlastLIFE, which is part of the LIFE programme of the EU. For example, the feedback from the steering group, international advisory panel, and the other participants (i.e., Demos Helsinki and 4Front) of the TYSTI project has been valuable for providing guidance during the process.

Second, thank you for all the colleagues at the Aalto University for providing a great place to work during my thesis project. Special thanks to my supervisor Pekka Töytäri, advisors Esko Hakanen and Joel Wolff, and my peer Juuso Heikkilä for all the guidance and insightful discussions that were invaluable for this thesis. You are great colleagues that taught me a lot and provided joy during the formal and informal discussions.

Third, thank you for all the informants for your willingness to participate in this study and for your openness to provide insights from your own perspectives.

Last but not the least, thank you for my friends and family for your endless love and support. This journey would have been totally different and less meaningful without you on my side during the ups and downs of the past decades.

Otaniemi, 29 December 2023

Juho Carpén

List of abbreviations

OKM	the Finnish Ministry of Education and Culture
R&D	research and development
RDI	research, development, and innovation
TA	thematic analysis
TEM	the Finnish Ministry of Economic Affairs and Employment
TIP	transformative innovation policy
STI	science, technology and innovation

1 Introduction

This chapter introduces the background, motivation, objectives, and research questions of this study. Furthermore, this chapter describes the empirical context and structure of the thesis.

1.1 Background and motivation

In an ideal scenario, innovation policy leads to optimal societal outcomes by leveraging effective market processes and by allowing the market forces to determine technology choices. This market-centric approach, typified by principles like technological neutrality, is traditionally seen as the most effective or "*first-best*" solution for policy interventions (Jaffe et al., 2005; Gawel et al., 2017; Lehmann and Söderholm, 2017; Rosenow et al., 2017; Agora Verkehrswende, 2020) and is often recommended by economists to prevent potential market distortions caused by government-led technology selection (Aghion et al., 2009; Wanzenböck et al., 2020). Regardless of the initial positive reception for neutrality, criticism of technological neutrality has increased since 2000s (e.g, Koops, 2006; Reed, 2007) as the earlier market-oriented innovation policies have failed to address major environmental and societal challenges (Diercks et al., 2019; Schot and Steinmueller, 2018). In response, technology specific policies, which offer focused public support for specific technologies, are increasingly seen as necessary complements to neutral policies (Jaffe et al., 2005; Azar and Sandén, 2011; Rosenow et al., 2017). This is because technology neutral policies can lead to sub-optimal societal outcomes due to factors, such as path dependencies (Aghion et al., 2009; Azar and Sandén, 2011; Lehmann and Söderholm, 2017) and lack of competition (Azar and Sandén, 2011; Fabra and Montero, 2022; Schmidt et al., 2016). This debate between technology neutral and specific policy designs remains a central focus of various policy studies, exploring the effectiveness of policy interventions (e.g., Kim and Tang, 2020; Bellamy et al., 2021; Fabra and Montero, 2022; Bergek et al., 2023).

However, the principle of technological neutrality can be still argued to remain under-theorised (Greenberg, 2016; Craig, 2016; Puhakainen and Väyrynen, 2021), as different meanings are attached to technological neutrality (Koops, 2006; Craig, 2016) and the choice between technology-neutral and technology-specific policies remains a focus on various policy studies (e.g., Kim and Tang, 2020; Bellamy et al., 2021; Fabra and Montero, 2022; Bergek et al., 2023). This under-theorisation can lead to ineffective and overgeneralised policy recommendations related to the application of technological neutrality if the mechanisms of technological neutrality are not well understood. For example, the partially overlapping rationales for technology

neutral and specific policies, such as cost effectiveness and even technological non-discrimination, can lead to conflicting recommendations if the contextual factors impacting the suitability of technological neutrality for a policy intervention are not understood.

The purpose of this study is to bridge this gap by examining the implications of the principle of technological neutrality for the effective design of transformative innovation policy mixes. This study concludes that the principle of technological neutrality is deeply embedded in various parts of policy mixes and has an important impact on the effectiveness of transformative innovation policy. These implications range from the impact of policy maker competence and perceived values of fairness on the chosen policy strategy for technology selection to different governance approaches for addressing the pitfalls of technological neutrality and specificity. Furthermore, this study contributes to the theorisation of the principle of technological neutrality by integrating literature from various streams of policy literature and by analysing the implications of technological neutrality in the Finnish innovation system. As the final outcome, this study proposes a four-step process for innovation policy design from the perspective of technological neutrality.

1.2 Research objective and research questions

The main purpose of this study is to examine the implications of the principle of technological neutrality for the effective design of transformative innovation policy mixes. In practice, this study has two goals to improve the understanding on the role of technological neutrality in innovation policy design. First, this study seeks to explain which mechanisms related to technological neutrality impact the design of innovation policy mixes. Second, this thesis aims to provide policy recommendations that help policy makers to apply the principle of technological neutrality as part of innovation policy mixes. To achieve these goals, this study integrates literature from various streams of policy literature and utilizes empirical data from the Finnish innovation system.

The study is guided by the main research objective of this study to examine the implications of the principle of technological neutrality for the effective design of transformative innovation policy mixes. Due to the breadth of the research topic, this study takes a holistic view on innovation policy while focusing on technological neutrality in more detail. The insights from the more established innovation policy literature streams on transformative innovation policy and policy mixes provide a necessary basis for understanding the implications of technological neutrality. Simultaneously, this study aims to

deepen this understanding based on empirical data from the key actors of the Finnish innovation system.

Research objective: Examine the implications of the principle of technological neutrality for the effective design of transformative innovation policy mixes.

The main research objective is divided into two related research questions (RQ1 and RQ2) to meet the objectives of this study. First, this study analyses how technological neutrality influences the policy outcomes in the context of transformative innovation policy. This question focuses on the review of relevant policy design literature to identify overarching characteristics, policy techniques, and rationales related to technological neutrality. Furthermore, the empirical analysis studies how the principle of technological neutrality has influenced innovation policy outcomes in the Finnish innovation system.

RQ1: How does technological neutrality influence the policy outcomes in the context of transformative innovation policy?

Second, this thesis studies the mechanisms related to technological neutrality that impact the design of innovation policy mixes. As this second question aims to describe connections between technological neutrality, policy design, and policy outcomes, this part integrates innovation policy and policy design literature with the findings from research question 1.1. Furthermore, the empirical analysis focuses on building an integrated model for governmental technology choices.

RQ2: How does technological neutrality impact the design of innovation policy mixes?

Finally, this study aims to draw from the conclusions of the research questions to contribute to the innovation policy design literature and to provide recommendations for policy makers.

1.3 Empirical context

This study is part of a wider analysis project called "*Technological neutrality and the strategic objectives of society in research and innovation policy*" (TYSTI project). The wider project was conducted by Aalto University, Demos Helsinki, and 4Front as part of Government's analysis, assessment and research activities governed by the Finnish Prime Minister's Office. The project aims to create insights on the role of emerging technologies, technological neutrality, and mission-oriented innovation policies in supporting

strategic societal goals to create a national approach for directing research and innovation policy (Valtioneuvoston kanslia, 2023). This thesis contributes to these overarching goals of the project by studying the implications of the principle of technological neutrality for the effective design of transformative innovation policy mixes.

Due to the nature of the wider analysis project, the empirical data is gathered from the Finnish innovation system focusing on high-tech sectors (See Chapter 3 for methodology). While the interviews focus on the private sector and the impacts of innovation policy, the parliamentary discussions and interviews from the public sector provide important insights into policy processes related to technological neutrality. This combination of empirical data aims to provide important insights of the Finnish innovation system from policy making to research and innovation activities of companies. Even though the Finnish innovation system provides the main context for this study, the literature review supports the generalisability of the results by drawing insights from existing theoretical discussions and additional empirical contexts.

1.4 Structure of the thesis

This thesis consists of five chapters. In the beginning, the first chapter introduces the background and motivation, the objectives and research questions, the empirical context, and the structure of this study.

The second chapter is a literature review which is structured under four sections to discuss the theoretical background for understanding technological neutrality in the context of policy mixes for transformative innovation policy. First, transformative innovation policy is described in the context of three generations of innovation policy together with main rationales and barriers for policy interventions. Second, innovation policy mixes are reviewed as an approach for designing innovation policy interventions. Third, this study analyses a wide range of literature on technological neutrality to identify common features and policy design mechanisms related of the principle of technological neutrality. Finally, the fourth subchapter synthesises the findings from the previous subchapters to discuss the implications of technological neutrality for innovation policy design. Furthermore, the literature review provides direction for the empirical research and a theoretical background to assess and connect the findings with existing theories.

The third chapter describes the methodology of this study and discusses the rationale for the methodological choices and the empirical sample. The first subchapter defines the general research design and methodology of this study, including an overview of the research process and rationale for the

methodological choices. The second subchapter describes the process for collecting the empirical data of this study, which consists of interviews and Finnish parliamentary discussions. The third subchapter explains the data analysis approach of this study, which follows the principles of reflexive thematic analysis. Finally, the fourth subchapter evaluates the research design focusing on construct validity, internal validity, external validity, and reliability.

The fourth chapter presents the results and discussion of the empirical analysis under three main topics and a concluding chapter to integrate the findings into one model. Due to the breadth of the empirical analysis, the results are presented together with discussion on relevant theoretical literature to avoid repetition and to create clear connections between the empirical data and literature (Braun and Clarke, 2013, p. 257 - 258). First, the policy maker competence, intensions, and perceived values of fairness are discussed as important political context that influences governmental technology choices by increasing policy support or by creating barriers for policy legitimisation. Second, the two identified policy strategies have important implications for policy mix design as they provide direction for policy making by defining overarching goals, policy logic, and principal plans of the policy. Third, the findings on policy mix design discuss how the intended policy strategy can be supported by policy mix design decisions related to governance architecture and policy goal setting. Finally, the findings are integrated into a single model that provides a strategic perspective for governmental technology choices.

The fifth chapter describes the main implications of this study. As the empirical results of this study are discussed together with relevant literature in Chapter 4, the fifth chapter focuses on the main contributions of this study. First, the main contributions of this study are discussed against the two research questions of this study. The second and third subchapters continue by discussing the main theoretical and policy implications. Finally, the limitations of this study are discussed together with a few avenues for future research. After the fifth chapter, the study provides the list of references and appendices.

2 Literature review

This chapter reviews literature from three streams of policy literature to provide a necessary theoretical background to understand the role of technological neutrality in innovation policy design. The first subchapter describes the characteristics of the three main innovation policy paradigms and discusses main rationales for policy interventions. Second, innovation policy mixes are reviewed as an approach for designing innovation policy interventions. Third, this study analyses a wide range of literature on technological neutrality to identify common features and policy design mechanisms related of the principle of technological neutrality. Finally, the fourth subchapter synthesises the findings from the previous subchapters to discuss the implications of technological neutrality for innovation policy design.

2.1 Transformative innovation policy as the third generation of innovation policy

This subchapter reviews literature on the different generations of innovation policy leading to transformative innovation policy as the latest paradigm. Transformative innovation policy provides important context for understanding increasing criticism towards technological neutrality, as the early generations of market-oriented innovation policies have been challenged as insufficient approaches to address environmental and societal challenges. This chapter begins with the introduction of transformative innovation policy as part of the three generations of innovation policy. The second subchapter focuses on the rationales and barriers for transformative innovation policy to provide supporting evidence for technology neutral and specific policy interventions.

2.1.1 Transformative innovation policy as the third generation of innovation policy

Transformative innovation policy is an emerging frame of innovation policy which has attracted significant attention in recent innovation policy discussions (Diercks, 2019) and scientific literature (Haddad et al., 2022). This new paradigm has emerged to address the deficiencies of earlier innovation policy paradigms, such as technology and science policy (Schot and Steinmueller, 2018), which have failed to address the importance of the direction of technological development on the societal impact of innovations (Acemoglu, 2023). Furthermore, the emergence of transformative innovation policy has important implications on technological neutrality which relies on the principles of the earlier generations of innovation policy (See Chapter 2.3 for discussions on technological neutrality). This chapter begins by explaining the

development of the different generations of innovation policy based on the three frames for innovation policy by Schot and Steinmueller (2018). This chapter continues by explaining the innovation policy paradigm framework by Diercks et al. (2019) to provide important context for technological neutrality and the design of innovation policy mixes. Finally, the five main characteristics of transformative innovation policy are explained based on the systematic review by Haddad et al. (2022).

Schot and Steinmueller (2018) define *three frames for innovation policy* which help to describe different generations of innovation policy leading to the emergence transformative innovation policy (See Table 1). This chapter focuses on the third frame of transformative innovation policy while providing an overview on the other frames. The first frame, "*Innovation for growth*", refers to traditional science and technology policy which focuses on technology push by stimulating pre-competitive research and development investments (R&D) (Schot and Steinmueller, 2018). The approach has been justified based on economic theories around a market failure related to insufficient private incentives for scientific and technological discovery (Schot and Steinmueller, 2018). These insufficient incentives are caused, for example, by knowledge spill-overs associated with public goods which can result in sub-optimal level of investments into research and development (Weber and Rohracher, 2012).

Table 1. Overview of the three frames for innovation policy based on (1) Schot and Steinmueller (2018) and (2) European Environment Agency et al. (2019).

Frame[1]	**What and why?**[1]	**When**[2]
1. Innovation for growth	Science and technology policy stimulate R&D investments to fix market failure related to insufficient incentives for discovery due to its nature as a public good.	Post World War II
2. National systems of innovation	The focus of STI policy shifts from a narrow focus on pre-competitive R&D to a more comprehensive focus on addressing system failures by building institutional links between different actors of the innovation system to improve national competitiveness.	Emerged in 1980s
3. Transformative change	A comprehensive and systematic approach to innovation policy aims to promote the transformation of socio-technical systems towards preferred social objectives as earlier frames are seen inadequate for confronting environmental and societal challenges due to transformational system failures.	Emerging

The narrow focus of the first frame was challenged already in 1970s and 1980s by the inability of the model to explain why the innovative and productive performance developed differently in different countries regardless of the assumed nature of scientific knowledge as a global public good (Schot and Steinmueller, 2018). To address this challenge, the assumptions of the old model were modified in four ways related to the identified system failures: (1) tacit elements of scientific knowledge limit global diffusion of knowledge, (2) absorption of global research knowledge requires capabilities and previous experience, (3) absorptive capability is based on education and entrepreneurial social capabilities, and (4) recognition of cumulative and path-dependent nature of technological change (Schot and Steinmueller, 2018).

These discoveries led to the emergence of the second frame, "*National systems of innovation*", with an increased focus on the institutional links between different actors of the national innovation system (Schot and Steinmueller, 2018). One of the main agendas of this second frame is to promote the competitiveness of the nation and domestic actors to create economic welfare and growth through exports (Schot and Steinmueller, 2018). The competitiveness agenda is supported with interventions directed still at pre-competitive research while shifting the focus towards building institutional links between different actors of the innovation system to avoid system failures (Schot and Steinmueller, 2018). These coordination activities can include various forms, such as collaborative R&D funding, promotion of cross-sectoral cooperation, and policies to support the growth of new firms (Schot and Steinmueller, 2018). Even though this second frame can be beneficial for supporting innovation activities, it does not address the importance that the direction of technological development has on the societal impact of innovations (Acemoglu, 2023).

The third frame, "*Transformative change*", has emerged to address this directionality failure and other challenges associated with the earlier frames, which are seen inadequate for confronting environmental and societal challenges (Schot and Steinmueller, 2018). This emerging innovation policy paradigm is commonly referred to as transformative innovation policy (e.g., Schot and Steinmueller, 2018; Diercks et al., 2019; Haddad et al., 2022), even though the same phenomenon is described with various more or less detailed variations, such as missions-oriented and transitions-oriented policies (Haddad et al., 2022). This comprehensive and systematic approach to innovation policy aims to promote the transformation of socio-technical systems towards preferred social objectives as earlier frames are seen inadequate for confronting environmental and societal challenges due to transformational system failures (Schot and Steinmueller, 2018). Even though the three frames are partly incompatible (Schot and Steinmueller, 2018) due to their

different agendas, various parts of the earlier frames, such as R&D investments and innovation systems thinking, remain relevant also for the transformative innovation policy (Schot and Steinmueller, 2018). However, it is important to understand the potential deficiencies of each frame and ensure that the different frames are aligned and coordinated purposefully (Schot and Steinmueller, 2018) based on the desired policy goal.

Diercks et al. (2019) provide an alternative way for classifying policy paradigms based on two policy agendas and the breadth of understanding of innovation process framework. This framework provides useful insights on how the frames and their focus have developed. First, the policy agendas are divided into economic and societal agendas which act as the ultimate objectives of the policy (Diercks et al., 2019). An innovation policy with an economic agenda focuses on the positive outcomes of innovations to support economic growth and competitiveness with economic and industrial policy (Diercks et al., 2019). As an alternative, societal policy agenda includes additional objectives, such as solving societal challenges, which are pursued in various policy domains by addressing the positive and negative outcomes of innovations (Diercks et al., 2019). Second, the innovation process can be understood in a narrow or broad sense. The narrow view focuses on supporting the commercialisation of science and the related "triple helix" of academia, industry, and government (Diercks et al., 2019). The broad understanding expands this view by including additional actors, such as the public and civil society (Diercks et al., 2019). Related to activities, the narrow view focuses on supply-side policies based on the linear model of innovation, while the broad understanding extends to also demand-side activities to emphasise the systemic view on innovations (Diercks et al., 2019). Finally, the narrow view is science, technology, and innovation oriented, while the broad view emphasises the interactive nature of knowledge development (Diercks et al., 2019).

Figure 1 presents the resulting framework, which includes four quadrants of different policies. This model helps to explain both the three frames of innovation policy (Figure 1, left) and more detailed approaches to innovation policy (Figure 1, right). The first frame is close to the defined science and technology policy paradigm, which has a narrow understanding of the innovation process focusing on supply-side innovation policy and (Diercks et al., 2019). However, these science and technology policies have included a mix of economic and societal goals, as various targeted mission-oriented programs have been used to drive societally important goals, such as the development of penicillin and nuclear energy (Diercks et al., 2019). The second frame of innovations systems policy shifted the focus towards a broader view on innovation while the societal agendas were partially abandoned to avoid "picking

winners" (Diercks et al., 2019) as part of traditional economic rationales providing a justification for neutral instruments (Aghion et al., 2009).

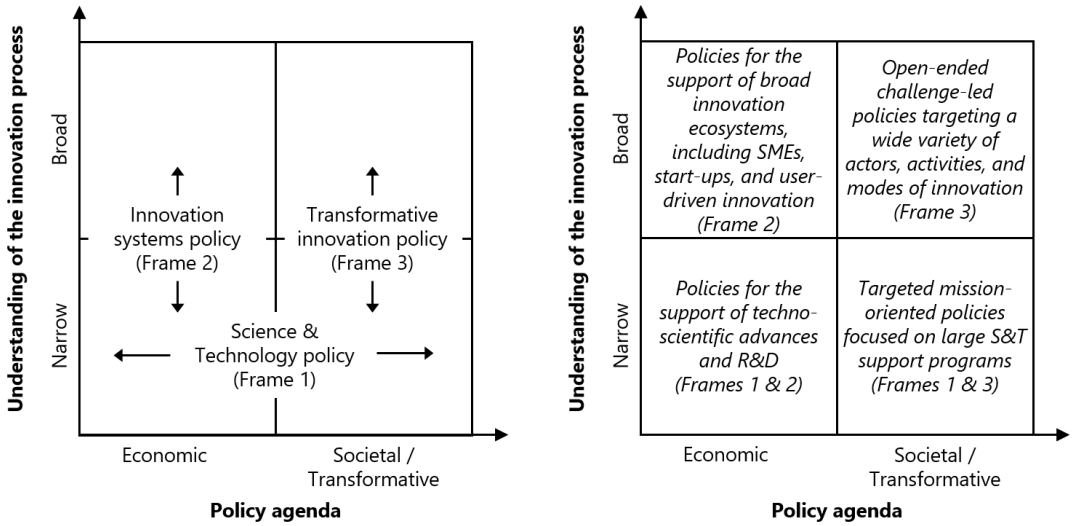

Figure 1. Innovation policy paradigms with indicative frames based on policy agenda and understanding of the innovation process. Adapted from Diercks et al. (2019).

Finally, the third frame of transformative innovation policies combines aspects from the two earlier frames while directing innovation activities towards broader societally desired objectives (Diercks et al., 2019). Transformative innovation policy takes a broad view on innovation from the second frame while re-orienting the agenda towards societal goals similar to the mission-oriented programs of the first frame. In contrast with the first frame, transformative innovation policy has introduced more complex challenge-oriented policies (top-right corner) involving a broad range of actors (Diercks et al., 2019). The original, narrowly focused mission-oriented programs target well-defined problems and objectives, such as the goal of the Apollo Program to land a man on the moon (Diercks et al., 2019; Wanzenböck et al., 2020). However, many of the complex societal challenges targeted by transformative policies can be considered as "*wicked*" problems which cannot be defined clearly, do not have clear solutions, and require systemic approaches to be addressed (Wanzenböck et al., 2020). This challenge can be demonstrated by a moon-ghetto metaphor by Nelson (1974): "*If we can land a man on the moon, why can't we solve the problems of the ghetto?*" It is crucial to recognise this wicked nature of societal challenges, as unawareness of this wickedness can lead to inefficient policy designs as recognised, for example, in the early designs of the Horizon 2020 programme of the EU (Wanzenböck et al., 2020). The wickedness is considered also later in this study by

highlighting the importance of comprehensive policy mixes when designing innovation policy.

Haddad et al. (2022) argue that transformative innovation policy (TIP), such as transitions-oriented and missions-oriented policy, has five unique characteristics which have important policy implications and address the complexity of societal challenges. First, TIP addresses grand and wicked challenges as described above with the goal of supporting inclusive growth that benefits the broader society (Haddad et al., 2022). Second, TIP includes a strong element of directionality as the policies aim to direct innovation towards preferred societal goals (Haddad et al., 2022). Third, multi-faceted policy interventions are seen necessary to address complex societal challenges. These interventions can include a broad set of policy instruments or a comprehensive policy mix to combine supply-side and demand-side policies (Haddad et al., 2022) which can support the creation of desired innovation while destabilising the harmful old regimes (Kivimaa and Kern, 2016). Fourth, TIP is based on a broad understanding of the innovation system as it highlights the importance of multiple actors and global networks to address the complex challenges (Haddad et al., 2022). Fifth, multi-level governance (e.g., different regional levels) is needed to coordinate the different actors and government agencies, while tentative governance enables flexibility and reflexivity to adapt during the processes (Haddad et al., 2022). Overall, these characteristics align well with the previous definitions while providing important context for designing purposeful policy mixes for transitions.

2.1.2 Rationales and barriers for transformative policy interventions based on failure models

Justifying transformative policy interventions requires a careful assessment on the ability of the policy maker to positively impact the desired goal as government interventions involve various risks, such as introducing new market distortions (Aghion et al., 2009), inability to steer the market efficiently (Boon and Edler, 2018), "picking the wrong winners" (Lehmann and Söderholm, 2017), and favouritism of specific political interest groups (Aghion et al., 2009; Lehmann and Söderholm, 2017). The designed government interventions must be suitable and necessary to achieve the desired goal of the policy according to the regulatory principle of proportionality (e.g., European Commission, 2023) which calls for additional attention in the context of transformative innovation policy aiming to drive sometimes significant transformations. Innovation policy is generally justified based on two high-level objectives of (1) competitiveness (Schot and Steinmueller, 2018; Edler et al., 2023) or economic agenda (Diercks et al., 2019) especially in the earlier innovation policy frames and (2) systems transformation (Schot

and Steinmueller, 2018; Edler et al., 2023) or societal agenda (Diercks et al., 2019) in the transformative innovation policy paradigm. However, these high-level goals do not provide sufficient justifications for government interventions, as the market actors could be argued to contribute sufficiently to these goals. Therefore, various failure models have been used to justify government interventions to support these overarching goals with more targeted interventions.

A diverse set of failure frameworks is used to analyse different aspects of socio-technical transitions for various reasons, such as explaining the effects of discrete failure events, identifying systemic deficits for corrective policy interventions, and understanding transition failures as barriers for transitions (Turnheim and Sovacool, 2020). Turnheim and Sovacool (2020) have divided these different failure frameworks into three descriptive "*families of perspectives*" based on various factors, such as their framing of failure and explanatory focus (See Figure 2, left). First, discrete failure frameworks, such as evaluations of project failures, mainly focus on single events of failures to explain the origins, development, and consequences of these failures (Turnheim and Sovacool, 2020). Second, systemic failure frameworks, such as generalised systemic failures, focus on the broader system-level dysfunctions to identify opportunities for corrective interventions (Turnheim and Sovacool, 2020). Third, processual failure frameworks, such as transition failures, view failure as an inevitable part of transitions where failures "*involve interactions with broader contexts and processes of development*" (Turnheim and Sovacool, 2020).

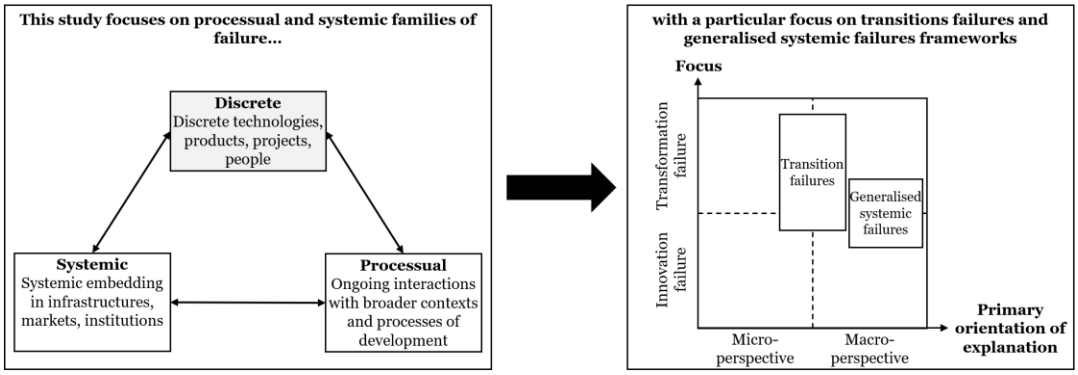

Figure 2. The chosen perspectives of failure in socio-technical change in this study. Frameworks adapted from Turnheim and Sovacool (2020).

This study focuses especially on the generalised systemic failures framework of systemic perspective and transition failures of processual perspective (See Figure 2, right). First, the generalised systemic framework provides a good framework for understanding rationales for transformative innovation policy

mixes, as it combines a macro-level perspective with explanations for both processes of emergence of innovations and transformation of systems (Turnheim and Sovacool, 2020). Second, the transition failures framework complements the systemic view by explaining the important dynamics of transitions as the framework operates on the meso-level to combine insights from the micro-level cases with a broader macro-level perspective (Turnheim and Sovacool, 2020).

Generalised systemic failures, also framed as comprehensive failure frameworks (Weber and Rohracher, 2012), have been proposed as an approach to legitimise transformative innovation policies (Weber and Rohracher, 2012) and corrective policy interventions (Turnheim and Sovacool, 2020) as traditional market failure rationales have been considered too simplistic to justify the systemic government interventions (Bleda and del Río, 2013) and address the directionality of transformative innovation policy (Diercks et al., 2019; Haddad et al., 2022). The relevance of market failures as the primary rationale for innovation policy has been questioned in evolutionary systemic view of innovation, such as innovation systems framework, which highlights the importance of systemic view (Bleda and del Río, 2013). However, this evolutionary perspective does not often provide an appropriate alternative that would explain the important role of markets and market malfunctions in the innovation processes (Bleda and del Río, 2013). As Bleda and del Río (2013) argue, it is important to integrate both perspectives, as the systemic view of the evolutionary perspective should be complemented with a definition of market failures. To address this more systemic view on failures and the characteristics of transformative innovation policy, this study presents the integrated framework of failures by Weber and Rohracher (2012) as the basis for understanding different failure rationales for transformative innovation policy.

The integrated framework of failures by Weber and Rohracher (2012) consists of three types of failures: (1) market failures, (2) structural system failures, and (3) transformational system failures (See Table 2). These three groups connect the rationales for policy intervention with the three frames for innovation policy illustrating the increasing complexity of innovation policy interventions (See Table 1 for the frames). First, addressing market failures, such as insufficient incentives for scientific discoveries (Schot and Steinmueller, 2018), has been the standard rationale for innovation policy especially in the first generation of science and technology policy (Weber and Rohracher, 2012; Schot and Steinmueller, 2018; Haddad et al., 2022), which aimed to stimulate R&D investments (Schot and Steinmueller, 2018). Second, the innovation systems policy highlighted a more systemic approach and shifted the focus towards addressing system failures (Weber and

Rohracher, 2012; Schot and Steinmueller, 2018; Haddad et al., 2022), such as institutional failures can hinder innovation (Weber and Rohracher, 2012). Third, these earlier failure frameworks are complemented with transformational system failures, which address typical challenges of transformative innovation policy with additional focus on directing transformative change towards societal goals (Weber and Rohracher, 2012; Schot and Steinmueller, 2018; Haddad et al., 2022). Overall, this integrated framework of failures provides initial guidance for justifying transformative innovation policy initiatives to address societal challenges (Weber and Rohracher, 2012; Schot and Steinmueller, 2018) as strong arguments are needed to justify the risk of introducing new market distortions with government interventions (Aghion et al., 2009).

Table 2. Overview of failures in transformative innovation policy. Adapted from (1) Weber and Rohracher (2012) and (2) Klein Woolthuis et al. (2005).

Market failures[1]	**Structural system failures[2]**	**Transformational system failures[1]**
1. Information asymmetries	1. Infrastructural failure	1. Directionality failure
2. Knowledge spill-over	2. Institutional failures	2. Demand articulation failure
3. Externalisation of costs	3. Interaction or network failure	3. Policy coordination failure
4. Over-exploitation of commons	4. Capabilities failure	4. Reflexivity failure

Market failures refer to a societally sub-optimal allocation of resources based on the market mechanisms (Turnheim and Sovacool, 2020), which has been used as a common rationale for innovation policy interventions especially in the first generation of science and technology policies (Weber and Rohracher, 2012; European Environment Agency et al., 2019, p. 16). Weber and Rohracher (2012) describe four types of market failures (See Table 2) which can lead to various challenges, such as under-investment in R&D and societally harmful innovations (Jacobsson and Bergek, 2011; Weber and Rohracher, 2012).

The first two types of market failures (i.e., information asymmetries, and knowledge spill-overs) tend to leave to underinvestment in R&D (Jaffe et al., 2005) as private investors avoid investments in long uncertain development projects (Jaffe et al., 2005; Weber and Rohracher, 2012), and as the public good nature of knowledge can lead to knowledge spill-overs (Weber and Rohracher, 2012) benefiting other firms than the developer (Schot and

Steinmueller, 2018; Raven and Walrave, 2020). The third and fourth type of market failures (i.e., externalisation of costs, and over-exploitation of commons) relate to transformative innovation policy (Weber and Rohracher, 2012) as the negative societal effects of innovations might not be internalised by the market actors (Jacobsson and Bergek, 2011; Weber and Rohracher, 2012) and the policies might lead to harmful over-exploitation of public resources referred to as the "*tragedy of the commons*" by Hardin (1968) (Weber and Rohracher, 2012). Overall, the correction of these market failures has been used as the rationale for a broad range of innovation policy interventions, such as generic R&D subsidies to support knowledge creation (Weber and Rohracher, 2012; Jacobsson et al., 2017), protection of intellectual properties (Weber and Rohracher, 2012), and carbon taxes to internalise external costs (Jacobsson et al., 2017). However, a singular focus on market failures as a policy rationale has been criticised as a too narrow perspective (Aghion et al., 2009; Dodgson et al., 2011; Weber and Rohracher, 2012; Jacobsson et al., 2017) for explaining the dynamics and interdependencies of complex innovation systems which impact the innovation process (Aghion et al., 2009; Dodgson et al., 2011; Jacobsson et al., 2017).

The second generation of innovation systems policies started to shift the focus from earlier market failures rationale and competitiveness agenda towards addressing broader structural system failures (Schot and Steinmueller, 2018), which acknowledges the evolutionary and systemic aspects of innovations (Raven and Walrave, 2020). The identification of the most significant structural system failures (Klein Woolthuis et al., 2005; Schot and Steinmueller, 2018), systemic problems (Wieczorek and Hekkert, 2012), or weaknesses (Jacobsson and Bergek, 2011) can help the policy makers to improve the functioning of a innovation system (Jacobsson and Bergek, 2011; Wieczorek and Hekkert, 2012) by addressing the weak elements of the innovation system (Klein Woolthuis et al., 2005; Weber and Rohracher, 2012).

The first type of system failure (i.e., infrastructural failure) refers to deficits in existing infrastructures, including physical, knowledge and technology infrastructures, required for innovation activities (Klein Woolthuis et al., 2005; Weber and Rohracher, 2012). These failures can justify government interventions related to infrastructural needs, as the large scale and long time horizons of infrastructure investments might provide insufficient returns for private investors (Klein Woolthuis et al., 2005). Second, institutional failures refer to formal (e.g., legislation) and informal (e.g., social norms) institutional mechanisms that can impede innovation (Klein Woolthuis et al., 2005; Weber and Rohracher, 2012). Third, interaction or network failure can be caused by too much interaction leading to partner lock-ins and "*group think*"

(i.e., strong network failure) or by weak interaction between actors leading to lack of interactive learning and innovation (i.e., weak network failure) (Klein Woolthuis et al., 2005; Weber and Rohracher, 2012). Fourth, capabilities failure can prevent companies from developing new technologies due to path dependencies and learning failures, as they do not have the expertise, resources, and development potential to adapt to emerging technologies and adopt new knowledge required for new innovations (Klein Woolthuis et al., 2005; Weber and Rohracher, 2012). Overall, these structural systemic failures can provide some initial justifications for systemic policy interventions (Weber and Rohracher, 2012) addressing structural deficits of innovation systems. Furthermore, the systemic failures rationale takes a more technology-oriented approach (Raven and Walrave, 2020) relevant for technological neutrality discussions, as the systemic failures and interventions are often specific to technological domain or sector (Raven and Walrave, 2020). However, these structural systemic failures and market failures rationales are argued to provide a too narrow perspective for transformative innovation policy which introduces additional challenges for policy makers (Weber and Rohracher, 2012).

Weber and Rohracher (2012) introduce the concept of transformational system failures as an attempt to extend the earlier perspectives on innovation failures related to legitimise transformative innovation policy (Capasso et al., 2019; Raven and Walrave, 2020). The four main categories of transformational failures defined by Weber and Rohracher (2012) remain still as a relevant basic classification even though some extensions and modifications have been introduced later, for example, based on the challenges to system transitions (Grillitsch et al., 2019), and a focus on the functions of technological innovation systems (Raven and Walrave, 2020).

The first transformational system failure (i.e., directionality failure) refers to challenges in directing innovation activities towards promoting desired transformative change by addressing societal challenges (Weber and Rohracher, 2012; Capasso et al., 2019; Raven and Walrave, 2020). Second, demand articulation failure relates to failures to understand user needs (Capasso et al., 2019) and articulate these potentially emerging user preferences (Raven and Walrave, 2020), which can hinder the diffusion of innovations (Weber and Rohracher, 2012; Grillitsch et al., 2019; Raven and Walrave, 2020) due to, for example, lack of support for market formation (Raven and Walrave, 2020). Third, policy coordination failure refers to coordination challenges between different vertical policy levels and horizontal sectoral policies (Weber and Rohracher, 2012; Capasso et al., 2019; Raven and Walrave, 2020), which provides a relevant perspective for complex multi-sectoral transformative innovation policy interventions (Weber and

Rohracher, 2012; Capasso et al., 2019) and related policy mixes. Fourth, reflexivity failure refers to the inability of the system to anticipate and adapt to the changes caused by the ambiguity, uncertainty, and complexity of transformative change (Weber and Rohracher, 2012). This reflexivity failure calls for adaptive policy and governance arrangements to keep options open (Weber and Rohracher, 2012; Capasso et al., 2019) and to support self-reinforcing development of the systems (Raven and Walrave, 2020).

It is important to emphasise that understanding these market and structural failures provides only the first basis for designing effective innovation policy as the policies target large systems with complex and interdependent relationships between the components (Aghion et al., 2009). One of the main critiques towards the generalized systemic failures frameworks (e.g., Weber and Rohracher, 2012) relates to ambiguity on designing policy interventions to fix these failures (Aghion et al., 2009; Grillitsch et al., 2019; Raven and Walrave, 2020) and excessive focus on static systemic structures (Bergek et al., 2008; Aghion et al., 2009; Wieczorek and Hekkert, 2012). However, most of this critique for structural focus seems to relate mainly to the earlier frameworks without transformational system failures, which includes also more dynamic elements, such as reflexivity failure. The critique towards ambiguity for designing policy interventions remains a partially valid concern, as the integrated failures framework can be understood as a generalised systemic failures framework covering broad range of failures with a focus on macro-perspective (Turnheim and Sovacool, 2020). Nevertheless, the integrated failures framework remains as a useful basis for more detailed, solutions-oriented, or functions-oriented frameworks (Raven and Walrave, 2020), as demonstrated by later works that complement or build on top of the earlier generalised systemic failures frameworks (Wieczorek and Hekkert, 2012; Capasso et al., 2019; Grillitsch et al., 2019; Raven and Walrave, 2020). To improve the understanding on the dynamics of transitions, transition failures are briefly discussed next.

Transition failures provide an alternative perspective on failures, which focuses on the dynamic barriers of transitions, including stagnation, destabilisation, and renewal (Turnheim and Sovacool, 2020). Transitions literature covers various perspectives for transitions failures, such as lock-in mechanisms (Klitkou et al., 2015; Seto et al., 2016), resistance to change (Geels, 2014), policy intervention points (Kanger et al., 2020), considerations for destabilisation, disruption, decline and phase-out (Kivimaa and Kern, 2016; Rosenbloom et al., 2020; Trencher et al., 2022), and conditions (Roberts and Geels, 2019) and challenges for acceleration of transitions (Markard et al., 2020). This study provides a brief overview on these challenges based on the

lock-in mechanisms as they cover broad range of these processual challenges and complement the earlier systemic failures models.

Table 3 provides an overview of three types of lock-in mechanisms based on the categorisation by Seto et al. (2016) and Geels (2019), which can lead to stability (Eitan and Hekkert, 2023; Groen et al., 2023) that resists policy change (Groen et al., 2023) and desired transitions (Klitkou et al., 2015; Seto et al., 2016; Eitan and Hekkert, 2023). Understanding these diverse lock-in mechanisms can help policy makers to design effective transformative policies (Seto et al., 2016; Eitan and Hekkert, 2023; Groen et al., 2023) by identifying low-cost opportunities for change with low resistance (Seto et al., 2016), by supporting the identification of "unlocking" strategies to overcome policy barriers (Groen et al., 2023), and by avoiding the creation of harmful lock-ins due to unintentional design or manipulation attempts by various actors (Eitan and Hekkert, 2023). Furthermore, it is important to understand the dual nature of lock-ins that the lock-ins can be beneficial by supporting necessary stability for technology diffusion while being possibly harmful by compromising the abilities to adapt and to transform current systems (Eitan and Hekkert, 2023).

First, techno-economic (Geels, 2019) lock-ins refer to various technological (Seto et al., 2016; Geels, 2019; Klitkou et al., 2015; Eitan and Hekkert, 2023; Groen et al., 2023), infrastructural (Seto et al., 2016; Groen et al., 2023), and economic (Geels, 2019; Eitan and Hekkert, 2023) mechanisms that increase the preference for using a specific technology (Eitan and Hekkert, 2023) and create inertia against change (Seto et al., 2016; Geels, 2019; Klitkou et al., 2015). For instance, the high performance of a technology due to economies of scale (Seto et al., 2016; Geels, 2019; Klitkou et al., 2015; Eitan and Hekkert, 2023; Groen et al., 2023) and learning effects (Geels, 2019; Klitkou et al., 2015; Groen et al., 2023) can create barriers for entry for new technologies. Second, institutional lock-ins (Seto et al., 2016; Geels, 2019; Klitkou et al., 2015; Eitan and Hekkert, 2023; Groen et al., 2023) refer to various institutional, political (Geels, 2019), and legal (Eitan and Hekkert, 2023) mechanisms that can support an uneven playing field (Seto et al., 2016; Geels, 2019) due to existing institutions. For example, changes to legislation might be challenging due to vested interests supporting the status quo even if the existing legislation might favour certain actors (Seto et al., 2016; Geels, 2019). Third, behavioural lock-ins (Seto et al., 2016; Groen et al., 2023) refer to behavioural, social (Geels, 2019; Eitan and Hekkert, 2023), cognitive (Geels, 2019), and psychological[4] mechanisms that can create lock-in through social structures and norms (Seto et al., 2016; Geels, 2019; Eitan and Hekkert, 2023), user practices (Seto et al., 2016; Geels, 2019), and individual decision making (Seto et al., 2016; Eitan and Hekkert, 2023). For example, habits can

strongly influence the daily decisions of individuals which can lead to lock-ins supporting the status quo (Seto et al., 2016). Overall, these various types of lock-ins can create significant barriers for change which can significantly affect the success of a policy intervention.

Table 3. Different types of lock-in mechanisms. Based on (1) Seto et al. (2016), (2) Geels (2019), (3) Klitkou et al. (2015), (4) Eitan and Hekkert (2023), and (5) Groen et al. (2023).

Type of lock-in	**Examples**
Techno-economic[2], including technological[1,2,3,4,5], infrastructural[1,5], and economic[2,4]	Existing investments (e.g., competence, infrastructure, interdependent networks) create inertia and vested interests against change[1,2,3] High performance of existing technologies[2] (e.g., economies of scale[1,2,3,4,5], economies of scope[3,5], and learning effects[2,3,5])
Institutional[1,2,3,4,5], including political[2], and legal[4]	Regulations, standards, and policy networks[2] Vested interests restrict regulatory change[1,2] Institutional learning effects[5]
Behavioural[1,5], including social[2,4], cognitive[2], and psychological[4]	Routines and shared mindsets[2] Social capital and alignments between groups[2] User practices[2]

In conclusion, various failure models provide policy makers valuable tools for understanding potential rationales and barriers for policy interventions. For example, generalised systemic failure frameworks, such as the integrated framework of failures by Weber and Rohracher (2012), can provide initial guidance to justify policy interventions based on various shortcomings of the existing innovation systems. However, understanding these failures provides only the starting point for legitimising policy interventions as the complexities of the targeted systems, transition failures (e.g., lock-ins), and high costs of the intervention can lead to policy failure and sub-optimal societal outcomes. Even though these frameworks can support decision making, technology choices and policy interventions are ultimately political decisions (Markard et al., 2015) which involve normative value judgement by policy makers (Lehmann and Söderholm, 2017). This highlights the importance of transparent processes for legitimising interventions so that the rationales and risks of the policy interventions can be assessed as objectively as possible.

2.2 Innovation policy mixes as a policy design tool

This subchapter reviews literature on innovation policy mixes as an approach for designing innovation policy interventions. The policy mix literature provides important insights on the complexity and dynamics of policy design which can impact the effectiveness of policies. Furthermore, the policy mix models help to understand the role of technological neutrality as a design feature of policy instrument mixes in a more complex system. The chapter begins with the review of policy mix models and the introduction of an extended policy mix model by Rogge and Reichardt (2016). It is followed by a synthesis of policy instrument typologies, which are critical for understanding the breadth of policy interventions.

2.2.1 Innovation policy mix overview

Designing effective innovation policy can be very challenging due to the complexity of policies and the targeted innovation systems. This challenge is further magnified by the increased complexity introduced by the new generation of transformative innovation policy (See Chapter 2.1). This new approach expands the scope of innovation policy from narrowly focused policies with an economic agenda towards comprehensive approaches to solve complex societal challenges involving multiple policy domains, broad range of actors and an array of policy failures (Kern et al., 2019). To address this complexity, policy mixes have gained increased attention among innovation scholars and policy makers in 2010s as a potential approach for designing effective science, technology, and innovation policy (Kern et al., 2019; Robert and Yoguel, 2022). As Aghion et al. (2009) argue, understanding the structure and interdependencies of a system is often as crucial in dictating its behaviour as the individual components. Inability to account for these interdependencies of innovation systems can lead to failures in promoting innovation (Aghion et al., 2009) which creates a rationale for studying policy mixes instead of focusing on single policy instruments. The goal of this chapter is to explain the concept of innovation policy mix which provides a useful tool for understanding the role of technological neutrality in transformative innovation policy. This chapter begins by explaining the emergence of the policy mix concept and continues with a description of an extended policy mix concept, which is adapted from Rogge and Reichardt (2016).

The current extended conceptualisations of policy mixes refer to comprehensive, multi-level, and multi-actor policy mixes, which broaden the initial focus on combinations of policy instruments towards a dynamic understanding of the mechanisms underlying policy formation, interaction, and impact (Flanagan et al., 2011; Kern et al., 2019). In addition to the interaction

between policy instruments, these extended policy mix concepts have introduced additional elements (Kern et al., 2019), such as the high-level policy strategy (e.g., Rogge and Reichardt, 2016; Mavrot et al., 2019) or paradigms (e.g., Flanagan et al., 2011), policy processes (e.g., Flanagan et al., 2011; Rogge and Reichardt, 2016; Kivimaa and Kern, 2016; Lindberg et al., 2019), characteristics (e.g., consistency) (e.g., Rogge and Reichardt, 2016) or evaluation criteria (e.g., Mavrot et al., 2019), and dimensions in which interactions occur (e.g., time, and policy space) (e.g., Flanagan et al., 2011; Rogge and Reichardt, 2016). This broader, multi-disciplinary approach to policy mixes is believed to help policy makers address the complexities of policy (Kern et al., 2019), such as dynamic effects of policy mixes on socio-technical change in sustainability transitions (e.g., Kivimaa and Kern, 2016; Edmondson et al., 2019; Kern et al., 2019; Köhler et al., 2019), and politics of transitions (e.g., Rogge and Reichardt, 2016).

The use of the policy mix concept has expanded over decades from its origins in economic policy to various fields, including environmental policy, innovation policy (Flanagan et al., 2011), and sustainability transitions (Kern et al., 2019). Flanagan et al. (2011) argue that the term "policy mix" has originated in economic policy literature in 1960s where it refers to the combination of fiscal and monetary policies used to achieve macroeconomic objectives. The application of the term started to extend from economic policy to other policy domains, such as environmental policy and regulation, during the late 1980s and 1990s (Flanagan et al., 2011). In the context of innovation policy, policy mixes started to be discussed in 1990s while the interest has started to significantly grow during the 2010s after some early publications in innovation (Nauwelaers and Wintjes, 2002) and climate policy (Sorrell and Sijm, 2003) in the beginning of 2000s (Kern et al., 2019). Simultaneously, the focus of the innovation policy mixes has shifted from simpler instrument mixes towards broader conceptualisations (Kern et al., 2019), such as the extended policy mix by Rogge and Reichardt (2016). This growing interest in policy mixes aligns well with the emergence of transformative innovation policy for which policy mixes offer a valuable framework for understanding its inherent complexity.

This thesis adopts the extended policy mix concept of Rogge and Reichardt (2016) as the basis for further analysis, because their concept summarizes extensively various important elements of innovation policy mixes (See Figure 3). In addition to the interaction of policy instruments, this comprehensive model includes crucial building blocks of policy mixes, such as policy processes, characteristics, and dimensions (Rogge and Reichardt, 2016), which help to understand also the political processes and important contextual factors behind policy mixes. This model extends the earlier

conceptualisations of policy mixes, such as the policy mix concept by Flanagan et al. (2011), by introducing links between the different building blocks of the policy mix and between the policy mix and technological change. The model has been also widely discussed and adopted in the policy mix literature (Kern et al., 2019) forming one of the central concepts for innovation policy mixes (Robert and Yoguel, 2022; Rommel et al., 2021).

The extended policy mix concept of Rogge and Reichardt (2016) consists of four building blocks, including (1) elements, (2) policy processes, and (3) characteristics, and (4) dimensions in which the policy mix interactions occur (See Figure 3). First, the elements refer to the overarching policy strategy and the instrument mixes to achieve the policy goals (Mavrot et al., 2019; Rogge and Reichardt, 2016). Second, the elements are formed and shaped in iterative policy processes comprising of policy making for designing the policies and policy implementation to execute and enforce the policies (Rogge and Reichardt, 2016). Third, the characteristics of the policy mix describe attributes and properties of policy elements and processes, such as the consistency of elements, and comprehensiveness of the policy mix. The fourth building block refers to abstract and concrete dimensions, including policy space, governance space, geography, and time, in which the policy interactions happen (Flanagan et al., 2011; Rogge and Reichardt, 2016). Next, each of these building blocks is described in more detail.

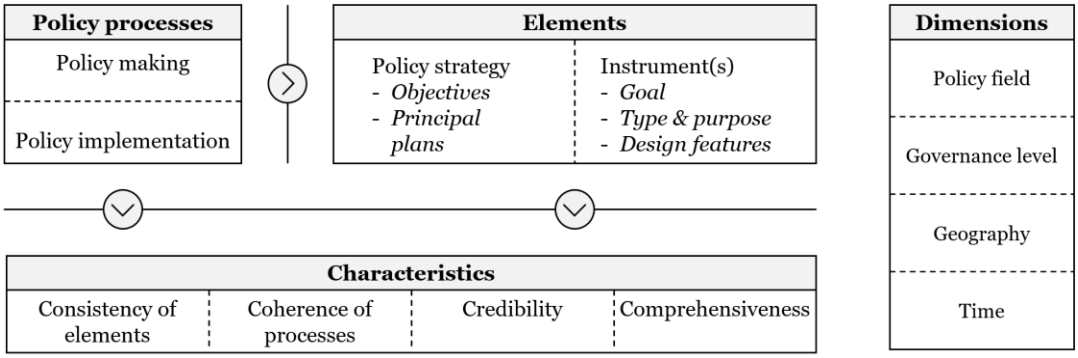

Figure 3. Extended policy mix concept. Adapted from Rogge and Reichardt (2016).

(1) Elements: The first building block of policy mixes involves the elements of policy mix (Rogge and Reichardt, 2016), which refer to the overarching policy strategy and the concrete means in the form of instrument mixes to achieve the policy goals (Rogge and Reichardt, 2016; Mavrot et al., 2019). The first part of the elements is the policy strategy, which refers to the combination of high-level policy objectives and principal plans based on strategy literature (Rogge and Reichardt, 2016). Whereas the policy strategy sets the

overarching policy goals, a mix of policy instruments forms an interacting set of practical means, tools, and governance techniques to contribute to the broader strategic goals (Rogge and Reichardt, 2016). In addition to strategy and instrument mixes, scholars have proposed the introduction of alternative parts, such as recipients (Mavrot et al., 2019), to complement the elements of a policy mix. Even though the addition of recipients can help to understand the important interaction between the instrument mixes and the target actors (Mavrot et al., 2019), the recipients are not included separately in this study, as it overlaps with other parts of the policy mix, such as the design features of policy instruments and policy field dimension.

Different policy instruments can be distinguished by their goals, type and purpose, and design features (Rogge and Reichardt, 2016; Mavrot et al., 2019). First, the goals refer to the intended outcomes of the policy instruments that advance the broader policy aims (Rogge and Reichardt, 2016). Alternatively, these instrument goals can be interpreted as specific policy targets, offering clear objectives for each tool, in contrast to broader policy objectives that encompass more abstract and overarching aims (Tuominen and Himanen, 2007). Second, the instrument type describes how the policy is implemented through different types of interventions, such as economic instruments, regulation, or information (Borrás and Edquist, 2013; Rogge and Reichardt, 2016). Each instrument can be also classified by its purpose, such as supporting technology push or demand pull, or addressing systemic concerns (Rogge and Reichardt, 2016). As the choice of the instrument type can have significant implications on the success of the policy (Rogge and Reichardt, 2016), these types and classification of policy instruments are discussed in more detail in the next chapter (See Chapter 2.2.2).

Third, the design features refer to descriptive and abstract features of the policy (Rogge and Reichardt, 2016) which can have a significant impact on the policy outcomes (Kemp and Pontoglio, 2011; del Río, 2012; Rogge and Reichardt, 2016). The descriptive design features form the basis of a policy design by describing various obvious parameters of a policy design, such as the legal form, duration, and target actors (Rogge and Reichardt, 2016). In contrast, the abstract design features include vaguer characteristics which might also result from the descriptive features (Rogge and Reichardt, 2016). Rogge and Reichardt (2016) argue for the importance of at least six abstract features as listed below:

- **stringency** (i.e., the ambition level) (Haščič et al., 2009; Kemp and Pontoglio, 2011; Rogge and Reichardt, 2016),
- **level of support** (i.e., the magnitude of positive incentives) (Rogge and Reichardt, 2016),

- **predictability** (i.e., the certainty on the direction of a policy) (Haščič et al., 2009; Kemp and Pontoglio, 2011; Rogge and Reichardt, 2016),
- **flexibility** (i.e., the freedom of policy targets to choose the means to achieve the policy goal) (Haščič et al., 2009; Rogge and Reichardt, 2016),
- **differentiation or specificity** (e.g., differentiation based on technology, sector, or geography) (Kemp and Pontoglio, 2011; Rogge and Reichardt, 2016), and
- **depth** (i.e., the range and extent of incentives to completely achieve the policy goal) (Haščič et al., 2009; Rogge and Reichardt, 2016).

This study focuses especially on the abstract design feature of technological specificity (See Chapter 2.3), while considering the importance of other design features when designing technology neutral or specific policy interventions.

(2) Policy processes: The second building block of policy mixes involves the policy processes which form and shape the policy elements in iterative problem-solving processes and impact policy characteristics (Rogge and Reichardt, 2016). Rogge and Reichardt (2016) use a simplified classification for policy processes and distinguish between policy making and policy implementation. First, policy making refers to dynamic problem-solving processes to design and redesign the elements of a policy mix (Rogge and Reichardt, 2016). Second, policy implementation means the actual execution and enforcement of policy instruments (Rogge and Reichardt, 2016). Even though this classification is a generalisation of the elements of various policy cycle models, such as Haddad et al. (2022), the purpose of these two policy processes is to cover all policy processes to provide valuable insights for policy makers (Rogge and Reichardt, 2016). The inclusion of policy processes into policy mix models can help policy makers to design more effective policies (Kern and Rogge, 2018; Haddad et al., 2022) as the policy processes can help to explain the dynamics of policy processes (Flanagan et al., 2011), policy path dependencies (Rogge and Reichardt, 2016; Haddad et al., 2022), the impact of politics on policy mixes (Rogge and Reichardt, 2016; Kern and Rogge, 2018), and even part of the effectiveness (Rogge and Reichardt, 2016) and outcomes of a policy (Kern and Rogge, 2018).

The policy cycle model offers a structured framework for dividing the complex policymaking process into manageable stages (Cairney, 2012; Haddad et al., 2022). This model provides both a prescriptive guide for systematic decision-making and a descriptive tool to simplify the analysis of these processes (Cairney, 2012). Despite criticisms for potentially oversimplifying the cyclical nature, complexities, and interdependencies of policymaking

(Haddad et al., 2022), it remains a popular approach for analysing policy-making (Cairney, 2012; Haddad et al., 2022). The stages of the model range from the initial agenda setting to implementation and evaluation with some variations in the literature (Cairney, 2012; Haddad et al., 2022). The stages should be understood as a continuous process, where the learnings from earlier policies feed into the design of following policies (Cairney, 2012; Rogge and Reichardt, 2016), highlighting the dynamic and iterative nature of policymaking. However, it is important to understand that the different stages can also have interdependent feedback loops even though the model is presented as a linear model (Haddad et al., 2022).

This study employs the six-step policy cycle model by Haddad et al. (2022) as an illustrative example to demonstrate important stages and dynamics of the policy processes in transformative innovation policy (See Figure 4). First, agenda setting focuses on the identification and prioritisation of challenges to set the overarching goals (Cairney, 2012; Haddad et al., 2022), policy domains, and policy logic of a policy intervention (Diercks et al., 2019; Haddad et al., 2022). Second, policy formulation is a dynamic process (Rogge and Reichardt, 2016) to identify, assess, and select suitable policy solutions to address the identified challenges (Cairney, 2012; Haddad et al., 2022). Third, legitimation aims to ensure public support for the designed policies (Cairney, 2012; Haddad et al., 2022; Boasson and Tatham, 2023) through broad stakeholder involvement (Cairney, 2012; Schot and Steinmueller, 2018; Haddad et al., 2022) and rationales (Weber and Rohracher, 2012) which are crucial to address potential resistance to policy change (Boasson and Tatham, 2023; Groen et al., 2023). Fourth, implementation refers to the actual execution and enforcement of policy instruments (Cairney, 2012; Rogge and Reichardt, 2016) through different implementation structures, stakeholder involvement, and modes of governance (Haddad et al., 2022). Fifth, monitoring and evaluation includes both summative evaluations to assess the policy impact (Cairney, 2012; Haddad et al., 2022) and formative evaluation methods to enable dynamic policy adaptation to changing circumstances based on policy learning (Fagerberg, 2018; Janssen, 2019; Magro and Wilson, 2019; Haddad et al., 2022). Finally, policy learning connects the learnings from the evaluation results to improve and re-design policies in a new policy cycle (Rogge and Reichardt, 2016; Haddad et al., 2022). As Rogge and Reichardt (2016) argue, their idea of policy making includes all steps of the policy making from agenda setting to policy learning to highlight the iterative nature of the process. However, their model differentiates between policy making and implementation to highlight the importance of policy implementation and related implementation structures (Rogge and Reichardt, 2016).

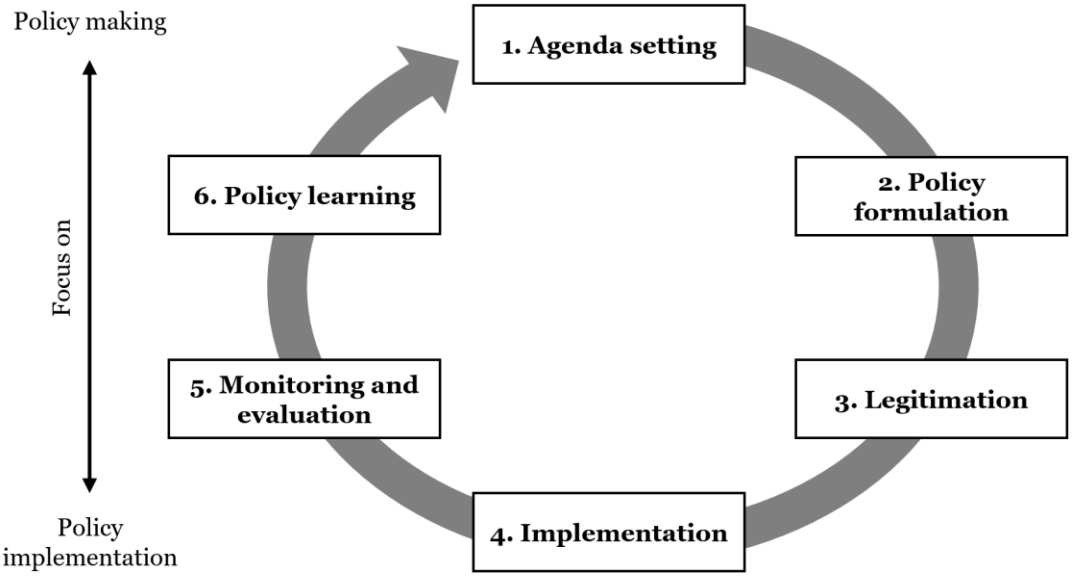

Figure 4. Six-step policy cycle and its relation to policy processes by Rogge and Reichardt (2016). Policy cycle adapted from Haddad et al. (2022).

(3) Characteristics: The third building block of policy mixes involves the characteristics of elements and policy processes which describe essential traits of a policy mix (Rogge and Reichardt, 2016; Reichardt and Rogge, 2016; Mavrot et al., 2019). These characteristics should not be confused with assessment criteria for a policy mix (e.g., effectiveness), which are used in various impact assessments and evaluation of policy performance (Rogge and Reichardt, 2016). Rogge and Reichardt (2016) propose four characteristics, including consistency, coherence, credibility, and comprehensiveness. First, consistency defines how well the policy elements work together toward shared policy objectives varying in strength from conflicting elements to lack of contradictions and finally synergistic elements (Rogge and Reichardt, 2016). The consistency of a policy may vary between different dimensions of the policy mix, such as time and geography (Rogge and Reichardt, 2016). Second, coherence describes whether the policy processes are systematically structured and work together in a complementary manner across policy fields and governance levels to effectively achieve policy goals (Rogge and Reichardt, 2016). The third characteristic refers to the credibility of the policy mix, elements and processes based on how believable and reliable the policy mix is (Rogge and Reichardt, 2016). Fourth, comprehensiveness defines how extensively and exhaustively the policy mix operationalises the policy strategy and uses policy processes to address the defined policy objectives (Rogge and Reichardt, 2016). Altogether, these policy mix characteristics and may significantly impact policy performance (Rogge and Reichardt, 2016;

Reichardt and Rogge, 2016; Mavrot et al., 2019) and provide important considerations for policy makers.

(4) Dimensions: The fourth building block of policy mixes involves the dimensions which define the boundaries of a policy mix (Reichardt and Rogge, 2016), describe the space for policy mix interactions (Flanagan et al., 2011; Rogge and Reichardt, 2016), and specify other building blocks (Rogge and Reichardt, 2016). This study adopts the classification of dimensions by Flanagan et al. (2011) and Rogge and Reichardt (2016) which defines four dimensions: policy field, governance level, geography, and time.

First, the policy field describes the specific policy domains in which the policy mix is applied or which impact the policy mix, such as energy, climate, or innovation policy (van den Bergh et al., 2006; Rogge and Reichardt, 2016). Understanding the policy dimensions involved in a policy mix can help policy maker to improve the consistency and coherence of a policy mix (Rogge and Reichardt, 2016), which can be critical for complex transformative policies covering multiple domains. Second, the governance level includes vertical differentiation between different levels of governance (e.g., from international to local) (Flanagan et al., 2011; Rogge and Reichardt, 2016) and horizontal differentiation among various administrative entities in different policy fields within these levels (Rogge and Reichardt, 2016). This dimension closely relates to transformative innovation policy through multi-level governance and coordination of different actors (Haddad et al., 2022). Third, geography describes the spatial origin and application of a policy mix (Flanagan et al., 2011; Rogge and Reichardt, 2016), which can be important, for instance, for regional cluster policy (Rogge and Reichardt, 2016). Fourth, time is a critical dimension in policy mixes as it captures the evolution of the elements, processes, and characteristics of policy mixes and the dynamic nature of policies (Rogge and Reichardt, 2016). Furthermore, the temporal dimension has an important role in transformative policy, where smart policy sequencing might be required to effectively address barriers for change at the right time (Pakizer et al., 2023). Overall, the analysis of policy mixes across different dimensions can help policy makers to identify potential inconsistencies and incoherencies that can compromise the credibility and effectiveness of the policy (Rogge and Reichardt, 2016). In addition, the different dimensions have important implications for assessing the technological neutrality of a policy mix, as inconsistencies can lead to undesired and unplanned technological discrimination against the principle of technological neutrality (See Chapter 2.3.1).

In summary, the extended policy mix concept (See Figure 3) offers a valuable tool for policy makers to systematically analyse and design policy

interventions. Each of the building blocks provide a starting point for a more detailed analysis from different perspectives. First, the elements (i.e., policy strategy and instrument mix) describe the actual means of the policy mix to support policy design. Second, the policy processes highlight the dynamic and political processes that shape the elements of the policy mix and can directly impact the characteristics of the policy mix. Third, the characteristics describe the essential traits of a policy mix, such a consistency and credibility, which can impact the performance of the policy mix. Finally, the dimensions describe the space of the policy intervention which help to understand assess the impacts of the policy across various dimensions, such as governance levels and time.

2.2.2 Classification of innovation policy instruments

Policy instruments can be classified into different groups based on various characteristics, such as the type, activities, and purpose of the policy instrument (Borrás and Edquist, 2013; Rogge and Reichardt, 2016; Edler and Fagerberg, 2017). This study focuses on the type-purpose typology by Rogge and Reichardt (2016) as a representative example which highlights the diversity of policy instruments (See Table 4). The typology for policy instruments by Rogge and Reichardt (2016) differentiates instruments into nine groups based on the type and purpose of the instrument. Furthermore, this chapter discusses how the instrument choices can influence the authoritative force and automaticity of the policy intervention. Both the authoritative force and automaticity help to understand the market-orientation of technological neutrality (See Table 5 for the characteristics of technological neutrality).

First, the type defines, how strongly the policy is enforced, ranging from obligatory regulations to voluntary information-based approaches to encourage desired behaviour (Borrás and Edquist, 2013; Hannon et al., 2023; Vedung, 1998). The division is based on the authoritative force of a policy instrument which refers to the degree of authority used to force compliance (Acciai, 2021; Vedung, 1998). The most authoritative instruments are regulations (Acciai, 2021), including various legal tools, that obligate actors to operate within certain boundaries (Borrás and Edquist, 2013; Oberthür and von Homeyer, 2023). There are various examples of these regulations, such as patent laws (Borrás and Edquist, 2013; Rogge and Reichardt, 2016), technology standards, and environmental liability laws (Rogge and Reichardt, 2016). In the middle, actors can be incentivised or disincentivised with economic instruments that impact cost-benefit calculations (Oberthür and von Homeyer, 2023) by providing economic support for desired options (Borrás and Edquist, 2013; Hannon et al., 2023; Vedung, 1998; Oberthür and von Homeyer, 2023) or increase the costs of undesired options, such as

environmental taxes (Hannon et al., 2023; Vedung, 1998; Oberthür and von Homeyer, 2023). Furthermore, Acciai (2021) separates expenditure and fiscal instruments as they have different impact on the actors. Examples of economic instruments include taxes on externalities (Borrás and Edquist, 2013; Vedung, 1998), fiscal incentives or direct support for R&D (Borrás and Edquist, 2013; Edler and Fagerberg, 2017; Rogge and Reichardt, 2016), demand-side subsidies (Borrás and Edquist, 2013; Rogge and Reichardt, 2016), and infrastructure provisions (Rogge and Reichardt, 2016). Finally, voluntary information-based approaches are the least authoritative (Acciai, 2021) as they encourage desired behaviour by creating awareness without monetary incentives or obligations (Borrás and Edquist, 2013; Hannon et al., 2023; Vedung, 1998; Oberthür and von Homeyer, 2023). These information measures can include, for instance, professional training, public debates (Rogge and Reichardt, 2016), and public information campaigns (Oberthür and von Homeyer, 2023; Rogge and Reichardt, 2016) with the goal to increase public support (Boasson and Tatham, 2023). To complement these three types of substantive policy instruments, procedural tools have been suggested as process-oriented tools to influence the policy processes and addres the dynamics of policy making (Oberthür and von Homeyer, 2023). These procedural tools include various considerations for improving the effectiveness and flexibility of policy processes, such as delegation, stakeholder participation, and revision clauses (Oberthür and von Homeyer, 2023). Therefore, they can have important implications for designing effective innovation policy mixes in the context of technological neutrality.

Table 4. Examples of policy instruments based on type and purpose. Adapted from (1) Rogge and Reichardt (2016) and (2) Oberthür and von Homeyer (2023).

	Primary purpose[1]		
Primary type[1]	Technology push[1]	Demand pull[1]	Systemic[1]
Regulation[1]	IPR laws	Technology standards	Environmental liability laws
Economic instruments[1]	R&D grants or tax incentives	Subsidies, public procurement	Infrastructure provisions
Information[1]	Professional training	Public information campaigns	Education system, public debates
Procedural tools[2]	Delegation, planning and monitoring, stakeholder participation, revision clauses[1]		

Second, the purpose refers to the overall orientation of the instrument, including technology push, demand pull (Edler and Fagerberg, 2017), and addressing systemic concerns (Rogge and Reichardt, 2016). First, the

technology push instruments support the supply of innovation with various instruments, such as direct financial support to innovators (Bloom et al., 2019; Edler and Fagerberg, 2017; Rogge and Reichardt, 2016) and IPR laws (Bloom et al., 2019; Rogge and Reichardt, 2016). These technology push instruments have been widely adopted in innovation policy since the first generation of innovation policies to address market failures leading to underinvestment in innovation (Weber and Rohracher, 2012). Second, innovation policy can aim to increase demand for innovations with demand pull instruments, such as subsidies (Edler and Fagerberg, 2017; Oberthür and von Homeyer, 2023; Rogge and Reichardt, 2016), public procurement (Fabra and Montero, 2022; Edler and Fagerberg, 2017; Rogge and Reichardt, 2016; Uyarra et al., 2020), and information campaigns (Oberthür and von Homeyer, 2023; Rogge and Reichardt, 2016). The importance of demand-side interventions has been increasingly recognised especially in transformative innovation policy (Edler and Fagerberg, 2017), where neutral supply-side interventions are not seen sufficient to address various transformational system failures, such as directionality and demand articulation failures (Weber and Rohracher, 2012). Third, instruments addressing systemic concerns support the functions of innovation systems at wider system levels (Rogge and Reichardt, 2016). For example, environmental liability laws, infrastructure provisions, and education system support the innovation systems broadly instead of targeting the demand or supply of innovations (Rogge and Reichardt, 2016). Even though these primary purposes are simplifications and include partially overlapping categories (Rogge and Reichardt, 2016), they provide a useful tool for designing comprehensive policy mixes.

Finally, the automaticity of a policy intervention describes, how different governance arrangements can be implemented to exercise different levels of government involvement in the policy mix (Acciai, 2021). While the authoritative force of a policy describes the degree of authority used to force compliance (Acciai, 2021; Vedung, 1998), the automaticity focuses on the delivery components and governance arrangements of the policy (Acciai, 2021). Figure 5 presents an overview of the levels of automaticity of different governance arrangements based on Acciai (2021). Highly automatic policies are market-based approaches where the activation of the policy does not require further interventions from public organisations (Acciai, 2021). In contrast, the activation of minimally automatic instruments relies on the actions of public agencies and bureaucracy (Acciai, 2021). In the middle of the spectrum, policy makers can utilise alternative governance arrangements, such as universities, public research organisations, and local actors to enforce policies (Acciai, 2021). This automaticity dimension can improve the understanding on policy design choices related to the market-oriented principle of

technological neutrality (See Table 5), as it illustrates the potential flexibility of market-based approaches in comparison with bureaucratic approaches.

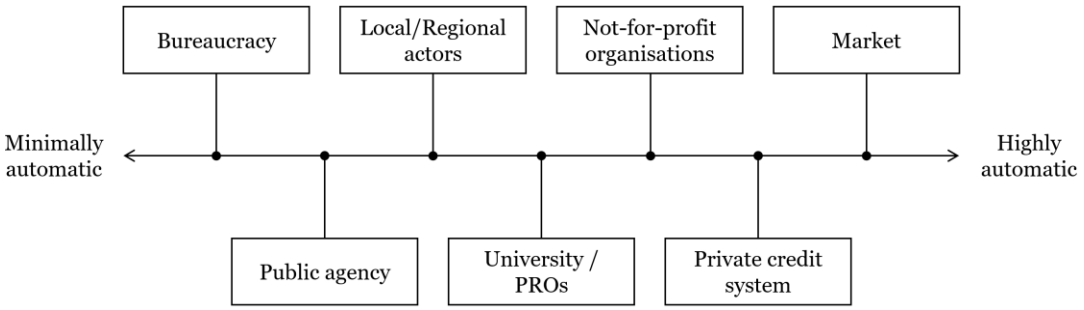

Figure 5. The level of automaticity of different governance arrangements. Adapted from Acciai (2021).

In summary, the policy makers have a broad range of different policy instruments available to support innovation policy. The type-purpose based classification by Rogge and Reichardt (2016) can be argued to provide a useful tool for identifying relevant policy tools to design comprehensive, and balanced policy mixes, as the diversification of policy instruments can support the effectiveness of policy mixes addressing complex societal challenges (Oberthür and von Homeyer, 2023). Furthermore, the level of authoritative force and automaticity of policy interventions provide an interesting perspective for assessing political resistance towards technology specific interventions. Next, the principle of technological neutrality will be discussed in the context of transformative innovation policy and innovation policy mixes.

2.3 The principle of technological neutrality in innovation policy

This chapter analyses and synthesises theoretical literature on the principle of technological neutrality to support evidence-based application of technological neutrality in policy design. The chapter begins by synthesising literature on technological neutrality to define the key characteristics of technological neutrality. Second, the different techniques to operationalise technological neutrality are covered to describe key policy design decisions that relate to the application of technological neutrality. The third subchapter provides an overview of the main rationales for technology neutral and specific policies to clarify often-conflicting goals of technological neutrality and specificity. Finally, these rationales are complemented in the fourth subchapter by providing an extensive list of contextual factors that impact the effectiveness of technology neutral and specific interventions.

2.3.1 The definition and characteristics of technological neutrality

Technological neutrality refers to a regulatory and policy principle that policy makers should design policies "*without discrimination among technologies or sectors in the public funding allocation process [or other policies], so that market signals remain the driving forces for the detailed [technology decisions or] allocation of investments*" (Aghion et al., 2009, p. 688). In contrast, technology specific policies discriminate certain technologies based on various technology related factors, such as the type, location or scale of the technology (Fabra and Montero, 2022). Even though the definitions of technological neutrality have some differences, the following three characteristics are commonly included in the definitions in some form (See Table 5): (1) no discrimination or differentiation across technologies (Jaffe et al., 2005; Koops, 2006; Moses, 2007; Kamecke and Korber, 2008; Aghion et al., 2009; Jacobsson and Bergek, 2011; Bergek and Berggren, 2014; Craig, 2016; Gawel et al., 2017; Lehmann and Söderholm, 2017; Foray, 2019; Briglauer et al., 2020; Haelg, 2020; Kim and Tang, 2020; Fabra and Montero, 2022), (2) focus on outcomes and effects instead of means (Jaffe et al., 2005; Koops, 2006; Ohm, 2009; Azar and Sandén, 2011; Greenberg, 2016), and (3) market mechanisms select technologies (Kamecke and Korber, 2008; Aghion et al., 2009; Jacobsson and Bergek, 2011; Briglauer et al., 2020). In other words, the government should not discriminate between any technologies provided by private parties by primarily targeting justified outcomes and effects instead of means in its policy interventions.

Table 5. Characteristics of technological neutrality.

Characteristic of technological neutrality	**Representative examples**
(1) No discrimination or differentiation across technologies	"*First, technology-neutral legislation would not unfairly or inefficiently discriminate between technologies.*" (Moses, 2007, p. 57) "*In contrast, technology-specific policy approaches promote selected technological fields, sectors or even projects based on differentiated support levels […].*"*(Lehmann and Söderholm, 2017, p. 476)* "*[…] whether auction designs are technology neutral, or whether they discriminate across technologies, either by type, location and/or scale.*" (Fabra and Montero, 2022, p. 669)
(2) Focus on outcomes and effects instead of means	"*Yet to avoid accidentally helping to entrench the wrong technology, it is desirable for policy to be technology neutral, encouraging all efforts that achieve specified objectives without focusing on a particular approach.*" (Jaffe et al., 2005, p. 171) "*Tech-neutral provisions refer to technology in general, vague, open-textured terms that specify purposes, effects, functions, and other general characteristics.*" (Ohm, 2009, p. 1687)
(3) Market mechanisms select technologies	"*The principle prohibits regulation that would eliminate the (evolutionary) selection function of the market mechanism.*" (Kamecke and Korber, 2008, p. 331) "*[…] without discrimination among technologies or sectors in the public funding allocation process [or other policies], so that market signals remain the driving forces for the detailed allocation of investments by private agents and corporate bureaucracies.*" (Aghion et al., 2009, p. 688)

The debate regarding the adoption of technology- or sector-specific policies versus technology-neutral approaches has been a longstanding topic in innovation policy literature (Bergek et al., 2023) as limited funding forces governments to allocate public science and technology funding (Schot and Steinmueller, 2018). According to (Reed, 2007), the term '*technology neutral*' started to emerge already in 1980s in the context of regulations in telecommunications sector in the US. Simultaneously, technological specificity of technology policies has been discussed, for example, by Ergas (1987) to differentiate between '*mission-oriented*' policies focusing on centralized governmental decision-making to promote a small number of technologies and

'*diffusion-oriented*' policies with focus on decentralization and facilitation of change without directing it. However, technological neutrality started to be adopted more widely in the end of 1990s when the principle was included in various policy documents in the EU and US as a widely desirable and agreed principle (Koops, 2006; Reed, 2007). Since the introduction of technological neutrality, the role of technological neutrality has been studied in numerous contexts, such as promotion of renewable energy (Haelg, 2020; Kim and Tang, 2020), sustainability transitions of industries (Bergek et al., 2023), telecommunications (Briglauer et al., 2020), and electrification of transportation sector (Bushnell et al., 2021), and related to various types of innovation policy instruments, such as renewable energy auctions (Fabra and Montero, 2022), ICT regulation (Puhakainen and Väyrynen, 2021), and policy mixes (Schmidt and Sewerin, 2019).

The popularity of technology neutral policies since 1990s can be argued to relate to the beliefs of the second frame of innovation system policy (See Chapter 2.1.1) which refrain from the directionality of transformative innovation policy (Wanzenböck et al., 2020). Regardless of the initial positive reception, critique towards technological neutrality started to increase in 2000s (e.g, see Koops, 2006; Reed, 2007). Furthermore, the principle of technological neutrality has been increasingly criticised as the challenges and pitfalls of the principle are better understood in the context of transformative innovation policy. This study contributes to this discussion first by clarifying the description of technological neutrality in this chapter and continues with methods for applying technological neutrality (See Chapter 2.3.2) and the rationales for and against the use of technological neutrality (See Chapter 2.3.3).

The first characteristic forms the primary goal of technological neutrality that the government policies should not discriminate or differentiate across technologies. This non-discrimination refers to the idea that neutral policies should not categorically pre-select which technologies (Greenberg, 2016; Briglauer et al., 2020), domains, or sectors can participate in the implementation of the policy (Foray, 2019). Instead, neutral policies should be highly inclusive to different technologies to promote all measures that can reach the designated objectives (Jaffe et al., 2005). This should not be confused with the idea that all competing services or technologies should be treated the same regardless of the effects of the technologies (Kamecke and Korber, 2008) as described related to the second characteristic of technological neutrality. Instead, the goal of neutrality is to prevent unjustified discrimination and differentiation of technologies which could create harmful market distortions (Kamecke and Korber, 2008).

The second characteristic of technological neutrality relates to the implementation of technologically neutral policies by focusing on outcomes and effects instead of means (Koops, 2006). Regulating effects and using outcome-oriented policy goals are seen as means to achieve the primary goal of technological neutrality to prevent unjustified technological discrimination (Koops, 2006). The focus on effects and outcomes has been traditionally supported to enable market-based competition (Schmidt et al., 2016) and to avoid the risk of politically "picking winners" (Lehmann and Söderholm, 2017) by promoting all measures that can reach the designated objectives (Jaffe et al., 2005). Even though this outcome-orientation can provide a compelling starting point for treating different technologies with similar effects similarly, the assumed neutrality of technology neutral policies is increasingly challenged as neutral policies contain their own challenges (See Chapter 2.3.3) and can also lead to picking "wrong winners" (Lehmann and Söderholm, 2017). In addition, technology specific policies or means-oriented regulations can be necessary if outcome-oriented regulations cannot be effectively enforced (Koops, 2006). Therefore, policy makers should decide how specific or neutral policies should be implemented to achieve the intended policy goals (Schmidt et al., 2016).

The third characteristic of technological neutrality clarifies how technological neutrality is related to the delegation of technology decision authority from public authorities to the market processes (Briglauer et al., 2020). As Aghion et al. (2009) and Kamecke and Korber (2008) argue, technology neutral policies aim to avoid governmental selection of winners by delegating detailed technology choices to market processes. These neutral policies have been traditionally recommended by economists as a way to avoid introducing new market distortions based on technology-specific government interventions (Aghion et al., 2009) as part of traditional discussions on the role of government. However, excessive delegation of decision authority to market forces has been challenged especially with the rise of transformative innovation policy where various types of market-based failures are used to justify government interventions (See rationales for transformative innovation policy in Chapter 2.1.2 and for technological neutrality in Chapter 2.3.3). Furthermore, the levels of intervention should be seen as a continuum where governments can use different mechanisms and policy instruments with varying levels of authoritative force and reliance on market forces (Acciai, 2021), as discussed in Chapter 2.2.2.

The three defined characteristics provide a valid starting point for understanding the principle of technological neutrality. However, the practical operationalisation of this principle poses various challenges for the policy makers. First, the principle of technological neutrality can be still argued to

remain under-theorised (Greenberg, 2016; Craig, 2016; Puhakainen and Väyrynen, 2021), as different meanings are attached to technological neutrality (Koops, 2006; Craig, 2016) and the choice between technology-neutral and technology-specific policies remains a focus on various policy studies (e.g., Kim and Tang, 2020; Bellamy et al., 2021; Fabra and Montero, 2022; Bergek et al., 2023). Second, objectively defining neutrality or discrimination is difficult (Azar and Sandén, 2011; Craig, 2016) as policies are outputs of political processes which are not expected to be neutral (Hildebrandt and Tielemans, 2013) and can support significant societal transformations (Azar and Sandén, 2011). Furthermore, it is argued that there is no clear distinction between technology-neutral and technology-specific policies as policies can be neutral at different technology hierarchy levels (Bergek and Berggren, 2014; Schmidt et al., 2016). Third, the principle of technological neutrality provides only a starting point for policy making, as demonstrated by many recent studies that argue the need for technology-specific policies in various circumstances (e.g., Kim and Tang, 2020; Bellamy et al., 2021; Fabra and Montero, 2022; Bergek et al., 2023). Therefore, decisions on technological neutrality or specificity of policies should be understood as context-dependent decisions, which do not guarantee the achievement of any valuable economic or other goals. Instead, the decisions on technological neutrality should be seen as a means for policy making and not as the main guiding principle (Ohm, 2009; Azar and Sandén, 2011).

One of the challenges of the concept of technological neutrality is whether regulation or policy can (Craig, 2016) or even should be neutral (Azar and Sandén, 2011; Schmidt et al., 2016; Puhakainen and Väyrynen, 2021). To clarify the meaning and level of discrimination in the context of technological neutrality, two important dimensions related to choosing a policy goal should be understood. First, the level of the policy goal based on technological hierarchy levels helps to understand how specific or neutral a policy might be on a general level (Azar and Sandén, 2011; Schmidt et al., 2016). Second, the level of differentiation at the hierarchy levels below the targeted policy goal helps to identify whether the policy clearly discriminates or differentiates between technologies. These two dimensions are demonstrated in Figure 6 in the field of renewable energy based on the technology hierarchy levels defined by Schmidt et al. (2016), visualisation adapted from Agora Verkehrswende (2020), and examples from Kim and Tang (2020).

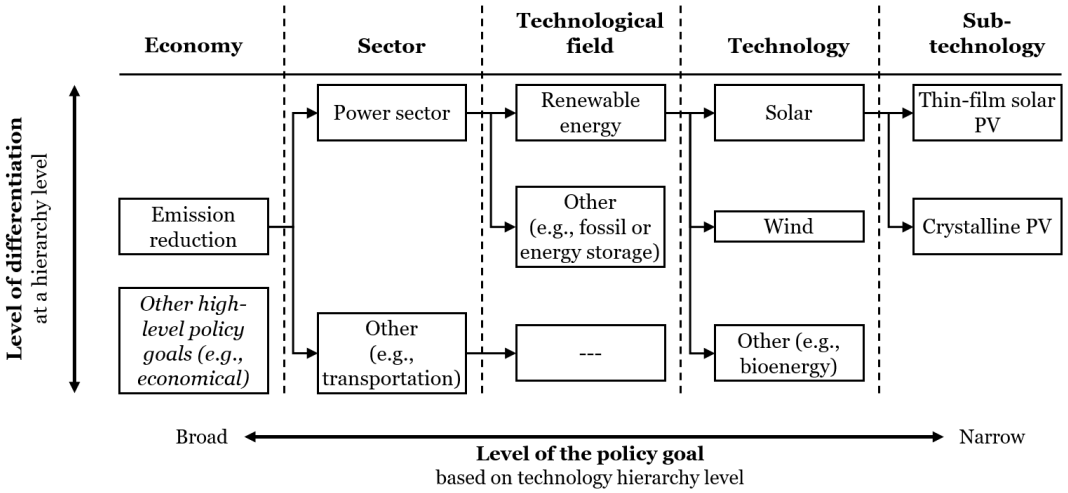

Figure 6. Hierarchical tree structure to visualise the level of neutrality. Adapted from Schmidt et al. (2016), Agora Verkehrswende (2020), and Kim and Tang (2020).

Technological neutrality of a policy should be understood as a scale where different policies can be more neutral or more specific based on the policy goal (Azar and Sandén, 2011; Schmidt et al., 2016; Kim and Tang, 2020). For instance, a policy can be technology specific at a certain technology hierarchy level while being neutral at the level below (Azar and Sandén, 2011; Schmidt et al., 2016; Kim and Tang, 2020). Schmidt et al. (2016) provide one classification example with six hierarchy levels adapted from the work of Winskel et al. (2014) and presented in Figure 7. As examples, economy level policies can include broad economy-wide carbon taxes whereas feed-in tariffs might target specific renewable energy technologies, such as wind power (Schmidt et al., 2016; Kim and Tang, 2020). The targeted technology hierarchy level of a policy can help to understand (1) how technology specific a policy might be (Schmidt et al., 2016; Kim and Tang, 2020), and (2) the levels of aggregation and involved system dynamics (Winskel et al., 2014). The first perspective refers to the basic idea of technological neutrality, that policies targeting lower hierarchy levels are likely to be more technology specific (Schmidt et al., 2016; Kim and Tang, 2020). The second perspective provides valuable insights for policy mix design by arguing that analysis on different levels has its own strengths and weaknesses for understanding system dynamics (Winskel et al., 2014). For instance, analysis of targeted systems at higher hierarchy levels might help to understand wider system dynamics and interactions but might fail to provide insights on the exact processes and institutions (Winskel et al., 2014). Related to this aggregation and wider system dynamics, Rogge and Reichardt (2016) argue similarly that broader policy mix

scope can challenge the consistency and coherence of a policy mix due to conflicting interests between the broad set of involved parties.

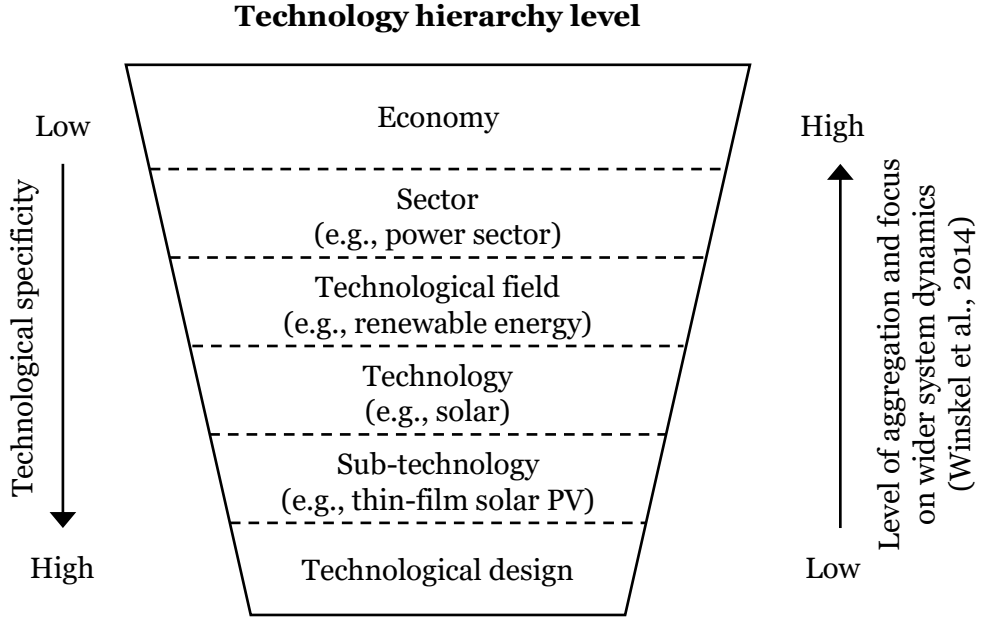

Figure 7. Technology hierarchy levels. Adapted from Schmidt et al. (2016).

The second dimension related to the level of specificity refers to the level of differentiation at the hierarchy levels below the targeted policy goal. After the policy makers have decided the targeted hierarchy level of a policy goal (e.g., technological field of renewable energy), the policy maker can still decide to use technology neutral approach or differentiate between the technologies (e.g., solar and wind) on the lower hierarchy levels (Azar and Sandén, 2011; Schmidt et al., 2016; Kim and Tang, 2020). Based on the characteristics of technological neutrality (See Table 5), technology neutral policy should not differentiate between the technologies below the policy goal, as the policy should focus on outcomes instead of means. Agora Verkehrswende (2020) argue similarly that technology neutral policies should at the level of the policy goal without discriminating across technologies. This perspective provides a good starting point for designing policies that do not unfairly discriminate against specific technologies. However, even technology-specific interventions can have valid justifications as argued in Chapter 2.3.3 but specific interventions call for extra attention from the policy makers to prevent inefficient differentiation.

Figure 8 provides an example on the two dimensions of specificity and illustrates how a policy can be specific at one hierarchy level while being neutral at the levels below. As an example, a policy for promoting renewable energy technologies to reduce emissions can be technology specific at the technology

field level by categorically excluding other options, such as fossil fuels or energy storage. Simultaneously, it can be considered neutral at the level below by allowing the participation of all different renewable energy technologies based on a targeted outcome. As an alternative for reducing emissions, the policy makers could consider broader policies by targeting higher hierarchy levels, which could enable the participation of other technological fields (e.g., energy storage) or even other sectors, such as transportation. However, decisions on the specificity of a policy requires a careful assessment of the potential benefits and challenges of each approach which are discussed in the Chapters 2.3.3 and 2.3.4. Before that this chapter introduces the concept of application specificity and concludes with a summary on the definition of technological neutrality.

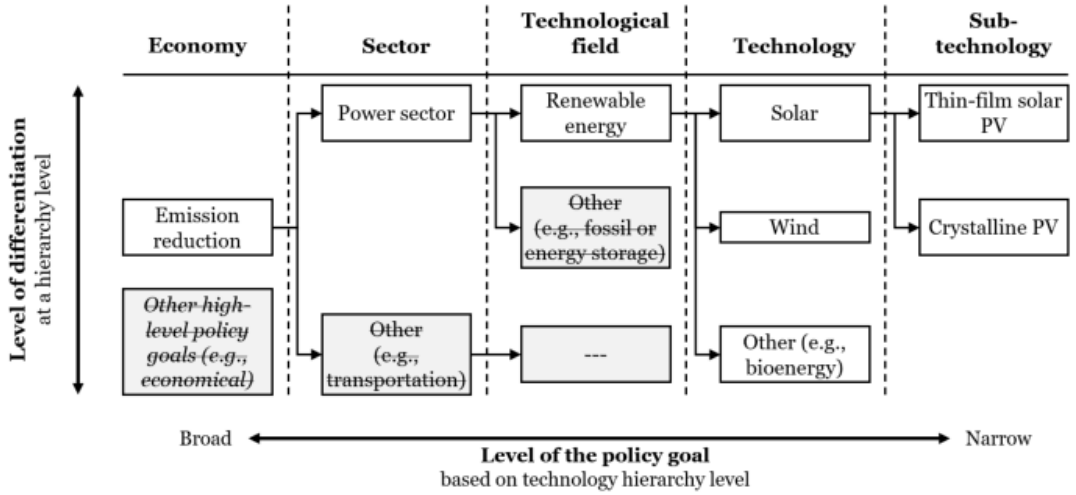

Figure 8. Example on how a renewable energy support policy differentiates between technologies when the goal is to reduce emissions.

Application specificity provides an alternative perspective for assessing the specificity of a policy intervention (Schmidt et al., 2016). In addition to differentiating between technologies, a policy maker can design interventions that target specific applications, such as fast-responding energy devices for spinning reserve (Schmidt et al., 2016). This is similar to sector-specificity In contrast, application neutral policies, such as broad carbon taxes, do not target any specific applications (Schmidt et al., 2016). Understanding the targeted applications and markets of a policy can have important implications on the success of the policy and likelihood of lock-ins, as competition and available options might differ significantly between different applications (Schmidt et al., 2016). If the competition is low in a specific application area, broadening the range of applications can help to reduce the risk of lock-ins due to increased competition (Schmidt et al., 2016). Furthermore, the policy makers should understand that supporting a multi-purpose or general-

purpose technology in one application area can lead to positive spill-overs to other application areas (Schmidt et al., 2016).

To conclude this chapter, the main characteristics of technological neutrality are summarised below together with key considerations for understanding the level of technological neutrality of a policy. First, technology neutral policy does not discriminate between technologies which can be used to reach the desired policy goal. Second, technology neutral policies should focus on outcomes instead of means to avoid unjustified discrimination of technologies. Third, the authority to select technologies should be delegated to market mechanisms to avoid market disruptions. Furthermore, the level of technological neutrality of a policy should be understood as a continuous scale where the level of neutrality depends on two dimensions related to the desired policy goal. First, a policy can be generally more neutral or specific depending on the technological hierarchy level of the policy goal. Second, the level of differentiation at the hierarchy levels below the targeted policy goal helps to identify whether the policy clearly discriminates or differentiates between technologies. Understanding these characteristics of technological neutrality and defining technology hierarchy trees (e.g., Figure 6) can help policy makers to assess the technological neutrality of a policy and adjust the policy as necessary to avoid unjustified discrimination of technologies. Next, this study introduces different approaches for implementing technological neutrality in practice.

2.3.2 Techniques to operationalise the principle of technological neutrality

This chapter introduces different approaches for implementing technological neutrality in policy design. Recognizing the complexity of the principle of technological neutrality, this study has identified five distinct techniques that can be used to operationalise technological neutrality within policy frameworks (See Table 6). These techniques range from strategic decisions on policy scope to practical legislative techniques, each contributing uniquely to the overarching goal of equitable technology policy. Next, each of these techniques is discussed in more detail.

Table 6. Five techniques to operationalise technological neutrality in policy design.

Techniques for technological neutrality	
- Examples	**Implications**
T1. Policy scope and level of differentiation with abstraction	
- Deciding technological specificity based on technology hierarchy levels (Schmidt et al., 2016) - Use open-ended formulations (Koops, 2006) - Defining proper level of specificity (Ohm, 2009)	Ability to adjust technological specificity of the policy to avoid unjustified discrimination and to customise intervention.
T2. The level and type of intervention	
- Differentiate in levels of regulation (Koops, 2006) - Frameworks of substantive principles (Koops, 2006)	Impact on authoritative force, automaticity, expected timeframe, and risk
T3. Policy timeframe	
- Inclusiveness of policy towards current and future technologies (Greenberg, 2016) - Evaluation and sunset clauses (Koops, 2006) - Technological Sunsets (Ohm, 2009)	Potential trade-off between stability and flexibility.
T4. Policy mix approaches	
- A multi-instrument (Bellamy et al., 2021) or mixed approach (E.g., neutral laws + specific regulations) (Koops, 2006) - Delegation (Greenberg, 2016) - Harmony with other policies, such as competition policy (Aghion et al., 2009)	Ability to combine benefits of neutral and specific policies. Delegation to improve flexibility and expertise Potential coordination and coherency challenges
T5. Policy interpretation	
- Three approaches to technological neutrality (Craig, 2016) - Allow for functional, teleological interpretation (Koops, 2006)	Broad interpretations can increase flexibility but lead to consistency challenges.

Technique 1: The first identified technique is defining policy scope and level of differentiation (e.g., Ohm, 2009; Schmidt et al., 2016) by applying different levels of abstraction. As described in Chapter 2.3.1, technology hierarchy levels and trees can be helpful tools for understanding the level of technological specificity associated with a certain policy (Azar and Sandén, 2011; Schmidt et al., 2016). This can provide a starting point for policy makers to decide the level of technological specificity based on technology hierarchy levels (Schmidt et al., 2016) and assess the level of technological differentiation in comparison with the level of the policy goal (Agora Verkehrswende, 2020). This comparison can help to identify risks related to

unjustified technological discrimination if the level of policy goal and specificity of the policy differ significantly. In practice, the policy makers can raise the level of neutrality with various abstraction techniques for drafting policies, such as using broadly defined laws (Greenberg, 2016) and using open-ended formulations, such as "mail or other confidential correspondence", to avoid excessively specific policies (Koops, 2006). Overall, this approach underscores the importance of carefully delineating the scope of policy and determining the degree of specificity or generality to set the foundation for a nuanced understanding and application of technological neutrality.

Technique 2: Second, choosing the level and type of intervention is important for designing a policy with a desired level of authoritative force and automaticity to enforce the policy (Acciai, 2021), as described in Chapter 2.2.2. Differentiation between the levels of regulation, such as high-level constitutions, laws, and lower-level regulations, can help policy makers to design suitable levels of specificity for different types of regulation (Koops, 2006) as the processes and goals vary between different types of regulations (Greenberg, 2016). For example, it is suggested to prefer broad and neutral laws (Koops, 2006; Greenberg, 2016), as the processes for drafting new laws can be too slow to adapt to quickly changing technological environment (Greenberg, 2016). Instead, the policy maker might want to use lower levels of regulatory mechanisms, such as implementing decrees (Koops, 2006) and delegation to administrative agencies (Greenberg, 2016), for detailed the technology decisions. In addition to the typical regulatory mechanisms, Koops (2006) suggests that frameworks of substantive principles can guide policy makers to interpret laws in a functional way by indicating the desired values and rationales of the policy. Similarly, this study aims to help policy makers to understand contextual factors when technological neutrality might be helpful or harmful instead of recommending technological neutrality as the main guiding principle.

Technique 3: Third, the optimal policy timeframes are widely discussed in the context of technological neutrality. One of the traditionally proposed arguments for technology neutral regulation is future-proofing of laws (Moses, 2007; Craig, 2016; Greenberg, 2016; Puhakainen and Väyrynen, 2021) and a capacity to remain relevant and effective over time, despite the rapid evolution of technology (Craig, 2016). However, this view has been criticised as excessive future-proofing and consistency can lead to overinclusive laws that are unsuitable for changing circumstances (Ohm, 2009) and to "*technology blindness*" (Craig, 2016) towards differences of existing and new technologies (Craig, 2016; Greenberg, 2016). This necessitates a careful consideration of the policy's lifespan and adaptability to changes. These dimensions of durability and flexibility are critical especially for complex and ambitious policies,

such as climate policy, that should be sustainable, resilient, and resistant to short-term disruptions (Jordan and Moore, 2023). The notion of inclusiveness of policy towards current and future technologies, as discussed by (Greenberg, 2016), is another critical aspect. It underscores the importance to consider how inclusive the policy can and should be towards current and emerging technologies (Greenberg, 2016). As Greenberg (2016) argue, emerging technologies might require new regulations as unforeseen technologies might introduce significant technological differences due to the radical novelty of emerging technologies (Rotolo et al., 2015). This raises the question of whether true inclusivity is attainable in an environment characterized by rapid and unpredictable technological advancements.

Techniques such as the implementation of evaluation and sunset clauses, as proposed by Koops (2006), offer a structured approach to periodically reassess the policy's effectiveness and relevance (Aghion et al., 2009). Similarly, Ohm (2009) proposes the idea of technological sunsets, advocating for policies that inherently acknowledge and plan for their own obsolescence, thereby ensuring continuous alignment with the evolving technological landscape. Moreover, the temporariness of technological specificity in policies should not be overlooked as merely a limitation (Ohm, 2009). Temporariness can be advantageous by allowing policymakers to retain control and flexibility to adapt to changing technological paradigms (Aghion et al., 2009) in certain contexts, where excessive consistency can lead to problems, such as abuse of power in surveillance laws (Ohm, 2009). This approach acknowledges that while long-term stability is desirable, the dynamic nature of technology sometimes necessitates shorter-term, more specific interventions that can be adjusted or sunsetted as technologies evolve.

Technique 4: Fourth, the application of policy mix approaches or systems thinking emerges as a vital technique to balance between the benefits and challenges of technological neutrality and specificity (Bellamy et al., 2021). This approach can be actualized through various techniques. Firstly, employing a mixed (Koops, 2006) or multi-instrument approach (Bellamy et al., 2021) can be used to combine neutral high-level policies with specific policies, which can help to enable a sustainable technology neutral regime while providing clarity for technology providers through specific low-level policies (Koops, 2006). Secondly, delegation can be used to delegate specific technology decisions to potentially better-suited parties which can enable better tailoring of the decisions and help overcome challenges with insufficient expertise and slowness of legal processes by using more flexible policy mechanisms (Greenberg, 2016). Thirdly, ensuring harmony with other policies, such as competition policy, is crucial to avoid policy conflicts and mitigate risks of technology specific policies (Aghion et al., 2009). Similarly, the importance

of horizontal and vertical policy coordination is highlighted in the context of transformative innovation policy to enable flexibility and reflexivity to adapt during the processes (e.g., Haddad et al., 2022). Overall, implementing a policy mix approach can help policy makers to address the dilemma between benefits of neutrality and specificity (Bellamy et al., 2021) as well as helps policymakers to adapt to emerging technologies which can require new regulatory frameworks (Greenberg, 2016). See Chapter 2.2 for additional considerations on policy mix approaches.

Technique 5: The fifth technique for operationalising technological neutrality relates to how policy goals and regulations are interpreted during their lifetime. Craig (2016) proposes three conceptual approaches how laws can be interpreted from the perspective of technological neutrality (See Table 7). First, the restrictive approach of formal non-discrimination focuses narrowly on the literal interpretation of policies to new technologies without acknowledging potential differences between the old and new technologies (Craig, 2016). This "*means-oriented*" approach can lead to discrimination between functionally equivalent technologies and potential conflicts with the second characteristic of technological neutrality (i.e., focus on outcomes and effects, see Table 5), as it can fail to account for differences in technological contexts (Craig, 2016). Second, the intermediate approach of functional equivalence expands the scope to consider the end result or function of an activity, which advocates for the application of the law in a functionally equivalent manner across both new and old technologies (Craig, 2016). This intermediate approach better aligns with the second characteristic of technological neutrality as it seeks to avoid unjustified discrimination against new technologies by ensuring similar treatment for different technologies that produce similar effects (Craig, 2016). Third, the expansive approach of prescriptive parallelism broadens the view further by guiding the interpretation of the law in a way that aligns with the overarching normative goals of the policy (Craig, 2016). Instead of focusing only on the functional equivalence, the idea is to ensure that the desired balance of fundamental rights is preserved to serve public interest when technologies evolve (Craig, 2016). For instance, the policy makers might need to balance between the rights of authors to get compensation and users to gain access to materials in the context of copyrights laws (Craig, 2016). Overall, the expansive approach can provide a more flexible approach to enable technological non-discrimination (Craig, 2016) but might face consistency challenges similar to broad policy goals as discussed in Chapter 2.3.1.

Table 7. Three lenses for interpreting technological neutrality. Adapted from the work of Craig (2016).

Approach	Application of law to new tech
1. Restrictive approach of formal non-discrimination	Interpret rules as written regardless of technology. E.g., digital copy same as physical copy.
2. Intermediate approach of functional equivalence	In a "functionally equivalent" way to apply similar effect on old and new technology (what, not how). E.g., treating on-demand streaming as a performance in public, analogous to traditional broadcasting
3. Expansive approach of prescriptive parallelism	In a purposive manner to advance normative goals to preserve balance of rights traditionally sought after. E.g., the newspaper could lawfully reproduce print editions in the searchable electronic database.

In conclusion, technological neutrality can be applied in various ways and the policy makers should consider different techniques that impact the operationalisation of technological neutrality. The identified techniques to operationalise technological neutrality in policy design range from traditional policy mix considerations, such as defining policy scope and type of intervention, to more specific considerations for technological neutrality, such as policy interpretation from the perspective of technological neutrality. Furthermore, the policy makers should understand the desired policy time frame and targeted sustainability of the policy as technological developments might challenge the future-proofness of laws. The following chapter continues to discuss the main rationales for technology neutral and specific policies.

2.3.3 The conflicting and overlapping rationales for technology neutral and specific policy interventions

Rationales for technology neutral and technology specific policies have been discussed for a long time in various policy contexts (Bergek et al., 2023) as each approach has their distinct benefits and challenges. However, deciding between technology neutral and specific policy interventions remains a challenge for policy makers which calls for additional knowledge on how the different approaches impact the targeted innovation systems. This chapter introduces the most common rationales for each approach (See Table 8) while the following chapter introduces a framework for assessing the suitability of each approach for a planned policy intervention based on various contextual factors (See Table 10).

Table 8 compares common rationales for technology neutral and technology specific policy interventions based on five categories: (1) the avoidance of policy failures vs. market failures, (2) positive discrimination of existing vs.

emerging technologies, (3) market-based vs. policy supported technological diversity, (4) effectiveness from broad vs. customised policies, and (5) policy sustainability vs. customisation. These categories can help policy makers to identify when the question between specific and neutral policies is relevant for solving their desired policy goal. The main rationale for technology neutral interventions could be argued to be effectiveness through market-based technology selection and avoidance of policy failures. In contrast, technology specific policies tend to aim to increase effectiveness and resilience through transformation and diversity by fixing market inefficiencies. Next, each of the five rationales is briefly introduced.

Table 8. Main rationales for technology neutral and specific interventions.

Rationales	**Neutrality**	**Specificity**
R1: Avoidance of policy failures vs. market failures	Avoid policy failures (e.g., creation of new market distortions) which might be caused by institutional shortcomings.	Address shortcomings of market processes (e.g., path dependencies, market failures, lock-ins, directionality) to support desired economic and societal transformations.
R2: Positive discrimination of existing vs. emerging technologies	Avoid "*tilting the playing field*" and discrimination of existing technologies due to unfair technology discrimination based on governmental technology selection.	Aim to "*level the playing field*" by supporting emerging technologies and by addressing path dependencies, market failures, and lock-ins.
R3: Market-based vs. policy supported technological diversity and sovereignty	Broad, technology neutral interventions can support diversity by creating inter-domain synergies as well as by reducing lock-ins and failures if competition is high.	Support diversity by addressing path dependencies, market failures, and lock-ins, which can support dominant technologies.
R4: Effectiveness from broad vs. customised policies	Broad, technology neutral policies can lead to cost efficiency using commercially available technologies and effective market-based technology selection processes and competition.	Customised, technology specific policies can lead to long-term efficiency by promoting emerging technologies, reducing rents of inframarginal producers, and addressing market inefficiencies.
R5: Policy sustainability based on inclusiveness vs. policy customisation	Broad and neutral policies can help to future-proof policies through inclusiveness to gain benefits of longevity.	Technological specificity can help to avoid undesired consistency with customisation and planned obsolescence.

First, the policy maker should consider how strong the preferences are to avoid policy failures and to address market failures. This question strongly relates to the third characteristic of technological neutrality that market mechanisms should be allowed to select technologies (See Chapter 2.3.1) to avoid risks of policy failures, such as introducing new market distortions (Aghion et al., 2009). The market-based principle of technological neutrality has been generally supported by economists as non-neutral policies can lead to policy failure based on various challenges, such as risky bets, picking winners in a political competition, market distortion, and decisions based on incomplete information (Aghion et al., 2009). However, the principle of technological neutrality is increasingly challenged especially with the introduction of transformative innovation policy as the earlier economic and often neutral focus are seen inadequate for confronting environmental and societal challenges (Schot and Steinmueller, 2018). In this context, technology specific interventions are seen necessary to address various market, structural, and transformational failures, such as pre-mature lock-in (Schmidt et al., 2016), obstacles to long-term risk taking, path dependencies, and challenges in designing policies to internalize the external costs of technologies (Lehmann and Söderholm, 2017). Overall, this first rationale is part of the traditional discussion on the role of government and these general rationales for transformative innovation policy are discussed in Chapter 2.1.2 in more detail.

Second, the rationales for non-discrimination, as the first characteristic of technological neutrality (See Chapter 2.3.1), differ significantly between technology neutral and specific interventions. Technology neutral policies have been commonly justified as a way to avoid "*tilting the playing field*" due to unfair technology discrimination based on technology specific policies (Aghion et al., 2009; Koops, 2006). However, technology neutral policies can lead to inefficient technology discrimination and unintentional lock-in by excessively supporting the dominant technology in the targeted application (Schmidt et al., 2016). In addition, existing path dependence lock-ins can create significant barriers for new technologies (Eitan and Hekkert, 2023), which can be argued to favour dominant technologies over emerging technologies. Therefore, van den Bergh et al. (2006) argue that emerging technologies might require directed support to enable an '*extended level playing field*' where alternative technologies and companies can compete with more dominant actors. Hildebrandt and Tielemans (2013) add that technology specific policies might be required sometimes to achieve substantive equality between technologies and technological neutrality.

Third, technological diversity and sovereignty can provide important rationales for innovation policy and the choice between neutral and specific

policies. Supporting technological diversity can become an important goal for innovation policy in addition to traditional economic goals (van den Bergh, 2008), as technological diversity can reduce the risk of lock-ins, enable recombinant innovations contributing to long-term efficiency, and increase resilience against unexpected changes (van den Bergh, 2008; van Rijnsoever et al., 2015). Simultaneously, the rise of geopolitical competition and industrial policy tests political will to invest into technological sovereignty[1] by supporting nationally critical technologies and reduction of international technological dependencies (Edler et al., 2023). On the other hand, specialisation can enable increasing returns based on economies of scale while avoiding potential high costs of diversity (van den Bergh, 2008). This partial conflict between the objectives of potentially short-term profit maximisation of specialisation and long-term benefits of diversity (van den Bergh, 2008) and sovereignty (Edler et al., 2023) forces the policy maker to identify and nurture an optimal level of diversity and sovereignty based on policy goals.

Both neutrality and specificity can be used to increase diversity depending on the level of competition related to policy goal and defined policy goal. First, broad, technology neutral interventions can support diversity by creating inter-domain synergies (Bergek et al., 2023) and reduce lock-ins if the level of competition is high (Schmidt et al., 2016). Second, technology-specific policies can improve diversity by directly supporting emerging technologies (Bellamy et al., 2021) and by addressing barriers for the emergence of new technologies (Azar and Sandén, 2011; Gawel et al., 2017; Lehmann and Söderholm, 2017) especially when there is little competition on the level of policy goal (Schmidt et al., 2016). Overall, the policy maker should choose the most suitable approach depending on the policy goals and related contextual factors (See Table 10).

Fourth, technology neutral and specific policies have their own rationales related to effectiveness and economic outcomes. As technology neutral policies promote market-based technology selection (See Table 5), the effectiveness of technological neutrality can be argued to rely on the possible superiority of market-based technology selection through competition over governmental technology differentiation. Even though market-based technology neutral policies are commonly seen as the "*first-best*" solution for various policy interventions instead of technology specific interventions (Jaffe et al., 2005; Gawel et al., 2017; Lehmann and Söderholm, 2017; Rosenow et al., 2017; Agora Verkehrswende, 2020), various barriers for market-based change can

[1] This study adopts the definition of technological sovereignty by Edler et al. (2023, p. 1) referring to a "*state-level agency within the international system, i.e. as sovereignty of governmental action, rather than (territorial) sovereignty over something*".

challenge the efficiency of neutral policies (See Chapter 2.3.4). In contrast, the effectiveness of technology specific policies relies on the government's abilities to efficiently address these shortcomings of market-based processes and to gain benefits from directed and customised interventions. Furthermore, technology specific interventions can enable necessary customization of policies to address technology- and sector-specific conditions (Bergek et al., 2023). As a result, this directionality of technology specific policies offers a high-risk high-reward approach for the policy makers (Aghion et al., 2009). Significant investments on specific technologies or industries can be necessary to reach critical mass and economies of scale to generate significant societal wellbeing, which might not be possible with neutral policies (Aghion et al., 2009). However, these focused policies introduce a significant risk for policy failures as the success of the policy relies on the policy makers' prediction on the future winners and uncertain technology development (Aghion et al., 2009).

Fifth, policy sustainability or futureproofing is one of the traditional rationales for technology neutral policies (See Chapter 2.3.2). As discussed, broad and neutral policies can help to future-proof policies through inclusiveness with the aim to gain benefits of longevity. However, excessive future-proofing and consistency can lead to to "*technology blindness*" (Craig, 2016) and inflexible policies that are unsuitable for changing circumstances (Ohm, 2009). In contrast, targeted and specific interventions can enable customization of policies to technology- and sector-specific conditions (Bergek et al., 2023) and avoidance of undesired consistency with technological sunsets and planned obsolescence (Ohm, 2009). In many cases, it is possible to balance between the sustainability of technological neutrality and customisation of technology specificity by using various policy mix approaches (See Chapter 2.3.2).

In conclusion, the main rationales for neutral policies are (1) the avoidance of policy failures, (2) non-discrimination of technologies based on governmental technology selection, (4) effectiveness through market-based technology selection, and (5) the creation of future proofed policies. In addition, technological neutrality might be able to support (3) technological diversity with broad policies if there is sufficient competition. In contrast, the main rationales for specific policies include (1) addressing shortcomings of the market, (2) providing "*an extended level playing field*"", (3) technology diversity by supporting emerging technologies, and (5) customisation of policies to technology and sector specific conditions. In addition, technological specificity can lead to positive economic and transformational outcomes, if the policies succeed in overcoming the shortcomings of market-based

processes. However, each of these outcomes depend on various contextual factors which are discussed in the following chapter.

2.3.4 Contextual factors as barriers and enablers of technology neutral and specific policies

This study has identified three central categories of contextual factors based on literature that should be considered when assessing the suitability of technological neutrality or specificity for a policy intervention (See Table 10). First, technology related barriers for market-based change relate to the third characteristic of technological neutrality that neutral policies should prefer market mechanisms to select technologies (See Table 5). However, various technology related barriers for market-based change, such as market failures and unavailability of options, can prevent the optimal performance of market activities. Second, policy makers should estimate the expected net impact of the planned policy to assess if the positive effects significantly exceed the risks and negative effects to justify an intervention of a certain type. Third, the feasibility of policy implementation refers to various factors, such as the level of uncertainty and barriers for policy adoption, which can support or hinder the success of a policy intervention. Each of these categories is discussed in more detail below together with implications for policy design. Even though the identified categories partially overlap with general considerations for policy mix design and justification for policy interventions, these contextual factors and implications provide important considerations for policy makers in relation to different techniques for operationalising technological neutrality.

Table 9. List of sources for Table 10.

No	Article	No	Article
1	Aghion et al. (2009)	7	Gawel et al. (2017)
2	Agora Verkehrswende (2020)	8	Lehmann and Söderholm (2017)
3	Azar and Sandén (2011)	9	Ohm (2009)
4	Bellamy et al. (2021)	10	Rosenow et al. (2017)
5	Bergek et al. (2023)	11	Schmidt et al. (2016)
6	Fabra and Montero (2022)	12	Technology Advisory Board (2021)

Table 10. Contextual factors to assess the suitability of technology neutral and specific interventions. Numbered sources listed in Table 9.

Contextual factor	**Concept**	***Implication***	**Aggregate**
Unavailability of suitable solutions[3,6]	Lack of competition and available options	*Expand policy scope or support emerging solutions if high.*	1. Technology related barriers for market-based change
Insufficient competition[2, 11]			
Requirement for infrastructure[2, 3, 8, 12]	Path dependencies (e.g., due to investments)	*Technology or sector specific policies might be needed if high.*	
Sector complexity creating path dependencies[5]			
Other path dependencies (e.g., network externalities)[1]			
Externalisation of costs[2, 7, 8]	Other market and system failures	*Complement neutral policies with specific policies, when necessary, if high.*	
Barriers to long-term risk taking[7, 8]			
Other market and system failures[2, 7, 8]			
Development gap[1, 2, 3, 4, 5, 10, 11]	Intervention potential	*Potential to intervene, if high*	2. Expected policy impact
Potential of the technology / intervention[3, 8, 12]			
Positive impact on other policy goals[2, 12]	Positive spill-over effects	*Specific interventions might be more justified, if high.*	
Positive technology spill-overs[4, 8, 11, 12]			
Cost of intervention[1]	Negative effects	*Avoid intervention if high*	
Inability to increase national competitiveness due to international spillovers[8].			
Risk of new market distortions[1]			
Inability to mobilise the target actors of the policy[5, 10, 11]	Barriers for policy implementation	*Avoid intervention if high.*	3. Feasibility of policy implementation
Political resistance[1, 12]			
Other barriers (e.g., institutional path dependencies)[2]			
Information asymmetry with advantage for private parties[2, 8]	Level of uncertainty and information asymmetry	*Prefer neutral, short-term, or flexible policies if high.*	
Incomplete information and insufficient technology expertise on future developments[2, 6, 8, 9]			
Other sources of uncertainty (e.g., rate of technological change)[9]			
Possibility to delegate technology decisions to experts[9]	Ability to manage risks and uncertainties	*Prefer neutral, short-term, or flexible policies if low.*	
Risk tolerance when circumstances change[9]			
Other options to mitigate risks[1, 8, 9]			

Concept: Lack of competition and available options. The first identified type of barrier for market-based change is the lack of competition and available options, which can influence the likelihood of lock-ins and the effectiveness of neutral or specific interventions (Schmidt et al., 2016; Agora Verkehrswende, 2020). Insufficient level of competition at the hierarchy level of a policy can lead to technology lock-in with neutral policies as the market tends to select the most efficient technology at the time of the intervention (Schmidt et al., 2016). In these cases, technology-specific policies are suggested as an option to decrease the risk of pre-mature lock-ins and to increase diversity by supporting emerging solutions (Schmidt et al., 2016). Alternatively, the policy maker could broaden or change the targeted application area of a policy to increase the level of competition (Schmidt et al., 2016). In contrast, neutral market-oriented policies are generally recommended when there is sufficient competition (Schmidt et al., 2016), high degree of technology substitutability among technologies to achieve a policy goal (Fabra and Montero, 2022), or commercially available technologies to reach the policy goal (Azar and Sandén, 2011).

Concept: Path dependencies (e.g., due to investments). Various path dependencies are commonly discussed as a potential rationale for technology-specific policy interventions, as the related lock-ins can create inertia against transitional change (Seto et al., 2016; Geels, 2019). First, the development of emerging technologies can depend on expensive infrastructure and investments, which increases the "*switching costs*" to new technologies and can create lock-in to existing technologies (Lehmann and Söderholm, 2017). Technology-specific policy interventions are seen necessary to prevent these investment-based lock-ins by supporting emerging technologies (Lehmann and Söderholm, 2017) and the development of related infrastructure (Azar and Sandén, 2011; Agora Verkehrswende, 2020). In addition, Technology Advisory Board (2021) argues that technology specific interventions might be justified for infrastructure-like technologies which benefit many parties but cannot be justifiably left to be developed by a single party. Second, Bergek et al. (2023) argue that sector complexity due to value chain interdependencies and user segment heterogeneity can create strong path dependencies impacting the capacity of the actors to react to policies. In addition, various other types of path dependencies, such as institutional, behavioural and technological lock-ins (Seto et al., 2016), and network externalities (Aghion et al., 2009), should be considered as potential barriers for market-based change, which could justify technology specific interventions.

Concept: Other market and system failures. The previous barriers for market-based change can be expanded by considering market and system failures as rationales for technology specific policy interventions (See also Chapter 2.1.2). Various types of market and systemic failures are mentioned in literature as potential justifications for technology specific interventions. These include failures, such as the externalisation of costs (Gawel et al., 2017; Lehmann and Söderholm, 2017; Agora Verkehrswende, 2020), barriers to long-term risk taking related to technology development (Gawel et al., 2017; Lehmann and Söderholm, 2017), and general market failures or distortions (Gawel et al., 2017; Lehmann and Söderholm, 2017; Agora Verkehrswende, 2020). Similar failures are commonly used to justify policy interventions as discussed in Chapter 2.1.2, but the role of these failures to justify technology specific interventions remains debated. Market-based technology neutral interventions are commonly seen as the "*first-best*" solution for fixing similar market failures instead of technology specific interventions (Jaffe et al., 2005; Gawel et al., 2017; Lehmann and Söderholm, 2017; Rosenow et al., 2017; Agora Verkehrswende, 2020). However, neutral interventions can be unable to fully address market failures due to various reasons, such as policy costs (Agora Verkehrswende, 2020), complexity of addressing the externalities (Gawel et al., 2017; Lehmann and Söderholm, 2017), and various political obstacles (Rosenow et al., 2017; Agora Verkehrswende, 2020) (See also "*3. Feasibility of policy implementation*" in Table 10). Therefore, technology specific interventions are seen as a necessary "*second-best*" option (Lehmann and Söderholm, 2017; Agora Verkehrswende, 2020) to complement neutral interventions (Jaffe et al., 2005; Azar and Sandén, 2011; Rosenow et al., 2017) when the "*first-best*" solution fails to address barriers for the desired change (Gawel et al., 2017).

Aggregate 2: Expected policy impact. The second central category of contextual factors is the expected policy impact, which refers to a cost-benefit analysis to legitimise a policy intervention based on positive net benefits as described by Jaffe et al. (2005). A positive net benefit of a policy intervention can mainly justify an intervention generally, as the policy maker can still decide between neutral and specific interventions to address the challenge. The expected policy impact consists of at least (1) the direct intervention potential, (2) positive spill-over effects (i.e., indirect policy impact), and (3) negative policy effects which are discussed in more detail next.

Concept: Intervention potential: First, the direct intervention potential of a policy forms generally the primary rationale for a policy intervention. The extent of a development gap between the current state of a targeted system and the policy goal is commonly discussed as an important factor for

justifying policy interventions and technology specific policies. The various development gaps discussed in the literature include the extent of market failures (Aghion et al., 2009) or technology openness (Agora Verkehrswende, 2020), requirement to commercialise early stage technologies (Azar and Sandén, 2011; Bellamy et al., 2021), the extent of required change (Azar and Sandén, 2011; Rosenow et al., 2017), the need for incremental vs. radical innovations (Bergek et al., 2023), and desired level of technological diversity (Schmidt et al., 2016). When a policy aims to promote a significant transformation, the policy interventions almost inevitably become political and discriminatory against undesired technologies as the goal is to transition to a more desired state (Azar and Sandén, 2011). Furthermore, significant transformations can rely on the incentivisation of a broad range of solutions, which can require the combination of market-based neutral interventions and technology-specific support for emerging technologies (Azar and Sandén, 2011; Rosenow et al., 2017). In addition to the development gap, the scalability of the technology can significantly impact the potential of the intervention. For example, policy interventions might be more justified to support a specific technology if there is a high potential to reach economies of scale (Azar and Sandén, 2011) and high expected degree of technology learning supporting improvements (Lehmann and Söderholm, 2017).

Concept: Positive spill-over effects. Second, positive spill-over effects can increase the attractiveness of a policy intervention, as the intervention benefits a broad set of stakeholders in addition to the direct beneficiary and addresses the market failure related to spill-overs (See Chapter 2.1.2 and Table 2). Even the development of a specific technology can have positive spill-over effects on other technologies ranging from intra-technology spill-overs on very similar technologies to external-technology spill-overs on unrelated technologies (Lehmann and Söderholm, 2017). The acknowledgement of the type of dependencies and spill-overs between technologies can help the policy makers to design an appropriate level of technological specificity for a policy intervention. A broad and technology neutral policy can be suitable for contexts benefiting from inter-domain synergies, whereas technology-specific policies might be needed for incentivisation of specific technologies (Bellamy et al., 2021) or in the contexts of technology-specific knowledge spill-overs (Lehmann and Söderholm, 2017). As the positive externalities of spill-overs can decrease lock-in of a deployment policy (Schmidt et al., 2016), the existence of strong spill-overs could be argued to reduce the risk of "*picking winners*" by specific policies. As an additional source of positive spill-overs, policy makers could decide to support general-purpose or multi-purpose technologies, which can enable economy-wide spill-overs through synergies with other technologies (Schmidt et al., 2016). For example, Technology Advisory Board (2021) has listed horizontal technological knowledge platforms

(cf. general purpose technology) as a potentially justified beneficiary for technology specific interventions. Finally, the intervention threshold of a policy could be reduced if the policy has also a positive impact on secondary policy goals outside of the main scope of the policy (Agora Verkehrswende, 2020), such as positive impact on green transition, and national resilience (Technology Advisory Board, 2021).

Concept: Negative effects. The policy makers should compare the potential negative effects of a policy intervention to the expected positive effects. First, the direct cost and complexity of a policy intervention to the government might be too high to justify an intervention even in the presence of significant market failures (Aghion et al., 2009). Second, the traditional argument against policy interventions and technology specific policies is the risk of creating new market distortions and "*tilting the playing field*" (Aghion et al., 2009) as discussed in Chapter 2.1.2. Third, the existence of international knowledge spill-overs due to the global nature of technology development can prevent a country from increasing its comparative national competitiveness through technology specific support policies (Lehmann and Söderholm, 2017). In contrast, some technologies and innovations rely on local innovation systems, which provides a rationale for traditional cluster policies aiming to support the creation of regional networks (Binz and Truffer, 2017). Overall, the policy maker should carefully assess the potential negative effects of the policy, as those could outweigh the potential benefits of a policy intervention. Next, the feasibility of policy implementation is discussed as it impacts the ability to maximise the positive effects and mitigate some of the negative effects.

Concept: Barriers for policy adoption. The first considerable group of factors related to feasibility of policy implementation is the existence of barriers for policy adoption. These barriers consist of (1) inability to mobilise the target actors of the policy, (2) political resistance, and (3) other barriers, such as institutional path dependencies. First, agency plays an important role in path dependencies (Schmidt et al., 2016) and policy adoption, which can cause policy implementation to fail due to incapacity of the target actors to respond to policies due to, e.g., path dependencies (Bergek et al., 2023), or insufficient stimulus to accelerate change (Rosenow et al., 2017). Second, the political nature of major transformations can create barriers for change, as policy makers might be unable to mobilise political support (Aghion et al., 2009) due to, e.g., political opposition to a specific intervention (Aghion et al., 2009; Schmidt et al., 2016). For instance, politicians or major stakeholders might oppose interventions close to market (Aghion et al., 2009) as demonstrated by the high intervention threshold defined for interventions close to market in Technology Advisory Board (2021). Furthermore, policy

adoption might be restricted by other barriers, such as institutional path dependencies (Agora Verkehrswende, 2020). The policy maker should carefully consider, how to overcome these obstacles for policy adoption. Otherwise, the intervention might not be justified if the barriers remain excessively high after the mitigations.

Concept: Level of uncertainty and information asymmetry. The second relevant theme related to the feasibility of policy implementation is the level of uncertainty and information asymmetry between private parties and policy makers. The implications of uncertainty on policy design decisions are moderated by various factors, such as (1) the completeness of information and level of technology expertise on future developments, (2) information asymmetry between private parties and policy makers, and (3) other sources of uncertainty, such as rate of technological change. First, the uncertainty and ambiguity associated especially with emerging technologies (Rotolo et al., 2015) can lead to risky policy interventions based on incomplete information (Aghion et al., 2009). Incompleteness of information on different technologies can challenge technology specific interventions, as the policy maker might be unable to meaningfully discriminate between technologies (Lehmann and Söderholm, 2017; Agora Verkehrswende, 2020) to reduce rents (Fabra and Montero, 2022). Therefore, technology neutral policies might be preferred in the presence of incomplete information especially, if the policy maker does not have institutional competence to understand different technologies (Ohm, 2009). Second, the policy makers should consider potential information asymmetry between private parties and policy makers. As private investors or parties might have easier access to at least some of the necessary information compared to the policy maker, technology neutral policies have been commonly preferred (Agora Verkehrswende, 2020) to minimise required policy decisions (Lehmann and Söderholm, 2017) and to avoid unnecessary market distortions (Aghion et al., 2009). However, the policy makers can reduce some of the risks related to asymmetry and technology specific policies with various ways similar to addressing reflexivity failure (See Chapter 2.1.2), such as policy learning, flexibility, and mechanisms to reveal private information (e.g., by auctions) (Lehmann and Söderholm, 2017). Overall, the policy makers should generally prefer neutral policies with short time frames (See Table 6) or flexible policy approaches under high level of uncertainty and information asymmetry.

Concept: Ability to manage risks and uncertainties. The third theme related to the feasibility of policy implementation is the policy makers ability to manage risks and uncertainties. First, the policy makers should assess their risk tolerance and need for control when circumstances change (Ohm, 2009). This leads to a balancing act between a need to "*future-proof*" policies

with highly inclusive, technology neutral policies and the risks of over-inclusiveness, such as unsuitability to new technologies and inability to retain control when new technologies are introduced (Ohm, 2009). As discussed in Chapter 2.3.2, the potential temporariness of technological specificity might be beneficial for retaining control, as the policy can be designed to be re-evaluated when new technologies are introduced. Second, possibility to delegate technology decisions to experts with institutional advantages can be argued to help the policy maker to overcome some of the key challenges of policy interventions, such as institutional shortcomings with technological expertise, and inability to differentiate neutral policies in various contexts (Ohm, 2009; Greenberg, 2016). As discussed in Chapter 2.3.2, these policy mix approaches and delegation can help policy makers to address the dilemma between benefits of neutrality and specificity (Bellamy et al., 2021). However, excessive delegation to lower-levels of governance might not be justified in cases (e.g., surveillance laws), when the lower-level government agency does not have relative institutional advantages and the legislator needs to retain control over the government agencies, for example, to avoid abuse of power (Ohm, 2009). Third, the risks of policy interventions can be mitigated with other safeguarding policies, such as high-level laws or background rules (Ohm, 2009), competition policy (Aghion et al., 2009), or by avoiding support for "single winners" (Lehmann and Söderholm, 2017). Overall, a high ability to manage risks and uncertainties can justify longer and potentially more technology-specific interventions, whereas flexible and potentially neutral policies should be preferred in the opposite case.

In conclusion, the suitability of technological neutrality or specificity for a specific policy intervention depends on various contextual factors. First, barriers for market-based change provide one of the main rationales for policy interventions (cf. Chapter 2.1.2) as they can prevent achieving the desired policy goal. If these barriers are high, neutral policies might need to be complemented with technology specific policies for optimal outcomes. Second, a cost-benefit assessment of the policy impact is central for legitimising policy interventions whether they are neutral or specific. In addition to the direct intervention potential, the policy maker should assess the negative effects and positive spill-over effects of the policy to assess the net impact of a policy intervention. If the policy is expected to create a significant positive net impact, even stronger interventions might receive stronger public support to legitimise an intervention. Third, the feasibility of policy implementation has a significant impact on the likelihood of reaching the desired policy goal and the optimal timeframe of a policy. Various barriers for policy adoption, such as lock-ins (See Table 3), can render the policy inefficient for addressing the policy goal. In addition, a high level of uncertainties and information asymmetry combined with an inability to manage and tolerate risks challenges the

policy maker ability to future-proof policies. Instead, these uncertainties pressure policy makers to prefer neutral policies with short time frames or flexible policy approaches to avoid policy failures.

2.4 Theoretical synthesis – Role of technological neutrality in designing effective innovation policy mixes

This chapter synthesises the findings from the literature review to discuss the main implications of technological neutrality for innovation policy design. The first subchapter combines the rationales and techniques for technological neutrality to discuss the impact of technological neutrality on three intermediate policy outcomes: (1) fairness, (2) technological goals, and (3) policy sustainability. Next, the second subchapter continues by describing a three-step process for innovation policy design from the perspective of technological neutrality.

2.4.1 The impact of technological neutrality on intermediate policy outcomes

The principle of technological neutrality provides a useful perspective for studying the impact of innovation policy on various technology-related policy outcomes. This subchapter connects a means-oriented view based on the techniques to operationalise technological neutrality (See Chapter 2.3.2) with an outcome-oriented view based on the rationales for technological neutrality (See Chapter 2.3.3) by utilising context-intervention-mechanism-outcome logic or so-called 'CIMO-logic' (Denyer et al., 2008). First, the interventions describe available tools to influence behaviour (Denyer et al., 2008), which are the techniques to operationalise technological neutrality in the context of this study. Then, the mechanisms are activated by the interventions and can potentially lead to the desired outcomes (Denyer et al., 2008). The goal of this model is to further the discussion on the impact of technological neutrality on policy outcomes by explaining potential mechanisms related to three categories of intermediate policy outcomes: (1) fairness, (2) technological goals, and (3) policy sustainability. These outcomes should be understood as intermediate policy goals to support the overarching objectives of innovation policy, such as national competitiveness and transformation goals (Edler et al., 2023), or economic and societal goals (Diercks et al., 2019). This follows similar logic for these three goals as Edler et al. (2023) who argue that it might be better to treat technology sovereignty as a means for achieving the ultimate policy goals instead of as an outcome itself. Figure 9 summarises these intermediate policy goals and discusses the related intervention-outcome logic to provide recommendations for policy makers.

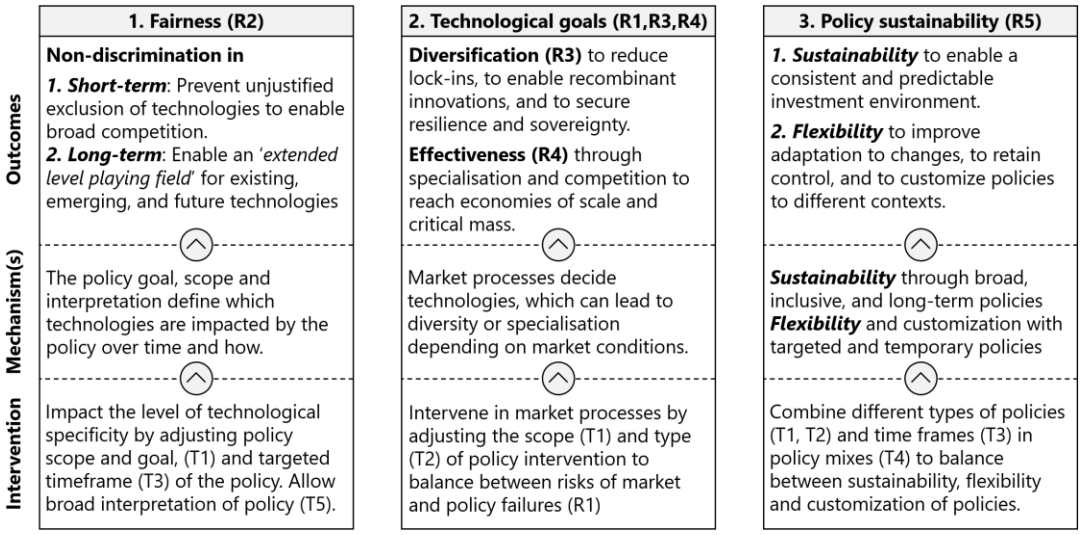

Figure 9. Summary of the three main implications of technological neutrality. Source: Own composition.

First, the intermediate goal of fairness relates to the first characteristic (See Table 5) and the second rationale (See Table 8) of technological neutrality to avoid unjustified discrimination of technologies. In short-term, the designed policy should not unjustifiably differentiate between existing technologies a priori (Briglauer et al., 2020; Foray, 2019), which can support broad participation and competition. Even if the policy is technology neutral at the time of enforcement, the neutrality of the policy can be challenged over time due to changing circumstances or unforeseen technologies that require new regulations (Greenberg, 2016). The concept of an '*extended level playing field*', where alternative technologies and companies can compete with more dominant actors (van den Bergh et al., 2006), provides a useful target for policy makers to consider fairness between existing, emerging, and future technologies. One of the main mechanisms influencing the non-discrimination is the level of technological specificity which defines how different technologies are positively or negatively impacted by the policy.

The policy makers can influence the potentially discriminatory effect of policy with various policy design choices. First, the policy scope can be modified by adjusting the level of policy goal and level of differentiation at a hierarchy level (See Figure 6), which impacts directly which technologies are impacted by the policy. Second, the policy makers can increase the stringency of a policy goal to narrow the range of eligible technologies, or decrease it to broaden this range, for example in the case of deployment policies (Briglauer et al., 2020). Third, the targeted timeframe for the policy and chosen approaches to influence policy sustainability can help to prevent "*technology blindness*"

(Craig, 2016) towards differences of existing and new technologies (Craig, 2016; Greenberg, 2016). Fourth, the policy makers can choose broader and more flexible approaches for the interpretation of policy goals which can enable a functionally equivalent or purposive treatment of different technologies to prevent unjustified non-discrimination (Craig, 2016).

The second main category of impacts include technological goals of technology diversification and sovereignty (See Rationale 3 in Table 8), and effectiveness through specialisation and competition (See Rationale 4 in Table 8). These partially conflicting goals of potentially short-term profit maximisation of specialisation and long-term benefits of diversity (van den Bergh, 2008) and technology sovereignty (Edler et al., 2023) force the policy maker to identify and nurture an optimal level of diversity and sovereignty based on the desired policy goals. In market economies, this balance between diversity and specialisation ultimately depends on the technology choices of market processes, which can lead to diversity or specialisation depending on market conditions and regulatory boundaries.

The policy makers have various tools available to intervene in the market-based selection processes if there are significant deficiencies and failures in the market processes compared to the risks of policy intervention (See Rationale 1 in Table 8). First, the policy scope and the level of technological differentiation (See Technique 1 in Table 6) can be adjusted to either narrow or broaden the range of technologies directly impacted by the policy. While defining the policy scope is the first step to set the targets of the policy, the type of policy intervention (See Technique 2 in Table 6) has a significant impact on the strength of the intervention (See Chapter 2.2.2). If there are little technology-related barriers for market-based change (See Table 10), technology choices can be delegated to market processes with highly automatic instruments by using outcome-oriented goals (See Characteristics 2 and 3 in Table 5). Furthermore, the market actors can be positively incentivised with various economic instruments to direct technological development to address important societal challenges. In contrast, the policy makers can enforce governmental technology choices with highly authoritative and minimally automatic policies if there are significant market deficiencies. However, the policy maker should still use technology specific and regulatory interventions sparingly as they increase the risks of inefficient discrimination and inflexibility.

The third intermediate goal of technological neutrality relates to the fifth rationale of technological neutrality to enable policy sustainability while maintaining options for flexibility and customisation (See Table 8). While the sustainability of a policy can be important for enabling a consistent and predictable investment environment, changing circumstances and emerging

technologies can challenge the effectiveness of excessively consistent and overinclusive policies (See Technique 3 in Chapter 2.3.2). To increase the sustainability in the context of technological neutrality, the policy makers are generally advised to use broad, inclusive, and long-term technology neutral policies (See Techniques 1 – 3). On the other hand, flexible and customized policies can help to adapt to changes, to retain control, and to customize policies to different contexts while increasing the risks of inconsistency and under-inclusiveness (See Technique 3). At the level of single policy instruments, the policy makers can increase flexibility by using temporary policies to plan the obsolescence of the policy and targeted interventions to ensure customization to different contexts (See Techniques 1 – 3). Even though the goals of sustainability and flexibility can be seen as partially conflicting targets, the flexibility of a policy complements the sustainability goal as the policy can endure short-term turbulence (Jordan and Moore, 2023). To balance between these goals of sustainability, flexibility, and customization, policy makers are often recommended to combine different types of policies in policy mixes (See Techniques 4). For example, broad and neutral high-level policies can be complemented with technology specific policies or decisions on the lower levels of governance.

In conclusion, technological neutrality and specificity play an important role in innovation policy through three intermediate objectives for innovation policy including (1) fairness, (2) technological goals, and (3) policy sustainability. The importance of each intermediate goal should be assessed against its ability to support the overarching goals of the broader policy mix. Once the necessity and the current status of each goal is understood, the policy makers should apply suitable policy design techniques to influence the mechanisms that drive the desired outcomes. The next chapter continues to discuss how these intermediate goals of technological neutrality should be seen in the broader context of innovation policy mix design.

2.4.2 Innovation policy mix design process from the perspective of technological neutrality

The principle of technological neutrality has various implications for effective design of transformative policy mixes as the neutrality or specificity can impact a wide range of intermediate policy goals (See Chapter 2.4.1). To understand the broader implications of technological neutrality on policy mixes, this study proposes a three-step process for innovation policy design from the perspective of technological neutrality (See Figure 10). First, the policy makers should take a broad perspective to understand and define the policy agenda, including overarching policy goals and general policy mix design (cf. agenda setting in Figure 4). This agenda setting provides important insights

for the more detailed policy mix design from the perspective of technological neutrality. Second, the policy makers should identify, define, and prioritise relevant intermediate goals related to technological neutrality. Third, the neutrality or specificity of a policy can be customised to support the desired goals by choosing techniques to operationalise technological neutrality in policy design. Finally, these intermediate goals and techniques should be customised based on the contextual factors that influence the effectiveness of technological neutrality and specificity. Even though the process is presented as a linear model, it is important to iterate between the different steps as necessary. Next, each of these steps is discussed briefly.

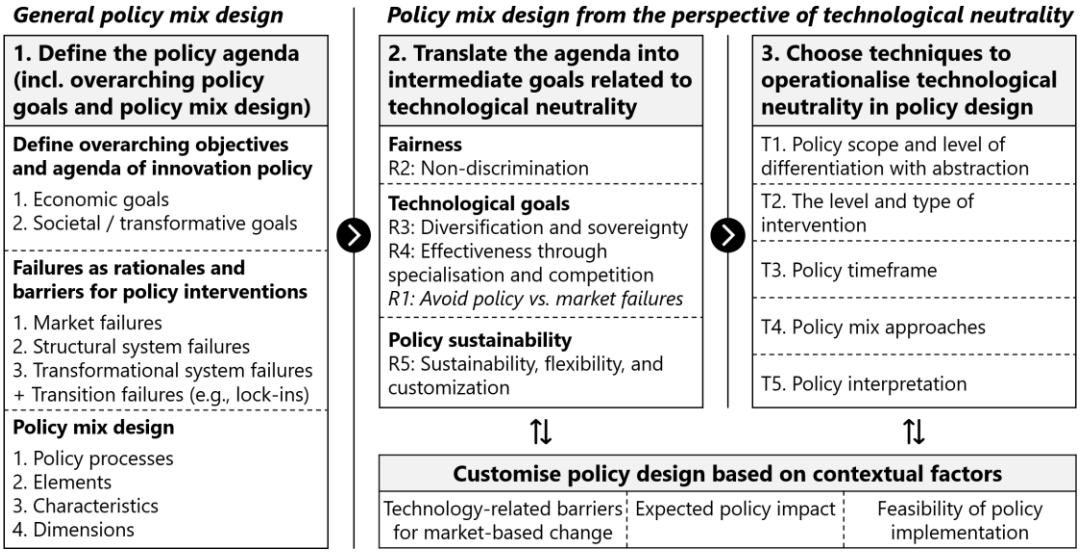

Figure 10. Three-step process for innovation policy design from the perspective of technological neutrality. Source: Own composition.

The first step of agenda setting should take a strategic perspective to identify and define high-level policy objectives and principal plans (cf. policy strategy in Figure 3). The purpose of this strategic agenda setting is to provide necessary direction for the more detailed policy design to improve consistency of policy mix elements. Furthermore, these strategies can be argued to support the creation of a shared vision to increase the sustainability of the policy (Jordan and Moore, 2023). During this stage, the policy makers should consider at least the following aspects of innovation policy. First, what are the overarching objectives and agenda of the policy, encompassing both economic and societal or transformative goals (See Chapters 2.1 and 2.2)? Second, what specific failures does the policy aim to address, and are there any barriers to policy interventions (See Chapter 2.1.2)? Third, what is the broader context of the policy mix, including its relationship with other related policies (See Chapter 2.2)? After this strategic perspective of the general policy mix has been formed, the policy maker will be better equipped to

address the more detailed questions related to technological neutrality or specificity of the policy interventions. The remaining steps of the process (i.e., steps 2 – 4) focus on the policy mix design from the perspective of technological neutrality.

Second, the policy makers should translate the policy agenda into relevant intermediate goals related to technological neutrality (See Chapter 2.4.1). At this stage, the policy maker should define how each of the intermediate goals is expected to contribute to the broader policy mix. The purpose is to assess the relevance of technological neutrality for reaching the strategic goals of the policy and to guide the selection of suitable policy design tools. Even though technological specificity has been described as an abstract design feature of policy instruments (See Chapter 2.2.1), this study recommends considering these goals also in relation to the policy mix design due to the broad implications of technological neutrality. Once the intermediate goals related to technological neutrality are identified, the policy maker can proceed to decide, how to achieve these intermediate goals.

Third, the techniques to operationalise technological neutrality (See Chapter 2.3.2) provide the basis for designing purposeful policy interventions to achieve the desired intermediate policy goals. The effectiveness of these interventions relies on the customisation of the policy intervention to influence the specific mechanisms that drive the desired outcomes (See Chapter 2.4.1). As these techniques focus on technological neutrality, the policy maker should simultaneously consider potential side effects of these techniques on general policy mix design.

Finally, the goals and techniques related to policy design should be customised based on the contextual factors that influence the effectiveness of technological neutrality and specificity (See Chapter 2.3.4). First, significant technology-related barriers for market-based change, such as path dependencies and lack of competition, might justify stronger and technology specific interventions as the market processes would be seen insufficient for achieving desired policy goals. Second, an anticipated considerable positive net impact of a policy can enhance public support to further legitimise the policy. This legitimisation can be essential for overcoming potential political barriers associated with technology specific policies. In addition to political barriers, the feasibility of a technology neutral or specific policy might be challenged by other factors, such as significant uncertainties, information asymmetries, and inability to manage risks.

In conclusion, this study proposes a three-step process for innovation policy design from the perspective of technological neutrality (See Figure 10). The

model connects a general policy mix design perspective based on innovation policy literature with a customised policy design tool for influencing the technological neutrality and specificity of the policy. The aim is to help policy makers to understand the implications of technological neutrality on policy mix design in the context of transformative innovation policy.

3 Research methodology

The main research design of this study is an embedded qualitative single-case study. The general research design of this study emphasises the approach of theory elaboration and abduction while including some traits of theory generation and induction (Ketokivi and Choi, 2014). This study incorporates such elements as it aims to elaborate the existing theories on policy mix design by applying the core concepts of policy mix in the context of technological neutrality and the Finnish innovation system. The first subchapter defines the general research design and methodology of this study, including an overview of the research process and rationale for the methodological choices. The second subchapter describes the process for collecting the empirical data of this study, which consists of interviews and Finnish parliamentary discussions. The third subchapter explains the data analysis approach of this study, which follows the principles of reflexive thematic analysis. Finally, the fourth subchapter evaluates the research design focusing on construct validity, internal validity, external validity, and reliability.

3.1 Research design and methodology

The main research design of this study is an embedded qualitative single-case study. The case study methodology was chosen as the research strategy because this study fulfils the three conditions defined by Yin (2009) that support the selection of case study method. First, this study addresses "how" and "why" questions, which are more explanatory and are likely to favour case studies, experiments, or histories (Yin, 2009). Second, experiments are excluded as the study has very limited ability to control the complex behavioural events of Finnish innovation system that are studied (Yin, 2009). Third, case study approach is preferred over histories as the study aims to understand contemporary events which are mainly accessible through observations and interviews (Yin, 2009). In addition, the qualitative approach is chosen because this study seeks to understand and interpret the meanings and contextual relevance of particular concepts (Yin, 2009).

This study was conducted as a single-case study focusing on the different actors of the Finnish innovation system. Even though multiple case studies can have substantial benefits over single case studies, single-case study approach can be justified under various circumstances (Yin, 2009). Yin (2009) define five rationales for single-case studies: "*(a) a critical test of existing theory, (b) a rare or unique circumstance, or (c) a representative or typical case, or where the case serves a (d) revelatory or (e) longitudinal purpose*". This study includes elements especially from typical and revelatory cases. First, the Finnish innovation system can be argued to have characteristics of a

typical case which can provide informative learnings for the policy makers of similar countries. For instance, the innovation system of Finland has been studied as part of various innovation policy studies related to transformative policy mixes (Kivimaa et al., 2023), innovation policy mixes (Vītola, 2015), and national innovation system as a policy program (Alaja and Sorsa, 2020). Second, the revelatory nature of the study relates to the access to quite unique data on technological neutrality in the Finnish innovation system. The combination of interviews of high-level policy makers, innovation system actors, and company representatives with parliamentary discussions can reveal insights that have not been previously identified. As Gustafsson (2017) argue, the single case study approach can enable a deeper understanding of the topic and a rich description of the studied phenomenon as it enables higher focus on the particular case.

The embedded case study was chosen over holistic design as the various subunits of the analysis (e.g., technology companies, regulators, and public financing agencies) have an important role on the larger case context (i.e., the Finnish innovation system) (Yin, 2009). The analysis of these sub-units can enhance the insights on the larger case context by allowing the examination of the studied phenomena in an operational detail (Yin, 2009). In addition, the embeddedness can improve the flexibility of the study as the analysis of subunits can help to refocus the study by providing new opportunities (Yin, 2009). This study aims to mitigate the risks of ignoring the holistic aspects of the case and excessive focus on sub-units (Yin, 2009) by using an iterative theory elaboration approach to reflect findings on the relevant theories.

The general research design of this study emphasises the approach of theory elaboration and abduction while including some traits of theory generation and induction. First, theory elaboration refers to a mode of case research which seeks to create theoretical insights by using general theory to approach an empirical context (Ketokivi and Choi, 2014). This study incorporates such elements as it aims to elaborate the existing theories on policy mix design by applying the core concepts of policy mix in the context of technological neutrality and the Finnish innovation system. To meet the first duality criterion for case studies (i.e., situational groundedness), the data analysis (See Chapter 3.3) is based on categories ultimately grounded in the empirical data while being guided by theoretical considerations (Ketokivi and Choi, 2014). This situational groundedness is combined with an effort to go beyond the specific empirical setting to attain a more generalized theoretical insight via abstraction (Ketokivi and Choi, 2014). To achieve generality, this study uses abstraction to interpret contextual idiosyncrasies to elaborate existing concepts and categories which is typical for theory elaboration studies (Ketokivi and Choi, 2014).

This study conducts theory elaboration through two of the three main implementation approaches and related tactics as defined by Fisher and Aguinis (2017). First, construct specification is used to identify new and refine existing theoretical constructs to improve the alignment of theories with the empirical reality (Fisher and Aguinis, 2017). This approach is used to improve the applicability of policy design theories related to the principle of technological neutrality, that has not been fully considered in the current policy design theories. Second, structuring is used to elaborate theoretical relations between constructs by either explaining underdeveloped relations or by identifying new relations (Fisher and Aguinis, 2017). This study uses structuring approach to improve the understanding of the relations between the different building blocks of policy mixes, as these relations require further attention (Rogge and Reichardt, 2016). To identify and study these relations, the analysis of the empirical data is divided into three main topics, which guide the analysis towards significant themes while retaining flexibility and groundedness in the empirical data. As a result, the aim of this study is to help policy makers to understand the role of technological neutrality in policy mixes for which there are no clear theories that could be utilised.

Second, the theory generation, also known as inductive case study, seeks to generate theories that derive from exploration focusing on empirical data (Ketokivi and Choi, 2014). This theory generation perspective is strongly present in the empirical analysis related to the principle of technological neutrality which has remained undertheorized (Puhakainen and Väyrynen, 2021). Eisenhardt (1989) argue that theory building from case studies can be appropriate in these circumstances as it helps to create novel theories when existing theories might be inadequate. This inductive focus is emphasised at the early stages of data analysis where explanations are derived from the empirical data. Overall, the different case research approaches should be understood as ideal types instead of mutually exclusive options as Ketokivi and Choi (2014) note.

The overview of the full research process is presented in Figure 11. The process aims to enable the simultaneous investigation of theory and the empirical context in a balanced way as it is required for successful theory elaboration (Ketokivi and Choi, 2014). These iterative matching processes, such as systematic combining, enable matching theory with reality and redirecting the data collection towards new discoveries when necessary (Dubois and Gadde, 2002). Eisenhardt (1989) promotes a similar view that iterative processes, such as overlapping data collection and analysis, and comparison with literature, can reveal valuable refinements for data collection and enhance the theoretical level of the case studies.

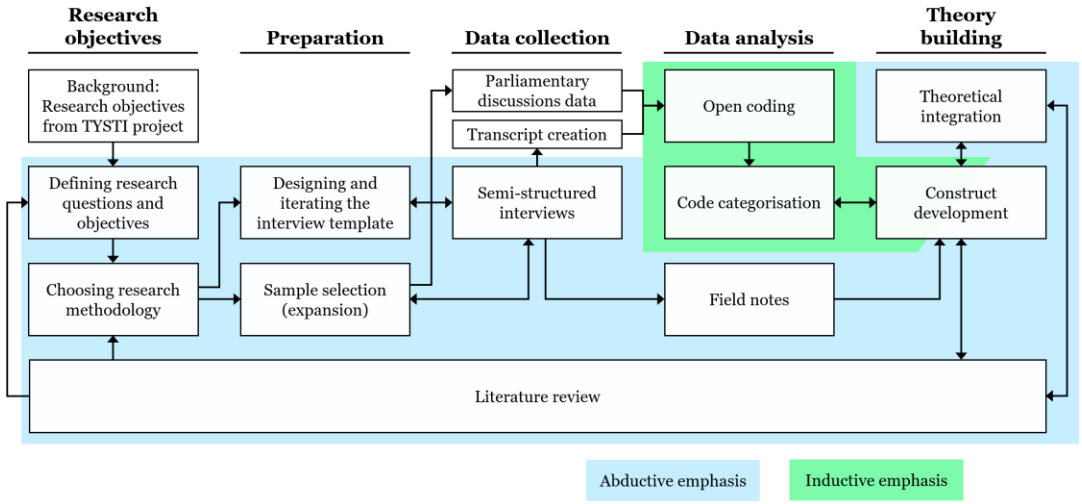

Figure 11. Overview of the research process. Adapted from Serna-Guerrero et al. (2022).

The research process (See Figure 11) started by defining the research questions (See Chapter 1.2) based on the main objectives of the TYSTI project (See Chapter 1.3) and an initial literature review. These research questions guided the choice of research methodology and design. In the next phase, initial theoretical sampling and interview template were designed according to the research methodology. During the following data collection phase, the initial sampling and interview templates were iterated according to the new findings from semi-structured interviews. In addition to interviews (See Chapter 3.2.1), parliamentary discussions data were obtained (See Chapter 3.2.2) to complement the empirical data. The transcripts of the interviews and parliamentary discussions data were analysed with an inductive thematic coding approach. In the beginning, open coding and inductive code categorisation were used to ensure data groundedness. In the following phase of theory building, construct development and theoretical integration are further developed based on the inductive categories of codes. In alignment with theory elaboration practices, existing theories are used to enhance the constructs to enable matching theory with reality. The next subchapters will describe the data collection and analysis processes in more detail and evaluate the research design.

3.2 Data collection

This chapter describes the process for collecting the empirical data of this study, which consists of interviews and Finnish parliamentary discussions. The first subchapter describes the main data collection process of this study, involving theoretical sampling and semi-structured interviews to obtain data

from 31 informants. The second subchapter describes the process for collecting data from Finnish parliamentary discussions related to technological neutrality to complement the interview data. Finally, the third subchapter provides an overview of the full sample consisting of the interviews and parliamentary discussions.

3.2.1 Data collection – Interviews

This study uses theoretical sampling as the main data collection process. Theoretical sampling refers to an iterative data collection process for theory generation where data is collected, coded, and analysed simultaneously (Glaser and Strauss, 2010). The adaptive process is controlled by the emerging theory as the researcher continuously decides what to collect next during the process (Glaser and Strauss, 2010). The initial sampling decisions are guided by general perspectives, subjects, or problem areas instead of predetermined theoretical frameworks (Glaser and Strauss, 2010). Similarly, the reflexive thematic analysis (TA) used for the data analysis highlights the importance of flexibility and iterations, even though reflexive TA emphasises more the role of a subjective researcher in interpreting the data (Braun and Clarke, 2022).

This study identified various actors of the Finnish innovation system as initial categories to be studied, even though the exact relevance of them for this study was not known as argued by Glaser and Strauss (2010). These initial sampling decisions were guided by the theoretical relevance of the categories as suggested by Glaser and Strauss (2010). This study uses theoretical sampling to balance between the benefits and challenges of similarities and differences. Regarding differences, the study started by including different types of dissimilar groups, such as actors from the public and private sector, to increase the generality of the findings, encourage discovery (Glaser and Strauss, 2010), and to address the complexity of policy mixes. The high-level comparison of these dissimilar groups can provide valuable insights from different viewpoints which can increase the generality of the theory and likelihood of finding strategic differences (Glaser and Strauss, 2010). Second, the study included also more similar groups inside the public and private sectors (e.g., different types of companies). The comparison between these more similar groups helps to identify previously undiscovered findings while supporting the verification of the findings (Glaser and Strauss, 2010). Furthermore, the included informants from both public and private sector have some similarities in their operating sectors to increase the likelihood of identifying strategic differences and similarities.

The initial categories were elaborated during the process in various ways as new knowledge emerged to maintain theoretical sensitivity. First, additional key categories and informants were identified based on the emerged findings and recommendations from the informants. Second, the sample of parliamentary discussions (See Chapter 3.2.2) was added to the study after conducting approximately two thirds of the interviews as the importance of legislators in the context of this study were highlighted by various informants from public and private sector. Third, the categorization of firm types (See Table 12) emerged during the process, as similarities between different firms were identified during the process.

Another important aspect of the data collection process is how many groups are needed for each category and how much data should be collected for each group, which relates to theoretical saturation and the depth of theoretical sampling (Glaser and Strauss, 2010). First, *theoretical saturation* refers to a situation when no additional data is found to develop the categories increasing the empirical confidence (Glaser and Strauss, 2010). It is important to note, that this process focuses on the saturation of the categories without any predetermined number of required informants or groups.

Second, reaching saturation requires considerations on *the depth of theoretical sampling*, which refers to "*the amount of data collected on a group and a category*" (Glaser and Strauss, 2010). The focus is still on the saturation of the studied categories, as theoretical sampling does not require full coverage of the studied groups (Glaser and Strauss, 2010). Even though theoretical sampling aims to saturate all studied categories, Glaser and Strauss (2010) highlight the importance of focusing on saturating the core categories as completely as possible. This focus enables a deeper development of the core categories with the most explanatory power, as the excessive saturation of less relevant categories should not divert necessary resources away from core categories (Glaser and Strauss, 2010). This study identified policy strategies and related fairness (See Chapters 4.1.1, 4.2.1, and 4.2.2) as the core categories which were saturated the most during the study. In addition, the other categories, which emerged later in the study, were saturated to a level, when the marginal improvements became small as suggested by Eisenhardt (1989).

However, theoretical saturation is partially challenged in the context of reflexive thematic analysis (TA), as approaches for data saturation can be argued to be subjective and incapable of providing definite answers for sample sizes (Braun and Clarke, 2021). As reflexive TA highlights the importance of data interpretation to uncover non-obvious meanings in data, new insights can be always developed from the data with additional analysis and reflection

(Braun and Clarke, 2021). Instead of assuming data saturation and non-existence of new data, Braun and Clarke (2021) argue that other concepts, such as information power, might be more relevant approaches for discussing samples. Therefore, this study acknowledges the challenges of data saturation and focuses on discussing next how the selection of informants supports the collection of meaningful data with high information power.

The key criterion for selecting informants for this study was to create a sample of numerous and highly knowledgeable informants who can provide diverse perspectives on the studied topic (Eisenhardt and Graebner, 2007). The set of interviewees includes a broad range of actors in the Finnish innovation system from private and public sector as well as innovation system experts (See Figure 13). This aims to provide important insights of the Finnish innovation system from policy making to research and innovation activities of companies. The sample includes informants at different hierarchy levels with the focus on top level management (e.g., C-level executives) to ensure highly knowledgeable informants related to innovation activities. Regarding technological sectors or industries, the study focused on areas of emerging technologies, such as climate technologies and AI, because they are often targeted by innovation policies. However, the sample also includes informants from traditional industries, such as basic materials, which are partly disrupted by emerging technologies and provide different insights on the impact of innovation policy. Even though the sample includes mainly single informants from each organisation, this study aims to reduce related risks, for example, by comparing findings between similar groups.

The final sample includes 31 interviews as presented in Table 11. The list includes the identifiers of the informants which are used later in the study to identify the informants. The informants from interviews are identified based on the unique combination of the group identifier and an upper case letter (e.g., Firm A or Policy maker B). In contrast, the data from the parliamentary discussions is identified based on the document ID of the parliamentary discussion as defined in Appendix D (e.g., PTK 43/2015/2). The duration of the interviews ranged between 28–83 minutes with typical interviews ranging between 40–70 minutes. All interviews were conducted during a single session except for a single interview that was conducted in two separate sessions (Innovation system expert A).

Table 11. List of interviews.

Identifier		Title	Company description	Length [min]
Firm	A	CTO	Listed industrial goods company	59
	B	VP of R&D	Listed industrial goods company	34
	C	Head of Business Unit	Listed industrial goods company	61
	D	Director of R&D	Listed basic materials company	54
	E	Process Manager	Listed basic materials company	57
	F	Co-Founder	Heavily funded AI / software company	61
	G	CTO	Deep tech startup	60
	H	CEO	AI / Software startup	64
	I	Chairman	Heavily funded AI / software company	28
	J	CEO	AI / Software startup	42
	K	Co-Founder	Heavily funded deep tech company	46
	L	Project manager	Service provider	54
	M	Partner, Technology	Service provider	59
	N	CEO	Pre-revenue climate tech company	43
	O	CEO	Heavily funded, pre-revenue climate tech company	56
	P	Public Relations Manager	Pre-revenue climate tech company	66
	Q	VP, Business Development	Heavily funded, pre-revenue climate tech company	60
Innovation system expert	A	Partner	Private sector funding entity	19+48
	B	CEO	Private sector funding entity	49
	C	Board professional	Technology sector	59
Policy maker	A	Senior official	Ministry	30
	B	Senior official	Ministry	54
	C	Senior official	Ministry	63
	D	Member of Parliament	The parliament	58
Public funding officer	A	CEO	Public sector funding entity	38
	B	Senior official	Public sector funding entity	63
	C	Analyst	Public sector funding entity	61
Scientist	A	Research Director	Research institute	44
	B	CEO	Research institute	58
	C	Research Professor	Research institute	58
	D	University Lecturer	Research institute	83

The theoretical sampling for firms resulted in 17 firms (one informant each) covering a broad range of firm types, business sectors, and functions. Table 12 presents the overview of the company sample and some of the main comparison groups used during the study. These firms include both dissimilar and similar companies to balance between discovery and verification of the results as discussed earlier. One of the groupings that provided valuable differences was the firm type. The firm types identified in this study are based on the stage of the company (e.g., pre-revenue or established) combined with

an indicative revenue growth rate and financial risk level (e.g., indebtedness or profitability). This study covers different firm types from heavily financed pre-revenue startups to stable publicly traded companies, which increases generalisability of the findings by providing insights on a broad range of actors in the Finnish innovation system. This grouping helps to understand the innovation processes as well as the implications of various innovation policies which are typically differentiated between company sizes. The included firms represent various business sectors from basic materials to software and emerging technologies, which is crucial as the business fundamentals vary from sector to another. These include different technology sectors from service and software to highly capital-intensive sectors requiring physical production facilities, such as various climate technologies. In addition, the interviewees were included from different functions to reveal potential differences. The different functions provided some additional insights, even though the results were quite comparable as most interviewees were high-level executives who had broad perspectives on the company operations.

Table 12. Overview of company sample. Design adapted from Hoppmann et al. (2013).

Category	**Group**	**Firm**																**n**
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	
Firm type	Fast growing loss-making or indebted growth companies						x	x	x	x	x	x							6
	Fast growing service company												x	x					2
	Pre-revenue, heavily financed startup														x	x	x	x	4
	Stable publicly traded company	x	x	x	x	x													5
Sector	Basic materials				x	x													2
	Climate technology														x	x	x	x	4
	Emerging technologies / Deeptech, other							x				x	x						3
	Industrial goods	x	x	x															3
	Software / AI						x		x	x	x			x					5
Function	General Management / Strategy			x					x	x	x	x			x	x		x	8
	Production / Operations					x							x						2
	Research and Development / Technology	x	x		x			x						x					5
	Strategic Marketing / Public Relations						x										x		2
Sum																			**17**

The theoretical sampling for the representatives of public sector and innovation system experts resulted in 14 informants covering innovation system experts, policy makers, public funding officers, and scientists (See Table 13). This combination provides an overview of the main public actors of the Finnish innovation system by focusing on highly knowledgeable senior officials. The policy or business sectors of these individuals were chosen to provide counterparts for the major technology sectors of private actors, such as

climate technologies and AI. This similarity of the sectors was chosen to compare and triangulate the views of public and private stakeholders on the relevant themes of the study.

Table 13. Overview of the expert and public sector sample. Design adapted from Hoppmann et al. (2013).

Category	ID	Description
Innovation system expert	A	Partner at a Private Sector Funding Entity
	B	CEO at a Private Sector Funding Entity
	C	Chairman at a Listed Technology Company
Policy maker	A	Senior Official at a Ministry
	B	Senior Official at a Ministry
	C	Senior Official at a Ministry
	D	Member of Finnish Parliament
Public funding officer	A	CEO at a Public Sector Funding Entity
	B	Senior official at a Public Sector Funding Entity
	C	Analyst at a Public Sector Funding Entity
Scientist or government officer at a public research institute	A	Research Director at a Research Institute
	B	CEO at a Research Institute
	C	Research Professor at a Research Institute
	D	University Lecturer at a Research Institute

The empirical data from the 31 informants was collected by conducting semi-structured interviews. This qualitative approach with semi-structured interviews was chosen for this study as semi-structured interviews provide flexibility to explore emerging topics in more detail as the interview proceeds (Saunders et al., 2009, p. 324). This type of exploration is important for studies with an interpretivist epistemology (Saunders et al., 2009, p. 324), such as this study, which follows the principles of reflexive thematic analysis highlighting the role of data interpretation (See Chapter 3.3).

The interviews were conducted by using interview guides with a list of themes and questions that were customised for each interview (Saunders et al., 2009, p. 320). The interview questions of the guide focused on understanding the individual cases as recommended by Yin (2009, p. 87), which supports the later analysis to generalise findings across multiple cases and at the higher levels of the entire study and policy recommendations (Yin, 2009, p. 87-88). More specific questions were used during the interviews when necessary to customise the questions for specific interviewees. Furthermore, higher-level questions were cautiously used in some cases when the interviewee was considered highly knowledgeable on wider dynamics of the innovation system.

The themes and questions of the interview template provided direction for the interviews while leaving space for additional questions and omitting of

specific questions to explore relevant themes that emerged during the interviews. Even though the overarching themes for the interviews remained mainly the same (e.g., technology selection processes, and the impact of innovation policy), these themes and especially the questions were customised to account for differences in the organisational contexts (Saunders et al., 2009, p. 320). Before each interview, publicly available information on the informant and the organisation (e.g., company websites and reports) were studied to customise interviews for the specific contexts, similar to Hoppmann et al. (2013). For instance, the interviews of the private actors emphasised aspects of technology development processes, whereas the interviews of public actors focused on the perspective of policy makers. Furthermore, the interview guide was developed iteratively during the study, when additional insights were gathered from the interviews and data analysis. This continuous improvement of the interview guide and flexible data collection methods were chosen to enable the analysis of emerging themes and account for the specificities of different cases (Eisenhardt, 1989). Appendix C provides an example of one interview guide. In addition to traditional questions, the study utilised frameworks of innovation policy instruments based on the taxonomy by Edler and Fagerberg (2017) and different technology foresight methods to support the discussion in some interviews, if the interviewee did not otherwise discuss relevant themes (See Appendix C).

In practice, the interviews were mainly conducted as online interviews with video connection in addition to few interviews by phone or face-to-face. The interviews were conducted during a three-month period between May 8th and August 8th, 2023. The duration of the interviews ranged from 28 to 83 minutes with typical interviews ranging from 40 to 70 minutes per interviewee (See Table 11). All interviews were conducted during a single session except for one interviewee who was interviewed in two separate sessions (Innovation system expert A).

All interviews, except for a single interview (Firm B), were conducted by at least two interviewers to enable one interviewer to focus on leading the interviewing process while the other one supported the interview. In addition to field notes, all interviews were audio- (phone and face-to-face interviews) or video-recorded (online) to enable accurate transcripts and focus on the interview process. After the interviews, all the 32 interviews from 31 participants were transcribed by a service provider and reviewed for accuracy by the interviewers. These transcripts together with Finnish parliamentary discussions data were imported to qualitative data analysis software (Atlas.ti) for data analysis.

Furthermore, ethical aspects have been considered for data collection. First, the study aims to protect the privacy and confidentiality of the participating informants or organisations, for instance, by not naming the participants (Rashid et al., 2019) due to potential sensitivity of the topics. Second, the participants have been informed about the study and their role in the research by delivering information sheet of the research project (Rashid et al., 2019). Third, each informant was asked for their informed consent to participate in the study and for the recording of the interview by delivering a consent form (Rashid et al., 2019) and confirming the consent in the beginning of the interview. Finally, the interviewees were given a chance to ask any questions related to the study before the start of the formal interview.

3.2.2 Data collection – Finnish parliamentary discussions in 2015 – 2023

This study includes data from Finnish parliamentary discussions related to technological neutrality to complement the interview data. These parliamentary discussions improve the sample by providing important insights about policy processes and rationales related to technological neutrality and governmental technology decisions. The combination of interview data from private and public actors with the parliamentary discussions provides a unique sample for analysing policy challenges and approaches in various policy context.

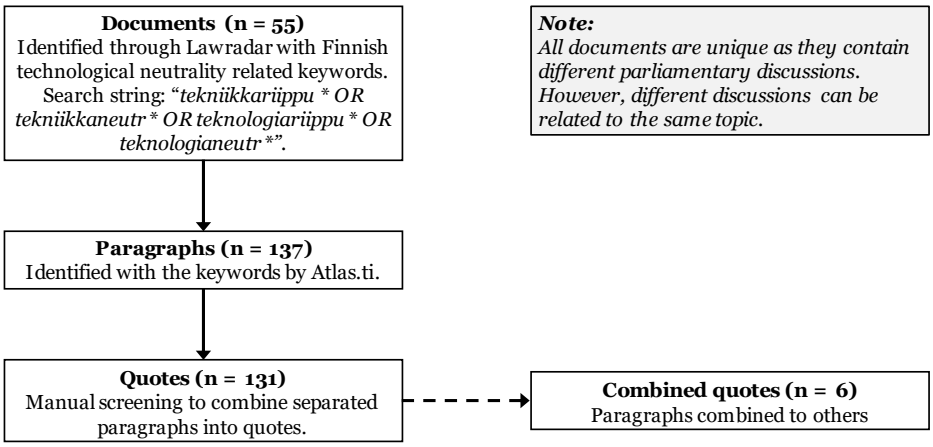

Figure 12. Data collection process for the data sample related to parliamentary discussions.

The overview of the data collection process for the Finnish parliamentary discussions is presented in Figure 12. First, the Lawradar service of University of Turku[2] was used to collect the research data related to Finnish parliamentary discussions (Data accessed on July 28th, 2023). The service includes

[2] Available at: https://lakitutka.fi/

records of the Finnish parliamentary discussions related to drafting of a law since 2015. The data was filtered with the Finnish keywords related to technological neutrality (”tekniikkariippu* OR tekniikkaneutr* OR teknologiariippu* OR teknologianeutr*”) which resulted in 55 documents from the available 6157 documents (0,9%). Second, the relevant sections of the documents (n = 137) were identified with the same keywords in a qualitative analysis software (Atlas.ti). Third, the paragraphs were manually screened to combine paragraphs into individual quotations (n = 131) for data analysis. The final sample consists of 55 documents with a total of 131 quotations from 61 Members of Parliament from 9 political parties (See Table 14). The full list of parliamentary discussions is presented in Appendix D. The data from the parliamentary discussions is identified based on the document ID of the parliamentary discussion as defined in Appendix D (e.g., PTK 43/2015/2).

Table 14. Data sample overview.

Sample	**n**
Documents	55
Members of Parliament	61
Parties	9
Quotations	131

The sample contains a broad range of topics, including 42 distinct topics (e.g., related to the preparation of a specific law) and 13 follow-up discussions on the same topics (See Table 15). Technological neutrality has been mentioned in various contexts with the most discussed topics being transport and traffic (n= 21), energy (n=13), and construction and environmental requirements (n = 6). Many of these topics relate to sustainability transitions, such as policies for renewable energy and alternative fuels, which often involve technology-specific policies making those a natural arena for discussions on technological neutrality. Besides energy policy (Sandén and Azar, 2005), the topics include other traditional technological neutrality related themes, such as copyright (Craig, 2016), telecommunications (Briglauer et al., 2020), and legislation more generally (Hildebrandt and Tielemans, 2013). In addition, the importance of technological has been highlighted also in national security related laws and the selection of strategic government investment areas (see “*State's Flagship Initiatives*”). The discussion on the strategic choices relate to the concerns if the state is the right entity for “picking winners” (See Quotation 31 in Table 19).

Table 15. Main topics of the parliamentary discussions.

Main topic of the discussion	n	unique
Construction and Environmental Requirements	**6**	**4**
Copyright	**3**	**2**
Criminal Law, Consumer Protection and Civil Rights	**4**	**4**
Instant Loans	1	1
Means of Payment	1	1
Remote Participation in Savings Banks and Mortgage Associations' Meetings	1	1
Telemarketing	1	1
Energy	**13**	**9**
Environmental Regulation	2	2
Renewable Energy Subsidies	8	5
Taxation	3	2
National Security	**2**	**1**
State's Flagship Initiatives	**1**	**1**
Telecommunications	**5**	**3**
Transport and Traffic	**21**	**18**
Distribution, Subsidies, and Taxation of Different Vehicle Power Sources	13	11
Railway traffic	1	1
Taximeter	3	3
Vehicle Purchase Subsidies	4	3
Total	**55**	**42**

The data sample consists of Finnish parliamentary discussions in 2015 – 2023 (See Table 16). Technological neutrality has been mentioned in the discussions between four to ten times per year during the full years of the sample (2015-2022). The number of discussions has remained quite stable over the years with the peak during 2017, when various policies were prepared related to energy, telecommunications, and transport and traffic. The main topics of the discussions have remained also quite similar throughout the years, even though there has been some natural variance depending on the prepared laws.

Table 16. Number of parliamentary discussions by topic and year.

Main topic	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Construction and Environmental Requirements	1		4			1					6
Copyright									2	1	3
Criminal Law, Consumer Protection and Civil Rights					1			2	1		4
Energy		2	1	5	3			1	1		13
National Security					2						2
State's Flagship Initiatives		1									1
Telecommunications				2			3				5
Transport and Traffic		1		3	1	5	3	5	2	1	21
Grand Total	**1**	**4**	**5**	**10**	**7**	**6**	**6**	**8**	**6**	**2**	**55**

The sample includes statements from 61 different members of parliament from nine different parties (See Table 17). The data sample covers speeches by all major Finnish parliamentary parties with more than two members of parliament during the sample years of 2014-2023 (See Table 17). As technological neutrality has been recognised by all major parties, the sample can be considered representative from that point-of-view.

Table 17. Data sample by parliamentary parties.

Political party	n	%
Blue Reform (*Siniset*)	3	5 %
Centre Party (*Keskusta*)	16	26 %
Christian Democrats (*Kristillisdemokraatit*)	1	2 %
Finns Party (*Perussuomalaiset*)	7	11 %
Left Alliance (*Vasemmistoliitto*)	4	7 %
National Coalition Party (Kansallinen *Kokoomus*)	13	21 %
Social Democratic Party (*Sosiaalidemokraatit*)	8	13 %
Swedish People's Party (*Ruotsalainen kansanpuolue*)	1	2 %
The Greens (*Vihreät*)	8	13 %
Total	**61**	**100 %**

3.2.3 Data collection – Overview of the full sample

The final sample of the study consists of 32 interviews and Finnish parliamentary discussions in 2014 – 2023 related to technological neutrality as

discussed earlier (See Figure 13). This combination of interviews and parliamentary discussions aims to provide a good overview on the Finnish innovation system and innovation policy related to governmental technology decisions. The full data sample was analyzed according to the data analysis process defined in Chapter 3.3.

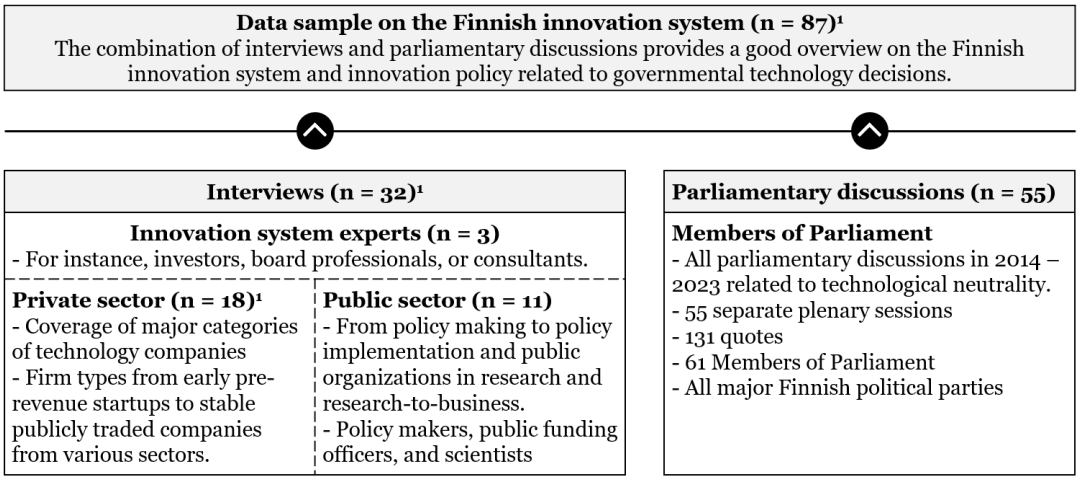

Figure 13. Overview of the research sample. 1. Includes two interviews from a single informant.

3.3 Data analysis

The data analysis approach of this study follows the principles of *reflexive thematic analysis* (TA) originally developed by Braun and Clarke (2006). At a basic level, TA refers to a robust qualitative analysis method for "*developing, analysing and interpreting patterns across a qualitative dataset*" (Braun and Clarke, 2022). This method includes flexible, yet systematic processes for coding data with the aim to develop themes (Braun and Clarke, 2022). The *reflexivity* of the method highlights that the "*subjective, situated, aware and questioning researcher*" has a major impact on the outcomes of the research (Braun and Clarke, 2022). Braun and Clarke (2019) argue that the subjectivity and reflexivity of the researcher should be understood as a resource, because qualitative data analysis includes active interpretation and meaning-making of context-bound data instead of discovering passively emergent truths from the data (Braun and Clarke, 2019). The more detailed methodological choices related to the application of reflexive TA are described below as the reflexive TA can be applied in various ways which can challenge the transparency without clearly defined assumptions (Braun and Clarke, 2019).

Braun and Clarke (2022) define four dimensions that impact the variations of reflexive TA. First, orientation to data can be more inductive (i.e., more

data-driven) or deductive (i.e., theory-driven) (Braun and Clarke, 2022). As described in Chapter 3.1, this study emphasises inductive approach in the data analysis process to encourage discovery and groundedness in data. In addition, some level of abductive analysis can be seen at the later stages of the analysis process to enable the elaboration of existing theories. Second, the focus of meaning can be semantic or latent (Braun and Clarke, 2022). Semantic focus explores meanings at the more explicit level instead of the more underlying or implicit levels in the latent focus (Braun and Clarke, 2022). This study uses a semantic focus on 1st order codes similar to the Gioia methodology (Gioia et al., 2013), which aims to accurately represent the language of the informants. The higher-level codes (e.g., 2nd order themes) involve a more latent focus, as the goal is to identify also potential underlying themes based on the semantic 1st order codes.

Third, the qualitative framework can be experiential (i.e., focus on people's own perspectives) or critical (i.e., exploring and clarifying the meaning related to the topic) depending on the aim of the analysis (Braun and Clarke, 2022). The analysis of this study emphasises the experiential approach which can be seen in the 1st order codes that "give voice" to the informants. However, some level of critical orientation was used especially later in the study and at the higher-level themes to ask critical questions on the findings (Braun and Clarke, 2022). This orientation aims to critically evaluate the justifications for technological neutrality as hidden intensions of the informants might guide their answers as identified during the study (See Chapter 4.1.2). Fourth, the theoretical framework can be realist, essentialist (i.e., capturing reality expressed in data) or relativist, constructionist (i.e., interrogating the reality expressed in data) (Braun and Clarke, 2022). Similar to the qualitative framework, this study started by emphasising the essentialist approach while using some constructive approaches later in the study to discover potential underlying assumptions. In conclusion, the data analysis of this study started by emphasising the typical inductive combination of semantic, essentialist, and experiential approaches, while incorporating some elements of a more abductive approach, including latent, critical, and relativist approaches, later in the analysis.

The data analysis process followed the six-phase process for reflexive TA as defined by Braun and Clarke (2022) and shown in Figure 14. Even though the process has six distinct phases, the process is not strictly linear and can include back-and-forth iterations to improve the analysis (Braun and Clarke, 2022). The first phase of familiarisation with the dataset included immersion, critical engagement, and note-making as suggested by Braun and Clarke (2022). The immersion in the data was started by being myself present in all interviews except Public funding officer B, which was conducted by two other

interviewers. The immersion was further supported by reading and re-reading the dataset to develop deep understanding of the dataset (Braun and Clarke, 2022) especially related to the data on Finnish parliamentary discussions which were obtained from public sources (See Chapter 3.2.2). Simultaneously, critical engagement with the dataset and my own interpretations were included to facilitate depth and distance in the engagement to critically assess my sense-making of the data (Braun and Clarke, 2022). Active note-making supported these two practices by forcing myself to explicitly describe my assumptions, which could be then critically assessed. This note-making process included notes on the individual data items (e.g., interviews) and related to the whole dataset to identify potential patterns which can help to develop a critical mindset (Braun and Clarke, 2022).

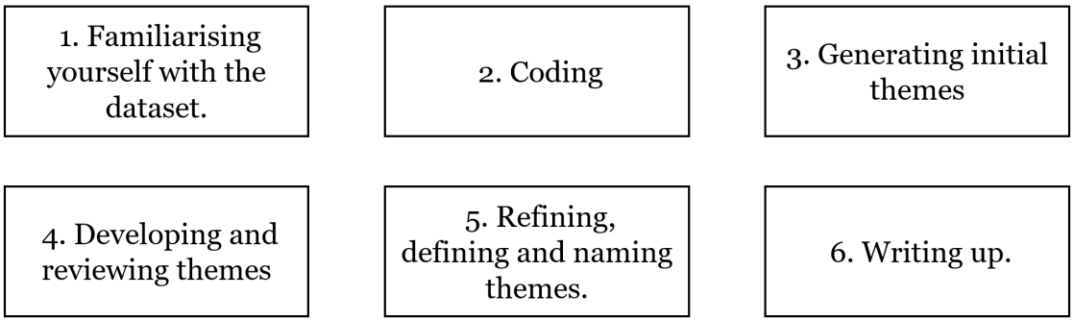

Figure 14. The six-phase process of reflexive TA (Braun and Clarke, 2022).

The second phase of coding started with the identification of 1st order codes from the dataset. These 1st order codes are defined as the smallest units of analysis in reflexive TA which capture relevant meanings related to the research questions (Braun and Clarke, 2022). As described earlier, the 1st order codes in this study focus on a more data-driven, inductive approach with semantic codes that "give voice" to the informants. These codes are presented as sentences with sufficient depth and detail instead of short single-word labels, so that the analysis would develop deeper insights on the dataset (Braun and Clarke, 2022). All data items were given similar importance in the coding process to capture repetition of meaning in the data by connecting codes to different data sources (Braun and Clarke, 2022). Even though all data items were analysed line-by-line, the coding focused on the data relevant to the research questions typical with reflexive TA in contrast with the more line-by-line approach of grounded theory (Braun and Clarke, 2022). The potential pitfalls of this more selective coding were countered with broad research questions which guided the analysis to include a broad coverage of the dataset. This approach supported the identification and inductive discovery of insights from the dataset. In practice, the 1st order codes were noted in a qualitative analysis software (Atlas.ti) where the codes were elaborated iteratively in multiple rounds. In the results section (See Chapter 4), the final 1st order

codes are presented together with representative quotations that demonstrate the sense-making process behind the 1st order codes.

Once the initial set of 1st order codes was developed, the generation of initial themes was started. In reflexive TA, themes are initially formulated by connecting codes and analytical observations around a central organizing principle to create collective, intricate meanings based on patterns in the dataset (Braun and Clarke, 2022). The formulation of the 2nd order themes shifts the focus from a semantic focus towards including a latent focus, as the goal is to identify also potential underlying themes based on the semantic 1st order codes. The 2nd order themes of this study focus on identifying relevant insights from the data instead of describing topic summaries. Topic summaries refer to summaries of everything that is said about a particular topic which can challenge the creation of shared meanings and useful conclusions (Braun and Clarke, 2022). However, these topic summaries are used in this study to organise broader research questions around relevant topics which are described as topics in the main subchapters of the results section (See Chapter 4).

After the development of initial 2nd order themes, 2nd order themes were organised into overarching themes which illustrate a more expansive conceptual framework that serves as the foundation for multiple themes (Braun and Clarke, 2022). The goal of these overarching themes is to provide structure and contextual information for the analysis (Braun and Clarke, 2022), which supports the connection of the findings of this study with the broader theoretical discussions and context. As these overarching themes are more abstract, theory-oriented names are used for these themes to connect the findings with relevant theory.

The development of the themes was an iterative process to avoid excessive attachment on the early themes which is reflected especially in the fourth phase of the process (Braun and Clarke, 2022). This phase focused on the review and assessment of the viability of the initial themes to identify potential improvements (Braun and Clarke, 2022). The process was supported with various visual thematic maps, which can support the discovery of relations between themes, the formulation of the overall story, and the relevance of each theme (Braun and Clarke, 2022). The themes and the visualisations were developed simultaneously with multiple versions, which helped to iterate some early data structures that were not able to provide sufficient insights on the research questions.

Finally, the fifth and sixth phase focused on refining the structure and analytic argument of the study (Braun and Clarke, 2022). This process of refining

themes and theme definitions can help to assess the clarity of the themes and overall story of the analysis (Braun and Clarke, 2022). During this phase, the themes, codes, and datasets were still revisited to ensure the groundedness of the analysis in data when necessary. The final data structure includes five levels which support the theoretical argument of this study (See Figure 15). This structure aims to ensure the groundedness of the arguments while contributing to the theoretical discussion on the role of technological neutrality in policy mixes.

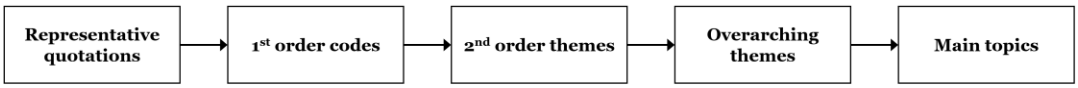

Figure 15. Data structure of the analysis from empirical data to overarching themes and main topics.

3.4 Evaluation of research design

The quality of empirical social research and case studies can be evaluated based on numerous different criteria and tests (Gibbert et al., 2008; Yin, 2009). This chapter evaluates the research design of this study against four criteria and tests, that are widely used for case studies, including (1) construct validity, (2) internal validity, (3) external validity, and (4) reliability (Gibbert et al., 2008; Yin, 2009). Next, each of the four criteria is defined and used to evaluate the research design of this study. Finally, interviewer and interviewee biases are assessed as potential sources of unreliability and invalidity.

Construct validity defines how accurately the conceptualised constructs reflect the actual concepts in the data and real world (Gibbert et al., 2008; Yin, 2009). It is especially important during the data collection phase to ensure that the study measures what is actually happening (Gibbert et al., 2008). This study has used various common tactics to increase the construct validity, including triangulation, establishment of chain of evidence (Gibbert et al., 2008; Yin, 2009), and review of constructs (Yin, 2009). First, triangulation and verification of the constructs are enabled in this study by using and comparing multiple sources of evidence (Yin, 2009), such as interviews, company reports, transcripts of parliamentary discussions, and government reports. Furthermore, the empirical findings are evaluated and discussed against the theoretical background in the results and discussions chapter (See Chapter 4) as part of the abductive theory elaboration approach. As the study involved only one informant per company, these other methods of triangulation were used to mitigate the risk of invalidity of the findings. Second, a chain of evidence has been established in the results section by connecting representative quotations to overarching themes with a levelled data structure (See

Table 18). Similar approach has been used also in literature review, for instance, for the characteristics of technological neutrality (See Table 5) and contextual factors (See Table 10).

Third, the initial constructs of the analysis have been continuously reviewed by and discussed with the instructors of the study and a peer thesis worker. Furthermore, I have presented different intermediate versions of the model for governmental technology strategies (See Figure 19) and the summary of the implications of technological neutrality (See Figure 9) to the international advisory board, project participants, and the steering group of TYSTI project for feedback (See Chapter 1.3). As a result of the feedback, the implications were clarified, the empirical model was simplified, and a three-step process for innovation policy design from the perspective of technological neutrality was introduced (See Figure 10).

Internal validity relates to the ability of the study to accurately explain and reason causal relationships between different events or variables (Gibbert et al., 2008; Yin, 2009). Internal validity is critical for this study as an explanatory case study (Yin, 2009), which aims to describe how technological neutrality influences policy mix design and its outcomes. Even though the multiple topics and themes included in the empirical study can create challenges with the depth of analysis, it was seen important to cover those topics to provide a meaningful contribution to policy design practices. To address these potential shortcomings, this study has used various techniques to increase the internal validity, such as clear research frameworks, theory triangulation (Gibbert et al., 2008), and logic models. First, theory triangulation and research frameworks, such as innovation policy mix concept (See Figure 3), have been used to compare the empirical findings to existing theories as part of the theory elaboration process. Second, this study uses logic models based on literature review, such as Figure 9, to improve the internal validity of the empirical findings.

External validity or generalisability refers to analytical generalisation of the empirical findings to formulate theory that is applicable to other contexts (Gibbert et al., 2008; Yin, 2009). Even though the generalisability of single case studies has been criticised in contrast to multiple case studies (Eisenhardt, 1989; Gibbert et al., 2008; Yin, 2009), various approaches can be used to increase the generalisability of single case studies (Gibbert et al., 2008; Yin, 2009). First, this study uses abductive theory elaboration approach to compare findings with theoretical literature from different contexts to increase generalisability (cf. Eisenhardt, 1989). Second, the embedded case study approach is used to balance between examination of operational detail and holistic aspects of the case (See Chapter 3.1). The generalisability

of the results is supported by the broad empirical data set consisting of 87 documents, that cover different technology sectors, company types, and actors of the Finnish innovation system (See Chapter 3.2). Furthermore, the rationale for the selection of the embedded single case approach for this study is discussed in Chapter 3.1, for instance, based on the revelatory nature of the study.

Fourth, *reliability* describes how likely it is that another researcher would arrive at the same insights and conclusions from the case study (Gibbert et al., 2008; Saunders et al., 2009; Yin, 2009) if they used the same case study protocol (Gibbert et al., 2008; Yin, 2009). This study uses various recommended approaches to increase the reliability of the study by improving transparency and replication with careful documentation (Gibbert et al., 2008; Yin, 2009), and by limiting interviewer and interviewee bias (Saunders et al., 2009). First, the research approach and methodology have been carefully documented in Chapter 3 to enable chain of evidence as discussed above related to construct validity. Second, the replication of the results is supported with a case study database (Gibbert et al., 2008; Yin, 2009) which consists of the interview transcripts, notes, relevant interview templates, and coding files for the empirical research. Regardless of these approaches to increase the reliability of this study, some sources of unreliability are likely to remain in this study as some subjectivity and reflexivity of the researcher is required for the meaningful interpretation of data as highlighted in reflexive thematic analysis (See Chapter 3.3).

Various interviewer and interviewee biases can limit the reliability and validity of a study (Saunders et al., 2009) in addition to previous limitations. First, the interviewer bias refers to sources of unreliability and invalidity based on the actions of the interviewer, such as the behaviour during the interview, biased interpretation of responses, and inability to create trust in the interviewee (Saunders et al., 2009). Second, the interviewee or response bias relates to the behaviour and responses of the interviewees which can be distorted, for instance, by unwillingness to reveal sensitive information, or by organisational pressure to answer in a specific way (Saunders et al., 2009). To address these potential biases and shortcomings related to the interview process, this study focused on thorough interview preparations to enable meaningful interview and to increase the trust between the interviewers and the interviewees (Saunders et al., 2009). The interview preparations and process included various recommended approaches, such as customisation of interviews based on publicly available materials, attentive listening, and neutral questions to avoid interviewer bias.

4 Results and discussion

This chapter presents the findings of the empirical research and compares the findings to relevant theories. This integrative approach was chosen for this abductive study to avoid repetition and to create clear connections between the empirical data and literature (Braun and Clarke, 2013, p. 257 - 258). First, the three identified main topics are discussed in their respective chapters: (1) policy maker competence, intensions, and perceived values of fairness in Chapter 4.1, (2) policy strategy and agenda for technology selection in Chapter 4.2, and (3) policy mix design in Chapter 4.3. Each of these main topic chapters begins by presenting an overview of the related overarching themes together with identified 2nd order themes (e.g., Figure 16). Accompanying tables for each overarching theme (e.g., Table 20) offer additional empirical data, enabling the reader to evaluate the evidence underlying the conclusions similar to Corley and Gioia (2004). Finally in Chapter 4.4, the overviews of the main topics and overarching themes are summarised into a theoretical model providing a strategic perspective for governmental technology choices (See Figure 19). Table 18 provides an overview of this data structure with related levels of analysis, structure of the chapters, and identifiers.

Table 18. Data structure. 1. x refers to a single digit number.

Level	Discussed in	Identifier[1]
1. Main topics	Chapters 4.1, 4.2, 4.3	Topic x, Tx
2. Overarching themes	Chapters 4.x.x (e.g., 4.1.1)	Theme x.x (e.g., T1.1)
3. 2nd order themes	Chapters 4.x.x.x (e.g., 4.1.1.1)	Numbers 1 – 4 under each overarching theme
4. 1st order codes	In relation to 2nd order theme	NA
5. Representative quotations	In relation to 1st order code	Quotations have unique numbers from 1 – 173 (e.g., Q95)

4.1 Topic 1. Policy maker competence, intensions, and perceived values of fairness.

Understanding the policy maker competence, intensions, and perceived values of fairness is important related to governmental technology decisions as the design of policy elements is an outcome of political and dynamic policy processes (See Chapter 2.2.1). Furthermore, the policy making processes play an important role in the application of technological neutrality, where information asymmetry between private parties and policy makers as well as political resistance can lead to inefficient policies (See Chapter 2.3.4). This

study identified two separate categories related to this main theme. First, the perceived values of fairness related to governmental technology decisions influence the policy makers preferences for deviating from neutrality principles and impacts their idea of a fair society. Second, the policy maker competence and understanding of hidden intensions create the basis for effective and transparent policy making. These two categories are discussed in their respective chapters including accompanying tables with identified 2nd order themes, 1st order codes, and representative quotations. Figure 16 presents an overview of the two categories and identified 2nd order themes.

T1.1. Perceived values of fairness related to governmental technology decisions
1. Fairness between technologies, implementation methods, and companies
2. Fairness between existing and emerging solutions
3. Fairness between regions
4. Preference for market-based or governmental selection of solutions

T1.2. Policy maker competence and hidden intensions
1. Competence to apply policy design features and principles in practice
2. Hidden intensions and readiness to deviate from shared principles, such as neutrality
3. Technological competence to regulate technologies

Figure 16. Overview of policy maker competence, intensions, and perceived values of fairness.

4.1.1 Theme 1.1. Perceived fairness in governmental technology decisions

Discussions related to different types of perceived fairness strongly emerged in various justifications for and against governmental technology interventions. However, the ideas of fairness varied between the informants leading to differing views on policy recommendations. This could pose important policy implications to consider the values of policy makers and relevant stakeholders when assessing their policy recommendations. This study identified four separate 2nd order themes related to this theme. First, fairness between technologies, implementation methods, and companies is a core goal of policy in the context of technological neutrality aiming to treat different actors with similar societal impact equally (e.g., see Characteristics 1 and 2 in Table 5). Second, fairness between existing and emerging solutions relates to the discussion should the government support the emergence of new solutions or protect the existing businesses (See Rationale 2 in Table 8). Third, fairness between regions concerns how the policy maker balances between the interests of different regions. This type of non-discrimination based on location is also part of the theoretical discussions on technological neutrality as demonstrated by the quotation from Fabra and Montero (2022, p. 669) in Table 8. Fourth, preference for market-based or governmental selection of solutions is part of a traditional discussion how strongly the policy maker

believes in the superiority of market decisions over government (See Characteristic 3 in Table 5). These four 2nd order themes are discussed in their respective chapters and presented together with 1st order codes, and representative quotations in Table 19.

Table 19. Data supporting interpretations of perceived fairness in governmental technology decisions (Q1 – Q34).

1st order code	Quotation ID and representative quotations
1. Fairness between technologies, implementation methods, and companies (Q1 – Q8)	
Government should not a priori decide the winning technologies, industries, or companies in RDI financing.	Q1: "*To my understanding, the government, per se, isn't deciding which companies or sectors, for instance, will do it. Instead, it's done precisely in a technology-neutral way […].*" (PTK 43/2015/2)
	Q2: "O*f course, such guidance [technology choices at a very detailed level] occurs every time a funding decision is made. But there's no a priori preference for any particular companies.*" (Public funding officer C)
	Q3: "*We were somewhat concerned about whether the state is really the entity picking the winning sectors. […] Private markets should always be the ones identifying the future success stories, and we should adapt to that."* (Public funding officer A)
	Q4: "*The activities there [in Korea's government support for companies] wouldn't withstand scrutiny under European ethical standards [such as EU anti-corruption legislation]. The way things are done on behalf of individual firms. In my opinion, they've done a remarkable job and truly elevated the country from obscurity to significant prosperity. […] But the power dynamics there also exhibit traits of oligarchy*." (Innovation system expert A)
Technologically neutral government policies should provide equal opportunities for all implementation methods that can be used to reach the policy goal.	Q5: "*[…] in a technology-neutral manner, ensuring that not only wind, solar, and CHP production but also other potential new technology forms can genuinely participate in the competition […].*" (PTK 49/2018/4)
	Q6: "*The question is about ensuring that all [clean, renewable energy sources] 'start on an equal footing'*." (PTK 117/2017/3)
	Q7: "*Indeed, it's a good principle that […] government shouldn't pick winners […]. When wanting to reduce emissions in passenger transport, government shouldn't choose the technology how emission reductions are achieved. Instead, it should be facilitated to be accomplished in various ways, and then see which one proves to be the best through competition.*" (Scientist B)
Application-specific standards can treat separate user groups of the same technology for same purpose differently depending on the application area.	Q8: "*One example that emerges now with the electrical definitions in place is that it inherently places electricity users in an unequal position. For instance, as an electric car user, a transport company can claim to be zero-emission because they purchase wind energy annually and drive on wind electricity, even if they don't drive exclusively when the wind blows. Someone else, in this context, is adjusting on their behalf. Meanwhile, hydrogen is more strictly regulated, requiring monthly matching with wind power, whereas an electric vehicle user can match it annually. This results in somewhat varied standards being imposed for different users.*" (Firm Q)
2. Fairness between existing and emerging solutions (Q9 – Q16)	
Technology neutral legislation should be inclusive of current and new implementation methods to prevent circumvention of the legislation.	Q9: "*The provisions of the Criminal Law are technically neutral […]. […] the proposal clearly extends the concept of a payment method to cover virtual currencies as well as electronic money.*" (PTK 43/2021/6)
	Q10: "[…] *there should be some form of technologically neutral legislation or something because on this side, they are, let's say, devilishly clever. They always find a new way, a new method. When interest was capped, an alternative method was devised. […] effectively circumventing the legislation. I slightly fear that we'll also see similar tactics with this marketing prohibition.*" (PTK 66/2018/10)

Policies based on existing industry boundaries can challenge equal treatment between emerging and existing technologies.	Q11: "*Our [product] is treated as if we were in the agricultural sector. Yet, our raw material is hydrogen. […] When considering its climate impact and the legislative framework regulating its emissions, this isn't part of the emissions trading sector. Instead, it's about agriculture […]. This is such a no man's land. […] We aren't affected by this regulation [hydrogen use in energy production]. Agriculture experts haven't thought of a hydrogen regulation yet because hydrogen isn't used in agriculture, except by us, which allows us to find a gap.*" (Firm O) Q12: "*Perhaps at this moment, we too, as a new technology, find ourselves in a situation, not necessarily falling through the cracks. But given that the government program did not mention carbon capture, even when climate neutrality is discussed […]. Hence, currently in Finland, we haven't had specific financial instruments that would directly address support for carbon capture businesses. There is an energy support which could relate to our operations […], but it can only finance specific purchases that focus on this energy transfer […]. So, in that sense, there have been some challenges with our first commercial plant.*" (Firm P)
The policy should not impose unreasonable impacts on existing investments.	Q13: "*In my opinion, transportation should treat different fuels and power sources technologically neutrally, meaning we shouldn't favour any particular fuel […]. Taxation should be fair [for vehicles using different power sources]. Most importantly, taxation should be predictable. […] a car is often the second-largest investment for many […], and making rapid changes now would have significant financial implications for many.*" (PTK 38/2019/6) Q14: "*[…] the recent carbon source regulation, which will ban waste incineration from 2040 onwards, is unfavourable. Many Finnish projects were reliant upon this, having planned long-term carbon capture from waste incineration. […] suddenly, the stance changes. […] 'we would not have […] planned a project on waste incineration if we would have known that you don't want such [projects]'.*" (Firm Q)
Policy instruments can favour mature or emerging solutions depending on the policy goal.	Q15: "*And when [competitive tender for renewable energy] is conducted in a technologically neutral manner, one must understand that those who already have the best efficiency and productivity will, of course, fare well in that competition.*" (PTK 49/2018/4) Q16: "*A viable alternative for a new renewable energy support system would be a technologically neutral competitive bidding procedure, which would have its own baskets for mature and emerging renewable energy forms. […] it could promote and increase the production of renewable energy in a technologically neutral manner.*" (PTK 31/2015/4)
3. Fairness between regions (Q17 – Q26)	
Policies should aim to consider regional prerequisites for market-driven operations.	Q17: "*It should also be noted that although we are discussing broadband services in sparsely populated areas, the current market-driven operator activities do not provide high-quality and sufficiently fast broadband services to many regions."* (PTK 64/2017/10) Q18: "*For instance, every major industrial country with prime contractors in major technology projects, have an extensive subcontracting chain from familiar companies, usually domestic. This often inadvertently creates connections easier to execute within their own chain than considering other member countries. Essentially, industrial policy aims to determine […], which countries are required for a large project, as they are known to be underfunded.*" (Public funding officer C)
Many EU-level R&D projects aim for fairness between countries by requiring participants from different countries which might lead to inefficiencies in project coordination.	Q19: "*[…] every EU project we've participated in seems, forgive me, highly inefficient. They're political, demanding representation from north, south, east, and west, with everyone doing as they please. […] There's an overwhelming amount of bureaucracy, and decision-making takes too long, requiring a larger coordinator which is a full-time job.*" (Firm E) Q20: "*[…] if we could accept that a specific country or a few countries take the leading role and all others simply pay, we probably would have reached a favourable semiconductor industry situation earlier. […] It's an equality principle rather than an equity one. In equity, the best gets [financing], whereas in equality, everyone receives the same. […] Industrial policy [at the EU level] strives for fairness, ensuring that large countries do not exploit their power to the detriment of smaller countries in the development of their industries.*" (Public funding officer C)

EU regulation dictates various national technology choices which might conflict with national interests.	Q21: "*One major influence has been EU legislation. Telecommunication regulation largely originates from the EU, which began to mandate technological neutrality at some point.*" (Policy maker A) Q22: "*The other is biogas, which is clearly a thorn in the EU's side, but for Finland, it's a flagship. There has been a persistent push [from Finland] for biogas within the EU, but with poor results. […]. However, the Commission has strongly decided to favour electricity and hydrogen as the primary propulsion methods.*" (Policy maker B) Q23: "*A message to our national government and also to the EU: 'move towards technologically neutral legislation'. The best results are achieved when we trust our innovators who solve issues with R&D efforts in Finland, the EU, Europe, and globally.*" (PTK 153/2022/5)
Policies promoting the use of domestic actors can create conflicting interests between the technology providers and funder when the expertise is already available elsewhere.	Q24: "*Of course, when reflecting upon the Business Finland funding criteria […], it strongly guides one to build that ecosystem here in Finland and utilize Finnish actors. Preferably, we would use international ones too, but there are specific conditions set by the funder. Unfortunately, Finland doesn't possess all the expertise we currently need.*" (Firm A) Q25: "*Occasionally, we face the fact that the best players for certain projects are not in Finland. But this is usually recognized, and then we will not pursue the Business Finland route. […] But understandably, accumulating Finnish expertise might not be the top priority for businesses, especially if it's already available or easily accessible elsewhere.*" (Firm D) Q26: "*Shouldn't the support for renewables rather focus on the development of domestic renewable energy production and simultaneously create new Finnish jobs?*" (PTK 121/2017/4)
4. Preference for market-based or governmental selection of solutions (Q27 – Q34)	
Governmental choices to support certain areas or technologies are seen necessary in practice and justified at early stages of innovation process.	Q27: "*Even though a small export-driven economy like Finland should naturally be a staunch supporter of the market economy, it doesn't mean we shouldn't make pragmatic choices, investing in certain things at specific times.*" (Scientist B) Q28: "*[…] we need to quite strongly guide our R&D funding, and I don't see that as conflicting with technological neutrality in any way.*" (Public funding officer C) Q29: "*[…] if we think about the value chain from knowledge to the customer, […] the state has a greater power, responsibility, and right to define things closer to the knowledge end, while on the customer end, the only acceptable examples relate to dual-use products […].*" (Innovation system expert C)
Governmental selection of winners or technologies is seen dangerous and instead the market should be allowed to operate freely.	Q30: "*On average, the state is quite poor at doing business. […] Funding various technologies based on our perception of which will succeed is risky since no one truly knows which will prevail.*" (Innovation system expert A) Q31: "*Representative is highly appreciative of these flagship projects and seems to trust, perhaps blindly, the government's ability to pick winners in the market, which usually might not be the most efficient way […] in a market economy. […] how will the ministry ensure that these flagship projects truly are the right areas of investment?*" (PTK 43/2015/2) Q32: "*[…] given that we operate in a market economy, winners shouldn't be chosen. Instead, we should let the markets function.*" (Policy maker B)
Strong arguments are required for governmental technology decisions.	Q33:"*A strong outlook is essential, when an area is raised to an active strategic decision-making level to set the scheme in motion. We need government entities and other stakeholders to believe it's sensible. Private investors should also be involved, as I wouldn't solely rely on subsidies.*" (Public funding officer A) Q34: "*NMT and GSM are good examples of the regulator eventually stating that we would move forward with a certain technology. It was chosen in a way where competition was enabled to lead to better results. […] it wasn't technologically neutral at all. Yet, decisions were made once the whole picture was taken into account.*" (Scientist B)

4.1.1.1 Fairness between technologies, implementation methods, and companies

Ensuring fairness between technologies, implementation methods, and companies is a core principle of policy making and technological neutrality. This

idea of neutrality aims to prevent discrimination of technologies or sectors in public processes, so that market forces are allowed to guide the allocation of investments (See Characteristics of technological neutrality in Table 5). Both the informants and members of parliament familiar with technological neutrality have widely recognized this aspect that the government *"should not pick winners*" and should provide equal participation opportunities for all applicable implementation methods. However, the informants have also raised some concerns where government policies have led to unequal treatment of different groups, for example based on application-specific standards.

It was considered important that the government should not a priori decide the winning technologies, industries, or companies in research, development, and innovation (RDI) financing. Even though individual governmental funding decisions can involve detailed technology selection between competing projects, it was seen important that the winning technologies or companies are not preferred already in the funding program design. This avoidance of governmental selection of winners was also justified with European ethical standards that would not allow the government to direct significant support to particular companies, similar to Korea's economically successful national technology programs (See Quotation 4).

Technological neutrality of government policies was seen as a good principle to provide equal opportunities for all implementation methods that can be used to reach the policy goal. For example, the Finnish competitive tendering system for renewable energy was stated to aim to allow different technology forms to genuinely participate in government support programmes (See Quotation 4) and to 'start on an equal footing' (See Quotation 6). This discussion especially relates to the outcome-oriented policy goal setting associated with technological neutrality which defines that the policies should primarily target outcomes instead of means (See Characteristic 2 in Table 5 and Chapter 4.3.2.3).

Government policies also include cases where different technology providers are treated unequally. For example, application-specific standards can treat separate user groups of the same technology for same purpose differently depending on the application area. For instance, different electricity users might be placed in an unequal position depending on their use case for electricity (See Quotation 8). Technology standards for electric cars allow users to match energy emissions on an annual basis, whereas hydrogen is more strictly regulated requiring monthly matching. This highlights the challenge of creating a fair and consistent policy mix when utilizing parallel policies for different application areas (e.g., see Chapters 2.3.2 and 4.3.2.2).

4.1.1.2 Fairness between existing and emerging solutions

Fairness between existing and emerging solutions is partly related to the previous discussion of avoiding discrimination of technologies and companies. However, it provides important context for balancing between the interests of technology providers with emerging and proven solutions (See Rationale 2 in Table 8). For instance, van den Bergh et al. (2006) argue that emerging technologies might require directed support to enable an '*extended level playing field*' where alternative technologies and companies can compete with more dominant actors. The empirical data supports this view for giving special consideration to the difference of emerging and dominant technologies by providing multifaceted insights from legislation, innovation funding, and deployment policies.

From legislative perspective, legislation should be inclusive of current and new implementation methods to prevent circumvention of the legislation. Especially in criminal law, it is found important that the laws apply similarly to the current as well as potentially emerging solutions. However, this '*future-proofness*' of legislation (cf. policy sustainability goal in Chapter 2.4.1) is challenged by '*devilishly clever*' actors who try to find new ways for effectively circumventing regulation (See Quotation 10). See Chapter 4.3.2.4 for findings on policy design considerations related to targeted policy time horizon.

Policies based on existing industry boundaries can challenge equal treatment between emerging and existing technologies. The policies may fail to recognize the specialties of emerging technologies, that operate outside the existing industry boundaries or between multiple industries, leading to under- or over-regulation. Firm O has been in a favourable position where all regulatory burden of hydrogen technologies does not apply to them as they are regulated according to their main product's industry, agriculture (See Quotation 11). In contrast, Firm P has faced challenges with lack of suitable governmental financial instruments as their technological solution does not fit into the industry boundaries of existing support programs (See Quotation 12).

In addition to acceleration of new emerging technologies, policies for sustainability transitions should consider how unsustainable technologies are phased out (Kanger et al., 2020; Kivimaa and Kern, 2016; Loorbach et al., 2017; Markard et al., 2020). Various informants found it important that policies and regulation should not impose unreasonable impacts on existing investments of companies and individuals. This view highlights the importance

of long-term policy goals with early signals for phase-out of technologies (Markard and Rosenbloom, 2020).

Policy instruments can favour mature or emerging solutions depending on the policy goal as it can be an important determinant for which type of technologies succeed. For example, a politician highlighted for other members of parliament in 2018 that the renewable energy technologies with the best efficiency (e.g., wind energy) will naturally emerge as winners in the technology neutral competitive tender (See Quotation 15). An alternative to create separate baskets for mature and emerging technologies was discussed earlier in the parliament (e.g., see Quotation 16) but disregarded in favour of the technology neutral tendering targeting cost efficiency. This is also an illustrative example on how technological neutrality can lead to technology selection in its own way.

4.1.1.3 Fairness between regions

Fairness between regions concerns how the policy maker balances between the interests of different regions. This includes both fairness among intra-regional actors as well as preferences for supporting intra-regional actors over and extra-regional actors. The first point relates to the traditional view that policies should not favour specific geographical areas of the internal market. However, various regional policy initiatives might aim to support specific regions and lead to conflicts between the interests of different regions. The second point of fairness between intra- and extra-regional actors concerns how heavily the policies favour intra-regional actors, even if better expertise would be available outside of the internal market. This favouritism of intra-regional actors has been an integral part of many innovation and industrial policies (See Chapter 2.1.1), which aim to increase national competitiveness.

Different regions can have different capabilities and prerequisites for market-driven operations due to existing value chains and infrastructure. This creates a rationale for policies to consider regional prerequisites for market-driven operations as a single policy might not be suitable for all regions. For example, sparsely populated areas might not provide sufficient incentives for market-driven development of broadband services (See Quotation 17). As another example, EU-level innovation policies might need to consider, if there is a need to support the development of EU-wide collaboration networks as the existing, often national, value chains might lead to overfunding of certain member states (See Quotation 18).

This brings us to the contradicting topic that many EU-level R&D projects aim for fairness between countries by requiring participants from different countries which might lead to inefficiencies in project coordination. Especially many large companies in the sample have found these inter-state collaboration projects inefficient for supporting their own development goals due to bureaucracy and conflicting interests between the project participants (e.g., Quotation 19). On the other hand, relatively smaller participating companies have benefited from these projects by gaining access to new networks and value chains of major companies (See Chapter 4.2.1.1 for additional discussions, e.g., Quote 62). Overall, this requires balancing between the interests of EU member states and the EU, as sometimes allocating funding towards a leading country might be the most effective way to reach the policy goal (See Quotation 20).

The EU, as a supranational organization, has also an important role in various national technology choices of the participating countries. This can lead to various conflicts between national interests as EU regulation dictates various national technology choices through its regulation. For example, Finland has tried to unsuccessfully lobby the European Commission to include biogas, a Finnish flagship, as a potential solution for the green transition of mobility services (See Quotation 22).

It is common to promote the use of domestic actors in various deployment policies (e.g., Quotation 26) and innovation funding programs (e.g., Quotation 24). However, these policies promoting the use of domestic actors can create conflicting interests between the technology providers and funder when the expertise is already available elsewhere (See Quotation 25). For example, public policies promoting the creation of national ecosystems might lead to the exclusion of optimal project partners with the right expertise (See Quotation 24). This might not always be a problem as the companies might recognize this funding criterion early enough and seek alternative routes through, for example, out-of-pocket financing (See Quotation 25). However, this might lead to the use of incapable partners and sub-optimal results if the options are narrowed too much. See Chapter 2.4.1 for theoretical background and Chapter 4.2.1.1 for empirical findings on how to enable broad, unrestricted competition for effective problem solving.

4.1.1.4 Preference for market-based or governmental selection of solutions

The preference for market-based or governmental selection of solutions is part of a traditional discussion on how strongly the policy maker believes in the superiority of market decisions over government decisions (See Chapter

2.3.1). Generally, market-based selection of solutions is seen as the baseline especially in technological neutrality, as strong arguments are required from policy interventions.

The selection between market-based or governmental selection of solutions should not be seen as a black or white decision. It is seen that governmental choices to support certain areas or technologies are necessary in practice and justified especially at early stages of innovation process. For instance, pragmatic choices to invest in certain areas are needed at specific times (See Quotation 27). Various informants consider that the principle of technological neutrality might be less relevant at early stages of innovation process, such as in research and development (R&D) funding (See Quotation 28) and knowledge end of the value chain, where research and education are financed (See Quotation 29).

One major rationale for avoiding governmental technology selection is that governmental selection of winners or technologies is seen dangerous and instead the market should be allowed to operate freely. These arguments range from the belief that the government might be incapable of identifying the right areas of investment (See Quotation 31) to ideological views that the government should not pick winners in a market economy (See Quotation 32). This has important policy considerations for evaluating the technological competence of the government officials (See Chapter 4.1.2.1) and for designing a governance architecture that enables utilizing the expertise of the most competent stakeholders (See Chapter 4.3.1).

As the market-based selection of solutions is seen as the baseline, strong arguments are seen essential for governmental technology decisions. Especially when raising an area to a strategic decision-making level, it is seen important that various stakeholders, including public and private entities, have a shared belief in the area (See Quotation 33). However, the government should be cautious with these categorical technology choices and enable space for competition to find better solutions (See Quotation 34). In the end, it is a delicate act of balancing between the risks of creating governmental lock-in with focused policies (See Chapter 4.3.2.1) and enabling potential economies of scale to emerge. See Chapter 2.4.1 in literature review for discussions on conflicting goals of diversification and effectiveness related to technological neutrality.

4.1.2 Theme 1.2. Policy maker competence and hidden intensions.

The policy maker competence (technology and policy design) and understanding of hidden intensions create the basis for effective and transparent

policy making. This study identified three separate 2nd order themes related to this theme. First, technology competence refers to the question, if the policy makers sufficiently understand technologies to regulate them effectively. Second, policy design competence concerns if the policy makers have competence to apply policy design features and principles in practice. For example, technological neutrality is one principle which should be properly understood to apply it successfully in various contexts for the intended outcomes. Third, hidden intensions mean that the policy makers might have various political or ideological goals that are not explicitly shared with others. Once these hidden intensions are combined with readiness to deviate from shared principles, it can lead to ideological exclusion of options and challenge the transparency of policy making. These three 2nd order themes are discussed in their respective chapters and presented together with 1st order codes, and representative quotations in Table 20.

Table 20. Data supporting interpretations of policy maker competence and intensions (Q35 – Q51).

1st order code	**Quotation ID and representative quotations**
1. Technological competence to regulate technologies (Q35 – Q38)	
Technological competence is required for purposeful technology decisions.	Q35: "*[...] 'let's just stick to this [old technology regulation], to avoid excessive work in understanding such a potential new solution', which of course restricts and ties the hands of both state actors and private entities in the sense that [...] we would have other solutions by which this same problem could be addressed [...].*" (Firm P)
	Q36: "*[...] there's a need for individuals who truly have insight into matters. [...] This understanding would likely come through dialogues from various sources. For instance, the Research and Innovation Council has not been used nearly as much as it could be for contemplating these kinds of matters or for forming a comprehensive view on various issues."* (Innovation system expert A)
Unintentional technological specificity due to policy requirements.	Q37: "*[...] there [in Finnish legislation] are many sort of non-technology-neutral provisions, which on the surface don't even seem to relate to technological neutrality at all. As an example: in our Road Traffic Act, decades ago, a provision was written that when parking a car uphill during winter, it must be parked in such a way that it doesn't start moving on its own [...]. [...] now with the rise of autonomous vehicles, this poses quite a serious limitation, [...] that a car should not start moving on its own.*" (Innovation system expert C)
	Q38: "*To ensure technological neutrality, the symmetry requirement must be relaxed. Otherwise, mobile solutions are not viable.*" (PTK 147/2020/7)
2. Competence to apply policy design features and principles in practice (Q39 – Q43)	
Technological neutrality has become a "mantra", but information is required to apply it in different contexts.	Q39: "*Technological neutrality has been like a "mantra" in Finland. [...] maybe, we need more information to think when each approach [technological neutrality and directing public financing towards technology areas] is justified.*" (Policy maker C)
	Q40: "*Technological neutrality has been a "mantra" [in their policy field]. [...] also [...] in influencing the EU where we don't want the commission or the state to choose winners [...]*" (Policy maker B)
Technological neutrality should be seen as a good servant but a bad master	Q41: "*In my opinion, sometimes we may overemphasize principles like technological neutrality, [...] and the like. The tool is elevated to a point where it becomes the master rather than the servant.*" (Scientist B)

Enforcing technological neutrality can challenge governmental technology programs.	Q42: " *[…] there has been a strong belief in pursuing a technologically neutral development policy. However, if followed in a purist manner, it poses challenges in implementing technology programs, like the 'AI for Business' programme of Business Finland.*" (Scientist C) Q43: "*Then we might have various authorities, like Business Finland, that support the achievement of specific political objectives, and this is where the grey area lies.*" (Innovation system expert C)
3. Hidden intensions and readiness to deviate from shared principles, such as neutrality (Q44 – Q51)	
Risk of goal customization towards the interests of technology provider to select a technology	Q44: "*Have the [minimum outgoing and incoming broadband] speeds been tailored according to the wishes of mobile operators, even though the objective was technological neutrality? Do these extensive exemptions […] ultimately result in non-functional data connections […]?*" (PTK 147/2020/7) Q45: "*I was thinking that it can't be the case that these speeds have been tailored according to the wishes of the current mobile operators […].*" (The same Member of Parliament as in Q44 later in the same parliamentary discussion (PTK 147/2020/7) after receiving clarifying answers from other members of parliament, e.g., Q38)
Ideological or political reasons to deviations from technology neutrality	Q46: "*The government has made some major industrial policy investments. […] It's interesting to ponder why and based on what criteria these particular investments were chosen to receive those hundreds of millions of euros. However, these decisions often have regional policy implications, reflecting a certain identified need that has been adequately justified, following a long-standing tradition in Finland to finance the infrastructure of large paper industry firms, and to some extent other industrial infrastructures, using state funds.*" (Policy maker D) Q47: "*The Greens [a Finnish political party] accepts corporate subsidies when it aligns with their green ideology. […] The support for wind power in this proposal still isn't sufficiently reduced, and the proposal isn't technologically neutral.*" (PTK 49/2018/4) Q48: "*[…] property tax probably wouldn't apply in the same way [for decentralized systems with individual panels] as it would for larger, more centralized power plants. However, in this respect, I am indeed willing to concede the slight advantage such highly decentralized small-scale solar production might attain in this manner.*" (PTK 109/2017/6)
Technological neutrality as a tool to support national goals	Q49: "*[…] we find the [Finland's] perspective of technological neutrality very important. […] Currently, it appears that the [EU] legislation is focusing on a few technologies that would be disadvantageous for Finland. Despite Finland's stance on technological neutrality, the question is how Finland can more strongly advocate for it, especially within EU institutions and bodies, as significant funding for commercial projects originates from these entities.*" (Firm P) Q50: "*The other is biogas, which is clearly a thorn in the EU's side, but for Finland, it's a flagship. There has been a persistent push for biogas within the EU, but with poor results."* (Policy maker B)
Overlooking an agreed funding criteria due to significance of project goals.	Q51: "*They [public funding agency] have mentioned that the funding for these projects, in a way, slightly exceeds our share, which would correspond to our turnover or the scope of our R&D activities. However, precisely because of the ambitious goals and their significance, they tend to overlook that slightly.*" (Firm E)

4.1.2.1 Technological competence to regulate technologies

Technological competence of the policy makers is an important aspect to effectively regulate technologies. Even if the policy makers intend to create technologically neutral outcome-oriented policy goals (See Chapters 2.3 and 4.3.2.3), the technologies of the decision field should be properly understood to create intended effects without excessive discrimination of technologies. Otherwise, there is a risk of unintentional technological specificity which could compromise reaching the policy goal.

Technological competence is required for purposeful technology decisions. Insufficient understanding of new technologies combined with limited resources might lead to reliance on old policies which can restrict the emergence of new suitable technologies (See Quotation 35). This can be apparent especially with technology-specific standards or regulations which might become outdated with the emergence of new technologies. The importance of technology competence is also highlighted in the context of choosing national strategic focus areas. It is seen important to have insightful individuals and government agencies that can form comprehensive views on various issues (See Quotation 36).

In addition, seemingly technology neutral policies can lead to unintentional technological specificity due to policy requirements. Some legal provisions might initially seem to be technology neutral but eventually have various implications on technologies setting limitations for future technologies (See Quotation 37). Avoiding this kind of unintentional technological specificity requires the policy makers to be aware how policy goals impact the choice of available options. For example, the Finnish policy makers noticed that a symmetry requirement for broadband speeds (i.e., to have same minimum outgoing and incoming broadband speeds) had to be relaxed to enable the participation of mobile solutions in addition to optical fibre solutions (See Quotation 38).

4.1.2.2 Competence to apply policy design features and principles in practice

Designing effective policies and comprehensive policy mixes can be challenging as the policy makers should understand numerous potential policy instruments while applying various, often vague, policy principles in practice. For example, technological neutrality is one principle which should be properly understood to apply it successfully in various contexts for the intended outcomes. This relates to the wider discussion that the principle of technological neutrality remains under-theorized leading to unawareness of relevant aspects related to the principle (See Chapter 2.3.1).

Various informants from the ministries have stated that principle of technological neutrality has become a repeated "mantra" in Finnish (See Quotation 39) and EU policy making discussions (See Quotation 40). However, the informants have occasionally faced challenges in applying the principle in different contexts as technological neutrality might conflict with other strategic goals set for the government agencies (See Quotation 39). For example, Technology Advisory Board (2021) suggests directing public financing towards prominent technology areas that might be seen to conflict with the

principle of technological neutrality. However, Technology Advisory Board (2021) has justified this "conflict" by providing guidance on when deviations from technological neutrality are allowed.

Policy principles, such as technological neutrality, might become problematic when they are overemphasized (See Quotation 41). As noted earlier, this simplistic approach can lead to challenges in applying the principle effectively by creating unnecessary conflicts between policy principles. As Scientist B notes, the tools should not be "*elevated to a point where it becomes the master rather than the servant*" (See Quotation 41). Therefore, it might be better to treat these principles as potential tools instead of ultimate outcomes that the policy should seek.

The principle of technological neutrality is not seen as an equally important aspect at all stages of innovation process (See Chapter 4.1.1.4). For instance, enforcing technological neutrality can challenge governmental technology programs "*if followed in a purist manner*" (See Quotation 42). Similarly, Innovation system expert C notes that the grey area for applying technological neutrality lies further away from the market, where the authorities might need to support the achievement of specific political objectives (See Quotation 43). Overall, this idea of technological neutrality as a guiding principle challenges policy makers to decide how it should be applied in different contexts.

4.1.2.3 Hidden intensions and readiness to deviate from shared principles

Reliance on vaguely defined principles, such as technological neutrality, can challenge the transparency of policy making, if the policy makers hide their true intensions behind favourable interpretations of such principles. These hidden intensions can include various political or ideological goals that are not explicitly shared with others. Once these hidden intensions are combined with readiness to deviate from shared principles, it can lead to ideological exclusion of options and challenge the transparency of policy making. This provides important considerations for the policy makers to prevent unequal treatment of different stakeholders by challenging potentially wilful policy goals.

Wide stakeholder involvement and lobbying are important parts of fair policy making processes but create a risk of favouring the most active lobbyists. This favouritism might be realized, for example, with goal customization towards the interests of a specific technology provider leading to selection of a specific technology. For instance, a member of parliament suspected that the

broadband speed requirements of a deployment policy were tailored for the tailored according to the interests of mobile operators compromising technological neutrality (See Quotation 44). However, this suspicion was demonstrated to be unnecessary by the other members of parliament, who clarified that the idea was indeed to enable the participation of mobile operators in the competition instead of wilfully favouring the mobile technologies (See Quotations 38 and 45).

Political parties and members of parliament have their own political agendas, which can encourage deviations from technology neutrality due to ideological or political reasons. Major industrial policy investments and corporate subsidies are suspected to be supported due to hidden or clear political agendas, such as regional policy goals (See Quotation 46) and green ideology (See Quotation 47). Furthermore, Quotation 48 provides an example, how a member of parliament is ready to deviate from the principle of technological neutrality and provide a small advantage for a particular technology over other available options. However, this is also related to the challenge of managing parallel policy initiatives to create a consistent policy mix which can lead to some inconsistencies in treatment of different technologies (See Chapter 4.3.2.2).

Technological neutrality at the EU level is seen as an important principle for Finland to support its national goals. It is seen challenging that various EU policies focus on few technologies that would be disadvantageous for Finland (See Quotation 49). In addition to regulatory exclusion of nationally relevant technologies, this can be particularly challenging as significant EU funding is directed towards the technologies favoured by the EU. As a result, various Finnish government agencies have tried to promote the principle of technological neutrality and the inclusion of nationally relevant technologies at the EU level to support national goals (See Quotations 49 and 50). See Chapter 4.1.1.3 for additional discussions on how this can create conflicts between the different member states of EU.

At the level of public project financing decisions, ambiguous evaluation criteria and hidden goals can create a risk of unequal treatment of different project applicants. For example, supporting a project with significant and ambitious goals might require overlooking another funding criteria of limiting public funding based on the company size (See Quotation 51). This leaves room for interpretation as it requires the government official to prioritize between partly conflicting targets. As a policy implication, it is important to clearly define the most important strategic policy goals (See Chapter 4.2) while designing a governance architecture that supports the purposeful delegation of decisions to different governance levels (See Chapter 4.3.1). In the

end, it requires balancing between empowering government officials to make flexible decisions and ensuring equal, transparent treatment of different stakeholders with clear funding criteria.

4.2 Topic 2. Policy strategy and agenda for technology selection

Public policies pursue a broad range of goals by implementing various means which creates conflicts and challenges the coherence of the policy mixes (Flanagan et al., 2011). Flanagan et al. (2011) argue that the impact of public policies is fundamentally influenced by these often-conflicting goals, rationales, and implementation choices. Therefore, this study analyses major technology policy strategies, which refer to different major combinations of these policy goals and principal plans as defined by Rogge and Reichardt (2016) and discussed in Chapter 2.2.1.

This study identified two separate policy strategies for technology selection which can create conflicts in policy mixes, as they utilize different mechanisms and favour different actors. First, "*A competitive market-led innovation system*" refers to a traditional pro-market view that market should be allowed to operate freely by minimizing government interventions. This approach can lead to economic efficiency by utilizing a high degree of competition, for example in deployment policies. However, it might fail to address various market failures leading to support for dominant technologies and incumbents. Second, "*A resilient and adaptive innovation system*" refers to a mission-oriented innovation policy where government interventions direct society towards desired policy goals, such as national sovereignty, technological diversity, or support for emerging technologies. As discussed in Chapter 2.4.1, the policy makers should prioritise and balance between partially conflicting technology goals of innovation policy which can significantly impact the policy outcomes. Therefore, it is important to understand the different policy strategies and prioritize between these conflicting strategies. These two strategies are discussed in their respective chapters including accompanying tables with identified 2nd order themes, 1st order codes, and representative quotations. Figure 17 presents an overview of the two policy strategies and identified 2nd order themes.

T2.1. A competitive market-led innovation system	T2.2. A resilient and adaptive innovation system
1. Broad market-driven competition as a mechanism for effective problem solving	1. Emerging solutions as a driver for positive change
2. Effective allocation of government-controlled resources	2. Flexibility during policy time horizon by postponing decision on the dominant design and by supporting diversity
3. Predictable and stable investment environment to enable investments	3. Regional Sovereignty

Figure 17. Overview of policy strategy and agenda for technology selection.

4.2.1 Theme 2.1. A competitive market-led innovation system

Policy makers are often recommended to preserve the use of non-neutral government interventions for fixing glaring market failures as the interventions introduce a risk of distorting market competition by supporting specific beneficiaries (Aghion et al., 2009). This view is highly present in the research data related to justifications for technological neutrality and governmental technology choices presenting three important themes. First, informants promote broad market-driven competition as a mechanism for effective problem solving. Second, various policies target the effective use of public finances by catalysing private capital towards societal goals instead of extensive governmental financial support programs. Third, informants find it important to create a predictable and stable investment environment which provides the basis for long-term investments of private actors. These three 2nd order themes are discussed in their respective chapters and presented together with 1st order codes, and representative quotations in Table 21.

Table 21. Data supporting traditional a competitive market-led society (Q52 – Q77).

1st order code	Quotation ID and representative quotations
1. Broad, unrestricted market-driven competition as a mechanism for effective problem solving (Q52 – Q65)	
Competition is believed to enable finding the best and most effective solutions, whereas technology-specific support can be over-compensatory for the technology provider.	Q52: "*[technological neutrality] enables things to be done in very different ways, and to see which one turns out to be the best among the competitors*." (Scientist B)
	Q53: "*Costs to the public finances decrease as the most cost-effective projects prevail*." (PTK 53/2018/5)
	Q54:"*The door is open for various energy efficiency solutions, but funding specifically targets the most effective solutions*." (PTK 84/2019/3)
	Q55: "*[…] on the other hand, the issue with [the wind power feed-in tariff] is that it has been over-compensatory, generating excessively high profits for wind power companies, and in this respect, it hasn't been very cost-effective […]*." (PTK 47/2015/4)

Legislation or public policy choices should not exclude technologies or means from participating to prevent outruling potentially better solutions.	Q56: "*it's crucial for us, as a new technology, that this new legislation does not exclude the development of new technologies, and perhaps technological neutrality is the easiest way to ensure that.* [...] *we have other solutions with which to address the same issue, perhaps even better, perhaps even more efficiently.*" (Firm P) Q57: "[...] *the government's program explicitly lists the goal of cost-effective and technologically neutral expansion of renewable energy production, which, in my view, signifies a broader energy mix, without disregarding wind energy at all.*" (PTK 47/2015/4)
Different development models have their own benefits and challenges, which makes them suitable for different goals and benefit different actors.	Q58: "*Recently, EU-level instruments have become so complex in structure that they have, to some extent, needed to be actively avoided. Various consortium requirements exert a chilling effect on how intellectual property is actually managed. [...] Consequently, these projects are not conducive to generating commercial products or technologies because the IP structure is exceedingly challenging. If we are involved in such a project, we must be cautious about what is being developed there. [...] in these sectors where there's global competition, it's rare that the winners are small to medium-sized companies from four different European countries collaborating on a concept. Rather, it's usually a clear individual actor with sufficient funding and drive to genuinely take global leadership in something. On the pure research side, leading research can emerge in many structures, but winning business rarely originates from a consortium.*" (Firm K) Q59: "*It is highly secretive. And understandably so, given the magnitude of the issue. As such, it hasn't been possible to bring it there [in collaboration projects].*" (Firm E) Q60: "*Once again, we are far away from the market, as other competitors are also present [in the projects] [...]. Competition law naturally comes into play under these circumstances. There are some joint projects or preliminary collaborations that we might occasionally engage in [...].*" (Firm D) *Q61: "We have the capacity to lead large-scale projects and capability to deliver these [solutions] globally everywhere which enable other companies to join our value chain*" (Firm B) Q62: "*A collaboration project with major players has opened up networks and created opportunities to participate in a value chain for us as a new player.*" (Firm Q in an EU project and Firm G in a Finnish research collaboration project)
Knowledge or expertise should be sought from where it's most accessible or of the highest quality as all best expertise cannot be found domestically.	Q63: "*It's a challenge finding the best experts or partners for certain projects within the home country.*" (Firm A & Firm D) Q64: "*Of course, one should always seek knowledge where it's most accessible or of the highest quality. [...] Yet, it doesn't rule out the possibility of developing ecosystems or value chains locally. In such cases, the international expertise is utilized by the participating companies or entities acquiring that knowledge from abroad.*" (Firm B) Q65: "*Collaboration with the world's top tier teams with industrial expertise can be an alternative approach for new projects instead of building our own team or considering your traditional suppliers.*" (Innovation system expert B)
2. Effective use of public finances by catalysing private capital towards societal goals (Q66 – Q70)	
A multitude of actions are essential to meet societal objectives.	Q66: "*The ten gigatonnes [of carbon emissions] remaining even after an 80 percent reduction in emissions is concerning [...] since it's impossible to capture as much carbon as we currently emit. Therefore, many things need to happen simultaneously. Apart from pushing for these massive emission reductions, we also need to invest in carbon capture technologies.*" (Firm P) Q67: "*The [Environment] Committee emphasizes that all measures to achieve emission reduction targets in transportation are needed, and they should be implemented as soon as possible.*" (PTK 124/2020/8)

Private capital should be catalysed for significant transformations as deviation from market-based conditions would require large-scale government support.	Q68: "*If we [the government] decide to support something that does not operate on market terms, it becomes significantly more challenging for that company to secure international capital later on. It would have to be a significant, large-scale support [from the government].*" (Public funding officer A) Q69: "*In hindsight, we'd know, though I'm not sure if even then we'd realize if our [state's] choices were right or wrong. [.] It's hard to evaluate as these usually involve large ecosystems where the state's contribution is just one component of the whole.*" (Innovation system expert A) Q70: "*We need hundreds or thousands of similar projects launched globally if we truly want to change the situation, and for that, massive capital is required. There needs to be a catalyst making it appealing for the capital markets to invest in this type of operation. We could clearly state that we will gradually make the use of aviation fuels that increase CO2 concentrations very expensive.*" (Innovation system expert C)
3. Predictable and stable investment environment to enable long-term investments (Q71 – Q77)	
Political risks create uncertainty for long-term investments and emerging solutions, which can push companies to focus on short-term competitiveness.	Q71: "*There's regulation that we need to consider and follow, like the upcoming EU AI act which has appeared to pose challenges to companies. They're trying to regulate something that evolves so quickly that the regulation might be outdated upon its inception, potentially harming European businesses."* (Firm I) Q72: "*[...] we still need to justify why this investment is worthwhile and competitive before these [emissions trading] systems [and carbon taxes] are imposed. [...] We cannot build our business and ask for money just based on the assumption that our business is likely to come under the emissions trading scheme in the future. There's a political risk that considerably reduces our attractiveness. Although it's expected, nobody can precisely tell the timeline or its impact."* (Firm Q) Q73: "*As infrastructure is taken forward, it's vital for us to promptly know how much each region is contributing, and whether regional power companies are involved, possibly with a larger operator. Once the information is available, people start to make purchase decisions. When there's assurance of mobility across the region and broader areas, a swift transformation is likely.*" (PTK 32/2017/3)
The lack of long-term funding causes interruptions in activities and poses a risk of losing partners.	Q74: "*All of Business Finland's tools last for two, at most three years. This dictates how the project should be structured. [...] For instance, a five-year project might indeed be relevant, especially in early-stage research. But we can't use the Academy of Finland's funding because we're not a research institution. [...] re-applying introduces a new set of challenges and a break in the process. You might risk losing partners at that point if a project is discontinued. [...] Having guaranteed financing for, say, five years means you can focus solely on research.*" (Firm D) Q75: "*The difference in those [strategic projects] compared to other funding was that, [...], quite a large amount of money was being competed for. Let's say those projects were supposed to last for four or five years, but they ended up being cut short after the elections. Still, they had some degree of longevity. Not just one-year ventures.*" (Firm O) Q76: "*[...] the issue with funding has actually been its unpredictability and extreme fluctuations. Sometimes funds are cut, sometimes they are increased, and you never know when either will happen. [...] And it's like poison that the funding goes up and down. Sometimes politicians think when they add an extra two million to something that we should be overjoyed, and of course, it's a good thing. But the issue with the funding sawing up and down is that the majority of the money goes to people's salaries. You would then assume that people are laid off and hired in the same fluctuating manner, and that just doesn't work at all.*" (Scientist B)
Precisely defined regulations are expected in some areas, such as taxation.	Q77: "*Of course, acting according to this principle [of technological neutrality] is easier said than done. Tax legislation should be precise yet as technologically neutral as possible. At the same time, it should allow and encourage the emergence and spread of innovations.*" (PTK 134/2021/9)

4.2.1.1 Broad, unrestricted market-driven competition as a mechanism for effective problem solving

Competition is widely utilized in various innovation and deployment policies, such as technology-neutral auctions for renewable energy (e.g., Fabra and Montero, 2022), and selection of publicly financed research projects (e.g.,

Cantner and Pyka, 2001). It is seen as a mechanism for finding the comparatively best solutions for the implementation of the policy goal both by the informants as well as in innovation policy literature (e.g., Cantner and Pyka, 2001). However, the potential benefits of competition are restricted by the availability of options which might be limited by the inclusiveness of the policy. Technological neutrality can be seen as one approach that aims to increase the policy inclusiveness by preventing the exclusion of specific technologies on an arbitrary basis (See Chapter 2.3.1). In addition, there are various other policy design features that might exclude potential options from participating in policy implementation, such as exclusion of international partners in research and development (R&D) projects. This categorical exclusion of available options can even compromise the achievement of policy goal if it leads to use of sub-optimal partners.

One of the more obvious findings from the research data is that competition is believed to enable finding the best and most effective solutions. This view has been promoted by various informants and members of parliament, especially in discussions related to technological neutrality. It is seen important that policies enable "*things to be done in very different ways*" to see which solutions emerge as "*the best among the competitors*" (See Quotation 52). The competitive approach is seen as an important way to decrease costs to the public finances as the most cost-effective projects prevail (See Quotation 53). This view has been prevalent, for example, in discussions related to technology-neutral auctions for renewable energy which target most effective solutions (See Quotation 54). In contrast, technology-specific support programs have been seen to lead to over-compensation for specific technologies, such as wind power when utilizing wind power feed-in tariffs (See Quotation 55).

To enable broad competition and prevent outruling potentially better solutions, it is seen important that legislation or public policy choices should not exclude technologies or means from participating. This idea of inclusiveness is in the core of goal-oriented neutrality principles, such as technological neutrality, which aim to provide equal participation opportunities for all applicable implementation methods (See Chapters 2.3.1 and 4.1.1.1). For instance, the informant from Firm P highlights that technological neutrality might be the easiest way to ensure that "*legislation does not exclude the development of new technologies*" which might lead to better solutions (See Quotation 56). This type of inclusiveness of different implementation methods can be seen as a widely agreed principle worth pursuing. However, there are various other forms of inclusiveness that are more challenged in current innovation policies.

The emergence of new technologies can be a complex process where technologies are developed in various settings. These different development models have their own benefits and challenges, which makes them suitable for different goals and benefit different actors. However, different innovation instruments often target different goals (e.g., promote collaboration), actors, and implementation modalities which can create conflicts in policy mixes (Flanagan et al., 2011) and potentially lead to exclusion of potential alternatives. Various informants from large companies have found large consortium projects to be ineffective for producing commercially viable solutions leading to even avoidance of such projects (See Quotation 58). True collaboration is challenged by various factors, such as project participants pursuing their own interests (See Quotation 19 in Table 19), unfeasible IP policies (See Quotation 58), protection of trade secrets (See Quotation 59), and competition law preventing cooperation between competitors (See Quotation 60). Instead, projects led by these large companies is seen as the preferred option by them (See Quotation 58) as they believe to have necessary capabilities to lead the creation of new value chains (See Quotation 61). In contrast, relatively smaller or newer companies have benefited from these collaborations at national and EU level by gaining access to new networks and value chains (See Quotation 62). In the end, it remains an important consideration for the policy makers to design policies that are inclusive for different development models suitable for the policy goals.

Innovation policies can have conflicting goals as they balance between supporting national actors and utilizing the best available expertise regardless of location. Various informants acknowledge that knowledge or expertise should be sought from where it's most accessible or of the highest quality as all best expertise cannot be found domestically. The companies have occasionally faced challenges in finding the best project partners domestically (See Quotation 63) which would be required by various public financing agencies. They find it important that international expertise is utilized in these research and development (R&D) projects either through the networks of participating companies (See Quotation 64) or through partnerships with world's top tier teams (See Quotation 65). Even though the excessive use of domestic partners can prevent access to leading expertise, it is found possible to support the development of national ecosystems through various policies. However, this poses a serious challenge for the policy makers to design policies that do not fall victim to excessive promotion of commercially unviable domestic partners when significantly better alternatives would be available abroad.

4.2.1.2 Effective use of public finances by catalysing private capital towards societal goals.

Governments are challenged by major societal challenges, such as the environmental crisis, aging of population, and geopolitical tensions, which require significant investments. This creates a rationale for policies to promote the effective use of public finances by catalysing private capital towards societal goals instead of extensive governmental financial support programs. This discussion strongly relates to readiness to rely on market processes (See Chapter 4.1.1.4), automaticity of policy interventions (See Figure 5), and enabling unrestricted competition with inclusive policies that can activate a broad range of private actors.

The environmental crisis and managing the related societal transition pose a serious challenge for societies. Meeting the ambitious environmental objectives is seen to require a multitude of actions to happen simultaneously as no single solution is sufficient to reach the goals (See Quotation 66). This is also widely understood in the Finnish parliament where, for example, "the [Environment] *Committee emphasizes that all measures to achieve emission reduction targets in transportation are needed, and they should be implemented as soon as possible*" (See Quotation 67). In addition to environmental goals, these can include other national goals, such as ensuring national sovereignty, which is discussed in Chapter 4.2.2.3 and recognised as an emerging frame for innovation policy (Edler et al., 2023). However, the means and sources of financing to drive this transition is often up to more debate.

It is seen important that private capital is catalysed for significant transformations as deviation from market-based conditions would require large-scale government support. It is highlighted that deviations from market terms in government support can require costly government interventions as the private actors might be unable to find private funding for these operations (See Quotation 68). These government interventions are further challenged by the complexity of targeted ecosystems where the state's contribution is only one part of the larger picture (See Quotation 69). Therefore, it is suggested that the government should catalyse private capital markets to invest into societally important areas with clear long-term policies, that incentivise the transition, for example, by pricing the harmful externalities (See Quotation 70).

4.2.1.3 Predictable and stable investment environment to enable long-term investments

Favourable institutional and political environments are important factors in the choice of location of foreign direct investments in addition to other factors, such as economic factors (Nielsen et al., 2017). The empirical research data highlights the importance of a predictable and stable investment environment to enable long-term investments especially in emerging industries. A predictable political environment is seen important for reducing political risks associated with large long-term investments as unstable regulatory environment can decrease the attractiveness of these investments by increasing uncertainty to the market development. In addition, precisely defined regulations are expected in some areas, such as taxation, to enable transparent policies. However, these precisely defined regulations can challenge the stability of the political environment, because narrowly defined regulations can be more vulnerable to changes when new solutions emerge (See "Policy sustainability" goal in Chapter 2.4.1).

Various informants have noted how political risks create uncertainty for their long-term investments and emerging solutions. New regulations, such as the EU AI act, can create challenges to companies operating in emerging fields (See Quotation 71). In addition, these new regulations can create challenges for policy sustainability, as the emerging fields "*evolve so quickly that the regulation might be outdated upon its inception*" (See Quotation 71). Even if the upcoming regulations are expected to have a significant positive impact on the companies (e.g., carbon taxes on climate tech companies), uncertain scope and timing of the future policies can push companies to focus on their short-term competitiveness to remain fundable (See Quotation 72). In addition to businesses, predictable environment is seen important for enabling the investments of private persons, which play an important role in various transformations (See Quotation 73).

The lack of long-term project funding and volatile basic funding of governmental agencies can cause instability and interruptions in activities which challenges consistent development of emerging solutions. Various informants have found it challenging that the current Finnish innovation project fundings for companies are relatively short (i.e., max 2-3 years), which introduces a risk of losing project partners between projects (See Quotation 74). In comparison, the earlier strategic project initiatives enabled longevity with significant funding for four to five years but were cut by the Finnish government (See Quotation 75). Despite the potential of this "*Strategic Centres for Science, Technology and Innovation*" program (SHOK), the program was evaluated to have various challenges, such as contradictory objectives, lack

of competition, support for incumbents, and lack of internationalisation (Lähteenmäki-Smith et al., 2013). In addition to project funding, long-term development of research institutes is challenged by unpredictable and fluctuating basic funding (See Quotation 76). As most of the funding is allocated to salaries due to knowledge-intensive nature of research and development, the organisations find it difficult to adjust their headcount based on these fluctuations in funding (See Quotation 76).

Policy makers must occasionally balance between creation of precisely defined regulations and encouragement of new innovations. Detailed regulations contain the risk of being under-inclusive towards emerging technologies as technological change can create uncertainty requiring new laws for new technologies (Greenberg, 2016). However, precisely defined regulations are expected in some areas, such as taxation (See Quotation 77), because ambiguity may complicate the identification of the law's scope and its appropriateness (Greenberg, 2016).

4.2.2 Theme 2.2. A resilient and adaptive innovation system

Innovation policies have been increasingly utilized to steer the direction of innovation systems towards addressing acute societal problems (e.g., Schot and Steinmueller, 2018; Hekkert et al., 2020), such as sustainability goals (e.g., Kirchherr et al., 2023). Simultaneously, major shifts in the global geopolitical and security landscape challenge policy makers to more explicitly consider the connection between global security concerns and innovation policy (Kivimaa, 2022). This rise of geopolitical tensions has led to the introduction of technology sovereignty as an emerging frame for innovation policy by Edler et al. (2023). These emerging frames are part of the third generation of innovation policy referred to as transformative innovation policy (See Chapter 2.1.1) which is pursued, for example, with partly overlapping missions-oriented and transitions-oriented policies (Haddad et al., 2022).

The second policy strategy defined in this chapter, "*A resilient and adaptive innovation system*" refers to one type of transformational innovation policy where government interventions direct society towards important societal goals. First, this strategy supports emerging solutions as a driver for positive societal change similar to first and second generations of science, technology and innovation policies (Schot and Steinmueller, 2018). Second, diversity and agility are supported to adapt to emerging challenges during policy time horizons. Third, the strategy aims to ensure sovereignty in geopolitical competition similar to the technology sovereignty frame for innovation policy introduced by Edler et al. (2023). These three 2nd order themes are discussed

in their respective chapters and presented together with 1st order codes, and representative quotations in Table 22.

Table 22. Data supporting interpretations of a resilient and adaptive innovation system (Q78 – Q117).

1st order code	Quotation ID and representative quotations
1. Support emerging solutions as a driver for positive societal change (Q78 – Q94)	
Governmental financial support and regulatory incentives are seen crucial for emerging industries as market-based financing is not found suitable for the industrial-scale manufacturing facilities of new deep technology companies.	Q78: "*Another financial aspect to consider [e.g., in manufacturing related industries] […] is the significance of demo and pilot-level investments. […] Business Finland should more strongly support these investments in addition to OPEX [operating expense] financing in projects. […] the benefits would likely be much greater if the necessary pilot and related infrastructure could be established alongside the development project.*" (Firm B) Q79: "*Often, in these kinds of projects, for investments to be made, the support from the state or some supranational entity is a crucial component. This also encourages customer companies to invest because then they can claim to have leveraged various supports, fit into different EU roadmaps, and save money simultaneously.*" (Firm N) Q80: "*In deep tech cases, it's typically such that when you need to build a factory, you require two to five million as a base, and then suddenly you have to cough up 20-50 million for those factories so that you can set up your first industrial-scale plant. No standard bank would believe in you at that stage. There, EU funds should be leveraged significantly, and both Business Finland and the Climate Fund have been there for that purpose.*" (Innovation system expert A) Q81: "*There needs to be a catalyst making it appealing for the capital markets to invest in this type of operation. We could clearly state that we will gradually make the use of aviation fuels that increase CO2 concentrations very expensive.*" (Innovation system expert C)
Streamlined administrative processes (e.g., environmental permits, immigration, public financing) are seen important for emerging solutions.	Q82: "*When discussing production facilities and development centers, from the point where an investment decision is made to its completion, there are several time-consuming pathways that emerge. […] Obtaining different types of permits, and then when building facilities, securing operating permits, finding suitable infrastructure or even assisting in its development for a larger new facility, are one aspect. Another crucial factor is the ease of immigration for work purposes; when that runs smoothly, it offers considerable advantages.*" (Firm N) Q83: "[…] in some cases, these decisions [about funding] have taken a long time." (Firm Q) Q84: "*Regarding what works and what doesn't, from a business perspective, the decision-making process at Business Finland takes quite a long time. Things are often awaited much longer than what companies are accustomed to. Streamlining such processes would certainly be beneficial."* (Firm B) Q85: "*[…] actually my personal view is that the Business Finland process is one of the best in the world.*" (Firm J) Q86: "*The threshold for domestic funding is appropriately set, while it appears absurdly high for EU funding. […] If we had to choose between the same amount of funding either from the EU under current rules or domestically, we would opt for Business Finland every single time. This is because it is far more straightforward and sensible to work with a local entity."* (Firm K)

Access to world-class assets (e.g., infrastructure, knowledge, and leading companies) can enable emerging solutions and influence where companies set their operations.	Q87: "*Firstly, public infrastructure, such as supercomputers, not only enables certain activities to be carried out but also attracts members and potential investments to this ecosystem who otherwise might not even consider Finland. [...] This conveys a message for technology policy: 'If there's foundational infrastructure, solid research, and proactive investment into the new, it significantly influences where innovations emerge and ultimately settle'.*" (Firm I) Q88: "*Collaborating with universities provides a shortcut to accessing top global talent and getting them involved in the project. [...] Investing in these methods for our own laboratory might not always make sense, especially in the early stages. Still, we obtain invaluable information that, when stamped with third-party and scientific neutrality validation, becomes highly trustworthy.*" (Firm N) Q89: "*We possess world-class research infrastructure. [...] Primarily, they are for our use and to fulfill our tasks. However, we aim for them to serve a broader audience.*" (Scientist A) Q90: "*When considering it as an investment environment, it remains a traditional industrial setting where such investments are customary. [...] But most importantly, one could argue that there are various potential applications for our product, so we aren't strictly tied to one specific use.*" (Firm Q) Q91: "*We, in a sense, have the capability to manage or lead large-scale projects, which also enables other companies to integrate into the value chain we oversee.*" (Firm B)
Interdisciplinary collaboration and project combinations can enable novel opportunities but have required inter-organisational cooperation and teams capable of executing the project.	Q92: "*This required a significant interdisciplinary presence in a large program. In contrast, likeminded researchers [...] gather amongst themselves, publish about the same topics, and peer-review each other's publications. This creates a sort of parallel reality, which is not conducive to innovation. [...] The essential "cross-breeding" that happens is crucial. Our company stemmed from this, as did many others.*" (Firm O) Q93: "*Currently, the idea is that we're building upon these existing foundations. This project merely needs execution. The technologies are essentially ready. However, the cost level is undoubtedly a challenge at this point. But, with the green transition being a major trend, bringing this project expertise to open the market might be our distinctive contribution. "* (Firm Q) Q94: "*I hope that it [the collaborative government funded project] offers new opportunities, especially in new technological ventures, where established value chains aren't yet present. [...] This is something we haven't historically done but it might be possible in newer ventures that we become a part of a different value chain, instead of taking on the full responsibility.*" (Firm B)
2. Adaptation to emerging challenges by supporting diversity and agility (Q95 – Q107)	
Proactive technology neutral approach and flexibility for regulatory amendments are seen as options to adapt to societal changes and rapid technological development.	Q95: "*Due to technological neutrality and the rapid development of technology, the proposal would not set detailed requirements for the technical implementation of remote participation, so that the proposal does not become obsolete as technology evolves.*" (PTK 49/2022/8) Q96: "*Drone technology is constantly evolving, and it is indeed beneficial that the law is constructed to be technologically neutral. The starting point should be that when a new innovation emerges that can do a lot of good but also possibly harmful things, the law should proactively be such that one doesn't have to amend it for every technological invention.*" (PTK 108/2018/4) Q97: "*[...] we have aimed for a technologically neutral approach in this proposal. However, if a new innovation falls through the cracks, there should undoubtedly be a readiness to amend this proposal.*" (PTK 134/2021/9)
Different technologies are suitable to different geographical realities and technological neutrality is seen as an approach to adapt to these regional differences.	Q98: "*One must also be technologically neutral in this matter, meaning that while broadband implemented via fiber optic might be the right solution for some places, it doesn't mean it's economically sensible or technically logical to implement everywhere.*" (PTK 64/2017/10) Q99: "*For instance, in carbon capture, every methodology has its pros and cons, so there isn't one single "winner" or best method for carbon capture. Often, different technologies might better suit different geographical realities.*" (Firm P)

Availability of a wide range of solutions is seen necessary to enable choices for consumers and to solve complex societal challenges.	Q100: "*As for charging station payment practices, we have emphasized that there should be the possibility to use various tools, like mobile phones.*" (Policy maker B) Q101: "*However, remote connections must be such that all participants have an equal opportunity, comparable to traditional meeting participation, to exercise their rights in savings banks and mortgage associations.*" (PTK 49/2022/8) Q102: "*The committee emphasizes that achieving climate targets in the transport sector requires a broad array of methods. For measures to be cost-effective, regulatory frameworks must take into account technological neutrality and the comprehensive utilization of various energy sources.*" (PTK 131/2022/17) Q103: "*We need hundreds or thousands of similar projects launched globally if we truly want to change the situation, and for that, massive capital is required.*" (Innovation system expert C)
Government interventions and parallel projects are seen as ways to postpone technology selection and maintain diversity.	Q104: "*The only exception, actually, to [technological neutrality] are the licenses for 2G networks, which remain tied to 2G technology. […] The discussion is influenced by the fact that […] there are various devices, not primarily consumer traffic, on 2G networks that need to be considered.*" (Policy maker A) Q105: "*Additionally, we seek to […] also to ensure there are secondary suppliers in crucial areas. The whole objective is to make Europe strongly self-sufficient.*" (Public funding officer C) Q106: "*[…] the ability to compare them side by side efficiently reduces the ultimate risk of your choice. From our perspective, this risk [cost of running parallel pilots] is quite small. This can be used as a quick acid test.*" (Innovation system expert B) Q107: "*The EU's decision that combustion engine vehicles will no longer be manufactured after a certain year is concerning, and it's not technologically neutral at all. If it's found that, for example, the vast mineral resources required for electric mobility can't be exploited within the given timeline, we might be in a deadlock where combustion engine technology and related emissions-free synthetic fuels haven't been developed as they could have been.*" (PTK 153/2022/5)
3. Ensuring sovereignty in geopolitical competition as a rationale for government interventions (Q108 – Q117)	
National security concerns challenge governments to adapt to changing circumstances.	Q108: "*The changing security situation is something that strongly impacts our field. The openness of information is perhaps undergoing a transformation. Up until now, there has been a strong desire for transparency, but now there might be countervailing forces suggesting some change in this stance. […] There might be a need for us to limit the kind of information and services we provide, as well as the rights assigned to them. […] Moreover, the current security situation also presents other challenges. There are many research projects in Finland on topics that might not need to be explored in an ideal world.*" (Scientist A) Q109: "*Additionally, from a security perspective, it might be crucial for us to take some action. If consensus on this is reached, then a more comprehensive, goal-oriented project could be initiated.*" (Public funding officer C) Q110: "*One could consider a scenario like the singularity in artificial intelligence, where a potentially threatening situation to humanity might arise. In such cases, it's entirely appropriate for the highest political level to intervene. However, such situations might arise once in a hundred years. But typically, there should be an emphasis on outcome-based thinking, allowing government officials to perform their tasks.*" (Innovation system expert C)

Global competition drives the EU to support the development of the internal market.	Q111: "*Specifically, if Europe doesn't take this seriously and invest, it could be said that competition is killed off here, and then the competition will come from the US. So, we're paving the way for non-European enterprises. There's a sort of battle ongoing. For instance, when looking at the green transition in the USA with an investment of 300-400 billion, it's purely public support, tax relief, and such. They clearly see that society can significantly accelerate market development. Europe needs a similar approach for AI.*" (Firm I) Q112: "*We have some 'next-level' initiatives. For example, quantum technology is likely to completely explode in the market in the next few years. […] Companies […] and the core technology originate from Finland. Next, a 300-million investment should be somehow secured to stay competitive in that race. Finding that level of funding in Finland can be very challenging. Investments are going quite clearly to those who have the means and have genuinely said that they're doing something in this area, like Germany and France within the EU. They have the funds and the ability to leverage additional resources from the EU, so that's where these investments are likely heading.*" *(*Innovation system expert A*)* Q113: "*The fact is industrial policy and technology policy have made a comeback. Other countries are doing it, the EU is doing it, the US is doing it, so we must also somehow participate in it. Even though a small export-driven economy like Finland should naturally be a staunch supporter of the market economy, it doesn't mean we shouldn't make pragmatic choices, investing in certain things at specific times.*" (Scientist B) Q114: "*One of the biggest challenges, in these sectors with global competition […], is that it's rare that the winners are small to medium-sized companies from four different European countries collaborating on a concept. Rather, it's usually a clear individual actor with sufficient funding and drive to genuinely take global leadership in something. […] When discussing global competition and aiming to produce winners in some way, the EU should operate on a scale larger than national entities; otherwise, they overlap.*" (Firm K)
The rise of geopolitical competition and industrial policy tests political will to support a move towards technological sovereignty.	*Q115: "When considering European, and Finnish, digital or technological sovereignty, […] we are creating the greatest ever dependency on non-European international actors in the most strategic area ever [AI]. […] Although it may not have been [clear] so far, we now see that as investments in generative AI are set to increase, significant public support is needed right now. This tests political will. […] Do we truly want to invest in preventing it [strong dependencies]?"* (Firm I) Q116: "*We strive for Europe to be less dependent on the world outside Europe, like the EU's own aspirations. Additionally, we seek to avoid redundant activities and to ensure there are secondary suppliers in crucial areas. The whole objective is to make Europe strongly self-sufficient."* (Public funding officer C) Q117: "*Currently, the tide seems to be moving towards a mission-oriented direction, and the geopolitical competition and emerging blocs emphasize it even more. We might be moving in the direction where national political decisions select certain directions, such as energy self-sufficiency requiring hydrogen technology and wind turbine construction.*" (Scientist C)

4.2.2.1 Support emerging solutions as a driver for positive societal change

Technological advancements have been a key driver of economic prosperity for long but the specific type and direction of innovations also play a critical role in creating positive societal impact (Acemoglu, 2023). This creates a rationale for the policy makers to influence the direction of technological development by supporting emerging solutions as a driver for positive societal change. The policy makers can utilize a broad range of innovation policy instruments, such as regulations, economic transfers, and soft instruments (See Chapter 2.2.2), to encourage favourable innovations or discourage unsustainable arrangements (Rosenbloom et al., 2020). This study has identified various ways for supporting emerging solutions, including direct support

for the emerging technologies, streamlined administrative processes, creation of world-class assets, and interdisciplinary collaboration. This chapter aims to pinpoint some of the challenges of Finnish innovation system for emerging solutions instead of providing an exhaustive list of options. See Chapter 2.2.2 for different types of innovation policy instrument classifications and Chapter 2.3.2 for policy design techniques for technological neutrality.

Governmental financial support and regulatory incentives are seen crucial for emerging industries as market-based financing is not found suitable for the industrial-scale manufacturing facilities of new deep technology companies. The informants from asset-heavy industries, such as manufacturing of climate technologies, have highlighted that the Finnish innovation agencies "*should more strongly support these investments [e.g., pilot facilities] in addition to OPEX*" (See Quotation 78). Public financial support is seen as a crucial component in investments into first-of-a-kind facilities (See Quotation 79), as standard market-based financing (e.g., bank loans and venture capital financing) is not found suitable for deep technology cases requiring 20-50 million euros for first industrial-scale plants (See Quotation 80). In addition to direct financial support, regulations for discouraging unsustainable arrangements (e.g., carbon emissions) are found necessary to incentivise large investments into favourable transitions (See Quotation 81).

Financial support and regulatory incentives for emerging technologies are not sufficient alone. Streamlined administrative processes (e.g., environmental permits, immigration, public financing) are seen important to realise the full potential of the government interventions. Complex and lengthy governmental processes can create unnecessary entry barriers for emerging technologies that already face major uncertainties during the long development processes (See Quotation 82). The informants have occasionally faced challenges with the long lead-times of public financing decisions that can be incompatible with business cycles (See Quotations 83 and 84). However, the processes of the national innovation agency (Business Finland) are often seen in a positive light (See Quotations 85 and 86) compared to complex EU-level project funding mechanisms (See Quotation 86). In addition to public financing, fluent processes related to various environmental permits and immigration are seen important enablers for emerging technology companies (See Quotation 82).

Science, technology, and innovation policy are still seen important for supporting the development of knowledge infrastructure and R&D (Schot and Steinmueller, 2018) which can enable the emergence of new technologies and companies as demonstrated by the case companies. First, public digital

infrastructure, such as supercomputers, available for private use is seen as a crucial enabler for attracting technology investments in the emerging field of artificial intelligence (See Quotation 87) where nations compete with significant industrial policy investments (Terzi et al., 2022). Research infrastructures can similarly provide private companies access to world-class facilities and expertise to develop and validate their ideas which would be otherwise out of their reach due to financial restrictions (See Quotations 88 and 89). Second, availability of leading knowledge centres (e.g., research) is seen as a shortcut to top global talent required for developing emerging technologies as well as a potential way to recruit talent (See Quotation 88). Third, existing industrial environments can provide various opportunities for emerging technologies to realise synergies by providing diverse use cases (See Quotation 90). Fourth, large and globally networked companies can be seen as an asset to provide opportunities in their value chains and to lead large-scale projects together with smaller participants (See Quotation 91).

One traditionally described fundamental characteristic of innovation is that innovations are new combinations of existing innovations, knowledge, and resources (Fagerberg, 2006). Realising the full potential of these combinatory innovations requires openness to new ideas and can be supported by greater variety of those knowledge components (Fagerberg, 2006) defined as the breadth of knowledge (Xiao et al., 2022). This breadth of knowledge can provide opportunities for new combinations enhancing innovation impact and breakthrough innovations (Xiao et al., 2022). The case companies include examples on how combinatory innovations have led to various outcomes ranging from radical innovations to utilisation of existing technologies for project implementation. First, Firm O is an example of a radical innovation in development that was a result of a large interdisciplinary research project combining expertise from various industries (See Quotation 92). Second, Firm Q is an example of a climate technology company that builds its product mainly on the foundations of existing technologies (See Quotation 93). As the company focuses on asset-heavy investments for supporting green transition, the company informant sees that their distinctive contribution comes from project execution expertise (See Quotation 93). Third, Firm B is an example of a large publicly listed company that has not traditionally been active in collaborative projects outside of its core domain and value chains (See Quotation 94). However, the company has recently started to consider the importance of participating in novel collaboration projects that could provide access to completely new value chains (See Quotation 94).

4.2.2.2 Adaptation to emerging challenges by supporting diversity and agility

Emerging science and technology challenge traditional assertive and persistent governance approaches (See Chapter 4.2.1.3), as the unpredictable nature of emerging science, technology, and innovation can create difficulties with unclear and frequently shifting objectives (Kuhlmann et al., 2019). Tentative governance is commonly suggested as a solution to adapt to these uncertainties by utilising "*provisional, flexible, revisable, dynamic and open approaches to governance*" (Kuhlmann et al., 2019). In addition to these tentative forms of governance and various forms of policy mix approaches (See Chapter 2.3.2), this study has identified diversity as a potential means to mitigate the risks involved with the uncertainty of emerging technologies.

Proactive technology neutral approach and flexibility for regulatory amendments are seen as options to adapt to societal changes and rapid technological development. New technologies can displace regulations as obsolete if the requirements are not applicable for future technologies, for instance, due to some detailed requirements (See Quotation 95). Therefore, proactive technology-neutral approaches are commonly seen as a starting point to prevent amendments for every technological invention (See Quotation 96). However, the occasionally unjustifiably assumed future-proofness of technological neutrality might lead to false impressions that laws do not require revisions (Greenberg, 2016), as discussed in Chapter 2.3. Therefore, it is important to have a readiness to amend the regulations, when necessary (See Quotation 97).

The targeted geographical region is an important dimension of innovation policy mixes (See Figure 3) as broad policies might apply to even multiple countries (e.g., EU policies) with different geographical realities. In the context of innovation policy, technological neutrality is seen as a potential approach to adapt to these regional differences as different technologies are suitable to different geographical realities. The parliamentary discussion related to deployment policy for broadband services provides an example, how different broadband technologies (optical fibre and mobile) can be suitable to different regions inside sparsely populated Finland (See Quotation 98). In addition, the different geographical realities can impact which climate technologies are most suitable for each region (See Quotation 99). Bergek et al. (2023) argue similarly that the complexity and heterogeneity of different sectors and application areas might require different technologies or tailored configurations.

Diversity can be argued to create various benefits, such as preventing technological lock-ins, supporting recombinant innovations, and increasing resilience against unexpected changes (See Chapter 2.3.3). Regarding diversity, the informants see the availability of a wide range of solutions necessary to enable choices for consumers and to solve complex societal challenges. First, the government officials and members of parliament highlight the importance of ensuring the availability of various options for consumers even with regulatory interventions if necessary (See Quotations 100 and 101). Second, the utilisation of a broad range of methods is seen important for tackling complex societal challenges, such as the environmental crisis (See Quotations 102 and 103).

Innovation policy can be utilised to influence the level of technological diversity by seeing diversity as an investment to realise the related potential benefits (van Rijnsoever et al., 2015). This study has identified various government interventions that can be utilised to postpone the risks related to technology selection and to maintain diversity. First, the regulator can require private actors to commit to legacy technologies, such as 2G mobile networks, for a longer period than would be commercially viable if the legacy technologies still have major societal value (See Quotation 104). However, this approach might incur unnecessary costs to the society unless the maintenance of legacy technologies can be incentivised as part of other projects. Second, the policy maker can choose to support secondary suppliers in crucial areas (See Quotation 105). Third, parallel development projects can be supported to reduce the ultimate risk of choice, especially if the cost of running parallel projects remains manageable (See Quotation 106). Fourth, it is seen necessary to avoid categorical regulatory exclusion of technologies as it can lead to a deadlock when alternative technologies are not developed (See Quotation 107).

4.2.2.3 Ensuring sovereignty in geopolitical competition as a rationale for government interventions

The recent rise of geopolitical tensions and global technology-based competition has increased the importance to evaluate the security implications of innovation policy (Kivimaa, 2022) and led to adding technology sovereignty to rationales of innovation policy (Edler et al., 2023). Similarly, this study has identified ensuring sovereignty in geopolitical competition as a rationale for government interventions. The key findings relate to national security concerns, supporting the development of the internal market, and motivations for technological sovereignty.

National security concerns challenge governments to adapt to changing circumstances in various ways. First, the changing security situation has challenged public organizations to restrict the openness of their information, which is against earlier desires for transparency (See Quotation 108). Second, public research institutes are facing pressure to direct research and development projects towards new security related topics (See Quotations 108 and 109), which "*might not need to be explored in an ideal world*" (See Quotation 108). Technology-neutral outcome-based thinking is still seen as a baseline in security related policy decisions (See Quotations 109 and 110) except when facing significant public threats which can justify high-level political interventions (See Quotation 110).

Staying competitive in the global race for the next big technology can require significant investments and governmental support in Finland and the EU (See Quotations 111 and 112), as countries compete with significant public support programs to win the technology competition related to green and digital transitions (See Quotation 111). Even though the national resources of a small country, such as Finland, to support technologies are limited (See Quotation 112), it is seen important to find ways to benefit from the industrial policy of other larger countries (See Quotation 113). Due to limited national resources, the EU is seen as a critical actor for Finnish innovation system in this global technology competition (See Quotation 111 and 114) as it has the potential to operate on a larger financial scale than national entities (See Quotation 114). Simultaneously, the increased state aid competition is seen as a challenge for small countries and the EU. First, it is seen as a risk that large countries with considerable industrial policy programs (e.g., USA) can 'kill off' the prerequisites for competition in the EU (See Quotation 111). Second, national industrial policies inside the EU (e.g., in Germany) might attract investments to specific EU countries (See Quotation 112) challenging fairness between the member states (See Chapter 4.1.1.3).

The rise of geopolitical competition and industrial policy tests political will to support a move towards technological sovereignty (See Chapter 2.3.3). Emerging technologies, such as artificial intelligence, can lead to large international dependencies when the technology has strategic importance for the nation but is developed elsewhere (See Quotation 115). Prevention of these dependencies is seen as an important policy goal (See Quotation 115) to ensure the regional self-sufficiency in the changed geopolitical circumstances (See Quotation 116 and 117). However, the prevention of these dependencies can test political will (See Quotation 115) as significant public support might be needed to stay globally competitive. This geopolitical competition can challenge governments to select technological directions, such as energy self-sufficiency (See Quotation 117), to secure national sovereignty while

balancing between potential costs and benefits of sovereignty. Even though technological sovereignty can be found important, it might be better to treat it is a means for achieving the ultimate policy goals instead of as an outcome itself as argued by Edler et al. (2023).

4.3 Topic 3. Policy mix design

Policy mixes are argued to play an important role for redirecting and accelerating technological change towards societal transitions (Rogge and Reichardt, 2016; Köhler et al., 2019) as discussed in Chapter 2.2.1. However, the design of these transformative policies does not always align with the policy rationales (Borrás and Schwaag Serger, 2022) or strategies due to the complexity, dynamics, and politics of policy mixes (Rogge and Reichardt, 2016). The aligned combination of policy strategy and policy mix design forms the basis for an effective policy mix. This study has identified two main categories of policy mix design that are of critical importance in policy design for governmental technology selection. First, governance architecture refers to deciding how responsibilities are delegated to different stakeholders, including various government agencies as well as the private market. Second, policy goal boundary setting is required to activate stakeholders, to adapt to the predictability of the decision field, and to create manageable objectives. These two categories are discussed in their respective chapters including accompanying tables with identified 2nd order themes, 1st order codes, and representative quotations. Figure 18 presents an overview of the two categories and identified 2nd order themes.

T3.1. Governance Architecture
1. Level of adaptation to market processes
2. Instrument's legal form and vertical governance level
3. Vertical coordination between governance levels and legal forms
4. Horizontal coordination between different government entities

T3.2. Policy goal setting
1. Balance between different policy goals
2. Mix of specific vs. broad neutral goals
3. Outcome-oriented vs. means-oriented policy goals
4. Targeted policy time horizon

Figure 18. Overview of policy mix design.

4.3.1 Theme 3.1. Governance architecture

Borrás and Radaelli (2014) define governance architecture as a unique type of institutional setup with three distinguishing characteristics: first, it takes a comprehensive, strategic, and long-term approach to tackling intricate issues; second, it focuses on achieving concrete, output-oriented objectives; and third, it utilizes a blend of both old and new organizational structures

within the context of the specific organization under consideration. This expanded view of governance provides a good basis for designing policy mixes in practice as it accounts for the complexity of policy mixes together with the institutional arrangements to reach the strategic goals. This chapter focuses on the institutional arrangements relevant for transformative innovation policy, such as different governance levels, the level of adaptation to market processes, and coordination of the activities. Furthermore, these findings expand the understanding on how to apply the principle of technological neutrality in practice (cf. Chapter 2.3.2). Related four 2nd order themes are discussed in their respective chapters and presented together with 1st order codes, and representative quotations in Table 23.

Table 23. Data supporting interpretations of governance architecture (Q118 – Q144).

1st order code	Quotation ID and representative quotations
1. Level of adaptation to market processes (Q118 – Q122)	
Adaptation to market processes and decisions is seen important.	Q118: "*[...] private markets are always the ones that find the future successes, and we should adapt to that*." (Public funding officer A)
	Q119: "*The support for renewable energy is tied to the electricity market price, and that's important*." (PTK 117/2017/3)
	Q120: "*[...] certain opportunities and risks are identified from the bottom and then, in a way, linked to that mission. [...] it doesn't solely stem from a centralized decision [...].*" (Public funding officer B)
Governmental technology selection is seen as less contradictory at early stages of innovation process	Q121: "*[...] the state has a greater power, responsibility, and right to define things closer to the knowledge end [of a value chain], while on the customer end, the only acceptable examples relate to dual-use products [...].*" (Innovation system expert C)
	Q122: "*[...] we need to quite strongly guide our R&D funding, and I don't see that as conflicting with technological neutrality in any way*." (Public funding officer C)
2. Instrument's legal form and vertical governance level (Q123 – Q129)	
Technology selection preferably as public servant decisions instead of regulation or political decisions, because categorical regulatory decisions can lead to dangerous prohibition of available options.	Q123: "*For us to succeed or thrive, we have to be agile in some respects, and for this reason, top-level regulation should remain at a high level, allowing the most knowledgeable entities, the authorities, to interpret or execute their duties in changing circumstances [...].*" (Innovation system expert C)
	Q124: "*[...] in the past, we haven't legislated specific technologies either. It has primarily been at the permit level, and a permit is an administrative decision, not legislation [...].*" (Policy maker A)
	"Q125: *Categorical regulatory decisions can be the most dangerous because they are regulation and thus, what they address is prohibited*." (Scientist C)
Politicians might not have the best qualifications for technology decisions.	Q126: "*[...] they [politicians] might not always be up to speed with all the new technologies, since it's not necessarily the politician's area of expertise. [...] one cannot consider the parliament, with perhaps the exception of the Committee for the Future, as a technological expert [...].*" (Policy maker D)
	Q127: "*The main point probably is that there's a need for individuals who truly have insight into matters. [...] It [technology knowledge] doesn't seem to be accumulating on the ministers, given their short terms nowadays*." (Innovation system expert A)

Utilize the expertise of government officials or employees at low governance levels instead of making high-level decisions for technology selection.	Q128: "*It [technology decisions] shouldn't be a political decision, nor should it be a decision of the highest-ranking government officials. Instead, it should be made leveraging the expertise accumulated within the government agencies.*" (Innovation system expert C) Q129: "*Ultimately, it [selection of research topics] rests on having visionary researchers and research professors who have a clear vision of what they want to accomplish. [...] we must trust that the skilled individuals will select areas that lead to smart outcomes in the future.*" (Scientist B)
3. Vertical coordination between governance levels and legal forms of policy instruments (Q130 – Q134)	
Flexible governance and agility are considered important to adapt to changing circumstances.	Q130: "*Technological development is so incredibly rapid [...] that the legislative process simply cannot keep up. [...] we have to be agile in some respects, [...] allowing the most knowledgeable entities, the authorities, to [...] execute their duties in changing circumstances, where the method of executing the task also changes and needs to be adaptable.*" (Innovation system expert C) Q131: "*[...] market principles and technological neutrality are implemented in future systems because it's essential to remember that these conditions for energy production will undoubtedly change very quickly in the coming years, and we must be able to respond to those changes.*" (PTK 47/2015/4)
Empower government officials to interpret high-level regulation instead of micromanaging them.	Q132: "*I don't think it's beneficial for a government that changes every four years to have to ponder [...], which technologies Finland should excel in and then micromanage downwards. [...] The Government or the legislator should set higher-level objectives [...]. This kind of a high-level directive and then the authorities interpret it and do their best with the funding available to them [...].*" (Innovation system expert C)
Freely thinking and operating researchers are considered important in academia and public research organizations.	Q133: "*It's more bottom-up [...] each of those [research teams] [...] within their research area then chooses [...] the kind of projects they work on [...], which then contribute partial solutions related to those high-level objectives.*" (Scientist B) Q134: "*[...] you need to have the team; you need to have those who think freely enough. In academia, there's an issue where many professors are dominant personalities, and they guide their Ph.D. students in the direction of their own interests. But I think it should be the other way around.*" (Scientist D)
4. Horizontal coordination between different government entities (Q135 – Q144)	
The innovation system should be managed in a balanced way ensuring a seamless pipeline from research to commercialization.	Q135: "*The best outcome comes when there's a flow throughout the entire [innovation] process, which requires a balance among the different components [e.g., basic research, and translating research findings into practice].*" (Scientist B) Q136: "*[...] there should be an exceptionally smooth and effective funding pipeline from both public and private sectors for these research-based innovations. [...] With such an approach [Solidium supporting pre-IPO companies], we would have a seamless pipeline all the way to the Helsinki Stock Exchange for these research-based companies.*" (Public funding officer A)
Innovations are seen important in various administrative sectors, but certain ministries are recognized as the main actors in public administration.	Q137: "*Even if R&D is a background factor, it is not necessarily the primary focus in our administrative sector as it is in Ministry of Economic Affairs and Employment (TEM) or the Ministry of Education and Culture (OKM).*" (Policy maker A) Q138: "*There is talk about this government approach where innovations are a matter that spans across all administrative sectors. [...] One of the tasks [of Ministry of Economic Affairs and Employment] is also to [...] produce knowledge, tools, skills, and practices that could be useful in other administrative sectors [...].*" (Policy maker C) Q139: "*The entire energy transition underway in transportation is purely a matter of research and innovation activities.*" (Policy maker B)
Innovation activities in ministries are challenged by lack of interagency collaboration and limited resources.	Q140: "*There's very little [collaboration between the Ministry of the informant and one of the public sector funding entities]. Overall, it [the funding entity] [...] doesn't really seek to collaborate much within the Finnish Government.*" (Policy maker B) Q141: "*But I do admit that, of course, government resources are incredibly limited and there's a lot of work to do. Even if RDI [research, development, and innovation] would be there in the background, it isn't necessarily the primary focus in our administrative sector [...].*" (Policy maker A) Q142: "*For instance, the Research and Innovation Council has not been used nearly as much as it could be for contemplating these kinds of [technology] matters or for forming a comprehensive view on various issues.*" (Innovation system expert A)

Interagency collaboration is sought to align strategic choices because separate evaluation processes can lead to differing strategic choices between government agencies.	Q143: "*[...] for example, [one Finnish innovation funding agency] has selected specific focus areas for their investments. One technology sector was not included based on their assessment [in contrast to the interviewee's organization]. [...] As part of our own strategy work, we have to ensure that our focus aligns naturally with what other public sector funding entities have chosen as their themes.*" (Public funding officer A) Q144: "*[...] most likely it comes more from performance negotiations and that direction, considering what the ministry thinks and wants and so forth. And it's not completely one-sided. We often propose specific things to the ministry, who then validates those ideas at their end, assessing whether they align with their goals and what they wish us to work on.*" (Public funding officer B)

4.3.1.1 Level of adaptation to market processes

Market-based technology selection processes are at the core of the principle of technological neutrality according to which the government should not discriminate against any technologies (See Chapter 2.3.1). Furthermore, such participatory processes are in the core of transformative innovation policies where a broad set of actors can be involved in setting the direction and implementing the policies (Haddad et al., 2022). The lack of stakeholder involvement can lead to various challenges that can become barriers to policy implementation (Haddad et al., 2022). However, excessive reliance on market processes can lead to various market failures, which can justify government interventions in various contexts (See Chapter 2.1.2). To prevent the adverse consequences of market processes, it is important to deliberately decide the level of adaption to market processes utilised for the innovation policy mix. This empirical study has identified two important findings related to this.

First, the adaptation to market processes and decisions is seen important in policy making as argued in the literature. The market-based technology selection is seen as the baseline that the government should adapt to (See Quotation 118). Various policies aim to increase flexibility by connecting the targeted policy outcomes to market processes. For instance, the renewable energy support is tied to the electricity market prices with the goal to ensure cost-efficiency by preventing excessive support in case of favourable development of market prices (See Quotation 119). The participatory processes are found important also by the representatives of public sector funding entity. For example, the missions of one public sector funding entity do not solely stem from centralised decisions, but they also identify opportunities from the participating companies (See Quotation 120).

Second, governmental technology selection is seen as less contradictory at early stages of innovation process, such as in research funding and knowledge creation. For example, Innovation system expert C sees that technology-specific government interventions are more justified "*closer to the knowledge end [of a value chain], while on the customer end, the only*

acceptable examples relate to dual-use products" (See Quotation 121). This statement relates to the wider discussion on the role of government and rationales for government interventions. See Chapter 4.1.1.4 for additional discussions on the identified preferences for market-based or governmental selection of solutions.

4.3.1.2 Instrument's legal form and vertical governance level

Instrument's legal form (e.g., regulation or guidance) and vertical governance level (e.g., at federal or local level, and government departments) are some of the more visible parts of innovation policy mixes (Rogge and Reichardt, 2016) as discussed in Chapter 2.2.1. These two concepts are highlighted here due to their significance in policy design as they have a major impact on the binding strength of the instrument (Rogge and Reichardt, 2016) defining the authoritative force of the policy intervention (Acciai, 2021) (See Chapter 2.2.2). This study highlights three important aspects related to these two concepts.

First related to instrument's legal form, technology selection should be preferably made as public servant decisions instead of regulation or political decisions. This approach is justified when the government has knowledgeable entities and public servants who can "*interpret or execute their duties in changing circumstances*" based on high-level regulation (See Quotation 123). This is seen as the basic approach also by the government officials, who have primarily used permits as administrative decisions to regulate technologies instead of technology-specific legislation (See Quotation 124). Overall, categorical regulatory technology decisions or laws are seen problematic as they can lead to dangerous prohibition of available options (See Quotation 125).

Second related to vertical governance level, it is important to consider which government entities are best positioned to make technology decisions. For example, politicians might not have the best qualifications for technology decisions. Technologies are not seen necessarily as the politicians' area of expertise except for specific entities inside the parliament, such as the Committee for the Future (See Quotation 126). Furthermore, the limited terms of politicians, such as ministers, make it challenging to accumulate necessary technology knowledge of the individual to make informed technology decisions (See Quotation 127).

Third, the expertise of government officials or employees at low governance levels should be utilised instead of making high-level decisions for technology selection. This relates to the previous challenge that the politicians or

highest-ranking government officials might not have the best expertise available. Instead of political decisions, it is seen important to "*leverage the expertise accumulated within the government agencies*" (See Quotation 128). Similarly, it is seen important that the research institutes "*trust that the skilled individuals will select areas that lead to smart outcomes in the future*" (See Quotation 129). Overall, the accumulation of knowledge and its purposeful utilisation are seen as important enablers of efficient governance.

4.3.1.3 Vertical coordination between governance levels and legal forms of policy instruments

The concept of multi-level governance is frequently employed in the fields of governance and political science to describe the interplay among different layers of jurisdiction and administrative governance, ranging from international and national to regional and local levels (Borrás and Schwaag Serger, 2022). The related policy coordination across different systemic levels, policies, and government agencies is important for preventing potential policy coordination failures, which can prevent reaching the policy goals due to incoherent policy mixes (Weber and Rohracher, 2012). Furthermore, reflexive governance arrangements are required for institutional coordination to create adaptive policies, so that distributed decision-making and intelligence as well as parallel developments can be utilised to adapt to uncertainties (Weber and Rohracher, 2012). This chapter focuses on the three identified main findings related to vertical coordination between governance levels and legal forms in a flexible way to enable adaptive policies.

First, flexible governance and agility are considered important to adapt to changing circumstances. The rapid development of technologies is seen as a challenge for the slow legislative processes, which calls for alternative, more "agile" governance processes (See Quotation 130). In the context of deployment policies, technological neutrality and adaptation to market processes are seen as potential ways to adapt to the rapid changes of the socio-technical system (See Quotation 131). This relates to the wider discussion on how to adapt to emerging societal challenges (See Chapter 4.2.2.2) and enable policy sustainability (See Chapter 2.4.1).

Second related to vertical governance, it is seen important to empower government officials to interpret high-level regulation instead of micromanaging them. The legislators and politicians are expected to avoid micromanagement by creating high-level objectives that the government agencies can interpret in their areas of expertise (See Quotation 132). This vertical coordination is expected to improve the government's ability to adapt to

uncertainties as the government officials are not restricted by stringent high-level policies.

In addition to flexible political structures, freely operating researchers are considered important in academia and public research organizations. A bottoms-up selection of research areas is seen necessary to enable radical innovations that can eventually contribute to the high-level objectives of the public research institutes (See Quotation 133). However, this approach can be challenged by "*dominant personalities*" of the research supervisors that might restrict the ability of research teams to "*think freely*" by directing the research towards "*their own interests*" (See Quotation 134).

4.3.1.4 Horizontal coordination between different government entities

Horizontal coordination between different government entities is another necessary activity that is required to create effective policy mixes consisting of a wide range of interventions (See Chapter 2.3.2). This empirical study has identified various aspects in the Finnish innovation system that can either support or prevent the creation of coherent policy mixes. A comprehensive innovation support system is seen as a desirable outcome, but the lack of interagency collaboration and limited resources have restricted the ability of government agencies to consider innovation activities in their daily operations.

The innovation system should be managed in a balanced way ensuring a seamless pipeline from research to commercialization. As the Finnish innovation support system consist of various public entities covering different sectors and stages of innovation process, the coordination between these entities becomes crucial. It is believed that the "*best outcome comes when there's a flow throughout the entire [innovation] process, which requires a balance among the different components [e.g., basic research, and translating research findings into practice]*" (See Quotation 135). This type of a systematic approach is seen necessary also in the funding side where the Finnish system has the potential to create a "*seamless*" pipeline covering both public and private sectors for research-based innovations all the way from basic research to the stock exchange (See Quotation 136).

Innovations are seen important in various administrative sectors, but certain ministries are recognized as the main actors in public administration. The governance modes for managing innovation policy mixes have important implications for the policy impact (Magro and Wilson, 2019). This is also recognised in the Finnish political context, where the discussions are ongoing, for example, for different options for the governance of research and innovation

policy (Parliamentary Working Group on Research, Development and Innovation, 2023), information and technology policy (Siilasmaa, 2023) and mission-oriented policies (Gronchi et al., 2023). Currently, the Ministry of Economic Affairs and Employment (TEM) and the Ministry of Education and Culture (OKM) and related government agencies are recognized as the main actors in the innovation system (See Quotation 137). The Ministry of Economic Affairs and Employment is seen as the central actor that supports other administrative sectors with innovation related knowledge and practices (See Quotation 138). Even though the importance of innovation activities is recognised in various administrative sectors (See Quotation 139), there are various challenges that can compromise the purposeful use of innovations to support the policy goals of these administrative sectors.

Innovation activities in ministries are challenged by lack of interagency collaboration and limited resources even if innovations are found important for their administrative sectors. Policy maker B notes how there has been very little collaboration between their ministry and one of the public sector funding entities (See Quotation 137). This type of limited interagency collaboration poses a challenge for policy coordination and decentralised governance models, which rely on active cooperation. This problem might be further expanded by the "*incredibly limited government resources*", that are focused on the primary focus areas of the administrative sectors instead of secondary goals related to research, development, and innovation (See Quotation 141). This governance challenge of innovation policy requires significant attention especially related to transformative innovation policy that requires coherent innovation policy to realise the full potential of emerging technologies to support the transitions. From the strategic technology governance perspective, the Research and Innovation Council is seen as an underutilized public actor that could help in forming a comprehensive view on strategic technology matters (See Quotation 142) in addition to the Ministry of Economic Affairs and Employment. This has been acknowledged also in the recent Finnish government programme, which aims to strengthen the role of the Research and Innovation Council to ensure that the coordination of research, development and innovation (RDI) activities is adequate, and planned additional RDI funding is allocated appropriately (Valtioneuvosto, 2023).

Even though there have been various challenges with interagency collaboration, there are also various attempts to for interagency collaboration to align the strategic choices of different government entities. For example, different public sector funding entities have cooperated in their strategy work to improve the alignment between their focus areas for funding (See Quotation 143). However, there have been cases where the focus areas of these funding areas have differed (See Quotation 143), which could lead to incoherent

policy mixes challenging the seamless funding pipeline for technologies. In addition to this cooperation between funding agencies, these organisations are steered by the responsible ministries as part of performance negotiations (See Quotation 144). However, these companies still operate independently with their own strategies, which can lead to differing strategic choices between government agencies. It would be important to deliberately decide how much cross-agency alignment is wanted as centralised and decentralised decision-making have their own benefits and challenges.

4.3.2 Theme 3.2. Policy goal boundary setting

Policy goals play a crucial role in influencing the impact of innovation policy mixes together with rationales and implementation choices (Flanagan et al., 2011) as they direct the implementation of policy interventions. However, creating purposeful policy goals can be challenging, as public policies can consist of a diverse and constantly shifting set of goals, including potentially conflicting goals (Flanagan et al., 2011). Simultaneously, the policy makers must balance between conflicting interests of different interest groups to create fair (See Chapter 4.1.1) but effective policies (Gawel et al., 2017) according to the desired policy strategy (See Chapter 4.2). This chapter provides empirical findings for different aspects of policy goal setting that are necessary for designing purposeful innovation and technology policies. These processes include decisions on (1) the balance between different policy goals, (2) using broad neutral goals vs. multiple specific goals, (3) the outcome-orientation vs. means-orientation of the goals, and (4) the targeted policy time horizon. Related four 2nd order themes are discussed in their respective chapters and presented together with 1st order codes, and representative quotations in Table 24.

Table 24. Data supporting policy goal setting (Q145 – Q173)

1st order code	Quotation ID and representative quotations
1. Balance between different policy goals (Q145 – Q148)	
Freedom and flexibility are needed in governmental RDI investments besides investment themes chosen by government organizations.	Q145: "*[...] I wouldn't want to give too much emphasis to the thematic areas selected by the public funding entities. They are areas that have been identified as having potential and thus are invested in, but alongside that, there must be freedom and flexibility for everything else.*" (Public funding officer A)
	Q146: "*[...] certain opportunities and risks are identified from the bottom and then, in a way, linked to that mission. [...] it doesn't solely stem from a centralized decision [...].*" (Public funding officer B)
The state should avoid too focused investments in single technologies or themes.	Q147: "*[...] the division that a public sector funding entity currently, at least tacitly, vocalizes is that 50 percent of themes are chosen, and 50 percent are left completely open-ended. The same should almost apply to other similar public organizations too. [...] no one can predict the future.*" (Public funding officer A)
	Q148: "*[...] the state shouldn't decide to allocate half of all our funds to a single technology; instead, we should let the market dictate that.*" (Innovation system expert C)

2. Mix of specific vs. broad neutral goals (Q149 – Q154)	
Overlapping of parallel technology-specific support systems should be avoided to prevent distortion of competition.	Q149: "*[...] the government proposal is based on the premise that it doesn't alter consistent, technology-neutral climate policy. Instead as an example, the goals of increasing the use of biofuels and biogas are still pursued through other legislation as before.*" (PTK 124/2020/8) Q150: "*We must also ensure that no other subsidies play a role in this competition format, to avoid any combinations. [...] the issue is ensuring that all [clean, renewable energy sources] start from the same baseline.*" (PTK 117/2017/3) Q151: "*Small hydroelectric power has the opportunity to receive its own subsidies, so it has a separate support system. [...] we can't have overlapping support systems.*" (PTK 49/2018/4)
Managing parallel policy initiatives targeting the same broad objective can create administrative challenges.	Q152: "*But it's very challenging [to build that expertise or introduce solutions related to these higher-level goals], due to the different timelines involved. By the time commercialization occurs based on the latest science and research, several years have passed. This makes it unclear for the researcher how their specific research area helps the big picture.*" (Scientist B) Q153: "*Overall, the use of support instruments, mixing them together, is challenging. It's difficult for us, the decision-makers and also for companies.*" (PTK 117/2017/3) Q154: "*[...] but of course, this [technology-neutral approach to standards] can be regulatively tricky. Instead of needing one expert group handling one methodology for carbon capture, more resources would be required from governments to develop competencies for setting standards for multiple technologies.*" (Firm P)
3. Outcome-oriented vs. means-oriented policy goals (Q155 – Q164)	
Policies are expected to target outcomes instead of means to allow different ways to achieve the goal.	Q155: "*Legislation should primarily be tied to results, outputs, or outcomes. Certain outcomes are desired and others not, but the legislation shouldn't focus on specifying how that outcome is achieved. Qualitative criteria, such as carbon dioxide emissions, might be tied to achieving certain outcomes in some cases.*" (Innovation system expert C) Q156: "*[...] when the goal is to reduce emissions in personal transportation, there shouldn't be a prescriptive choice of technology on how that reduction is achieved. Instead, enable it to be accomplished in various ways and see which of those proves most effective through competition.*" (Scientist B)
Policy goal impacts which technologies are likely to win.	Q157: "*Linked to technology neutrality is the question of whether to measure only exhaust emissions or the entire life cycle, and to what extent this is taken into account in technology neutrality.*" (Policy maker B) Q158: "*When implementing [competitive bidding for renewable energy] in a technology-neutral way, it's essential to understand that those with the best efficiency and productivity metrics are likely to perform well in the competition.*" (PTK 49/2018/4) Q159: "*Renewables can broadly participate in the competition, but the likely winners are wind energy and wood biomass facilities, as they are the most competitive renewable energy forms that means providing the cheapest capacity. And the goal here is to invite tenders for and identify this cheapest capacity.*" (PTK 49/2018/4)
Technologies might not be comparable in open, outcome-oriented technology competitions.	Q160: "*If there's a completely open competition, [...] for technological development, then these projects aren't even comparable. They are freely defined by the bidders based on their objectives, meaning no specific technological choice can be made in a way.*" (Public funding officer C) Q161: "*It [a subject-free research call] involved diverse topics like brain surgery and battery chemistry, assessed together. Reviewers had to compare industries or sectors with potentially different future prospects, comparing, in a sense, apples to oranges.*" (Firm O)
A combination of outcome-oriented regulations can be used to prevent participation of specific technologies instead of technology-specific exclusion.	Q162: "*If the perspective is that hydropower should not be further produced in Finland, there are also other ways to prevent its production. But does it need to be excluded here [in competitive bidding for renewable energy], if and when it is likely a very cost-effective means of generating renewable, clean energy?*" (PTK 117/2017/3) Q163: "*Hydropower is excluded on the basis that [...] there's no competition in large-scale hydropower and no basis for subsidies.*" (PTK 49/2018/4) Q164: "*[...] companies are no longer required to use a specific technology. [.] And for protecting consumers, there are conditions in the network operating license stipulating that technologies cannot be changed overnight without notification.*" (Policy maker A)

4. Targeted policy time horizon based on predictability of the decision area (Q165 – Q173)	
Temporary regulation can allow the evaluation of regulatory impacts and necessary regulatory adjustments to changes in the regulatory environment.	Q165: "*They always find a new way, a new method. When interest was capped, an alternative method was devised. […] effectively circumventing the legislation. […] these issues need to be tackled piece by piece, and we should be ready to be make adjustments and corrections […].*" (PTK 66/2018/10) Q166: "*[…] from the perspective of […] businesses […], it's quite a drastic measure if the ban were to continue indefinitely. Therefore, it [the regulation] was decided to be temporary, so its effects can be evaluated over time and also to ensure compliance with developments in European Union legislation.*" (PTK 51/2021/6)
Preventable surprises ("knowable unknowns") could be potentially prevented, for example, with trend analysis based on reliable trends at least in short term.	Q167: "'*Knowable unknowns', which means that an outcome or event surprised us—it was unknown, but for the wrong reasons. We could've anticipated it by following basic trends or indicators, but we didn't. There are countless examples, a private sector example is Kodak, which invented the digital camera. The digital camera capabilities surpassed those of film cameras, catching them off guard and leading to bankruptcy. […] We should build a toolkit around this concept ['knowable unknowns'], focusing on trends that have a reliable predictive capability, like population growth, for instance.* " (Innovation system expert C) Q168: "*Over short timeframes, one can reasonably predict trends, but in the longer term, many unpredictable variables can emerge quickly.*" (Firm F)
Predicting certain unexpected events ("unknowable unknowns") and the next breakthroughs is found very challenging.	Q169: "*[…] no one has a crystal ball. We simply don't know what the next big thing in the future will be.*" (Public funding officer A) Q170:"*These days, we constantly face these unexpected 90-degree turns. Forecasting technologies is incredibly difficult. Especially these breakthrough technologies, like artificial intelligence and ChatGPT, it's challenging. Or consider that maybe next year or the year after, we might start seeing some practical applications from quantum computers. That would instantly open up entirely new worlds.*" (Innovation system expert A) Q171: "*[…] the "unknowable unknowns". For instance, Russia's attack on Ukraine. Again, it was likely that Russia will cause some difficulties […]. However, the exact timing and Ukraine as the target were quite unpredictable until just weeks prior the attack. The best and possibly only remedy for such situations is agility, creating systems that can respond swiftly. Organizations like NATO have rapid response forces designed for such unexpected events. Exactly similar mechanisms can be instituted within the public sector for various needs.*" (Innovation system expert C)
Predicting the timing of technological breakthroughs or turning points is found challenging even if the turning point can be expected to happen.	Q172: "*A turning point that hasn't yet happened, for example, is foldable and rollable screens. They've been researched for 20 years, but the expected turning point hasn't occurred, even though it is technically feasible. […] I assumed this turning point would've happened a year or two ago, but it hasn't.*" (Firm C) Q173: "*Scientists have warned for decades that a pandemic is inevitable, though the exact timing is uncertain. This unpredictability often leads politicians, government officials, and business leaders to delay actions because it is unlikely […] in the next quarter but likely […] during the following 20 years. […] However, when it eventually happens, it surprises us as a knowable unknown that needlessly catches us off guard.*" (Innovation system expert C)

4.3.2.1 Balance between different policy goals

One of the key activities of policy making is to prioritise between the broad set of often conflicting goals and initiatives included in the policy mixes, such as conflicting goals related to technological neutrality (See Chapter 2.3.3). Even though policy interventions are commonly justified with economic incentives and correction of market failures, standard economy theories and various informants suggest limiting government interventions to decrease the risk of government failures (Bloom et al., 2019). If these risks of government failures and opportunity costs are high compared to the potential benefits of the policy, modest policies might be a preferable choice compared to

overly ambitious initiatives (Edler et al., 2016). Policy makers should recognise that it is impossible to fix all of these market and government failures at once (Mazzucato et al., 2020). This calls for prioritisation of the policy goals to balance between different policy goals, so that the ambitious goals do not lead to unmanageable risk of government failures due to excessive focus of societal resources. Overall, this empirical study has identified that there is a perceived need to avoid excessive targeting and rigidity in public technology choices especially related to public innovation funding. In addition, avoidance of excessive targeting can be seen as a good starting point for other innovation policy interventions even though strong interventions might be justifiable, for example, related to sustainability transitions.

This study has identified that freedom and flexibility are seen necessary in governmental RDI investments besides investment themes chosen by government organizations. Even though Finnish public sector funding entities choose strategic focus areas for financial support, there is hesitation "*to give too much emphasis to these thematic areas*" (See Quotation 145). It is believed that "*there must be freedom and flexibility for everything else*" alongside these areas (See Quotation 145), so that the organisations do not miss out on significant opportunities outside the chosen themes. The Finnish public sector funding entities already aim to improve this flexibility with various mechanisms, such as bottoms-up identification of opportunities (See Quotation 146) and open-ended funding programs regardless of the theme (See Quotation 147).

This diversification of government investments is seen important to avoid the risk of government failures related to too focused public investments without the involvement of market processes. This can be most relevant in strategic technology choices where "*the state shouldn't decide to allocate half of all our funds to a single technology*" but instead it "*should let the market dictate that*" (See Quotation 148). Similar views are presented related to the public funding agencies, which direct significant amounts of innovation funding. For instance, a combination of theme-based and open-ended funding programs is found beneficial due to the difficult predictability of the future (See Quotation 147). The government should balance between the potential benefits, such as economies of scale, and the risks, such as government failure, of focused investments (cf. discussion on technological goals in Chapter 2.4.1).

The balance between focused investments and diversification should be adjusted based on the desired policy strategy (See Chapter 4.2). First, "the competition strategy" (See Chapter 4.2.1) should mainly utilise open-ended programs to enable broad participation and competition in the project calls.

Second, “the resilience strategy” (See Chapter 4.2.2) should combine focused investments and diversification similarly to the current approach. Strategic areas of focus can be required to support the emergence of nationally critical technology areas, so that they can reach economies of scale. On the other hand, diversification and open-ended programs can support flexibility and enable the emergence of unpredictable technologies.

4.3.2.2 Mix of specific vs. broad neutral goals

Multiple policy mix design choices impact the boundaries where the policy is and is not applied. These boundaries have a significant impact on the inclusiveness of the policy, as narrow boundaries can lead to under-inclusiveness and potential discrimination whereas broad boundaries might be over-inclusive and challenge the effective implementation and governance of the policy (See Chapter 2.3). The specificity of these boundaries is mainly influenced by two policy design choices: the level of the policy goal based on technology hierarchy level and the specificity on the chosen hierarchy level (See Figure 6 in Chapter 2.3.1). The combination of these policy design choices introduces a set of approaches to divide the main policy goal with the extreme ends ranging from a single, broad and neutral goal to a complex mix of specific policies. In addition to the clear impact on policy inclusiveness, the different combinations of these policy design choices influence the management of the policy mix by introducing their own benefits and challenges. This empirical study has identified various important considerations related to these different approaches.

Parallel technology-specific policies are used in practice due to various reasons, such as easier management of the individual policy and legacy reasons. The Finnish parliamentary discussions on energy policy provide an interesting example of the challenges related to managing parallel technology-specific support systems. The government aims to create “*consistent, technology neutral climate policy*” (See Quotation 149) and to enable fair competition between different energy technologies (See Quotation 150), while it comprises of various technology-specific policies (See Quotations 149 and 151). However, the management of these parallel policies has challenged the consistency of the policy mix as the separate policies might create unexpected combinations that can distort competition (See Quotation 150).

Simultaneously, the parallel policies can create an administrative challenge for the policy makers leading to inconsistent and non-neutral policy mixes. The management of broad, high-level objectives can be very challenging for various stakeholders, as they involve the coordination of different timelines, projects (See Quotation 152) and instruments (See Quotation 153). First, a

broad mix of specific instruments creates difficulties for policy makers (See Quotation 153), as they should properly understand the mechanisms of all the involved instruments and technologies (See Quotation 154). Second, companies might find instrument mixes challenging (See Quotation 153) as they should navigate through all the different instruments. Third, high-level and long-term goals can obscure the relation between the individual's contribution and the organisational goals.

4.3.2.3 Outcome-oriented vs. means-oriented policy goals

Policy goals can be designed to be outcome-oriented or means-oriented, which means that the policy can target and regulate either the outcomes and effects or the means, tools, and technologies to achieve the outcome. Outcome-oriented interventions are generally seen as the preferred option in various contexts, such as legislation (European Commission, 2023), mission-oriented innovation policies (Mazzucato et al., 2020), technological neutrality (See Chapter 2.3.1), and sustainability transitions (Díaz et al., 2020). These outcome goals are used to direct actions (Díaz et al., 2020) without specifying the exact means, so that a broad range of means can be motivated to solve the goal (Mazzucato et al., 2020). This chapter discusses the key empirical findings related to outcome-oriented and means-oriented policy goals, including the benefits and challenges.

Policies are expected to target outcomes instead of means to allow different ways to achieve the goal. First, legislation is expected to be "*primarily tied to results, outputs, or outcomes*" instead of "*specifying how that outcome is achieved*" (See Quotation 155). Second, other policies, such as emissions reduction acts, should not either include "*prescriptive choice of technology on how that reduction is achieved*" (See Quotation 156). The justification for these technology-neutral interventions is to "*enable the goal to be accomplished in various ways and see which of those proves most effective through competition*" (See Quotation 156). These findings align with the literature as described above.

When considering outcome-oriented policies, it is important to understand that the policy goal impacts which technologies are likely to win. This is natural as the policy goal and its boundaries create the ground rules for participation in policy implementation and inclusiveness of the policy. As the policy goals can be defined in various ways targeting different areas and actors, the policy goal setting could have important implications for the application of the principle of technological neutrality (See Quotation 157). It has been occasionally noticed also in the Finnish parliament that the policy goal and design impact which technologies are likely to perform well even with

technology neutral policies (See Quotation 158). For example, one member of the parliament tells how "*the likely winners [in the competitive bidding for renewable energy] are wind energy and wood biomass facilities*", even though "*renewables can broadly participate in the competition*" (See Quotation 159). This policy approach still aligns with the main principles of technological neutrality as the policy does not a priori define the winners and enables broad competition. Technological neutrality should not be confused with equality principles, where each technology would receive the same regardless of their performance towards the policy goal.

One of the challenges with broad outcome-oriented challenges relates to the evaluation of potentially very different initiatives. For example, technologies might not be comparable in open, outcome-oriented technology competitions as the bidders are allowed to freely propose projects based on their own objectives (See Quotation 160). These subject-free project calls can involve "*diverse topics like brain surgery and battery chemistry, assessed together*", which can lead to "*comparing, in a sense, apples to oranges*" (See Quotation 161). This openness and broadness of the goals can lead to, for example, overemphasis on the familiar technologies over radical innovations because the evaluators are more likely to understand the effects of mature technologies. Furthermore, this can create administrative challenges as the evaluators should familiarise themselves with a wide range of solutions instead of focusing on their areas of expertise.

Means-oriented or technology specific policy goals can be seen as a tempting option for excluding potentially harmful solutions from the policy scope. For example, hydropower was excluded from the Finnish competitive bidding for renewable energy, even though it could be seen as "*a very cost-effective means of generating renewable, clean energy*" (See Quotation 162). The categorical exclusion of hydropower has been justified in the parliamentary discussions with the lack of competition (See Quotation 163), separate support systems (See Quotation 151), environmental impact and technological differences. However, the decision to categorically exclude hydropower from participating has been challenged, as there could be other ways to prevent its production if desired (See Quotation 162). For example, the policy makers could use other outcome-oriented approaches, such as environmental laws to regulate the environmental effects or requirements for competition. These combinations of outcome-oriented policies or requirements can be used to prevent participation of specific technologies instead of technology-specific exclusion. For example, Policy maker A notes that various conditions of operating licenses have been used for protecting consumers instead of technology specific requirements (See Quotation 164).

Outcome-oriented policy goals should be seen as the starting point for both policy strategies (See Chapter 4.2). The outcome-orientation purposefully directs the policy making process towards thinking about the critical outcomes and decreases the risk of harmful technology exclusion. Especially, the "competition strategy" requires outcome-orientation to enable broad market-driven competition without unnecessary disruptions. Outcome-orientation is also critical for "resilience strategy" to direct the goals of transformative policy to the desired outcomes to prevent political exclusion of available solutions to solve the complex societal challenges. On the other hand, means-oriented or technology-specific policies might be required in certain circumstances, for instance, if the outcome-oriented goals fail to accelerate the transitions towards critical societal outcomes.

4.3.2.4 Targeted policy time horizon based on predictability of the decision area

The dimension of time is a vital part of policy mixes due to their dynamic and complex nature where the elements, processes, and characteristics of policy mix evolve over time (Rogge and Reichardt, 2016). The selection of an appropriate policy time horizon can be a difficult process as it is influenced by various factors. First, the targeted transitions can take several years or even decades, which require the coordination of different interventions at different stages to maintain consistency over time. Second, the uncertainty of sustainability transitions, changing contexts, and technological change increase the importance of policy adaptation and learning as the policy goals and effects can vary over time (Rogge and Reichardt, 2016). Simultaneously, the development of internationally competitive knowledge areas might require long-term commitments, as discussed in Chapter 4.2.1.3. The empirical findings in this chapter especially focus on the predictability of the decision field and its impact on the targeted policy time horizon. Other aspects of policy sustainability are discussed in literature review related to technological neutrality in Chapter 2.3 and the summary of the literature in Chapter 2.4.

Permanent policies or regulation might not be suitable for all circumstances, due to various challenges, such as changing contexts. The future-proofness of the regulation can be compromised by various actors that "*always find a new way*" to "*effectively circumvent the legislation*" (See Quotation 165). The legislators have noticed the importance of flexibility in these situations that "*these issues need to be tackled piece by piece, and we should be ready to be make adjustments and corrections*" (See Quotation 165). Another challenge with permanent regulations is that it can be a "*drastic measure*" for businesses, for example, if certain solutions are banned indefinitely (See Quotation 166). As an alternative, temporary regulation can be a lighter

intervention that allows the evaluation of regulatory impacts and necessary regulatory adjustments to changes in the regulatory environment (See Quotation 166). Even though permanent regulations and policies have their challenges, the policy makers can still strive for a mix of flexibility and stability, for example with policy mix approaches (See Chapter 2.4.1).

Related to future-proofing, the policy makers should start by identifying surprises that could be potentially prevented ("knowable unknowns"), for example, with trend analysis based on reliable trends at least in short term. The "knowable unknows" refer to "*an outcome or event [that] surprised us [...] but for the wrong reasons*" (See Quotation 167). Project management literature suggests that these "knowable unknowns" could be uncovered with various project design and behavioural approaches, such as scrutinization of project plans, interpretation of weak signals, and systems thinking (Ramasesh and Browning, 2014). Similar approaches could be applicable also in policy design, even though the contexts might be even more complex. The informants also suggest the creation of "*a toolkit around this concept*", which could focus, for example, on reliable trends, such as population growth (See Quotation 167). However, it should be noticed that some of these trends might be applicable only for short timeframes, as "*many unpredictable variables can emerge quickly*" in the longer term (See Quotation 168).

The "unknowable unknowns" are another aspect that challenges the sustainability of policies. Predicting these unexpected events ("unknowable unknowns") and the next breakthroughs is found very challenging, as "*we simply don't know what the next big thing in the future will be*" (See Quotation 169). Overall, the task of "*forecasting technologies is incredibly difficult*" and this challenge is amplified when dealing with breakthrough technologies that have the potential to cause "*unexpected 90-degree turns*" and "*open up entirely new worlds*" (See Quotation 170). In addition to technology forecasting, other "unknowable unknowns", such as Russia's attack on Ukraine, can cause significant challenges to societies (See Quotation 171). Perhaps one of "*the best and possibly only remedy for such situations is agility, creating systems that can respond swiftly*" (See Quotation 171). Overall, these "*unknowable unknows*" highlight the importance of flexible governance arrangements, as discussed, for example, in Chapters 2.3.2 and 4.2.2.2.

Predicting the timing of technological breakthroughs or turning points introduces another challenge even if the turning point can be expected to happen. I will present two illustrative examples from the research sample to demonstrate this. First, foldable and rollable screens have "*been researched for 20 years, but the expected turning point hasn't occurred, even though it is technically feasible*" (See Quotation 172). The informant from Firm C "*assumed*

this turning point would've happened a year or two ago, but it hasn't", even though the person had closely followed the development of the field (See Quotation 172). Second, the recent COVID-19 pandemic surprised politicians, government officials, and business leaders, even though "*scientists have warned for decades that a pandemic is inevitable, though the exact timing is uncertain*" (See Quotation 173). The challenge with these events is that those are "*unlikely […] in the next quarter but likely […] during the following 20 years*" which can lead to delay of necessary actions (See Quotation 173).

The targeted policy horizon has the following policy implications. First, adjust the targeted policy time horizon based on the predictability of the decision area, as high uncertainty is likely to challenge the future-proofness of the policy. Second, develop capabilities to uncover "knowable unknowns" to prevent policy failure for the wrong reasons. Third, prepare for remaining uncertainties during the policy time horizon with flexible policy arrangements, such as tentative governance. Fourth, temporary policies can be used as a lighter intervention compared to permanent policies, as it naturally enables impact evaluation and policy adjustments at the end of lifetime. Related to the different policy strategies (See Chapter 4.2), flexible arrangements are particularly critical in the "resilience strategy" that aims to accelerate major transitions with multiple uncertainties. On the other hand, robust and long-term policies are important for both strategies as various investments benefit from certain degree of stability. However, the importance of political and regulatory stability is highlighted in the "competition strategy" to enable undistorted market-driven development.

4.4 Synthesis of the empirical findings – Model for governmental technology selection strategies in the context of technological neutrality

The outcome of this empirical study is a model (See Figure 19) that provides a strategic perspective for governmental technology choices. The model integrates the empirical findings of the study (See Chapters 4.1 – 4.3) into a unified framework. It links policy maker competence and values (See Chapter 4.1) with policy mix elements (See Chapters 4.2 and 4.3), ultimately influencing policy outcomes through policy adoption. Next, the various elements of the model are briefly discussed, beginning with policy maker competence and values as the political context, followed by policy strategy and policy mix design as the policy mix elements, and finally policy outcomes and other contextual factors.

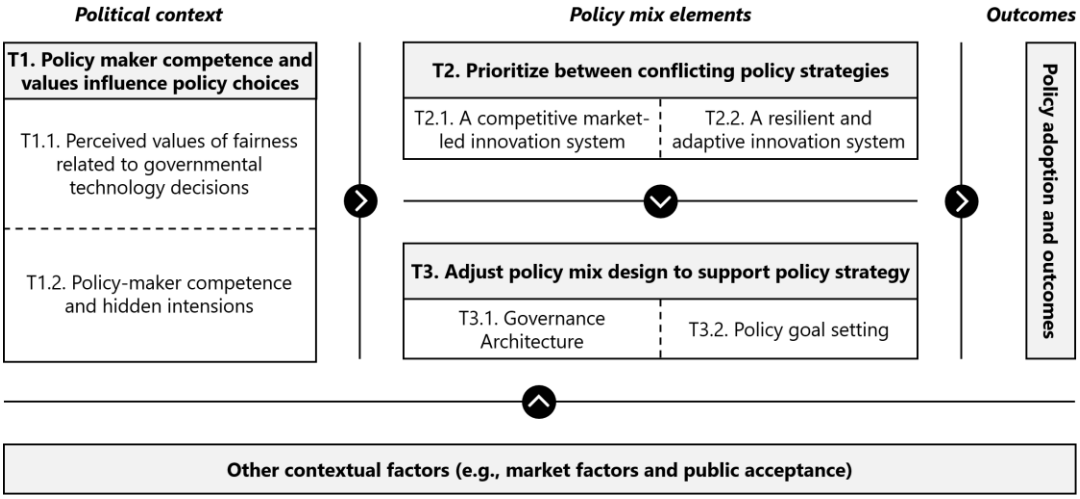

Figure 19. Model for governmental technology selection strategies in the context of technological neutrality.

The policy maker competence and values are an important part of the political context that influences governmental technology choices by increasing policy support or by creating barriers for policy legitimisation. First, the perceived values of fairness related to governmental technology decisions influence the policy makers preferences for deviating from neutrality principles and impacts their idea of a fair society (See Chapter 4.1.1). The identified values in the context of technological neutrality include (1) fairness between technologies and implementation methods, (2) fairness between existing and emerging solutions, (3) fairness between regions, and (4) preference for market-based or governmental selection of solutions. Second, the policy maker competence, coupled with an understanding of the hidden intensions, forms the foundation for effective and transparent policy making (See Chapter 4.1.2). The design of complex innovation policy mixes requires technological competence to regulate technologies effectively regardless of the technological neutrality or specificity of the policy. Furthermore, the policy makers need policy design competence to translate strategic policy goals and vague policy principles, such as technological neutrality, into effective policy mixes that are suitable for the specific context. Finally, the hidden intensions refer to various political or ideological goals of the policy makers that are not explicitly shared with others. If these hidden intensions are combined with readiness to deviate from shared principles, it can lead to ideological exclusion of options and challenge the transparency of policy making. Overall, the political context can provide important insights for policy makers which help to understand potential political barriers and enablers for innovation policy design.

The policy strategy or agenda has important implications for policy mix design as it provides direction for policy making by defining overarching goals, policy logic, and principal plans (See Chapter 2.2.1). This study has identified two policy strategies related to governmental technology selection which vary in their approaches related to technological neutrality (See Chapter 4.2). First, "*a competitive market-led innovation system*" strategy emphasises a traditional pro-market view that market should be allowed to operate mostly freely by minimizing government interventions with predictable and technology neutral policies (See Chapter 4.2.1). This approach is believed to lead to cost-efficient policies by utilizing a high degree of competition, for example in deployment policies. However, it might fail to address various market failures leading to support for dominant technologies and incumbents. Second, "*a resilient and adaptive innovation system*" strategy is closer to mission-oriented transformative innovation policy where government interventions direct society towards desired societal goals (See Chapter 4.2.2). This strategy focuses on supporting emerging technologies as a driver for positive societal and economic change. Both technology neutral and specific policies are used to help emerging technologies to overcome various barriers for market entry. Due to the uncertainties of emerging technologies, resilience and adaptiveness of the innovation system are seen as key characteristics of this strategy. The resilience and adaptiveness are supported by increasing the technological diversity of the system, by using flexible governance techniques, and by investing into technology sovereignty. As these two policy strategies utilise different mechanisms to drive desired policy goals, the policy makers are forced to prioritize between these partially conflicting strategies. However, these strategies should not be seen as fully exclusive options for transformative innovation policy as various policy mix design techniques can offer ways to balance between the benefits of each strategy.

The actual policy mix and related instruments should be designed to support the intended policy strategy (cf. policy formulation in Figure 4). In this empirical study, these policy mix design decisions have been divided into two main categories that contribute to the effectiveness of technology policy (See Chapter 4.3). First, policy mix design decisions defines how responsibilities are delegated to different stakeholders, including government agencies and the private market (See Chapter 4.3.1). The different dimensions of governance architecture have important implications for the practical application of technological neutrality in policy design as they influence the acceptability, benefits, and risks of technology policy. The four core dimensions of governance architecture identified in this empirical study include (1) the level of adaptation to market processes, (2) instrument's legal form and vertical

governance level, (3) vertical coordination, and (4) horizontal coordination between government entities. Second, policy goal boundary setting is required to activate stakeholders, to adapt to the predictability of the decision field, and to create manageable objectives (See Chapter 4.3.2). This process of goal setting includes decisions on (1) the balance between different policy goals, (2) using broad neutral goals vs. multiple specific goals, (3) the outcome-orientation vs. means-orientation of the goals, and (4) the targeted policy time horizon. These aspects of goal setting are also in the core of theoretical discussions for technological neutrality as the policy goal has a significant impact on the specificity or neutrality of a policy (e.g., see Figure 6). Overall, the policy mix design, including policy goals and governance architecture, should be customised to support the desired policy strategy.

While a well-aligned combination of policy strategy and policy mix design is crucial for an effective policy mix, it does not automatically ensure the achievement of desired policy impacts and outcomes. The linkage between policy design and societal outcomes is often governed by complex processes (Haddad and Bergek, 2023; Janssen et al., 2022). Therefore, a deep understanding of causal mechanisms, contextual factors, and drivers of socio-technical change is vital in assessing the efficacy of policy designs in facilitating societal transitions (Haddad and Bergek, 2023). For instance, market factors and firm characteristics (Reichardt and Rogge, 2016) play a significant role in shaping market actors' responses to policy initiatives (Hoppmann et al., 2013; Reichardt and Rogge, 2016), which are integral to realizing societal objectives.

In conclusion, the proposed model for governmental technology strategies provides a strategic perspective for innovation policy design in the context of technological neutrality (See Figure 19). This empirical model contributes to the literature on innovation policy design and practical guidance for policy makers. First, the insights on the political context help to explain how the policy maker competence and values can drive or restrict policy design choices (cf. barriers for policy implementation in Table 10). Second, the two primary strategies, one emphasizing market-driven competition and the other policy-supported resilience, contribute to the debate about balancing technology neutral and specific policy designs, as discussed in Chapter 2.4. These strategies offer policymakers a viable approach to integrate the intermediate goals and techniques associated with technological neutrality, as outlined in steps 2 and 3 of Figure 10, into coherent strategic plans. Lastly, the insights into policy mix design advance the practical application of technological neutrality (See Chapter 2.3.2) by highlighting the significance of governance architecture and policy goal setting in the context of technology policy design.

5 Implications

This chapter describes the main implications of this study. As the empirical results of this study are discussed together with relevant literature in Chapter 4, this chapter focuses on the main contributions of this study. First, the main contributions of this study are discussed against the two research questions of this study. The second and third subchapters continue by discussing the main theoretical and policy implications. Finally, the limitations of this study are discussed together with a few avenues for future research.

5.1 Discussing the contribution of this study

This chapter discusses the main contributions of this study against the two research questions defined in Chapter 1.2. First, how does technological neutrality influence the policy outcomes in the context of transformative innovation policy? This question is addressed by comparing the theoretical summary of the implications of technological neutrality (See Figure 9) with the findings of the empirical study. Second, how does technological neutrality impact the design of innovation policy mixes? The answer to this question is guided by a comparison between the theory-based three-step process for innovation policy design from the perspective of technological neutrality (See Figure 10) and the empirical model for governmental technology selection strategies in the context of technological neutrality (See Figure 19).

5.1.1 The impact of technological neutrality on innovation policy outcomes

The technological neutrality or specificity of an innovation policy intervention has been argued to impact the policy outcomes in various ways. These expected policy outcomes are commonly used to justify either technology specific or neutral policies (See Chapter 2.3.3). For instance, technological neutrality has been seen as a way to avoid technological discrimination and to enable cost efficient policies by allowing the market processes to select technologies (See Rationales 2 and 4 in Table 8). However, various contextual factors can challenge the suitability of technological neutrality or specificity for a specific policy intervention (See Chapter 2.3.4), which can lead to excessively simplified policy recommendations based on the generalised rationales. Furthermore, the under-theorisation of the principle of technological neutrality (See Chapter 2.3.1) can lead to policy making challenges in applying the principle in practice, as demonstrated in the empirical context of the Finnish innovation system (See Chapter 4.1.2.2).

To improve the understanding on the connection between technological neutrality and policy outcomes, this study proposes a model focusing on the three main implications of technological neutrality: (1) fairness, (2) technological goals, and (3) policy sustainability (See Figure 9). As the ultimate policy outcomes, such as economic and societal goals, can be influenced by complex processes (Haddad and Bergek, 2023; Janssen et al., 2022), this model focuses on explaining the causal mechanisms leading to the more immediate intermediate policy goals related to technological neutrality. This theory-based model is compared with the empirical insights from the Finnish innovation system. Before discussing these implications of technological neutrality, the definition of technological neutrality is clarified to provide common grounds for the following discussions.

This study defines technological neutrality based on the three identified characteristics and the level of technological neutrality (See Chapter 2.3.1). First, technological neutrality should not discriminate or differentiate across technologies which can be used to reach the justified policy goal (See Characteristic 1). The empirical insights on perceived fairness in governmental technology decisions support the importance of non-discrimination by highlighting three potential sources of conflicts between different stakeholder groups, including (1) conflicts between different technologies, implementation methods, and companies, (2) fairness between existing and emerging solutions, and (3) inter-regional fairness (See Chapter 4.1.1). Second, technology neutral policies should focus on outcomes instead of means to avoid unjustified discrimination of technologies (See Characteristic 2). Even though the outcome-oriented policy goals should be seen as the basis for policy design (See Chapters 2.3.1 and 4.3.2.3), partial means-orientation or technological specificity might be required in certain circumstances, for instance, to level the playing field for emerging technologies (See Chapters 2.3.3 and 4.1.1.2) or to ensure technological sovereignty (See Chapters 2.3.3 and 4.2.2.3). Third, the authority to select technologies should be delegated to market mechanisms to avoid market disruptions (See Characteristic 3). Even though the market-based selection of technologies is seen as the baseline for policies (See Chapter 4.1.1.4), both the literature review and the empirical analysis acknowledge that governmental technology choices can be justified in some circumstances based on strong arguments (See Chapters 2.4.1 and 4.1.1.4). Finally, the level of technological neutrality of a policy should be understood as a continuous scale where the level of neutrality depends on the level of the policy goal and amount of discrimination at that hierarchy level (See Figure 6). In summary, technological neutrality refers to a principle that the government should not discriminate between any technologies provided by private parties by primarily targeting justified outcomes and effects instead of means in its policy interventions.

The first intermediate goal of technological neutrality in the model is fairness which refers to the first characteristic of technological neutrality to avoid unjustified technological discrimination in short and long-term (See Chapter 2.4.1). The theory-based analysis argues that the fairness can be influenced by adjusting the technological specificity of the policy with various policy design decisions, such as policy goal setting, policy timeframe, and policy interpretation (See Chapter 2.4.1). The empirical study emphasizes several key factors in addition to policy goal setting and timeframe (See Chapter 4.3.2). These include the need to ensure fairness among various stakeholders (See Chapter 4.1.1) and to recognize the competence and underlying intentions of policymakers, which are crucial for enabling transparent and fair policies (Chapter 4.1.2).

The second intermediate goal includes technological goals, such as technology diversification, sovereignty, and effectiveness (See Chapter 2.4.1). As these technological goals rely on the technology choices of market processes in market economies, this study argues that a policy might need to intervene in the market-based selection processes to impact these goals (See Chapter 2.4.1). In addition to the theory-based techniques to adjust the scope and type of the policy intervention (See Chapter 2.4.1), the empirical analysis emphasizes different governance architecture approaches to influence the delegation of responsibilities to different stakeholders, including government agencies and the private market (See Chapter 4.3.1). The importance of these technological goals is discussed also related to the two policy strategies of the empirical analysis, which highlight different technology goals and approaches to technology selection (See Chapter 4.2). While the "competition strategy" pursues efficiency by enabling broad market-based competition, the "resilience strategy" acknowledges the importance of directed support for emerging technologies to enable agility, technological diversity, and sovereignty (See Chapters 4.2 and 4.4).

The third intermediate goal is policy sustainability, which involves a balancing act between the sustainability and flexibility of policy mixes (See Chapter 2.4.1). Even though sustainable and predictable policies can be important enablers for private investments (See Chapters 2.4.1 and 4.2.1.3), quickly changing circumstances and emerging technologies can challenge excessively consistent policies and require more flexible approaches (See Chapters 2.4.1 and 4.3.2.4). To address this partial conflict between sustainability and flexibility, this study suggests combining different types of policies and time frames into comprehensive policy mixes (See Chapter 2.4.1). First, different governance arrangements, such as instrument types, coordination, and adaptation to market processes, can be used to influence how flexibly decisions

can be made (See Chapter 4.3.1) by adjusting the automaticity and authoritative force of the intervention (See Chapter 2.2.2). Second, broad and outcome-oriented technology neutral policy goals can support policy sustainability by increasing the inclusivity of the policy (See Chapter 2.4.1) and by avoiding arbitrary exclusion of potential solutions (See Chapter 4.2.1).

In summary, the first aim of this study was to find out, how technological neutrality influences the policy outcomes in the context of transformative innovation policy. Based on the combination of literature review and empirical evidence, this study suggests that technological neutrality impacts innovation policy outcomes through three intermediate policy goals, including (1) fairness, (2) technological goals, and (3) policy sustainability. The policy makers can pursue the desired goals by customising the policy design related to technological neutrality with different governance arrangements (See Chapter 4.3.1), policy goal boundary setting (See Chapter 4.3.2), and five different techniques to operationalise technological neutrality (See Chapter 2.3.2). Furthermore, this study suggests plausible mechanisms that connect the policy design decisions to the intermediate policy goals (See Chapters 2.4.1 and 5.1.1).

5.1.2 The impact of technological neutrality on the design of broader innovation policy mixes

The second research question of this study focuses on the impact of technological neutrality on the design of innovation policy mixes. The aim is to connect the previous model focusing on technological neutrality (See Chapters 2.4.1 and 5.1.1) into the broader context of innovation policy mix design. The answer to this question is guided by a summary of the theory-based three-step process for innovation policy design from the perspective of technological neutrality (See Figure 10) and the empirical model for governmental technology selection strategies in the context of technological neutrality (See Figure 19). Finally, the strategic perspective of the empirical model is incorporated into the theory-based process. The outcome is a revised four-step process for innovation policy design from the perspective of technological neutrality (See Figure 20).

First, the theory-based three-step process connects a general innovation policy mix design with a customised policy design tool for influencing the technological neutrality and specificity of the policy (See Figure 10). The first step of agenda setting involves a strategic perspective to identify and define high-level policy objectives, principal plans, and rationales for the intervention (See Chapter 2.4.2). This policy agenda is used to direct the following steps of policy design related to operationalisation of technological neutrality (See

Chapter 2.4.2). The second step involves the translation of the agenda into relevant intermediate goals related to technological neutrality (See Chapter 2.4.2). Finally, the neutrality or specificity of the policy should be customised to support the desired goals by choosing techniques to operationalise technological neutrality in policy design (See Chapter 2.4.2). Furthermore, the policy mix design from the perspective of technological neutrality should be customised based on various contextual factors, such as technology-related barriers for market-based change (See Chapter 2.4.2).

Second, the empirical study provides a model for governmental technology selection strategies in the context of technological neutrality (See Figure 19 in Chapter 4.4). First, the policy maker competence and underlying values provide important political context for the policy design which influences governmental technology choices by increasing policy support or by creating barriers for policy legitimisation (See Chapters 4.1 and 4.4). Second, the two identified policy strategies for technology selection provide insights into different policy approaches related to technological neutrality which emphasise different overarching goals, policy logic, and principal plans (See Chapters 4.2 and 4.4). Third, the empirical study identified governance architecture and policy goal boundary setting as the two main categories of policy mix design decisions that contribute to policies for governmental technology selection (See Chapter 4.3). In comparison with the theory-based model, this empirical model involves a more strategic perspective to policy design related to technological neutrality. This strategic perspective helps to understand how different techniques, policy design decisions, and policy goals could be implemented as comprehensive policy mixes. Therefore, these policy strategies for technology selection are incorporated into the theory-based process for policy design in the context of technological neutrality (See Figure 20).

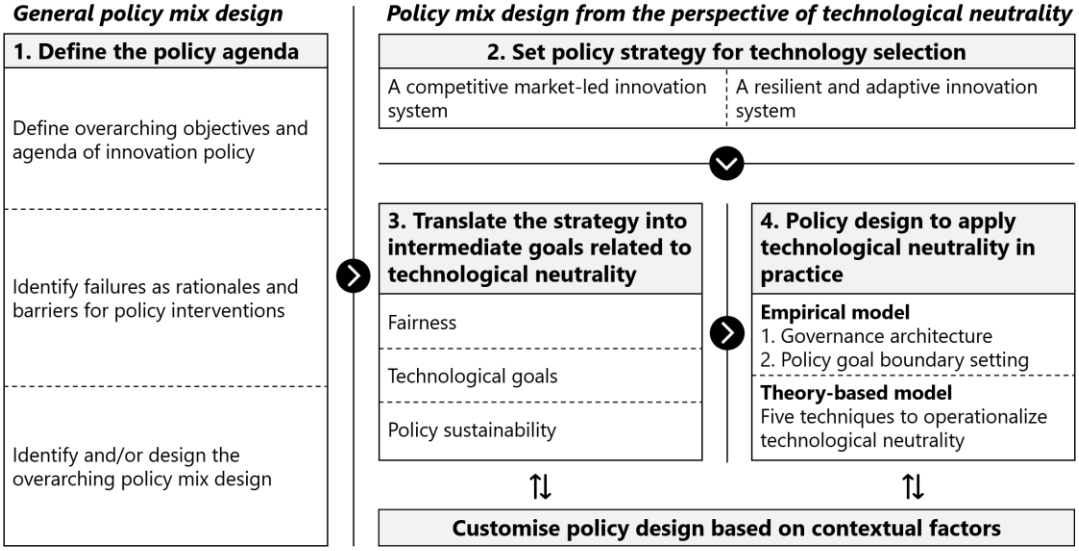

Figure 20. Revised process for innovation policy design from the perspective of technological neutrality.

Finally, Figure 20 presents the final outcome of this study as a revised four-step process for innovation policy design from the perspective of technological neutrality. An additional step for setting a policy strategy for technology selection has been introduced before the translation of the policy agenda into intermediate goals related to technological neutrality. These policy strategies for technology selection, as defined in Chapter 4.2, help to connect the broader policy agenda and policy mixes to the context of technological neutrality. This revised process provides an overview for answering the second research question: How does technological neutrality impact the design of innovation policy mixes? This overview and the answer are complemented by the more detailed theory-driven models, such as the summary of the three main implications of technological neutrality (See Figure 9) and the list of contextual factors to assess the suitability of technology neutral and specific interventions (See Table 10). Furthermore, the empirical analysis provides valuable insights to understand the role of technological neutrality in innovation policy.

5.2 Theoretical implications

This study contributes to multiple areas within policy literature, encompassing a broad range of research on technological neutrality, innovation policy design, and transformative innovation policy. The main contributions of this study relate to the theorisation of the principle of technological neutrality in innovation policy. As the principle of technological neutrality has remained under-theorised (Greenberg, 2016; Craig, 2016; Puhakainen and Väyrynen,

2021) with different meanings attached to technological neutrality (Koops, 2006; Craig, 2016), this study has important implications for this stream of literature. First, the literature review on technological neutrality improves the understanding on the main characteristics, policy design techniques, rationales, and contextual factors related to technological neutrality. Second, the empirical analysis of the interviews and parliamentary discussions provide a unique perspective for understanding how technological neutrality impacts the innovation activities of private actors and the policy processes related to technological neutrality in the Finnish innovation system. Third, the described impact logic of technological neutrality related to the three identified categories of intermediate policy goals helps to understand the role of technological neutrality in innovation policy design.

This study contributes also to the wider innovation policy design and policy mix literature, as technological specificity has been described as one of the abstract design features of policy instruments (Kemp and Pontoglio, 2011; Rogge and Reichardt, 2016). First, this study broadens the understanding on technological neutrality by providing a strategic perspective to policy design related to technological neutrality. Second, the proposed process for innovation policy design from the perspective of technological neutrality contributes to a better understanding on the role of technological neutrality in broader policy mixes.

Finally, this study contributes to the emerging literature on transformative innovation policy and sustainability transitions where technological choices play an important role. The insights on the impact of technological neutrality on policy design and intermediate policy outcomes can support the design of meaningful, justified, and transparent policy interventions to accelerate desired societal transitions. Furthermore, the empirical insights on the policy maker competence and underlying values provide important political context for the policy design which can help to overcome political barriers for policy legitimisation.

5.3 Policy implications

This study has four main policy implications. First, the clarified definition for technological neutrality based on its key characteristics provides the basis for understanding the role of technological neutrality in innovation policy (See Chapter 2.3.1). As the first characteristic, technology neutral policy should not discriminate or differentiate across technologies which can be used to reach the justified policy goal. Second, technology neutral policies should focus on outcomes instead of means to avoid unjustified discrimination of technologies. Third, the authority to select technologies should be delegated to

market mechanisms to avoid market disruptions. These characteristics mean that technological neutrality aims to prevent only unjustified technological discrimination to enable technologies to be selected in market-based competition. Finally, the level of technological neutrality of a policy should be understood as a continuous scale where the level of neutrality depends on the level of the policy goal and amount of discrimination at that hierarchy level. Understanding these characteristics of technological neutrality and defining technology hierarchy trees (See Figure 6) can help policy makers to assess the technological neutrality of a policy and adjust the policy as necessary to avoid unjustified discrimination of technologies.

Second, the three main implications of technological neutrality can help policy makers to focus on the intermediate policy goals that are more directly related to technological neutrality than broader policy outcomes. The identification of these intermediate goals and related mechanisms help to direct the policy making process to design purposeful policy interventions to achieve the desired goals (See Figure 9). When considering the potential policy impact of technological neutrality, this study recommends focusing on the following three intermediate goals: (1) fairness, (2) technological goals, and (3) policy sustainability. First, ensuring fairness can require both technology neutral and specific interventions to enable an extended level playing field for different stakeholders, such as emerging technologies. Second, a combination of technology neutral and specific policies might be needed to support the desired technology goals, such as technology diversity, sovereignty, and specialisation, depending on market conditions. Third, the use of comprehensive policy mixes helps to balance between partially conflicting goals of policy sustainability and flexibility to adapt to changing circumstances. Most importantly, the policy makers should understand the intervention-mechanism-outcome logics related technological neutrality to purposefully customise the policy intervention to pursue desired policy goals.

As the third policy implication, the proposed four-step process for designing policy mixes from the perspective of technological neutrality provides guidance for applying the principle of technological neutrality in practice (See Figure 20). First, it is important to define an overarching policy agenda to identify and define high-level policy objectives, principal plans, and rationales for the policy mix. This agenda provides high-level guidance for applying the principle of technological neutrality in practice during the following steps. Second, the policy agenda should be translated into a policy strategy for technology selection to connect the broader policy agenda and policy mixes to the context of technological neutrality. Third, the strategy should be translated into intermediate goals related to technological neutrality. Finally, the neutrality or specificity of the policy should be customised to support the

desired goals by choosing techniques to operationalise technological neutrality in policy design.

Fourth, the empirical findings highlight the importance of policy maker competence and underlying values for policy design in the context of technological neutrality. First, the technologies of the decision field should be properly understood to create intended effects without excessive discrimination of technologies even if technology neutral policies are used. Second, applying the principle of technological neutrality in practice to specific contexts requires a thorough understanding of the properties of the decision field and the implications of technological neutrality. Finally, the values and potential hidden intensions of policy stakeholders should be understood to avoid unintentional or ideological exclusion of technologies.

5.4 Limitations and further research

This study has three main limitations based on the chosen research design. First, the generalisability of the findings is limited by the embedded single case study approach focusing on the Finnish innovation system. As the generalisability of single case studies has been criticised in contrast to multiple case studies (Eisenhardt, 1989; Gibbert et al., 2008; Yin, 2009), this study uses various recommended approaches to increase the generalisability of this single case study, such as embedded case study approach, comparison of findings with theoretical literature from different contexts, and a broad data set (See Chapter 3.4). As the empirical data focuses on the Finnish innovation system, the generalisability of the empirical analysis might be limited to countries with similar national innovation systems and with similar approaches to innovation policy. However, this embedded single case approach was justified by its ability to enable a deeper understanding of the topic (Gustafsson, 2017) in the Finnish innovation system to support the wider analysis project (See Chapter 1.3). Therefore, the models developed in this study provide a fruitful basis for further studies to validate the implications of technological neutrality on innovation policy design in other empirical contexts.

Second, the emphasis of this study on theory elaboration and abduction creates some limitations. First, theory elaboration research relies on the strength of the underlying theories and their relevance for studying the new contexts (Fisher and Aguinis, 2017). This study has tried to avoid this pitfall by choosing relevant and widely used theories of innovation policy as the basis for the theoretical perspective. Nevertheless, this potential pitfall provides avenues for further research to study the implications of technological neutrality through other theoretical lenses, such as transition management (e.g.,

Loorbach, 2010; Rotmans et al., 2001), ecosystems (e.g., Gomes et al., 2021), or technological innovation systems (e.g., Raven and Walrave, 2020). Second, theory elaboration studies can lead to excessively complex theories if multiple contexts and relationships are integrated (Fisher and Aguinis, 2017). While the aim of this study is to examine the complex implications of the principle of technological neutrality for effective innovation policy design, this study has tried to avoid excessively complex models. To achieve this, this study has tried to generalise some of the more complex models (e.g., Figure 10) while providing necessary details in the more focused models (e.g., Table 10). Nevertheless, the proposed models provide an opportunity to study and validate the interdependencies between the different elements.

Finally, the construct validity and internal validity of the results could be influenced by various factors. Abductive approaches can lead to confirmation bias if the existing literature is analysed excessively during the early stages of the process (Gioia et al., 2013). This study has balanced between the fine line of knowing too little and too much by starting the interviews early in the process and by emphasising an inductive approach in the data analysis of the empirical data. Regardless of the attempts to ensure the validity of the results, further research would be warmly welcomed to validate these results. Furthermore, see Chapter 3.4 for additional discussions on the validity and reliability of this study.

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A. List of figures

B. List of tables

C. Example of an interview guide for companies

Introduction

- Consent for recording
- Introduction of the researchers and the thesis
- Introduction of the interviewee

R&D investments

- What is the role of R&D in your company?
- How has your R&D intensity developed in past years? Why?
- Are you planning to increase or decrease R&D investments in future? Why?
- What determines how much your company invests in R&D relative to other expenses?
- What has enabled your current investment level in R&D?
- What prevents you from investing more in R&D?
- What determines where do you do R&D? Why?

Technology selection

- Which technological inventions (or innovations) have affected your company the most?
- How have you invested in these innovations? / How have these innovations affected your R&D investments?
- Can you mention a few examples of your most important R&D themes from the past years?
- Why did your company choose to invest in this way instead of doing something else?
- Which factors made the investment possible?
- Why did your company choose to invest now, not later or earlier?
- Can you mention any R&D projects that were not started? Why not?
- How would you prioritize the following objectives in your R&D strategy? Why?
    - Staying ahead of competition
    - Using the current resources as efficiently as possible
    - Staying at the forefront of emerging technology development
    - Keeping many options open (vs. clear focus)
    - Something else

Technology futures analysis

- In future, how do you see that emerging technologies affect your company?
- Which (kind of) technologies do you expect to have the most significant impact? Why?
- How do you identify and anticipate potential emerging technologies?

- Which future-related information affects your R&D strategy the most? Why?
- Which of the following information do you use in strategic R&D decisions? Please prioritize the options:
    - Expert opinions
    - Trend analysis, such as extrapolating the growth curve
    - Statistics, such as number of patents and publications
    - Simulations, such as system dynamics models
    - Economical calculations, such as cost-benefit analysis
    - Technology roadmaps published by firms, industry associations, or other organizations
    - Results of brainstorming and workshops
    - Intelligence, such as surveys
    - Impact analysis
    - Risk assessment
    - Decision analysis, such as analytic hierarchy process
    - Something else
- Can you describe how future-related information has affected your R&D strategy?
- Which information has been the most influential? Why?
- Can you give a concrete example of the most influential aspect and what does it mean?

Impact of policy

- Which of the following policies affect your R&D strategy? Please select the most positive and most negative policies for your company.
    - Supply-side
        - R&D tax incentives
        - Direct funding for R&D
        - Training skilled workforce
        - Advice, such as technical advice or business incubators
        - Cluster, collaboration, and innovation network policies
    - Demand-side
        - Subsidies for your customers
        - Public procurement
        - Competition policy
    - Mixed
        - Innovation prizes
        - Standards
        - Regulation
        - Visions and forecasts
    - Something else
- In general, how does the public policy affect your R&D strategy?
- Do the government's activities have effect on the composition of your innovation portfolio? Why / why not?
- Can you describe how did the policy (that you selected as most important) impact your R&D strategy? Why?

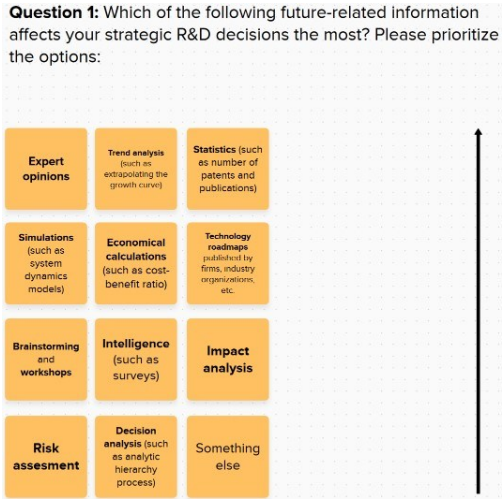
- Is your industry open to competition? Why / why not?
    - How does the public policy affect competition in your industry?
    - Especially, how does the regulation affect competition?
    - Can you name any regulations that have disturbed or improved competition in your industry?
- How could the current policies be adjusted to have a positive impact on your company's R&D activities?
- If I asked these questions from someone else from your company, would they give me similar answers?

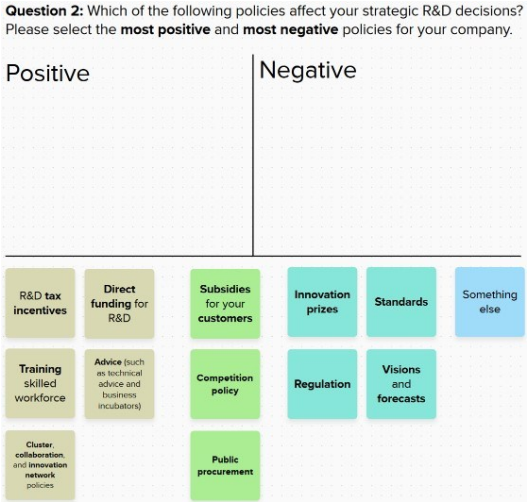
Ending

- Is there anything else that is important but not yet discussed?
- Do you know someone who we should interview next?

Interactive frameworks to support the discussion

- Different technology foresight methods
- Innovation policy instruments based on the taxonomy by Edler and Fagerberg (2017)





D. List of parliamentary discussions included in the analysis

	Document ID and subject of the parliamentary discussion by main theme	Date
Construction and Environmental Requirements		
NA	PTK 43/2014/2 vp: Kansalaisaloite: Energiatodistuslain muuttaminen (KAA 1/2014 vp)	24.4.2014
	PTK 107/2016/10 vp: Hallituksen esitys eduskunnalle laiksi maankäyttö- ja rakennuslain muuttamisesta	26.10.2016
	PTK 120/2016/8 vp: Hallituksen esitys eduskunnalle laiksi maankäyttö- ja rakennuslain muuttamisesta	24.11.2016
	PTK 135/2016/4 vp: Hallituksen esitys eduskunnalle laiksi ympäristönsuojelulain muuttamisesta	15.12.2016
	PTK 137/2016/7 vp: Hallituksen esitys eduskunnalle laiksi ympäristönsuojelulain muuttamisesta	19.12.2016
	PTK 84/2019/3 vp: Hallituksen esitys eduskunnalle valtion talousarvioksi vuodelle 2020 Hallituksen esitys eduskunnalle vuoden 2020 talousarvioesityksen (HE 29/2019 vp) täydentämisestä	17.12.2019
Copyright		
NA	PTK 24/2022/3 vp: Hallituksen esitys eduskunnalle vuoden 2022 lisätalousarvioksi Hallituksen esitys eduskunnalle vuoden 2022 lisätalousarvioesityksen (HE 2/2022 vp) täydentämisestä	11.3.2022
	PTK 46/2022/6 vp: Hallituksen esitys eduskunnalle laeiksi tekijänoikeuslain ja sähköisen viestinnän palveluista annetun lain muuttamisesta	28.4.2022
	PTK 172/2022/4 vp: Hallituksen esitys eduskunnalle laeiksi tekijänoikeuslain ja sähköisen viestinnän palveluista annetun lain muuttamisesta	21.2.2023
Criminal Law, Consumer Protection and Civil Rights		
Instant Loans	PTK 66/2018/10 vp: Lakialoite laiksi kuluttajansuojalain 7 luvun muuttamisesta	14.6.2018
Means of Payment	PTK 43/2021/6 vp: Hallituksen esitys eduskunnalle laiksi rikoslain 37 luvun muuttamisesta	20.4.2021
Remote Participation	PTK 49/2022/8 vp: Hallituksen esitys eduskunnalle säästöpankkien ja hypoteekkiyhdistysten kokouksiin etäyhteydellä osallistumista koskevaksi lainsäädännöksi	4.5.2022
Telemarketing	PTK 51/2021/6 vp: Hallituksen esitys eduskunnalle laeiksi sähköisen viestinnän palveluista annetun lain 3 ja 351 §:n ja tietoyhteiskuntakaaren muuttamisesta ja väliaikaisesta muuttamisesta annetun lain voimaantulosäännöksen muuttamisesta	5.5.2021

Energy		
Environmental Regulation	PTK 106/2016/3 vp: Hallituksen esitys eduskunnalle Pariisin sopimuksen hyväksymisestä ja sopimuksen lainsäädännön alaan kuuluvien määräysten voimaansaattamisesta	25.10.2016
	PTK 53/2022/6 vp: Hallituksen esitys eduskunnalle ilmastolaiksi	11.5.2022
Renewable Energy Subsidies	PTK 31/2015/4 vp: Hallituksen esitys eduskunnalle laiksi uusiutuvilla energialähteillä tuotetun sähkön tuotantotuesta annetun lain muuttamisesta	10.9.2015
	PTK 47/2015/4 vp: Hallituksen esitys eduskunnalle laiksi uusiutuvilla energialähteillä tuotetun sähkön tuotantotuesta annetun lain muuttamisesta	8.10.2015
	PTK 93/2017/2 vp: Hallituksen esitys eduskunnalle valtion talousarvioksi vuodelle 2018	26.9.2017
	PTK 117/2017/3 vp: Hallituksen esitys eduskunnalle laeiksi uusiutuvilla energialähteillä tuotetun sähkön tuotantotuesta annetun lain ja tuulivoiman kompensaatioalueista annetun lain 6 §:n muuttamisesta	14.11.2017
	PTK 121/2017/4 vp: Hallituksen esitys eduskunnalle vuoden 2018 talousarvioesityksen (HE 106/2017 vp) täydentämisestä	21.11.2017
	PTK 49/2018/4 vp: Hallituksen esitys eduskunnalle laeiksi uusiutuvilla energialähteillä tuotetun sähkön tuotantotuesta annetun lain ja tuulivoiman kompensaatioalueista annetun lain 6 §:n muuttamisesta	15.5.2018
	PTK 53/2018/5 vp: Hallituksen esitys eduskunnalle laeiksi uusiutuvilla energialähteillä tuotetun sähkön tuotantotuesta annetun lain ja tuulivoiman kompensaatioalueista annetun lain 6 §:n muuttamisesta	22.5.2018
	PTK 62/2018/2 vp: Hallituksen esitys eduskunnalle vuoden 2018 lisätalousarvioksi	6.6.2018
Taxation	PTK 106/2017/2 vp: Hallituksen esitys eduskunnalle laiksi kiinteistöverolain 14 §:n muuttamisesta	18.10.2017
	PTK 109/2017/6 vp: Hallituksen esitys eduskunnalle laiksi kiinteistöverolain 14 §:n muuttamisesta	24.10.2017
	PTK 134/2021/9 vp: Hallituksen esitys eduskunnalle energiaverotusta koskevan lainsäädännön muuttamiseksi	16.11.2021
National Security		
NA	PTK 61/2018/5 vp: Hallituksen esitys eduskunnalle laiksi puolustusvoimista annetun lain muuttamisesta	5.6.2018
	PTK 108/2018/4 vp: Hallituksen esitys eduskunnalle laiksi puolustusvoimista annetun lain muuttamisesta	26.10.2018
State's Flagship Initiatives		
NA	PTK 43/2015/2 vp: Hallituksen esitys eduskunnalle valtion talousarvioksi vuodelle 2016	1.10.2015

Telecommunications		
NA	PTK 64/2017/10 vp: Hallituksen esitys eduskunnalle laajakaistarakentamisen tukea haja-asutusalueilla koskevan lainsäädännön muuttamisesta	6.6.2017
	PTK 67/2017/3 vp: Hallituksen esitys eduskunnalle laajakaistarakentamisen tukea haja-asutusalueilla koskevan lainsäädännön muuttamisesta	9.6.2017
	PTK 113/2020/3 vp: Hallituksen esitys eduskunnalle laiksi sähköisen viestinnän palveluista annetun lain muuttamisesta ja eräiksi siihen liittyviksi laeiksi	16.9.2020
	PTK 147/2020/7 vp: Hallituksen esitys eduskunnalle laiksi laajakaistarakentamisen tuesta	18.11.2020
	PTK 156/2020/9 vp: Hallituksen esitys eduskunnalle laiksi laajakaistarakentamisen tuesta	2.12.2020
Transport and Traffic		
Distribution, Subsidies, and Taxation of Different Vehicle Power Sources	PTK 32/2017/3 vp: Hallituksen esitys eduskunnalle laiksi liikenteessä käytettävien vaihtoehtoisten polttoaineiden jakelusta	30.3.2017
	PTK 149/2018/4 vp: Hallituksen esitys eduskunnalle laeiksi biopolttoöljyn käytön edistämisestä, biopolttoaineiden käytön edistämisessä liikenteessä annetun lain muuttamisesta sekä biopolttoaineista ja bionesteistä annetun lain 2 §:n muuttamisesta	29.1.2019
	PTK 153/2018/4 vp: Hallituksen esitys eduskunnalle laeiksi biopolttoöljyn käytön edistämisestä, biopolttoaineiden käytön edistämisessä liikenteessä annetun lain muuttamisesta sekä biopolttoaineista ja bionesteistä annetun lain 2 §:n muuttamisesta	5.2.2019
	PTK 155/2018/16 vp: Lakialoite laiksi tuloverolain 64 §:n muuttamisesta	7.2.2019
	PTK 38/2019/6 vp: Kansalaisaloite KAA 6/2019: Dieselautojen käyttövoimaveron poisto	26.9.2019
	PTK 75/2019/8 vp: Hallituksen esitys eduskunnalle laeiksi nestemäisten polttoaineiden valmisteverosta annetun lain liitteen ja valmisteverotuslain 5 §:n muuttamisesta	4.12.2019
	PTK 124/2020/8 vp: Hallituksen esitys eduskunnalle laeiksi sähköajoneuvojen latauspisteistä ja latauspistevalmiuksista rakennuksissa sekä rakennusten automaatio- ja ohjausjärjestelmistä ja maankäyttö- ja rakennuslain 126 §:n muuttamisesta	6.10.2020
	PTK 41/2021/6 vp: Hallituksen esitys eduskunnalle laiksi biopolttoaineiden käytön edistämisestä liikenteessä annetun lain muuttamisesta ja eräiksi muiksi laeiksi	15.4.2021
	PTK 93/2021/15 vp: Kansalaisaloite KAA 6/2019: Dieselautojen käyttövoimaveron poisto	8.9.2021
	PTK 138/2021/10 vp: Hallituksen esitys eduskunnalle laeiksi vuoden 2022 tuloveroasteikosta, tuloverolain muuttamisesta ja väliaikaisesta muuttamisesta sekä eräiden muiden verolakien muuttamisesta	23.11.2021
	PTK 131/2022/14 vp: Hallituksen esitys eduskunnalle laiksi ajoneuvolain muuttamisesta sekä siihen liittyviksi laeiksi	29.11.2022
	PTK 131/2022/17 vp: Hallituksen esitys eduskunnalle laiksi uusiutuvien polttoaineiden käytön edistämisestä liikenteessä annetun lain muuttamisesta ja väliaikaisesta muuttamisesta	29.11.2022

	PTK 153/2022/5 vp: Hallituksen esitys eduskunnalle laiksi ajoneuvo- ja liikennepalveluhankintojen ympäristö- ja energiatehokkuusvaatimuksista annetun lain muuttamisesta	20.1.2023
Railway traffic	PTK 62/2015/6 vp: Hallituksen esitys eduskunnalle laeiksi rautatielain ja ratalain muuttamisesta	11.11.2015
Taximeter	PTK 36/2017/3 vp: Hallituksen esitys liikennekaareksi ja eräiksi siihen liittyviksi laeiksi	6.4.2017
	PTK 68/2018/4 vp: Hallituksen esitys eduskunnalle laiksi ajoneuvojen katsastustoiminnasta annetun lain muuttamisesta ja eräiksi muiksi laeiksi	18.6.2018
	PTK 135/2020/4 vp: Hallituksen esitys eduskunnalle laeiksi liikenteen palveluista annetun lain, tieliikennelain 155 ja 171 §:n sekä ajoneuvolain muuttamisesta	21.10.2020
Vehicle Purchase Subsidies	PTK 129/2017/20 vp: Hallituksen esitys eduskunnalle laiksi henkilöautojen romutuspalkkiosta ja sähkökäyttöisten henkilöautojen hankintatuesta sekä henkilöautojen kaasu- tai etanolikäyttöisiksi muuntamisen tuesta	4.12.2017
	PTK 138/2020/9 vp: Hallituksen esitys eduskunnalle laiksi henkilöautojen romutuspalkkiosta ja sähkökäyttöisten henkilöautojen hankintatuesta sekä henkilöautojen kaasu- tai etanolikäyttöisiksi muuntamisen tuesta	3.11.2020
	PTK 116/2021/11 vp: Hallituksen esitys eduskunnalle laiksi sähkökäyttöisten henkilöautojen hankintatuesta ja kaasukäyttöisen kuorma-auton hankintatuesta sekä henkilöautojen kaasu- tai etanolikäyttöisiksi muuntamisen tuesta annetun lain 14 §:n muuttamisesta	13.10.2021
	PTK 134/2021/12 vp: Hallituksen esitys eduskunnalle laiksi vaihtoehtoisella käyttövoimalla toimivan ajoneuvon hankinnan sekä ajoneuvon vaihtoehtoisella käyttövoimalla toimivaksi muuntamisen määräaikaisesta tukemisesta	16.11.2021