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Insights from Denmark and Sweden regarding Onshore Wind Farms and District Heating Systems

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OWNERSHIP MODELS FOR RENEWABLE SMART ENERGY SYSTEMS

INSIGHTS FROM DENMARK AND SWEDEN REGARDING ONSHORE WIND FARMS AND DISTRICT HEATING SYSTEMS

BY
LEIRE GORROÑO-ALBIZU

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ENGLISH SUMMARY

In the context of the climate crisis and the Paris Agreement, the EU has set the target of reducing its carbon emissions by 55% compared to 1990 levels by 2030 and reaching carbon neutrality by 2050. The transformation of the energy system through the substitution of fossil fuels with energy demand reductions, variable renewable energy and other low-carbon fuels and technologies will be crucial to meeting those goals. However, the positive and negative consequences of different socio-technical paths are still not fully understood, and in particular, more knowledge is needed regarding the potential socio-political, market and local acceptance of these paths, as this is essential for a timely energy transition. This study contributes to this understanding by studying which ownership characteristics and models could best promote (a) the implementation of onshore wind farms and district heating systems in renewable smart energy systems and (b) the reduction of the related energy costs and prices.

The study builds on existing theoretical understandings (about citizen ownership, citizen energy project development and suitable approaches for the design of alternative energy plans) to develop a theoretical approach that − by particularly focusing on the distinct characteristics of different ownership models and the concrete contextual factors surrounding the energy project − reveals the benefits that different ownership models can or cannot deliver and why, thereby facilitating the design of suitable policies to promote the best-performing ownership models.

Three in-depth studies are conducted:

1. The ownership of wind turbines and district heating systems in Denmark in 1977-2016.
2. Consumer power in Denmark and Sweden (1903-2020): Conditions promoting district heating companies' trustworthy behaviour.
3. The benefits of consumer co-ownership of wind turbines and power-to-heat in district heating systems in different locations of the power grid in Denmark.

The studies utilise various data sources, including literature and documents, archival records, relevant actors' websites, interviews and contact with

experts. A quantitative analysis is conducted to estimate wind power capacity shares by type of owner in Denmark for the 1977-2016 period. Qualitative analysis is used for the rest of the study, applying a codebook-based thematic analysis. A different codebook is used for each of the three in-depth studies, in line with the specific theoretical approach.

The results of the study indicate that local and inclusive citizen ownership models (such as utilities owned by local municipal companies or local consumer cooperatives) could be particularly advantageous to promote the implementation of onshore wind farms and district heating systems in renewable smart energy systems – even under current market conditions and project sizes. The local and inclusive utility model could enhance local acceptance of wind turbines, lower district heating prices, increase consumers' willingness to choose district heating, improve project economics and facilitate the necessary coordination to reduce electricity grid costs. When local and inclusive citizen ownership models cannot raise the necessary capital for onshore wind farms, joint ownership models (where local and inclusive citizen ownership models are combined with exclusive models) could be an effective solution to facilitate access to capital while enhancing local acceptance.

Further research is necessary to fully comprehend the appropriate design, implications, drivers and barriers of the abovementioned citizen ownership models in Denmark, Sweden, the EU and beyond. The study has also identified other important research outlooks for citizen ownership. Amongst others, the benefits and drawbacks of different governance (and ownership) models to facilitate the necessary coordination in renewable smart energy systems constitute an important and understudied area of research.

All in all, it can be concluded that the Danish move from broad support for local and inclusive citizen ownership models towards increasingly supporting large commercial ownership models could be counterproductive to the achievement of the country's ambitious climate and energy targets. In fact, the results suggest that Denmark would benefit from the design and implementation of energy policies that promote the redevelopment of local and inclusive citizen ownership of onshore wind farms and the modernisation of local and inclusive citizen-owned utility companies so that their full potential benefits to the energy transition can be realised. Regarding the EU and its Member States, the study suggests several points that could be considered for the improvement of policies and regulatory frameworks. These include focusing increasingly on the differences between local and inclusive citizen ownership models and other citizen ownership models, improving district heating regulation to ensure consumers’ rights and interests are safeguarded, registering the ownership model of energy assets and monitoring ownership developments quantitatively, reviewing the auction scheme for renewable electricity generation technologies and removing obstacles for sector integration (such as high grid tariffs or taxes).

DANSK RESUMÉ

I sammenhæng med klimakrisen og Parisaftalen har EU sat som mål at reducere CO_2-udledningen med 55% i 2030 i forhold til 1990-niveauet og at opnå CO_2-neutralitet i 2050. Omdannelsen af energisystemet via udskiftningen af fossile brændsler med reducerede energibehov, fluktuerende vedvarende energi og andre brændsler og teknologier med lavt kulindhold vil blive afgørende for at opnå disse mål. De positive og negative konsekvenser af forskellige socio-tekniske tilgange er dog stadig ikke fuldt oplyste, og specielt kræves mere viden om den potentielle accept på socio-politisk, markeds- og lokalt niveau af disse tilgange, da dette er essentielt for et rettidigt energiskifte. Dette studie bidrager til denne forståelse ved at undersøge, hvilke ejerskabskarakteristika og –modeller som bedst kan fremme (a) implementering af landbaserede vindmøllefarme og fjernvarmesystemer i smarte energisystemer og (b) reducering af relaterede energiomkostninger og –priser.

Studiet bygger på en eksisterende teoretisk forståelse (af borgerejerskab, udvikling af borgerenergiprojekter og passende tilgange til udformningen af alternative energiplaner) for at udvikle en teoretisk tilgang som – ved at være særlig opmærksom på forskellige ejerskabsmodellers tydelige karakteristika og de konkrete kontekstuelle faktorer omkring projektet – gør det muligt at identificere de fordele, som forskellige ejerskabsmodeller kan eller ikke kan levere og hvorfor, samt at designe passende politikker til at fremme de ejerskabsmodeller, som klarer sig bedst.

Der udføres tre dybdegående studier:

1. Ejerskab af vindturbiner og fjernvarmesystemer i Danmark i 1977-2016.
2. Forbrugermagt i Danmark og Sverige (1903-2020): Forhold som fremmer fjernvarmeselskabers pålidelige adfærd.
3. Fordele ved forbrugeres medejerskab af vindturbiner og power-to-heat i fjernvarmesystemer på forskellige lokaliteter i det danske elnet.

Studierne anvender forskellige datakilder, inklusiv litteratur og dokumenter, arkivoptegnelser, relevante aktørers hjemmesider, interviews og kontakt med

eksperter. En kvantitativ analyse udføres for at estimere andele af vindkraftkapacitet ud fra ejertype i Danmark for perioden 1977-2016. Kvalitativ analyse bruges i resten af studiet ved at anvende tematisk analyse baseret på datakodning. En anden datakodning bruges til hvert af de tre dybdegående studier på linje med den specifikke teoretiske tilgang.

Studiets resultater indikerer, at lokale og inkluderende borgerejerskabsmodeller (så som forsyningsværker ejet af lokale, kommunale selskaber eller lokale forbrugerkooperativer) kunne være særligt fordelagtige til at fremme implementeringen af landbaserede vindmøllefarme og fjernvarmesystemer i smarte energisystemer – også under nuværende markedsforhold og projektstørrelser. Den lokale og inkluderende forsyningsmodel kunne forbedre lokal accept af vindturbiner, sænke fjernvarmepriser, øge forbrugeres villighed til at vælge fjernvarme, forbedre projektøkonomier og muliggøre den nødvendige koordinering for at reducere elnetspriserne. Modeller med fælles ejerskab (hvor lokale og inkluderende borgerejerskabsmodeller kombineres med ekskluderende modeller) kunne være en passende løsning for at muliggøre adgang til kapital for landbaserede vindmøllefarme.

Yderligere forskning er nødvendig for fuldt ud at forstå det rette design, implikationer, drivkræfter og barrierer for de borgerejerskabsmodeller, som nævnes ovenfor, både i Danmark, Sverige, EU og længere ud i verden. Studiet har også identificeret andre vigtige forskningsudsigter for borgerejerskab. Fordele og ulemper ved forskellige ledelses- og ejerskabsmodeller for at muliggøre den nødvendige koordinering i smarte energisystemer skiller sig blandt andet ud som et vigtigt og underforsket felt.

I det hele taget er det muligt at konkludere, at det danske skifte fra bred støtte til lokale og inkluderende borgerejerskabsmodeller hen mod øget støtte til store kommercielle ejerskabsmodeller kunne modarbejde landets opnåelse af sine ambitiøse klima- og energimål. Faktisk tyder resultaterne på, at Danmark kunne drage fordel af design og implementering af energipolitikker, som fremmer en ny udvikling af lokalt og inkluderende borgerejerskab af landbaserede vindmøllefarme og modernisering af lokale og inkluderende borgerejede forsyningsselskaber, så alle deres potentielle fordele ved energiomstillingen kunne høstes. I forhold til EU og dens medlemslande foreslår studiet nogle pointer, som kunne overvejes i forbedringen af politikker og regulatoriske rammer. Disse kunne eksempelvis være øget fokus på forskellene mellem lokale og inkluderende borgerejerskabsmodeller og andre borgerejerskabsmodeller, forbedret fjernvarmeregulering for at sikre forbrugernes rettigheder og interesser, registrering af ejerskabsmodellen for energiaktiver og kvantitativ overvågning af ejerskabsudvikling, revidering af auktionssystemet for teknologier inden for vedvarende elproduktion samt fjernelse af hindringer for sektorintegration (så som høje nettariffer eller skatter).

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PUBLICATION OVERVIEW

List of Appended Articles

A. Gorroño-Albizu, L., Sperling, K. and Djørup, S. (2019) ‘The past, present and uncertain future of community energy in Denmark : Critically reviewing and conceptualising citizen ownership’, *Energy Research & Social Science*, 57, p. 101231. doi: 10.1016/j.erss.2019.101231

B. Gorroño-Albizu, L, & de Godoy, J, (under review) ‘Consumer Power and District Heating Companies’ Trustworthy Behaviour: Insights from Denmark and Sweden’, *Energy*

C. Gorroño-Albizu, L. (2020) ‘The benefits of local cross-sector consumer ownership models for the transition to a renewable smart energy system in Denmark. An exploratory study’, *Energies*, 13, p. 1508. doi: 10.3390/en13061508.

Other Publications on the Topic

- Gorroño-Albizu, L., Yang, J, Kuiken, D., Moncreiff, H., Kilmartin, A., Sperling, K. and Hvelplund, F. (2021) *From NOwnership to Ownership: How to Define and Promote Local and Inclusive Citizen Ownership in Renewable Energy Projects.*
- de Godoy, J., Gorroño-Albizu, L., Yang, J. and Otrel-Cass, K. (2020) *Annotated Bibliography: Actor Behavior and Interactions in the Context of Sustainable Energy Transitions*.

Contributions to other publications

- IRENA Coalition for Action (2020) *Stimulating investment in community energy: Broadening the ownership of renewables*, International Renewable Energy Agency, Abu Dhabi.

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CHAPTER 1. INTRODUCTION

The energy system in the EU is at a crossroads, with multiple socio-technical paths that could lead to carbon neutrality by 2050. The positive and negative consequences of the various socio-technical paths are still not fully understood, and more knowledge regarding the potential social acceptance[1] of those paths is crucial for a timely energy transition. This study contributes to this understanding by analysing citizen ownership models and their benefits. The study's final goal is to inform policy design and implementation processes for the energy transition.

The introduction chapter presents the background of the study and the state-of-the-art in citizen ownership, leading to the identification of research gaps in this topic. The chapter also highlights the significance of studying citizen ownership in the context of the European energy transition. Finally, the chapter introduces the structure of the dissertation.

1.1. BACKGROUND: THE CONTEXT OF THE ENERGY TRANSITION IN THE EU

Mitigating climate change is one of the biggest challenges in human history. The Paris Agreement was signed within the framework of the United Nations Climate Change Conference in 2015, consolidating the commitment of countries around the world to work towards and cooperate in *'holding the*

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[1] **Social acceptance** can be defined as '*a favourable or positive response (including attitude, intention, behaviour and – where appropriate – use) relating to a proposed or in situ technology or socio-technical system, by members of a given social unit (country or region, community or town and household, organization)*' [174, p. 103]. As this definition suggests, social acceptance has been regarded as a condition for the diffusion of technologies and can be understood as consisting of three dimensions: **socio-political acceptance, market acceptance** and **local acceptance** (or community acceptance) [110]. Socio-political acceptance refers to the public, key actors and policy-makers' general acceptance of technologies and policies. In practice, it relates to policy-makers, regulators and other relevant actors' ability to design and implement policies and regulations that promote market and local acceptance of a given technology. Market acceptance relates to consumers' technology adoption and investors' support in making the technology available on the market. Finally, local acceptance refers to the acceptance of specific projects by local actors, including local authorities, residents and organisations [86], [110]. In this dissertation, it is argued that ownership of energy technologies and systems can influence the three dimensions of social acceptance.

increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels'. Failing to meet this target could have serious consequences for ecosystems and life on Earth, ultimately leading to issues such as food and water scarcity, increased poverty and health problems, increased human migration [1], [2] and the exacerbation of social and political conflicts. In this context, the EU has set the target of reducing its carbon emissions by 55% compared to 1990 levels by 2030 and reaching carbon neutrality by 2050 [3]. The energy system (including the electricity, heating and cooling, transport and industry sectors) is the major source of CO_2 emissions in the EU [4]; thus, its transformation will be crucial. This is expected to be accomplished by phasing out fossil fuels through energy demand reductions, variable renewable energy and other low-carbon fuels and technologies [5]. Such a transformation entails fundamental changes in the energy system and presents multiple and diverse challenges and opportunities; these are reflected in, e.g., the flourishing of new ownership and business models [6]–[9]. At the same time, there is still no political consensus on the specific features of the future European energy system regarding, e.g., the chosen technologies and their future installed capacities [5] or the share of centralised and decentralised solutions to be implemented [10]. Nonetheless, in 2015, the European Commission stated that '*our vision is of an Energy Union with citizens at its core, where citizens take ownership of the energy transition, benefit from new technologies to reduce their bills, participate actively in the market, and where vulnerable consumers are protected*' [11, p. 2]. Moreover, as part of the strategy to make the EU the '*world number one in renewable energy*', the Commission added that '*the EU is committed* [to] *support* [...] *the empowerment of its citizens in energy, be it through home-producing energy, energy cooperatives or municipal initiatives*' [12, p. 9]. The Clean Energy Package for all Europeans has set the framework in order to advance the EU's political commitment. The recast Renewable Energy Directive and the recast Internal Electricity Market Directive include, amongst others, provisions that should promote citizen-owned energy projects in EU countries. However, the outcomes of the new Directives are still uncertain as these depend on national transpositions and the new State Aid Guidelines for Environmental Protection and Energy [13]. These policy design and implementation processes are being influenced by the advocacy work of diverse stakeholders representing multiple interests and holding unequal power; however – most importantly – the processes are also being constrained by the limited understanding of citizen ownership, including (1) the meaning of the concept of 'citizen ownership' and the multiple ownership models it encompasses, (2) the key distinctive characteristics of the various citizen ownership models, (3) their benefits for the energy transition and (4) suitable policies for citizen ownership promotion in different socio-technical contexts. As a result of these knowledge gaps, energy policies may result in unintended consequences, such as insufficient support for citizen ownership projects [14]–[16], large commercial investors qualifying for support schemes targeted at citizen initiatives [17], [18] or ineffective ownership policies, e.g., to mitigate local opposition [19]–[21]. These issues are elaborated further in the following section.

1.2. CITIZEN OWNERSHIP OF ENERGY: THE STATE-OF-THE-ART AND SIGNIFICANCE

Citizen ownership (often referred to as ‘community energy’) has received remarkable attention in recent years, and literature on the topic is growing swiftly [22]. However, there are still important knowledge gaps that hinder the design and implementation of effective policies to enhance social acceptance of the energy transition.

1.2.1. An Ambiguous Concept

There is no agreement on the meaning of ‘citizen ownership of energy’ or ‘community energy’ either in academia or among practitioners or policy-makers [23], [24]. For some, community energy implies citizens’ involvement in the decision-making process of a project, for others, the fact that citizens benefit from the energy project, and for the rest, a combination of the two. Besides, some stakeholders think that community energy entails an open and participatory process and/or local and collective project benefits, whereas for others, this concept may also include closed and top-down processes and/or distant and individual project benefits [24]. In addition, some stakeholders may believe community energy can only apply to small-scale projects, while others may believe it can include medium- and large-scale projects as well [23], [25]. Lastly, different vocabulary is used in different countries (e.g. ‘local ownership’ and ‘consumer ownership’ in Denmark, ‘shared energy’ in France, ‘citizen energy’ in Germany, ‘community energy’ in the UK, etc.) [25], [26], adding to the confusion. The different uses of community energy (and other similar terms) could be explained by stakeholders’ diverse normative understandings and different levels of awareness about the multiple (and relatively new) types of citizen ownership as well as by a lack of vocabulary to refer to this young and heterogeneous phenomenon [25].

The advantage of not sharing a common understanding of what citizen ownership or community energy is – or is not – is that more space exists for innovation and experimentation [24]. However, the still 'ambiguous' utilisation of the concept of citizen ownership [27] represents an obstacle to effective policy design [27], [28]. For example, the definition of citizen-owned projects specified in the German Renewable Energy Act of 2016 proved to be too broad when large, distant investors managed to fit the criteria and participate in the onshore wind tenders under the special conditions designed to support local citizen initiatives [17], [18]. Another example is the new EU Directives, which clearly reflect the differences in the understanding of citizen ownership and the lack of common (and meaningful) vocabulary. The Renewable Energy Directive includes the term 'renewable energy community' while the Internal Electricity Market Directive – approved only a few months later – uses the term 'citizen energy community' instead. The Directives provide similar but not equal definitions for these two terms, whereby the main differences include (1) the requirement (or not) that investors remain local and (2) the maximum size of shareholding companies. The aspects common to both definitions are (a) the emphasis on open and voluntary participation; (b) effective control by shareholders or members, who could be natural persons, local authorities or companies; and (c) the idea that the primary purpose of the organisation should go beyond obtaining financial profits.

It is important to highlight that the challenges caused by the ambiguous utilisation of this concept are not merely related to providing a 'good' legal definition for citizen ownership; they also hinder advancing in the understanding of the implications of promoting citizen ownership or not and of promoting some citizen ownership models and project types over others. The reason is that the broad and ambiguous label 'community energy' overlooks the diverse qualities and characteristics of the multiple citizen ownership models [25] – qualities and characteristics that can be determinants for achieving (or not) the desired policy outcome, e.g. local acceptance [29]. This argument is further elaborated in the following sub-section.

1.2.2. The Benefits and Drawbacks: An Understudied Field

Research on citizen ownership has largely focused on the factors that promote or hinder the initiation and implementation of citizen-owned renewable energy projects. However, much less attention has been paid to the benefits and drawbacks of (different types of) citizen ownership [29], [30]. Nonetheless, several studies have concluded that citizen ownership may deliver benefits for the energy transition as well as for other social challenges (see Table 1) [23], [29]. Yet, according to Berka and Creamer [29], the evidence base for this interpretation is 'too weak' and mainly built on qualitative research on project-specific case studies, providing greatly varying results. This means that some studies conclude, for example, that citizen ownership may reduce energy costs and prices, enhance local acceptance of new energy projects or build social capital, whereas others conclude the opposite (see e.g. [14], [29], [31], [32]). Understanding the benefits and drawbacks of citizen ownership requires identifying and describing (1) the key characteristics of the project (including the ownership model, the technology, the local community engagement and the financial model) as well as (2) the contextual factors and (3) motivations [28], [29]. However, Berka and Creamer point out that '*a large proportion of the literature* [dealing with the impacts of citizen ownership] *does not distinguish between different project types or provide sufficient context for project types to be deduced from the analysis*' [29, p. 3412]. Clearly, this missing distinction is problematic, as it impedes researchers from advancing the understanding of the benefits and drawbacks of citizen ownership and creates confusion about which benefits could (or could not) be expected from a given type of citizen energy project (within a specific socio-technical context), hindering the design and implementation of effective policies.

The strongest evidence base on the potential benefits of citizen ownership is found for knowledge and skills development and increased local acceptance of energy projects [29]. Access to affordable energy, empowerment and participation, and increased innovation seem to be the least studied benefits [23], [29]. Nevertheless, statistical analysis is lacking for all types of benefits. In addition, the benefits and drawbacks of collective citizen ownership models are relatively understudied. [29]

Table 1: The potential benefits of citizen ownership [23], [29], [32]. The benefits are dependent on the project type (i.e. a combination of the ownership model, the technology, the community engagement and the financial model) as well as the contextual factors and motivations [28], [29].

Benefits for the energy transition	Benefits for other societal challenges
- Enhanced local acceptance of new energy projects - Access to affordable energy, e.g. by promoting lower energy costs and prices - Capital contribution to renewable energy generation and energy efficiency implementation - Energy literacy and the adoption of environmentally benign lifestyles - Boosting of innovation	- Socio-economic regeneration or, in other words, local development - Knowledge and skills development, e.g. in project management, democratic participation - Building of social capital - Promotion of citizen empowerment, participation and democratic practices

Altogether, the lack of scientific evidence on the benefits different citizen ownership models can or cannot deliver means that:

- It is necessary to be more critical about the benefits of citizen ownership (under different contextual conditions) and to conduct studies that can both identify the citizen ownership models that can deliver the desired benefits and develop the understanding of effective policies to support the implementation of those models within different socio-technical contexts. To Creamer *et al.* [30], this is the main task in the field of citizen ownership research for the coming years.

- It is very easy for opponents of citizen ownership to disqualify it arguing that, in practice, citizen ownership does not deliver its commonly associated benefits. The main criticisms to citizen ownership is that it is more expensive and time consuming than large commercial ownership solutions [33]. With the urgency of climate change requiring a massive transformation of the technical energy system in the EU in the coming two to three decades, these arguments against citizen ownership (although not evidence-based) could seriously undermine socio-political acceptance of citizen ownership, leading to insufficient institutional incentives to promote its implementation and realise its benefits. Hence, investigating which ownership models are quicker and cheaper (for the society and consumers) to implement and operate a renewable energy system is highly relevant.

1.2.3. The Challenges and Opportunities: A Changing Technical, Institutional and Organisational Context

The new EU Directives could trigger new opportunities for citizen ownership in the EU Member States. Technological developments are also opening up new opportunities, such as collective self-consumption and storage, peer-to-peer trading, and (local) sector integration [6], [34]–[37]. However, citizen-owned energy projects still face several challenges. These may be direct challenges (which reduce or eliminate opportunities for citizens to own energy projects) or indirect challenges (which reduce or eliminate opportunities to implement certain technologies that are suitable and attractive for citizen ownership).

Contextual factors are determinant in promoting or challenging citizen ownership. Amongst them, the institutional incentive system has been found to be the greatest driver or barrier [23]. Oddly enough, despite the EU's commitment to supporting citizen ownership, important institutional incentive system changes that deter citizen ownership (directly or indirectly) have been adopted in recent years. Examples of these include the substitution of feed-in tariffs by auction schemes [14], [16], [17], [38], the introduction of more stringent spatial planning regulations in Germany [17], and the abolition of the '20% local ownership rule'[2] for onshore wind and solar farms in Denmark [39]. In the heat sector, a strong debate has taken place in Denmark (pressured by neoliberal ideologies) on the possibility of removing the cost-based pricing principle and liberalising district heating (DH) [40], [41]. All these policy changes and debates occur in an increasingly challenging context for citizen ownership, with, e.g. curtailment due to grid congestions [42], [43] and the merit-order-effect [34], [44], [45] reducing the attractiveness of investing in

[2] The Danish Act for the Promotion of Renewable Energy of 2008 introduced the 'local citizens' option to purchase wind turbine shares', more commonly known as the '**20% local ownership rule**'. This rule required that 20% of the shares of any (onshore and open-door offshore) wind turbine higher than 25 m were to be offered to local residents at cost price; first, to residents within 4.5 km from of the wind turbine(s), and, the remaining, to local residents in the local municipality where the wind turbine(s) was/were installed. This rule aimed at enhancing local acceptance of wind turbines. In 2018, the rule was extended to be also applicable to solar farms. The rule was abolished in 2020.

variable renewable energy, energy policies and public regulation discouraging energy savings and sector-coupling [34], [35], [46], and the saturation effect [16], [23] and large developers' strategic appropriation of land for energy projects [18], [34] decreasing the availability of good wind and solar plots. All these issues and others raise the question of whether the vision of 'an Energy Union with citizens at its core' has the necessary socio-political support to be realised or whether it will prove to be an empty slogan.

At this point, it is important to highlight that the institutional incentive system is the result of a political process. As mentioned previously, this political process is constrained by the limited understanding of both the impacts of the multiple socio-technical solutions (including citizen ownership) that could help achieve carbon neutrality by 2050 and effective policies for promoting the 'best' solutions. Moreover, the process is influenced by stakeholders representing diverse interests and holding imbalanced power, and tends to favour the dominant market actors [47], [48]. Several studies (see e.g. [15], [49], [50]) show that the governance of the political policy-making process may be an important cause of the drivers or challenges of citizen ownership. In this sense, political governance models that acknowledge power imbalances and promote more equitable participation may be expected to result in more favourable conditions for citizen ownership than those that ignore power imbalances [47], [49].

Power struggles challenging citizen ownership have also been observed at the project implementation level, for example, due to difficulties in entering into partnerships for joint project ownership [21], [51], [52]. The literature also highlights informal institutional[3] challenges (e.g. scepticism about engaging in collective investments in energy projects) and organisational[4] challenges (e.g. a lack of resources and expertise) [9], [23]. Organisational challenges have

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[3] Following North's definition [175], **institutions** constitute the formal and informal rules of society and shape actors' economic, political and social behaviours or, in other words, actors' participation and interactions in economic, political and social processes. Formal institutions, also known as regulatory institutions, encompass, e.g., public regulations and policies. Informal institutions comprise norms and habits as well as beliefs and values. Formal and informal institutions are dynamic (changes may take place in the short, medium and long terms), interrelated and embedded in socio-technical systems. Section 3.4 offers more details on how institutions are understood to shape the technical and governance characteristics of an energy system's implementation and operation.

[4] **Organisations** are '*groups of individuals bound together by some common purpose to achieve objectives*' [175, p. 361]. Organisations can have an economic, political, social or educational purpose. Companies, trade unions, associations, NGOs, political parties and universities are examples of organisations.

emerged mainly from the (generally) small scale of citizen-owned energy projects and organisations [23].

In the light of these new opportunities and challenges, citizen ownership is undergoing a process of business model innovation; among other developments, these organisations are becoming more professional and resilient by increasing in size and/or diversifying their revenue streams [8], [53]. The strengthening of networks and collaborations working towards citizen ownership has also been observed [54]–[56]. Whether and how these contextual and business model changes will influence citizens' motivation to engage in projects, the level of democratic practices within the organisations, the degree of involvement from the local community, the extent to which citizen ownership will be implemented (and for which technologies and services), and the benefits that the projects will deliver for the energy transition remain open questions.

1.2.4. Summary and Research Gaps

Literature on citizen ownership suggests that it could help address some of the main challenges of the energy transition (e.g. local acceptance, capital contribution and cost-efficiency). However, there are important knowledge gaps:

1. The confusion regarding what community or citizen ownership is (or is not) persists, and there is little understanding among researchers, policy-makers and practitioners of the key distinctive characteristics of the many existing citizen ownership models.
2. Scientific evidence is lacking on the benefits of citizen energy projects. There is little understanding of how the distinctive characteristics of the diverse citizen ownership models, in combination with other project characteristics (e.g. the technology), influence the benefits that citizen energy projects can (or cannot) deliver. Furthermore, there is little understanding of how those benefits may vary under different socio-technical contexts.
3. Changes in the contextual factors and motivations of citizen ownership are creating new opportunities and challenges, resulting in new ownership and business models and the strengthening of

networks supporting citizen ownership. The benefits and drawbacks of the new models are still to be seen.

4. Advancing the understanding of citizen ownership requires, amongst others, moving beyond project-specific case studies to conduct statistical analyses and develop clear criteria and typologies for collective citizen ownership that can inspire policy-makers.

Given the significance citizen ownership could have for supporting a timely energy transition via enhanced local, market and socio-political acceptance, this study contributes to advancing the knowledge on citizen ownership and addressing the above-listed research gaps.

1.3. THE STRUCTURE OF THE DISSERTATION

This section introduces the structure of the dissertation and explains how the different chapters are linked with the aim of contributing to the knowledge of citizen ownership and its benefits for the energy transition.

Chapter 2 presents the problem statement and the research questions of the study. Chapter 1 has underlined the importance of studying the benefits of citizen ownership models in combination with specific technologies and within specific socio-technical contexts. Therefore, Chapter 2 presents (a) the chosen technologies, (b) the ownership-related challenges of the chosen technologies and (c) the socio-technical context in which those technologies and their challenges are studied in combination with diverse ownership characteristics. Points a-c form the problem statement of the study, leading to the research questions.

Chapter 3 presents the theoretical approach and its delimitations. The chapter starts by introducing the understanding of citizen energy projects, their development, citizen ownership models and their distinctive characteristics. The chapter situates the analysis within the context of a radical technological change and presents Concrete Institutional Economics as a suitable approach for the design of alternative energy plans and the study of the benefits and drawbacks of different ownership models. The chapter also introduces the analytical framework developed to analyse the benefits of citizen ownership in combination with specific technologies and within a specific socio-technical context. Finally, the chapter presents the central concepts to in-depth study 2.

Chapter 4 presents the research design and the three in-depth studies that contribute to building the overall theoretical approach and answering the research questions. The chapter begins by explaining the reasoning behind the research design. Afterwards, the three in-depth studies with their individual theoretical approaches and methodologies are described. The methodological delimitations regarding data collection and analysis are also discussed.

Chapter 5 presents the results from the three in-depth studies and discusses these results in relation to both the existing literature and the study's delimitations. Thereby, the chapter answers the sub-questions and the main research question.

Chapter 6 presents the main theoretical and analytical conclusions of the study as well as relevant research outlooks. The chapter includes a discussion on the policy implications of this research for Denmark, Sweden and other EU countries.

CHAPTER 2. PROBLEM STATEMENT AND RESEARCH QUESTIONS

Chapter 1 highlighted the significance of studying citizen ownership in the context of the energy transition in the EU. It also identified important research gaps and underlined the relevance of studying the benefits of the diverse citizen ownership models in combination with specific technologies and within specific socio-technical contexts. In line with the main outcomes of Chapter 1, Chapter 2 presents the problem statement, which frames the study by introducing (a) the chosen technologies, (b) the ownership-related challenges of the chosen technologies and (c) the socio-technical context in which those technologies and their challenges are studied (in combination with diverse ownership characteristics). Points a-c lead to the research questions, which are presented together with the research objectives.

2.1. THE CHOSEN TECHNOLOGIES: ONSHORE WIND FARMS AND DH SYSTEMS

Many studies have been conducted on technical strategies for meeting EU energy targets. Within those studies, it is possible to identify some general trends and ongoing discussions, which can be broadly grouped under (1) single-sector vs. cross-sector approaches and (2) centralised vs. decentralised solutions. The former relate mainly to the flexibility of the energy system to accommodate large shares of variable renewable energy, whereas the latter relate to the geographical re-organisation of the energy system.

Amongst the single-sector and cross-sector approaches, the smart energy system approach stands out with its holistic energy system perspective. The smart energy system *'is defined as an approach in which smart electricity, thermal and gas grids are combined with storage technologies and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system'* [57, p. 560]. Thus, the smart energy system approach provides several benefits compared to other approaches. The benefits include higher system flexibility [58]–[61], which increases the potential for variable renewable energy integration and results in higher system efficiency and lower demand for biomass [62]–[65]. Besides, compared to the single-sector approaches, the smart energy system approach could help reduce the socio-economic costs of low-carbon energy systems with high shares of variable renewable energy (see e.g. [61], [64]).

Studies investigating the smart energy system approach have been conducted at international [61], [64], [66], national [62], [67], [68] and local scales [69]–[71] and have identified, e.g., the optimal balance between the implementation of DH, individual heat pumps and energy efficiency measures in buildings in the EU from a socio-economic perspective [64], [72]; the sector integration, energy efficiency and socio-economic advantages of fourth-generation DH (4GDH) systems compared to previous generations [65], [73]; the need to electrify the heating, cooling and transport sectors to the greatest extent possible and to use hydrogen for electrofuel production in order to avoid unsustainable use of biomass in 100% renewable energy systems [63]; and the need to substantially increase the installed wind and solar power capacities [61], [62], [66], [67].

This study focuses on onshore wind farms and DH systems in the context of a transition to a renewable smart energy system. The reasons for this focus are listed below:

1) These are key technologies for the North Sea Region and hold significant untapped potential for implementation in EU countries [61], [72], [74], [75].
2) These two technologies are seen as technically and economically interrelated in a smart energy system. Power-to-heat units and thermal storage in DH systems contribute to integrating larger shares of wind power in the energy system [64] and to mitigating the merit-order-effect [45], while wind power contributes to the decarbonisation of DH systems and enhances their sustainability by reducing biomass consumption [63].
3) They are mature technologies that have been implemented for decades. Nonetheless, the transition to a renewable smart energy system poses important challenges (including ownership and other

governance[5] challenges) to their implementation and operation. These challenges are introduced in the following section.

4) They are decentralised technology solutions that have expanded opportunities for collective citizen ownership, as evidenced by examples in, e.g., Germany, Sweden, the UK and, most remarkably, Denmark [20], [76]–[81].

5) The existing literature suggests that citizen ownership could help accelerate the implementation of onshore wind capacity and 4GDH systems during the transition to a renewable smart energy system while supporting the reduction of energy system costs and protecting consumers' interests against monopolistic (DH) companies (see e.g. [14], [20], [32], [34], [77], [78], [80], [82], [83]). However, there are still important knowledge gaps and institutional hindrances, as previously mentioned in section 1.2.

Points 3 and 5 are further elaborated in the following section.

2.2. GOVERNANCE CHALLENGES OF ONSHORE WIND FARMS AND DH SYSTEMS AND THE RELEVANCE OF OWNERSHIP

2.2.1. Onshore Wind Farms

Wind turbines convert the wind's kinetic energy into electricity. The capacity of modern wind turbines can range from several kW to several MW and they can be installed individually or in groups, both onshore and offshore. Wind is

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[5] **Governance** can be understood as '*the totality of interactions, in which public as well as private actors* [and the civil society] *participate, aimed at solving societal problems or creating societal opportunities*' [176, p. 4] and as '*the condition that creates the opportunity to collaborate, cooperate and participate*' [177, p. 26]. In Transaction Cost Economics, governance '*is an effort to craft order, thereby to mitigate conflict and realise mutual gains*' [178, p. 599]. Energy system governance models can be very diverse in areas including the openness of participation (e.g. the range of actors involved in the design of energy policies or in the ownership of energy assets), distribution of decision-making power, transparency (e.g. regarding investment decisions or system costs) or coordination of actors' interactions (e.g. bottom-up coordination, as in peer-to-peer energy trading or municipal energy planning, or top-down coordination, as in electricity spot markets or national energy planning). Furthermore, governance takes place at multiple levels (including international, national and sub-national levels), which can be vertically and horizontally coordinated [179].

a distributed and variable natural resource, meaning that onshore wind energy is produced closer to the consumers than fossil fuels and only when available. Wind power offers several benefits compared to fossil fuel electricity; for example, wind turbines do not emit CO_2 during the production of electricity and large onshore wind turbines have reached similar or even lower levelised costs per MWh than other power production technologies based on fossil fuels [84]. However, as the implementation of wind turbines advances, problems regarding local opposition [85], the merit-order-effect [34], [44], [45] and curtailment due to electricity grid congestion [42], [43] are increasing, challenging the economics and implementation of new onshore wind farms. Therefore, it is highly relevant to design and implement technical, governance and institutional solutions that address these challenges effectively [34], [35].

Several studies suggest that cross-sector integration alleviates the merit-order-effect and reduces congestion issues and the need for additional electricity grid transmission capacity, resulting in lower energy system costs (see e.g. [34], [43], [45], [61]). To that end, it is necessary to coordinate investment in and operations of wind turbines and sector integration technologies (such as power-to-heat in DH systems and power-to-X) in time, size and location [35]. Gill *et al.* [43] and Hvelplund and Djørup [32] suggest that local (co-)ownership could reduce the transaction costs of this coordination and improve the economics of wind turbines. However, the benefits and drawbacks of local (co-)ownership models as well as their institutional hindrances and opportunities have not yet been sufficiently investigated.

Several studies (see, e.g. [29], [34], [86]) suggest that local citizen ownership may enhance local acceptance of onshore wind farms. However, locally owned projects have also experienced strong opposition. For example, in 2012, 6 out of 7 wind projects initiated by local residents were cancelled due to local protests in Thisted municipality, Denmark (personal communication with Nordic Folkecenter). Other cases of local opposition to wind projects initiated by local residents have been documented e.g. in [87]. Besides, some policy measures aimed at promoting local acceptance of wind farms through local ownership have proven ineffective [18], [19], [21]. Berka and Creamer [29] argue that inclusiveness could be a determinant of local citizen ownership to enhance local acceptance of renewable energy projects. However, it remains unclear which local citizen ownership models are inclusive. Furthermore, some actors have questioned whether (local) citizen ownership is effective in promoting a quick and affordable energy transition, based on arguments about larger project and capital investments, riskier market conditions, the goal of reducing wind subsidies, etc. In line with these ideas, some have suggested that while citizen ownership was positive for the initial stages of wind power development and implementation, it is insufficient for the medium and advanced stages. However, others (see e.g. [14]) have argued that citizen ownership could be cheaper than commercial ownership. Besides, local citizen ownership is in the process of organisational innovation to adapt to the changing context and build more resilient business models.

The research described above indicates that it is relevant to differentiate inclusive and exclusive ownership models, conduct statistical analysis of the shares of wind capacity implemented by different owners under different contextual conditions, and advance the understanding of new local and inclusive citizen ownership models, including cross-sector co-ownership models.

2.2.2. DH Systems

DH systems are collective heating systems in which hot water is distributed via pipelines from the production and storage points to the end consumers. The water can be heated using various energy sources, such as fossil fuels, biomass, waste, geothermal energy, solar energy, electricity or waste heat [65]. In Denmark, these systems commonly involve from a few hundred to several thousand consumers [88]. DH systems, like other network infrastructures (e.g. electricity or gas grids), are natural monopolies [89]. This means that having more than one DH system in the same area results in higher costs than having only one system. In contrast to other network infrastructures, DH systems are of a local character. Therefore, competition between production and storage units and between retailers is constrained by the limited size of the local market. Consequently, the unbundling of heat production, distribution and retail does not necessarily lead to lower heat prices. Hence, DH systems are (vertically integrated) local natural monopolies, whereby often one single company is in charge of the heat production, distribution and retail. Nonetheless, it is common that DH systems have more than one heat producer, e.g., when waste heat from industrial processes or power plants is used [25]. A few cases also exist (in large DH systems) in which transmission is unbundled from distribution and retail [90].

In certain locations − mainly in areas with high demand densities and/or cheap thermal sources − DH systems can provide several advantages compared to individual heating solutions. These advantages include opportunities to use local heat resources (e.g. waste heat from industrial processes and geothermal energy), higher flexibility to accommodate variable renewable energy (through power-to-heat and larger thermal storages) [64] and higher efficiency in the burning of fuels (e.g. biomass and natural gas) [91], [92]. Thus, DH systems can provide environmental benefits and reduce the socio-economic costs of implementing and operating a renewable energy system [64]. DH solutions may also provide advantages to the users (in other words, to the heat consumers), e.g. a reduced risk of accidents at the heat consumption site, less required operation and maintenance, smaller space usage for heating equipment in buildings, improved indoor environments, and decreased noise [93]. Furthermore, with the right institutional incentives and governance, DH solutions may reduce consumers' energy bills [81], [94]. However, the exploitation of those advantages requires the 'right' institutional incentives, i.e. those that adequately address the challenges of DH systems, to be established.

First, and most importantly, the institutional incentive system should protect consumers' interests and rights. Since DH is a natural monopoly, dissatisfied consumers cannot choose another DH supplier; they can only invest in another heat supply system. Empirical examples from various EU countries prove that DH companies can misuse their monopoly status and the consumer lock-in effect, offering dissatisfactory products and/or quality of customer relations and/or charging unreasonable heat prices [89], [94]–[98]. Thus, DH involves some important risks for consumers, which could reduce consumers' willingness to choose DH over other heating options [97]–[100]. This is highly problematic because the economy of the DH system depends, amongst others, on the density of heat demand and, hence, on the local consumers' connection rate to the system. Therefore, it is important that the institutional framework promotes DH companies' trustworthy behaviour, thus encouraging consumers to choose DH. Note that such trustworthy behaviour implies high cost-efficiency [101], which is a major concern and regulatory challenge in natural monopolies. Hvelplund and Djørup's study on distribution system operators (DSOs) suggests that ownership could be a determinant for ensuring the effective control of prices charged by monopolistic companies [32]. However, this has not yet been investigated for DH.

Second, achieving the other advantages listed above will require both the transformation of the existing DH systems into 4GDH and the implementation of new DH systems with 4GDH qualities [65], [73], where socio-economically beneficial. To that end, it will be necessary for institutions to promote the needed investment in DH and energy efficiency in buildings and for there to be coordination between investment in the supply side and the demand side [46]. Some studies suggest that local municipal ownership and local consumer cooperatives could improve the economic attractiveness of the necessary investment [102] and reduce the transaction costs of the necessary coordination [32]. Furthermore, the co-ownership of power-to-heat units and wind turbines by DH companies could have some advantages over separated ownership [34]. However, this could depend on the location and type of connection [103]. Ultimately, the benefits of citizen ownership in accelerating and reducing the costs of implementing and operating 4GDH have not yet been sufficiently investigated.

2.3. THE CHOSEN SOCIO-TECHNICAL CONTEXTS: DENMARK AND SWEDEN

Denmark is the EU country with the highest share of citizen ownership of energy assets [104]. Citizen ownership in Denmark is common for onshore and open-door offshore wind farms, combined heat and power (CHP) plants, DH systems, distribution system operators (DSOs), biogas plants, household wind turbine and photovoltaic installations, etc. [105]. Large-scale citizen ownership models are also common in Denmark [105], unlike in other EU countries [104]. Furthermore, there is at least one empirical example of co-ownership of wind turbines and DH systems [34], [103], which was implemented in response to the insufficient institutional incentives for investment in wind power and power-to-heat [35]. Denmark's long-term experience with and great variety of citizen ownership models and projects make it a precious and underexploited source of knowledge about citizen ownership, its diverse qualities and characteristics, and its benefits and drawbacks.

Interestingly, while political support for citizen ownership seems to be increasing in the EU, Denmark seems to be moving in the opposite direction by increasing political support for large commercial investor models, to the detriment of citizen ownership [15], [21], [25], [40], [41], [106], [107]. This shift is putting pressure on the citizen ownership of onshore wind farms and DH systems and could result in major changes in the ownership of these technologies in the coming years (see e.g. [25]). This is problematic because the implications of enhancing support for large commercial companies are not fully understood, but could presumably slow down the energy transition and raise energy system costs and consumer prices [32]. This presumption is in line with the research results presented later on in this dissertation.

Denmark is also relevant to analyse because of the stage of the energy transition it has reached and the perspective it provides on new challenges and the need for new strategies to address the next steps. This country stands out for having the largest share of wind power in the EU [108] – wind energy produced about 52% of the final electricity demand in 2019 – and a big share of CHP plants and DH systems, which supply about 65% of the residential buildings [109]. Furthermore, Denmark has set ambitious climate and energy targets. The Energy Agreement of 2018 sets the objectives of meeting 55% of the energy demand, 100% of the electricity demand and 90% of the heating demand with renewables by 2030 and of phasing out fossil fuels with a 100% renewable energy system by 2050. The Climate Act of 2020 aims at a 70% CO_2 emission reduction compared to 1990 levels by 2030 and becoming climate neutral by 2050.

Denmark is at a stage of development in citizen ownership and in the energy transition that offers the chance to investigate different and new research questions regarding citizen ownership. Overall, Denmark provides the ideal context to advance the understanding of citizen ownership models and their ability to address some of the main challenges of onshore wind farms and DH systems during the transition towards a renewable smart energy system. However, to examine the benefits of different ownership models for DH under different institutional conditions, this research compares Denmark with Sweden, where there have been more significant changes in regulation and ownership of DH companies than in Denmark [80], [81], [96].

2.4. RESEARCH OBJECTIVES AND QUESTIONS

This study was conducted as part of the ENSYSTRA project (an EU-funded H2020-MSCA-ITN action project), which stands for ‘Energy Systems in Transition’ and focuses on the countries of the North Sea Region. The final goal of the study is to inform policy design and implementation processes in the North Sea Region and the EU to promote a timely energy transition in line with society’s goals and users' expectations. To this end, the study’s analysis advances the understanding of citizen ownership by answering the following research question and sub-questions:

Based on knowledge from Denmark and Sweden, which ownership characteristics and models could best promote the implementation of onshore wind farms and DH systems in renewable smart energy systems and the reduction of related energy costs and prices?

SQ1: How much wind capacity has been installed by type of owner in Denmark under different institutional incentive systems and contexts? How have ownership characteristics and models changed over time? What are illustrative examples of current local and inclusive ownership models that promote broad local acceptance?

SQ2: How much DH demand has been supplied according to the type of owner in Denmark and Sweden? How have ownership and institutional conditions changed over time and influenced DH companies' motivation to exhibit trustworthy behaviour regarding DH prices?

SQ3: Under the current institutional incentive system and context in Denmark, how does the co-ownership of wind turbines and power-to-heat in DH systems promote the implementation of these technologies and the reduction of electricity grid costs? How does location influence the identified benefits and drawbacks?

By investigating these research questions, the study advances the understanding of which ownership characteristics and models could best enhance the market, local and socio-political acceptance of onshore wind farms, DH systems and cross-sector integration. The following chapter introduces the theoretical approach and analytical framework guiding the research.

CHAPTER 3. THEORETICAL APPROACH

Chapter 3 presents the theoretical approach that guides the research and discusses the theoretical delimitations as well as relevant research outlooks. The theoretical approach addresses the confusion about citizen ownership and develops a suitable analytical framework to answer the research questions. The chapter begins by introducing citizen energy projects, citizen ownership models and their characteristics. It also introduces the concepts of trust, DH companies' trustworthy behaviour and consumer power, which are central for in-depth study 2 (see Chapter 4 and Appendix B for more details). Moreover, the chapter situates the study within the framework of developing alternative energy plans in a context of radical technological change. Finally, the chapter presents the socio-technical understanding of renewable smart energy systems' implementation, operation and performance, thereby explaining the causal relationships between (1) the governance of the political process, (2) the institutional incentive system, (3) other contextual factors, (4) the technical and governance characteristics that determine the operation and implementation of renewable smart energy systems and (5) the benefits of the energy system (or the energy system performance[6]). For more details on the understanding of important overarching concepts, see the footnotes in Chapters 1-3.

3.1. CITIZEN ENERGY PROJECTS AND OWNERSHIP MODELS

Diverse understandings exist about the meaning of citizen (or community) energy projects [23], [24]. Given the purpose of the study, a broad understanding is adopted for the analysis. In this study, 'citizen energy projects' and 'citizen ownership models' are understood to imply that citizens hold decision-making power over the energy project and company and benefit economically or socially from the project. This understanding excludes only centralistic structures (common to state-owned or large international commercial energy companies) and citizen participation without control.

[6] The **energy system performance** relates to the fulfilment of society's goals and users' expectations. The (mis)alignment of technology and institutions determines the energy system performance [180].

Hence, individual ownership (e.g. by landowners or prosumers), local and national wind cooperatives, citizen-owned utility companies, etc. all qualify as citizen energy projects in this study. Moreover, citizen energy projects may engage in energy savings, production, distribution, supply, aggregation, etc.

The **scope of the study** is limited to the analysis of the ownership of wind and DH companies after implementation; in other words, citizen ownership in the pre-implementation phase and the impacts of this ownership on the projects' characteristics and benefits are not examined. It is acknowledged that the (lack of) distribution of decision-making power in the pre-implementation phase can influence the characteristics of both citizen and commercial energy projects and, hence, the benefits the projects will deliver. Local and inclusive citizen ownership in the pre-implementation phase may be especially influential in supporting e.g. local acceptance [29], [110]. In this study, it is assumed that the ownership of the project in the post-implementation phase is indicative of the ownership in the pre-implementation phase. Thus, this study does not assess the benefits of, for example, large commercial investors' projects that have broad citizen ownership in the pre-implementation phase yet little or no citizen ownership in the post-implementation phase. Given the Danish tradition of citizen ownership, such an alternative is seen as quite improbable and to the best of the author's knowledge, there are no empirical cases thereof. Nonetheless, analysing such cases could be more relevant in contexts where there is little tradition of or even a reluctance towards citizen ownership of energy projects. The analysis of ownership in the pre-implementation phase could also be relevant to understand the drivers and barriers of the implementation of diverse citizen ownership models. However, this analysis is beyond the scope of this study.

The characteristics of citizen energy projects are understood to be shaped by contextual factors and motivations; these influence decisions regarding the ownership model, the approach towards local community engagement, the economic activity, the business model and the financial model (see Figure 1). In turn, the characteristics of citizen energy projects determine the benefits the projects will (or will not) deliver. [28] The wide range of contexts and motivations involved explains the diversity of citizen energy project types and citizen ownership models. Furthermore, citizen initiatives may adapt to changing contextual factors and motivations, resulting in new types of citizen energy projects and ownership models (see e.g. [8], [25], [27], [36]).

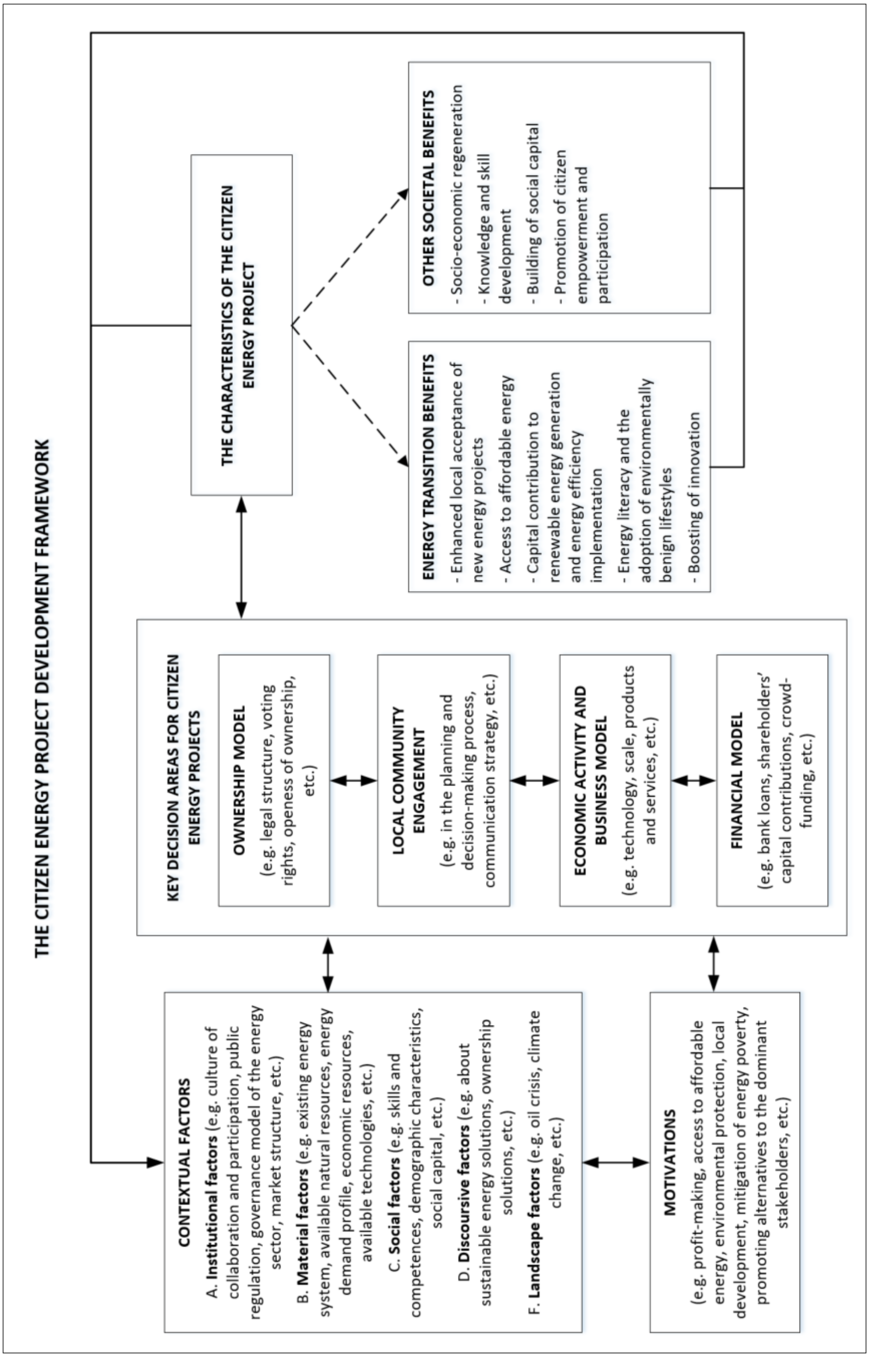

Figure 1: The citizen energy project development framework, inspired by [20], [23], [26], [28], [29], [50], [53] and others.

The difference in motivations and company values can explain some of the most fundamental differences between commercial energy companies and (some types of) citizen-owned energy companies, leading to different behaviours regarding e.g. technology choices and investment decisions, distribution of benefits, distribution of decision-making power, and transparency with consumers and regulatory authorities [25], [32], [35], [78], [101], [111], [112]. Given the purpose of this study, it is important to break with the Neoclassical Economics' tradition of considering all companies as '*identical and neutral "dots" behaving in a similar way on the market*' [111, p. 53] and highlight the key differences between the diverse ownership models.

Figure 2 provides an overview of the citizen ownership models implemented for wind turbines and DH systems in Denmark before December 2016 [25]. This figure advances the existing knowledge on the diversity of citizen ownership models (see e.g. [9], [27], [29], [113]) and offers new vocabulary to refer to it by providing information about the distinctive characteristics of the ownership models. These distinctive characteristics are often overlooked due to the ambiguous utilisation of the concept of 'community energy' and other similar terms, leading to confusion and policy design challenges, as explained in the introduction chapter. The distinctive characteristics found in this study concern (1) the geographical scope, (2) the distribution of economic benefits and decision-making power and (3) the type of economic benefits [25].

- **The geographical scope** of project ownership can be 'distant', 'local' or a combination of both. In the Danish context, local ownership means that the owner(s) reside(s) or develop(s) his/her/their main economic activity within the boundaries of the local municipality (or municipalities) where the project is being implemented.
- **The distribution of economic benefits and decision-making power** can be 'inclusive' or 'exclusive'. Inclusive ownership models are those in which '*all citizens within a pre-determined geographical area have an equal opportunity to* [gain economic benefits] *from the energy project* [and make decisions regarding the project]*; this may be the result of open ownership (either in the form of shareholder or consumer with direct or delegated decision power) or spread distribution of profits through financing of development projects'* [25, p. 9] and broad stakeholder representation in the organisations' boards. In contrast, exclusive ownership models are those in which '*the project promoter(s) decide(s) to keep the possibility to* [gain

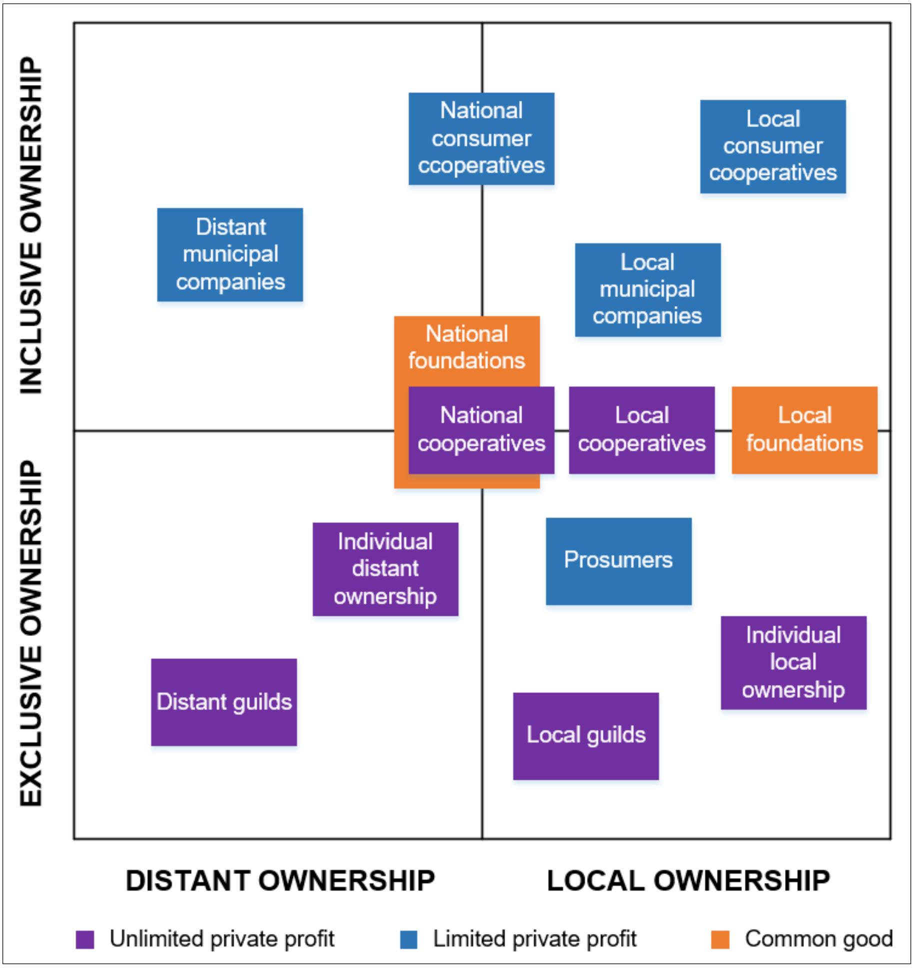

Figure 2: The Danish citizen ownership models for wind turbines and DH companies and the main citizen ownership categories, as presented by [25] but with the foundation models placed in between the inclusive and the exclusive ownership categories. The categories consider only the ownership of the energy projects post-implementation, not pre-implementation, i.e. in the planning process. The ownership of energy projects and companies may involve several ownership models, including both citizen and non-citizen ownership models such as commercial and state ownership. Therefore, the ownership may belong to diverse ownership categories. When reading the diagram, note that the categories are represented in boxes and not in axes. This means that the location of the citizen ownership model within the category box does not indicate a lower or higher degree of the ascribed characteristic. However, it is important to note that some ownership models are placed in between more than one category, which indicates that they do not completely meet the definition of one category or the other. The original figure presented in [25] was published under a CC By 4.0 Creative Commons license.

economic benefits and make decisions] *within a selected group of people, excluding the rest of the community or society from the ownership'* [25, p. 9]. There are a few important considerations about inclusive ownership to keep in mind. The first is that distant inclusive ownership does not share the economic benefits or the decision-making power with the local community. The second is that not everyone in a society has the necessary resources to invest in shares or contribute with upfront capital. This means, for example, that the wind cooperatives in Denmark are not completely inclusive. The third is that the inclusiveness regarding of decision-making power may depend on the by-laws of the organisation, such as, for example, the rules for the formation of the board. This is particularly important in foundations, where the election of board members and the range of actors' interests represented in the board may result in inclusive or exclusive ownership regarding decision-making power. Another important consideration (although not dealt with in this study) is the extent of the inclusion/exclusion of groups of citizens that are often underrepresented in energy debates and ownership, e.g. women, people with limited education, people with limited economic resources, immigrants, or people of different ethnicities. It is reasonable to think that the inclusion levels of these underrepresented groups could have important implications for the social acceptance of technologies and (citizen) ownership models. Therefore, it would be relevant to research this topic further.

- Finally, several **types of economic benefits** exist; benefits can be for 'unlimited private profit', 'limited private profit' or the 'common good'. In the case of unlimited private profit ownership models, there are no external or internal regulations limiting investment and profits, whereas in limited private profit ownership models, external and/or internal regulations set a cap on investment and/or profits.

3.2. TRUST, CONSUMER POWER AND DH COMPANIES' TRUSTWORTHY BEHAVIOUR

Trust has been identified '*as an important feature of well-functioning and prosperous societies*' [114, p. 1]. Trust '*lubricates cooperation*' [115] and can be a condition for technology adoption [99], local acceptance [29], [87], [110], participation in renewable energy projects [87], [116], etc. From an economic perspective, trust reduces transaction costs [114]. Therefore, trust has a positive connotation and enhancing trust is an explicit goal of several legislations. However, Hult [114] warns that trust is only positive when the trustee is trustworthy; otherwise, the trustor could be at risk. Furthermore, Hult argues that rather than aiming at enhancing trust, legislation ought to aim at promoting trustworthy behaviour which can result in enhanced system trust (also known as institutional trust). To understand Hult's statement, it is necessary to differentiate between 'interpersonal trust' (i.e. trust in another individual or organisation) and system or 'institutional trust' (i.e. trust in the institutional system).

Interpersonal trust refers to the belief in another actor's competence and benevolence to accomplish a specific task [114]. Institutional trust can be understood as the belief '*with feelings of relative security, that favorable conditions are in place that are conducive to situational success in a risky endeavor* [..]' [117, p. 37] or, in other words, the belief that the institutional system protects one in the accomplishment of a given task. Legislation and other mechanisms of control are not suitable for enhancing interpersonal trust because they eliminate the possibility of assessing whether the trustee is acting out of benevolence or obligation. On the other hand, legislation and other mechanisms of control may be necessary to protect diverse actors' rights and interests in certain situations. This can be achieved by promoting targeted actors' trustworthy behaviour through legislation and other mechanisms of control and can result in enhancing protected actors' institutional trust [114]. Therefore, promoting DH companies' trustworthy behaviour can be fundamental to increasing residential consumers' willingness to use DH [97]–[100]. From the consumer's perspective, DH companies exhibit trustworthy behaviour by delivering heat with satisfactory product and customer relations quality and at reasonable prices [100].

Study 2 analyses how different configurations and levels of consumer power support the effective control of DH prices. Consumer power has four dimensions: state regulative power, ownership power, buying power and communicative power [32], [118]. These dimensions can be understood as mechanisms of control that can motivate DH companies to exhibit trustworthy behaviour [101], [114]. This understanding of consumer power has been successfully applied to the study of DSOs' (i.e. other monopolistic energy companies) price behaviour [32]. Therefore, it is considered appropriate for this study's analysis of DH companies' behaviour.

3.3. THE DESIGN OF ALTERNATIVE ENERGY PLANS IN THE CONTEXT OF RADICAL TECHNOLOGICAL CHANGE

From a technical perspective, the traditional fossil fuel based system is considerably different from a renewable energy based system, which is characterised by significant energy demand reductions and a substantial share of variable renewable energy (see Table 2). Transitioning from the traditional fossil fuel based system into a renewable energy based system requires the geographical re-organisation of the energy system in order to harvest decentralised energy resources and realise energy demand reduction potentials. Thus, a renewable energy based system is geographically much closer to consumers than the traditional fossil fuel based system. Moreover, this transition implies the loss of flexibility provided by the easily and cheaply storable fossil fuels and the need to replace that flexibility somewhere else in the system so that production meets demand. These technical differences are so substantial that they require significant changes in the knowledge and governance of energy systems and lead to significant changes in profits [119]. Hence, the transition entails a radical technological change[7] and poses great challenges as well as new opportunities [119].

Because of these changes, the energy transition introduces a great power struggle – with large economic interests involved and a great power imbalance between the actors influencing the political process [47], [48] – while the positive and negative impacts of different socio-technical solutions are still not fully understood. This becomes evident, for example, in discussions about suitable technical and/or governance solutions, the adequate speed of the transition and energy justice considerations. In fact, this power struggle and lack of understanding is highly problematic because when a society re-defines its goals and expectations (e.g. regarding the acceptable levels of CO_2 emissions in the energy system) in such a way that a radical technological change is required to meet the new goals and expectations, existing

[7] **Technology** consists of five components: technique, knowledge, product, organisation [181] and profit [119]. Here, 'organisation' refers to the act of organising and, thus, aligns with the understanding of 'governance' (as presented in footnote 5 on page 15). According to Müller, '*a qualitative change in any of the components* [that form a technology] *will eventually result in supplementary, compensatory, and/or retaliatory change in the others*' [181, p. 30]. This means that fundamental changes in one of the components of a technology will be either followed by changes in the other components or dismissed. A **radical technological change** implies significant modifications in at least two of the components of a technology [119].

Table 2: Main technical differences between fossil fuel based systems and renewable energy based systems and their implications for the governance of the energy system.

Fossil fuel based systems	Renewable energy based systems	Implications for the governance of the energy system
Fossil fuels are concentrated in a few locations.	Variable renewable energy resources (such as wind and solar energy), energy efficiency improvements and behavioural changes are distributed.	Need for geographical re-organisation of the energy system. Increased visibility of energy infrastructure. Significant changes in the value-creation chain [49].
Fossil fuels are extracted, distributed and stored for their use when necessary.	Variable renewable energy can only be stored after their transformation into an energy carrier (e.g. electricity or hot water).	The loss of flexibility on the production side needs to be compensated in other parts of the energy system with integration technologies and strategies. Multiple technical approaches are being considered [57]. New business models (e.g. aggregators and virtual power plants) have been observed [6], [36].
Fossil fuels have marginal production costs.	The marginal production cost of variable renewable energy technologies is close to zero.	The techno-economic optimisation logic for energy systems is altered, which requires the reconsideration of e.g. market design [45], [120] The higher asset specificity of renewable energy based systems demands higher investment coordination to reduce the overall system costs.
Countries without DH, have preferred large fossil fuel power plants due to economies of scale.	Variable renewable energy technologies such as wind turbines and solar panels are scalable/modular providing the opportunity to have installations ranging from a few hundred watts to several hundred megawatts.	New ownership opportunities, e.g. for individual or collective citizen ownership [6], [7]. Small energy projects are not suitable for the traditional business model of incumbent energy companies [121], [122]. Incumbent energy companies are losing their market shares.

organisations '*will hinder the development of new solutions* [,] *eliminate certain alternatives and* [..] *seek to create a perception indicating that society has no choice but to implement technologies* [i.e. techniques and governance models] *that will save and constitute existing positions*' [123, p. 30]. Especially relevant to this study is the observation of empirical examples of mechanisms used to eliminate the opportunities for citizen energy projects (see, e.g., [15]). In this context, it is extremely important to advance knowledge of technical and governance solutions that could maximise the energy system performance and raise stakeholders' choice awareness by informing the policy design and implementation processes about those solutions [123]. With this purpose, this study is based on the Concrete Institutional Economics approach [47], [124] developed for the design of alternative energy plans that meet society's goals and users' expectations in the context of radical technological change.

Concrete Institutional Economics [47], [124] acknowledges that (energy) markets are human-made and politically constructed in a '*process dominated by the largest actors in the market*' [47, p. 391]. Furthermore, Concrete Institutional Economics argues that (energy) markets have inbuilt (fossil fuel) path dependencies. Consequently, this approach asserts that policies and public regulations that address the power imbalances and the path dependencies in the market design are necessary to enable the fundamental transformation of the energy system that is needed to meet society's goals and users' expectations in the current context of radical technological change. To that end, it is necessary to study the concrete construction of the market, identify if and how it is 'misleading' societal development and, through this analysis, design markets and institutions that support the fulfilment of societal goals, e.g. climate change mitigation, environmental protection, access to affordable and clean energy, consumer protection, and a sustainable economy. Therefore, Concrete Institutional Economics claims that the idea of 'free' and 'perfect' markets depicted by Neoclassical Economics does not provide a useful description of reality to analyse, for example, the design of markets and institutions to support radical technological change.

The emphasis on concreteness allows e.g. the differentiation between ownership models and the analysis of which ownership characteristics could support the implementation of onshore wind farms and DH systems and the reduction of related costs and prices. Such an analysis would not be possible within Neoclassical Economics, where all companies are seen as 'equal dots' moved by the same (economic) motivations and rationales. Yet Concrete Institutional Economics does not fully address what the 'right' level of concreteness is for the analysis. The answer to this question is determined by the researcher and, hence, will always be open to discussion. The approach recommends defining the level of (institutional and technological) concreteness based on the problem to be analysed and the purpose of the study [111]. The appropriate level of concreteness would likely change depending on whether the purpose was to understand if and how some ownership models are better at promoting the implementation of onshore wind farms and DH systems or to understand what factors affect the implementation of certain ownership models for onshore wind farms and DH systems. The former purpose requires an analysis of the benefits of different ownership models and may (at least initially) omit the influence of factors such as cultural characteristics and knowledge, whereas the second approach does the opposite. The details on the level of concreteness chosen for this study's analysis are presented in section 3.4. Despite the correctness of the recommendation, it does not solve the issue completely. One should be aware that defining the problem intrinsically entails some degree of choice regarding the level of concreteness used in an analysis. In this study, the choice was made to analyse the governance challenges of onshore wind farms and DH systems from the perspective of the ownership of wind and DH companies. Other alternatives could have included analysing the market design, the strategic energy planning at multiple levels, or even the challenges of other technologies. Although such alternatives are acknowledged, it is considered that sufficient arguments exist to support the choices presented within this study, which were made following the steps proposed by the Concrete Institutional Economics approach.

Concrete Institutional Economics proposes four steps (the first one being implicit) for the design of alternative energy plans in the context of a radical technological change [124]. These steps aim at addressing the issue of the previously introduced path dependencies. Figure 3 presents those four steps and adds another: the analysis of the appropriateness of diverse governance scenarios (i.e. step 3 in the figure). This additional step is considered essential given the need to reconsider and redesign the governance of the energy system [119], the diverse alternatives that could be (and are being) implemented (see e.g. [6], [7], [36]) and the evidence that suggests that coupling the same technical scenario with different governance solutions could result in better or worse energy system performance (see e.g. [23], [29], [32]). These arguments are also supported by the research results from the three in-depth studies synthesised in this dissertation. The details about in-depth studies 1-3 are presented in Chapter 4.

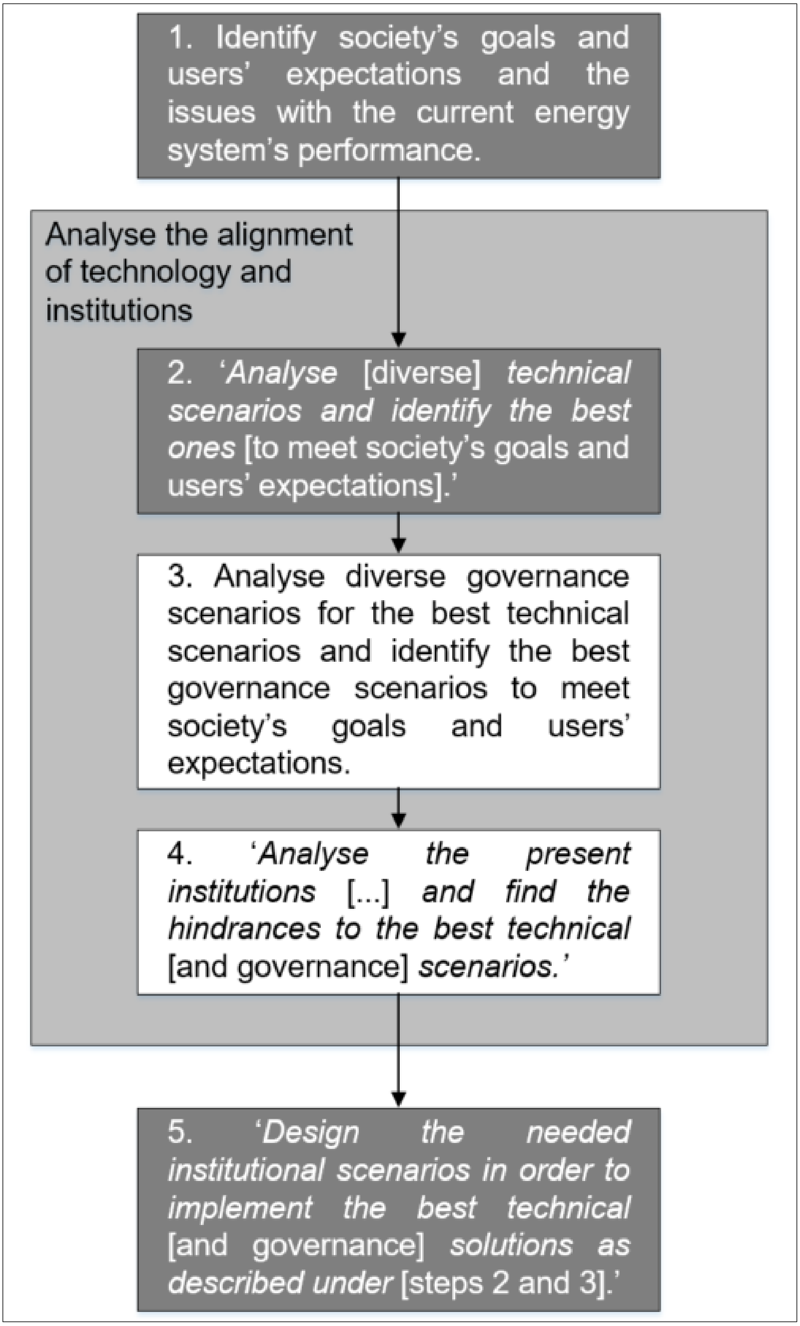

Figure 3: Steps for the design of alternative energy plans in the context of a radical technological change, inspired by [125].

Following the steps presented in Figure 3, previous studies have identified renewable smart energy systems, onshore wind farms and DH systems as some of the ‘best’ technical solutions to meet society’s goals and users’ expectations in the EU in general and in the North Sea Region in particular (see e.g. [61], [62], [72]). Furthermore, there are large unexploited potentials for these technologies in many EU countries [74], [75]. The study presented here contributes to the analysis of appropriate governance scenarios for those technical solutions (step 3) and to the study of the concrete institutional conditions that support or hinder the implementation of the ‘best’ technical and governance solutions (step 4). This is done by examining the benefits and drawbacks of different ownership characteristics to address some of the main governance challenges of implementing onshore wind farms and DH systems in the context of transitioning to a renewable smart energy system. These challenges have been introduced in section 2.2.

Overall, the Concrete Institutional Economics approach provides a framework for action-oriented research, as it enables the development of scientific and practical knowledge that addresses ‘real-world’ issues at a level of concreteness that is useful for action. Moreover, it is suitable for dealing with both productivity issues and ethical issues. Therefore, the approach is in line with the author’s normative approach to researching energy planning, inspired by Flyvberg’s work on ‘phronetic planning research’ [126].

3.4. THE ANALYTICAL FRAMEWORK: RENEWABLE SMART ENERGY SYSTEMS’ IMPLEMENTATION, OPERATION AND PERFORMANCE

Figure 4 presents the understanding of energy systems’ implementation, operation and performance that guides the analyses conducted to answer the research questions. In this theoretical framework, the political process – influenced by market-dependent and independent actors as well as by factors such as informal institutions and landscapes – defines the institutional incentive system, i.e. the formal institutional framework, the ‘rules of the game’. The institutional incentive system strongly influences the implementation and operation of energy systems (including both the technical system and the governance model); together with physical and other factors, the institutional incentive system determines what is (or is not) possible in the implementation and operation of energy systems. The distinction between the technical system and the governance of the energy system (i.e. actors’

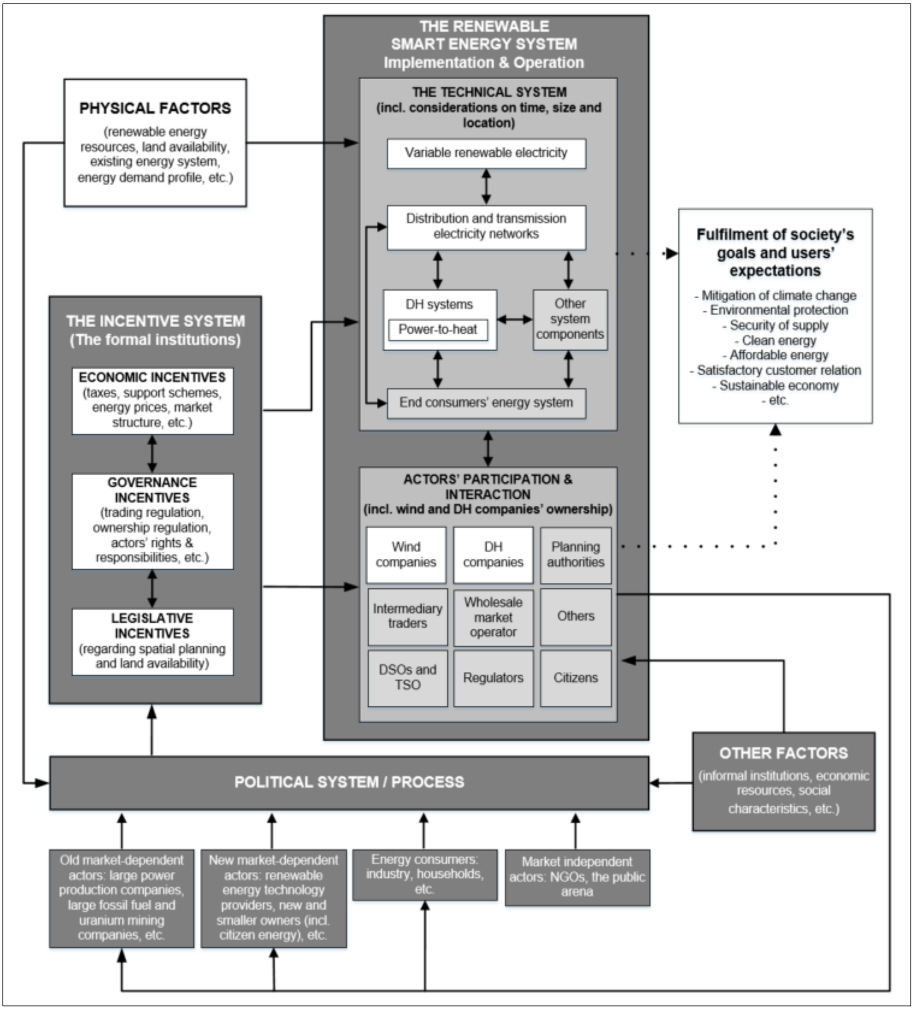

Figure 4: The theoretical framework and delimitations. The understanding of energy systems' implementation, operation and performance in Denmark, Sweden and the EU countries. Inspired by [47], [50] and the three in-depth studies presented in Chapter 4. The figure presents the causal relations between (1) the governance of the political process, (2) the institutional incentive system, (3) other contextual factors, (4) the technical and governance characteristics that determine the operation and implementation of renewable smart energy systems and (5) the benefits of the energy system or the energy system performance. The white boxes present the elements included in the scope of the study. The actors' interactions are not drawn because one of the aims of the study is to question and analyse these interactions. The lines representing interactions between technologies are meant at drawing the attention to the fact that these technologies are technically and economically related in a renewable smart energy system.

participation and interactions in the implementation and operation of the technical energy system) is essential to understanding how the technical characteristics of a technology or energy system and its governance (including the ownership of energy assets) are interrelated and influence each other. This understanding has thus far been under-prioritised in energy planning research. However, it could have important implications for research and policy-making, as explained in the following.

In this study, it is understood that political choices about the characteristics of the technical system (i.e. what technologies will be promoted or not) influence actors' participation and interactions in the implementation and operation of the system; similarly, political choices about the characteristics of the governance model (e.g. what ownership solutions will be promoted or not, unbundling or re-bundling of energy services or sectors) will influence which technologies are implemented and how they are operated. The reason is that some governance and ownership models are better suited for some technologies and technical energy system characteristics than others, and vice versa. Political support for centralised energy systems (consisting of large offshore wind farms, large hydropower plants, large hydrogen networks, etc.) could demand and result in centralised energy system governance models (with large energy companies, centralised energy planning, etc.), whereas political support for decentralised energy systems (consisting of decentral onshore wind farms, DH systems, rooftop solar installations, etc.) could demand and result in decentralised energy system governance models (with more local ownership, local planning, etc.). This becomes evident, for example, when looking into how the governance of the electricity sector has changed in Denmark or Germany as a result of the political support for onshore wind power and solar photovoltaic power (decentralised solutions) or offshore wind power (centralised solution) [25], [78]. This can be explained, amongst others, by the efforts to reduce transaction costs, the development of business models that can deliver the necessary value propositions and core competences, and organisational innovation capabilities (see e.g. [8], [121]). On the other hand, it also means that political support for large energy companies could result in more centralised energy systems and that political support for local citizen ownership could result in more decentralised energy systems. These relationships can be explained by the fact that different business models have different strategic advantages, core competences and, thus, investment preferences. Hence, the understanding that the technical characteristics of technologies and energy systems and their governance (including ownership of energy assets) are interrelated and influence each other aligns with transaction cost theories and strategic business management theories. This understanding has important research and policy implications:

- Most importantly for this study, the understanding suggests that some governance and ownership models could be better than others in the implementation of onshore wind farms and DH systems in a transition to renewable smart energy systems. Hence, as explained in section 3.3, it is relevant to analyse the benefits and drawbacks of different ownership models for these technical solutions.
- This understanding underlines how ownership concerns (i.e. concerns about who will own the future energy system or, in other words, concerns about 'who will eat the cake') are a strong underlying component in discourses about the 'best' technology choices in the public and political debate, as energy companies (whether commercial-, state- or citizen-owned) will promote those technology solutions that best suit their business models, competences, organisational innovation capabilities and, ultimately, economic interests.
- It calls for increased attention to organisational innovation in the energy planning field to better understand how organisational innovation challenges and opportunities could support or hinder diverse socio-technical paths for the energy transition.
- In line with Yildiz's observations [78], it indicates that political support for both centralised and decentralised governance, business and ownership models will be necessary so that a combination of centralised and decentralised technical solutions can be implemented to meet society's goals and users' expectations in the energy transition in the EU. However, decentralized solutions are currently not given the same priority as centralized ones.

At this point, it is important to highlight that it is the combination of technical solutions and governance solutions (including ownership) that determines the level of fulfilment of society's goals and users' expectations (see Figure 4).

At a macro level, the theoretical framework presented in Figure 4 is considered adequate for the analysis of Denmark, Sweden and the EU countries. Nonetheless, when applying it to a specific context and zooming in on the image to achieve the ‘right’ level of concreteness, the details will change. For example, the governance of the political process may be different from country to country or over time. Hence, the form and extent to which diverse market-dependent and independent actors are involved in and influence the political process are details that belong to the concrete level of analysis. The same applies to all of the other components of the theoretical approach.

The theoretical framework is in line with the citizen energy project development framework presented in Figure 1 in section 3.1. Figure 4 elaborates some of the components of the framework in Figure 1 and combines the individual project perspective with the national energy system perspective to develop what is considered the ‘right’ level of concreteness for the study. In this way, Figure 4 provides the framework to analyse which ownership characteristics could promote the implementation of onshore wind farms and DH systems and the reduction of related costs and prices under different concrete institutional incentive conditions and technical and governance contexts. Figure 4 also introduces most of the delimitations of the study by articulating which components of the theoretical framework are examined (the white boxes) and which ones are not (the grey boxes). Each of the three in-depth studies adding to the analysis examines concrete details of this macro theoretical framework and covers a different scope. For more details on the three studies and the level of concreteness defined for each of them, see Chapter 4 and Appendices A-C. The lines representing the interactions between the actors are not drawn because questioning the governance of the energy system is one of the objectives of the study. In contrast, the lines representing the interactions between technologies (e.g. variable renewable energy and DH systems) are meant to highlight the fact that these technologies are technically and economically related in a renewable smart energy system. This interrelatedness implies a new governance challenge due to an increased need to coordinate investment and operations (in time, size and location [35]) in order to use variable renewable energy when available, promote the necessary investment and optimise the energy system costs [32], [34], [46]. The **research scope and delimitations** introduced by Figure 4 are further elaborated and discussed in the following.

The coordination of investment and operations encompasses all the components of the technical energy system. However, only the coordination between onshore wind farms and power-to-heat in DH systems (seen as a factor influencing project economics, overinvestment and additional costs in power grids) is analysed in this study. Amongst others, power-to-X could have also been considered for analysis of coordination needs and would probably provide some additional advantages for the electricity grid compared to power-to-heat in DH. The reason is that heat demand has a strong seasonal profile in countries with cold winters, like Denmark. Other coordination needs to reduce system costs include investment in improving the energy efficiency of buildings and transitioning to 4GDH systems [46]. While these other coordination needs are acknowledged, they are beyond the scope of the study. Nonetheless, they are seen as relevant research outlooks to advance the understanding of new governance challenges in coordinating investment and operations in renewable smart energy systems. Thus, such studies are considered complementary to the research conducted for in-depth study 3 (see section 4.4 for more details on study 3).

Only the governance of the energy systems' implementation and operation is studied, with a special focus on the ownership of wind and DH companies (post-implementation) (see section 3.1). The participation of and interactions with other actors are not disregarded but considered as the context in which the ownership of wind and DH companies develops, resulting in certain benefits. In other words, this research does not examine how changes or differences in other actors' participation and interactions can promote the implementation of onshore wind farms and DH systems or the reduction of related costs and prices.

By studying citizen-owned wind and DH companies, citizens' views as (direct or delegated) owners are captured to some extent. A stronger research focus on citizens would be useful, for example, to assess DH consumers' satisfaction levels, both to evaluate the level of institutional trust in DH and identify the factors influencing it, and to better comprehend citizens' understanding of e.g. what affordable and reasonable energy prices are, the risks of investing in onshore wind turbines or DH under different institutional conditions, the pros and cons in co-ownership of wind turbines and power-to-heat in DH systems, agency issues in citizen-owned wind and DH companies, the relevance of interpersonal trust, and factors hindering some groups of citizens from engaging in wind and DH projects. Such analyses could provide a further in-depth understanding of the issues examined in this study and are relevant research outlooks. However, it is believed that they would not have significant impacts on the results and conclusions of this study, which focuses on the ownership characteristics that could promote the implementation of onshore wind farms and DH systems and the reduction of related costs and prices.

Regarding the external factors that influence decisions about the implementation, operation and ownership of onshore wind farms and DH systems, only the institutional incentive system and material factors (mainly related to the characteristics of the current and future energy systems) are analysed. Cultural characteristics, economic resources, level of education, discourses, changes in norms, etc. are not examined. Such an analysis would be necessary, e.g., to gain a comprehensive understanding of the factors promoting or hindering citizen ownership. However, this is beyond the scope of the study, as is the governance of the political process that defines the institutional incentives for renewable smart energy systems. Analysing the governance of the political process could help clarify why the incentive system takes the form it does and what the institutional hindrances and solutions are for changing the incentive system. Such an analysis would belong to step 4 in Figure 3 in section 3.3.

Finally, Figure 5 presents the three cases of cross-sector integration of variable renewable energy that are examined in in-depth study 3 in relation to the coordination of investment in and operations of onshore wind farms and power-to-heat in DH systems. Hence, the definition of the three location cases is necessary to answer sub-question 3. The location cases should not be regarded as either/or alternatives, as they already co-exist and will probably continue to do so in the future.

Chapter 3 has presented a suitable theoretical approach to advance the understanding of citizen ownership and its benefits for the energy transition and to answer the research question. The following chapter presents the research design and methodology of the study.

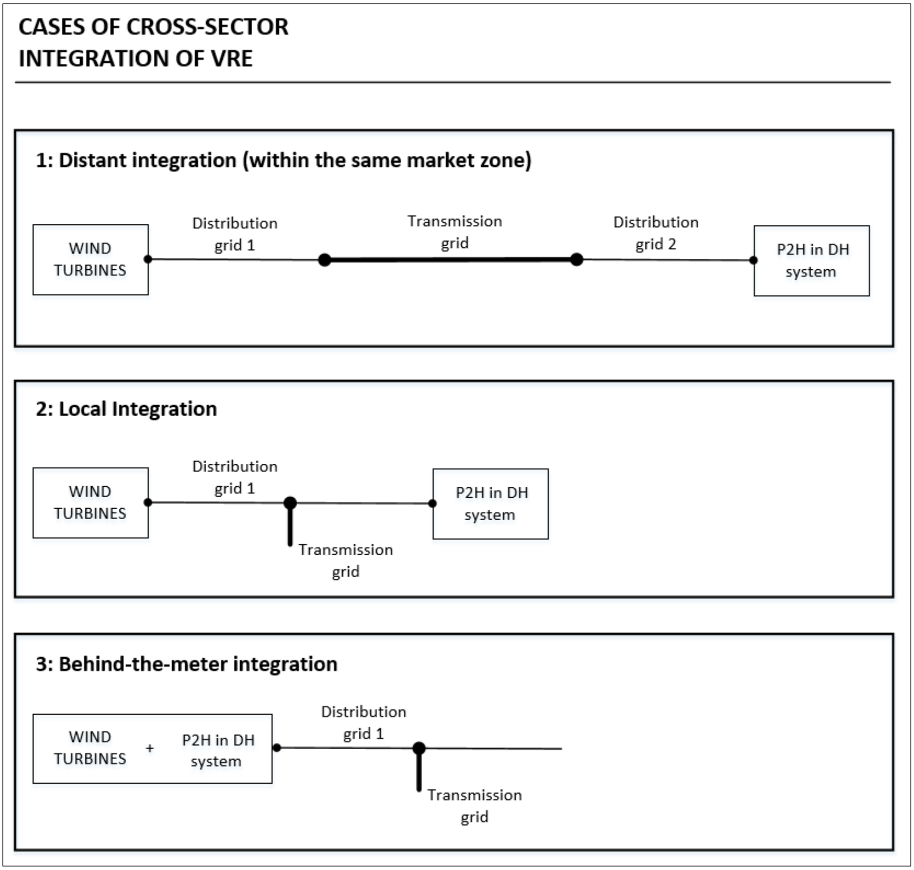

Figure 5: The location cases of cross-sector integration considered for the analysis of onshore wind turbines and power-to-heat in DH systems in Denmark. The location cases should not be regarded as either/or alternatives, as they already co-exist and will probably continue to do so in the future. P2H: power-to-heat. VRE: variable renewable energy. The figure was first published in [35] under a CC By 4.0 Creative Commons license.

CHAPTER 4. RESEARCH DESIGN AND METHODOLOGY

The theoretical approach in Chapter 3 highlighted that there are multiple and diverse citizen ownership models as well as multiple and diverse socio-technical contexts in which citizen energy projects are embedded. Chapter 3 also explained the causal relations between (1) the socio-technical context, (2) the citizen energy project (including technology and ownership characteristics) and (3) the various benefits the project can (or cannot) deliver. Besides, it argued that different types of ownership could be beneficial for different technologies. Consequently, when analysing the benefits of citizen ownership, it is extremely important to:

a. Pay particular attention to the analysis and description of the diverse citizen ownership models' characteristics. This has already been done in section 3.1.
b. Analyse citizen ownership in relation to specific technologies. For this study, onshore wind farms and DH systems were chosen for the reasons introduced in sections 2.2 and 3.3.
c. Remain highly conscious of the specific socio-technical context that surrounds a citizen energy project. This requirement is the reason section 3.4 provided a systematic description of the applied theoretical approach. Furthermore, Denmark and Sweden were chosen as the specific socio-technical context of the study for the reasons presented in section 2.3.
d. Carry out in-depth studies to develop a thorough understanding of the relations between the characteristics of the diverse citizen ownership models, the technology, the socio-technical context and the benefits of certain ownership characteristics to improve the energy system performance.
e. Carry out more than one in-depth study to focus on different levels of concreteness related to the socio-technical context, diverse ownership model characteristics and potential benefits.

This chapter presents the research design of the study, which follows points a-e to provide theoretically sound and action-oriented answers to the research questions. The chapter also discusses the delimitations of the research design.

4.1. RESEARCH DESIGN

The research design of this study is built on three in-depth studies (see Figure 6). Each of the individual studies has a different focus and together they provide the necessary inputs to answer the sub-questions. The overall study as well as the individual studies are designed following the same logic. First, the problem and the research questions are defined. Then, a suitable theoretical approach is developed. The theoretical approach explains the core concepts and the researchers' understanding of the causal relations between the context, the project characteristics (including technology and ownership) and the potential benefits. Moreover, the theoretical approach defines the analytical framework and the study's delimitations, guiding the design of the data collection strategy (including decisions about data sources and collection methods) as well as the data analysis. Since the three studies each have a different focus, different levels of concreteness are necessary for the analysis. Therefore, three theoretical approaches have been developed to suit each of the studies. Study 1 provides a general theoretical framework that situates ownership within the context of the energy transition. Studies 2 and 3 are based on that general framework but are much more concrete. Study 2 defines consumer power in DH and relates it to DH companies' motivation to exhibit a trustworthy behaviour surrounding DH prices. Study 3 presents the technical and economic relations between the technical components of renewable smart energy systems; the need to coordinate investment and operations in time, size and location; and the impact of ownership on factors that influence system operations, the attractiveness of investments, local acceptance and system costs. Combining the multiple levels of concreteness used for the different studies made it possible to develop a theoretical approach that is suitable to study the benefits of diverse ownership characteristics for renewable smart energy systems in general and onshore wind farms and DH systems in particular. This theoretical approach is the one presented in Chapter 3.

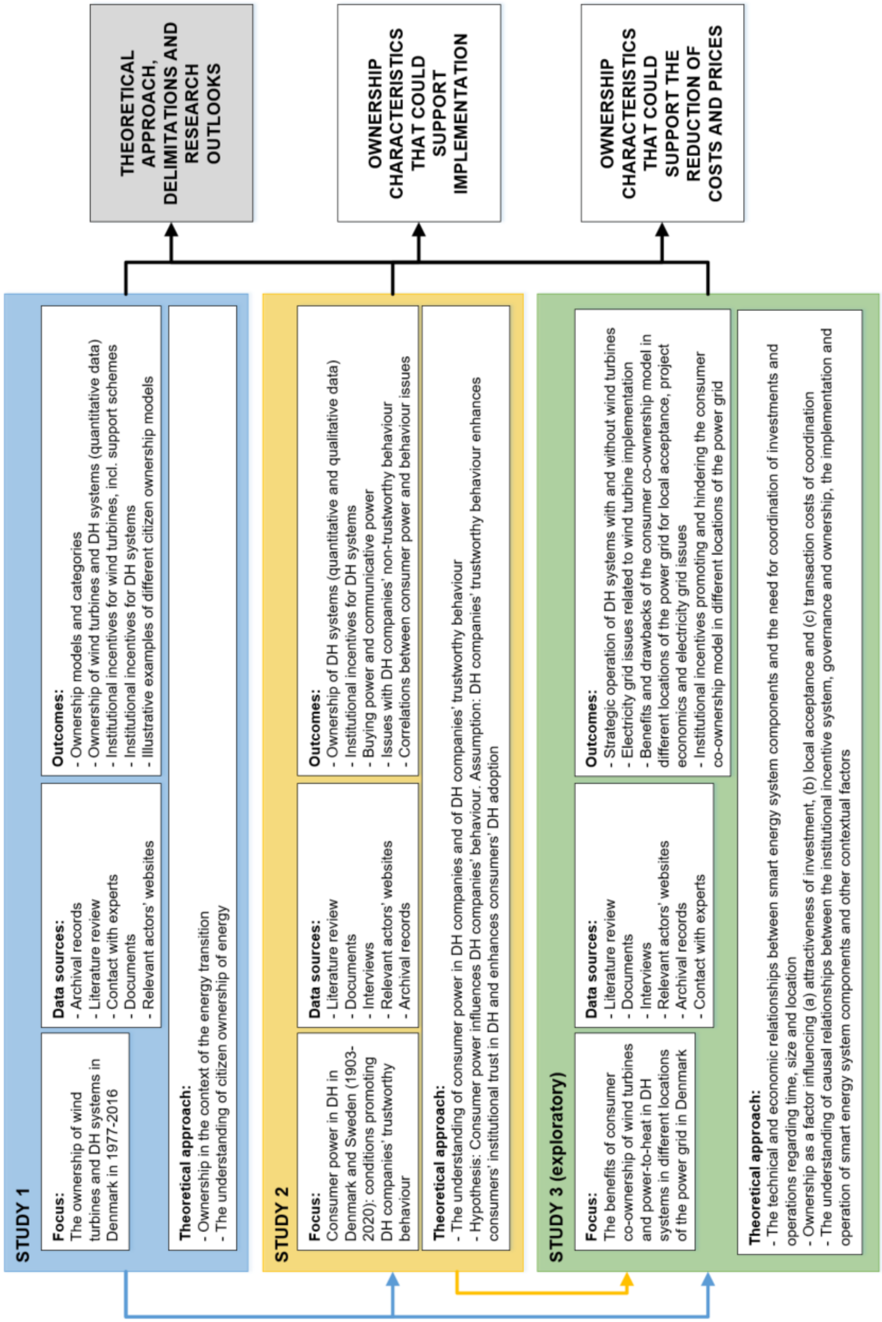

Figure 6: Research design. The focus of the three studies and their contribution to the development of the theoretical approach, the definition of delimitations, the identification of research outlooks and the resolution of the research question.

Table 3: Secondary data sources.

	Study 1	**Study 2**	**Study 3**
Literature review	scientific articles, book chapters, reports	scientific articles, books, book chapters, reports	scientific articles, books, book chapters, reports, conference proceedings
Documents	national policy documents, legal documents (laws and regulations)	national policy documents, legal documents (laws and regulations)	national policy documents, legal documents (laws and regulations), local energy plans, environmental impact assessment reports
Archival records	wind turbine master data register, EMD's wind turbine ownership database, the Danish Energy Agency's wind turbine owners database, DH technical and ownership databases, DH ownership statistics	energy and DH statistics, regulatory authorities' verdicts on consumer complaints, the Swedish DH Board's annual reports	spot market prices, energy statistics, applications to local planning authority, local governments' decisions on project applications, articles in media, annual financial reports, assembly minutes, official communications, bylaws, etc.
Relevant actors' websites	illustrative examples of current local and inclusive ownership models	DH companies and associations, regulatory authorities, policy-makers, consumer and tenants' associations, consumer agency, consultancy companies	all interviewed stakeholders, other DSOs

Table 4: Primary data sources.

	Study 1	Study 2	Study 3
Interviews		researchers, DH companies and associations, policy-makers	DH companies, the local DSO, TSO, local planning authorities, DH consultant company
Contact with experts	The Danish Energy Agency, the Danish Wind Turbine Owners' Association, EMD and Nordic Folkecenter		TSO, colleagues with knowledge about electric grids

All individual studies rely on data triangulation, i.e. the use of multiple data sources. This is done to develop an in-depth understanding of the study area (including e.g. relevant actors' concordant and discordant views on the topic) and to strengthen the reliability of findings. The iterative process between data collection and data analysis allows questions about the preliminary findings to be clarified and the findings to be corroborated. Tables 3 and 4 provide details on the data sources consulted for each of the individual studies.

As previously mentioned, the data collection and analysis strategy is guided by the theoretical approach developed for each of the studies. The theoretical approach defines **the scope of the study and its delimitations.** In all three studies, particular attention is paid to the influence of the (economic, legislative and governance) conditions set by the institutional incentive system on the benefits diverse ownership models can deliver to promote the implementation of onshore wind farms and DH systems and the reduction of related costs and prices. Whereas the influences of other contextual factors (e.g. the governance of the political process, discourses, social characteristics) are not disregarded, they are beyond the scope of the analysis (see Figure 4 in section 3.4). For this reason, the data collection and analysis strategy includes e.g. national policy documents, laws and regulations, expert interviews and energy statistics, but not e.g. articles in the media, content in social media, answers to public hearings of political processes, or statistics on demographics. Since the focus is on the conditions that e.g. motivate DH companies' to exhibit trustworthy behaviour regarding DH prices and not on the conditions that motivate consumers to choose DH over other heating technologies, it was decided not to assess e.g. DH consumers' satisfaction levels, the level of institutional trust in DH, or what constitutes affordable and reasonable energy prices. Thus, no surveys or interviews with citizens have been conducted. Nonetheless, the selection of literature includes studies analysing articles in the media regarding consumers' protests and surveys of residential DH consumers. The vast literature on the institutional incentive system and the ownership of Danish wind turbines and Danish and Swedish DH systems renders the literature review a rich source of scientific knowledge, particularly for the historical analyses in studies 1 and 2. Furthermore, the literature review is complemented with other data sources (listed in Tables 3 and 4) to develop a comprehensive understanding of the issue and advance the existing knowledge on the benefits of citizen ownership.

The theoretical approach also stipulates that special attention must be paid to the distinct ownership characteristics of the different wind and DH companies, many of which are owned by citizens. Therefore, citizens' views as owners (either direct or delegated) are captured to some extent. However, the researcher decided not to focus on citizen ownership in the pre-implementation phase of projects or investigate the inclusivity levels of inclusive citizen ownership models (see section 3.1). Hence, issues regarding reasons to vote for or against the co-ownership of wind turbines and power-to-heat in DH systems in Hvide Sande, agency issues in citizen-owned wind and DH companies, the relevance of interpersonal trust for citizens' to participate and invest in the projects, factors hindering some groups of citizens from engaging in wind and DH projects, etc. are outside the scope of the study – even though they are considered relevant research outlooks.

The purpose served by each of the data sources and the chosen data analysis techniques is explained in the following sub-sections.

4.2. STUDY 1: OWNERSHIP OF WIND TURBINES AND DH SYSTEMS IN DENMARK

Study 1 analyses historical data regarding the ownership of wind turbines and DH systems in Denmark for the 1977-2016 period. This long-term analysis is deemed suitable to identify the relations between changes in the institutional incentive system, in the ownership characteristics and in the ownership-related benefits. The study identifies, describes and categorises citizen ownership models implemented in Denmark for the two technologies and provides illustrative examples of projects for each of the identified citizen ownership models. The data was collected via a literature review, public databases, websites describing some of the illustrative examples and personal communication with Nordic Folkecenter, a Danish NGO working on the topic since 1983. The identified ownership models and the categories were already presented in Figure 2 in section 3.1. The cross-technology analysis highlights the distinctive features of diverse ownership models related to profit as well as diverging and converging trends in the ownership of onshore wind turbines and DH systems. Such observations would have likely not been possible in a single technology analysis.

The literature review conducted for the state-of-the-art revealed the lack of comprehensive statistical knowledge about wind turbine ownership in Denmark after 2001 [20]. Building on Mey and Diesendorf [20] and Wierling and colleagues' [77] work, study 1 addresses this knowledge gap. To this end, the study combined data from two databases and carried out a quantitative analysis of wind turbine ownership for the 1977-2016 period. The database owners and the Danish Wind Turbines Owners' Association were contacted for assistance in understanding the data and for advice on how to perform the analysis. In order to understand the inconsistencies, gaps, and substantial changes in the data itself as well as the way it is collected and registered by the respective authorities over time, the researcher complemented the database analysis with a literature review on the evolution of wind turbine ownership. In addition, a literature review was conducted on the evolution of the institutional incentive system for wind power. All the data were analysed following a time-series approach to identify the relationships between changes in the institutional incentive system, the ownership and the ownership-related benefits regarding technology implementation. It should be noted that the quantitative estimation of citizen ownership of onshore wind turbines in Denmark for the 1977-2016 period conducted in study 1 is not completely accurate (see Appendix A for more details). Nonetheless, together with the literature review, the quantitative estimation provides an improved understanding of how ownership characteristics in onshore wind turbine implementation changed under different socio-technical contexts.

The Danish Regulatory Authorities publishes statistical data on DH companies' ownership. Furthermore, a literature review was conducted on the evolution of ownership and the institutional incentive system. As with wind turbines, the data is analysed following a time-series approach to identify the relationships between changes in the institutional incentive system, the ownership characteristics and the ownership-related benefits related to technology implementation.

4.3. STUDY 2: CONSUMER POWER AND CONDITIONS PROMOTING DH COMPANIES' TRUSTWORTHY BEHAVIOUR IN DENMARK AND SWEDEN

Study 2 analyses historical data about DH systems in Denmark and Sweden, from the beginning of this technology's implementation until 2020. Study 1 reveals little variations in DH ownership and regulation in Denmark after 1979. Therefore, analysing historical data about DH systems in Denmark alone is not adequate to understand how different configurations and levels of consumer power can manage or fail to motivate DH companies to exhibit a trustworthy behaviour. To overcome this issue, the researcher decided to conduct a cross-country comparison. Sweden shares some cultural characteristics with Denmark but has applied very different regulatory and ownership solutions to DH systems [80], [81], [96], making the country appropriate for an initial cross-country analysis on the topic.

The data was collected via a structured literature review, expert interviews and other data sources such as law documents, relevant actors' websites and archival records on consumer complaints and resolutions (see Tables 3 and 4 for more details). The list of interviewed experts includes researchers, policy-makers, DH companies and their representative associations. The experts hold a broad and in-depth understanding of the DH sector, including changes in consumer power and issues with DH companies' non-trustworthy behaviour. The regular consumer will likely not hold this in-depth knowledge. The expert interviews are essential to clarify doubts about preliminary findings, obtain suggestions about relevant literature, collect data that is missing in the (selected) literature and understand different actors' concordant and discordant views. Additional interviews with other relevant actors (e.g. regulatory authorities, other researchers, other policy-makers) were initially planned. However, there has been no opportunity to conduct these additional interviews. Nonetheless, the data triangulation approach provides strong evidence to support the results and conclusions of the study.

A thematic analysis of the data is conducted following the codebook outlined in the theoretical approach. This codebook defines the four dimensions of consumer power (including the institutional incentive system and ownership characteristics) and DH companies' trustworthy behaviour (see section 3.2 and Appendix B for more details). Besides, as in study 1, the data is analysed following a time-series approach to identify the correlations between changes in consumer power and arising issues with DH companies' non-trustworthy behaviour. The study provides inputs to understand the influence of DH ownership and the institutional incentive system on (1) technology implementation and (2) DH companies' motivation to exhibit trustworthy behaviour related to DH prices.

4.4. STUDY 3: THE BENEFITS AND DRAWBACKS OF CONSUMER CO-OWNERSHIP OF WIND TURBINES AND POWER-TO-HEAT IN DH SYSTEMS IN DENMARK

Study 3 explores (a) the relatively new field of the coordination of investment and operations for developing renewable smart energy systems and (b) the relevance of conducting further research to test theories that support the separate ownership of energy sectors. This is done by, first, comparing the (theoretical) benefits of co-ownership models and separate ownership models for onshore wind turbines and power-to-heat in DH systems to address issues regarding (1) local opposition, (2) the project economics and (3) grid issues, including overinvestment and additional costs. The study considers different ownership models based on the results from study 1 and pays special attention to the location of the wind turbines and power-to-heat units of DH systems in the electricity grid (see Figure 5 in section 3.4). Study 3 only analyses municipal companies and consumer cooperatives; it does not examine commercial DH companies, which only represent a small share of the DH market in Denmark [106] and − as study 2 suggests − show to be less advantageous than the local municipal company and local consumer cooperative models to motivate DH companies' trustworthy behaviour related to DH prices. Second, study 3 analyses the institutional incentive system in place in 2019 and how this system promotes or hinders the analysed co-ownership models and their benefits. As this is an exploratory study, relevant questions for further research are developed and interim policy recommendations are identified for further discussion.

Multiple data sources were consulted for the study (see Tables 3 and 4). The study is inspired by what is probably the first empirical case of utility-scale co-ownership of wind turbines and power-to-heat in Denmark. This means that scarce literature is available on the topic. Therefore, data on the specific case and on the knowledge developed for the project implementation is essential to obtain the necessary theoretical and practical understanding of the benefits and drawbacks of co-ownership in different locations of the electricity grid. Hence, the insights from relevant actors who have been involved in the project are considered crucial to the understanding of the issue. The interviews with the DH companies and the DH consultant provide inputs to understand the operations of DH systems (with and without wind turbines), the benefits and drawbacks of the analysed co-ownership models for local acceptance and project economics, and the opportunities and obstacles to implement the analysed co-ownership models under the existing institutional incentive system. The interviews with the DSO and the TSO provide inputs for the understanding of grid issues, the benefits and drawbacks of the analysed co-ownership models to address the grid issues, the opportunities and obstacles for the analysed co-ownership models under the existing institutional incentive system, and the identification of possible negative impacts on consumers. Finally, the interview with the local planning authority is aimed at understanding the local energy system and the role of municipal strategic planning in the coordination of investment and operations. A thematic analysis of all the collected data is conducted, guided by the codebook defined in the theoretical approach (see Appendix C for more details). Doubts regarding regulatory issues about peer-to-peer trading were discussed with the TSO by email after the interview. Furthermore, the assistance of colleagues with expertise in electricity grids was necessary to understand the electricity grid issues.

Chapter 4 has introduced the research design and methodology used to answer the research questions. The following chapter presents and discusses the results obtained from applying this methodology and the theoretical approach presented in Chapter 3.

CHAPTER 5. ANALYSIS OF OWNERSHIP MODELS FOR ONSHORE WIND FARMS AND DH SYSTEMS

This chapter presents the results obtained from each of the three in-depth studies and answers the research questions. The results are discussed with regard to the overall theoretical approach and research design of the study (presented in Chapters 3 and 4) as well as the existing literature on the topic. At the end of each section, a table summarises the main findings of the in-depth study and answers the corresponding sub-question. Finally, the results are combined to answer the main research question.

5.1. ONSHORE WIND TURBINE OWNERSHIP IN DENMARK: CAPACITY SHARES AND LOCAL ACCEPTANCE

Study 1 analyses the evolution of the ownership of onshore wind turbines in Denmark, both quantitatively and qualitatively, for the 1977-2016 period. The following analysis also presents several updates for the 2017-2020 period. In the study, the ownership models are grouped under two general categories: citizen ownership and large commercial ownership. Special attention is paid to the identification and description of the multiple citizen ownership models that have been implemented and their main characteristics, which were already introduced in Figure 2 in section 3.1. Through this process, it becomes possible to observe the changes in ownership characteristics regarding investment behaviour and capacity shares within different institutional incentive systems and contexts as well as illustrative examples of ownership models that may enhance local acceptance. Such observations are deemed crucial to analysing suitable ownership solutions and policies to increase the social acceptance of onshore wind farms and ensure that energy and climate targets are met on time.

5.1.1. Citizen Ownership Characteristics and Wind Capacity Shares

Wind power supplied 52% of Denmark's final electricity consumption in 2019 [109], and the total installed capacity in December 2020 was 6,178 MW (4,478 MW onshore and 1,701 MW offshore) [127]. Study 1 estimates that 68% of the existing onshore wind capacity in Denmark in 2016 had citizen ownership; 30-57% was individual citizen ownership and 11-38% was collective citizen ownership. Local wind cooperatives (i.e. local and inclusive citizen ownership) installed the largest share of onshore wind power in 1985-1994. However, contrary to what could be expected based on the vast literature on local wind cooperatives in Denmark, individual owners and wind guilds (i.e. exclusive citizen ownership, both local and distant) have contributed significantly to onshore wind power implementation in the country since the second half of the 1990s. This observation supports the relevance of studying citizen ownership beyond the normative understanding of 'community energy', which considers only local and collective citizen ownership models. Study 1 also estimates that citizen projects implemented 61% of the new installed onshore wind capacity in the years 2008-2016. Hence, study 1 seems to contest the understanding that Denmark's onshore wind power installation has been dominated by large investors in recent years, as argued by e.g. Bauwens *et al.* [54]. However, after the introduction of the auction scheme in 2018, it appears that only 11% of the onshore wind capacity was installed by citizens in the years 2019 and 2020 [127]–[130]. Besides, only one out of the seven wind projects (corresponding to 10% of the capacity) granted in the auctions of 2018 and 2019 had citizen ownership [131].

5.1.2. Local and Inclusive Citizen Ownership Models for Local Acceptance

During the early years of onshore wind power in Denmark, the collective citizen ownership of wind turbines was organised as local wind cooperatives [20], [47], [132]. In cooperatives, participation is open and each member holds one vote regardless of the number of shares they possess [133]. It was common practice for collective citizen projects' promoters to call for public meetings to present the idea and offer other local residents the possibility to participate in the project. Often, neither the location nor the size of the wind installation had been decided at the time the initial open meeting was held [132]. Therefore, the decision-making power was democratically distributed amongst the local citizens who showed interest in the project. In this period (which came immediately after the oil crisis in the 1970s), wind power was seen as a solution to improve the security of the energy supply as well as an alternative to nuclear power [20], [134]. This, together with open participation, democratic practices and strong project economics (supported by the institutional incentive system), created an attractive environment for citizen investment in wind power as well as broad local acceptance [47], [132].

From 1985 to 2000, the loosening of ownership regulations, introduction of repowering schemes, more constricting wind planning regulation and increasing wind turbine sizes resulted in significant changes in the ownership of wind turbines and wind planning practices [20], [132], [135], which have persisted until now. Large commercial ownership as well as distant and/or exclusive forms of citizen ownership have become the dominant models. The sharp increase in individual citizen ownership (mainly by farmers [47]) in the second half of the 1990s [20] is particularly notable. Moreover, besides wind cooperatives, collective citizen ownership also started to become organised as wind guilds, which are neither democratic (members hold votes based on the number of shares they own) nor open for participation. Nowadays, most wind companies with collective citizen ownership in Denmark appear to be organised as guilds; Wierling et al. [77] calculate that 60% of the collectively owned citizen wind companies have 5 members or less. Hence, collective citizen ownership is not a synonym of inclusive citizen ownership. More recently, the introduction of the auction scheme has further reduced the opportunities for citizen ownership, as has also been the case in other countries [16], [18]. The introduction and now dominance of ownership models that exclude the local community from the decision-making process and the economic gains have been identified as a major cause of the considerable increase in local opposition to onshore wind turbines in Denmark [47], [132].

In 2012, 6 out of 7 wind project applications were rejected in Thisted Municipality due to strong local protests. The project applications added up to 40 turbines and about 20 local residents as shareholders (personal communication with Nordic Folkecenter). The low number of shareholders indicates that these projects had a local but exclusive citizen ownership model. In stark contrast, local and inclusive ownership models that have achieved broad local acceptance have engaged up to several hundreds of local citizens in the ownership, as illustrated by the examples presented below.

- The four 7 MW nearshore wind turbines connected to the grid in Thyborøn in 2017, are owned by a **local wind cooperative** (55%) and a **local consumer cooperative** (45%). The wind cooperative has approximately 1,400 members, who are local residents in Lemvig municipality. The local consumer cooperative has approximately 30,000 consumers in the local area. 100% of the wind shares were initially offered to local residents and the remaining were sold to the consumer cooperative. (personal communication with Nordic Folkecenter)

- In 2002, ten 2 MW nearshore wind turbines were installed by the island of Samsø. Five of the turbines used to be owned by a **local municipal wind company**. The wind project was part of the Renewable Energy Island project, which had managed to actively engage local stakeholders and citizens [136].
- In 2011, three 3 MW wind turbines were erected on the beach in Hvide Sande to partly finance the local harbour's expansion project and, in this way, support the local economy. Initially, the wind turbines were owned by a **local wind foundation** (80%), who had the purpose of supporting the harbour project and sustainable tourism in Hvide Sande, and a **local wind cooperative** (20%) with approximately 400 local residents as shareholders [137]. Currently the three wind turbines are owned by the local DH company, which is a **local consumer cooperative** with more than 1,500 consumers (understanding consumers as consumption meters) [88].

The foundation model combined with the purpose of promoting local economic development has shown extremely important in generating local acceptance, e.g., in Hanstholm harbour (where very strong opposition to a former commercial project turned into broad local acceptance for a project with common good purpose [138]) or in Nørrekær-Enge (where local acceptance was achieved after the project developers − Vattenfall and some local farmers − agreed to offer some shares to a local wind foundation that would support local development [51], [52]).

Although ownership is certainly not the only factor influencing local acceptance of onshore wind turbines [85], [139], it does have an impact on procedural and distributional justice, which can determine whether local acceptance is achieved [110] − as illustrated by the examples of Hanstholm habour and Nørrekær Enge. This observation is not new. However, the systematic description of the diverse characteristics of citizen ownership models allows for the observation of important differences between diverse local citizen ownership models and their implications for local acceptance or opposition. Through this observation, it can be discerned that local and inclusive citizen ownership models may enhance local acceptance, while local and exclusive citizen ownership models might not. Insufficient attention has been paid thus far to the distinction between different local citizen ownership models and to whether and how different local citizen ownership models may (or may not) enhance local acceptance (see e.g. [32], [86], [140]–[142]). The lack of attention to differences between inclusive and exclusive local citizen ownership models could explain the ineffectiveness of some of the policy measures adopted to enhance local acceptance, e.g. 'the 20% local ownership rule' [21] (see footnote 2 on page 7 for a description of the rule). Identifying local and inclusive ownership models, as it was done in this study, could facilitate effective policy-making.

5.1.3. Reflections on New Ownership Models

Study 1 shows that exclusive ownership models (both citizen and large commercial models) have substantially contributed to onshore wind capacity implementation in Denmark. This means that such ownership models could be essential to implementing the necessary investment in onshore wind farms to meet the Danish energy and climate targets. On the other hand, exclusive ownership models are one of the major reasons for local opposition [132], which has become a major problem for the further development of onshore wind in Denmark, with projects summing approx. 305 MW cancelled in 2017 due to protests [143]. To introduce a comparative reference, 300 MW was the average annual installation target for the period 2014-2020 set by the Danish Energy Agreement of 2012. This means that new strategies and ownership solutions are needed to promote both market and local acceptance of onshore wind farms and meet the country's climate and energy targets for 2030. In the following sections, joint ownership models and new trends in local and inclusive citizen ownership models are discussed as potential ownership solutions. These ownership solutions have already been implemented in Denmark, but other solutions could also apply, as further explained in the research outlooks in section 6.3.

5.1.3.1 The Danish Experience with Policies for 'Joint Ownership' Models: The '20% Local Ownership Rule'

The quantitative analysis of onshore wind capacity implementation by type of owner suggests that joint ownership between local and inclusive citizen ownership models and exclusive ownership models could increase the implementation potential of onshore wind farms. The ‘20% local ownership rule’ (see footnote 2 on page 7 for a description of the rule) can be seen as a failed attempt to promote such joint ownership models. An analysis conducted by the Danish Ministry of Climate, Energy and Supply and the Danish Energy Agency in 2019 [21] concluded that the rule encountered several issues and, most problematically, was an ‘expensive’ solution that did not achieve its target, i.e. enhancing local acceptance of onshore wind projects through local citizens’ engagement. Here, it is important to clarify that the solution was ‘expensive’ for the project developer, who had to renounce the profits generated by the sold shares. Problems identified with the rule include over-priced shares, poor wind project economics, increased percentage of unsold shares, minimal purchases from neighbouring residents, few local residents buying large numbers of shares and little decision-making power in the hands of local residents. Some of these observations support the argument that open participation (like in wind cooperatives) is not completely inclusive (as depicted in Figure 2 in section 3.1). In line with this, Johansen and Emborg [19] identified that gender, age and income influence local residents’ willingness to invest in wind shares offered as part of the ‘20% local ownership rule’. Moreover, the authors found that power in the decision-making process, the companies’ reputation, and the wind company’s location (i.e. whether it is local) can also influence residents’ support. Overall, it is possible to conclude that the rule (as it was designed) did not enhance procedural and distributional justice and, therefore, was not effective in promoting local acceptance.

The results and conclusions of the analysis seem to be correct for the specific provisions of the ‘20% local ownership rule’ and the specific regulatory and governance model surrounding the rule. Thus, the Danish experience with the ‘20% local ownership rule’ underlines the challenges in designing and implementing policies for joint ownership that can effectively deal with local acceptance. However, the appropriateness of the proposed and implemented solution to address the identified issues within the rule [39] is questionable. The ‘20% local ownership rule’ was replaced by a renewable energy bonus scheme which creates a small dividend for nearby residents. The bonus scheme is complemented by compensation for the loss of property value, a sale option for nearby residents, and a green fund for the local municipality [39]. Thus, the measures are aimed at compensating the closest residents and to some extent the local community for the nuisance of the wind turbines. Furthermore, the compensation scheme is meant to be cheaper for the project developer. However, the changes in regulation do not address the lack of local and inclusive decision-making power about the wind project; in addition, they reduce the opportunities for the local community to earn economic benefits from the new wind turbines. Another solution would have been offering 20% of the shares to local and inclusive citizen initiatives, e.g. local consumer cooperatives, municipal companies or local foundations for local development. A better alternative could have been to follow the Dutch model, where a target of 50% of local community ownership is set for onshore wind and solar farms [144]. Such local ownership could engage citizens, municipal and private businesses and other organisations and include a minimum of local and inclusive ownership for a fair distribution of benefits in the local community. This solution could help the local community to see the new wind turbines as a positive development that brings improvements to the local community, thereby reducing local opposition by promoting distributional justice. One step further would be to change the principles that guide current wind turbine planning. As Kirch Kirkegaard *et al.* argue, *‘seeing local communities as active co-creators and innovators rather than simply state-citizens that need to “be consulted” about what they can accept may provide a new perspective*’ [107, p. 107]. For example, instead of letting the developer make the main decisions and then think about a strategy to obtain local acceptance, it could be possible to gain local acceptance and decision-making power before inviting the developer into the process. This could create a higher degree of energy democracy in local energy planning. None of the abovementioned alternatives is analysed in the report produced by the Danish Ministry of Climate, Energy and Supply and the Danish Energy Agency in 2019 [21]. In fact, only one solution is mentioned – the one that is most beneficial to project developers, which seems suspicious. This observation suggests the need to investigate the governance of the political process and the barriers it raises for local and inclusive citizen ownership.

The above discussion highlights the need to conduct further research to understand how to respond effectively to procedural and distributional justice issues in joint ownership models and determine what policy measures are suitable for promoting such ownership solutions. This recommendation is in line with those of Goedkoop and Devine-Wright [145], who found important challenges to the implementation of renewable energy projects with joint ownership models in the UK. In addition to the Danish studies, Goedkoop and Devine-Wright’s study on early practices for joint ownership in the UK reveals that a lack of trust between project developers and community members as well as differences in interests can create major issues. Furthermore, the authors underline the risk of using the joint ownership model to silence the local community by offering some benefits to obtain project approval, rather than entering into genuine partnerships that enhance procedural and distributional justice. Further research on joint ownership models requires studying ownership in both the pre- and post-implementation phases of projects.

5.1.3.2 New Trends in Inclusive Citizen Ownership: Consumer-owned Wind Power

In a hostile environment for onshore wind power and citizen ownership, a new trend in Denmark deserves attention: the implementation of onshore wind farms by utilities owned by municipal companies and consumer cooperatives. JyskEnergi, HOFOR, NRGI and the DH company in Hvide Sande are examples of citizen-owned (or consumer-owned) utilities that have invested in onshore wind farms in recent years [25], [35]. Thy-Mors Energi is also considering this possibility [146]. Here, it must be highlighted that some of these municipal and consumer-owned cooperative utilities have invested outside the locality where they conduct their main economic activity. Thus, they can be seen as distant and exclusive investors by the local community where the project is being implemented and thus meet local opposition. Hence, such ownership models on their own are likely not effective for the promotion of onshore wind farms in Denmark. In contrast to the distant consumer ownership models, the trend towards local consumer ownership is interesting for several reasons. First, these ownership models have been common for DH, but not for wind turbines. Moreover, they recover the 'limited private profit' characteristic that was common of the ownership of wind turbines in the 1980s and early 1990s due to the consumption criterion. Hence, after years of a divergent trend in the ownership of onshore wind turbines and DH systems in Denmark, the few existing examples of citizen-owned utilities investing in onshore wind power locally could imply the beginning of a convergent trend. Second, wind turbines owned by local municipal companies and local consumer cooperatives (i.e. local and inclusive ownership models) could achieve higher local acceptance than exclusive ownership models (whether commercial or citizen-owned) [35]. Third, local citizen-owned utilities can be seen as large players, with larger project portfolios and improved possibilities for arranging power-purchase agreements or even self-consumption [35] than the traditional wind cooperative model. These ideas are further elaborated as part of study 3, where the benefits and drawbacks of the co-ownership of wind turbines and power-to-heat in DH systems are analysed.

5.1.4. Reflections on Quantitative Figures and Onshore Wind Farm Ownership in the International Sphere

As mentioned in section 4.2, the quantitative estimation of citizen ownership of onshore wind turbines in Denmark for the 1977-2016 period carried out in study 1 is not completely accurate. Nonetheless, together with the literature review, the approximate estimation provided by the quantitative analyses enables the research to advance the work of Mey and Diesendorf [20] and Wierling *et al.* [77]. Furthermore, it adds to the (recently developed) quantitative understanding of citizen ownership of onshore wind farms in other countries.

As is the case in Denmark, citizen ownership in Germany and Sweden has substantially contributed to the implementation of onshore wind farms. In 2012, 50.4% of the onshore wind capacity in Germany was owned by citizens [78], while this number is 40-50% in Sweden [76]. Furthermore, Pons-Seres de Brauwer and Cohen [83] estimate that citizens could invest EUR 176 billion in renewable energy projects by 2030 and that onshore wind farms organised as local cooperatives are the preferred investment option for citizens. Hence, citizens could substantially contribute to the financing of onshore wind farms. However, citizen ownership of onshore wind farms has been negligible in e.g. France [147], the UK [79] and Spain [148], i.e. where the institutional incentive system and other contextual factors have hindered the citizen ownership of onshore wind power. From the above discussion, it can be concluded that EU countries could accelerate wind power implementation by implementing policies that promote citizen ownership and local acceptance. To that end, special attention could be paid to (1) local citizen-owned utilities and, (2) joint ownership models wherein local and inclusive citizen models are combined with exclusive models when it is necessary to raise capital and expertise. The policies to be implemented to support such ownership models could be different in different EU countries as a result of differences in economic, governance, cultural, social and other conditions.

5.1.5. Summary: Ownership Characteristics for Onshore Wind Farms

Table 5 summarises the main findings from the analysis of the development of ownership characteristics of onshore wind farms in Denmark and highlights the ownership characteristics that could promote onshore wind power implementation.

Table 5: Summary. Answer to sub-question 1.

The ownership characteristics of onshore wind turbines in Denmark. Capacity shares and local acceptance
- Wind power supplied 52% of the final electricity consumption in 2019, and the total installed capacity in December 2020 was 6,178 MW (4,478 MW onshore and 1,701 MW offshore). - Study 1 estimates that 68% of the existing onshore wind capacity in Denmark in 2016 had citizen ownership; 30-57% was individual citizen ownership and 11-38% was collective citizen ownership. - In 1985-1994, local wind cooperatives (i.e. local and inclusive citizen ownership) installed the largest share of onshore wind power. Thereafter, exclusive ownership models, whether citizen or commercial, have contributed substantially to the implementation of onshore wind farms. - Since the implementation of the auction scheme, new citizen ownership has decreased to 10-11%. - Local and inclusive ownership models may enhance local acceptance, whereas local and exclusive citizen models might not. Examples of local and inclusive ownership models are local consumer cooperatives, local municipal companies, local wind foundations and, to some extent, local wind cooperatives. - Joint ownership models (where local and inclusive citizen models are combined with exclusive models) could promote the implementation of onshore wind farms by enhancing local acceptance and providing access to more capital. Further research is necessary to understand how to ensure procedural and distributional justice via joint ownership models. - Local utilities owned by municipalities and consumer cooperatives could improve both local acceptance and project economics. - Citizen ownership has also largely contributed to onshore wind capacity implementation in other EU countries, such as Sweden and Germany, and could be a determinant to realise the wind power implementation targets.

5.2. DH OWNERSHIP IN DENMARK AND SWEDEN: MARKET SHARES AND CONDITIONS FOR TRUSTWORTHY BEHAVIOUR

Study 2 analyses the evolution of the ownership of DH systems in Denmark and Sweden, both quantitatively and qualitatively, from the implementation of the first DH system to 2020. In the interest of understanding consumers' ownership power, special attention is paid to identifying and describing the multiple citizen ownership models that have been implemented and their main characteristics. By studying changes in the four dimensions of consumer power in DH companies (i.e. state regulative, ownership, buying and communicative power) and DH companies' motivation to exhibit trustworthy behaviour related to DH prices, it is possible to observe correlations between different configurations and levels of consumer power and issues with unreasonably high DH prices. Such observations are deemed crucial to identify appropriate ownership solutions and policies for effective control of DH prices and, in this way, enhance consumers' institutional trust in DH and willingness to choose it. This could be an essential step in allowing the potential benefits of DH systems (e.g. higher energy efficiency, lower economic costs, increased comfort for the consumer) to be realised.

5.2.1. Ownership Characteristics and Market Shares by Type of Owner

In Denmark, DH ownership has been dominated by local municipal companies and local consumer cooperatives both before and after DH regulation was implemented. These are local and inclusive ownership models, where consumers have direct or delegated decision-making power. The cost-based price regulation introduced in 1979 and still in effect appears to have discouraged commercial investors [81]. Currently, 64.8% of the residential buildings are connected to DH [109]. Local municipal companies supply 60% of the DH demand, local consumer cooperatives 34% and commercial companies 6% [106].

In Sweden, DH ownership has been dominated by local municipal companies. However, the ownership of DH systems has been much more diverse than in Denmark, especially after the liberalisation of the electricity sector in 1996, which instigated a considerable re-organisation of DH ownership as many local municipal companies sold their DH systems together with their power plants to commercial and state-owned companies [80]. In 2014, local municipal companies supplied about 63% of the DH demand, followed by joint municipal and state or commercial companies (18%), commercial companies (12%), state-owned companies, distant municipal companies, cooperatives and others [80]. Currently, 51% of the residential buildings in Sweden are connected to DH [149].

The Danish and Swedish cases show that investment in DH can be very attractive for local municipal companies and local consumer cooperatives when favourable conditions for DH and citizen ownership are in place [80], [81], [94], [96]. The cross-country comparison also shows that informal institutions can play an important role in the preference for the municipal or the cooperative model; there are almost no cooperatives in Sweden [80], but 83% of DH companies are owned by consumer cooperatives in Denmark [106].

5.2.2. Ownership Characteristics, Consumer Power and DH Companies' Trustworthy Behaviour regarding DH Prices

Denmark and Sweden have implemented very different DH regulations, the former with strict price regulation and the possibility of obliging consumers to connect and stay connected to the local DH system, the latter with no price regulation and 'free' competition between DH and individual heating solutions. Despite this, in both countries, local and inclusive citizen ownership models (i.e. local municipal companies and consumer cooperatives) have resulted in more reasonable DH prices than other ownership models. This can be explained by the fact that consumers have more power to influence these companies' decisions than those of commercial or state-owned DH companies. Common to both countries is also the emphasis that public regulation places on transparency, which together with high levels of ownership power has proven to be essential to controlling DH companies' behaviour regarding DH prices. Transparency has been increased through, for example, the regular publication of DH prices by the regulatory authorities [81], [94], [150]–[152], access to financial [152] and technical reports [153] and the creation of the Swedish District Heating Board to mediate between DH consumers and companies on prices and other issues in accordance with the District Heating Act [154]. Since 1996, the Nils Horgesson Report [155] – an initiative started and supported by several organisations representing residential consumers' interests – has also made it possible to compare the DH prices charged in different municipalities in Sweden. Having access to such information can be fundamental for consumers to put pressure on the local municipal company or consumer cooperative to optimise system costs. Furthermore, it allows consumers to support the Regulatory Authority in identifying any questionable practices or law infringements. In addition to public regulation, voluntary self-regulation, such as the Price Dialogue initiative, has contributed to enhancing transparency about DH prices in

Sweden by requiring that the members (i.e. DH companies) inform their customers well in advance about any changes in DH prices and the reasons for these. Another remarkable finding is that the Swedish experience shows that allowing 'free' competition between DH and individual heating solutions might not be sufficient to control DH prices; it is necessary that economically competitive solutions exist so that consumers have a real choice. Given that in some locations DH is socio-economically cheaper than individual heating solutions [64], [72], creating real competition between heating solutions would imply additional costs for society.

In Sweden, with no price regulation for municipal companies since 1996, most municipal DH companies have kept the cost-based price-setting principle, but several have opted to apply the market-based price-setting principle instead [82]. In general terms, the former charge their consumers lower DH prices, while the latter use the profits to finance projects and activities that benefit the local community. Although DH consumers could see this as an advantage over commercial companies, state-owned companies or distant municipal companies who would take the profits out of the local community, there is the ethical issue of using the exploitation of a natural monopoly for indirect taxes. Diverse opinions exist about this matter in Sweden, as evidenced by the fact that different municipal companies have chosen to apply different price-setting principles.

In Denmark, the regulatory authority argues that the very low competition between DH systems and individual DH systems leads to sub-optimal cost-efficiency in Danish DH companies [156]. Whereas a few experts think that increased competition could help improve DH prices and services, several others point to information asymmetries, agency issues and lack of expertise as the causes for lower cost-efficiencies in some local municipal companies and local consumer cooperatives. Furthermore, these experts claim that only a very small percentage (5-10%) of the municipal companies and consumer cooperatives are badly managed (moderately or severely). For more details on this discussion, see Appendix B. Examples from Denmark also suggest that small DH companies may improve their cost-efficiency by merging with other companies.

In general terms, local municipal companies and local consumer cooperatives have behaved in a more trustworthy way, as they have had more reasonable DH prices than commercial and state-owned companies. This is in line with the results of previous studies on the influence of ownership power in electricity distribution grid tariffs [32]. By adopting more trustworthy behaviour related to DH prices, these ownership models could increase consumers' institutional trust in DH and, thus, their willingness to choose DH over other heating solutions. Ultimately, this could lead to higher consumer connection rates, improved DH system economics and higher levels of DH implementation.

5.2.3. Reflections on the Ownership of DH Systems in the International Sphere

Local municipal companies and local consumer cooperatives have contributed significantly to the implementation and operation of DH systems in Denmark, as have local municipal companies in Sweden. Furthermore, these ownership models have shown to be more effective in motivating DH companies' trustworthy behaviour related to DH prices. The results from Sweden and Denmark suggest that it would be advisable to design and implement institutional incentive systems that promote local municipal companies and local consumer cooperatives for DH. Studies such as [32], [112] suggest that these ownership models would also facilitate the implementation of 4GDH systems. However, further research on this topic is necessary.

The ownership of DH is very diverse among EU countries [157], [158]. Public regulation and other contextual factors also vary from country to country [94], [158]–[160]. Moreover, mixed solutions (e.g. public ownership with private management through leasing, concessions or operation and management contracts) have become more popular in some countries [157]. Hence, it is relevant to study the heterogeneous DH development in the EU and assess both consumer power under different socio-technical contexts and its correlation with effective control of DH prices. This would contribute to the understanding of suitable ownership (and management) models and policies that could enhance the social acceptance of DH systems in different EU countries. Other research outlooks could also include the analysis of different socio-technical contexts with a focus on consumers' satisfaction with DH, the level of consumers' institutional and interpersonal trust in DH and the factors influencing it, the impact of trust on connection rates, etc. Such questions would also help advance the knowledge on the social acceptance of DH and effective policies to enhance it. Nevertheless, they are beyond the scope of this research, as mentioned in section 4.3.

Table 6: Summary. Answer to sub-question 2.

The ownership characteristics of DH systems in Denmark and Sweden. Market shares and DH prices
- 64% of residential buildings are connected to DH in Denmark compared to 51% in Sweden. - Despite important regulatory differences, local and inclusive citizen ownership is the most common ownership model in both countries. In Denmark, local municipal companies supply 60% of the DH demand, local consumer cooperatives 34% and commercial companies 6%. In Sweden, local municipal companies supplied close to 100% of the DH demand before 1990. The re-organisation of DH ownership in the years surrounding the liberalisation of the electricity sector reduced local municipal ownership to about 63% of the DH demand. Other ownership models are joint municipal and state or commercial company (18%), commercial company (12%), state-owned company, distant municipal company, cooperative and others. - Besides the institutional incentive system, cultural characteristics (as part of the informal institutions) may influence ownership preferences. There are almost no cooperatives in the DH sector in Sweden, but in Denmark, 83% of the DH companies are consumer-owned cooperatives. - High levels of ownership and communicative power have been crucial in promoting lower DH prices in both countries. In this regard, local consumer cooperatives and local municipal companies facilitate DH price control due to consumers' direct or delegated decision-making power (i.e. internal pressure). Additionally, it has been crucial that public regulation has been improved to promote high levels of transparency through the publication of DH prices and other data that can inform consumers and facilitate comparative evaluations. - In general, local consumer cooperatives and local municipal companies have a stronger motivation to exhibit trustworthy behaviour related to DH prices. Hence, local municipal companies and local consumer cooperatives could result in higher institutional trust and consumer DH connection rates. - The Swedish example shows that 'free' market competition between DH and individual heating solutions is not sufficient to keep DH prices reasonable. Medium to high levels of state regulative power, ownership power and communicative power may be necessary. Besides, in some locations, making individual solutions economically competitive with DH may increase socio-economic costs because DH can be the cheapest option for society in some locations. - Ownership, the institutional incentive system and other contextual factors vary significantly across EU countries. Hence, further research under different socio-technical contexts is necessary.

5.2.4. Summary: Ownership Characteristics for DH systems

Table 6 summarises the main findings from the analysis of the development of consumer power in DH companies in Denmark and Sweden and points out the ownership characteristics that could promote DH implementation and continuation.

5.3. CONSUMER CO-OWNERSHIP OF WIND TURBINES AND POWER-TO-HEAT IN DH SYSTEMS IN DENMARK: ELECTRICITY GRID COSTS, LOCAL ACCEPTANCE AND PROJECT ECONOMICS

Motivated by the problem description introduced in section 2.2 and the results from studies 1 and 2, study 3 analyses the benefits and drawbacks of the consumer co-ownership of wind turbines and power-to-heat in DH systems in Denmark. Special attention is paid to the ownership and location factors that could promote (1) the reduction of electricity grid costs and (2) the implementation of those technologies via enhanced local acceptance and improved project economics. The analysis considers the institutional incentive system and the contextual factors in place in 2019. As previously mentioned, study 3 is exploratory, meaning that its purpose is to develop the necessary understanding of the topic to define relevant research outlooks regarding (a) the relatively new field of the coordination of investment and operations for the development of renewable smart energy systems and (b) the potential need to test theories that support the separate ownership of energy sectors.

5.3.1. The Operation of Wind Turbines as Part of DH Systems

DH companies calculate the optimal operation strategy of the DH system for every hour. In Denmark, DH systems may consist of CHP units, boilers, power-to-heat units, solar thermal collectors and large thermal storage [109]. Hence, the calculation of the optimal hourly operation strategy may include demand and variable renewable energy production forecasts, electricity and fuel prices, and available production and storage capacities. In the case of Hvide Sande, the wind turbines are part of the DH system; therefore, wind resource forecasts and electricity sale prices are also considered in the calculation. As a result, the optimal hourly operation strategy of the DH system determines when wind power production is sold on the market and when it is self-consumed through the power-to-heat units. In a separate ownership model, wind power is either sold in the market or, in some cases, curtailed – and wasted.

The co-ownership model in Hvide Sande was designed to achieve the highest possible use of wind power and, in this way, reduce natural gas consumption. It was also believed that wind power would be self-consumed in hours with unattractive spot market prices and sold on the market in hours with attractive market prices. Thus, it could be expected that the co-ownership solution is beneficial for the national electricity system because wind power will be consumed in hours with low market prices (i.e. when the wind power is needed) and sold on the market in hours with high market prices (i.e. when there is excess electricity in the system). However, it is important to note that the attractiveness of market prices is dependent on the total costs of meeting the heat demand. This means that on a sunny summer day with low heat demand and high (cheap) production from the solar collectors, wind power may be sold at lower prices than on a cloudy winter day with high heat demand when the alternative heat production technology to power-to-heat is the (expensive) natural gas boiler. Hence, the co-ownership solution is not fully optimal from the perspective of making the best use of wind resources to meet the national energy system's demand. However, separate ownership with the current institutional incentive system does not ensure full optimisation either, as wind power continues to be curtailed when it could be used for DH.

The comparison between the differences in operational strategies of wind turbines under separate and co-ownership models shows that ownership and governance models impact project economics and the operation of renewable smart energy systems, as argued in the theoretical approach (in section 3.4) and further elaborated in the following.

5.3.2. The Co-ownership Model and the Promotion of Electricity Grid Costs Reduction

Study 3 identifies three electricity grid issues that could arise in Denmark from the increased installation of wind capacity if no mitigation strategy (e.g. grid reinforcement or sector integration) is implemented: (A) increased number of hours with congestion in the two Danish market zones, (B) the creation of new congestion zones within the two market zones and (C) additional electricity grid losses at the distribution level in areas with excess production of variable renewable energy. For more details on why these issues originate, see

Appendix C, section 3.1.2. Sector integration through distant, local and behind-the-meter solutions (as presented in Figure 5 in section 3.4) could be suitable to reduce congestions in the two Danish market zones. However, only local and behind-the-meter solutions are suitable to mitigate the creation of new congestion zones within the two market zones and additional electricity grid losses at the distribution level in areas with excess production of variable renewable energy. Nonetheless, given that congestions in Denmark do not occur at the point where the wind turbines connect to the public electricity grid, behind-the-meter solutions might not be necessary. Ultimately, local cross-sector integration seems to be the most advantageous and necessary solution to promote the reduction of electricity grid costs in the transition to a renewable smart energy system. To that end, local coordination is necessary regarding the time and size of investment in and operations of onshore wind turbines and power-to-heat in DH systems. However, the current institutional incentive system does not promote such local coordination in any way.

For years, the Danish institutional incentive system has promoted the ‘integration over distance’ strategy [161] over the sector integration strategy. This is illustrated e.g. by the construction of new interconnectors to the Netherlands and the UK [162], while only 1.2% of the DH demand was supplied by power-to-heat units in 2019 [109]. Grid operators have only been allowed to address congestion issues through grid expansion and reinforcement. Electricity grid tariffs do not differentiate between local or distant electricity consumption and do not signal moments of grid congestion. Furthermore, high electricity grid tariffs and electricity taxes for heat production have been the main reasons for the delay in the uptake of power-to-heat in DH [163]. Although the ongoing improvements in the economic conditions for power-to-heat in DH systems [164]–[167] could promote greater sector integration, the need for local coordination of investment and operations necessary to reduce electricity grid costs remains unsolved.

Compared to the separate ownership model, co-ownership of wind turbines and power-to-heat units by DH companies could reduce the transaction costs of the necessary investment and operations coordination. The reason is that, in a co-ownership model, decisions regarding the coupling of wind power production and demand are made by one single actor. Therefore, the local co-ownership of onshore wind farms and power-to-heat in DH systems (i.e. local off-site self-consumption) could be an advantageous solution to promote the reduction of electricity grid costs in the transition to a renewable smart energy system. Nonetheless, given the strong seasonal profile of heat demand, other sector coupling technologies (e.g. power-to-X) would also be necessary to reduce grid congestions and losses and, hence, potential overinvestment or unnecessary costs.

5.3.3. The Co-ownership Model and Enhanced Local Acceptance of Onshore Wind Farms

Local municipal companies and local consumer cooperatives supply 94% of the DH demand in Denmark [106]. As previously mentioned, these are local and inclusive citizen ownership models where consumers have direct or delegated decision-making power. Furthermore, in combination with the cost-based DH price regulation, any reduction in DH system costs benefits consumers in the form of lower DH bills. The ownership of onshore wind farms by these types of local DH companies would promote procedural and distributional justice by sharing the decision-making power and the economic benefits of wind turbines with the local consumers. Hence, such an ownership solution could enhance the local acceptance of onshore wind farms in comparison with the current dominant trend of exclusive wind farm ownership [25]. However, it is important to highlight that in a local co-ownership solution (i.e. off-site self-consumption), the closest residents to the onshore wind farm would probably have individual heating rather than DH. The reason is that wind turbines are usually placed in the countryside, away from the urban areas in which the DH system is situated. Hence, in most cases, the residents closest to the wind farms (i.e. the ones who will suffer the highest impacts) are not DH consumers. Therefore, for local co-ownership solutions to obtain broad local acceptance, it could be important to find ways to involve the residents who live close to the wind farm in the decision-making process and the distribution of the economic benefits.

The ownership of onshore wind turbines by distant DH companies would likely not enhance local acceptance compared to the current dominant trend of exclusive ownership. The reason is that distant municipal companies and consumer cooperatives could be viewed as exclusive ownership models from the local community’s perspective.

5.3.4. The Co-ownership Model and Project Economics

In a co-ownership model, the DH company decides when to sell wind power to the spot market and when to self-consume it via the power-to-heat unit. In this way, it is possible to avoid curtailment and low market prices (at least to some extent), resulting in higher utilisation and value for wind power. Besides, onshore wind turbines are the cheapest source of electricity in Denmark [168]. Hence, the economics of the power-to-heat unit(s) could also improve as a result of owning wind turbines (especially in areas with good wind resources) rather than purchasing electricity. However, the high grid tariffs and electricity taxes [103] (which do not discriminate between distant and local consumption) and the low spot market prices of recent years [169] discourage investment in co-ownership solutions that use the public grid. On the other hand, the possibilities for co-ownership solutions with a private grid are very limited as the wind turbines, the private cable and the power-to-heat units must be on the same piece of land with the same cadastral number. This is quite uncommon given that DH systems are located close to urban areas and onshore wind farms are usually situated in the countryside. Hence, the cost of solutions such as building power-to-heat units by wind farms and expanding the DH pipelines might counteract the economic benefits of not paying electricity grid tariffs and taxes in a behind-the-meter solution.

The current institutional system does not enable the realisation of the potential economic benefits of the co-ownership of wind turbines and power-to-heat in DH systems. However, the amendment of the law on electricity supply, which is aimed at implementing the Internal Electricity Market Directive, includes the possibility of reducing electricity grid tariffs for citizen energy communities as long as grid benefits are proven [170]. This could potentially open up some space for (especially local) co-ownership solutions.

5.3.5. Reflections on Research Outlooks and the Benefits and Drawbacks of the Consumer Co-ownership Model

Despite the limited number of interviews, sufficient data has been collected to conclude that local coordination is necessary regarding the time and size of investment in and operations of onshore wind turbines, power-to-heat in DH systems and other integration technologies (e.g. power-to-X) to promote the reduction of electricity grid costs in the transition to a renewable smart energy system. Similarly, it can also be concluded that the current institutional incentive system does not promote such local coordination. There are several ways the Danish institutional incentive system could be improved to that end, namely geographical bids for the regulating power market, new electricity grid tariffs, subsidies on investment in variable renewable energy or sector integration technology in targeted areas, etc. The results of study 3 suggest that local co-ownership of wind turbines and the power-to-heat of DH systems by local municipal companies or local consumer cooperatives could also be a solution, which could additionally enhance local acceptance and improve project economics. Furthermore, the potential economic advantages of cross-sector ownership identified in study 3 suggest that it would be relevant to analyse the economic attractiveness of 'single-sector companies' transitioning to 'smart energy companies'. For example, local wind cooperatives or local consumer-owned electricity utilities could invest in wind turbines, power-to-heat units and electrolysers to sell electricity, heat and hydrogen, which might improve their business case. However, further analysis is needed to understand the suitability of these interim policy and business recommendations.

It will be necessary, for example, to assess the economic magnitude of the identified grid issues, the attractiveness of DH companies investing in heat pumps and wind turbines under the new institutional system conditions, the transaction costs linked to different governance alternatives that promote coordination, the impacts of co-ownership on the spot market price and on the distribution of electricity grid costs for consumers, etc. Interviewing more DSOs and DH companies as well as DH consumers, the Tax Ministry, The Danish Utility Regulator and the Energy Ministry could provide valuable insights for such analysis. Moreover, following the smart energy systems approach, it would be relevant to expand the analysis to the other energy system components as well because these are technically and economically interrelated, as illustrated by Figure 4 in section 3.4. Such a study would require a systematic mapping of the coordination needs and the assessment of the impacts of various (time, size and location) coordination scenarios on system costs. These studies could lead to considerations about market and grid tariff designs as well as the (re-)bundling of energy sectors and/or some energy services or activities, requiring analysis of the implications for consumers and the legal implementation. In this regard, it could be especially critical to analyse the implications of bundling natural monopolies (i.e. DH, electricity and gas grids) with other activities for consumers.

Finally, it would also be relevant to expand the analysis to other EU countries. As illustrated in the theoretical approach in Figure 4, the institutional incentive system, ownership of DH companies, characteristics of the energy system and other contextual factors may vary from country to country. This means, for instance, that the electricity grid may be weaker in other EU countries [43], [171], [172], there may be few DH systems [75] or other electricity sources that are cheaper than onshore wind power (e.g. hydropower) [84], or the DH companies may be owned by distant and exclusive ownership models [157], [158]. Consequently, the findings from study 3 might not be fully generalizable to other EU countries. Nonetheless, the issue of implementing and integrating large shares of variable renewable energy is common to other EU countries. Hence, identified research outlooks on coordination needs and suitable governance models and institutional conditions are also relevant outside Denmark.

5.3.6. Summary: The Benefits and Drawbacks of the Co-ownership of Onshore Wind Turbines and Power-to-Heat in DH Systems

Table 7 summarises the main findings from the analysis of the benefits and drawbacks of the co-ownership of onshore wind turbines and power-to-heat in DH systems for electricity grid costs, local acceptance and project economics.

Table 7: Summary. Answer to sub-question 3.

Consumer co-ownership of wind turbines and power-to-heat in DH systems in Denmark. Electricity grid costs, local acceptance and project economics
- The increased installation of wind capacity could lead to three grid issues if no mitigation strategy (e.g. grid reinforcement or sector integration) is implemented: (A) increased number of hours with congestion in the two Danish market zones, (B) the creation of new congestion zones within the two market zones and (C) additional electricity grid losses at the distribution level in areas with excess variable renewable energy. - Sector integration anywhere within the same market zone could help address issue A. However, local sector integration is necessary to reduce the grid costs related to B and C. - For sector integration to reduce grid costs, coordination is necessary regarding the time, size and location of investment in and operations of onshore wind turbines and integration technologies (such as power-to-heat in DH systems and power-to-X). - The co-ownership of onshore wind turbines and power-to-heat in DH could facilitate the necessary local coordination. Furthermore, co-ownership could improve the project economics of onshore wind farms and power-to-heat units and accelerate their implementation. Moreover, as almost all DH companies in Denmark are owned by local municipal companies and local consumer cooperatives, the local co-ownership model could enhance local acceptance as long as the residents closest to the wind turbines are properly involved in the distribution of decision-making power and project benefits. - The current institutional incentive system does not promote the necessary local coordination to reduce electricity grid costs, and it discourages the co-ownership of onshore wind turbines and power-to-heat in DH systems. There are several alternatives that could promote local coordination, including geographical bids for the regulation market, changes in grid tariffs, geographically targeted support schemes, local co-ownership solutions, etc. Further research is needed to develop a comprehensive understanding of the benefits and drawbacks of these solutions and, particularly, of the identified innovative ownership models. During this research, it would be important to pay particular attention to the implications of the different solutions for consumers.

5.4. SUMMARY: OWNERSHIP CHARACTERISTICS FOR ONSHORE WIND FARMS AND DH SYSTEMS IN RENEWABLE SMART ENERGY SYSTEMS

In the previous sections of this chapter, the results from studies 1-3 were presented and sub-questions 1-3 were answered. This section combines the results from the three studies (see Tables 5-7) to answer the main research question:

Based on knowledge from Denmark and Sweden, which ownership characteristics and models could best promote the implementation of onshore wind farms and DH systems in renewable smart energy systems and the reduction of related energy costs and prices?

The ownership analyses conducted in studies 1-3 indicate that:

- **Citizen ownership** could promote the implementation of onshore wind farms and DH systems when favourable conditions for the technologies and citizen ownership are in place. Citizen ownership models have been shown to be capable of gathering the necessary capital and knowledge to develop and implement onshore wind and DH projects in Denmark, Sweden and other EU countries. Here, it is important to underline that, based on knowledge from Denmark and Sweden, some citizen ownership models seem to perform better than others in addressing the governance challenges of onshore wind farms and DH systems, as further elaborated in the following points.
- **Local and inclusive citizen ownership models (such as local consumer cooperatives and local municipal companies)** confer direct or delegated decision-making power and a broad distribution of benefits among the members of the local community, thereby fostering procedural and distributional justice. Such ownership models could be essential to promoting the implementation of onshore wind farms and DH systems. The reason is that these ownership models enhance the local acceptance of onshore wind turbines and promote DH companies' trustworthy behaviour regarding DH prices (leading to consumers' enhanced institutional trust in DH and, likely, higher consumer connection rates).

Furthermore, these ownership models could also improve onshore wind farms' project economics by facilitating the arrangements of power-purchase-agreements or self-consumption. To motivate DH companies to exhibit trustworthy behaviour regarding DH prices, these ownership models must be supported by public regulation that ensures high levels of transparency through the regular publication of DH prices and access to technical and financial reports. High levels of transparency allow consumers to monitor the local municipal companies and local consumer cooperatives, incentivising them to optimise the DH system costs. Furthermore, transparency and communicative power allow consumers to support the Regulatory Authorities in identifying any questionable practices and law infringements.

- **Joint ownership models (where local and inclusive citizen ownership models are combined with exclusive ownership models)** could be necessary to ensure greater access to capital and, in this way, accelerate the implementation of onshore wind power. Careful attention should be paid to the design of joint ownership models so that procedural and distributional justice is ensured, which could be essential to achieving the necessary local acceptance.
- **The local co-ownership of onshore wind turbines and power-to-heat in DH systems by local municipal companies and local consumer cooperatives** could provide several benefits compared to the current characteristics of the separate ownership models. (1) The co-ownership model could contribute to reducing electricity grid costs by facilitating the necessary local coordination regarding the time and size of investment in and operations of onshore wind turbines and power-to-heat in DH systems. However, other integration technologies (e.g. power-to-X) will also be necessary to integrate wind power and reduce electricity grid costs. (2) The local co-ownership model could enhance local acceptance as long as residents who live close to the wind turbines are properly involved in the distribution of decision-making power and economic benefits. (3) The local co-ownership model could improve project economics for onshore wind turbines and power-to-heat in DH, leading to accelerated implementation of these technologies. However, the existing institutional incentive system in Denmark discourages this ownership model. Besides, further research is necessary to develop

a comprehensive understanding of the benefits and drawbacks of different co-ownership models and alternative governance models.

Overall, the right design of local and inclusive citizen ownership models could be particularly advantageous to support the implementation of onshore wind farms and DH systems and the reduction of related costs and prices. The results suggest that it would be extremely relevant to further study these ownership models in combination with onshore wind farms and DH systems under different socio-technical contexts in the EU countries.

The following chapter elaborates on the implications of the findings for future research and policy-making.

CHAPTER 6. CONCLUSIONS AND RESEARCH OUTLOOKS

In the context of the climate crisis and the Paris Agreement, the EU has set the target of reducing its carbon emissions by 55% compared to 1990 levels by 2030 and to reach carbon neutrality by 2050 [3]. The transformation of the energy system by phasing out fossil fuels through energy demand reductions, variable renewable energy and other low-carbon fuels and technologies will be crucial to meeting those goals [5]. However, the positive and negative consequences of the various socio-technical paths are still not fully understood, and advancing knowledge of the potential socio-political, market and local acceptance of these paths is particularly vital, as this knowledge is essential for a timely energy transition. This study contributes to this understanding by analysing citizen ownership models and their benefits for the implementation and operation of onshore wind farms and DH systems in renewable smart energy systems.

The potential benefits of the citizen ownership of energy have increasingly attracted the interest of academics, policy-makers and practitioners in the EU and internationally. However, scientific knowledge of the benefits of citizen ownership is still limited [29]. Some studies conclude, for example, that citizen ownership may reduce energy costs and prices, enhance local acceptance of new energy projects or build social capital, whereas others conclude the opposite [14], [29], [31], [32]. This means that, it is necessary to be more critical about citizen ownership and investigate which citizen ownership models can deliver the desired benefits and within which contextual factors. It also means that it is very easy for opponents of citizen ownership to disqualify it by arguing that, generally, citizen ownership cannot deliver the commonly associated benefits. This argument (although lacking of scientific evidence) could undermine the socio-political acceptance of citizen ownership, creating challenges to its implementation and realisation of benefits. Therefore, advancing the understanding of the benefits and drawbacks of citizen ownership is crucial. To that end, this study investigates the ownership characteristics that could promote the implementation of onshore wind farms and DH systems in a renewable smart energy system and reduce the related energy costs and prices. Denmark and Sweden have been chosen as the specific socio-technical contexts for the analysis. The following presents the main theoretical and analytical conclusions of the study and discusses the identified research outlooks.

6.1. THEORETICAL CONCLUSIONS

The theoretical approach of this study builds on the existing theoretical understanding about the meaning of citizen ownership (see e.g. [23], [24], [26]); the interrelations between contextual factors, motivations, citizen energy project characteristics and the benefits of citizen ownership (see e.g. [28], [29]); and suitable approaches for designing alternative energy plans that meet society's goals and consumers' expectations in a context of radical technological change (see e.g. [15], [47], [123], [124]). The developed theoretical approach also provides new contributions to research into citizen ownership. The main theoretical contributions and their implications and significance for future research and policy-making are discussed below. The theoretical contributions are also summarised in Table 8 at the end of the section.

6.1.1. The Distinction and Categorisation of Citizen Ownership Models

The study has shown the importance of and need to distinguish between the diverse key characteristics of the multiple citizen ownership models to analyse and identify the benefits different types of citizen ownership models can or cannot deliver and why. Moreover, the study has developed citizen ownership categories that have proven useful for such an analysis. The categories describe the ownership models' characteristics regarding (a) the geographical scope, (b) the distribution of decision-making power and economic benefits and (c) the type of profits (i.e. private or for common good and limited or unlimited as a result of public regulation or internal rules); see Figure 2 in section 3.1 for more details. These categories have been useful in, for example, advancing the understanding of:

- the important contribution of exclusive citizen ownership models to onshore wind capacity implementation in Denmark,
- why some ownership measures designed to enhance local acceptance of onshore wind turbines in Denmark have not been effective or

- how different ownership models result in higher or lower consumer power in DH companies and change their motivation to exhibit trustworthy behaviour related to DH prices.

Such knowledge is considered extremely useful to support the design and implementation of effective energy policies that will enhance the social acceptance of onshore wind farms and 4GDH systems. Hence, it is recommended that future studies on the benefits of citizen ownership also pay special attention to the diverse characteristics of the multiple citizen ownership models. To that end, it could be helpful to employ the categories developed in this study.

6.1.2. The Elaboration of the Concrete Institutional Economics Approach: An Enhanced Focus on Different Governance Scenarios and Organisational Innovation

In this dissertation, it has been argued that:

1. The same technical energy system combined with different energy system governance (and ownership) models can result in higher or lower energy system performance (with regard to meeting society's goals and users' expectations). In other words, some governance (and ownership) models can be more advantageous than others for the specific technical characteristics of a given technology (e.g. onshore wind turbines, DH systems, etc.) or energy system (e.g. a renewable smart energy system).
2. The technical characteristics of technologies and energy systems make them more attractive for some business (and ownership) models than for others.

The first point is supported by the research results of this study, which suggest that local and inclusive citizen ownership models (such as local utilities organised as local municipal companies or local consumer cooperatives) could be the 'best' ownership models for the implementation and operation of onshore wind farms and DH systems in a renewable smart energy system. In the light of these results, it is recommended that the Concrete Institutional Economics approach incorporate a new step for the analysis of diverse governance scenarios to implement the 'best' technical scenario; see Figure 3 in section 3.3 for more details.

The second point is illustrated by e.g. differences between citizen-owned energy companies and large international energy companies' technology investment preferences. The former showed a preference for decentralised technologies (such as DH systems and onshore wind farms) and smaller project scales, the latter for centralised technologies (such as large offshore wind farms or large hydrogen networks) and larger project scales. This can be explained by, amongst others, efforts to reduce transaction costs, differences in strategic advantages and core competences, and challenges and opportunities for organisational innovation (see e.g. [8], [121]). Hence, the second point has important research and policy implications:

- In line with Yildiz's observations [78], it indicates that political support for both centralised and decentralised governance, business and ownership models will be necessary so that a combination of centralised and decentralised technical solutions can be implemented to meet society's goals and users' expectations in the energy transition in the EU. However, decentralized solutions are currently not given the same priority as centralized ones.
- It calls for increased attention to organisational innovation in the energy planning field to better understand how organisational innovation challenges and opportunities could support or hinder diverse socio-technical paths for the energy transition; and
- It underlines how ownership concerns may influence discourses about the 'best' technology choices in the public and political debate, as energy companies (whether commercial-, state- or citizen-owned) will advocate the technology solutions that best suit their business models, competences, organisational innovation capabilities and, ultimately, economic interests.

This last point is important to understand the risks presented by those political processes that exclude some actors or fail to address power imbalances between actors in the political process; such political processes may result in political support for technical solutions that benefit private economic interests rather than societal interests. Hence, inclusive political processes (involving both old and new market actors, consumers and market independent actors) that address power imbalances could be essential to ensure that society's goals and users' expectations are met. This is in line with the recommendations from previous studies (see e.g. [49]).

6.1.3. The Development of a Comprehensive Theoretical Approach for the Analysis of the Benefits of Citizen Energy Projects

The study has shown the importance of and need to pay special attention to contextual factors to analyse and identify the benefits that different types of citizen ownership models can or cannot deliver and why. To this end, the theoretical approach developed in this study situates the concept of ownership in the context of the energy transition and describes the causal relationships between (1) the governance of the political process, (2) the institutional incentive system, (3) other contextual factors, (4) the technical and governance characteristics that determine the operation and implementation of renewable smart energy systems and (5) the benefits of the energy system (or the energy system performance). Paying special attention to the institutional incentive system and other contextual factors has been useful to advance the understanding of e.g.:

- How changes in the institutional incentive system, the technical energy system and the normative understanding of wind turbine implementation in Denmark has posed increasing challenges for (the traditional) local and inclusive citizen ownership of onshore wind farms.
- The limitations of the 'free market' approach − with no DH regulation − and the need of public DH regulation that ensures high levels of transparency and strengthens consumers' communicative power to motivate DH companies to exhibit trustworthy behaviour related to DH prices.
- The fact that in a context with no DH price regulation, like in Sweden, some municipal companies may choose to earn profits from the exploitation of the DH system or, in other words, to apply an indirect municipal tax on DH consumers.
- The barriers the institutional incentive system poses in Denmark to local cross-sector ownership.

The study has developed a comprehensive theoretical approach that is suitable for the analysis of (a) the benefits of citizen ownership for the transition to renewable smart energy systems and (b) effective policies for promoting citizen ownership in different socio-technical contexts. This theoretical approach is deemed appropriate for Denmark, Sweden and other EU countries. Besides, the theoretical approach is useful for long-term analysis and provides a strong framework for in-depth studies, as the elements in the theoretical approach can be further elaborated to reach the necessary level of concreteness for the specific aim of the study. Hence, the developed theoretical approach could be used for future research on the topic within the EU and perhaps beyond.

6.1.4. Summary: Theoretical Conclusions

Table 8 summarises the theoretical conclusions of the study.

Table 8: Summary. Theoretical conclusions.

Theoretical contributions to future research and policy-making

- The study has developed a comprehensive theoretical approach for the analysis of (a) the benefits of different citizen ownership models for the energy transition and (b) effective policies for promoting citizen ownership. The theoretical approach is appropriate for such analysis within different socio-technical contexts in the EU countries.
- The main contributions of the theoretical approach are that
  - it highlights the importance of and need to distinguish between the diverse key characteristics of the multiple citizen ownership models,
  - it provides citizen ownership categories that have proven useful for analysing the benefits citizen energy projects can or cannot deliver and could also help effective policy design,
  - it develops the steps defined by the Concrete Institutional Economics approach to emphasise the need to study multiple governance models while developing alternative energy plans that meet society's goals and users' expectations in a context of radical technological change, and
  - it underlines the importance of studying the contextual factors when analysing the benefits that different citizen ownership models can or cannot deliver and why.
- The theoretical approach suggests that it would be beneficial to:
  - promote a combination of centralised and decentralised governance and ownership solutions,
  - design and implement inclusive political processes which minimise power imbalances between the diverse actors (this will be essential to promote an energy transition that is in line with societal goals); and
  - pay more attention, in the field of energy planning, to the study of organisational innovation and its implications for the implementation of different socio-technical solutions.

6.2. ANALYTICAL CONCLUSIONS

The analysis builds on three in-depth studies which combine multiple data sources and quantitative and qualitative analysis. The main analytical contributions and their implications and significance for future research and policy-making are discussed below.

6.2.1. Onshore Wind Farms

The study results suggest that the implementation of onshore wind farms in Denmark could be promoted via:

- **joint ownership models**, which combine local and inclusive citizen ownership models (e.g. local municipal companies, local wind cooperatives, local consumer cooperatives and local foundations) with exclusive ownership models (e.g. wind guilds, individual ownership, commercial ownership, etc.),
- **local utility companies**, organised as local municipal companies or local consumer cooperatives, and
- **local cross-sector ownership models**, or local smart energy companies, such as DH companies that own local wind turbines.

Joint ownership models could facilitate access to capital while enhancing local acceptance. Local utility companies and local cross-sector ownership models could enhance project economics and enhance local acceptance. Furthermore, local utility companies and cross-sector ownership models could have some advantages in facilitating the coordination of investment and operations between the different components of the smart energy system, as this dissertation suggests is the case for onshore wind turbines and power-to-heat in DH systems. This could potentially lead to lower energy system costs, as indicated by the analysis of electricity grid congestions. This idea aligns with the results of the preliminary assessment presented by Hvelplund and Djørup [32]. Although some promising potentials have been identified for all three types of citizen ownership models listed above to foster the implementation of onshore wind farms in Denmark, further research is necessary to develop a comprehensive understanding of the implications of these ownership models and, if appropriate, effective policy measures to promote them.

The Danish experience with the ‘20% local ownership rule’ shows the challenges in the design of joint ownership models that ensure procedural and distributional justice and, hence, can enhance local acceptance. The results of the study suggest that

- requiring not just local but also local and inclusive citizen ownership models could be a determinant factor in the effectiveness of the joint ownership model;
- it would be worth analysing the Dutch experience with local citizen ownership and their target for 50% local citizen ownership of onshore wind and solar farms [144]; and
- it could also be important to study planning practices to understand the benefits and drawbacks of more democratic planning practices. In a similar vein, large wind developers and other project initiators could consider innovative approaches to project planning and implementation that could enhance local acceptance and project success rates.

The ownership of onshore wind farms by local utility companies and local cross-sector ownership models (or smart energy companies) requires further research to understand

- the competitive advantages of such ownership models,
- the implications for consumers and
- their advantages and drawbacks for coordination of investment and operations and system costs compared to other governance solutions.

The latter research area will require the systematic mapping of coordination needs; an assessment of the costs of implementing higher or lower levels of coordination in time, size and location; and an evaluation of the benefits and drawbacks of different governance solutions to provide the right level of coordination. Additionally, the analysis will require understanding the technical energy system design and how diverse institutional system conditions influence the results for the previously listed aspects of the necessary coordination.

6.2.2. DH Systems

Based on the analysis of DH in Denmark and Sweden, the results of the study suggest that the ownership solution that best promotes the implementation and continuation of DH systems is

- the **local utility company,** organised as a local municipal company or local consumer cooperative.

Generally, such ownership models have resulted in more trustworthy behaviour of DH companies, as they tend to charge lower prices. This can enhance consumers' institutional trust in DH and, thus, consumers' DH adoption rates. Notably, along with the local (municipal or consumer-owned) utility model, public regulation that requires high levels of transparency regarding DH costs and price construction for different consumers − thus conferring high levels of communicative power to consumers − has been essential in motivating DH companies to exhibit trustworthy behaviour related to DH prices in both Denmark and Sweden. The local (municipal or consumer-owned) utility models have also proven to contribute significantly to the implementation of DH systems in Denmark and Sweden. Furthermore, they are expected to be more suitable than other ownership models for developing 4GDH [32], [112]. The local co-ownership of wind turbines could partly drive this advantage, as it provides better project economics for power-to-heat. However, further research is necessary to fully understand the benefits and drawbacks of different ownership characteristics to address the governance challenges of implementing 4GDH systems.

First, the EU has a diverse range of DH ownership, management and regulation [94], [157], [158]. Hence, it would be relevant to replicate the analysis of consumer power and its influence on DH companies' trustworthy behaviour related to DH prices in other EU countries. This is necessary to develop a more comprehensive understanding of the ownership and public regulation characteristics that are most effective for ensuring DH companies' trustworthy behaviour in different socio-technical contexts.

Second, it is important to advance the understanding of governance models (including ownership characteristics) and policies that could promote the necessary investment and coordination that could lower energy system costs. To this end, it would be relevant to study whether and how different ownership characteristics and institutional incentives have influenced investment in DH. In other words, it is necessary to study whether and how different ownership characteristics lead to greener or more sustainable DH systems, as suggested by [112], and what other factors may be determinant. Effective coordination must include both the demand side (investment in energy efficiency in buildings) and the supply side (investment in and operations of power-to-heat units, thermal storage, waste heat sources, etc.). Coordination between the demand side and the supply side could reduce the costs of the DH system

[46]. Moreover, in a renewable smart energy system, the coordination between the DH system's supply side and other system components such as wind turbines will also be necessary to reduce system costs [32], as corroborated by the findings in this study. As previously mentioned, advancing the understanding of suitable governance and ownership models to address the coordination needs of renewable smart energy systems will require the systematic mapping of coordination needs; the assessment of the magnitude of the implications of various levels of coordination in time, size and location; and the evaluation of the benefits and drawbacks of several governance solutions to meet the coordination needs. Additionally, the analysis will require an understanding of the technical energy system design and how diverse institutional system conditions influence the results for the previously listed aspects.

6.2.3. Implications for Energy Policy

The results suggest that local and inclusive ownership models, particularly those of municipal or consumer-owned utilities, could promote the implementation of onshore wind farms and DH systems – even under current market conditions and project sizes. Hence, the current trend towards increased support for large commercial companies in Danish energy policies and debate (both for onshore wind power [107] and DH systems [21], [40], [41]) seems problematic. Instead of continuing to diminish the local and inclusive citizen ownership of onshore wind farms and DH systems, it would be beneficial for Danish energy policy to promote the redevelopment of local and inclusive ownership and the modernisation of such energy companies so that their full potential benefits for the energy transition can be realised. For onshore wind farms, it could also be relevant to closely follow the Dutch target for 50% local ownership of onshore wind and solar farms [144], combining it with requirements for local and inclusive ownership to enhance local acceptance. Besides, it could be relevant to reconsider the principles that guide current wind turbine planning by starting to view *'local communities as active co-creators and innovators rather than simply state-citizens that need to 'be consulted' about what they can accept*' [107, p. 107].

These ownership recommendations have been obtained from the analysis of the concrete conditions in Denmark and Sweden. While the governance challenges of onshore wind farms and DH systems during development and implementation of renewable smart energy systems could be similar in other

EU countries, and similarities could also apply to governance models, technical, institutional and other contextual conditions, the results cannot all be generalised to other EU countries due to the high level of concreteness that is needed to understand the benefits of citizen ownership and how motivations and contextual factors influence the emergence and definition of citizen energy projects. Nonetheless, the study contributes to the understanding of the potential benefits of citizen ownership models and provides improved theoretical knowledge to further advance in this field. It also provides some insights that could be relevant to the ongoing policy process in the EU:

- Not all citizen ownership models promote procedural and distributional justice, which are factors that can be determinant in the local acceptance of new energy projects in many contexts [110]. Hence, there may be a need for increased emphasis on local and inclusive citizen ownership models to achieve the necessary local acceptance for implementing some technologies, e.g. onshore wind turbines. Whereas the ‘renewable energy communities’ definition in the new Renewable Energy Directive aligns closely with the understanding of local and inclusive ownership models, the ‘citizen energy communities’ definition in the new Internal Electricity Market Directive does not. This could lead to unintended or unexpected issues with local opposition. Therefore, the recommendation could be made to revise the definition of ‘citizen energy communities’ and to investigate opportunities for joint ownership models.
- DH regulation in different EU countries could be improved to enhance consumers’ communicative power through increased DH price and cost transparency. Furthermore, DH regulation should also ensure that DH consumers’ rights are respected by e.g. ensuring the security of heat supply [95].
- The study has highlighted the relevance of registering the ownership models of energy assets and monitoring ownership developments quantitatively, i.e. monitoring changes in what share of wind power capacity and DH demand is owned by different types of investors. This is necessary to monitor how changes in the institutional incentive system and other contextual factors influence the ownership of onshore wind turbines and DH systems. Furthermore, the quantitative monitoring of ownership is also necessary to understand e.g. the reasons for changes in the local acceptance of onshore wind power

or DH companies' trustworthy behaviour related to DH prices. Ultimately, such monitoring is necessary to evaluate whether new policies are delivering the targeted outcomes, to understand why or why not and to make any necessary improvements. Therefore, and in line with Wierling and colleagues' suggestion [77], it is recommended that Denmark, Sweden and other EU countries (re-)start or continue the registration of ownership model data for wind farms, solar farms, DSOs, DH companies, biogas plants, etc. and make this data available to the public. Substantial data is already registered for energy assets (see e.g. [127]); registering the ownership model would only require adding one extra column to the existing databases.

- The auction scheme seems to hinder the implementation of citizen-owned wind farms in Denmark. These results are in line with results from international studies on auction schemes [14], [16], [18]. These studies have pointed out different auction designs, but, most importantly, the studies have identified the uncertainty of getting the project granted as a major constraint for starting citizen wind projects. Given the EU's political commitment to promoting citizen ownership, it is advisable to consider different policy schemes or other support measures to ensure that citizen ownership can materialise.
- High fixed DH tariffs and electricity grid tariffs and taxes may worsen the economy of investment in energy efficiency in buildings and sector integration technologies [46], [163]. Hence, such tariffs and taxes could be decelerating the investment needed for a cost-optimal and sustainable transition to a renewable energy system (see e.g. [61]–[64]). Therefore, it is advisable to revise the current energy policies and regulations creating this problem and analyse how to improve them.

6.2.4. Summary: Analytical Conclusions

Table 9 summarises the analytical conclusions of the study.

Table 9: Summary. Analytical conclusions.

Analytical implications for future research and policy-making

- The results suggest that local and inclusive ownership models, particularly those of municipal or consumer-owned utilities, could promote the implementation of onshore wind farms and DH systems, even under current market conditions and project sizes.
- The analysis concludes that further research is necessary regarding
  - how to design joint ownership models that ensure procedural and distributional justice,
  - the implications of local utility companies and local cross-sector ownership models for consumers,
  - the influence of the four dimensions of consumer power on DH companies' trustworthy behaviour related to DH prices in other EU countries,
  - the benefits and drawbacks of different governance and ownership models to address the coordination needs in renewable smart energy systems and
  - the influence of ownership and other contextual factors on DH companies' investments in sustainable technologies.
- The analysis suggests that policies could be improved by
  - re-developing and modernising local and inclusive ownership models for onshore wind farms and DH systems in Denmark;
  - revising the definition of 'citizen energy communities' and other policy measures (such as the auction scheme) that could be preventing local and inclusive ownership models for onshore wind farms (both in single and joint ownership models);
  - promoting high consumer communicative power via public regulation that requires high DH cost and price transparency;
  - registering and monitoring the development of ownership and its implications to evaluate the effectiveness of policies and, if necessary, introduce the necessary changes; and
  - revising public regulations that could be preventing investments in energy efficiency in buildings and cross-sector integration technology as a result of e.g. high fixed DH tariffs, electricity grid tariffs and electricity taxes.

6.3. FURTHER RESEARCH OUTLOOKS

In addition to the research outlooks resulting from the theoretical approach and the analysis, there are several other research outlooks resulting from the reflections and delimitations in the study. Further research could be relevant into

- The benefits and drawbacks of multiple energy system governance scenarios (with different actors' participation and interactions) within different contextual factors for the implementation and operation of renewable smart energy systems in line with society's goals and consumers' expectations. This could help better understand e.g. the role of ownership within different governance models.
- The ownership of other energy technologies and the benefits of the diverse citizen ownership models in combination with those technologies.
- Citizens' views about the benefits and drawbacks of different ownership models for onshore wind farms and DH systems and the opportunities and barriers they see to engage in different ownership models and exercise decision-making power.
- Other benefits commonly associated with local and inclusive citizen ownership, e.g. economic regeneration or local economic development, empowerment and democratic practices, boosting of innovation, etc. [23], [29].
- The level of inclusiveness and democratic practice in inclusive citizen ownership models. It would be interesting to advance the understanding of the extent to which such ownership models engage diverse social groups in their ownership and of the barriers and opportunities for greater inclusiveness. Furthermore, it would be relevant to study what the benefits of inclusiveness are, not only for local acceptance but also for market and socio-political acceptance of different energy technologies. Finally, it would be relevant to collect best practices in promoting inclusiveness in citizen ownership models.
- The benefits and drawbacks of large renewable energy cooperatives. Such a study could include, for example, insights into governance and solidarity principles from industrial cooperative groups, like Mondragon Cooperative Corporation. It could also be relevant to investigate the dynamics of consumer power and influence in large

consumer-owned DSOs in Denmark and other consumer-owned cooperatives in the EU.

- Processes of the re-municipalisation of energy infrastructure and other examples of ‘taking back the ownership’ of the energy system (see e.g. [80], [94], [173]) to better understand their benefits and drawbacks and the factors that could enable or impede it.
- How other factors beyond the institutional incentive system hinder the emergence and development of citizen ownership models (especially local and inclusive models), particularly in Eastern European countries, and how those obstacles could be overcome.
- The influence of ownership and other factors on consumers’ technology adoption or behavioural change (e.g. energy efficiency in buildings, choosing DH or not).

This research has highlighted the significance of studying citizen ownership models and their benefits for the energy transition. The findings suggest that local and inclusive citizen ownership models (such as local municipal companies and local consumer-cooperatives) could be particularly advantageous to promote the implementation of onshore wind farms and DH systems and reduce related costs and prices. Organisational innovation, inclusive political processes and supportive policies will be necessary to promote such ownership models and harvest their benefits. The research has also identified important research outlooks and provided a comprehensive theoretical approach that could support future studies. Amongst others, the benefits and drawbacks of different ownership models to facilitate the necessary coordination in renewable smart energy systems stand out as an important and under-researched field.

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APPENDICES

The following pages include the three scientific articles that present the three in-depth studies conducted for this study.

Appendix A:

Gorroño-Albizu, L., Sperling, K. and Djørup, S. (2019) 'The past, present and uncertain future of community energy in Denmark : Critically reviewing and conceptualising citizen ownership', *Energy Research & Social Science*, 57, p. 101231. doi: 10.1016/j.erss.2019.101231

Appendix B:

Gorroño-Albizu, L, & de Godoy, J, (under review) 'Consumer Power and District Heating Companies' Trustworthy Behaviour: Insights from Denmark and Sweden', *Energy*

Appendix C:

Gorroño-Albizu, L. (2020) 'The benefits of local cross-sector consumer ownership models for the transition to a renewable smart energy system in Denmark. An exploratory study', *Energies*, 13, p. 1508. doi: 10.3390/en13061508.

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