Towards a just heating transition

Exploration of socio-spatial inequalities in individual and collective access to clean heating technologies for The Hague

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by

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Preface

Before you lies my master thesis, which marks the end of my student years at the Delft University of Technology, and the beginning of my journey to contribute to better and more just cities. My education in Engineering & Policy Analysis provided me with analytical tools to address the pressing societal questions of today, which I am very grateful for. I enjoyed the thesis process from beginning to end, diving into the social dimension of the heating transition, a transition that will reach all our homes. I am very proud of the result and I wish you joy in reading this thesis, but first a few acknowledgements.

This achievement would not have been possible without the great support, enthusiasm and feedback of my committee. I would like to thank Trivik, for introducing me to the topic and your help in translating ideas into research and meaningful analyses. I want to thank BinBin, for sharing your knowledge of invaluable theories, bringing the conceptual basis to a higher level. I also want to thank Juliana, for your perspectives on complex socio-spatial processes, enhancing contextual sensitivity to my research. Furthermore, I want to thank Neelke, for your interest and trust in this research. High-quality research is hard to achieve, and I am grateful that I could learn from you all, and develop my research skills.

I enjoyed conducting my thesis at Generation.Energy, exposing me to the Dutch energy transition and the spatial puzzle, and learning about the social implications together. I would like to thank everyone at GE, for ensuring that I had a good time, access to knowledge and skills, and support when needed. I would especially like to thank Jaap, for your valuable perspectives and knowledge on energy transitions, models in a policy context, and municipal perspectives, bringing the thesis closer to reality.

Last but not least, I would like to thank my friends and family, for your support during my thesis - from discussing initial ideas to study sessions and coffee breaks. In particular, I want to thank Reinoud, for always being there and supporting me unconditionally.

Susan Ruinaard
The Hague, December 2024

Summary

Cities are rapidly decarbonising in the face of climate change, necessitating a heating transition of the residential built environment. As of 2019, about three-quarters of natural gas in the residential sector is used for heating the home, with 92% of the dwellings being connected to the gas network. Simultaneously, cities face increasing socio-spatial inequalities, among which concerns around energy poverty. Given that access to clean, reliable and affordable energy touches many basic needs, it needs to be ensured that nobody is left behind in the decarbonisation process.

This research seeks to uncover socio-spatial inequality in access to opportunities in the heating transition. By shifting the focus from spatial goods to access to opportunities, we address the roots of why people are vulnerable to being left behind in the decarbonisation process. We employ energy justice, enriched with spatial and capability thinking, as conceptual framework. We use computational modelling to uncover spatial disparities in access for The Hague. In a nutshell, this research uncovers patterns of local vulnerability in access to opportunities in the heating transition (*recognition justice*), evaluates how spatial patterns of vulnerability relate to the spatial distribution of well-being, adaptation of clean energy technologies and future opportunities (*distributive justice*), and evaluates policies and resources on effectiveness to alleviate spatial inequalities while decarbonising (*procedural justice*). In the following sections, the conceptualisation, implementation and results of each energy justice dimension are presented, followed by a concluding section.

Recognition justice

Recognition justice concerns whose needs should be recognised and prioritised, and where. We conceptualise this as the recognition of local vulnerabilities in terms of personal and built environment characteristics, that influence people's freedom to participate in the heating transition. We implement this by identifying socio-spatial vulnerability indicators, uncovering and understanding localised challenges, and developing an index of socio-spatial vulnerability.

Socio-spatial vulnerability indicators. The vulnerabilities of interest were determined by reasoning for all data available on a small spatial scale, whether it could result in increased vulnerability or not. Literature on vulnerability to energy poverty served as a basis for identifying vulnerability indicators, adapted to the Dutch heating transition context. This resulted in the following subset of vulnerability indicators: age groups (0 to 15 year-olds, 15-25 year-olds, 65 years and older), migration background (EU and non-EU), household structure (single person and single parent), income (state benefit recipients and low property valuation), home ownership structure (private renting, different owners and function mix), energy (energy-inefficient properties and high gas usage), and dwelling type (monuments and multiple units per building)

Localised challenges. The collected data on street-level, containing extensive information on sociodemographics and the built environment, was aggregated into 426 localities using the max-p regionalisation algorithm. Each locality is spatially coherent, contains 500-1277 dwellings, and has a coherent data profile that is distinct from neighbouring localities. Multiple localities exist in administrative boundaries, reflecting the diversity within administrative zones. For each locality, scorecards were created that describe the socio-demographic and built environment characteristics, while highlighting local vulnerabilities. This provides a single overview of what characteristics need to be recognised in policy-making, to ensure inclusion in the decarbonisation process.

Level of socio-spatial vulnerability. Aggregating vulnerability indicators into a single index enables an evaluation of the emerging pattern of socio-spatial vulnerability in access to opportunities in the heating transition for the whole of The Hague. The spatial pattern largely overlaps with known socially vulnerable areas, while bringing forward areas that receive less attention in relation to inequality in opportunities. The pattern of access inequality is used to evaluate distributive and procedural justice.

Distributive justice

Distributive justice is concerned with the fair allocation of well-being, spatial energy goods and future opportunities through society and space. The distributive nature behind these factors is conceptualised through societal factors, regarding public policies, social norms and power dynamics. For each factor, the distribution through society is evaluated across the four quartiles of socio-spatial vulnerability, and the distribution through space by comparing spatial patterns.

Distribution of well-being. The spatial patterns of lower well-being outcomes regarding energy poverty, livability, socio-economic status and health, follow similar spatial patterns, overlapping with The Hague Zuidwest, Schilderswijk and surroundings, and Laakkwartier. In our interpretation, these distributive patterns of well-being are caused by structural dynamics that (re)produce patterns of inequality. We recognise that these places might be systematically disadvantaged, assuming that the causes lie in the lack of local agency in power dynamics and the misrepresentation of local needs in public policies. The pattern in lower well-being outcomes largely overlaps with higher vulnerability in accessing opportunities in the heating transition. Therefore, we argue for creating policies that address the structural drivers behind patterns of inequality, rather than distributing spatial energy goods.

Distribution of spatial energy goods. To evaluate who and where already has access to clean energy technologies, we consider the distribution of district heating, heat pumps, gas-free solutions, and solar PV. Due to the nature of the technologies and policies that incentivised adaptation of technologies, different spatial patterns emerge per technology, intersecting with vulnerability in access. There is a clear distinction between individual solutions (e.g., heat pumps and solar PV), with higher adaptation among the less vulnerable population. District heating is more fairly distributed across society and space, although vulnerable private renters and homeowners are prone to be excluded, as transition efforts are primarily made by housing corporations.

Distribution of future opportunities. People experience higher freedom in access to the heating transition when societal factors align with the issue at stake. We evaluate these factors along the lines of public policies (heating transition vision, sustainability targets housing corporations) and social norms (willingness to take energy transition measures, presence of local energy cooperatives). Public policies reach the more vulnerable localities, while the patterns of social norms largely follow a contrasting pattern.

Procedural justice

Procedural justice is concerned with fairness in the opportunity to participate in the decision-making process, no matter where you live or who you are. This expands the societal factors, as recognition in public policies and agency in power dynamics is enhanced. To achieve procedural justice, we first design policy rationales, then evaluate them on effectiveness, and what is needed to foster collective citizen engagement.

Policy rationales and policy catchment areas. Based on used indicators for distributive justice, six policy rationales are defined. The first three policy rationales are considered business-as-usual: implement The Hague's Heating Transition Vision, provide individual subsidies and support local energy cooperatives. We propose three alternative rationales: link efforts with housing corporations, activate willing residents, and alleviate energy poverty. Policy effects are often underpinned by spatiality, and therefore are catchment areas defined for each policy rationale. Through spatial intersections of vulnerability in access and the policy catchment areas, is found that each policy rationale covers vulnerable localities to varying extents. .

Evaluative framework for policy rationales. Each policy is evaluated on effectiveness in covering vulnerability in access, potential decarbonisation (gas usage) and investment needed (insulation upgrades and new heating source). This is done on the aggregated municipal level and the disaggregated balance through space. We find two approaches to be the most effective in covering vulnerability city-wide: *link efforts with housing corporations* and *alleviate energy poverty*. For both rationales, the decarbonisation potential per dwelling is slightly lower than The Hague's median, due to smaller dwelling types requiring less energy for heating, paired with lower investment. Figure 1 presents how the three indicators are balanced through space.

(a) Policy rationale: Link efforts with housing corporations

(b) Policy rationale: Alleviate energy poverty

Figure 1: Spatial balance between vulnerability, decarbonisation and investment for two selected policy rationales. Localities coloured orange, brown and grey represent cost-effective decarbonisation, while covering vulnerability.

Collective citizen engagement factors. As meaningful citizen engagement is considered to be a key factor in the success of the heating transition, it is evaluated which factors are in place that foster collective decarbonisation efforts. Generally, these factors relate to the presence of local energy co-operatives, financial capacity and (digital) communication structures. It is found that these factors are on the lower side when there are no energy cooperatives or housing corporations present.

Synthesis and concluding remarks

Three overarching conclusions are derived that enhance local residents' capabilities, to achieve a more just heating transition. These conclusions serve as the basis for the policy recommendations.

Overarching conclusions

1. Policy tools are lacking that make the heating transition accessible for more vulnerable homeowners and private renters. Thereby, in administrative area-based approaches, local realities can be overlooked, leading to insufficient consideration of local vulnerabilities.
2. Distributing opportunities that enhance access to the heating transition, over the fair distribution of spatial energy goods, can contribute to bending dynamics that cause socio-spatial inequalities. To achieve this, special attention needs to be given to the nature of public policies, local social norms, prioritised demands of justice, and local agency in power dynamics.
3. Local energy cooperatives contribute to collective decarbonisation efforts while guaranteeing local agency regarding public policies, shaping social norms and engaging in power dynamics. This factor could contribute significantly to improving vulnerable communities' access to opportunities in the heating transition.

Recommendations for policy making

1. Link policy resources with the efforts of housing corporations to include surrounding homeowners and private renters in the heating transition, as properties of housing corporations are often located in vulnerable places.
2. Treat the heating transition as an opportunity to structurally alleviate disadvantaged areas, that foster local agency in order to bend structural dynamics that (re)produce patterns of inequality.
3. Initiate local energy cooperatives in vulnerable areas of The Hague to foster local agency and alleviate local barriers (e.g., social norms towards issue, inability to make individual investments).

Given the limitations in this research and possibilities for the framework to be applied in different contexts, distilled *recommendations for future research* are:

- *Revisit the conceptualisation of the energy justice dimensions from other academic fields*. New conceptualisations bring forward new perspectives on how to enhance local residents' capabilities and create new understandings of structural drivers that (re)produce patterns of inequality.
- *Approach procedural justice first*. This provides a starting point to create an understanding of localised societal freedom factors, capturing local agency regarding public policies, social norms and power dynamics.
- *Redefine the spatial unit of analysis from localities to communities*. Spatial communities based on social coherence as an analytical unit will open up exploration of collective citizen engagement in transitions, as the key factor for fostering local needs and well-being.
- *Uncover patterns of inequality in opportunities and barriers for different spatial fields*. As our cities are shaped by a wide variety of structural dynamics, it is relevant to apply similar approaches to understand the accumulation of injustices, for instance regarding climate, housing and transport, and how these fields might interact with each other.

Contents

1 Introduction

In the face of climate change, the world, countries, regions and cities need to decarbonise. This brought energy transitions to the top of the political agenda (Sequeira et al., 2024), including the heating transition of the residential built environment. As socio-spatial inequalities in European and non-European cities are increasing (Cassiers and Kesteloot, 2012), transition measures should address the complex dynamics that (re)produce patterns of socio-spatial inequality (Bouzarovski and Simcock, 2017; Garvey et al., 2022). Doing this for the heating transition is especially relevant, being intertwined with housing affordability, adequate housing and resilience to climate change. Thereby, equitable access to clean, reliable and affordable energy enhances well-being outcomes, as access to energy enables one to achieve other goals (Melin et al., 2021).

The challenge of the heating transition of the residential built environment. About 25% of all gas in The Netherlands is used by households (Centraal Bureau voor de Statistiek, 2022a). In 2019, 92% of the dwellings had a central heating system or block heating, connected to the gas network (Centraal Bureau voor de Statistiek, 2021b). In the same year, about three-quarters of the natural gas used in the residential sector was used for heating the home (Centraal Bureau voor de Statistiek, 2018). There is a lot of potential for energy savings and replacing heating systems operating on gas. In the Dutch context, the primary heating alternatives are district heating, heat pumps, and possibly hydrogen for the most complex built environment. Generally, the heating transition is approached as technically complex, lacking sensitivity to the social implications. Planning the heating transition is primarily guided by technical and economical feasibility, using tools such as the spatial energy model for the built environment, developed by Planbureau voor de Leefomgeving (2012). Such models fail to address the socio-spatial inequalities in the heating transition and underestimate the engagement of local residents, a key factor for success (Beauchampet and Walsh, 2021). It is therefore socially relevant to approach the issue holistically and to include justice aspects.

Increasing concern of energy poverty. As energy prices have been rapidly rising and awareness of growing inequalities, concerns about energy poverty have emerged in The Netherlands (Mulder et al., 2023). Mulder et al. (2023) found that 7% of the Dutch households are energy poor, in terms of energy affordability of energy efficiency of the home. In addition, Mulder et al. (2023) found that 48% of the households cannot participate in the energy transition by themselves, being renters or having insufficient financial resources. Until recently, the problem of excessive energy bills was treated as an issue related to income poverty, ignoring the multifaceted drivers and outcomes of energy poverty (Mulder et al., 2023). While the inability to pay the energy bill is an important aspect of energy poverty, it ignores the roots of the problem. Sociodemographic and built environment characteristics contribute to higher socio-spatial vulnerability to energy poverty, besides energy-efficiency of dwellings, financial capacity and home ownership (Robinson et al., 2019)

Decarbonisation as individual responsibility. Despite the fact that almost half of the households cannot participate in the heating transition, is the responsibility of decarbonisation within urban areas often put on individuals, where governmental agencies provide subsidies to individual households for renovating their houses or adopting new heating sources. Such self-referral approaches have led to socio-spatial patterns of exclusion of vulnerable population groups (Nordholm and Sareen, 2021; Reames, 2016), by neglecting the diverse needs and vulnerabilities of citizens, particularly those with limited access to resources for participation. Reames (2016) suggests that proactive area- or community-based targeting may be more effective in increasing residential energy efficiency fairly, given the spatial concentration of vulnerable block groups. Therefore, empowering citizens to adopt decarbonisation solutions collectively is desirable to ensure that nobody is left behind in the decarbonisation process (Carley and Konisky, 2020).

Policy context. The European Union, The Netherlands and Dutch municipalities have developed strategies and action plans for enabling the heating transition in a just way, consisting of plans for insulation, heating and energy poverty. While these plans overlap and have co-benefits, it's complex to tie these aspects together, due to the differences in technical potential, social acceptance and cost-effectiveness.

Research aim. This research seeks to uncover socio-spatial inequality in access to opportunities in the heating transition. By shifting the focus from spatial goods to access to opportunities, we address the roots of why people are vulnerable to being left behind in the decarbonisation process. We employ energy justice, enriched with spatial and capability thinking, as conceptual framework. We use computational modelling to uncover spatial disparities in access for The Hague. In a nutshell, this research uncovers patterns of local vulnerability in access to opportunities in the heating transition (*recognition justice*), evaluates how spatial patterns of vulnerability relate to the spatial distribution of well-being, adaptation of clean energy technologies and future opportunities (*distributive justice*), and evaluates policies on effectiveness to alleviate spatial inequalities while decarbonising (*procedural justice*).

Case study: The Hague. The city of The Hague in The Netherlands is used as a case study to uncover patterns of inequality in access to opportunities in the heating transition. The Hague is an especially interesting case study city being the 3rd city in the Netherlands in terms of population size, with around 550,000 residents. The coastal location of The Hague and its proximity to the Westland greenhouses and industrial areas of the Rotterdam port positions the city uniquely for technical opportunities in the heating transition. The diverse population of The Hague, existing of Hagenezen and Hagenaren, new and long-term residents, students, public servants, and a large international population, give an interesting social dimension to the heating transition.

Report outline. This report is structured as follows. In chapter 2, background literature is presented where energy justice is introduced from a spatial & capability thinking perspective. In chapter 3, an extensive research approach is introduced to find patterns of socio-spatial inequality. The results are given in chapter 4. The conclusion, discussion and future directions are presented in chapter 5.

2
Background literature

Considering justice aspects while creating policies for shaping the heating transition, is essential to help decision-makers make informed choices that effectively address the causes of energy poverty, and what makes people vulnerable to being left behind in the energy transition (Bouzarovski and Simcock, 2017). This research seeks to address the concept of energy justice by adopting a holistic and spatially sensitive approach, enriched by capability-thinking. Firstly, the three underlying theories of justice are discussed (2.1). Secondly, we're interested in the factors affecting access to the heating transition, to understand what drives inequality (2.2). Thereafter, we discuss the three dimensions of energy justice in more detail - recognition (2.3.1), distributive (2.3.2) and procedural (2.3.3). Finally, the background literature is synthesised in the conceptualisation (2.5).

2.1. Theories of justice

From a social justice perspective, policies must ensure that marginalised and disadvantaged groups are included in societal benefits to create a fair and equitable society. The discourse of social justice has developed over centuries and continues to evolve, addressing contemporary challenges or expanding theories with new dimensions and considerations. This provides a variety of perspectives and possibilities for defining fairness and justice in the heating transition context, of which we selected:

- *Energy justice*, given the elaborate application in analysing fairness in energy transitions, systems and policies;
- *Spatial justice*, as the heating transition unfolds in urban environments that are shaped by complex spatial processes;
- *Capability approach*, as the heating transition affects people's daily life, and participation is a key factor for the success of the heating transition.

This research seeks to approach justice in the heating transition at the intersection of energy justice, spatial justice and the capability approach, a three-theory cross-over not earlier explored or applied. Generally, the theories are shaped and applied in independent academic disciplines. Only recently, researchers explored two-theory cross-overs, providing unique interdisciplinary perspectives. An overview of theories and cross-overs is presented in figure 3.1.

- In *Spatializing energy justice*, Bouzarovski and Simcock (2017) introduce the spatial dimension to understandings of energy justice, bringing forward geographical underpinnings of energy inequalities, such as energy poverty;
- In the *Special Issue on Energy Justice and the Capability Approach*, Melin et al. (2021) explore the application and benefits of the capability approach to the field of energy justice, and find enhanced understanding of the multidimensional impacts of energy poverty and its socio-material nature.

- Recent literature on spatial justice shifts the focus from spatial goods to opportunities (Hananel and Berechman, 2016; Nordberg, 2020). Conversely, the capability approach is applied directly to urban contexts and processes (Basta, 2015; Frediani, 2021). Both approaches bring a socially oriented perspective to city-making.

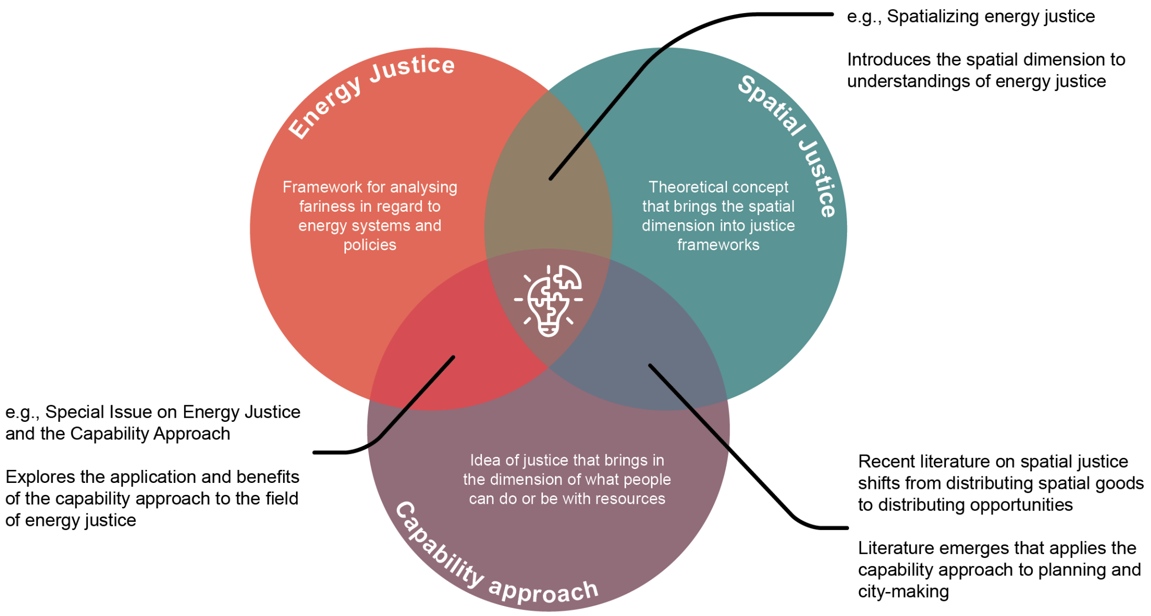


Figure 2.1: Theory diagram presenting the three selected theories of justice, and interdisciplinary applications. Previous research combined two out of three perspectives. We contribute to academica by combining three theories as a guiding framework.

Without considering the spatiality of energy justice, the focus lies on differences between social groups, and not on how this differs through space. Bouzarovski and Simcock (2017) present evidence that spatial differences in vulnerability to energy poverty are not the result of individual choices, but emerge from structural spatial inequities, present throughout the whole energy system. Therefore, to achieve a just heating transition, the underlying structural dynamics should be analysed that (re)produce patterns of injustice (Bouzarovski and Simcock, 2017; Garvey et al., 2022; Soja, 2010). In the capability approach language, these dynamics affect the capabilities and opportunities of people. This brings us to conceptualise the energy justice dimensions with the spatiality of factors that affect people's opportunities in the heating transition.

2.2. Access to opportunities in the heating transition

Similarly to Kraaijvanger et al. (2023), our interest is in people's freedom to access opportunities and enable them to decide whether to participate. This aligns with capability thinking, where control over one's environment is an important capability, and the focus on opportunities over spatial energy goods (Hananel and Berechman, 2016; Nordberg, 2020). We define access similar to Kraaijvanger et al. (2023), using Burns (1979)'s definition: "the freedom of individuals to decide whether or not to participate in different activities".

Where Kraaijvanger et al. (2023) employ the Theory of Planned Behaviour to determine if the action of adopting solar PV is accessible, we use a concept from the capability approach that is similar to perceived behavioural control: 'conversion factors', which reflect the 'conditions that influence the freedom people have to convert resources into a functioning' (Frediani, 2021), with functionings being the variety of 'goods, services, activities and positions that a person would like to consume, undertake, or be' (Hananel and Berechman, 2016). We refer to this concept as 'freedom factors', to avoid confusion with energy conversion.

The freedom factors provide a structured approach to conceptualise the three dimensions of energy justice, which is further elaborated on in the next section. Generally, the factors are classified into three types: personal, societal and environmental (Frediani, 2021; Robeyns and Byskov, 2023):

- **Personal freedom factors**:
  - Relate to personal abilities, capacities and skills to use a particular resource, and are internal to the person (Frediani, 2021; Robeyns and Byskov, 2023).
  - For example: Do people have the finances, authority and knowledge for insulation upgrades or changing heating sources, and could they access subsidies for that?
- **Societal freedom factors**:
  - Relate to the society one lives in, consisting of public policies, social norms, and power relations (Frediani, 2021; Robeyns and Byskov, 2023).
  - For example: Are there subsidies available for making energy upgrades to the home? And is changing heating systems socially acceptable?
- **Environmental freedom factors**:
  - Relate to the geographical area where one lives, where the built environment characteristics play a role in the possibilities available (Frediani, 2021; Robeyns and Byskov, 2023).
  - For example: Are there heating sources and/or systems available close by? And is making changes effective, looking at the built density, building types and current energy efficiency of the dwellings?

2.3. Dimensions of energy justice

For each dimension of energy justice, different types of freedom factors are emphasized. Regarding recognition justice (2.3.1), we are interested in personal and environmental factors as people are unique and have diverse needs, abilities, capacities and skills to participate in the heating transition. Thereby, their home location provides different opportunities and barriers through the built environment. As energy decision-making cannot change personal or environmental characteristics, efforts to enhance justice in the heating transition focus on societal factors. Therefore, distributive justice (2.3.2) is conceptualised concerning public policies, social norms and power dynamics to reflect on disparities in societal freedoms. Procedural justice (2.3.3) explores how societal freedom factors can be enhanced, and whether policies are effective in reaching vulnerable groups.

2.3.1. Recognition justice

Recognition in the *context of energy justice* covers broadly two efforts to foster just outcomes: (1) Acknowledgement of historic and ongoing inequalities, that have shaped the identities, histories, and power dynamics (Bouzarovski and Simcock, 2017; Carley and Konisky, 2020; Garvey et al., 2022), and (2) Efforts to reduce inequalities and energy poverty and ensuring equal opportunities in the transition (Carley and Konisky, 2020; Mulder et al., 2023). Applying *spatial thinking* to this context, recognise therefore that (1) Places and communities have their own local identities, which may shape the access and acceptability of transition measures (Garvey et al., 2022), and that (2) Some places are more vulnerable than others (Bouzarovski and Simcock, 2017). *Capability thinking* is sensitive to such spatial contextual diversity, and asks the question of what people can do or be with, for instance, opportunities related to the heating transition to improve their welfare (Frediani, 2021), particularly considering the disadvantaged (Hananel and Berechman, 2016).

As local characteristics influence the freedom in access to opportunities, some places are more vulnerable to being left behind in the decarbonisation process. Therefore, the aim for recognition is to *uncover socio-spatial vulnerability*, where we first discuss the spatial scale of recognising vulnerabilities, followed by what vulnerability entails.

Recognising local realities

Heating transition plans are made neighbourhood by neighbourhood, developing the district heating network street by street, and insulating house by house. The nature of these efforts allows us to consider a smaller spatial scale, making efforts to find local realities that otherwise could be overlooked in the policy-making process, as municipalities often allocate their resources based on neighbourhood-level information.

Local realities are not necessarily defined by administrative boundaries, since for example within administrative neighbourhoods the built environment could differ, with building blocks built in different time periods, with different building heights, densities and styles. Also, some areas might be more mixed-use, with local shopping streets, industrial sites, or other functions. On the social side, could home-ownership structures differ through administrative zones, as housing corporations could have properties close to each other in a part of it, and in other areas there might be only bought houses or more mixed situations. Also, environmental barriers could play a role in different social groups living in different areas, like on other sides of a river or main roads. Thereby, such local realities might exist crossing administrative zones.

Bringing the above together, multiple local realities could exist within administrative zones and could cross various zones. As different local realities exist, with different environmental and personal freedom factors (described in section 2.2), these localities experience different levels of freedom in accessing opportunities in the heating transition, which is further elaborated on in the next section.

Socio-spatial vulnerability in access to opportunities

Achieving recognition justice entails ensuring equal opportunities in the heating transition and reducing inequalities and energy poverty (Carley and Konisky, 2020; Mulder et al., 2023). We define socio-spatial vulnerability in the heating transition in terms of access to opportunities, as we're concerned with enhancing the capabilities needed to participate in the heating transition. Bouzarovski and Simcock (2017) describe that spatial differences in (vulnerability to) energy poverty are not caused by variations of individual 'choices', but do result from structural geographical inequalities in various stages of the energy systems, as well as the 'infrastructural, economic, and cultural make-up of societies'. We, therefore, examine the multidimensional drivers that underlie processes that make people vulnerable to being left behind in the decarbonisation process. The literature on vulnerability to energy poverty serves as a base, adapted to the Dutch heating transition context.

Multifaceted nature of energy poverty. Energy poverty, defined as the inability of households to afford energy, such as heating, is seen as a major energy justice concern (Bouzarovski and Simcock, 2017; Reames, 2016). While this definition makes it seem that an excessive energy bill is an issue related to income poverty, it shouldn't be neglected that the problem is multifaceted in causes and outcomes (Mulder et al., 2023). The combination of low incomes, high energy bills and energy-inefficient housing could, even in wealthy countries, lead to harmful social effects, such as health issues, accumulated utility debts, loneliness, uncomfortable indoor temperatures and material deprivation (Mulder et al., 2023; Reames, 2016) - and thus negatively influences the freedom people to be healthy, debt free, and included in society.

Capturing energy poverty. Efforts are made to capture energy poverty on the household level, such as Mulder et al. (2023) did in the Dutch context, measuring: (i) the affordability of energy, (ii) the energy-efficiency of houses and (iii) households' ability to participate in the energy transition, in terms of inability to invest in renovation. Capturing energy poverty with measures focusing on income, efficiency and price neglects other socio-spatial vulnerabilities and failures to capture diverse vulnerability dimensions evident in wider energy poverty research (Robinson et al., 2017). Thereby, measuring energy poverty at the aggregated household level masks the vulnerabilities of individuals within those households (Pelz et al., 2018). Vulnerability factors that could lead (in)directly to energy poverty and a loss of well-being, internal and external of the home, relate for instance to: energy efficiency, access, financial capacity, energy-related needs and practises, energy prices, social networks, precarity of housing, and welfare and state support (Robinson et al., 2019). The research by Robinson et al. (2019) identifies a diverse range of indicators and associated vulnerability factors and found that by applying a spatialised approach, those hidden localised vulnerabilities could be exposed.

Access to opportunities in the heating transition. A lack of access contributes to energy poverty and a loss of well-being, due to 'inability to access appropriate fuel types' and the inability 'to benefit from new technologies' (Robinson et al., 2019). We argue that limited freedom for decicing to participate, also leads to a loss of well-being as one lacks behavioural control. The vulnerability in access to heating transition opportunities entails thus more than vulnerability to energy poverty. We therefore measure the level of opportunity (thus, access to opportunities) as the socio-spatial vulnerability indicator, 'not only by income or property ownership, but also by non-income factors' (Hananel and Berechman (2016)).

2.3.2. Distributive justice

Distribution in the *context of energy justice* covers the fairness in the distribution of resources, benefits and burdens across society (Bouzarovski and Simcock, 2017; Carley and Konisky, 2020; Garvey et al., 2022), and thus that everyone can access affordable, reliable and clean energy services (Mulder et al., 2023). Applying *spatial thinking* to this context, acknowledges that distributions could be uneven across space, possibly intersecting with existing inequalities or (re)enforcing them, due to underlying mechanisms (Bouzarovski and Simcock, 2017; Garvey et al., 2022; Nordberg, 2020). *Capability thinking* is inherently distributive, shifting the focus from distributing spatial goods to enhancing opportunities for participation (Basta, 2015; Frediani, 2021). Therefore, we aim to *find multidimensional socio-spatial disparities*, in burdens, benefits and opportunities.

The distribution of benefits, burdens and opportunities is interpreted through societal freedoms, encompassing public policies, social norms and power dynamics. We use these factors to understand how well-being, spatial energy goods and future opportunities are distributed through society and space, and how disparities in societal freedoms contribute to this. We use well-being indicators to uncover wider patterns of inequality and which areas might have been overlooked (burdens). We use the adaptation of spatial energy goods to evaluate who and where already realised access (benefits). We explore resources for change through public policies and social norms (opportunities).

Importance of well-being

The capability approach is concerned with the distributive effects of opportunities that enable people to achieve well-being (Frediani, 2021). Well-being is a broad concept, and describes a state of overall health, happiness, and life satisfaction, with definitions varying across disciplines. Although a clear definition is lacking, there is consensus on the multidimensional character of the concept (Boelhouwer, 2010). By considering how well-being is distributed, a strong emphasis is placed on the multifaceted societal outcomes of people living with energy poverty, which encompasses for instance health issues, loneliness and debts (Mulder et al., 2023). A spatial intervention as the heating transition could improve livability and health outcomes locally, and thus improve well-being.

Adaptation of spatial energy goods

The adaptation of different energy goods is incentivised by different policies and the nature of these energy goods, and thus also who has been able to access them. When considering the existing built environment, individuals can make use of subsidies to purchase solar panels or a heat pump, and they are responsible themselves for installation. District heating requires enough density of houses to be connected to the network, to make the project feasible. Since housing corporations are incentivised by sustainable targets set by the central government and have large housing stocks, they seek the help of heating providers to make their properties more sustainable. It is assumed that individual households have so far lacked access to district heating, as they fall out of the scope of projects led by housing corporations. For newer and future urban developments, often clean energy technologies are incorporated in the planning process, with the people moving in thus having access to them.

Distribution of future opportunities

Opportunities in the heating transition are primarily created by changes in societal freedom factors, as local factors regarding sociodemographics and the built environment only change over longer periods. We identify two societal factors that align with enhancing access to opportunities in the heating transition: the availability of public policies and social norms aligned with the issue at stake.

Public policies. Given the urgency to decarbonise the existing built environment, public policies such as heating transition visions are in place, with more in the making (neighbourhood implementation plans) or effective soon (Warmtewet).

Social norms. As public engagement is a key factor in the success of the heating transition (Beauchampet and Walsh, 2021), behavioural aspects towards the issue at stake are relevant to consider. Social norms contribute to the adoption of new technologies and making insulation upgrades, given the Theory of Planned Behaviour (Kraaijvanger et al., 2023).

2.3.3. Procedural justice

Procedural justice in the *context of energy justice* refers to the fairness in the opportunity to participate in the decision-making process (Bouzarovski and Simcock, 2017; Carley and Konisky, 2020; Garvey et al., 2022; Mulder et al., 2023). Applying *spatial thinking* is acknowledging that in certain places, there might be less engagement, or opportunity to engage, in decision-making (Garvey et al., 2022). In *capability thinking*, having political control over one's environment is an important capability (Hananel and Berechman, 2016), where people can participate effectively in the choices affecting one's life. And therefore, there should be proactively reached out to vulnerable voices and local communities, to expand their agency (Basta, 2015; Frediani, 2021). Therefore, we aim to *identify effective policies and resources*, that enhance fairness in decision-making and distribution of resources.

The fairness in decision-making and distribution of resources is interpreted with societal factors, with a focus on enhancing freedoms through public policies, social norms and power dynamics. Therefore, first, a reflection is given on how resources can be allocated. Then, factors for effective collective citizen engagement are presented.

Policy evaluation

It is a municipal task to allocate resources effectively, with decisions often based on technical and economic feasibility. In doing so, resources are distributed from a utilitarian point of view, missing sensitivity to the socio-spatial distribution of benefits, and disregarding individual diversity and actual needs of residents (Hananel and Berechman, 2016). This (re)enforces existing patterns of inequality. To achieve a just heating transition, proactive efforts need to be made to reduce inequalities, energy poverty and differences in opportunities (Carley and Konisky, 2020; Mulder et al., 2023). By employing a framework that incorporates both social and spatial dimensions besides the normally nonspatial technical and economic indicators, the fairness in resource allocation is improved.

Effective collective citizen engagement

Meaningful public engagement is a key factor in the success of the heating transition, and achieving that is a complex challenge. This is due to the nature of the technological solutions central to this research and the Dutch heating transition, district heating and heat pumps, as they do not offer the same opportunities for actively engaging individual households in the energy transition and thus fostering energy citizenship (Beauchampet and Walsh, 2021). Beauchampet and Walsh (2021) describe all-electric approaches as socially exclusive, as they require high investment costs, but found active citizen engagement as people consciously choose a heat pump. In contrast, they found district heating to be socially inclusive, while citizen engagement is passive due to the centralized and distant top-down policies. Although, this could be mitigated by developing local energy co-operatives.

Where Beauchampet and Walsh (2021) argue that those two contrasting ends are not mutually exclusive, and that a mix could be a sustainable option to move forward in the heating transition. Given this, we focus on community energy initiatives, that capture 1) active citizen engagement, 2) collective efforts enhancing social inclusion, and 3) local communities, embedding the use of the concept in our spatialised approach. Community energy initiatives are recognised by researchers and policymakers for their importance in the heating transition, promoting local ownership and citizen participation (Teladia and Van Der Windt, 2024). The research by Teladia and Van Der Windt (2024) explores the challenges and processes of local ownership and participation in community energy initiatives, and identifies factors that enhance successful citizen engagement: an enabling participatory environment, inclusive participation, information sharing and the presence of energy cooperatives.

Although the factors are comprehensive, and successfully used to analyse engagement in local community energy initiatives, they are not directly actionable in our context as we are concerned with residents in a locality, unrelated to community structures. With taking the factors of Teladia and Van Der Windt (2024) as inspiration, we consider three practical resources that foster collective citizen engagement: the presence of local energy cooperatives, financial capacity (of households), and (digital) communication structures).

- **Presence of local energy cooperatives**

The presence of local energy cooperatives is used as it is considered a success factor for active citizen engagement in the heating transition, promoting local ownership and citizen participation (Teladia and Van Der Windt, 2024; Beauchampet and Walsh, 2021). Such participation is not without first reaching a social tipping point, where the attitudes (values and beliefs), social norms (collective and individual) and behaviours align with the heating transition task at hand. Djinlev and Pearce (2024) describe how collective actions, such as taking part in energy communities, are ”effective means to reach a social tipping point, with individuals and local organisations acting as catalysts”. Reaching the social tipping point would enhance the social freedom factors of localities, where otherwise social norms could decrease the freedom local residents have in accessing opportunities in the heating transition.

When resources are low in regards to the presence of local energy cooperatives, the implication for policymaking is initiating local energy co-operatives (or other local energy communities). The development of energy co-operatives depends on local factors, and is not a one-size-fits-all. that the diverse nature of local factors ”makes it challenging to draw generalisable conclusions about how community energy initiatives engage local residents in energy projects”, with the local factors relating to ”the project design, local needs, technology, scale, social settings, levens of engagement, types of home ownership, and motivations for participation” (Teladia and Van Der Windt, 2024). From another perspective, Geskus et al. (2024) explored the role of social capital in fostering energy cooperatives, shedding new light on the importance of local community ties (bonding social capital) to boost energy cooperatives.

- **Individual financial capacity**

Among the main barriers to the participation of households is the cost of clean heating alternatives (Beauchampet and Walsh, 2021). Logically, the inability to invest in renovation and changing heating systems, lowers access to the heating transition. When individual households cannot make a financial contribution or cannot access subsidies, it leaves them vulnerable. Therefore, individual financial capacity is relevant to incorporate.

When individual financial capacity is insufficient and not (partly) collectively organised, the implication for policymaking is to create accessible funding structures. Although there are several subsidies in place, they are not accessible to everyone, given barriers such as language, knowledge, paying upfront or a borrowing structure.

- **(Digital) communication structures**

Transparent (digital) communication structures are important for sharing information and receiving feedback. The latter enables the inclusion of broader community perspectives into the project design (Teladia and Van Der Windt, 2024), crucial for local support as citizens need to make substantial changes to their home environment. In addition, local knowledge improves municipal plans, as local citizens identify local issues and provide new ideas (Beauchampet and Walsh, 2021).

Iterative dialogue between local citizens and powerful stakeholders (e.g., planners and developers), timely communication, meaningful consultation and public dialogues are effective in increasing local engagement with, and the acceptance of, energy transition projects (Beauchampet and Walsh, 2021). We therefore argue that clear, transparent and bidirectional communication improves the power dynamics between communities and powerful actors, enhancing local societal freedoms.

Communication structures, digital and non-digital, enable long-term communication and engagement strategies. The implication for policymakers is to include designing accessible and transparent communication structures that fit local residents' needs (e.g., language and digital skills) and fostering community communication and feedback mechanisms.

Role of municipalities
Local governments have a critical role in pushing the heating transition, having political, administrative and economic resources available (Schmieder et al., 2023). In The Netherlands, municipalities have the directing role in coordinating and facilitating the heating transition, and implementing policies from the central government (Beauchampet and Walsh, 2021). The Hague describes their responsibility for

setting the energy transition framework, with the role depending on what is needed in specific situations. Roles therefore vary from driving force, determiner of preconditions, guardian of the public interest, director, (partial) financier and executor (Den Haag, 2022).

The Hague does not touch on brokering citizen engagement, while this is a key aspect for the success of the heating transition. In the guiding principles, The Hague describes the involvement of local residents in the making of the implementation plans. In both top-down (development of heating policies) and bottom-up (involvement in community energy initiatives) situations, supporting and incorporating citizen engagement enhances participation in the transition towards a gas-free built environment:

- *Top-down*: By integrating citizen engagement in the heating transition plans (from conceptualisation to completion), the acceptance and adaptation of the clean alternatives is increased (Beauchampet and Walsh, 2021).
- *Bottom-up*: Active involvement of local governments in community energy initiatives increases participation rates (Teladia and Van Der Windt, 2024). Successful initiatives are fostered by trust between local policymakers, initiatives and local residents, developed action plans, and policymakers' professional networks to acquire resources (Hoppe et al., 2015).

2.4. Policy rationales

The Hague's Heating Transition Vision is not created to address ongoing inequalities or disparities in opportunity. As our notion of justice is concerned with lowering inequalities, we aim to evaluate policy approaches that prioritise vulnerable groups. Therefore, we consider three business-as-usual policy rationales: implement heating transition vision, provide individual subsidies and support local energy cooperatives, and three alternatives: link with housing corporations, activate willing residents and alleviate energy poverty.

- **Implement Heating Transition Vision**

The Hague shaped their Heating Transition Vision in collaboration with a variety of parties in the city, combining insights from participation with technical information to arrive at their neighbourhood vision for clean heating solutions. They defined guiding principles for the next steps, with one of them being: *Putting not technology but the impact for people central (social transition)*. They acknowledge that the energy transition is often viewed through a technical lens, but also provides social benefits although their policy assumes a general population, and has no mention of energy poverty or other injustices.

- **Provide individual subsidies**

Individual subsidies lean on a market-oriented approach and are widely available. Typically, these policies tend to benefit households that are already in a position to make the transition, often at the expense of groups facing additional barriers, such as high upfront costs or limited access to the relevant information. As a result, such subsidies, while beneficial to specific individuals, result in (re)enforcing socio-spatial inequalities and do not allow for systemic changes.

- **Support local energy cooperatives**

The promotion of local energy cooperatives can be seen as a progressive policy, fostering procedural justice through collective ownership and active citizen engagement. With considering the spatial dimension, it is evaluated whether access to these policies is fair, or that areas are left behind.

- **Link with housing corporations**

Housing corporations have an active role in the heating transition, acting on financial incentives and sustainability targets set by the central government for social housing. Although they are a catalyst in the heating transition, their resources and interests are not linked to municipal policy. They are only responsible for their own housing stock, and not for surrounding dwellings. And despite these developments, Mulder et al. (2023) found that 'about 75% of the energy poor households live in a dwelling owned by a social housing corporation'.

By linking heating transition projects of housing corporations with municipality plans, municipalities could support surrounding residents as a co-opportunity to accelerate the heating transition in these areas.

- **Activate willing residents**

As there might be a gap between people willing to take energy transition measures and their freedom to do so, the rationale of engaging with willing areas is based on the fulfilment of their desires. The expectation is that such areas are likely to have a high social acceptance of technological changes in their living environment, having an easier realisation of the engagement needed for a successful heating transition in those areas.

- **Alleviate energy poverty**

Energy poverty is seen as an unjust outcome, with some policies of the central government aiming to alleviate this phenomenon. By actively allocating municipal resources to neighbourhoods where energy poverty is more prevalent, the people that experience the highest burden of the energy system, are helped effectively and unwanted social side effects caused by energy poverty are remedied.

2.5. Conceptualisation

Each of the energy justice dimensions is explored through the lens of key spatial justice and the capability approach, offering a comprehensive foundation for understanding how to achieve a just heating transition. These notions serve as conceptualisation of how the dimensions of energy justice are addressed to create new insights for The Hague using spatial data analysis. In figure 2.2 the aim for each dimension is presented, including relations between the elements and the position of policy rationales.

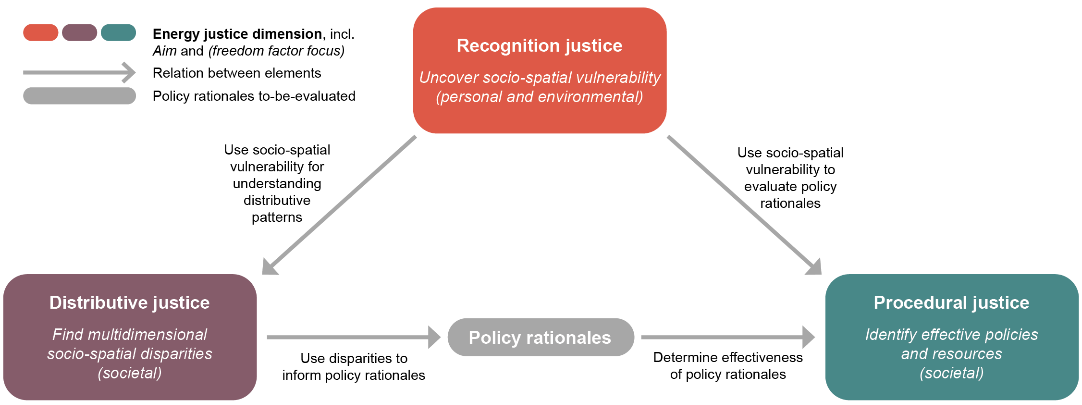


Figure 2.2: Conceptual diagram, representing relations between the energy justice dimensions and policy rationales. For dimension, the aim and freedom factor focus are presented.

3

Research approach

This chapter outlines the research approach to address the three dimensions of energy justice, as presented in figure 3.1. Section 3.1 presents the data collection and dataset creation process. Section 3.2 describes the approach for finding local realities. Section 3.3 explains how the distribution of barriers, benefits and opportunities is examined. Section 3.4 outlines how policy rationales are evaluated.

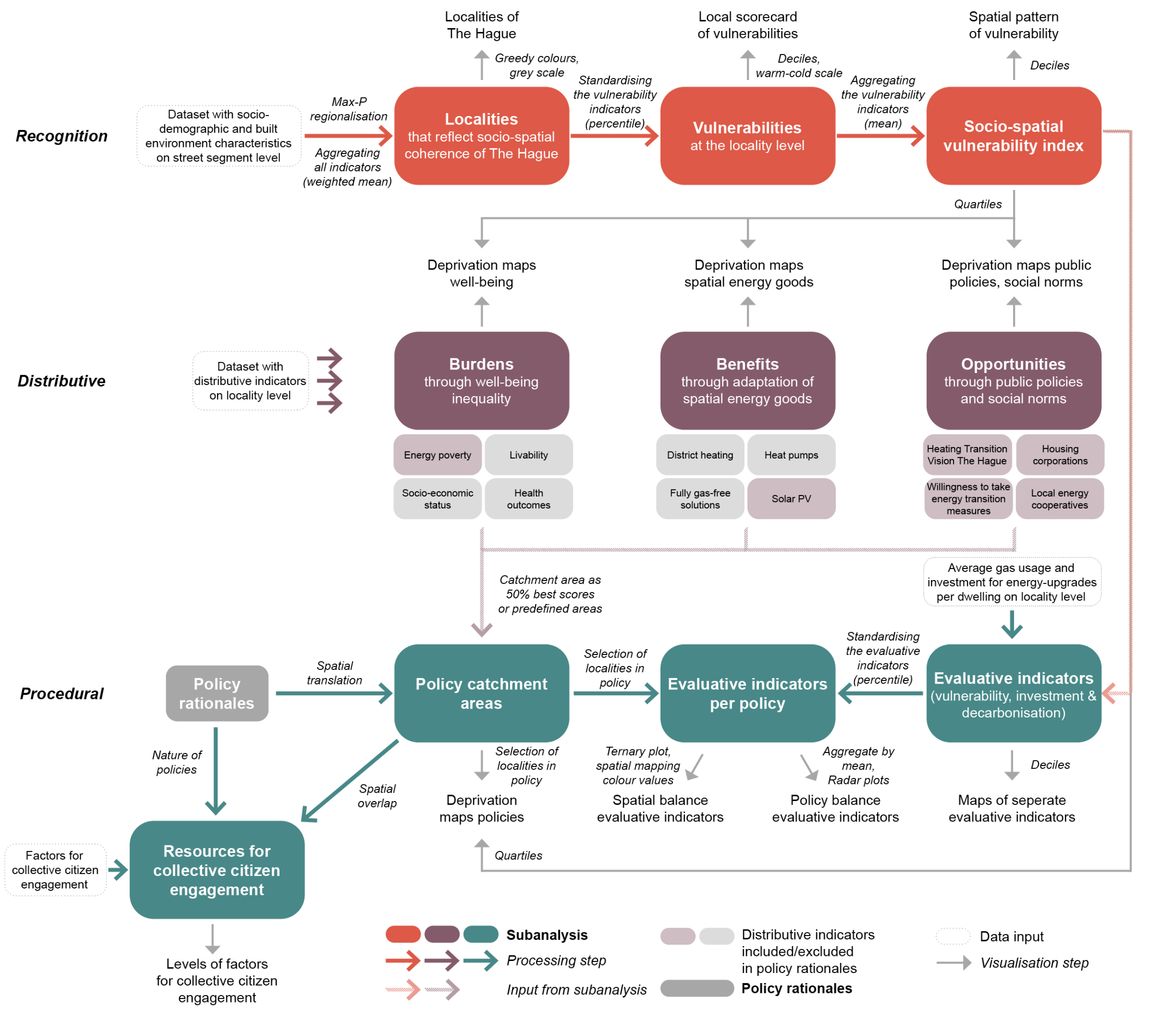


Figure 3.1: Approach diagram, outlining how analysis of the three energy justice dimensions is enabled, and how results are presented and how subanalyses are related.

3.1. Data collection and dataset creation

A variety of data sources was combined into two street-level datasets, to enable our data-driven approach on a local scale. The first dataset is created to identify spatial units that reflect local realities, described in section 3.1.1. The second dataset enables analysis of distributive effects, described in section 3.1.2.

3.1.1. Dataset for finding local realities

To uncover spatial patterns of local realities, we first created a street-level dataset containing information on sociodemographic characteristics, the built environment and energy indicators. As this information was available on different spatial scales, with information hidden due to privacy regulations or not openly available, we conducted a comprehensive process to combine, clean and enrich the data. The data processing consisted of three processes: (1) preparing geometries and appending administrative attributes to enhance connections to other datasets, (2) processing sociodemographic and energy attributes from zip-code datasets, and (3) processing built environment attributes from building and address datasets. The data sources and processing steps are presented in Figure 3.2, with an elaborative description included in Appendix A.1.

The attributes from the street-level dataset are presented in Table 3.1. The sociodemographic attributes entail age groups, migration backgrounds, household structures, income and home ownership structures. The energy attributes entail energy labels and energy usage. The built environment attributes entail dwelling type, building characteristics and specific built periods, relating to effective building regulations.

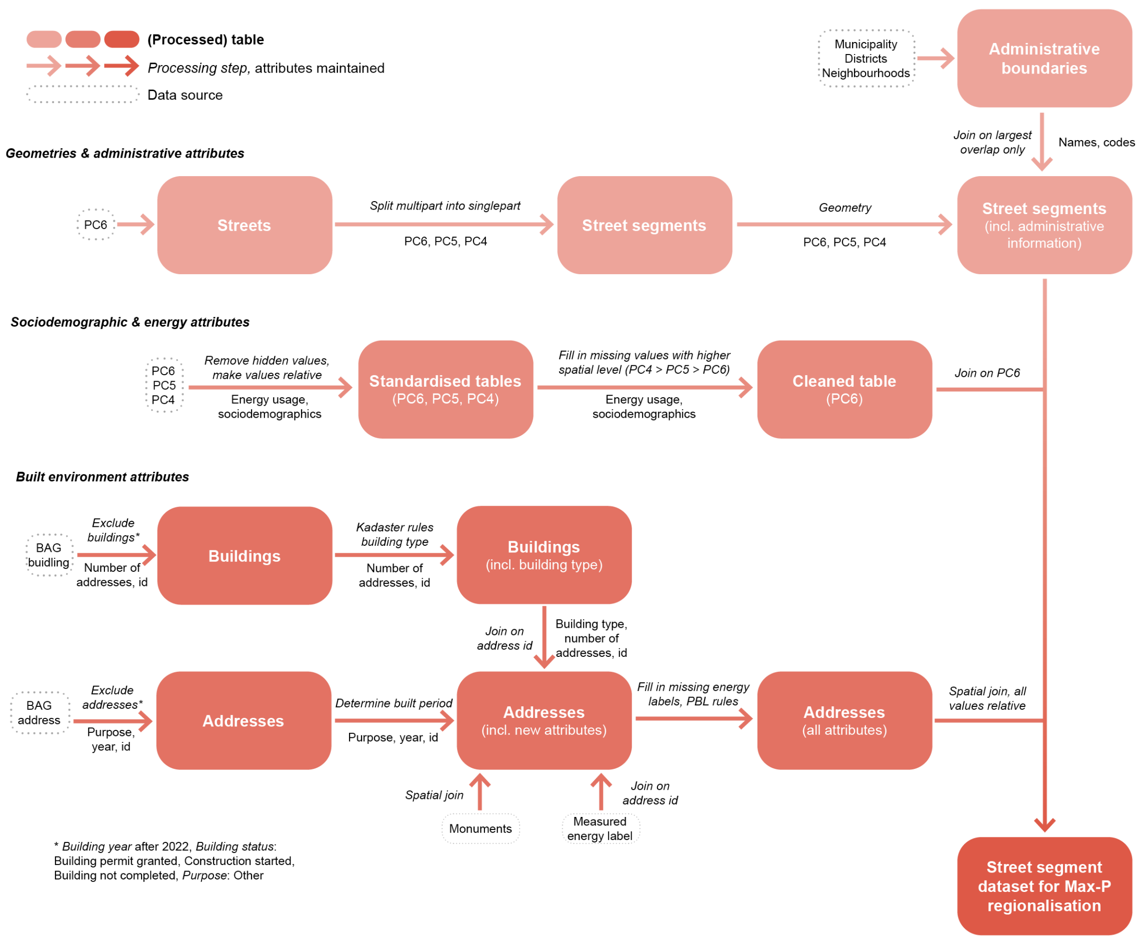


Figure 3.2: Data processing diagram for street segment dataset for Max-P regionalisation

Table 3.1: Influence of local characteristics on accessibility to opportunities in the heating transition

Type	Variable	Influence on accessibility (+/-/0)	Increased vulnerability (yes/no)	Explanation	Reference
Age	% 0-15	-	yes	Increased vulnerability to energy poverty (proxy young children)	Robinson et al. (2019), Gouveia et al. (2019)
	% 15-25	-	yes	The Hague is a city where many students live, who are more vulnerable to energy poverty. In addition, young residents are less likely to make large investments in their house, as they might move again	
	% 25-45	+	no		
	% 45-65	+	no		
	% 65+	-	yes	Increased vulnerability to energy poverty (older old, retired)	Robinson et al. (2019), Gouveia et al. (2019)
Migration background	% Dutch	+	no		Robinson et al. (2019)
	% EU	-	yes	Increased vulnerability to energy poverty (proficiency in Dutch, ethnicity)	Robinson et al. (2019)
	% non-EU	-	yes	Increased vulnerability to energy poverty (proficiency in Dutch, ethnicity)	Robinson et al. (2019)
Household structure	% single person	-	yes	Overrepresented in energy-poor households in NL	Mulder et al. (2023)
	% multiple persons	+	no		
	% two parents	+	no		
	% single parent	-	yes	Overrepresented in the energy-poor households in NL, Increased vulnerability to energy poverty (lone parents)	Mulder et al. (2023); Robinson et al. (2019)
Income	% state benefit	-	yes	Increased vulnerability to energy poverty (proxy disability or limiting illness, unemployment)	Robinson et al. (2019)
	property valuation (proxy income)	+	yes	Increased vulnerability to energy poverty (financial capacity to pay energy bills or energy improvement measures, several groups reliant on low income: part-time or precarious employment, looking after family or home, provision of unpaid care, unemployment, elementary education or occupation, full-time student)	Robinson et al. (2019), Mulder et al. (2023), Gouveia et al. (2019)
Home ownership structure	% bought	+	no	home ownership	
	% private renting	-	yes	Inability to invest in energy improvement measures by tenants, Increased vulnerability to energy poverty (private renting)	Robinson et al. (2019), Mulder et al. (2023), Gouveia et al. (2019)
	% cooperation	+/-	no	Although residents are reliant on housing cooperation for energy improvement measures, the cooperation must meet sustainability regulations set by the government while protecting their tenants. Although there are cases where housing cooperatives fall short.	
	% different owners	-	yes	In the case of a district heating, enough neighbours need to join to make the project feasible. If many homes have individual owners, many opinions count.	
	% housing	+	yes	In a dense city such as The Hague, there are many non-residential functions in the lower building layer, with different interests and motivated by different policies.	
	% vacant	-	no	With vacant buildings, there is less interest from, or access to, the owner to make the property sustainable.	
Energy	% energy label AB	+	no	Building with good energy labels are less likely to need insulation upgrades	
	% energy label CD	-	yes	Requires some insulation upgrades, with the investment not always being bearable for certain groups	
	% energy label EFG	-	yes	Increased vulnerability to energy poverty (energy-inefficient property)	Robinson et al. (2019), Gouveia et al. (2019), Mulder et al. (2023)
	gas usage	-	yes	High energy bill, gas is particularly expensive in The Netherlands	Gouveia et al. (2019), Mulder et al. (2023)
	electricity usage	-	no	Electricity costs contribute relatively low to the energy bill in NL, compared to gas	
Dwelling type	% apartments	0	no		
	% disconnected	0	no		
	% connected	0	no		
	% monumental	-	yes	A monumental status of the building limits the freedom to make changes to the building.	
	units per building	-	yes	Increased vulnerability to energy poverty (shared building)	Robinson et al. (2019)
Built period	different built periods	-	no	Buildings built in different periods, needed to meet different building regulations. This makes the heating transition more complex due to tailored insulation upgrades, but does not influence an individual's vulnerability.	
	specific built periods	0	no		

3.1.2. Dataset for evaluating distributive effects

To find multidimensional socio-spatial disparities, a variety of datasets are combined on street-level, of which the data sources and processing are presented in figure 3.3. Burdens are explored through disparities in well-being, with indicators on energy poverty, socio-economic status, health indicators and livability. Benefits are explored through spatial energy goods adaptation, encompassing heating sources and solar PV. Opportunities are explored through the societal factors public policies (heating transition vision, housing corporations) and social norms (willingness, energy cooperations).

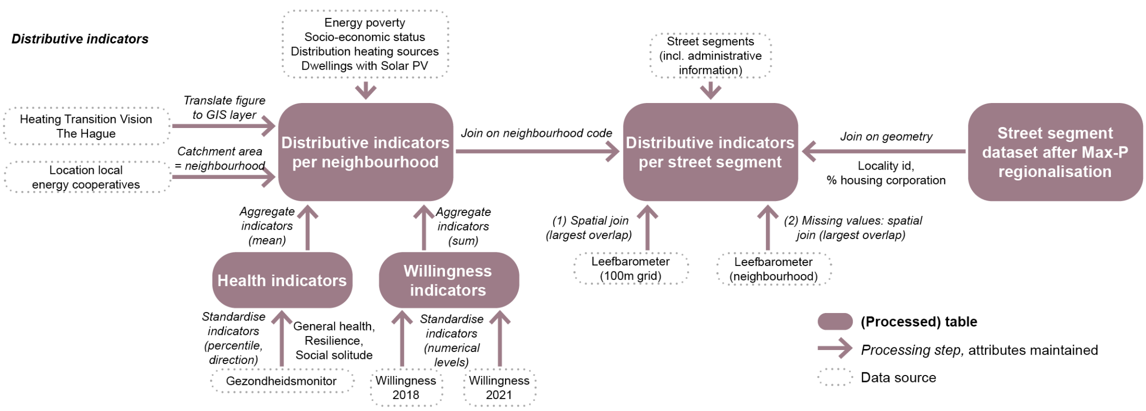


Figure 3.3: Data processing diagram for street segment dataset with distributive indicators.

3.2. Uncovering socio-spatial vulnerability

Regarding recognition justice, we take a three-step approach to determine the localities to recognise (3.2.1), to understand their localised challenges in accessing opportunities in the heating transition (3.2.2), and what their localised level of vulnerability is (3.2.3). We use the localities as the unit of analysis in the following steps. The localised level of vulnerability is used as an indicator in our evaluative framework.

3.2.1. Localities of socio-spatial coherence

This study seeks to identify local realities that risk being overlooked by focusing on administrative boundaries. As administrative boundaries result from political processes, the statistical inference is affected by aggregation problems such as the modifiable areal unit problem, aggregation bias, and the neighbourhood effect averaging problem (Duque et al., 2007; Kwan, 2018). Therefore, we take a bottom-up approach to cluster streets into localities, based on local coherence in built environment and sociodemographic characteristics.

Regionalisation methods enable aggregating zones (streets) into a number of regions (localities), while optimising for a threshold criterium (e.g., a minimum of dwellings), ensuring that streets in a locality are spatially connected and that each street is assigned to one locality, and vice versa (Duque et al., 2007). In the survey on supervised regionalisation methods, Duque et al. (2007) provides an extensive overview of the benefits and challenges of different methods available, with Duque et al. (2011) introducing the max-*p*-problem that combines strengths of different methods.

What sets max-*p* apart from other regionalisation methods, is that the number of regions is maximised instead of predefined. This ensures minimal spatial aggregation, minimal aggregation bias, data dictating the shape, valid statistical inference, and precision of the estimation (Duque et al., 2011). Although max-*p* is promising to create small and valid spatial units, the exact method to solve the problem is computationally expensive (Duque et al., 2011). An efficient heuristic solution was proposed by Wei et al. (2020), enabling large-scale neighbourhood delineation using max-*p*. The algorithm was publically made available as part of *spopt* in the open-source Python Spatial Analysis Library (PySAL) (Feng et al., 2021, 2022)[1].

Given the methodological benefits of max-*p* compared to other regionalisation methods and an efficient algorithm available open-source, we employ this algorithm to create our localities. Using a random seed for reproducibility, we implement max-*p* with standardised street-level data (Z-scores, all attributes listed in table 3.1), Queens' spatial weights, threshold of 500 dwellings, and 2 candidate regions for assigning enclaves.

When all streets are assigned a locality, the geometries of the streets are dissolved into the locality geometry for further analysis. The street-level data is aggregated by taking the mean of the variables, weighted by the number of dwellings per street, per locality. This is done for the variables used in max-*p* and the distributive indicators. The mathematical notations are:

$$\text{variable}_i^L = \frac{\sum_{s \in L} \left(\text{variable}_{i,s} \times \text{dwellings}_s\right)}{\sum_{s \in L} \text{dwellings}_s}$$

$$\text{dwellings}^L = \sum_{s \in L} \text{dwellings}_s$$

where:

- L denotes a locality containing streets,
- s indexes the street within locality L,
- $\text{variable}_{i,s}$ represents the value of the variable i for street s,
- dwellings_s is the number of dwellings in street s.

[1] PySAL: https://pysal.org, spopt:https://pysal.org/spopt/

3.2.2. Vulnerabilities at the locality level

To get a grip on understanding local realities, we chose to make informative scorecards describing the personal and environmental freedom factors of each locality. We do this by presenting the per locality aggregated values of each included characteristic. Thereafter, a colour scheme is used that classifies the level of the identified socio-spatial unfreedoms. The direction of all indicators (positive, negative or neutral), and whether we consider it to contribute to vulnerabilities in accessing opportunities in the heating transition (yes or no), is presented in table 3.1 in the columns 'influence on accessibility' and 'increased vulnerability'.

The colour scheme is used to draw attention to which vulnerabilities are present within each locality, compared to the Hague. We therefore standardise the values of the characteristics indicated as increased vulnerability, in the direction of the influence on accessibility, using deciles. To these deciles, we append a cold-warm colour scale, where blue reflects relatively lower values for that indicator and red reflects higher values, compared to The Hague. The variables that do not influence the opportunity to engage in the heating transition, from the population's perspective, are grey.

Scorecards contribute to a single locality overview per locality, capturing the occurrence of different socio-demographic groups and how the built environment is characterised, as well as which vulnerabilities are present. This overview can help with customising engagement strategies.

3.2.3. Socio-spatial vulnerability index

As this research is concerned with socio-spatial patterns in vulnerability to accessing opportunities in the heating transition, we create a composite index capturing all identified characteristics that increase the vulnerability in accessing those opportunities, as the level of local vulnerability. We do this by aggregating all characteristics presented in table 3.1, that are indicated to increase vulnerability in the direction of influence on accessibility. The aggregation is performed by standardising all indicators with percentile ranking, and thereafter taking the mean of all 17 vulnerability indicators. This results in the level of local vulnerability.

3.3. Finding multidimensional socio-spatial disparities

To address distributive justice, the focus lies on how well-being (3.3.1), spatial energy goods (3.3.2) and opportunities (3.3.3) are distributed across levels of local vulnerability (society) and localities (space). Deprivation maps and tables are presented per indicator, in conjunction with the vulnerability level (quartiles), providing socio-spatial distributive patterns for each indicator.

3.3.1. Burdens through well-being inequality

In a recent study on left behind neighbourhoods in the UK, Houlden et al. (2024) listed underlying factors that lead to places being systematically disadvantaged, encompassing: 'uneven investment, austerity, state retrenchment, and high levels of socio-economic inequality'. In this light, we assume the accumulation of lower well-being outcomes corresponds to inequality in societal factors (public policies, social norms and power dynamics) that drive spatial well-being disparities.

The measurement of well-being is complex, and often uses composite indicators of features related to, for instance, level of wealth and standard of living (Ferrara et al., 2016). We employ several aggregated indicators, measuring different aspects of well-being that can be affected by the heating transition: energy poverty, livability, socio-economic status and health outcomes.

3.3.2. Benefits through adaptation of spatial energy goods

Considering the current distribution of spatial energy goods, it is derived where policies have been effective so far and thus, who and where already has access to clean energy technologies. By finding intersections with levels of vulnerability in accessing technologies, one can evaluate the fairness of the distribution of these spatial goods across society and space.

Spatial energy goods are not allocated randomly through society and space, as adaptation is underpinned by policy incentives and the nature of technologies. As the energy transition of the existing built environment is not a one-technology transition, the adaptation of different clean energy technologies is assessed: district heating, heat pumps, fully gas-free solutions (excluding hybrid heating solutions), and solar PV (more mature technology in the existing built environment).

3.3.3. Opportunities through policies and social norms

Future opportunities in the heating transition are created when policies and social norms align with the issue at stake, enhancing societal freedom factors.

Public policies. The Heating Transition Vision of The Hague gives an indication of what local residents await in terms of heating technology, where The Hague aims for local involvement in creating implementation plans. In addition, housing corporations are incentivised to make homes more sustainable by the national government.

Social norms. When local social norms are aligned with the issue at stake, it is more likely that people adopt clean heating technologies when an offer is presented. Given the connection density needed to make district heating locally feasible, this positively influences the local societal freedoms to access the heating technology. Two indicators are used to derive patterns in positive social norms. Firstly, the local willingness to take energy transition measures individually is considered. This reflects individual attitudes towards the issue at stake, and whether those are more or less aligned. Secondly, the presence of local energy cooperatives is used as an indicator. In such structures, social norms are shaped collectively, and thus enhance local support for the issue at stake (Djinlev and Pearce, 2024).

3.4. Identifying effective policies and resources

A three-step approach is taken to analyse procedural justice, focussing on the spatiality of proposed policy rationales (3.4.1), the evaluative framework assessing spatial resource allocation and policy coverage (3.4.2) and how to built collective citizen engagement effectively (3.4.3).

3.4.1. Policy catchment areas

The spatiality of policy effects is underpinned by access to policies and technologies, with opportunities distributed through space related to local personal and environmental barriers (see section 3.2). While these spatially distributive policy effects could be intended or unintended, we assume likely catchment areas regarding the different policy rationales in advance. This is done by pairing policy rationales with the spatial distribution of indicator datasets, largely corresponding to indicators used for distributive justice (see section 3.3). For each policy rationale, we assume the following underlying indicators as an effective proxy for determining the catchment area:

- *Implement Heating Transition Vision.* Using the administrative neighbourhoods with an existing policy vision for main heating technology from the Heating Transition Vision;
- *Provide individual subsidies.* Using the adaptation of solar PV as a proxy, as these developments within the energy transition already extend further into the existing built environment, compared to the heating transition. We assume that the same households have access to this policy instrument (largely for individual heat pumps), as local personal and environmental barriers are similar.
- *Support local energy cooperatives.* Using the neighbourhoods where a local energy cooperative is active;
- *Link with housing corporations.* Using localities where many housing corporations are present;
- *Activate willing residents.* Using localities with high willingness, derived from the created index reflecting households' willingness to take energy transition measures individually;
- *Alleviate energy poverty.* Using localities with a high share of energy-poor households.

The catchment areas for the different policy rationales emerge through underlying data. Given the differences in the underlying data, we assume the catchment areas to be the 50% highest scoring localities for the indicators without a predefined catchment area. We consider this a robust approach to uncover where different policies might be effective. Deriving the effectiveness is not without notice that this research does not assume engagement, which differs through space. In the context of achieving procedural justice, this engagement needs to be built to enhance policy effectiveness and inclusion of vulnerable local populations, which will be returned to in section 3.4.3.

Despite using areas to derive policy effects, there is no necessity to implement the policy rationales as an area-based approach. There is a lot of variety in the types of localities that exist within these catchment areas, where different local residents and local communities exist with their own needs. Defining the catchment areas provides a line of reasoning to identify where and for who policy resources end up, by linking the catchment areas to the analyses resulting from recognition justice (see section 3.2). For this reason, community approaches are also supported.

3.4.2. Evaluative framework for policies

The evaluative framework capturing cost-effective decarbonisation while covering socio-spatial vulnerability in accessing opportunities in the heating transition consists of three steps: 1) construction of decision-supporting indicators, e.g. vulnerability, decarbonisation potential and investment costs; 2) evaluation of the socio-spatial balance between the three indicators, and 3) evaluation of policy coverage of the three indicators. Each element is presented in the following sections.

1) Evaluative indicators

Three simple indicators are computed to give a first overview that reflects the potential of engaging each community, assuming perfect engagement and that it is technically possible to achieve a gas-free built environment, for the assumed individual investment costs. Simple calculations are chosen, as actual outcomes will differ based on technical, economic and social realities, and capturing this complexity would result in many scenarios and more complex interpretability. Therefore, firstly, the used computations are presented, and secondly, what is left out in this computation. The calculation of each indicator for assessing the energy transition potential of localities is outlined below:

- **Decarbonisation** potential per locality (D_l):

$$D_l = \sum_{i=1}^{s_l} \left(\text{average gas usage per dwelling}_{s,l} \times \text{number of dwellings}_{s,l}\right)$$

  where l denotes the locality, s represents each street segment, and n_c is the total number of street segments in locality l. The decarbonisation potential D_l is calculated by summing the product of average gas usage and the number of dwellings for all street segments within the locality.

- **Investment** costs per locality (I_l):

$$I_l = \sum_{j=1}^{d_l} \left(\text{insulation costs}_{j,l} + \text{heating system costs * (100 - \% gas-free heating solutions)/100}_{j,l}\right)$$

  where j represents each building, d_l is the total number of dwellings in locality l, and the investment cost C_c is the sum of the insulation and heating system costs for all dwellings in the locality, corrected for gas-free heating solutions in place.

- **Vulnerability** score of each locality (V_l):

$$V_l = \text{vulnerability}_l$$

  Vulnerability V_l is computed for each locality based on the methodology described in section 3.2.3. This indicator captures the vulnerability of locality l in accessing opportunities in the heating transition.

Thus, given the unique distributions of vulnerability, decarbonisation and investment, we standardise the indicators with percentile ranking. Percentile ranking divides the indicators into equal-sized and ordered intervals, enhancing the understanding of the relative position of the data point within the distribution. This provides a scale-independent, robust, and easy-to-understand way of describing and comparing the three indicators. Useful to standardise skewed distributions, toavoide outliers, and to allow easy communication on the spatial patterns of each indicator separately, and in balance. The mathematical representation is as follows:

- **Percentile rank** of each indicator per locality ($P_{X,l}$):

$$P_{X,l} = \text{Percentile Rank of indicator } X \text{ for locality } l$$

where X represents each indicator (Vulnerability V, Decarbonisation D, Investment I), and l denotes each locality. The percentile rank $P_{X,l}$ is computed for each locality across the entire dataset, giving each locality a position relative to all others based on the value of indicator X.

2) Spatial balance between the three indicators
The proposed evaluative framework is concerned with cost-effective decarbonisation, while maintaining information about vulnerability. Comparing three maps side by side is challenging, especially when one needs to derive how the three maps are related. Representing vulnerability, decarbonisation, and investment in a tripartite framework allows for an integrated view of the trade-offs and links between these three indicators. Ternary diagrams provide a graphical way to map each point in an equilateral triangle representing the balance of these three indicators for data point (Schöley, 2021), enabling deeper exploration into scenarios where they meet. This methodology underlines the interconnectivity of the three components — vulnerability, decarbonisation, and investment — while keeping their synergies well understood. A ternary plot can be used for visualising these indicators all at once, helping to identify configurations that enable cost-efficient decarbonisation while accounting for potential vulnerabilities.

Using a ternary plot to reflect colour mixtures, data points can be assigned a colour code based on their relative position in the ternary plot. As the data points correspond to a geographical zone, our localities, the balance between the three indicators can be plotted through space, e.g. The Hague or specifically for policies, in the corresponding policy catchment area. The tricolore R library by Schöley (n.d.) provides a flexible implementation of the logic of ternary balanced colour scheme, with options to centre data points. This library generates the ternary plots and assigns the colour codes, given the position in the ternary plot, to the data table. This colour code is used for mapping each data point.

3) Policy balance overview
To evaluate the overall balance between the three indicators for each policy rationale, an additional aggregation step is made. This follows the logic presented for the balance between the three indicators through space, where the percentile ranked values are averaged across the catchment area of each policy rationale. The mathematical representation for this is as follows:

- **Mean percentile rank** for each indicator over policy catchment areas ($M_{X,P}$):

$$M_{X,P} = \frac{1}{|\{l : \mathrm{C}_P(l) = 1\}|} \sum_{l:\mathrm{C}_P(l)=1} P_{X,l}$$

where P denotes each policy, X is each indicator (Vulnerability V, Decarbonisation D, Investment I), and l denotes each locality. $\mathrm{C}_P(l) = 1$ specifies that locality l is within the catchment area C for policy P. The mean percentile $M_{X,P}$ is calculated by averaging the percentile ranks $P_{X,l}$ of indicator X over all localities l that are within the catchment area C of policy P.

The mean percentile ranks of each indicator are visualised with radar charts, for each policy rationale. Radar charts give the possibility to represent various indicators simultaneously, presenting a comprehensive overview of each policy rationale. It therefore becomes easy to recognise patterns and trade-offs between policy rationales. The mean percentile ranks are compared to The Hague's median as the common reference point. This design allows assessment of each indicator for policy rationale, and whether it is exceeding or falling short compared to The Hague's median. This highlights thus the sensitivity of each policy to the three indicators.

Policies whose indicators are above the median to a significant degree may be very effective in covering that indicator, while those below the median may highlight under-represented coverage of that indicator. Policies that have scores close to the median on many indicators suggest a balanced coverage, where large deviations from this course might signal a more targeted or specialised policy.

3.4.3. Resources for collective citizen engagement

In the context of achieving procedural justice, collective citizen engagement is an effective tool to enhance policy effectiveness, while including vulnerable local residents. Three main components for enabling collective engagement are described the building blocks *Presence of local energy cooperatives*, *Financial capacity (of households)* and *(Digital) communication structures*. The current state of these factors is presented as low, medium, or high availability, or mixed when divergent patterns are identified. Generally, when the levels are on the lower side, more allocation of resources is needed to enhance collective citizen engagement, which has implications for the municipality's role.

The levels of the factors are determined based on the nature of the actors involved, which could either provide collective financial capacity or foster communication with their community. The presence of local energy cooperatives is derived from the spatial intersections of each policy rationale's catchment areas with the catchment areas of local energy cooperatives. While this approach gives a general overview of building blocks for collective citizen engagement, these factors differ through space, and more can be identified that enhance citizen collectives.

4
Results

This chapter outlines the results of the conceptualisation of the three dimensions of energy justice. First, recognition justice is addressed (4.1), where the identified localities are presented, the local vulnerabilities are made insightful, and the level of local vulnerability is determined. Thereafter, we elaborate on distributive justice (4.2), where the distribution of well-being, spatial energy goods and opportunities are evaluated through society and space, using the level of local vulnerability from recognition justice. Finally, procedural justice is addressed (4.3), where a framework is presented for evaluating different policy rationales, followed by the catchment areas of different policies, and the effectiveness of each. Thereafter, building blocks for effective collective engagement are presented.

4.1. Recognition justice: Socio-spatial vulnerability

The results of the implementation of the three-step approach for recognition justice, described in section 3.2, are presented in this section, in the same consecutive steps. First, the identified localities are presented that establish the analytical zones for subsequent analyses (4.1.1). Secondly, we describe these localities in terms of their socio-demographic and built environmental characteristics, and highlight vulnerabilities (4.1.2). As the third step, we present the emerged spatial pattern in vulnerability to accessing opportunities in the heating transition (4.1.3).

4.1.1. Localities of spatial coherence in local characteristics

Our focus lies on finding localities that reflect local realities in terms of socio-demographic composition and built environment characteristics. By processing street-segment level data (approximately 15.000 street segments), containing the socio-demographic and environmental characteristics presented in table 3.1 with the max-p regionalisation algorithm (see section 3.2.1), 426 localities are found. The identified localities are presented in figure 4.1a. All these localities have coherent data profiles, with the shape of the localities emerging directly from the data. Thereby, the max-p algorithm ensures that we find the highest number of distinct localities, when meeting the minimum number of 500 dwellings in each locality. The number of dwellings in each locality ranges from 500 to 1277 dwellings.

Comparing this to the 114 neighbourhoods of The Hague presented in figure 4.1b, where the number of dwellings ranges from 0 to 8362, the localities give a finer resolution for finding local realities. Thereby, the localities give a practical division of the residential built environment, reflecting where people live while maintaining a manageable number of dwellings to design policies for.

The identified localities are not conditional upon the administrative neighbourhood boundaries, as multiple localities are found within administrative boundaries, and localities are not bound by them and could overlap with more than one administrative neighbourhood. Each street segment is connected to only one locality, and thus localities do not overlap.

(a) Identified localities within The Hague

(b) Administrative neighbourhood boundaries of The Hague

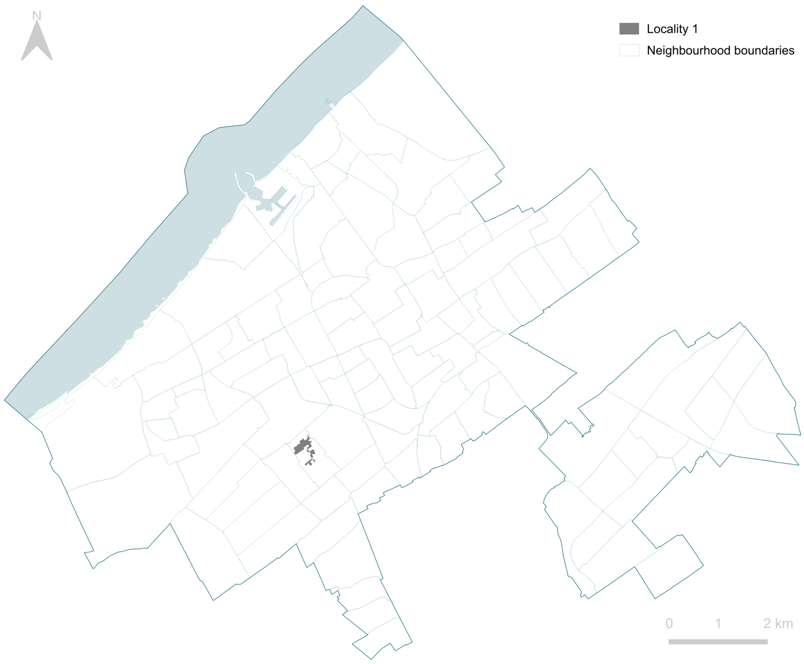
Figure 4.1: Identified localities compared to administrative neighbourhoods. The created analytical units are the result of the Max-P regionalisation algorithm that processed approximately 15.000 street segments into 426 regions (e.g., localities), that are coherent in their socio-demographic and built environment characteristics, containing 500 to 1277 dwellings. Compared to the 114 neighbourhoods of The Hague, with the number of dwellings ranging from 0 to 8362, this gives a finer resolution for finding local realities.

4.1.2. Scorecards of local vulnerabilities

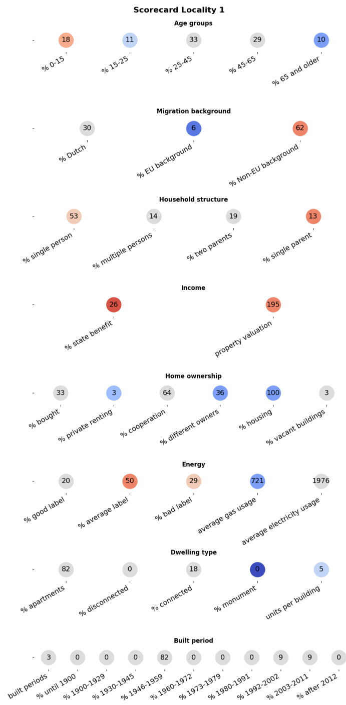
To make local realities insightful, scorecards are constructed that reflect the socio-demographic and environmental characteristics, and highlight local vulnerabilities (see section 3.2.2). For the locality assigned number 1 by the regionalisation algorithm, the location and scorecard are presented in figure 4.2. An enlarged scorecard is available in figure 4.3. Generally, policies and engagement strategies should be designed to acknowledge the needs of vulnerable groups present in the locality, to ensure they are not left behind in the decarbonisation process.

For each category, corresponding to the categories and indicators presented in table 3.1, the interpretation of the scorecard of locality 1 is the following:

- **Age:** relatively many residents are 0-15 years old, which is used as a proxy for the presence of young children;
- **Migration background:** is mixed, with relatively many residents having a non-European migration background;
- **Household structure:** relatively many single-person and single-parent households;
- **Income:** relatively many state benefit recipients before retirement age, in combination with a low property valuation indicating lower incomes;
- **Home ownership:** relatively low share of private renting and high share renting from housing corporations, resulting in a low share of private owners. Thereby, all buildings have a residential function.;
- **Energy:** relatively many dwellings that need insulation upgrades, with the highest share having energy labels C or D, followed by energy labels E, F or G. Although the need for energy upgrades, the gas usage is relatively low compared to The Hague. This could be the result of smaller sized dwellings (not incorporated in this research);
- **Dwelling type:** In this locality, there are primary apartments (82%), with the remaining share being connected dwellings. On average, there are five units per building, which is in the lower division compared to The Hague;
- **Built period:** Buildings are built in 3 different periods, with everything built pre-war. 82% of the dwellings is built in the period 1946-1972, with the remaining share between 1992-2011.



(a) Location of locality 1.



(b) Description of Locality number 1, larger picture included on the next page.

Figure 4.2: Scorecard of an example locality, describing socio-demographic and built environment characteristics, with vulnerabilities in access highlighted. Red indicates a higher level of occurrence of the vulnerability in access in this indicator compared to The Hague, and blue the opposite. Grey is used for indicators that do not reflect vulnerability in accessing opportunities in the heating transition from the households' perspective.

In summarisation, the example locality is characterised by a built environment that is fully residential, with the building stock consisting of primarily apartments (82%) and connected dwellings (18%), with on average having 5 units per building. The dwellings are mainly built post-war, in the period 1946-1959 (82%) with the remaining dwellings built in the period 1992-2011 (18%). The largest share of dwellings (79%) however, do not meet current insulation standards. These building characteristics imply, with regards to policy making, that the largest share of dwellings need similar insulation upgrades, due to the effective building regulations in those periods, and the consistency in dwelling types.

In this locality, socio-demographic characteristics prevail that make this locality more vulnerable. Therefore, the needs and barriers to the transition of these specific social groups should be actively recognised in policy-making and tailored engagement strategies. The social groups that should be actively reached out to are: (parents of) young children, people with a non-European migration background, single-person and single-parent households, people with a lower income, and state benefit recipients. These social groups are a rough estimate of target groups and may be more diverse within the locality, for example in terms of what nationalities live in this locality, as well as what the financial characteristics are (e.g., employment situation and personal circumstances leading to receiving state benefits before retirement age).

Although for some characteristics where the prevalence is lower compared to The Hague, this does not indicate that no efforts should be made to include their perspectives into policy making or tailored engagement strategies.

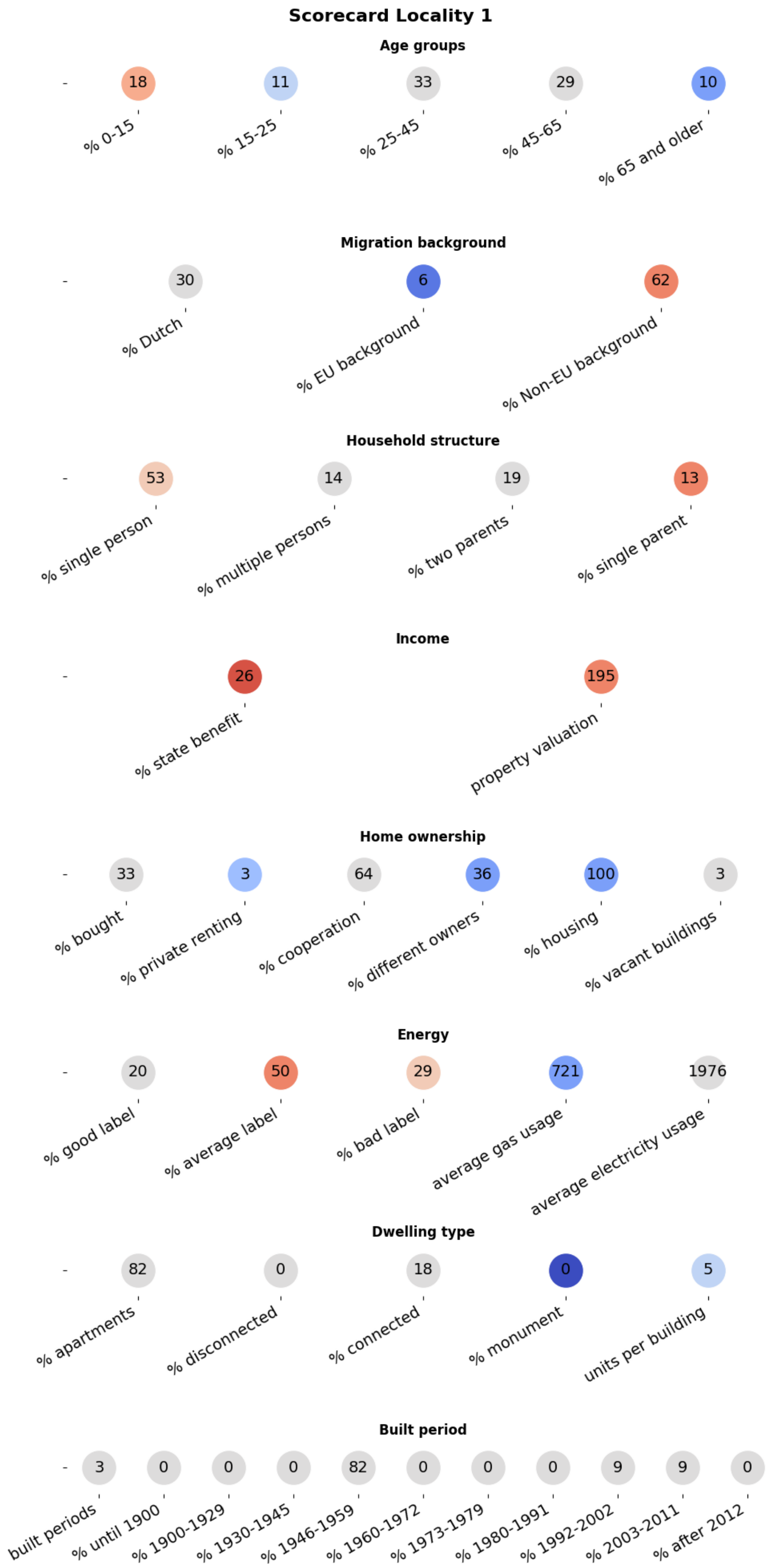


Figure 4.3: The scorecard of the example locality, enlarged.

4.1.3. Socio-spatial pattern of vulnerability

When many vulnerabilities are present in a locality, it is assumed that the local residents experience a higher level of local vulnerability in accessing opportunities in the heating transition. Using the method described in section 3.2.3, the vulnerabilities are aggregated into a local value of this vulnerability. The result of this is presented in figure 4.4, where orange values represent the localities that fall into the 50% highest levels of local vulnerability. Although some localities have lower levels of vulnerability compared to The Hague, there still might be specific vulnerabilities present in these localities. Therefore, each vulnerability indicator is presented separately in Appendix B.

The spatial pattern emerging in levels of vulnerability, corresponds roughly to the administrative areas of The Hague Zuidwest (districts Bouwlust en Vredelust, Leyenburg, Morgenstond, Moerwijk) and Centrum (districts Groente- en Fruitmarkt, Transvaalkwartier, Schildersbuurt, Stationsbuurt, Centrum, Zeeheldenkwartier and Achipelbuurt en Willemspark), plus districts Mariahoeve, Laakkwartier, Spoorwijk and parts of Scheveningen. Some of these administrative areas might already be known by policymakers as more vulnerable in general, while others are not the usual suspects. This is due to that this indicator measures not only social determinants of vulnerability, and also includes build environment characteristics as well as characteristics that are specific for the heating transition.

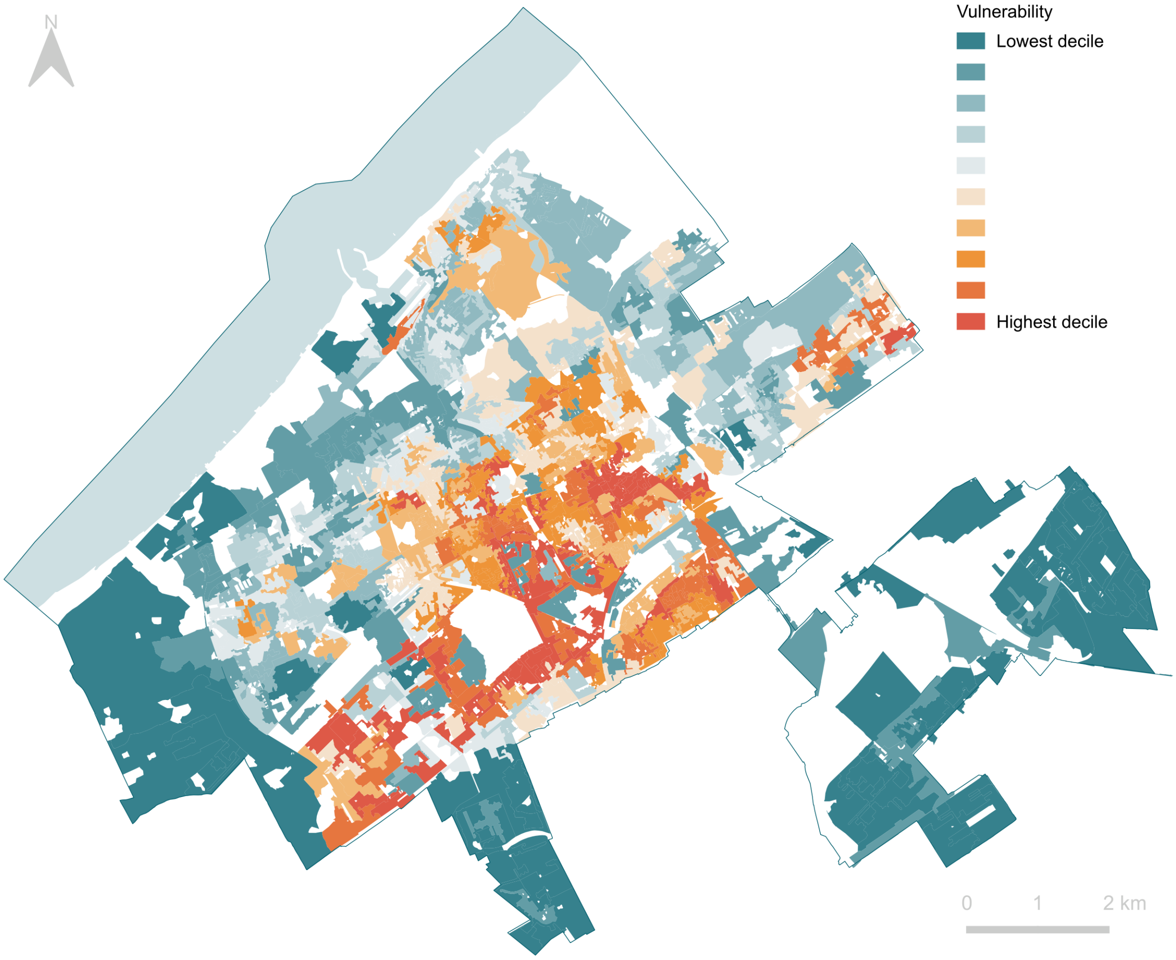


Figure 4.4: Level of local vulnerability to access the opportunities in the heating transition, based on 17 indicators that decrease the household's accessibility of heating transition solutions, based on table 3.1. Separate vulnerability indicators are presented in Appendix B.

The pattern of levels of local vulnerability serves as a basis for accessing the distributional patterns through society and space, described in section 4.2, and as an indicator of the evaluative framework.

4.2. Distributive justice: Multidimensional socio-spatial disparities

In this section, the patterns of well-being, spatial energy goods and opportunities are compared to the levels of local vulnerability (see section 4.1.3), to assess how they are distributed through society and space. First, four indicators of well-being are evaluated to assess intersections with other spatial inequalities (4.2.1). Thereafter, different spatial energy goods are evaluated, to assess who already has access to clean energy technologies (4.2.2). Finally, an assessment is made of how opportunities are distributed (4.2.3).

4.2.1. Disadvantaged localities through well-being disparities

By considering how well-being is distributed among levels of vulnerability in accessing opportunities in the heating transition, we expand on the scope of enabling the heating transition as a transition that can improve other aspects of well-being. This consideration is deemed relevant, as inequalities in well-being could intersect with the inability to participate in the heating transition and therefore (re)enforce spatial inequalities. Thereby, as heating (and generally, energy), are important means to reach well-being, a lack of access could eventually lead to loss of well-being.

To first focus on how well-being is distributed across levels of vulnerability, we address how well-being is distributed among 'society'. Therefore, the four indicators of well-being are evaluated across the quartiles of levels of vulnerability, presented in table 4.1. From this table, we learn that the most and more vulnerable localities generally experience a higher prevalence of energy poverty, worse scores on livability, socioeconomic status and health outcomes in terms of lower general health, lower resilience and higher social solitude.

Table 4.1: Distribution of well-being indicators by vulnerability level quartiles. This table illustrates that the most and more vulnerable localities generally experience a higher prevalence of energy poverty, and worse scores on livability, socio-economic status and health outcomes in terms of lower general health, lower resilience and higher social solitude.

	Most Vulnerable	**More Vulnerable**	**Less Vulnerable**	**Least Vulnerable**
Number of dwellings	71,049	67,274	68,538	70,780
Number of inhabitants	132,400	125,000	123,000	162,650
Well-being indicators				
Energy poverty	15.8%	12.1%	9.2%	6.8%
Livability	5	6	8	7
Socioeconomic status	-0.45	-0.24	0.00	0.07
Index of health indicators	0.65	0.56	0.47	0.47

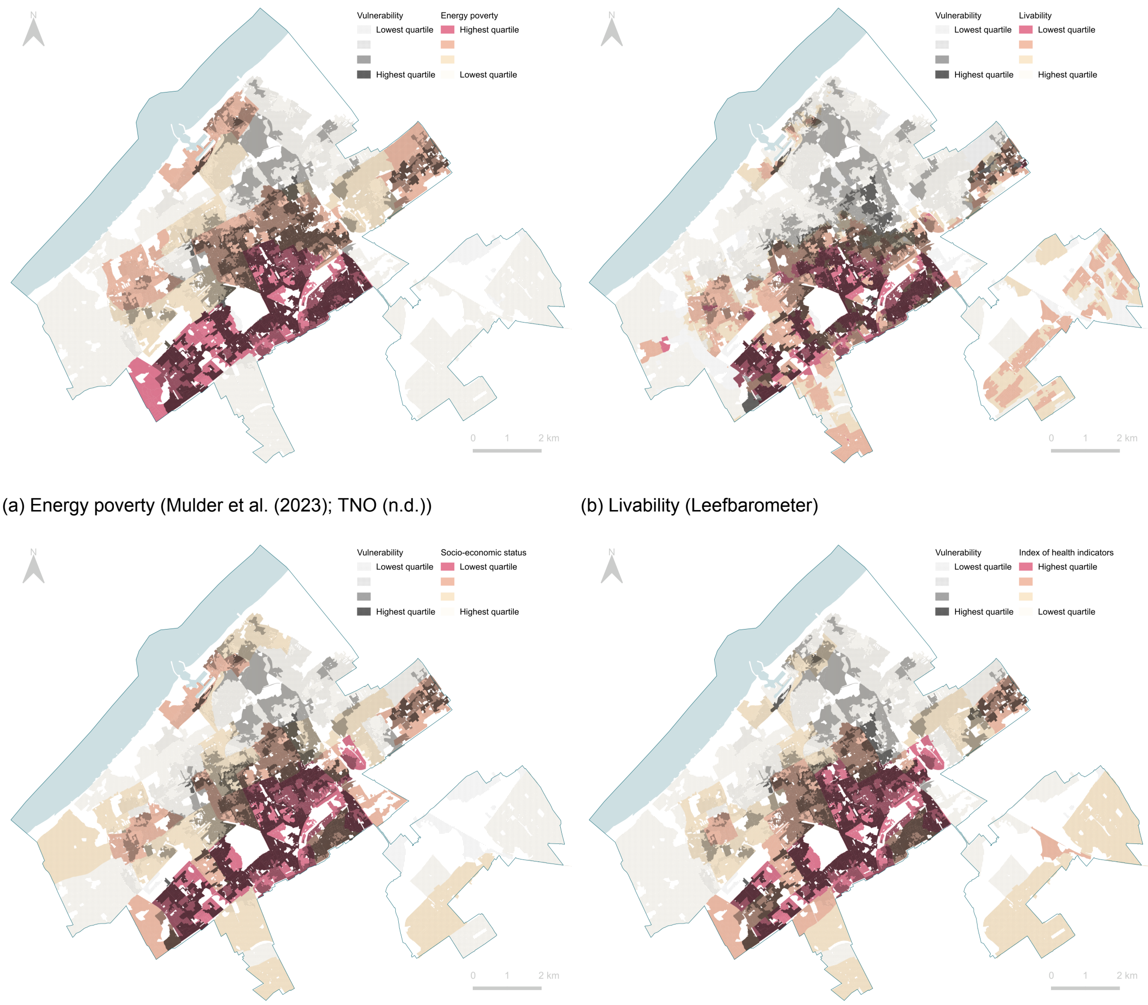
To consider how these well-being indicators are distributed through space, the quartiles of each indicator are mapped in figure 4.5. What captures attention, is that the undesired outcomes of each indicator, follow the same spatial pattern. The administrative zones that, therefore, experience both more vulnerability in accessing opportunities and lower general well-being, are The Hague Zuidwest, Schilderswijk, Laakkwartier and Mariahoeve.

This is not unexpected, as spatial inequalities intersect and (re)enforce each other. Despite the inequalities in well-being spatially intersecting with the pattern of vulnerability, causality is not assumed as the vulnerability indicator is designed with regard to access to opportunities in the heating transition, capturing local vulnerability in sociodemographic and built environment characteristics. This does not take away from that some vulnerability indicators are also used in the other well-being indicators.

To return to causal mechanisms, which are more complex and dynamic than the spatial snapshot under study, and are thus not explainable from the indicators themselves. Therefore, we return to the social freedom factors (see section 2.2), where Robeyns and Byskov (2023) describe them as factors within society that influence the freedom people have relating to "public policies, social norms, practices that unfairly discriminate, societal hierarchies, or power relations related to, for example, class, gender or race". Arguing from the knowledge that the inequalities in well-being and vulnerability in accessing opportunities intersect, the conclusions therefore do indicate that:

- These social freedom factors should be acknowledged in terms of understanding why some places are generally experiencing lower outcomes on general well-being. For instance, caused by misrecognition in policy-making for these communities, or that these communities have too little agency in the power dynamics; and

- That other outcomes on well-being could be taken into account to use the heating transition as a starting point to reduce other inequalities, by shifting the focus from handing out spatial goods to creating opportunities that align with the prioritised demands of justice.



(a) Energy poverty (Mulder et al. (2023); TNO (n.d.))

(b) Livability (Leefbarometer)

(c) Socio-economic status (SES WOA)

(d) Index of lower health, lower resilience and higher social solitude

Figure 4.5: The spatial distribution of well-being indicators, compared to patterns of vulnerability in access to opportunities in the heating transition.

When engaging with or policy-making for more vulnerable localities - especially in The Hague Zuidwest, Schilderswijk and surroundings, and Laakkwartier, considerations need to be made whether to include other demands of justice. Certain places will benefit more from other social or spatial interventions than just being offered a clean heating solution or insulating the home, as handing out such spatial energy goods does not address the underlying spatial dynamics that cause such socio-spatial patterns of inequality.

4.2.2. Realised access through adaptation of spatial energy goods

The current distribution of spatial energy goods is used to understand who already has access to them, and where. First, the distribution of these spatial energy goods across levels of vulnerability is presented in table 4.2.

Table 4.2: The distribution of adaptation of spatial energy goods, compared to patterns of vulnerability in accessing opportunities in the heating transition. Adaptation of spatial energy goods follows distributional patterns fitting the nature of the technologies and the policies that incentivised adaptation.

	Most Vulnerable	**More Vulnerable**	**Less Vulnerable**	**Least Vulnerable**
Number of dwellings	71,049	67,274	68,538	70,780
Number of inhabitants	132,400	125,000	123,000	162,650
Clean heating solutions				
Gas-free heating sources	5.6%	5.6%	6.8%	22.1%
District heating adaptation	6.9%	6.9%	6.7%	19.2%
Heat pump adaptation	1.4%	1.7%	2.4%	4.5%
Clean energy solutions				
Solar PV adaptation	2.6%	3.6%	5.7%	14.2%

In regards to the clean heating solutions, the distributional effect emerges where the gas-free and district heating technologies are equally distributed among the most, more and less vulnerable populations, with a distributive spike to the least vulnerable. This distributive effect is explained by first, the construction of the vulnerability indicator where both personal and environmental vulnerability in accessing opportunities is captured. Thereby, the vulnerability levels are partly dependent on the presence of housing corporations, energy efficiency of dwellings, and measured gas usage which is generally lower where already clean heating solutions are implemented. Given the nature of how the vulnerability indicator is constructed, the pattern of vulnerability is more scattered through space, compared for instance to the well-being indicators used in section 4.2.1. This results in a more even distribution of gas-free heating sources and district heating adaptation for the most, more and less vulnerable levels. The contrast with the least vulnerable level is also partly explained by the construction of this vulnerability indicator, as the more newly built environment by default translates into a lower level vulnerability, as there are fewer monumental dwellings and the buildings being more energy-efficient.

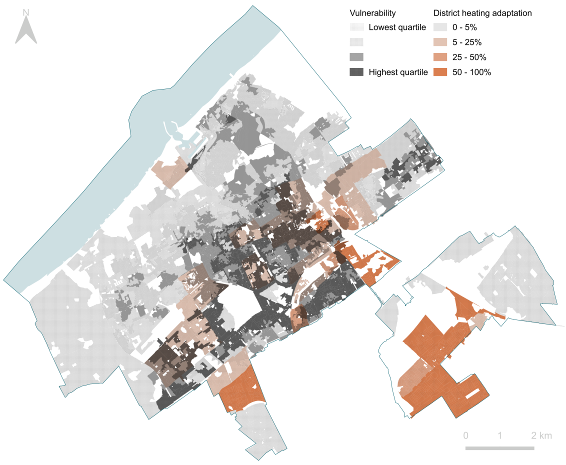
The latter is related to the second reason why the distribution of gas-free solutions and district heating adaptation is skewed towards the least vulnerable, being the nature of policies and processes within the heating transition. The more recent built environment by regulation already needs to incorporate clean heating solutions, therefore resulting in high adaptation rates for the least vulnerable population. With regards to the most, more and less vulnerable populations, another mechanism distributed the gas-free heating sources and district heating. In this case, the main efforts within the existing built environment for district heating are made through housing corporations that own dwellings across multiple vulnerability levels, and thus the technology is available in vulnerable environments.

In regards to individual solutions such as heat pumps and solar PV, the distribution is more skewed within the most, more and less vulnerable levels within society, with an outburst towards the least vulnerable group. The latter results from similar reasons as described above. The explanation of the skewed distribution within the most, more and less vulnerable can be explained by the differences in the personal and environmental freedom factors, as we consider more aspects increasing vulnerability (e.g., lower income, shared buildings and language barriers), that relate to the access to individual energy solutions given the (individual) subsidies and policies in place to adopt these technologies. Heat pumps are characterised by high investment costs, and require space within the home, making apartments in shared buildings less suitable for this technology. Thereby, larger changes to homes within shared buildings require permission from the VVE. Similarly, for solar PV, the adaptation is more straightforward when one does not live in a shared building, can carry the investment costs and access subsidies, and has a suitable roof for instalment (the latter not included in this analysis). These results confirm what Kraaijvanger et al. (2023) found in their research.

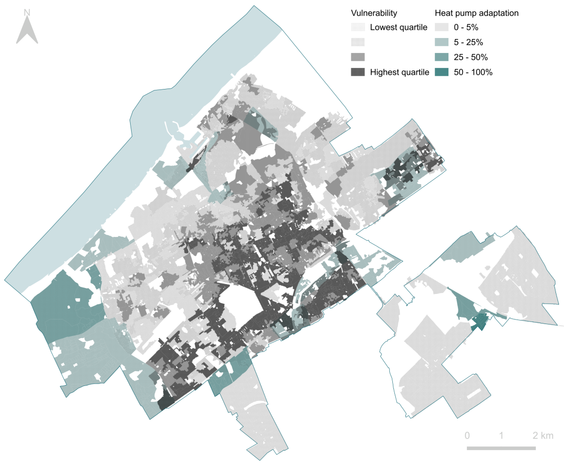
To evaluate the distribution of spatial energy goods through space, the adaptation rates of the technologies are mapped together with the levels of vulnerability, presented in figure 4.6. The patterns of each technology reflect the nature of the policy incentives and how this translates to the spatial distribution.

In the case of district heating (figure 4.6a), the highest adaptation rates are in Ypenburg, Hoge Veld and Binckhost. Ypenburg and Hoge Veld are built in the 1990s and 2000s, with policies in place to develop district heating as part of the development. The development of Binckhorst started more recently, where the redevelopment of the industrial area started in 2017, and therefore incorporates the sustainability targets from the municipality. Within the pre-existing built environment, efforts are made by the municipality, housing corporations and developers which results in adaptation within other neighbourhoods.

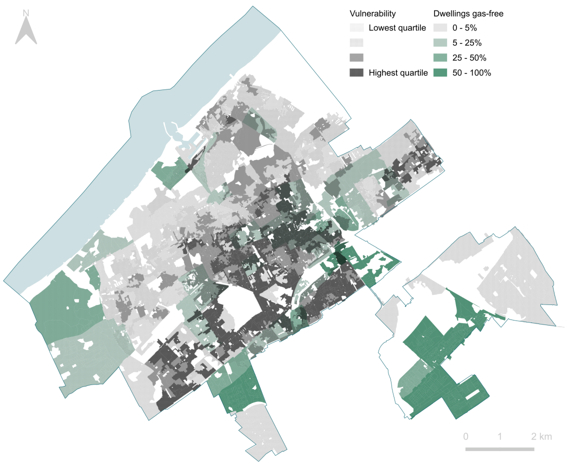
The adaptation of heat pumps is mainly at the outskirts of The Hague (figure 4.6b), and is similar to district heating driven by newer urban developments. As district heating is more feasible with higher building densities, the districts with higher heat pump adaptation rates are assumed to have lower building densities, which are also often the more affluent areas explaining the skewed distribution found between the different vulnerability levels presented in table 4.2. A heat pump for a single tall building is also possible, especially if a timely connection to the heat grid cannot be made or when suitable heating sources are unavailable. This explains a higher adaptation rate around The Hague Hollands Spoor and in Scheveningen, for example.



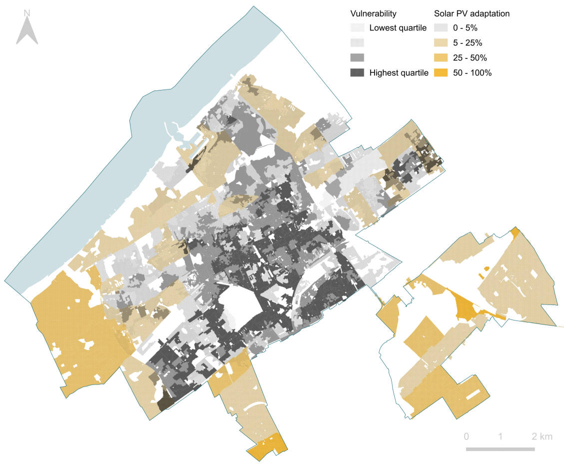
(a) District heating adaptation



(b) Heat pump adaptation



(c) Gas-free dwellings



(d) Solar PV adaptation

Figure 4.6: The spatial distribution of spatial energy goods, compared to patterns of vulnerability. The patterns in the distribution of different clean energy technologies differ due to the nature of the technology, policies that incentivised adaptation and thus who has been able to access them, and where.

On the face of it, the maps for district heating and heat pumps combine into the map for the percentage of dwellings that are fully gas-free (figure 4.6c). This map is the result of the presented logic of both technologies, although the numbers slightly differ. This map reflects the situations where the dwellings are fully gas-free, while the maps of the two different technologies sometimes have residual gas consumption.

The pattern of the solar PV adaptation is interesting because of the reach within the existing built environment. Strongly incentivised with individual subsidies and financial benefits for returning energy to the grid, this drove the homeowners of connected and (semi)detached dwellings to adopt this technology. The adaptation pattern is virtually reversed from the two highest levels in vulnerability to accessing opportunities in the heating transition, where many vulnerabilities also play a part in accessing solar PV, without the barriers of floor size and roof type (both not included in the vulnerability indicator).

While local characteristics in the built environment and sociodemographics might not fully explain the behaviour towards adopting clean energy sources due to missing knowledge of attitudes and social norms, the policy drivers behind them give an understanding of who has been able to access the different technologies, and where. It can be concluded that the policy efforts with distributing district heating do reach the more vulnerable localities in the existing built environment so far, mainly due to the efforts of housing corporations that have properties across different levels of vulnerability in accessing opportunities. It should be noted here, that although reaching the different populations fairly, homeowners and private renters are generally excluded from these efforts. Housing cooperatives have, after all, no obligation to include the surrounding residents in their efforts. There may be a role here for the municipality and/or a heating provider as a co-benefit for transitioning the locality together, to seize the opportunities provided by projects of housing corporations. In contrast, it can be concluded that individual approaches such as subsidies for heat pumps and solar PV lead to the exclusion of those who either don't have suitable dwellings (e.g., apartments), financial resources or personal skills and abilities, leading to skewed distribution through society and space.

4.2.3. Resources for change through policies and social norms

To complement the understanding of the distribution of well-being and spatial energy goods, opportunities are considered that increase access to clean heating technologies. These opportunities relate to the social freedom factors described in section 2.2, regarding public policies (heating transition vision, sustainability targets housing corporations) and social norms (willingness to take energy transition measures and the existence of local energy cooperatives).

Opportunities regarding public policies

Firstly addressing the public policies, where The Hague created a Heating Transition Vision. This vision contains plans for the main heating technology in each administrative neighbourhood for 2040. How their plans are distributed among different levels of vulnerability, is presented in table 4.3.

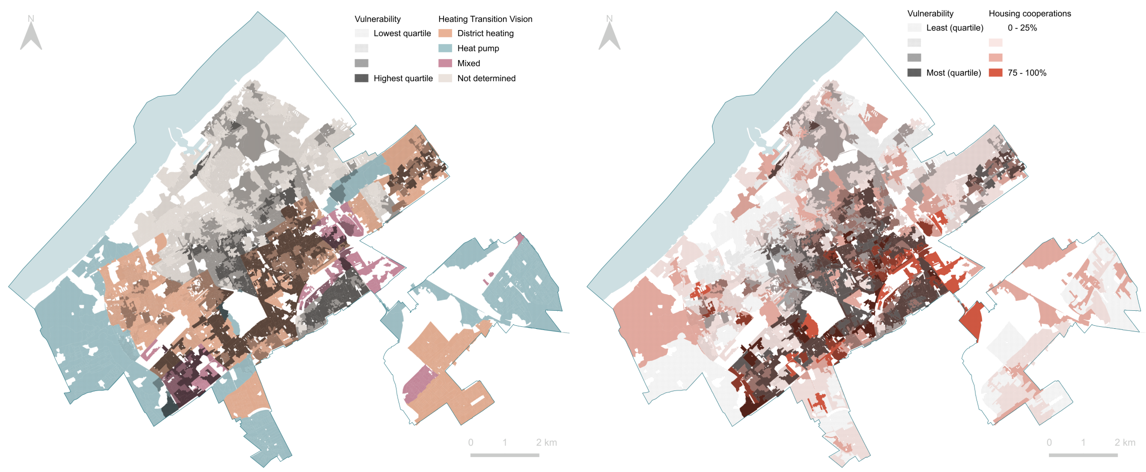
Table 4.3: The top-3 clean heating solutions per vulnerability level, derived from the proposed in the Heating Transition Vision of Den Haag (2022), presented as % of streets.

	Most Vulnerable	**More Vulnerable**	**Less Vulnerable**	**Least Vulnerable**
Number of dwellings	71,049	67,274	68,538	70,780
Number of inhabitants	132,400	125,000	123,000	162,650
Proposed plans for the main clean heating solutions for each neighbourhood in 2040 (Den Haag, 2022), % of streets	• District heating (54.4%) • Not determined (35.8%) • Mixed (9.0%)	• Not determined (48.0%) • District heating (44.7%) • Mixed (6.8%)	• Not determined (62.5%) • District heating (30.2%) • Heat pump (5.6%)	• District heating (35.5%) • Not determined (33.0%) • Heat pump (24.4%)

For the most and more vulnerable levels, the largest share of the streets is assigned to district heating or plans have not been determined yet. The allocation of district heating is a logical distribution as the more vulnerable localities have generally more apartments, and thus higher density making this technology feasible. Regarding the vulnerability in these localities, the implementation plans should recognise the barriers local residents experience, as it might not be straightforward for them to actually opt in when the opportunity is provided. Further, in the localities where a heating solution is not determined yet, the built environment is assumed to be characterised by more environmental unfreedoms, with expectations that follow-up policies will acknowledge these barriers.

For the less and least vulnerable levels, district heating and technology not determined also make up the largest share of the plans of The Hague. This is due to the generally higher building density in cities, as well as the complexity of the built environments in The Hague with lower personal vulnerability determinants. For these levels of vulnerability, it is logical that heat pumps make up a share of the neighbourhood vision, relating to the more affluent and lower-density areas existing within these vulnerability levels.

Regarding the distribution of the policy plans through space, presented in figure 4.7b, the assigned vision for the main clean heating technology in each administrative neighbourhood reflects the logic described in the Heating Transition Vision for assigning technologies. In general, the areas with lower building densities have heat pumps assigned, and areas with higher building densities are assigned district heating. For the areas where the technology has not been determined yet, the built environment is found more complex or large-scale heating sources are unknown, and thus need further study to develop the plans towards 2050. The benefit of the developed plans, which are defined for the outer areas of the city, is that they overlap with the most and more levels of vulnerability. Thereby, a large share of these dwellings is owned by housing corporations, as seen in figure 4.7b. Although housing corporations act on different incentives, they have valuable resources.



(a) Municipal vision for the main clean heating solution

(b) Percentage of dwellings owned by housing corporations

Figure 4.7: The spatial distribution of municipal plans and dwellings owned by a housing corporation, compared to patterns of vulnerability.

The plans of the Hague are an example of what policies lie ahead for the administrative neighbourhoods and localities. In reality, policies related to the heating transition and the insulation are more diverse to enable the heating transition of the residential built environment, with for instance subsidies for living labs, individual subsidies, neighbourhood action plans (in development), and the central government's heating policy in-the-making, where municipality council members could determine which neighbourhoods will be disconnected from the gas network, in what year. Each of these policies changes over time, and could either enhance or lower decline the level of access regarding social freedom factors.

Given the presented considerations, is concluded that the plans developed in The Hague's Heating Transition Vision reach the more vulnerable localities. This is not without consideration that policies and engagement strategies need to be tailored to local conditions to enhance the access of the localities to the heating transition, by recognising the local needs and agency in policy-making. The latter is relevant to enhance the local social freedom factors, relating to public policies, social norms and power relations.

Opportunities regarding social norms

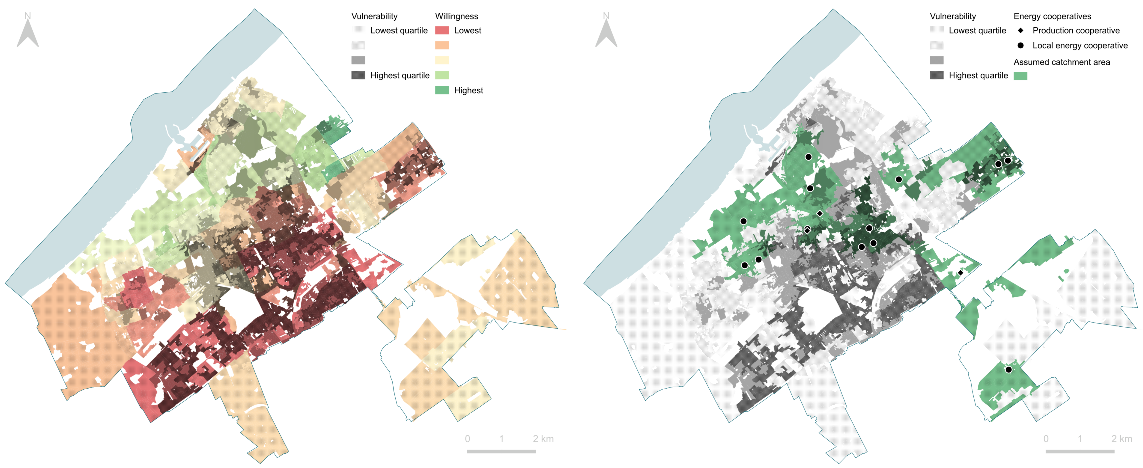
Secondly addressing opportunities relating to social norms, using two indicators on the willingness of people to take energy transition measures and the presence of local energy co-operatives. The willingness of people gives an interesting perspective, as the local attitudes towards the heating transition are more positive, and local residents are more likely to get support from their local environment thus overcoming barriers regarding social norms. Grassroots innovations such as the presence of local energy co-operatives have a broader role, as such community energy initiatives already actively engage local residents and thus, build towards shared social norms. How these two indicators are distributed across levels of vulnerability, is presented in table 4.4.

Table 4.4: Local engagement indicators for the heating transition, with the number of local energy cooperatives (including production co-operations) and the willingness of households to take energy transition measures.

	Most Vulnerable	**More Vulnerable**	**Less Vulnerable**	**Least Vulnerable**
Number of dwellings	71,049	67,274	68,538	70,780
Number of inhabitants	132,400	125,000	123,000	162,650
Cooperatives	5	5	5	5
Willingness	Low-Medium	Medium	Medium-High	Medium-High

How the willingness and local energy cooperatives are distributed through space, is presented in figure 4.8. What catches the attention regarding willingness to take energy transition measures, is that low willingness is spatially intersecting with higher levels of vulnerability. This is not surprising, as the indicators used for constructing the index for willingness, capture the financial willingness to make a personal contribution, whether the household has already made energy upgrades to enhance their indoor comfort, or that they would consider taking measures because of the climate. This does not indicate that people in these localities do not want the benefits coming with the heating transition, such as lower energy bills or better indoor comfort, and thus a demand of justice. It indicates that their personal efforts will not be prioritised towards undertaking tasks regarding the energy transition, which is understandable if people are more vulnerable.

Regarding the presence of local energy cooperatives, it stands out that the locations where these cooperatives are registered are mostly based in the north of The Hague, despite being evenly distributed across levels of vulnerability. This excludes a large and especially more vulnerable part of The Hague from the benefits that such local energy cooperatives bring to these areas regarding local agency and recognition in policy, collaborative decision-making and investment, and shaping norms and perspectives towards positive attitudes towards the heating transition. Therefore, it can be concluded that The Hague as director of the heating transition, can make efforts to initiate and act as a catalyst for enhancing community energy initiatives in those areas.



(a) Willingness to take energy-transition measures (b) Local energy cooperatives and their derived catchment area

Figure 4.8: The spatial distribution of willingness and energy cooperatives, compared to the pattern of vulnerability. What stands out is the spatial overlap between low willingness to take energy transition measures, and the highest vulnerability communities. Local energy co-operations are mostly placed at the boundaries of the more vulnerable areas, or in less vulnerable areas.

In conclusion, opportunities in public policy regarding the plans of the Heating Transition Vision reach the more vulnerable localities in the outer areas of The Hague, being assigned district heating technology. A policy vision for a locality or neighbourhood is insufficient to broaden people's social freedom factors, as the policy tools and incentives must be accessible to the local residents, and not (re)enforce the unequal distributions in individual approaches, found in section 2.3.2. Thereby, it remains to be seen how homeowners and private renters stand towards participating in the transition, as housing corporations have so far taken the leading role in the existing built environment, thus excluding other local residents. Implementation of the vision plans is therefore not without considering the local realities, with regard to local needs and enhancing the agency of local residents, as meaningful citizen engagement is a key factor for transitioning these localities.

Thereby, opportunities regarding social norms present themselves for both willingness to take energy transition measures and the presence of local energy cooperatives in the Northern part of The Hague, and as part of newer urban developments. A large and more vulnerable part of The Hague therefore experiences lower social freedoms, as the attitudes towards the energy transition and individual contribution are less aligned with the municipal goals at hand, and the lack of existence of local energy cooperatives where social norms and perspective are shaped together, and decision-making and investment are made in collaboration. A relevant policy approach is, therefore, to take a leading role in initiating community energy initiatives, due to the benefits that come with collaboration, making the heating transition more accessible in these localities.

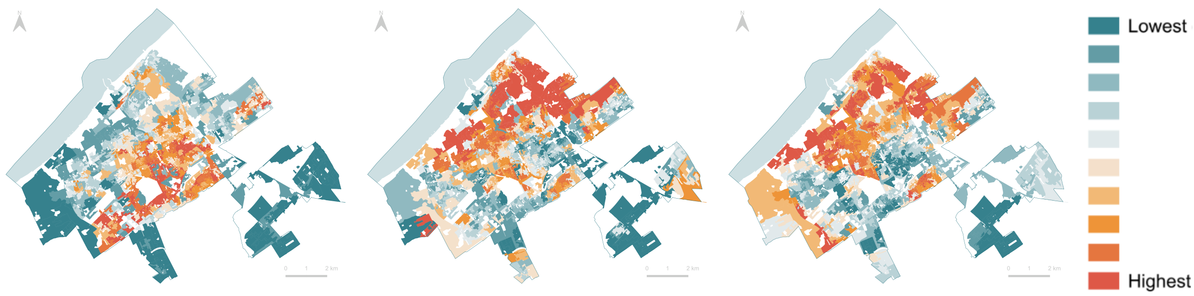
4.3. Procedural justice: Effective policies and resources

This chapter presents the results of procedural justice, consisting of four elements. First, the spatially-sensitive framework for evaluating the distribution of resources is presented (4.3.1). Second, a reflection is given on the catchment areas for different policy rationales (4.3.2). Third, for each of the policy rationales, it is determined how sensitive these approaches are regarding vulnerability, decarbonisation and investment (4.3.3). Finally, combining the lessons in this research, actionable building blocks are presented to enhance collective citizen engagement per policy rationale (4.3.4).

4.3.1. Spatial balance evaluative indicators

This section presents the evaluative framework that incorporates both a social and a spatial dimension besides the usually nonspatial technical and economic indicators. By evaluating the balance between the three indicators for each locality, a tool is created to verify how fair the allocation of resources is through society and space.

The map presenting the balance of the three indicators is created by determining the theoretical decarbonisation of each locality, the investment paired with it for insulation and the clean heating technology, and the level of vulnerability used in previous sections. The computation of each indicator is described in section 3.4.2. Therefore, the deciles of each indicator are firstly presented in figure 4.9.



(a) Vulnerability (b) Decarbonisation (c) Investment (d) Decile

Figure 4.9: Deciles of vulnerability, decarbonisation and investment.

What can be learned from the three separate indicators, is that at first sight the decarbonisation potential and investment needed, follow similar patterns, apart from some localities on the outskirts of The Hague where building densities are lower. A logical result as these peripheral areas have generally higher investment costs due to the dwelling types that are there (e.g., (semi-)detached) and the more expensive heat pumps assigned to these areas by the Heating Transition Vision.

The second conclusion that can be drawn considering the patterns of individual indicators, is that vulnerability for the largest share is inverted to the patterns of decarbonisation and investment, explained by the newer built environment (more energy-efficient dwellings, less investment needed) and that more vulnerable social groups, live in smaller dwellings (e.g., apartments), hence using less gas for heating and lower investment costs. This is considered a limitation of this study, as floor space is not used to create a better understanding of the gas needed for heating the home.

Given the first insights provided by considering the separate indicators, for evaluation, it is relevant to see how these indicators are balanced through space, as it is hard to compare three maps one by one. Therefore, the balanced map of the three indicators is presented in figure 4.10.

The ternary diagram reflects the balance between the three indicators for each locality, standardised as percentiles, with a colour code assigned based on the location in the diagram. These colours are plotted for each locality on the map of The Hague. Vivid colours of the corners represent a strong balance towards that dimension, whereas mixed colours indicate that the locality leans towards two of the three indicators, with the position and colour determined towards which indicator is stronger in that balance. The middle, corresponding to the greyish colours, represents that the three indicators are balanced relatively equally.

Given an allocation rationale where cost-efficient decarbonisation is achieved, localities can be prioritised that are assigned a more green colour. When this allocation rationale includes prioritising more vulnerable localities, this green is mixed towards pink, resulting in orange and brownish colours on the map. An example locality that fits such an allocation rationale, is highlighted in the figure and is part of the administrative neighbourhood Moerwijk.

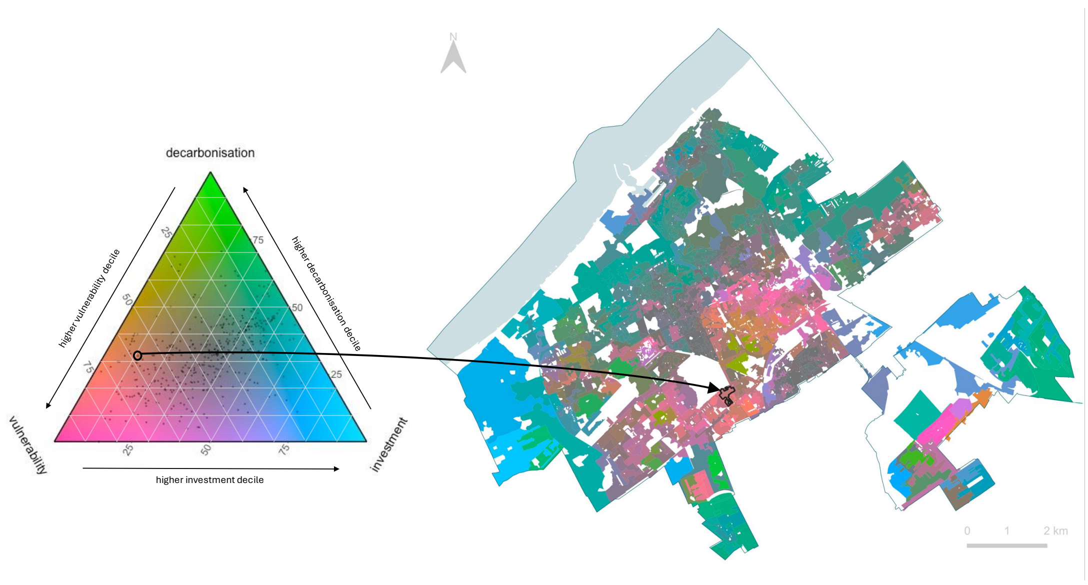


Figure 4.10: A ternary diagram showing the balance between the vulnerability, decarbonisation and investment indicators for each locality. The colours resulting from the location in this ternary diagram are plotted on the map of The Hague.

In conclusion, in the allocation rationale for cost-efficient decarbonisation, sensitive to vulnerability, localities of interest have assigned colours on the green-pink axis, resulting in orange-ish and brownish colours. This logic can be applied to different policy rationales, further elaborated on in further sections. The balanced maps for each policy rationale are included in the policy sheets in Appendix C.

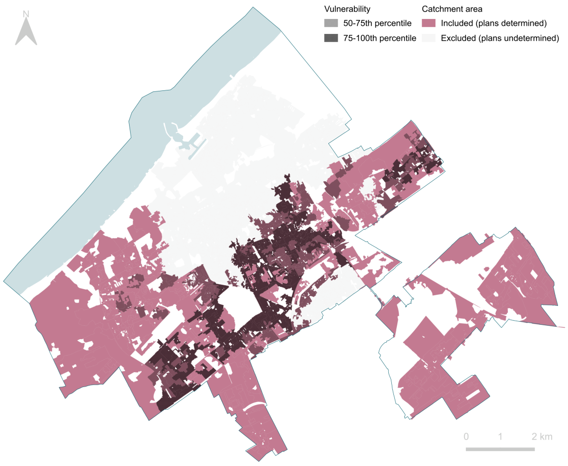
4.3.2. Spatial translation of policy rationales

Determining where policies are effective, and for whom, is a delicate execution as this research assumes nothing about engagement. Therefore, based on underlying data, catchment areas are defined for the different policy rationales. This results in unique emerging patterns for each policy rationale, presented in figure 4.11. These are compared to the spatial patterns of the two highest levels of vulnerability, to obtain a first understanding of which policy rationales cover the distribution of resources across society and space. The extended evaluative framework is included in Appendix C, which incorporates the balance between the vulnerability, decarbonisation and investment indicators to justify the spatial allocation of resources within a policy rationale.

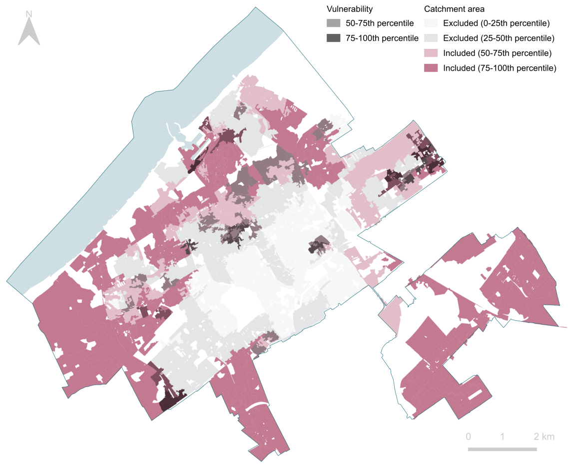
Reflecting on the patterns that emerge for different policy rationales, is that the catchment area for defined plans of The Hague (figure 4.11a) contains largely the outer areas of The Hague, also covered by the policy rationales of linking with the efforts by housing corporations (figure 4.11d) and alleviating energy poverty (figure 4.11f). These policy rationales largely cover spatial patterns of vulnerability.

In contrast, individual subsidies (figure 4.11b, supporting local energy cooperatives (figure 4.11c) and interacting with the willingness to take energy transition measures (figure 4.11e), cover areas where The Hague has not developed a vision yet for the main heating technology. These policy rationales on themselves, cover spatially less vulnerable localities, although there are more vulnerable localities in each of these policy rationales.

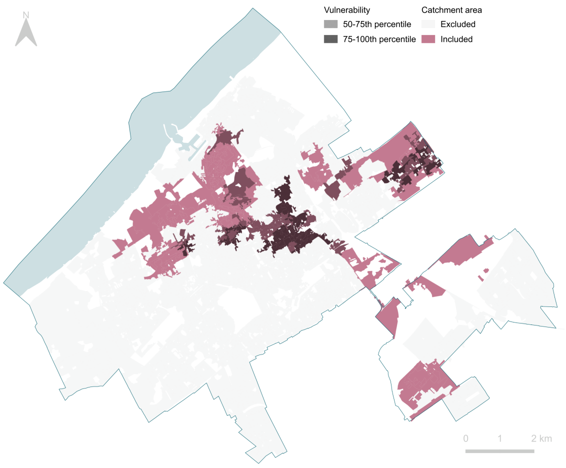
In conclusion, the combination of policy rationales covers almost all of The Hague. Multiple policy rationales might overlap locally, indicating that different approaches could be taken. Policy rationales relating to housing corporations and alleviating energy poverty reach mainly vulnerable localities, although there are also vulnerable localities covered by interacting with local energy cooperatives and localities with a higher willingness to take energy transition measures. This is also the case for individual subsidies, although since the adaptation of solar PV is used as the indicator for this, it is not guaranteed that more vulnerable households adopted solar PV themselves, or that it is the result of urban developments or the efforts of housing corporations. How sensitive each policy rationale generally is towards the three indicators of vulnerability, decarbonisation and investment, is discussed in the next section.



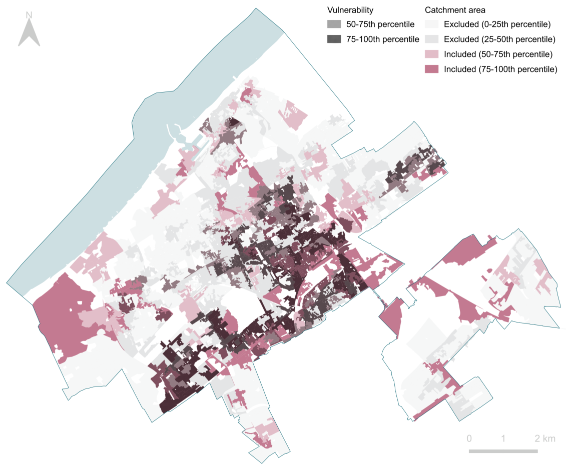
(a) Implement Heating Transition Vision



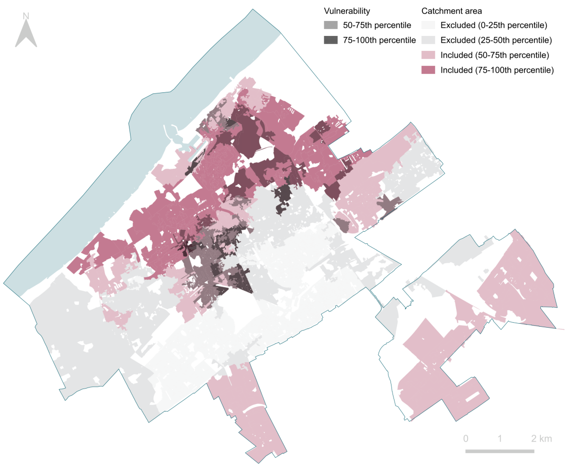
(b) Provide individual subsidies



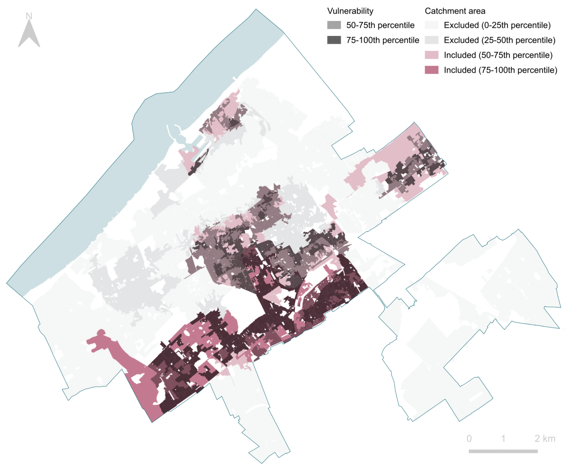
(c) Support local energy cooperatives



(d) Link with housing corporations



(e) Activate willing residents



(f) Alleviate energy poverty

Figure 4.11: Catchment areas of policy rationales. The patterns emerge from underlying data, spatially translating policy rationales without assuming engagement. Compared to vulnerability levels.

4.3.3. Policy balance evaluative indicators

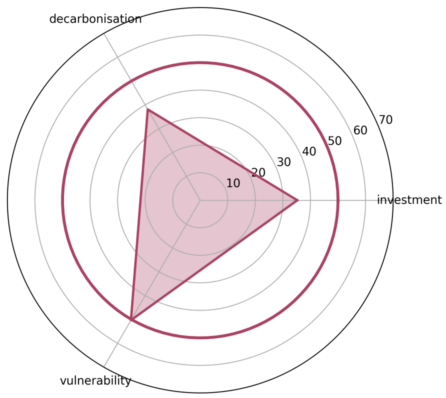
The sensitivity of each policy rationale towards the indicators of vulnerability, decarbonisation and investment are captured in radar diagrams, presented in figure 4.12. With the spatial patterns presented in the previous section in the background, the same conclusion can be drawn that the plans of The Hague, linking in with initiatives of housing corporations and alleviating energy poverties are more effective in covering vulnerable localities.

Bringing in the dimensions of decarbonisation and efforts, for each policy rationale can be derived if these policy rationales also contribute to covering the decarbonisation challenge, and the investments paired with it. Due to the aggregation, and the fact that decarbonisation and investment are highly correlated due to the high investment costs needed for insulation, these indicators are fairly equal to each other across policy rationales. However, the radar diagrams give an overview of how the combination of investment and decarbonisation compares to vulnerability. For local balances in these indicators, capturing the local differences within the three indicators, see Appendix C.

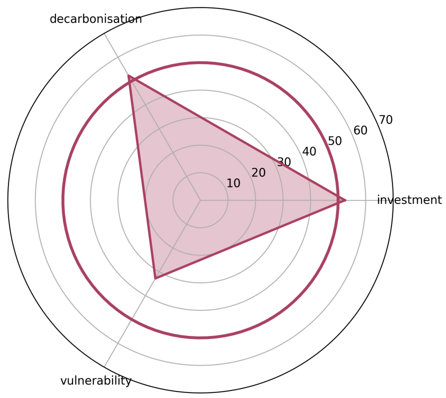
Regarding the plans that cover more vulnerability, differences exist in how effective they are in covering vulnerabilities, as well as covering decarbonisation and the paired investments. Firstly addressing the plans of The Hague (figure 4.12a), the vulnerability indicator is equal to the median of the whole of The Hague, while decarbonisation and investment are relatively lower. The result of the vulnerability indicator can be explained by that about half of The Hague's plans cover the more vulnerable localities, and the other half covers the less vulnerable localities (see figure 4.11a). Therefore, the result for covered vulnerability is in the middle range. The results for decarbonisation and investment are explained by, that in the plans of The Hague, policy visions are assigned for districts that already have transitioned, and thus have little decarbonisation and future investment left. This is an outcome due to the methodological approach, where the adaptation rates as of 2022 were taken into account in the calculation of the indicators, but not in defining the policy catchment areas.

Secondly addressing locking in with initiatives of housing corporations (4.12d), where this policy rationale covers relatively more vulnerability. This is a logical result, as housing cooperatives house relatively more vulnerable social groups, as well that the historical distribution of social housing has taken place across the more vulnerable areas, and a displacement has been found that more vulnerable target groups move away from better neighbourhoods with less cooperative housing, to more vulnerable neighbourhoods with more affordable and cooperative housing (Haag, 2024). As dwellings owned by housing corporations, and assumably surrounding dwellings, fall in the social and lower rental segments, the dwelling types are more often apartments or smaller connected dwellings, and thus having less floor space. This results in both less gas usage and potential decarbonisation due to the smaller dwelling size, as well as less investment needed for energy upgrades due to the dwelling type.

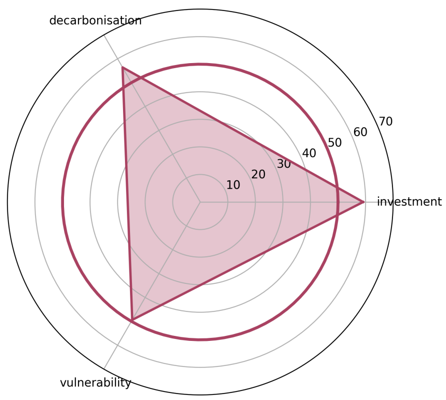
Thirdly, addressing efforts to alleviate energy poverty (4.12f), with this policy rationale covering more vulnerability than housing corporations, but paired with higher decarbonisation and investment but not higher than The Hague median. This is a logical result, as the underlying indicator indicates what share of the population experiences either a low income & high energy costs or a low Income & house with low energetic quality. Generally, these indicators relate to the conditions of lower energy labels and higher energy usage, both included in the vulnerability indicator. Reasoning from these indicators, energy-inefficient dwellings use more gas to heat the home, and more investment is needed to improve the insulation level. As energy poverty is related to income, and lower income groups live generally smaller, these investments do not exceed The Hague's median values for decarbonisation and investment.



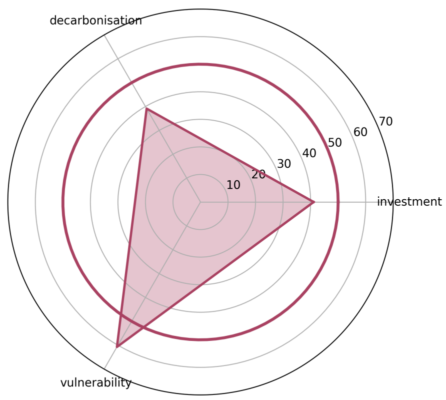
(a) Implement Heating Transition Vision



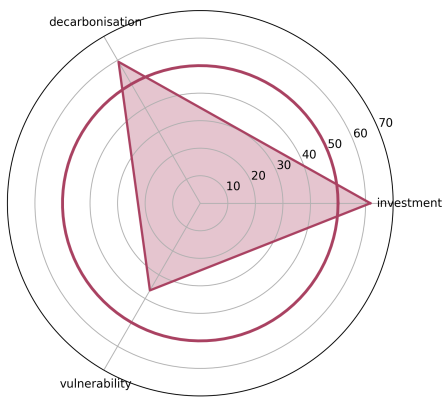
(b) Provide individual subsidies



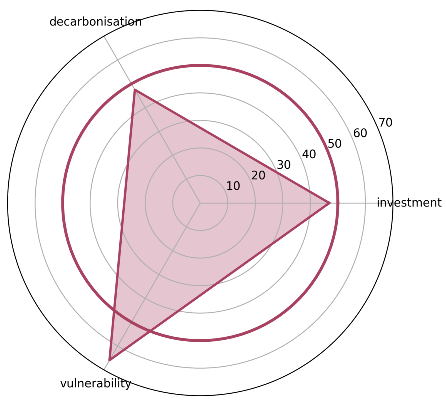
(c) Support local energy cooperatives



(d) Link with housing corporations



(e) Activate willing residents



(f) Alleviate energy poverty

Figure 4.12: Policy coverage plots. The radar charts present the average percentile coverage for each policy rationale, compared to The Hague's median (circle). This uncovers how sensitive policies are towards vulnerability, decarbonisation and investment.

Finally, interacting with local energy cooperatives (4.12c), covers on average the same median value as the whole of The Hague. The decarbonisation and investment are slightly higher compared to the median of The Hague, as the catchment area of local energy cooperatives overlaps with the areas where The Hague has not defined a vision for the main clean heating technologies, due to the more complex built environment. This more complex built environment is characterised by both a higher decarbonisation potential and investment needed, as derived from figure 4.9.

Regarding the plans that cover less vulnerability, differences exist in decarbonisation potential and paired investment needed. On sight, the willingness (4.12e) covers slightly more vulnerability than individual subsidies (4.12b). The main difference is found in the decarbonisation and investment indicators, as the catchment area of willingness covers more of the complex built environment than individual subsidies, where the plans of The Hague have not defined a vision yet and the vulnerability indicator is higher due to these complexities. This more complex built environment is characterised by both a higher decarbonisation potential and investment needed, as derived from figure 4.9.

In conclusion, the different policy rationales cover different proportions for the indicators of vulnerability, decarbonisation and investment. Proceeding with individual subsidies and engaging with willing residents, cover generally less vulnerability and hence, contribute less to a just heating transition. Thereby, the catchment areas of these policy rationales correspond to the more complex built environment, resulting in higher decarbonisation potential and corresponding investment costs. The plans of the Hague and local energy cooperatives cover localities that differ in level of vulnerability, a proportionally just approach, of which the local energy cooperatives have higher relative decarbonisation potential and investment costs, due to the more complex built environment. If the heating transition is used to address socio-spatial inequalities, linking projects with housing corporations and alleviating energy poverty are the most effective approaches, whereof alleviating energy poverty has relatively higher decarbonisation potential and investment costs, due to the energy-inefficiency of dwellings and corresponding investment needed for insulation.

4.3.4. Resources for effective collective citizen engagement

As citizen engagement is key for the success of the heating transition, building blocks are presented to enhance collective citizen engagement per policy rationale, presented in table 4.5. These levels of these building blocks give a direction on how to enhance societal freedoms, as starting point for tailored engagement strategies that foster participatory environments and inclusive participation.

Generally, when several building block levels are on the lower side, more resources for enabling collective engagement are needed to successfully shift from individual to collective decarbonisation efforts. This has implications for policymaking, being per factor:

- The presence of *local energy cooperatives*: Initiate community energy initiatives based on local ownership. This expands the *municipal role* to include brokering of collective citizen engagement;
- Households' *financial capacity*: Support local residents and communities with accessing funding structures such as subsidies, or create accessible municipal funding structures. This expands the *municipal role* to include facilitator of accessible subsidies and (partial) financer of initiatives, depending on the local needs.
- *(Digital) communication structures*: Establishing an appropriate and accessible (digital) infrastructure to share information and receive feedback to incorporate local knowledge, needs and concerns into the implementation plans. This expands the *municipal role* to include facilitating community engagement and co-creation of policy implementation.

Table 4.5: Factors for effective collective citizen engagement. The levels for each factor are derived from the nature of the policy rationale and patterns of distributive effects. When factors are on the lower side, more needs to be invested in building collective citizen engagement.

Factors	**Implement Heating Transition Vision**	**Provide individual subsidies**	**Support local energy cooperatives**	**Link with housing corporations**	**Activate willing residents**	**Alleviate energy poverty**
Local energy cooperatives	Low	Mixed	High	Mixed	Medium	Low
Financial capacity	Mixed	High	High	High and Low	Medium	Low
(Digital) communication structures	Low	Low	High	Medium	Low	Low

Considering the levels of collective engagement factors, it is concluded that resources for collective citizen engagement are lacking for all policies where no energy cooperative or housing cooperation is involved. With municipal support and involvement, the effectiveness of available resources is fostered, as the involvement of municipalities brings the available resources a step further, expands the legitimacy of the initiatives and enhances citizen engagement.

While these practical building blocks give municipalities an idea of what resources to create or improve to foster access to the heating transition, tailored engagement strategies should also include processes that enable a participatory environment and inclusive participation. All efforts regarding these aspects and presented building blocks enhance social freedom factors.

Stepping back from the freedom factors to general procedural justice considerations, tailored engagement strategies should consider local realities, and actively reach out to the more vulnerable voices within a locality. Thereby, given the spatial intersections of different patterns of inequality, from some localities and city parts, a broader scope could be considered that embraces prioritised demands of justice, than the heating transition only.

5 Conclusion, Discussion, and Future Directions

This chapter brings together the findings for the three dimensions of energy justice, with conclusions regarding the research aim drawn in section 5.1. These conclusions are discussed in section 5.2 within the context of existing literature and societal trends. The methodological limitations of this study are presented in section 5.3, followed by recommendations for future research presented in section 5.4. Implications for policy making are addressed in section 5.5.

5.1. Conclusions

This researched aimed to enhance local residents' capabilities in the heating transition, by addressing the three dimensions of energy justice from a spatial and capability thinking perspective, using a computational approach. The three dimensions of energy justice were conceptualised with personal, societal and environmental factors that influence the level of access to opportunities in the heating transition locally. This approach uncovered patterns of inequality and opportunities in regards to recognition justice, distributive justice and procedural justice. For each of these justice dimensions, in subsequent sections the conclusions are presented, followed by a synthesis how these dimensions interact with each other.

5.1.1. Recognition justice

The key question in this study regarding recognition justice is whose needs should be recognised and prioritised, and where. Therefore, close attention is given to what local characteristics regarding sociodemographics and the built environment contribute to the level of local vulnerability. In doing this, we shift from defining the the city through administrative neighbourhoods, to localities that reflect local realities.

The localities were found by employing the max-p regionalisation algorithm, that clustered approximately 15,000 street segments containing information on sociodemographics and the built environment, into 423 local realities. The allocated street segments in each locality are spatially connected, and the localities contain between 500 and 1277 dwellings, have coherent data profiles, are distinct from adjacent localities, and each street segment belongs to only one locality. This result allows further analysis for understanding what defines a locality and how this plays a role in the local vulnerability for accessing opportunities in the heating transition. The following conclusion is drawn:

- **Within and accross administrative neighbourhoods of The Hague exist a variety of local realities. Recognising this is important, as local realities might be averaged out in the neighboudhood statistics, resulting in being overlooked in policy making and the allocation of resources.**

The data profiles of localities allow for visualising the local characteristics, using a scorescard that reflects the values for different indicators relating to age, migration background, household structure, income, home ownership, energy, dwelling type and built period. Some characteristics contribute to vulnerability, determined with factors that exist within the energy poverty literature, adapted to the Dutch heating transition context. These characteristics are highlighted in the scorecard, providing an overview of local characteristics. This provides us with the following conclusion:

- **In each locality, there are prevalent vulnerabilities regarding personal and built environment characteristics, that limit the freedom of local residents for accessing opportunities in the heating transition. These local vulnerabilities should be recognised in policy-making in relation to local heating implementation plans, to ensure that nobody is left behind in the decarbonisation process.**

Thereafter, the seventeen vulnerability characteristics were used to create an index reflecting the level of local vulnerability, which emerged in a spatial pattern of vulnerability, overlapping roughly with The Hague's districts Zuidwest, Centrum, Mariahoeve, Laakkwartier, Spoorwijk and parts of Scheveningen. This pattern of vulnerability is used in the analysis of distributive and procedural justice. In general, the following conclusion can be drawn:

- **By combining all local vulnerabilities, a vulnerability index was created. This index reveals a socio-spatial pattern of vulnerability in accessing opportunities in the heating transition for The Hague. This vulnerability pattern largely overlaps with known socially vulnerable areas, while also bringing forward localities that receive less attention in relation to social inequalities. This implies that some more well-off areas also experience less access to opportunities in the heating transition.**

The above constancy results from the framing of vulnerability in terms of access, with some localities experiencing less freedom for participation due to their personal characteristics (other than social vulnerability) and barriers existing through the built environment.

5.1.2. Distributive justice

The key question in this study distributive recognition justice is how well-being, spatial energy goods and opportunities are distributed accross society and space. To achieve this, the distributional patterns are evaluated with regards to the levels and pattern of local vulnerability in access. The outcomes are interpreted in relation to social freedom factors, relating to public policies, social norms and power dynamics. The choice to take social freedom factors as the analytical framework, is based on the knowledge that spatial inequalities are often driven by structural dynamics that (re)produce such patterns. Although identification of such driving factors nor causality is under study, it is assumed that distributive patterns emerge as outcomes of barriers in the social freedom factors.

Distributive patterns of *well-being* are relevant to consider, as access to energy enables people to achieve other goals, enhancing their well-being. The opposite is the case considering energy poverty, leading to loss of well-being as it affects people's health, inclusion in society, and financial peace of mind, among other things. To evaluate the distribution of well-being accross society and space, four indicators were used: energy poverty, livability, socio-economic status & health. Each of these indicators follow a similar spatial pattern, with The Hague Zuidwest, Schilderswijk and surroundings, and Laakkwartier having lower outcomes on all well-being indicators. These city parts experience generally more vulnerability in accessing opportunities in the heating transition as well. In regards of distributive patterns of well-being, is argued that these patterns emerge from a lack of agency in the *power dynamics*, resulting in that these places are systematically disadvantaged. Therefore, the following conclusion is drawn:

- **The heating transition provides a staring point for elevating disadvantaged areas, but is only successful when addressing the structural dynamics that (re)produce patterns of inequality, for instance for well-being. This implies shifting the policy focus from handing out spatial energy goods to creating opportunities that match the local needs.**

The current distribution of *spatial energy goods* is used to understand who already has access to them, and where. To evaluate the distribution of spatial energy goods accross society and space, four indicators were used: the adaptation of district heating, heat pumps, fully gas-free solutions, and solar PV. These indicators follow each a distinct pattern, appropriate to the technology and *public policies* that incentivised adaptation. Generally, individual solutions such as heat pumps and solar PV are adopted in localities that are less vulnerable, of which solar PV is extending further in the existing built environment. This is in contrast to the adaptation of district heating, that in the existing built environment takes place in the more vulnerable localities. This is to the credit of the efforts by housing cooperatives. These results lead to the following conclusion:

- **Individual solutions have been limitely adapted in places that are more vulnerable, leading to an unequal distribution of these spatial energy goods through society and space. Due to the efforts of housing corporations, district heating is becoming available within the existing built environment and the more vulnerable localities. This is not without notice that in many cases, neighbouring residents do not co-profit from heating projects by housing corporations. This implies that policy efforts need to enable more vulnerable groups that own or privately rent their house, to transition the existing built environment.**

Having addressed power dynamics through the distribution of well-being and public policies through the distribution of spatial energy goods, we expand on the distribution of *opportunities* regarding plans from The Hague's Heating Transition vision, local willingness to take energy transition measures and the presence of local energy local energy cooperatives.

The Hague's Heating Transition Vision contains plans for the main heating technology for most administrative neighbourhoods. As these plans are determined based on building types, urban densities, and the availability of clean heating sources and heating networks, the neighbourhood visions are mainly defined for the outer areas of The Hague. These are not coincidentally also the more vulnerable neighbourhoods, as vulnerable communities more often live in higher density areas, thus suitable for district heating. Although it is clear what lies ahead for these areas, tailored implementation strategies are still in-the-making. These plans are mostly concerned with technological solutions, where local residents and businesses can participate in co-creating those plans, although it remains unclear how this co-creation will look like, and thus whether it will enhance social freedom factors. This brings forward the following conclusion:

- **The heating transition implementation plans for most vulnerable districts of The Hague are in-the-making, often with district heating as main technology. Although these plans will incorporate local input, no clear principles are defined regarding participation and thus whether it will expand social freedom factors through these policy efforts.**

Social norms and attitudes play an important role in the acceptance of energy transition measures. Therefore, the willingness to take measures and the presence of local energy cooperatives are considered to understand differences in social norms, accross society and space. Higher willingness and local energy cooperatives prevail mostly in the northern areas of The Hague, and are thus lacking for the more vulnerable southern districts. Especially the presence of local energy cooperatives is an important aspect, as social norms are created together. The following can be concluded regarding social norms:

- **The presence of local energy cooperatives or other community energy initiatives are important drivers to enhance social norms towards the heating and insulation challenge at face. Such initiatives are currently missing in the southern areas of The Hague, wich experience higher vulnerability in accessing opportunities in the heating transition.**

5.1.3. Procedural justice

Different policy rationales are evaluated for procedural justice, considering whether they would fairly distribute spatial heating goods through society and space. In addition, building blocks are presented that would enhance collective citizen engagement, and thus social freedom factors relating to public policies, social norms and power dynamics.

Six different policy rationales were defined, and for each catchment areas were derived through underlying data without assuming anything about engagement. The policy rationales are: 1) Implementing the plans of The Hague, 2) Providing individual subsidies, 3) Supporting local energy cooperatives, 4) Linking with decarbonisation efforts of housing corporations, 5) Activate local residents willing to take energy transition measures, and 6) Focus on alliviating energy poverty.

Reflecting on the catchment areas of the different policy rationales, is found that the combination of rationales covers almost all of The Hague, with some localities covered by multiple rationales. The rationales that cover spatially primarely vulnerability, are the rationales regarding linking with housing corporations and alleviating energy poverty. The patterns in spatially covered vulnerability differ between the two approaches, where the catchment area of allivating energy poverty corresponds to a few city districts, and housing corporations are more scattered through the city, while also including many localities covered by allivating energy poverty. Rationales that cover both more and less vulnerable places relatively equally, are the plans of The Hague and supporting local energy cooperatives. The rationales of individual subsidies and willingness address generally less vulnerable places, although some vulnerable localities are included. This brings us to the following conclusion:

- **Policy rationales that focus on alliviating energy poverty and linking with efforts of housing corporations, cover spatially mostly vulnerable localities. These rationales are thus promising to ensure that policy resources are allocated to the more vulnerable communities.**

As the main priority of the heating transition is to decarbonise, each policy rationale is evaluated on three indicators, being covered vulnerability, potential decarbonisation and corresponding investment costs. As expected, cover the rationales of alliviating energy poverty and linking with housing corporations relatively the higest vulnerability, with different outcomes for potential decarbonisation and investment. This is due to that energy poverty is measured in relation to gas usage and energy inefficiency of dwellings, both correlated with higher decarbonisation potential and corresponding investment costs for insulation. The policy rationales relating to individual subsidies, supporting local energy cooperatives and willingness to take energy transition measures, have generally higher decarbonisation potential as well as investment costs, due to these policy rationales being related to a more complex built environment and more affluent areas in The Hague, and thus have larger dwelling types. Based on this, the following conclusion is drawn:

- **The policy rationales of alliviating energy poverty and linking with efforts of housing corporations cover generally more vulnerability than other policy approaches. By considering the coverage of decarbonisation potential and paired investment, it can be concluded that alliviating energy poverty covers relatively more decarbonisation with corresponding higher investment costs needed for insulation, compared to linking with housing corporations.**

The policy rationales are evaluated as the overall relative coverage of the three indicators within the catchment area, while the balance between the indicators varies locally. How the balance between the three differ locally is included in policy sheets available in Appendix C. From these policy sheets, it can be evaluated in which localities the most decarbonisation can be achieved cost-effectively, in relation to coverage of vulnerability. This results in the following conclusion:

- **The balance between local vulnerability, potential decarobisation and needed investment varies between localities. This results in a subset of localities in each policy rationale, where cost-effective decarbonisation can be achieved in conjunction with covering vulnerability.**

Knowing how effective each policy rationale is for covering vulnerability and decarbonisation, the question remains how collective decarbonisation efforts can be realised. Therefore, levels of three key factors are considered that enable collective citizen engagement, enhancing social freedom factors: the presence of local energy cooperatives, financial capacity and (digitial) communication structures. When resources are low of one or more factors, the implication for policy makers is to take on new roles that concern building these resources to enhance collective citiszen engagement. Generally, the factors are higher where housing corporations or energy cooperatives are involved. This brings forward the following conclusion:

- **Generally, there are few resources present that facilitate collective citizen engagement beyond the resources of existing housing corporations and local energy cooperatives. Developing these resources should be taken up by the municipality to realise the benefits of collective decarbonisation efforts. This requires the municipality to take on new roles within the heating transition, where they operate as brokers of citizen engagement.**

5.1.4. Synthesis of energy justice dimensions

Given the conclusions drawn in previous sections, three overarching lessons can be derived to enhance local residents' capabilities, to achieve a more just heating transition. The first lesson relates to ensure that nobody is left behind in the decarbonisation process. A variety of local realities exist within and across administrative neighbourhoods, with local vulnerabilities at risk to being overlooked in neighbourhood-level plans. Given the current public policies and policy incentives, certain local communities lack access to opportunities in the heating transition. These are especially the more vulnerable homeowners and private renters, as they fall out of the scope of projects led by housing corporations in their living area. Therefore, the first overall lesson is:

- ***Current policies do not reach all vulnerable groups*. Policy tools are lacking that make the heating transition accessible for more vulnerable homeowners and private renters. Thereby, in administrative area-based approaches, local realities can be overlooked, leading to insufficient consideration of local vulnerabilities.**

The second lesson is concerned with distributing opportunities that enhance access to the heating transition. As vulnerability in access differs accross space and spatially intersects with well-being inequality, policies should aim for systematic solutions that bend dynamics causing patterns of inequality. Therefore, it is not sufficient to aim for fair distribution of spatial energy goods, or keeping the policy scope to only cover the goal of achieving decarbonisation. Given the conclusions regarding distributive effects, for the more vulnerable areas is found that driving factors of inequality might relate to differences in outcomes due to the nature of public policies, differences in local social norms and lack of local agency in power dynamics. Therefore, the second overall lesson is:

- **Distributing opportunities that enhance access to the heating transition, over the fair distribition of spatial energy goods, can contribute to bending dynamics that cause socio-spatial inequalities. To achieve this, special attention needs to be given to the nature of public policies, local social norms, prioritised demands of justice, and local agency in power dynamics.**

The third lesson has to do with expanding local residents' capabilities in the heating transition. Based on literature, it is concluded that the presence of local energy cooperatives contributes the progress of the heating transition, while fostering communities' social freedoms factors. In addition, they have tools at their disposal to facilitate collective engagement. As not all of The Hague currently has access to this resource, especially the more vulnerable areas, the third overall lesson is:

- **Local energy cooperatives contribute to collective decarbonisation efforts while guranteering local agency regarding public policies, shaping social norms and engaging in power dynamics. This factor could contribute significantly in improving vulnerable communities' access to opportunities in the heating transition.**

5.2. Discussion

This study successfully uncovered patterns in spatial inequalities regarding the three dimensions of energy justice, conceptualised with personal, social and environmental freedom factors from the capability approach, examined through a data-driven approach. This research created an analytical framework that uses the recognition of local realities in terms of personal and environmental barriers to participate in the heating transition, to determine the level of local vulnerability for accessing opportunities in the heating transition (*recognition justice*). This level of vulnerability was used to address socio-spatial inequalities in the distribution of well-being, spatial energy goods and opportunities in terms of local social freedom factors, relating to public policies, social norms and power dynamics (*distributive justice*). The outcomes of recognition and distributive justice gave a baseline to define six policy rationales, and to evaluate where and how effective these rationales are considering how much vulnerability, decarbonisation and investment is covered. Thereby, actionable building blocks were identified to enhance local collective engagement for each policy rationale, a key factor for the success of the heating transition, including implications for the role municipalities have in the heating transition (*procedural justice*).

The *scientific contribution* is threefold. Firstly, this research contributes by conceptualising all three dimensions of spatialised energy justice through conversion factors[1] from the capability approach, where relatively procedural energy justice has been under-examined (Melin et al. (2021)). The conversion factors are useful for conceptualising dimensions of energy justice, since they help to understand and address the different ways people experience access to energy resources, focusing not only on distribution of spatial goods, but also on enabling equitable opportunities and freedoms. Melin et al. (2021) describe that attention to these factors contribute to more equal and fair outcomes in access to energy goods, with Frediani (2021) calling for interventions that address uneven distribution of burdens and opportunities. In our interpretation, we relate these conversion factors to the structural dynamics that (re)produce patterns of spatial inequality, as theories on spatial justice argue for the shift from distributing spatial goods to distributing opportunities to break these spirals (Soja, 2010, Bouzarovski and Simcock, 2017, Garvey et al., 2022). Although we are advancing towards the application of conversion factors to enhance freedoms and opportunities in city-making and specifically the heating transition, our research scope covers only a small part of all the processes that have thus far shaped our cities, and many other perspectives and conceptualisations exist, further elaborated on in the sections on limitations (5.3) and recommendations for future research (5.4).

Secondly, this research contributes by enabling a local understanding of the freedoms people have in their living environment. The difference in opportunities differs through space, and multiple realities exist within administrative boundaries. Vulnerabilities in these local realities could be underexposed in research and policy making, when the focus lies on understanding outcomes and opportunities in administrative zones. This is due how these boundaries are established, as they are not related to the tasks at hand (such as, the heating transition). An analysis on administrative zone-level could inherently have problems known as the neighbourhood effect averaging problem (Kwan, 2018), the modifiable areal unit problem, aggregation bias or ecological fallacy, among other things (Duque et al., 2007). The local realities are uncovered by using a bottom-up approach where we employ the max-p regionalisation algorithm, that ensures geographical coherence in these localities, optimising for coherent data profiles and aiming for minimal aggregation given a spatially extensive attribute (Duque et al., 2011, Wei et al., 2020). This minimises the problems listed that normally exist in neighbourhood delineation. Thereby, we have as of today not found any academic literature applying the max-p algorithm for neighbourhood delineation, as most related research efforts are made in regards to creating novel algorithms for new applications.

The third contribution relates to the methodology created to uncover spatial patterns of inequality in accessing opportunities for all three dimensions of energy justice, with the dimensions being intertwined in analysis. Previous research addressing the dimensions of energy justice from a critical spatial perspective provided a theoretical framework serving as basis for our analysis (Bouzarovski and Simcock, 2017; Garvey et al., 2022). This research includes mention for the need for creating spatially-sensitive instruments that address inequalities in opportunities and underlying structural dynamics that cause patterns of inequality, what we achieved in this research. Similar efforts were made by Kraaijvanger et al. (2023), where this research distinguishes itselves by using conversion factors from the capability approach, as opposed to (perceived) behavioural control the Theory of Planned Behaviour to explain inequalities in accessing opportunities in the energy transition, besides de difference in focus in terms of technologies. The benefit we experienced using conversion factors, is the disaggregation between personal, social and environmental factors that influence access to opportunities.

The *societal relevance* of this study lies in its potential to see the heating transition as one that can alleviate disadvantaged areas and reduce spatial inequalities, by shifting the focus from the distributing spatial energy goods (e.g., district heating or heat pumps) to distributing opportunities that enhance the capabilities of local residents. Many policies focus on handing out technological or spatial solutions to disadvantaged areas in effort to reduce inequalities, while the difference might be in facilitating local

[1] In this research the conversion factors are refered to as freedom factors, to prevent confusion with energy conversion.

agency and recognition in policymaking, among other things. That making spatial goods available do limetly contribute to systematically alleviate disadvantaged neighbourhoods, is due to that such approaches do not address structural dynamics that (re)produce socio-spatial patterns of inequality.

Despite spatial inequalities growing in cities all accross Europe, there is still little understanding of how to overcome and reverse underlying processes. In efforts to reduce inequalities, municipalities generally make efforts in the social domain, and apply spatial interventions paired with urban (re)developments to make the infrastructural interventions feasible. In the latter, it is too little understood how this affects local communites in the long run, and whether these developments and interventions cause new vulnerabilities (e.g., regarding housing affordability or gentrification).

Given the recent societal and political developments, where people feel their problems are not recognised in public policies and trust in institutions is decreasing, it is more relevant than ever to recognise local realities and give local residents the agency to express their needs and providing them with resources to change their home environment in a way that benefits them and expands their well-being. Despite many vulnerable people having little concern about the climate, especially due to other things to worry about, everyone deserves an adequate home that does not drive them into high energy costs. This research aimed to give a start in thinking about local needs and opportunities, and to provide new pathways to a just heating transition.

5.3. Limitations

While successfully uncovering patterns of inequality for each dimension of energy justice, choices in this research come with their limitations. Generally, results for reognition justice are used to understand patterns of distributive and procedural aspects of justice, and an approach departing from another dimension of energy justice could provide other perspectives and outcomes. In addition, an approach from other justice domains could give a fruitful analysis of how decarbonisiation efforts link with for instance, housing affordability and adequate housing (housing justice), or exposure to extreme tempratures (climate justice).

Further, the conceptualisations of each dimension of energy justice and how these are impelemented are an first approach to eploy a data-driven, spatially-sensitive approach to the dimensions of energy justice, enriched by capability thinking. This could have been done in many ways. Therefore, for each dimension of energy justice, the limitations and possible improvements are presented.

Recognition justice. Local realities in terms of unfreedoms through personal characteristics and the built environment are chosen as a starting point, to create an understanding of socio-spatial patterns of vulnerability in accessing opportunities in the heating transition. These local realities are determined by data availability on a small spatial scale, and while many relevant characteristics were included, an improvement could be achieved by for example including information on floor size, roof type, building heights, and other spatial densities. Including such data would improve defining locality boundaries, but is not expected to result in significantly different patterns of socio-spatial vulnerability in access, due to the correlation between included and not-included characteristics. Thereby, as with every spatial aggregation method and data availability, the identified localities are not perfect. This does not detract from the fact that realistic patterns have been found for inequalities in recognition, distribution and procedural justice.

Further, due to the analysis on a small spatial scale, less variety within socio-demographic characteristics was available. This interferes minimally with determining socio-spatial patterns in vulnerability to access opportunities, but does interfere with interpreting what is actually going on in a locality given specific factors regarding personal or environmental freedom factors (see for instance, the vulnerability factors to energy poverty used by Robinson et al. (2019)), and whether local vulnerability is unevenly distributed across gender (Robinson, 2019). Thereby, due to the place-based charachteristics used to create localities, these identified localities do not reflect social ties that normally exist within communities (e.g., home owner associations (VVE), community meeting places or local iniatives). An approach from communities is relevant, given the level of social cohesion and how this relates to social freedom factors.

Lastly, the vulnerability index is created by treating all vulnerability indicators equally, while in reality some aspects could contribute more to unfreedom in accessing opportunities than others. Thereby, the indicators were standardised with percentiles before averaging all indicators in the aggregation. The above results in easy interpreation of measure of relative vulnerability, overcoming data problems regarding outliers, skewed distributions and indicators with different scales. This approach might be less ideal for policy decisions, where absolute values of vulnerability are preferred.

Distributive justice. The distributive effects are eveluated with the spatial pattern of level of local vulnerability. While general and telling distributive patterns are derived, in understanding local realities the distribution within localities should be acknowledged, as the distribution of well-being, spatial energy goods and opportunities might differ between households. Thereby, only a set of indicators is employed in this study, and given another angle other distributive indicators might be relevant (e.g., relating to social freedom factors such as social capital or community initiatives, or envinmental freedom factors relating to for instance, the urban heat island effect, with relevance for insulation). The distributive effects in this research have been interpretated with regards to social freedom factors (e.g., public policies, social norms and power dynamics), and the spatial intersections with vulnerability. Therefore, it does not assume any causality, but addresses outcomes of structural dynamics that (re)produce patterns of spatial inequality.

Procedural justice. Regarding procedural justice is a less localised and more general approach taken, to enable evaluating different city-wide policy rationales in their potential to cover vulnerability, and which resources to allocate to enable collective decarbonisation efforts. The catchment areas of different policies are defined generally, based on underlying data without assuming engagement, and could be improved by a more elaborate policy design. The spatial coverage of used policy rationales is, however, telling due to the relation with the distributive effects and corresponding findings regarding social freedom factors.

As the effectiveness of policies largely depends on meaningful citizen engagement, for each rationale the levels of building blocks are presented as starting point for tailored collective citizen engagement strategies. As engagement and local resources for engagement differ through space, our analysis only provides a starting point for further in-depth study of local conditions, including building a more elaborative framework of factors to consider for collective citizen engagement.

5.4. Recommendations for future research

Given the limitations presented in previous section, we distil some relevant recommendations for future research. Firstly, the conceptualisation of the energy justice dimensions can be revisited, and approached from other academic fields. New conceptualisations bring forward new perspectives on how to enhance local residents' capabilities and better understanding of structural drivers that (re)produce patterns of inequality, that were not addressed in this research.

Secondly, as a just transition should incorporate local needs and realities, an approach focusing firstly on spatial procedural justice is highly recommended. This gives a starting point to create better understanding of local social freedom factors, with the goal of expanding local residents' agency regarding public policies, social norms and power dynamics. This is especially given in through our believe that local agency contributes to bending strucutral dynamics that create patterns of inequality, and thus prevents unwanted societal effects in the long run.

Thirdy, we recommend to redefine the spatial unit of analysis from localities in terms of coherent socio-demographic and built environment characteristics, to communities in terms of social coherence. Spatial communities as analytical unit will on it's turn open up opportunities to explore collective citizen engagement in transitions, as key factor for fostering local needs and enhancing local well-being.

Finally, as our cities are shaped by a wide variety of structural dynamics, we encourage to uncover similar patterns of inequality in opportunities and barriers for different spatial fields, related for instance to climate, housing and transport, and how these might intersect and interact with each other.

5.5. Recommendations for policy making

Following from the overarching conclusions, we draw up three implications for policy making that would enhance access to the heating transition for the vulnerable groups, who are otherwise prone to be left behind in the decarbonisation process. As we conclude that the development of district heating is reaching more vulnerable localities, we find that through the policy incentives behind it, that mainly social renters have access through the efforts of their housing cooperation. This in itself is very valuable as it reaches vulnerable population groups, but the question remains how neighbouring homeowners and private tenants can also be included in these heating transition efforts. This brings forward the first recommendation for policy making:

- **Link policy resources with the efforts of housing corporations to include surrounding homeowners and private renters in the heating transition, as properties of housing corporations are often located in vulnerable places.**

In order to alliviate disadvantaged areas, policies should focus on enhancing access to opportunities in the heating transition, rather than fairly distributing clean heating technologies. This is due to that there are complex spatial dynamics driving the (re)production of spatial inequality, such as the lack of local agency and recognition in public policy and power dynamics. This results in that local needs might be overlooked, and contribute less in improving well-being of the local residents. Therefore, the second recommendation for policy making is:

- **Treat the heating transition as an opportunity to structurally alleviate disadvantaged areas, that fosters local agency in order to bend structural dynamics that (re)produce patterns of inequality.**

Collective citizen engagement is a key factor in the transition towards a gas-free built environment, and current policies do not address how this might be achieved. Collective engagement is enabled through community initiatives, financial capacity and (digital) communication structures. A promising structure that fosters these factors and local agency, are local energy cooperatives. The analysis found that these largely do not exist in more vulnerable areas of The Hague, and therefore the third recommendation for policy making is the following:

- **Initiate local energy cooperatives in vulnerable areas of The Hague, as such structures foster local agency and alliviate barriers that might exist locally, such as social norms towards the heating transition or the inability to make individual investments.**

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A

Description of datasets

A.1. Street-segment level dataset

A.1.1. Geometries & administrative attributes

As data is available on different spatial scales, we made the decision to aggregate all available data on the street segment-level. This street segment-level dataset is created by first, splitting streets (six-digit zip codes, PC6) that are disconnected into separate segments. The main reason to use disjoint street segments, is that we employ an algorithm with a spatial contiguity constraint, and it would interfere with which streets would be considered 'neighbours'. Thereby, it improves connections to other datasets, as sometimes the same six-digit zip code exists in multiple administrative boundaries, and building characteristics differ between disjoint street segments. We determine the administrative zoning information for each street segment by a spatial join on the largest overlap only, so that each street segment belongs to only one neighbourhood, district or municipality.

A.1.2. Built environment attributes

The publically available datasets of the BAG are used for the building unit-level datasets. The BAG contains the official data of all addresses and buildings in The Netherlands, such as year of construction, surface area, purpose of use and location (Kadaster, 2024), and we downloaded the GeoPackage containing the data sets on May 1st 2024. As we are concerned with the situation in 2022, we exclude data on buildings that were built after 2022. From this BAG dataset, the following attributes are used for further analysis:

- The **year of construction** is relevant as the **built period** is derived from it, defined based on the history of building regulations in The Netherlands, that state what a building must comply with, e.g. in terms of energy efficiency. Buildings built in the same period therefore need similar technological upgrades to make the property more energy-efficient.
- The **purpose of use**. The BAG has 11 distinct classes of usage, among others living, shopping, health care, working, and industrial. When an area is more mixed in functions, different types of owners are involved who have different needs, interests and incentives regarding the heating transition.
- The **number of objects per building** is relevant as in The Netherlands, often permission must be asked from the association of owners (VVE) to make larger adjustments to your property when the building is shared. Thereby, it indicates whether the building height is low-, mid- or high-rise.

In addition to the above information, more characteristics are derived by either computational efforts or connections to other datasets. The following characteristics were added to the building-unit dataset:

- The **dwelling type**, determined on the rules described by Kadaster, n.d., that classifies each building into either apartment, corner house, terraced house, semi-detached house or villa, based on the number of units in a building and spatially connected neighbours of buildings. The building classification is thereafter appended to the dwellings within the building.

- The (estimated) **energy label**, by completing the incomplete measured energy labels data set with estimated values:
  - The **measured energy label**. The central government maintains a publically available dataset of measured energy labels on dwelling-level, which is not completed yet (Rijksdienst voor Ondernemend Nederland, 2019).
  - The **estimated energy label**, based on the *year of construction* and *dwelling type*, using a classification table by the environmental assessment agency (Planbureau voor de Leefomgeving, 2012).
- The **investment for insulation improvement to B+**, using key figures for insulation investments from the VESTA MAIS model of the environmental assessment agency (Planbureau voor de Leefomgeving, 2012), based on *dwelling type* and *energy label*.
- The **dwellings with monumental status** are determined based on spatial intersections with shapefiles maintained by the state department for cultural heritage that indicate if the building is a monument (Rijksdienst voor het Cultureel Erfgoed, 2019)
- The proposed **clean heating solution**, derived from a spatial intersection with neighbourhood plans in the heating transition vision of The Hague (Den Haag, 2022), including the individual financial contribution for district heating connection, a heat pump or the average between the two when the plans are mixed or not determined.

More datasets contain valuable information for describing the built environment emerging from building characteristics, such as 3D BAG (building height, roof type) and Rudifun (spatial densities such as MXI, L, FSI, GSI). We chose not to use these datasets because we did not deem them relevant in the context of the heating transition, experienced aggregation issues (Rudifun is available on the building block-level), or could use proxies (e.g., function mix or units per building).

We append the above-described building-unit level information to our main street segment-level dataset by appending the count or average value of each characteristic appended in the building unit-level dataset, based on the nature of the indicator, using spatial joins.

A.1.3. Sociodemographics & energy attributes

Our second primary dataset is on the zip code-level. The national publically available datasets of the Census Bureau are used for this, primarily the six-digit zip code dataset (PC6), where the five- and four-digit zip code data sets (PC5, PC4) are used to handle missing values. These data sets contain key figures on inhabitants, private households, housing, energy, income, social security, densities and distance to facilities (Centraal Bureau voor de Statistiek, 2024). From the zip code-level datasets, mainly the attributes about socio-demographics, housing ownership structures, and energy are maintained and used in further analysis.

The more detailed the spatial resolution, the more values are hidden due to privacy regulations. Therefore, we replace the hidden values with values of coarser spatial resolution. For this process, we first cleaned our datasets, and then used the PC4-level dataset to handle hidden values on the PC5-level, and thereafter used this dataset to handle hidden values on the PC6-level. Thereafter, we append this data to the main street segment-level dataset, based on a join with the six-digit zip code (PC6).

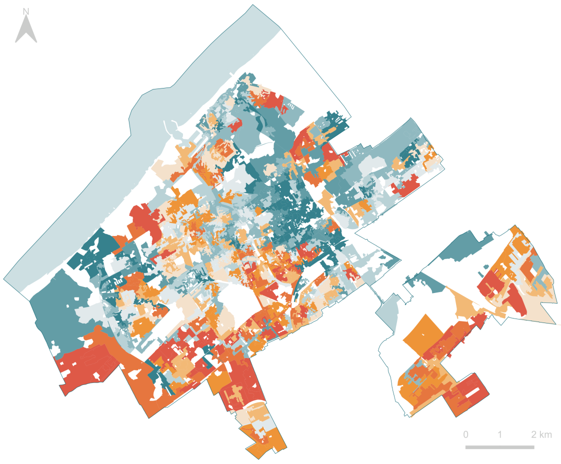
A.2. Connection to other datasets

The described data in the previous section is used to find localities. As we are concerned with distributive effects, we use several datasets regarding well-being, spatial goods and resources. Most of this information is available for administrative zones. We use zoning codes to join with the other dataset on either the six-digit zip-, neighbourhood- or district code. The variables appended to the street segment-level per distributive category are:

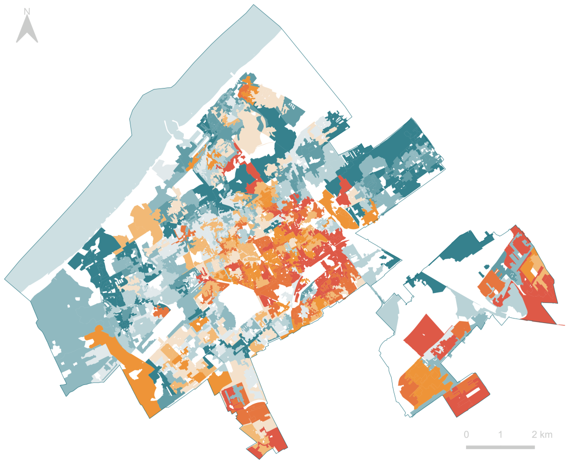
- Well-being
  - **Energy poverty**, measured by either having a Low Income & High Energy Costs (LIHC) or Low Income & house with Low Energetic Quality (LILEQ) (available per neighbourhood, provided by TNO (n.d.), based on the work by Mulder et al. (2023));
  - **Livability**, using the Leefbarometer, an instrument governmental to estimate liveability on different spatial scales (ranging from 100x100 metres to municipalities), for the whole of the Netherlands. The composite indicator includes a wide range of characteristics about the residential environment, grouped into five classes: housing stock, physical environment, facilities, social cohesion, and nuisance and insecurity (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2019);
  - **Socio-economic status**, using the SES-WOA score, reflecting the socio-economic status scores for each neighbourhood, based on financial wealth, educational levels and recent employment history of households (Centraal Bureau voor de Statistiek, 2023b);
  - **Index for general health, resilience and social solitude** using indicators from the Health Monitor Adults and Elderly 2022, which includes neighbourhood-level information regarding health and health-related topics (RIVM, 2022). We created an index by aggregating the three indicators by transforming the data for consistent directions, computing the deciles and averaging the three indicators.
- Spatial energy goods
  - **Adaptation of district heating, heat pumps and fully gas-free solutions**, as percentage of dwellings that have adapted district heating, heat pumps and fully gas-free solutions (regardless of the chosen solution) (Centraal Bureau voor de Statistiek, 2023c)
  - **Solar PV adaptation**, as percentage of dwellings with registered solar panels (Centraal Bureau voor de Statistiek, 2021a)
- Resources for future opportunities
  - **Proposed plans for the main clean heating solution** for each neighbourhood in 2040, based on the Heating Transition Vision (Den Haag, 2022).
  - **Willingness to take energy transition measures:** as summed score of 5 indicators that reflect different attitudes to willingness to take energy transition measures, with levels low (1), medium (2) and high (3) (Centraal Bureau voor de Statistiek, 2022b; Centraal Bureau voor de Statistiek, 2023a).
  - **Energy cooperatives** Location of registration of local energy and production cooperatives, on the six-digit zip-code. We assume that all cooperatives operate on the neighbourhood level, to determine where they have influence. Although, some might operate in larger administrative zones (HIER, n.d.)

B

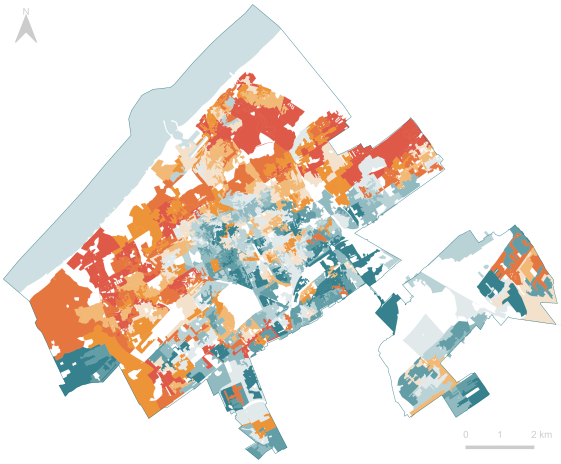
Vulnerability indicators



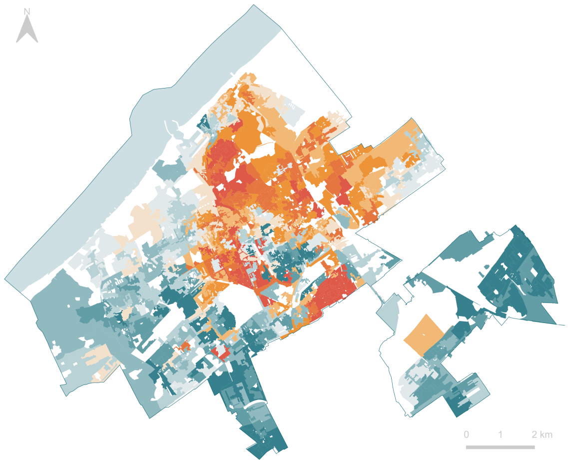
(a) 0 to 15 year-olds



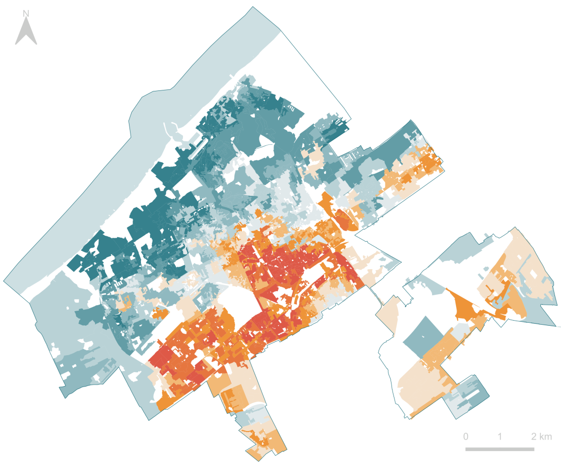
(b) 15 to 25 year-olds



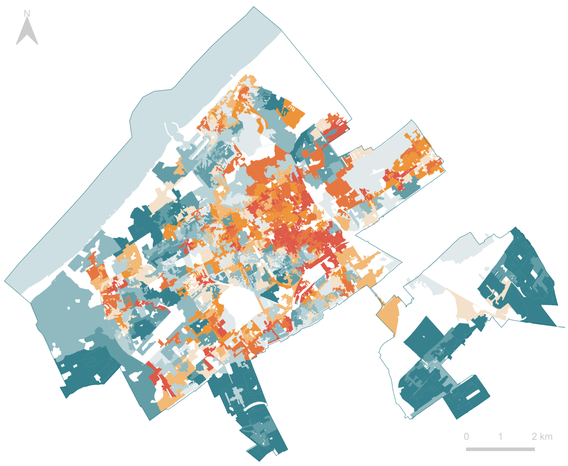
(c) 65 years and older



(d) European migration background

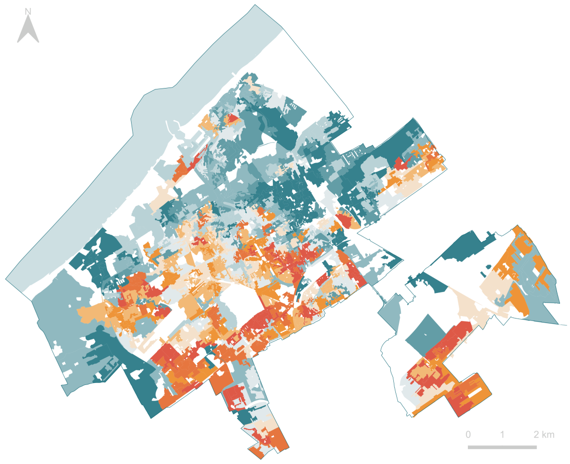


(e) Non-European migration background

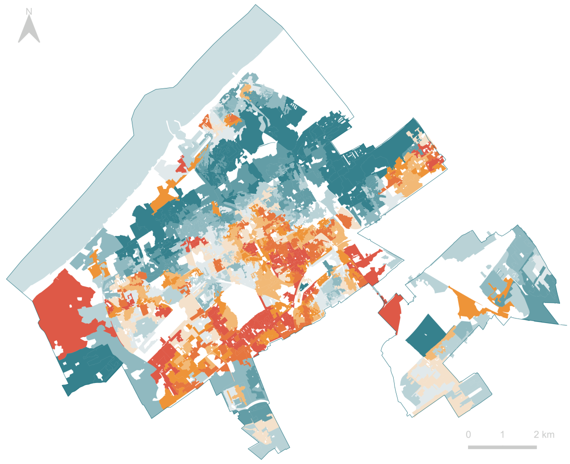


(f) Single person households

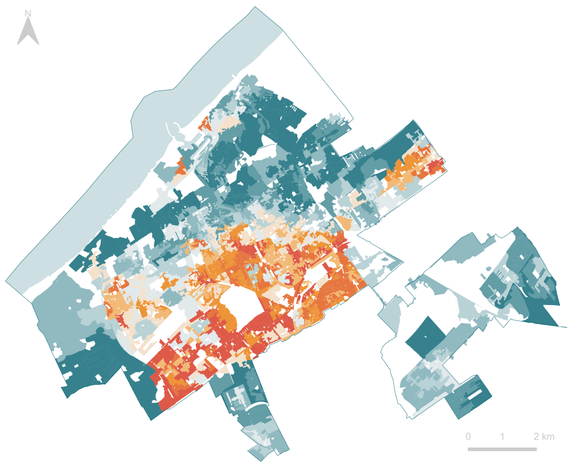
Figure B.1: 10% deciles of each vulnerability indicator, with blue indicating low occurrence and orange high occurrence.



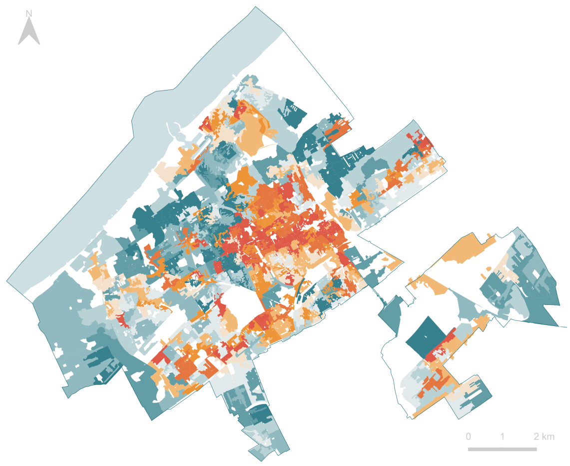
(a) Single parent households



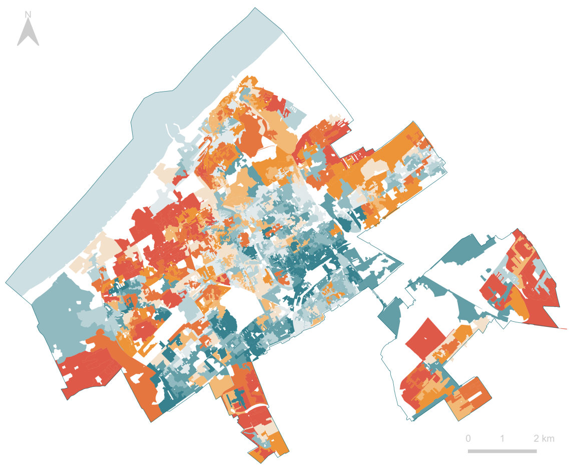
(b) State benefit receiptants before retirement age



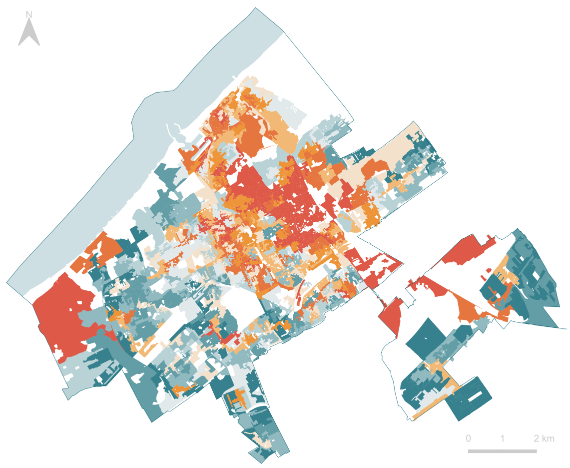
(c) Low property valuation (proxy low income)



(d) Private renting

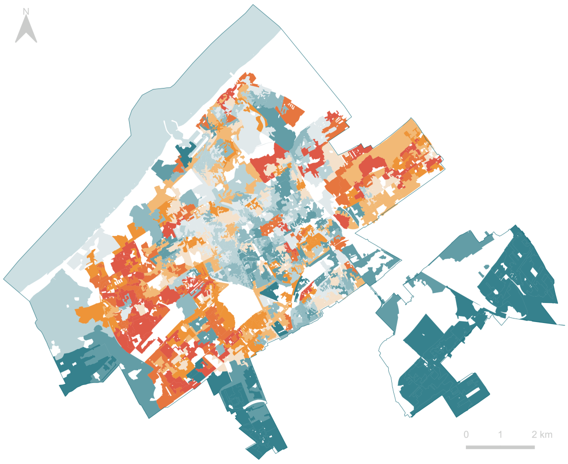


(e) Different owners

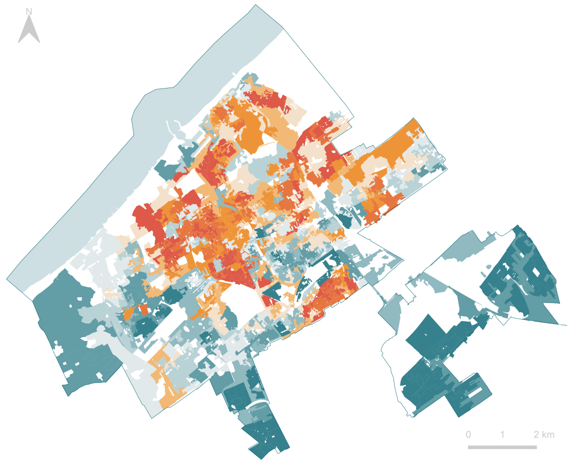


(f) Non-residential functions

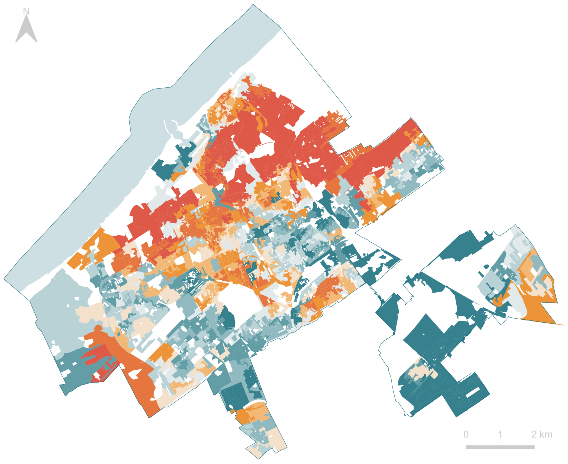
Figure B.2: 10% deciles of each vulnerability indicator, with blue indicating low occurrence and orange high occurrence.



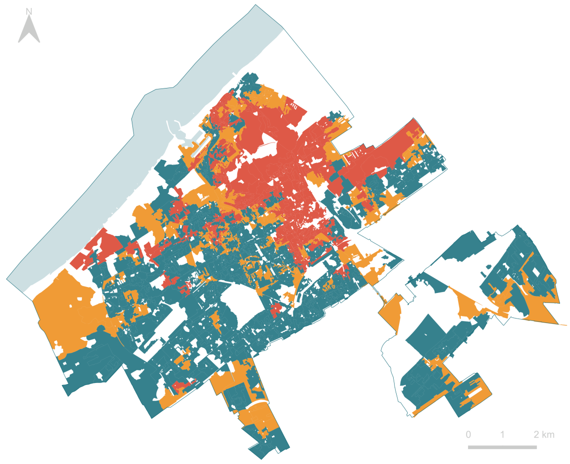
(a) Energy labels C & D



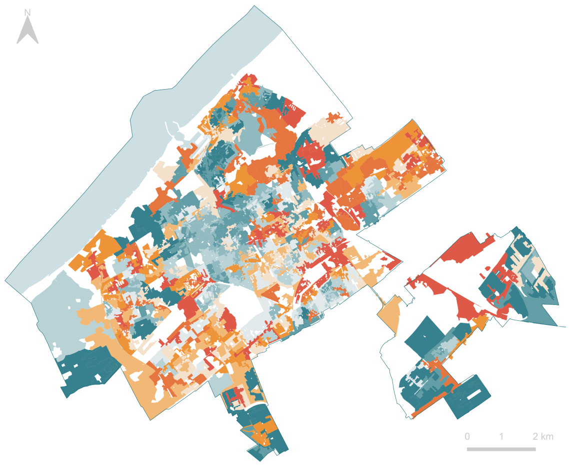
(b) Energy labels E, F & G



(c) High average gas usage per dwelling



(d) Dwellings with monumental status



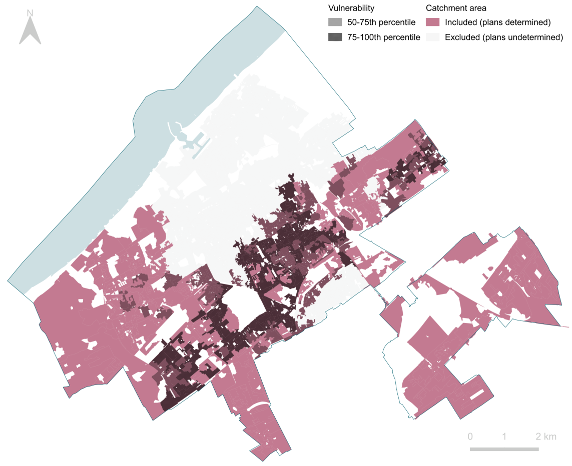
(e) Number of objects per building

Figure B.3: 10% deciles of each vulnerability indicator, with blue indicating low occurrence and orange high occurrence.

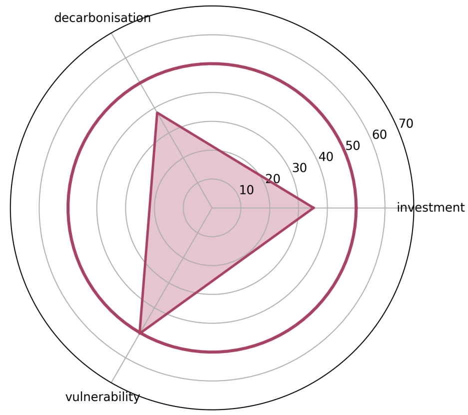
C

Policy sheets

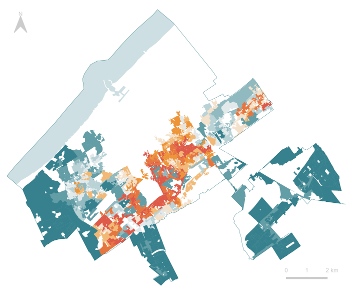
C.1. Implement Heating Transition Vision



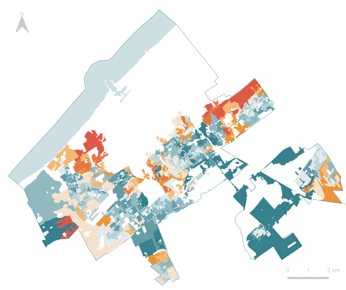
(a) Catchment area of policy rationale, with vulnerable localities highlighted.



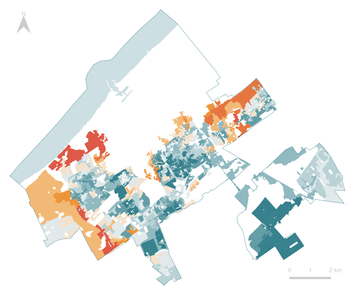
(b) Policy coverage presented as radar plot, presenting the average percentile of the policy catchment area compared to The Hague median (circle).



(c) Vulnerability

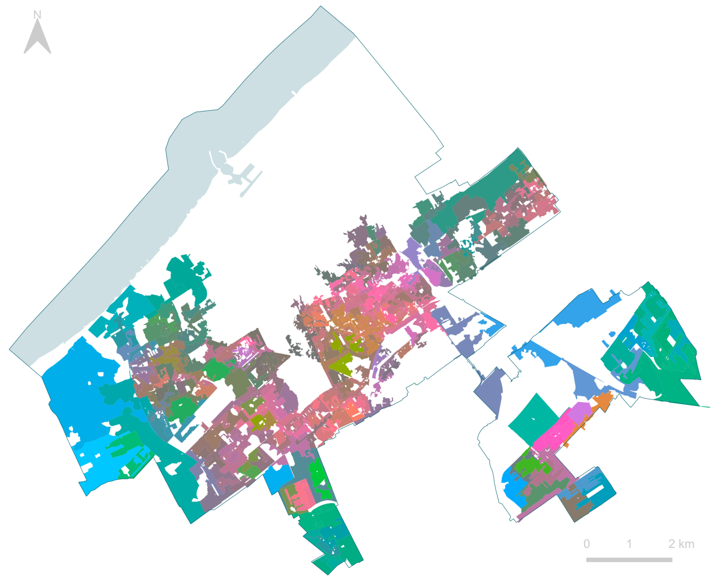


(d) Decarbonisation



(e) Investment

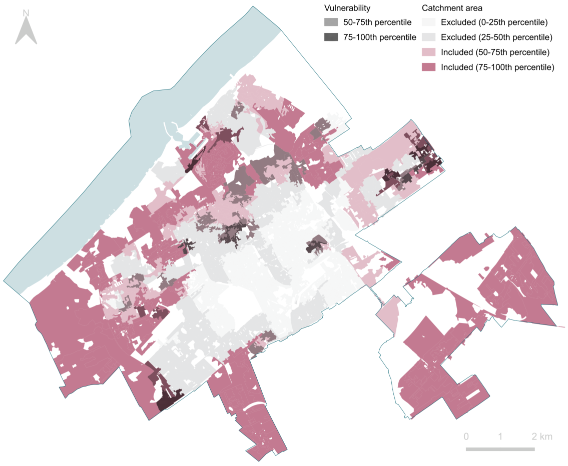
(f) Decile



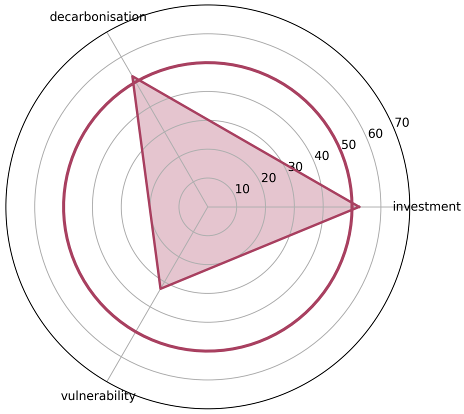
(g) Spatial balance between vulnerability, decarbonisation and investment for policy rationale. Localities coloured orange, brown and grey represent cost-effective decarbonisation, while covering vulnerability.

Figure C.1: Policy sheet for Implement Heating Transition Vision

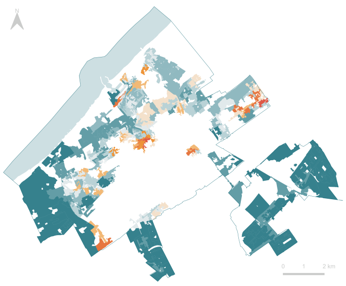
C.2. Provide individual subsidies



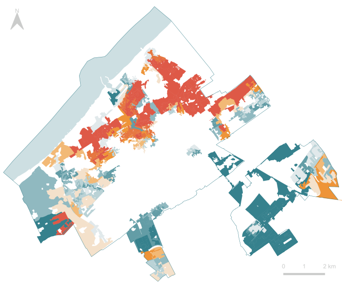
(a) Catchment area of policy rationale, with vulnerable localities highlighted.



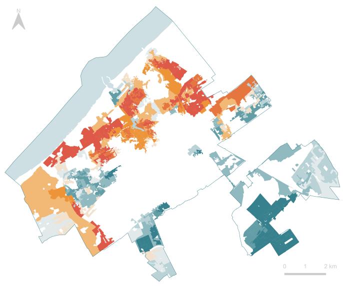
(b) Policy coverage presented as radar plot, presenting the average percentile of the policy catchment area compared to The Hague median (circle).



(c) Vulnerability



(d) Decarbonisation



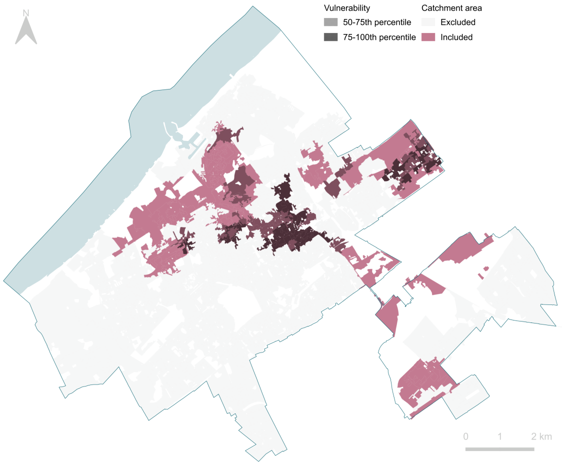
(e) Investment

(f) Decile

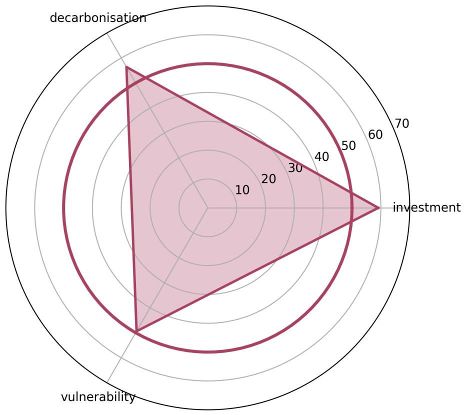
(g) Spatial balance between vulnerability, decarbonisation and investment for policy rationale. Localities coloured orange, brown and grey represent cost-effective decarbonisation, while covering vulnerability.

Figure C.2: Policy sheet Provide individual subsidies.

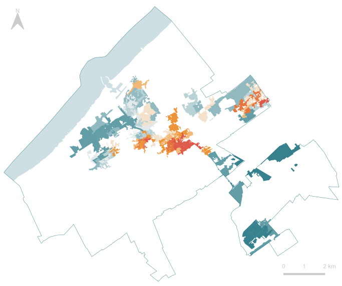
C.3. Support local energy cooperatives



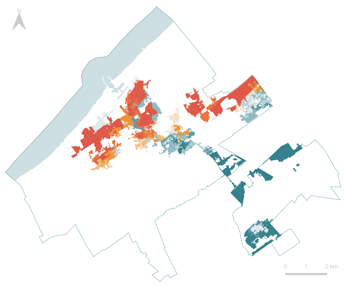
(a) Catchment area of policy rationale, with vulnerable localities highlighted.



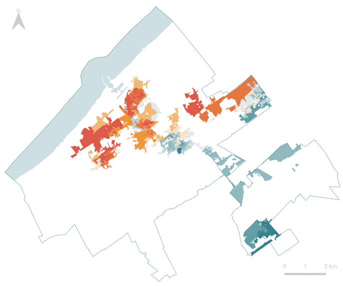
(b) Policy coverage presented as radar plot, presenting the average percentile of the policy catchment area compared to The Hague median (circle).



(c) Vulnerability

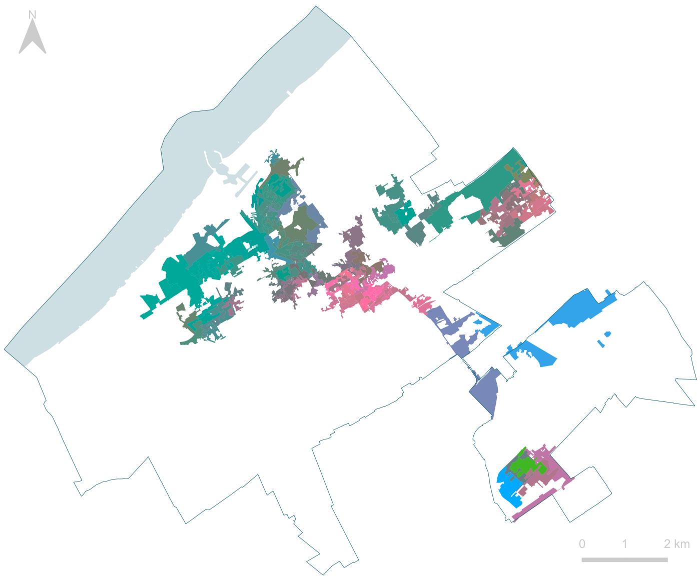


(d) Decarbonisation



(e) Investment

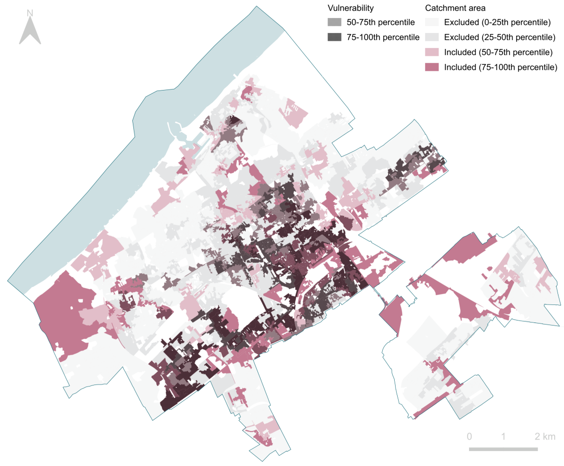
(f) Decile



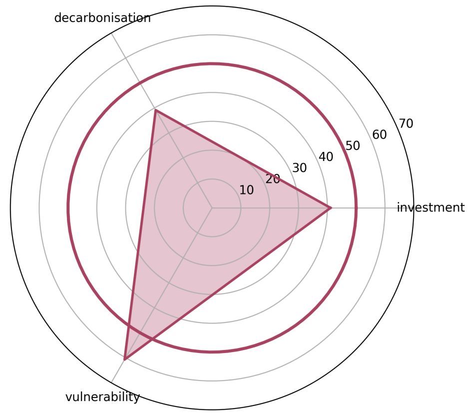
(g) Spatial balance between vulnerability, decarbonisation and investment for policy rationale. Localities coloured orange, brown and grey represent cost-effective decarbonisation, while covering vulnerability.

Figure C.3: Policy sheet for Support local energy cooperatives.

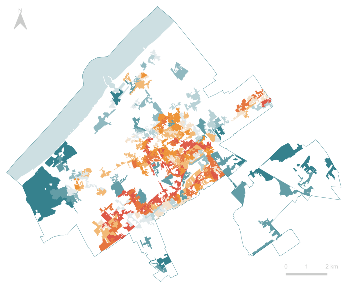
C.4. Link with housing corporations



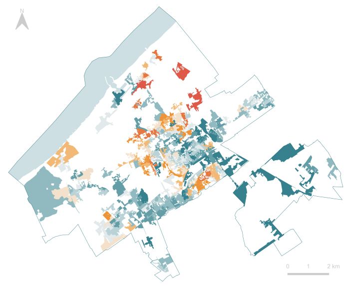
(a) Catchment area of policy rationale, with vulnerable localities highlighted.



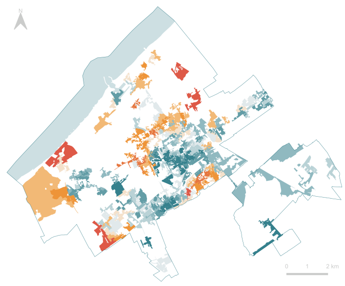
(b) Policy coverage presented as radar plot, presenting the average percentile of the policy catchment area compared to The Hague median (circle).



(c) Vulnerability

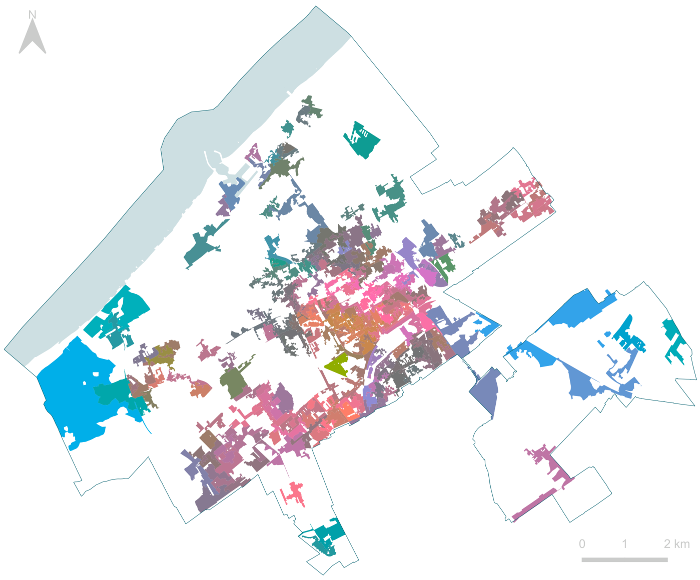


(d) Decarbonisation



(e) Investment

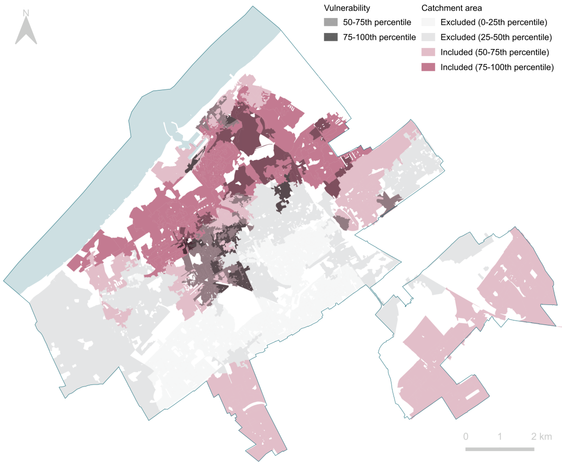
(f) Decile



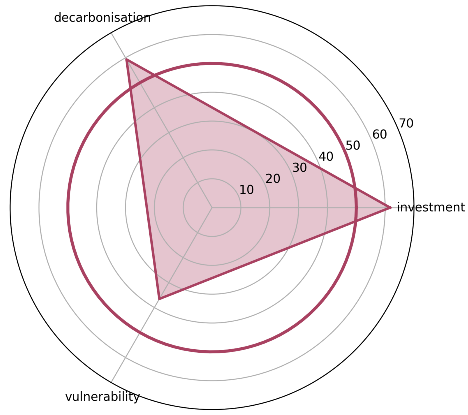
(g) Spatial balance between vulnerability, decarbonisation and investment for policy rationale. Localities coloured orange, brown and grey represent cost-effective decarbonisation, while covering vulnerability.

Figure C.4: Policy sheet for Link with housing corporations.

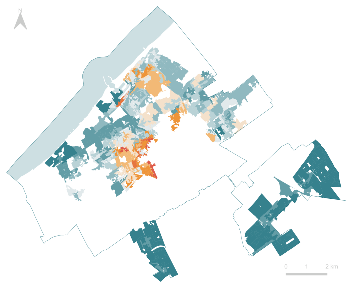
C.5. Activate willing residents



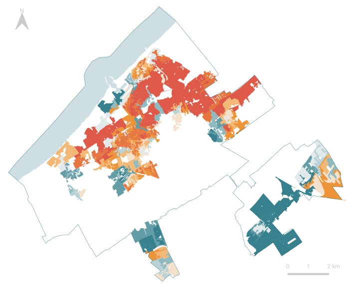
(a) Catchment area of policy rationale, with vulnerable localities highlighted.



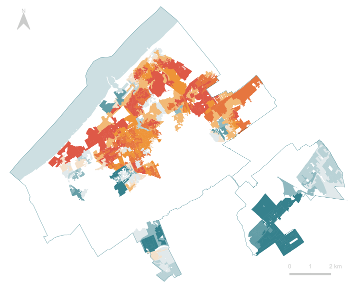
(b) Policy coverage presented as radar plot, presenting the average percentile of the policy catchment area compared to The Hague median (circle).



(c) Vulnerability

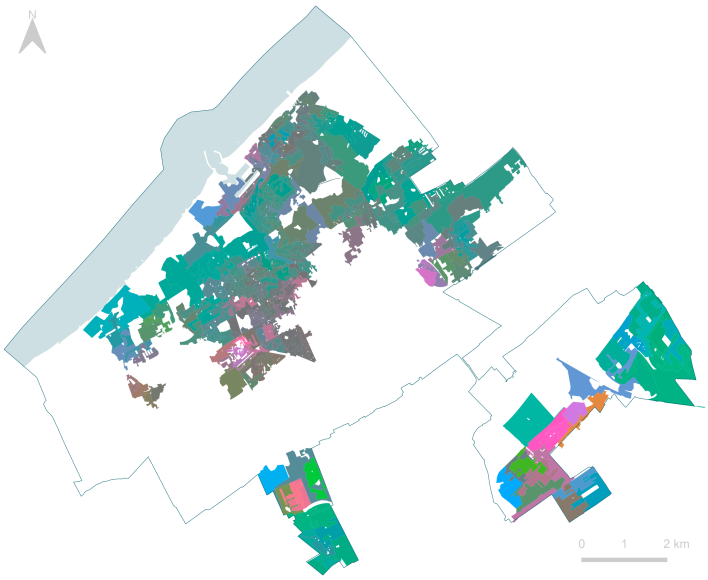


(d) Decarbonisation



(e) Investment

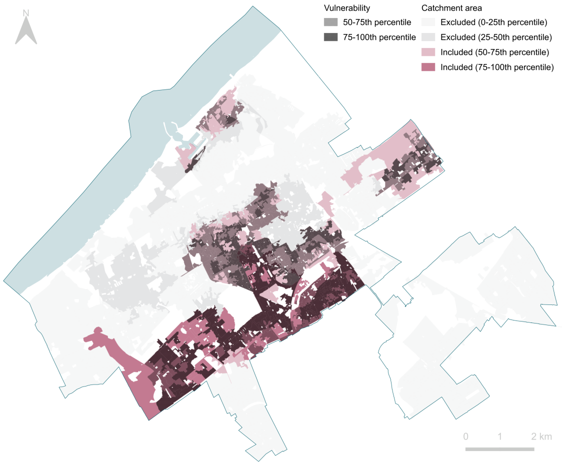
(f) Decile



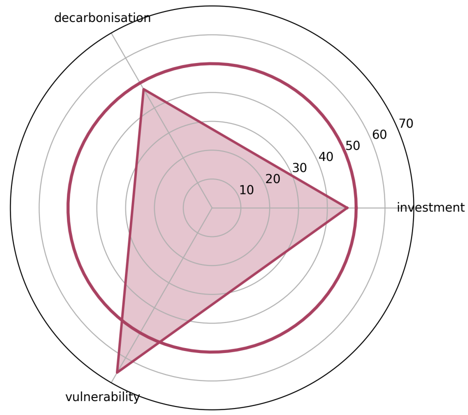
(g) Spatial balance between vulnerability, decarbonisation and investment for policy rationale. Localities coloured orange, brown and grey represent cost-effective decarbonisation, while covering vulnerability.

Figure C.5: Policy sheet for Activate willing residents.

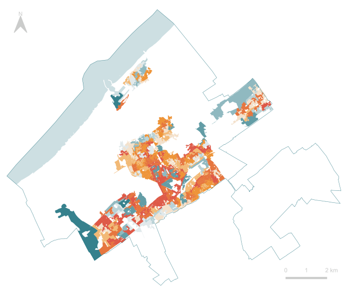
C.6. Alleviate energy poverty



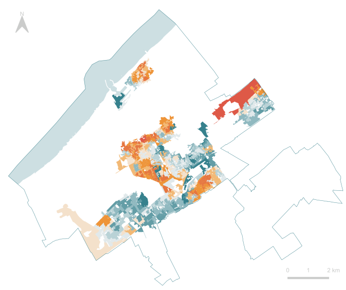
(a) Catchment area of policy rationale, with vulnerable localities highlighted.



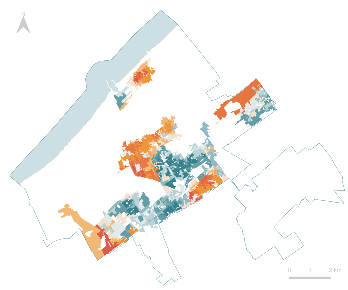
(b) Policy coverage presented as radar plot, presenting the average percentile of the policy catchment area compared to The Hague median (circle).



(c) Vulnerability

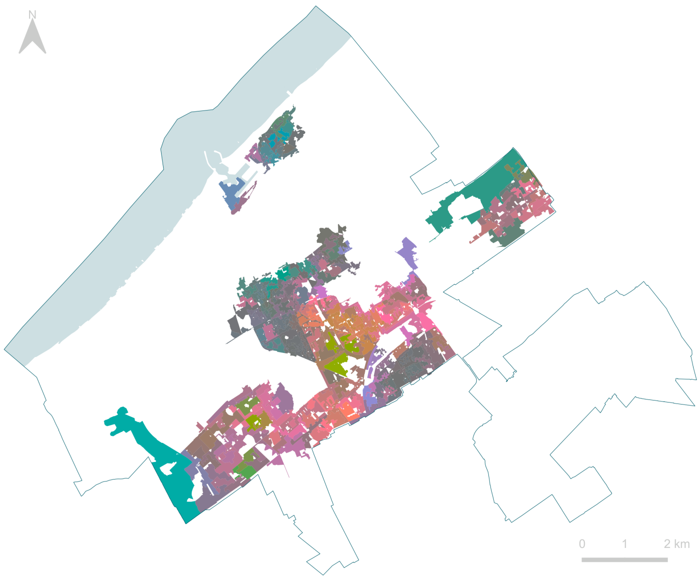


(d) Decarbonisation



(e) Investment

(f) Decile



(g) Spatial balance between vulnerability, decarbonisation and investment for policy rationale. Localities coloured orange, brown and grey represent cost-effective decarbonisation, while covering vulnerability.

Figure C.6: Policy sheet for Alleviate energy poverty.