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Urban Climate Plans in Major European Nations: Analysing Factor Interactions

submitted by

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Summary

Effective climate action is increasingly recognised to not only require implementation on a national level but also action by local governments and cities. Against this background, recent years have seen an ever-growing body of literature exploring urban climate action. While progress has been made in understanding why cities voluntarily engage in climate action, findings are not conclusive. Several factors have been identified as important, but their presence or absence appears insufficient to predict climate action. To address this issue, attention is given not only to single factors but also to their interplay.

Using qualitative comparative analysis (QCA), this thesis explores climate action in four Western European countries, accounting for a great part of the population of Europe. Their similarities in political and economic conditions represent a common background, allowing for better comparability.

Results show that the two factors associated with capacity, affluence and population size, are individually sufficient for explaining mitigation action. Yet, for this research context, they are not equally suited. Affluence, as measured by GDP per capita, has been shown to explain mitigation planning more generally. While individually sufficient, both conditions worked primarily in the absence of high levels of unemployment. For cities lacking institutional capacity, national-level obligation can lead to climate mitigation plan development even in the face of adverse socio-economic conditions such as high unemployment. However, as the notable differences between France and the UK highlighted, the efficacy of national-level obligation for promoting plan development is dependent on its practical implementation.

The effect of unemployment has been identified as not unidirectional. While unemployment can be a barrier, there are indications that, in the absence of affluence, it can serve as a motivator to engage in climate action. This can be explained by cities wanting to leverage the potential of green growth associated with sustainable development. Lastly, air pollution co-benefits could not reliably be linked to mitigation efforts. While German and Italian cities, characterised by low unemployment and high air pollution, often mention air pollution in their planning documents, the plans provide insufficient evidence that air pollution reduction co-benefits motivated plan development. The multitude of pathways identified underlines the complexity of climate planning.

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Abbreviations

AFL	Affluence
CCPI	Climate Change Performance Index
COB	Co-benefits
CoM	Covenant of Mayors
EEA	European Environment Agency
EU	European Union
Eurostat	Statistical Office of the European Union
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
LUZ	Larger Urban Zones
NDC	Nationally Determined Contribution
NUTS	Nomenclature of Units for Territorial Statistics
OBL	Obligation
OECD	Organisation for Economic Cooperation and Development
OUT	Outcome
POP	Population
QCA	Qualitative Comparative Analysis
RoN	Relevance of Necessity
SEAP	Sustainable Energy Action Plan
UNE	Unemployment
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

1. Introduction

1.1. Background

Anthropogenic climate change represents one of the great challenges of our time. Over the course of the last decades, not only the understanding of impacts increased but also the need for action (Grassl, 2011; IPCC, 2023c). As climate change is a global phenomenon, it is generally accepted that climate action calls for cooperation between states. A significant step in international climate action was the adoption of the Paris climate agreement in 2015. The agreement stipulates limiting global warming to "well below 2°C above pre-industrial levels" UNFCCC (2016, p. 3). It requires all signatory states to contribute to reductions in greenhouse gases. To achieve this, each state is committing to reduce emissions through so-called Nationally Determined Contributions (NDC).

Yet, almost a decade onwards emissions continue to rise, with global CO_2 concentrations reaching a new high (IPCC, 2023b). If every state were to fulfil their NDCs, global warming would be limited to 2.0 to 2.1°C until 2100 (Tibrewal, Tanaka, Boucher, & Ciais, 2023). While technically achievable, this is not the current trajectory of emissions reduction. Reaching even just the minimal target would necessitate all conditional NDCs to be implemented. So far, the level of ambition is not sufficient (UNFCCC. Secretariat, 2022).

The shortcomings of national climate action direct attention to subnational governance levels. Increasingly, the importance of subnational policy has been recognised by the international community. The role of cities is mentioned in the Fifth Assessment Report of the IPCC (IPCC, 2014), while the Paris Agreement acknowledges the importance of subnational levels of governments (UNFCCC, 2016). Furthermore, the increased importance of subnational governments as actors is evidenced by the literature, as recent years saw a surge of attention to sub-national climate action (Castán Broto & Westman, 2020).

Cities occupy a prominent role in the multi-level governance structure. The particular interest for cities can be explained by their role as centres of economic activity. Compared to the rather rigid implementation on higher levels, city governance has the advantage of being more familiar with local conditions (Ostrom, Tiebout, & Warren, 1961). They can enact policies with direct impact, for example, on the building and transport sector (Sethi, Lamb, Minx, & Creutzig, 2020)

1.2. Problem Statement

Cities are of prime interest for reducing emissions. They are centres of population and human activity (OECD, 2010). It is expected that by 2050, about 68% of the world's population will live in urban environments (Kundu & Pandey, 2020). In highly industrialised regions such as Europe, this number is even higher, with 75% already living in urban environments (Population Reference Bureau, 2023). Due to their central role for the economy, resource use in cities is also considerably higher than in rural areas (Heinonen & Junnila, 2011). This makes them a key target of mitigation efforts. With increasing urbanisation, global emissions associated with cities are expected to rise further. At the same time, cities themselves are often more affected by climate change than rural environments. Geography, demographics, and urban form make many city dwellers more vulnerable to climate impacts such as sea level rise or increases in extreme events (IPCC, 2023a; OECD, 2010).

Climate action, particularly mitigation, is not attached to immediate benefits (Stavins, 2011). Yet, research has shown that cities are not passive when it comes to addressing climate change. In fact, they engage in voluntary climate action more willingly than nation states (Reckien et al., 2014).

A variety of contextual factors have been linked to climate action (Reckien, Flacke, Olazabal, & Heidrich, 2015). To support cities and increase mitigation, it is pivotal to increase understanding of what drives and, crucially, what hinders local climate action. However, as cities are complex and highly heterogeneous, instead of single factors, it is context-dependent interactions that influence mitigation planning (Castán Broto, 2017).

1.3. Current Knowledge

In recent years, motivations for cities to engage in climate action have been explored extensively. Factors associated with climate action are manifold and include both exogenous, such as shocks, and endogenous factors, such as the motivation of key actors (Castán Broto, 2017).

Correlation analysis determined the association of a number of socio-economic, institutional, and environmental factors with mitigation planning in European cities. Institutional factors commonly identified as drivers of mitigation efforts are membership in climate networks and higher-level support. Amongst the most important socio-economic drivers are indicators related to a city's capacity, such as population size and GDP per capita. Commonly identified barriers to mitigation action are a city's unemployment rate, but also geographic or environmental factors, such as proximity to the coast and higher summer temperatures. However, correlation with the existence of climate plans is weak for most factors, hinting at the need for a more comprehensive analysis (Reckien et al., 2015).

A systematic review has produced evidence for the relationship of mitigation planning with further institutional factors. Legal embeddedness in supportive climate legislation and vertical integration are important factors for determining whether a city will engage in climate action. Adequate higher-level legislation may support or require city-level action or create necessary checks and balances. Similarly, horizontal integration – be it across different departments or between cities through networks – has been found to significantly influence climate planning (van der Heijden, 2019a).

Apart from the institutional settings, the characteristics of a city have a significant impact. Sufficient autonomy allowing a city to implement legislation suited to local circumstances, sufficient financial resources, influential leaders, and stakeholder engagement all significantly spur climate action. However, factors may be overlapping and are connected to one another (van der Heijden, 2019a).

1.4. Research Objective

While factors affecting local mitigation planning have been identified, it has become increasingly clear that they are interdependent and understanding of their interactions and overlap remains vague (van der Heijden, 2019a). Furthermore, research long overrepresented large cities and cities that are particularly active, while only in recent years the inclusion of a broad range of different city typologies in large-n studies has gained momentum. Reckien et al. (2018) found that amongst cities in EU countries distinct patterns of mitigation planning can be found. These patterns indicate that local climate plans develop through different pathways. Therefore, equifinality and conjunctural causation apply to climate mitigation planning. Eisenack and Roggero (2022) instrumentalised these two concepts making use of crisp-set Qualitative Comparative Analysis (QCA). Their research supports the theory that most conditions do not act in isolation but rather in configurations with the effect of conditions depending on the presence of other conditions.

City networks represent an exception to that as network membership was deemed an essentially sufficient condition for climate action. Scholarly attention has extensively featured network membership as a factor explaining membership (Bertoldi, Kona, Rivas, & Dallemand, 2018; Betsill & Bulkeley, 2006; Castán Broto, 2017). However, questions remain about whether city network membership can be seen as a response to conditions or how local mitigation plans can be explained outside of network membership.

In a similar vein, affluence, measured by GDP per capita, has been found to play an important role. It was, however, not identified as sufficient (Eisenack & Roggero, 2022). Therefore, it appears appropriate to look at alternative factors that can be used to proxy a city's capacity. One such factor commonly brought up is population size. Additionally, it is useful to look at how factors that are deemed adverse, such as unemployment, interact with other factors. However, some scholars also mention that in a certain context, unemployment can have a positive effect on cities' mitigation efforts (Del Pablo-Romero, Sánchez-Braza, & Manuel González-Limón, 2015). It is, therefore, appropriate to further investigate the effect of unemployment in the context of other conditions. Based on these considerations, the primary research questions to be addressed in this thesis are the following:

1. **Are GDP per capita and population equally suited to represent capacity?**
2. **Is the role of unemployment always negative?**
3. **How do factors, aside from city network membership, contribute to climate mitigation planning in European cities?**

As QCA has proven suited for analysing climate mitigation planning, the following analysis will build on the findings by Eisenack and Roggero (2022) by introducing further conditions that have been found to correlate with climate mitigation planning. With the inclusion of the factor unemployment, this will, for the first time, make use of a primarily negatively associated factor.

For the subsequent analysis, four of the most populous European countries have been selected: Germany, the UK, France, and Italy. In 2015, these countries together made up half of the population of the EU (Eurostat, 2024b). While Western Europe is generally considered to be a frontrunner in environmental policies (Reckien et al., 2015) and therefore well-researched, understanding of motivations of climate action even in these countries is far from perfect.

The selection of countries is based on two main reasons. First, the countries share many similarities, making comparisons and identification of patterns easier. For instance, all of them have a history of urbanisation dating back centuries, which has considerably influenced their infrastructure and urban design. Additionally, at the time of data collection the countries were all members of the EU and operating within a common policy framework. These similarities may lead to more conclusive results, as opposed to working with a greater selection of countries, while still allowing for a great variety of different city typologies. In contrast, Eisenack and Roggero (2022) concluded that climate action in eastern EU countries may be explained merely by meeting requirements for accessing EU funds.

Despite the similarities, the four countries differ in many ways. There are considerable differences in urban typology, with distinct patterns of density and the degree of centralisation. Despite all of them being members of the EU at the time, national and subnational-level policy implementation varied considerably.

Additionally, the four countries belong to three distinct country groups in the way of how climate action is approached. Germany belongs to a group of countries with a large proportion of cities with climate plans developed without national-level obligation and outside the context of climate city networks. The UK and France both have national legislation mandating the development of climate plans. In Italy, a significant number of cities developed their climate plans as members of the Covenant of Mayors (CoM) (Reckien et al., 2018). Thus, the conditions for the development of local climate plans differ notably.

The research approach is aiming to combine the advantages of a large-n dataset with the advantages of relatively homogeneous conditions. This is believed to reduce noise induced by incomparable city types and produce results that are easier to interpret. The aim is to create insights into climate governance which may aid successful policy implementation.

1.5. Expected Results

It is expected that no factor alone will be sufficient to explain the development of mitigation plans. Accordingly, the role conditions play in the outcome will be affected by the presence or absence of other conditions. It is likely that the two factors used to proxy capacity, GDP per capita and population, will have a strong influence on the results independently from the other conditions.

Unemployment is expected to primarily have a negative impact on the outcome. It may also offset the higher capacity of affluent and populous cities. High unemployment might also mean that cities with high capacity do not have plans. Alternatively, some cities may seek to leverage mitigation plan development to fight unemployment.

Co-Benefits and obligation are expected to have a generally positive influence on plan development. However, the role of air pollution co-benefits is complex (Roggero, Gotgelf, & Eisenack, 2023). Eisenack and Roggero (2022) found that co-benefits in the form of reduced PM2.5 did not influence mitigation plan development. Nonetheless, the more homogenous redefined selection of countries may uncover themes regarding the explanatory power of co-benefits that could not be observed with a larger dataset.

2. Literature Review

In the following, an overview of the background and current debates on urban climate action will be presented. At first, urban climate action will be situated in the international climate regime. This will help to understand the development of climate governance, as it highlights the evolution and shifting perspective over the past decades. This will be followed by conceptual and practical considerations of urban climate action. Finally, the current state of research pertaining to factors explaining urban climate action and research gaps will be explored.

2.1. International Climate Action

Climate change represents a pressing issue affecting the whole planet. The global dimension of its impact has far-reaching implications for policies addressing it. Historically, governance of climate change has therefore been first and foremost the responsibility of the highest governance level, the nation-state (Bulkeley & Betsill, 2003).

International climate action experienced increasing attention since the late 1980s. A first major milestone was the 1992 Rio Declaration, which laid the foundation for the representation of environmental concerns on the highest levels of governance and introduced the concept of "common but differentiated responsibilities" (UNFCCC, 1992, p. 3). This concept became a cornerstone of international climate action and was later implemented in the 1997 Kyoto Protocol, according to which industrialised nations, for the first time, committed to binding emission targets. The Kyoto Protocol also introduced a range of market-based mechanisms in an effort to make achieving emission targets cost-effective (Falkner, Stephan, & Vogler, 2010).

A next turning point in international climate action was the 2009 COP15 in Copenhagen, which aimed to produce a global climate agreement but failed to do so, instead ending in disarray. While the conference could not produce an agreement, the apparent inability of states to act is credited with shifting attention away from nation states and bringing attention to climate action of subnational actors, such as cities (Hoffmann, 2011).

In subsequent years, the perception of local climate action changed from an alternative to a complement to national climate action. In the 2015 Paris Agreement, local climate action was formally recognised as an integral part of climate action (Castán Broto & Westman, 2020). The Agreement notably also introduced the target of limiting warming to "well below 2°C above pre-industrial levels" (UNFCCC, 2016, p. 26) and led to the introduction of Nationally Determined Contributions (NDCs) as individual commitments by countries (UNFCCC, 2016).

2.2. Multi-level Governance

The above outlined trajectory of international climate policy highlights the change of perspective over the years. Over the past decades, it became clear that national efforts would not suffice. While the nation state remains a prominent player in climate action, complementary elements across different levels of governance have garnered attention. The concept of multi-level governance extends climate governance to a network of actors across a variety of levels.

To understand the framework of multi-level governance, it is useful to revisit the motivation of climate action as a global phenomenon. In the face of the absence of binding authority, governance of climate change has been seen to be, first and foremost, the responsibility of the nation state (Bulkeley & Betsill, 2003). The fact that nation states cooperate and form international agreements despite the apparent incentive to free ride can be explained by regime theory, according to which nation states are understood as having interests and bargaining power, which then, through bargaining, determine international regimes. It is advantageous for nation states to cooperate and form climate agreements (Bulkeley & Betsill, 2003; Keohane, 1982). However, this approach has been criticised for assuming predetermined interests and the negligibility of non-state actors. The latter play not only a crucial role in the formation of national interests but also engage as actors themselves (Bulkeley & Betsill, 2006).

Accordingly, climate governance is not taking place on only one - the national - but multiple levels. These multiple levels interact and influence each other. Multi-level governance can be described as the dispersion of decision-making authority over multiple levels of governance. This includes multiple stakeholders and their interactions (Hooghe & Marks, 2001).

Conceptualisations of multi-level governance vary, but generally, a distinction between vertical and horizontal levels of governance can be made. Vertical elements capture the hierarchical structuring of governance. This often corresponds to tiers of authority, e.g. national, regional. Horizontal levels of governance concern the interactions of state and non-state actors. Interactions of this type can occur between non-state and state actors or also between different state actors, e.g. different departments (Hooghe & Marks, 2001).

Applied to climate mitigation planning, the debate of effective climate governance revolves around the question of responsibility with respect to optimal management (Castán Broto, 2017). Efficient climate action requires actors on different levels, both vertical and horizontal, to cooperate, as each of them fill in a different gap (van der Heijden, 2019a). The complexities of multi-level governance are exemplified by the case of international city networks, which have been of particular interest to researchers in recent years. They are made up of local governments yet tend to bypass the hierarchical government structure of their nation state. Through the interactions of member cities, this creates another arena of governance and takes on some of the responsibilities usually assumed to be the responsibility of the national government. This does by no means mean that the role of the state should be deemed obsolete but rather that climate action is often a product of interactions of these different levels. Supportive policies at the national level can spur action on the local level. However, case studies have shown that even in the absence of such policies, certain conditions at the local level, such as strong local leadership, may result in climate actions (Betsill & Bulkeley, 2006).

2.3. The Role of Cities

In the framework of multilevel governance of climate change, a particular role has been given to cities. Attention to cities as actors for climate mitigation can be traced back to the 1987 "Brundtland Report". The report can be seen as laying the foundation for policies addressing sustainability on an international level. It emphasised the need for global cooperation when dealing with environmental issues. A whole chapter, "The Urban Challenge" is dedicated to the role of cities (Brundtland, 1987). However, attention to cities was long limited. This gradually changed over the course of the last decades. Particular interest in cities could be seen in the aftermath of COP15 in Copenhagen and again after COP21 in Paris (Castán Broto & Westman, 2020). The unique characteristics of urban areas make them particularly important (OECD, 2010). In the following, the role of cities will be explored.

Before examining the role of cities, it is worthwhile to consider the concept of the *city*. Cities are not a monolithic existence but vary considerably (Castán Broto, 2017). There is no universally accepted definition of the *city* (Marcotullio & Solecki, 2013). Commonly used definitions are often based on the size of a municipality, while other commonly used criteria include population density. As this analysis uses a Eurostat dataset, this analysis will use the definition of the European Commission. Accordingly, cities are defined by their degree of urbanisation, which is based on a grid cell with a population density of at least 1500 and an aggregate population of the urban area of at least 50,000 (Dijkstra & Poelman, 2014).

When discussing cities, they are often perceived as separate entities from their surroundings. This leads to the idea of them being a drain on the resources of their environment. It has to be noted, though, that administrative boundaries are often somewhat arbitrary and that interactions are not fully understood (Castán Broto, 2017). Cities are deeply interwoven with their surroundings.

Cities are of particular interest to climate action research for their multifaceted role. They are, at the same time source, victim, and part of the solution to climate change (Mukim & Roberts, 2023; OECD, 2010; van der Heijden, 2019a).

Their role as source of climate change is explained by their central role for most countries. The per capita resource consumption in cities tends to be considerably higher than in rural environments (Heinonen & Junnila, 2011; OECD, 2010). Furthermore, much of the world's economic activity is concentrated in cities. The top 100 cities alone were found to account for 18% of global greenhouse gas emissions (Moran et al., 2018). The importance of cities is set to further increase, with 68% of the world's population expected to live in towns and cities in 2050. Population growth will occur primarily in developing countries. Accordingly, not only the total urban population will increase but an increase in urbanisation is expected to go along with further development (IPCC, 2022). As, in turn, this is associated with increasing per capita resource consumption, further increases in carbon-intensive lifestyles are likely (Mukim & Roberts, 2023). The combination of these factors points to an increase in the share of urban greenhouse gas emissions and underscores the increasing importance of cities for climate mitigation.

Cities are also particularly vulnerable to the impacts of climate change. Vulnerability is commonly conceptualised as consisting of exposure, sensitivity, and adaptive capacity (IPCC, 2001). When considering urban vulnerability, exposure and sensitivity are of particular importance.

Cities often have a heightened exposure to the impacts of climate change due to their location and distinct characteristics. The location of many of the world's major cities in close proximity to coasts make them vulnerable to rising sea levels (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013). Furthermore, extreme events are expected to increase in both magnitude and frequency, with the urban environment further magnifying many extreme conditions. Surfaces of concrete and asphalt absorb incoming radiation and reduce evapotranspiration, causing cities to heat up more than their surroundings, in what is called the urban heat island effect. Thus, extreme heat events pose a particular threat to city dwellers. The abundance of impervious surfaces also means that cities are particularly prone to changing rainfall patterns, with the occurrence of pluvial floods set to increase (IPCC, 2023a; OECD, 2010).

Aside from their heightened exposure, cities are often also particularly sensitive. They are concentrations of people and economic activity. Therefore, climate impacts in cities affect many people simultaneously, leading to economic disruptions and posing a risk to key infrastructure. Additionally, cities tend to house high concentrations of marginalised populations that often lack the means to cope or adapt to climate impacts. A large and further increasing part of the world's poor population are city dwellers (IPCC, 2022).

The heightened vulnerability of cities can be limited by cities' greater adaptive capacity as compared to rural environments. However, the relationship between wealth and adaptive capacity is not inherently one-directional. Institutional and psychosocial factors are major determinants of adaptive capacity (Eriksen et al., 2020). Accordingly, noticeable disparities in terms of adaptive capacity and, therefore, vulnerability can be observed between cities.

While more prone to its impacts, cities are not only victim and cause of climate change. They are also a notable part of the solution. The high density of cities makes implementation of climate action more cost-effective. Compact urban form is advantageous for reducing emissions (IPCC, 2023b). Furthermore, cities are often places of experimentation with new approaches. They can test new technologies and implement policies more easily than nation states (van der Heijden, 2019a). Direct engagement is also easier, as much of the world's power is concentrated in cities (Sassen, 2019). Lastly, cities have shown particular effort to reduce emissions, as evidenced by the increase in voluntary commitments (IPCC, 2022).

This combination of factors is why cities have increasingly been hailed as central to effective climate action. They are deemed more ambitious than nation states, more willing to experiment with novel approaches, and strong at collaborating with each other. However, it remains questionable whether their role is as overwhelming as some scholars believe. Past research focussed primarily on few frontrunner cities. Some scholars argue that the role of cities should be seen as rather complementary to higher-level legislation (van der Heijden, 2019a). Nonetheless, effective climate mitigation efforts will also require action in urban areas.

2.4. Urban Climate Action

Having established the central role of urban areas in the framework of climate change mitigation, it is important to consider the practical implications of climate action. The most commonly used instrument of urban climate action are climate plans. They may be stand-alone documents or incorporated into other plans and can greatly differ in terms of detail and focus (Reckien et al., 2018). While a clear distinction is not always possible, following Reckien et al. (2018), they can be defined as plans incorporating policies relevant to climate mitigation or adaptation. The classification along these two specific domains is also used by various IPCC reports. However, for the sake of completeness, it should be noted that alternative conceptualisations of climate action such as low-carbon or resilience exist, too (Castán Broto & Westman, 2020).

Adaptation, often perceived as a local issue, aims to make the city ready for climate change impacts. Mitigation, on the other hand, is the process of reducing greenhouse gas emissions. While most plans address primarily one of the two, addressing both simultaneously can spur effective action and while separation may impede action (Castán Broto, 2017).

Climate mitigation action, as implemented by cities, can encompass a range of measures. Mitigation plans commonly address specific sectors such as buildings, transport, infrastructure and energy generation (Mokhles & Acuto, 2024). Number and type of actions vary from city to city and are often affected by local characteristics. Larger cities tend to employ a more diverse set of policies, while smaller cities focus more on municipal self-governing and education (Palermo, Bertoldi, Apostolou, Kona, & Rivas, 2020).

Many mitigation plans define targets for emissions reduction. In the European context, 78% of a sample of 254 cities were found to have defined targets. Targets differ in both magnitude and timeline, with population and network membership correlating with more ambitious mitigation targets. Furthermore, spatial patterns can be observed. Cities in Northern and Western Europe adopted more ambitious targets than cities in the East and South (Salvia et al., 2021).
Considerations about how to effectively address climate change have become a key debate of urban climate action research in recent years. Apart from considerations regarding the type of measures, which determine the effectiveness, motivations for cities to become active in climate action in the first place have emerged as the other core topic in the literature (Castán Broto & Westman, 2020). It is this second debate that this analysis is aiming to contribute to.

2.5. Factors Explaining Climate Planning

The development of climate plans has been subject to extensive research, specifically over the past decade. In the following, the current state of research of factors influencing the motivation behind the development of climate plans will be summarised.

Research of factors associated with climate mitigation planning uncovered a wide range of factors associated with plan development. These factors belong to a variety of different categories. Correlational analysis identified institutional, socio-economic, environmental, and composite vulnerability factors (Reckien et al., 2015).
Institutional factors identified as drivers of mitigation efforts are higher-level support and membership in climate networks (Reckien et al., 2015). Legal embeddedness in supportive climate legislation and vertical integration are important factors for determining whether a city will engage in climate action. Some countries have implemented legislation on the national level, obligating municipalities to draft climate plans (Heidrich et al., 2016). Adequate higher-level legislation can also come with the additional advantage of creating necessary checks and balances (van der Heijden, 2019a). Similarly, horizontal integration, whether across different departments or between cities through networks, has been found to significantly influence climate planning. In some European countries lacking supportive legislation, such as Italy and Spain, climate networks such as the Covenant of Mayors have taken on a central role (Reckien et al., 2018; van der Heijden, 2019a).
Aside from the political and legal context, effective climate action also depends on a variety of additional factors. To optimally implement climate legislation, cities need sufficient autonomy, as this allows them to implement legislation suited to local conditions. Furthermore, by stimulating collaboration and integrating different perspectives, stakeholder engagement can improve the outcome yet also hinder it as it opens climate action to vested interests (van der Heijden, 2019b).

Lastly, the presence of strong leadership can have a significant influence, as mayors can considerably influence mitigation planning, for example, by instigating climate network membership. However, it should be noted that they are, in turn, limited by institutional settings and, crucially, resources (Reckien et al., 2015; van der Heijden, 2019a).
Both climate emission patterns and also climate planning depend considerably on socio-economic factors. In terms of climate planning, socio-economic factors influence a city's capacity, which is generally determined by fiscal resources and human resources of trained and qualified personnel (Homsy, 2018b). Population size and GDP per capita are commonly used to proxy capacity. A greater population is associated with scaling effects. Larger cities can employ more and better trained staff and generally have more access to a pool of well-trained individuals (Otto, Göpfert, & Thieken, 2021). GDP per capita on the other hand is used as an indicator of tax income and therefore the financial resources of a city.
In the face of limited capacity, cities are believed to favour addressing more immediate issues over issues with future consequences (Homsy, 2018b). Accordingly, unemployment is commonly interpreted as a barrier to mitigation planning, as it requires the commitment of resources for social programmes, which then cannot be used for climate planning (Reckien et al., 2015; van der Heijden, 2019a). However, the impact of unemployment may vary (Ürge-Vorsatz, Herrero, Dubash, & Lecocq, 2014). The development of environmental programmes can be associated with a positive economic impulse, e.g. through the creation of new industries. Therefore, cities with high unemployment may want to use this potential to decrease unemployment (Feiock, Kassekert, Berry, & Yi, 2009).

In addition to institutional and socio-economic factors, there is some evidence that environmental factors play an important role for mitigation efforts. Climatic characteristics such as summer and winter temperatures affect energy consumption and have been shown to influence climate network membership. Research shows that there is a correlation between cities with higher summer and winter temperatures and with closer proximity to the sea and the existence of climate plans. This is despite the higher climate risk of many coastal cities (Reckien et al., 2015).

Aside from these commonly associated factors, the literature increasingly explored other motivations for why cities engage in mitigation planning beyond the primary motivation of addressing climate change. In this context, attention has shifted to side-effects of climate action (Castán Broto & Westman, 2020).
The IPCC's fifth assessment report refers to positive side-effects as "co-benefits" (IPCC, 2014). While not empirically linked to climate mitigation, the concept of co-benefits has been mentioned as a potential rationale behind climate action. This argumentation is based on the idea that climate mitigation is a collective action problem. Free riding at the cost of other places and future

generations seems rational. The global nature and delayed impact of climate change detach costs and benefits of climate mitigation efforts. As cities are nonetheless actively engaging in climate mitigation, they may be motivated to do so by its co-benefits.

Development of a climate plan comes with side effects such as air quality improvements or energy efficiency increases (Ürge-Vorsatz et al., 2014). For CoM signatories, it has been shown that CO_2 emission reductions are associated with air pollution reduction. However, interactions are complex, and trade-offs between the two exist (Peduzzi et al., 2020). Roggero, Gotgelf, and Eisenack (2023) highlighted the importance of the context for co-benefits to act as a rationale behind climate mitigation efforts.

2.6. Biases and Gaps of Current Literature on Local Climate Action

Current knowledge about factors driving the development of city mitigation plans has reached a mature state. However, while knowledge is increasing, there are gaps needing to be filled. The following lists some of the biases of current research.

The majority of studies exploring enabling factors do so in isolation. For example, Reckien et al. (2015) determined relationships between different factors using correlation analysis. While significant, correlation with existence of climate plans is weak for most factors. At the same time, correlations between individual factors could be observed, hinting at a possible interplay of factors (Reckien et al., 2015).

Literature indicates that factors do not act in isolation but rather affect and depend on each other. Some more recent publications shifted attention to combinations of factors in recognition of the heterogeneity of cities. The interplay of factors implies that climate action can be reached through different pathways. This thinking has been operationalised by Eisenack and Roggero (2022) by using QCA. Their findings support the idea that the presence or absence of specific factors shapes causal relationships by interacting with other factors.

While they explored network membership, GDP per capita, national legislation and obligation, and co-benefits, other crucial factors were not considered. Therefore, their research represents only a first step in the research of conjunctural causation of climate mitigation planning. Understanding of interactions between factors is still limited.

One example illustrating this is network membership. Climate network membership has a prominent role in explaining climate action. Studies examining factors that influence climate mitigation planning often feature network membership as a principal component. Eisenack and Roggero (2022) showed that network membership can be deemed a sufficient condition for explaining mitigation plan development. However, network membership itself has been shown to correlate with both population and GDP per capita. As such, it is left open whether it acts as a driver or a consequence of climate mitigation planning (Reckien et al., 2015).

Another bias concerns the selection of cities that are commonly researched. Not all city types are equally represented in the literature. Urban climate literature focuses primarily on large cities. Most case studies explore cities with more than one million inhabitants. Research on smaller cities is mostly confined to relatively wealthy or frontrunner cities. The relatively homogenous settings of cities represented in research leave doubts about whether findings obtained apply to smaller cities, too (Creutzig et al., 2019; Lamb, Creutzig, Callaghan, & Minx, 2019). Small and medium-sized cities, however, are the most common type of urban settlement, with much of the world's urban population concentrated in this settlement type (IPCC, 2022). Accordingly, research should incorporate a wider range of population sizes.

Additionally, the bias of focussing on cities in the global north has been stressed. While European cities are generally relatively well researched, the disparity in coverage of larger and smaller cities can be observed for Europe, too. This is particularly problematic as on no other continent smaller cities house a greater part of the population (Lamb et al., 2019).

Finally, literature reviews showed that most studies are based on individual or small-sized comparative case studies. While those have the advantage of necessitating familiarisation with local conditions, the use of case studies may also produce results that are difficult to generalise. While there is the possibility of synthesising results from case studies using reviews, differences in methodology make this difficult, too. Against this background, the need for comparative studies with greater coverage has been stressed (Lamb et al., 2019; van der Heijden, 2019a). The incorporation of a wide variety of different city typologies appears crucial.

2.7. Research Question Formulation

Based on the considerations the literature review produced, a number of gaps and biases have been identified. The following section will identify questions that will be addressed with this analysis.

As outlined in section 2.5, commonly used proxies for institutional capacity include affluence and population size. Eisenack and Roggero (2022) included the former in their QCA of 885 European cities and found it not to be sufficient. Population size represents a common alternative. Roggero, Fjornes, and Eisenack (2023) used both affluence and population size in a fuzzy-set QCA, examining emissions reduction progress, with both found to meet the requirement for individual sufficiency. Yet the two factors were interacting differently with other factors.

Additionally, the rationale behind the use of the two factors differs. The use of affluence is explained by richer municipalities having higher tax income and, hence, disposable resources for climate issues. The effect of population size is usually explained by scaling effects. Larger cities usually have a greater base of skilled personnel. If the assumptions behind their functioning are true and both employ different mechanisms in relation to climate planning, the question arises whether they interact differently with other factors. To determine the relative strengths and weaknesses of the two indicators, with relevance for their context-dependent suitability, research question 1 is as follows:

1. **Are GDP per capita and population equally suited to represent capacity?**

The second focus of this analysis concerns unemployment. As established before, unemployment is commonly seen to have a negative impact on climate planning. In its presence, resources have to primarily address immediate socio-economic problems, with more long-term mitigation efforts having no priority. However, this view is not uncontested. It has been suggested that cities may use climate action to spur economic development. Yet, growth through climate action is primarily associated with green industries. As not every city is equally suited for green industries, the advocacy potential of green growth may vary, too (Ürge-Vorsatz et al., 2014). Therefore, the effect of unemployment on climate mitigation efforts may also be highly context-dependent. This leads to the second research question:

2. **Is the role of unemployment always negative?**

Lastly, many studies on urban climate action have focused on network membership (Castán Broto & Westman, 2020). Through transnational networks, cities can enhance their capacity in spite of limited resources. Eisenack and Roggero (2022) showed the importance of network membership unrelated to the other factors employed. Yet, it is not clear under which circumstances network membership occurs. Accordingly, this analysis uses their research as a point of departure, seeking to shift focus away from network membership to explore climate planning through other factors without considering network membership. This leads to the following question:

3. **How do factors, aside from city network membership, contribute to climate mitigation planning in European cities?**

In contrast to the other two research questions, this question primarily pertains to the research design of the analysis. It shifts the focus of climate mitigation planning away from network membership to reveal interactions between factors.

2.8. Summary of the Chapter

Scope and shape of climate action has changed and diversified. While initially limited to negotiation between nation states, it has since expanded to include sub-national levels of governance. Vertical and horizontal integration have become increasingly important.

In the multilevel governance framework, cities play a particularly important role. They are cause, victim and solution at once and have shown particular willingness to implement climate action. Cities address climate change primarily through climate action plans. While climate adaptation plans prepare a city for the impacts of climate change, climate mitigation plans lay out measures to reduce greenhouse gas emissions. Climate mitigation measures are mostly sector specific, with varying ambition.

Cities' motivation to engage in climate mitigation planning is influenced by institutional (such as national legislation or network membership), socio-economic (such as population size and affluence) and environmental (such as geographic and climatic conditions) factors. These factors do not act in isolation but depend on one another and other contextual factors, such as additional benefits of mitigation efforts.

The understanding of causal relationships between these factors is still limited. Research is focused primarily on frontrunners and big cities, limiting generalisability. This is further compounded by research being dominated by case studies. There is a need for comparative studies featuring a diverse selection of cities. Based on these shortcomings, the research design of this analysis has been informed.

3. Context of the Case

To locate the cities featured in this analysis in their multi-level framework, in the following, relevant higher level mitigation action will be summarised. As, at the time of the collection of data, all four countries in this analysis were members of the EU, first, its climate policy will be summarised. This will be followed by an overview of contextual factors and climate policy for each country.

3.1. European Climate Policy

Due to its ambitious targets, the EU is often considered a pioneer of climate action. Climate change first appeared on the EU's agenda in the late 1980s. Since then, the EU's climate policy has consistently expanded and notably changed in scope (Delbeke & Vis, 2015b; Jordan & Rayner, 2010).

Up until the early 1990s, the only just emerging field of climate policy was characterised by action of individual member states without EU orchestration. In the early 2000s, the EU increasingly emerged as a single actor in international issues. This included climate policy, exemplified by the ratification of the Kyoto Protocol as a single block. Through a burden-sharing agreement, member countries committed to reducing their collective emissions jointly by 8%, against a 1990 baseline by the end of the first commitment period. Individual country-level targets were set according to relative wealth (Delbeke & Vis, 2015b; Jordan & Rayner, 2010).

In 2003, the EU adopted the Emission Trading System (ETS), which came into effect in 2005 and has become a key tool of EU climate policy. The ETS is a cap-and-trade tool creating a market for carbon. It sets a limit for total carbon emissions for which allowances are issued and allocated. These allowances can be traded, ensuring emission reductions in the most cost-effective way. As ambition increases, emission caps are stepwise lowered. The ETS applies to certain sectors and is covering a little under 50% of the EU's greenhouse gas emissions (Jordan & Rayner, 2010; Meadows, Slingenberg, & Zapfel, 2015).

Emissions of sectors outside the ETS, such as buildings, agriculture, waste, small industry and transport, make up more than half of the EU's emissions. For emission reductions in these sectors, the climate and energy package stipulated a decrease of 10% by 2020 against a 2005 baseline (Delbeke & Vis, 2015a; Skjærseth, 2021). While the overall target is set for the EU in total, responsibility for implementation is assigned to member states. For each country, binding reduction targets were calculated based on their relative wealth as determined by their GDP per capita (European Parliament & European Commission, 2009). Targets are translated by member states into national policy.

Aside from mitigation policies to be implemented on the national level, increasingly, the EU recognises the role of the local level for climate action. For example, the need for policies at the local level is explicitly mentioned in the Energy Strategy 2020 (European Commission, 2010), and urban mitigation action has been integrated into the EU's vision for urban development (European Commission, 2011).

Yet, as the EU does not have competencies on the local level, hard policy instruments such as regulations have to be transposed into national law first. To directly address local climate action, the EU primarily relies on voluntary policy instruments aiming to increase cities' capacity (Kern, 2023). Cities can apply to obtain funds for urban development and green infrastructure through funding instruments such as the European Structural and Investment Funds (European Commission, 2024). Aside from funding instruments, further instruments such as the European Energy Award the EU are aiming at increasing voluntary climate action (Kern, 2023).

Since 2008, local authorities are additionally provided guidance through the EU Covenant of Mayors (CoM). Signatories of the CoM commit to a range of objectives, notably the setting of mid- and long-term targets. To this end, they commit to developing Sustainable Energy Action Plans (SEAP) within two years of signing. Signatories have to create emission inventories and action plans. They also must regularly report on their progress regarding the emission target. The minimum emission reduction target for 2020 was 20% against a 2005 baseline. The aim of the initiative was to align cities' mitigation efforts with the EU's 20-20-20 targets. The fulfilment of requirements is monitored by the European Commission's Joint Research Centre (JRC), and non-compliance can be sanctioned (Kern, 2023).

The CoM also allows for cities to exchange knowledge and offers assistance and training. In 2015, the CoM was renewed, integrating climate adaptation and setting targets for 2030, before eventually merging with the Compact of Mayors to form the "Global Covenant of Mayors for Climate and Energy" (Bertoldi et al., 2020; Kern, 2023).

3.2. National Frameworks

In accordance with the scope of this analysis, the chosen countries exhibit a range of similarities. Attributes shared between countries are mainly explained by geographical and cultural proximity. All four of them are located in Western Europe and have comparable populations (see Table 1). They are among the most sizeable European countries and, in 2013, accounted for more than half of the EU's greenhouse gas emissions (EEA, 2015). Furthermore, they can be described as stable democracies with advanced economies (see Table 1) and are (or *were* in the case of the UK) embedded in the EU legislative framework.

Nonetheless, there are some notable differences between the four countries. While all were at the time members of the EU, they differ due to historical, geographical and cultural reasons. Furthermore, while the EU's legislative framework determines the guardrails of its members' climate policy, national implementation is up to individual members and depends on the country's unique socio-economic, energy- and industry-related and legislative circumstances. In the following, the individual characteristics will be outlined for each country. As the data used in this analysis covers the years 2013-2015, the outlined circumstances will, where possible, focus on this timeframe, in favour of more recent data.

Table 1: Overview of important metrics of each country

Variable	**Source**	**France**	**Germany**	**Italy**	**UK**
Population (in million)	(Eurostat, 2024b)	65.6	80.5	59.7	64.9*
GDP per capita (t USD in 2015 prices, corrected by PPP)	OECD (2024a)	40.4	46.5	37.0	41.0
Exposure to PM2.5, Micrograms per cubic metre	OECD (2024c)	13.45	13.72	17.91	11.37
Unemployment rate (total, % of labour force)	OECD (2024b)	10.3	5.0	12.4	7.6
GHG emissions in CO_2-equivalent (excl. LULUCF) (million tons)	EEA (2015)	490.2	950.7	437.3	572.1

3.2.1 *France*

In 2013, France had a population of 65.6 million inhabitants (Eurostat, 2024b). France, like much of Europe, is highly urbanised. In 2011, almost 80% of the population was living in urban areas, with almost half of the population living in urban areas of more than 100,000 inhabitants. The country is strongly centralised, with one quarter living in the urban area of Paris (Creusat & Morel-Chevillet, 2015). Cities in the rest of the country are sparsely distributed (Eurostat, 2015). The French economy is diversified, with the service sector being the most important for both GDP and employment. Economic activity, particularly of the service sector, is concentrated in the capital region Ile-de-France. This region alone contributes 30% of the nation's GDP. Industrial activity can be found primarily in the north and east of the country but has experienced a decline over the past decades (OECD, 2016a). Aside from the preponderance of the capital, regional disparities are not as pronounced as in the other countries of this analysis (OECD, 2006).
French unemployment is high in comparison to other advanced economies. Noteworthy is also the high youth unemployment. It is connected to inequalities in education as the socio-economic background has a particularly high impact on a child's education. As much of the poor population

* Refers to 2015 data

is living in metropolitan areas, unemployment is higher in cities than in the countryside (OECD, 2017a). The trend of high unemployment is somewhat pervasive regardless of economic development. It rose, however, in response to the 2008 financial crisis, reaching its peak in 2015 (OECD, 2021).
Regional patterns can be observed, with unemployment being higher in the overseas departments and within metropolitan France in the southern regions (Bessone, Dorothée, Robin, & Vugdalic, 2015). A declining manufacturing sector in the North and East has also contributed to higher unemployment in these regions (Maschke, 2024).

In 2015, nuclear energy accounted for 77.7% of France's electricity generation and 46.4% of the primary energy supply. Due to the prominent role of nuclear energy in the country's energy mix, emissions from the energy sector are low (IEA, 2017). Accordingly, per capita emissions are lower than in most other European countries. Greenhouse gas emissions are mainly generated in the transport, agriculture and residential-tertiary sectors, together accounting for about two-thirds of total emissions. Within these sectors, the highest shares can be attributed to road transport, buildings and cattle breeding. Emission reductions have been slow in these sectors, with emissions in the transport sector even increasing, likely due to increasing urban sprawl (OECD, 2021).
The transport and residential-tertiary sectors are also major sources of air pollution. Road transport leads to high levels of NO_2 and PM10. Regulatory thresholds for these pollutants are regularly exceeded in urban areas. In 2011, France faced legal action when the EU took it to court for insufficient reduction of PM10 levels. PM2.5 is less problematic with threshold exceedance only due to fluctuation caused by meteorological conditions (OECD, 2016a).

Already in the early 2000s, climate change mitigation was declared a priority as the 2005 POPE Act set a 75% reduction target for 2050 against a 1990 baseline. Sectoral targets were set with the Grenelle laws. Furthermore, France has a diverse set of climate legislation, implementing EU policy. While the country's climate policy can be described as ambitious, in some domains, even exceeding EU policy, it was lacking coordination (OECD, 2016a).
France is divided into regions, departments and municipalities. Climate action is significantly driven by the state, which exerts a high level of influence (Heidrich et al., 2016). Nonetheless, France recognises the role of local climate action and its impact on emissions reduction. Urban climate planning in France has been mandatory at the national level since 2010. The "Grenelle de l'environnement" act calls on regions, departments, and municipalities with a population of more than 50,000 to develop climate action plans (Plans Climat Territoriaux). With the Grenelle II Act, adopted in 2010, these plans became mandatory, and the population threshold was lowered to 20,000 starting in 2016 (Yalçın & Lefèvre, 2012). However, while cities are required to develop

climate plans, coordination between different government levels is not always given (OECD, 2021).

3.2.2 Germany

In 2013, Germany had a population of 80.5 million (Eurostat, 2024b). While the country is predominantly urban, a comparatively large proportion of the urban population is living in smaller cities with less than 100,000 inhabitants. Germany is decentralised, with urban areas spread across the country. Relatively large cities can be found in all parts of the country, however, population density is particularly high in the western parts in what is the German part of the “blue banana” (Eurostat, 2016).

The economy is highly diversified, with a particular focus on export-oriented manufacturing and technology-intensive goods (OECD, 2018). Important industries can be found throughout the country, although there are still considerable regional differences, particularly between East and West (Statistisches Bundesamt, 2015).

As the most populous country and due to its strong economy, Germany accounted for approximately 21% of the EU’s greenhouse gas emissions, representing the largest emitter of the block (EEA, 2015). The energy sector is the largest source of emissions. Fossil fuels account for 80% of total primary energy production (IEA, 2020). The country has been continually increasing its share of renewable energy but still largely depends on fossil fuels (Statistisches Bundesamt, 2015).

Air pollution was lower than the EU-27 and OECD average (OECD, 2012). Emission trends for all major pollutants have been decreasing (OECD, 2012, 2023b). However, while German cities are less exposed to air pollution than the EU-27 average, in urban areas, it can come to temporary exceedance of thresholds (OECD, 2012).

Germany’s unemployment rate has been low with little fluctuation. Compared to other European countries, it was little affected by the 2008 financial crisis. Since 2009, the unemployment rate continuously fell, eventually reaching a new low of 5.0% in 2019 (Bundesagentur für Arbeit, 2020). Unemployment in East Germany was notably higher than in the West. This has been primarily attributed to the economic changes following the reunification (Statistisches Bundesamt, 2016). It is expected that job loss due to a green transition will impact regions relying on carbon-intensive energy supply, like East Germany, more (OECD, 2023a).

The country exceeded its 21% emission reduction target for the Kyoto Protocol’s first commitment period. However, this is in part due to the effects of economic change and efficiency increases of the energy sector, following the German reunification (Shishlov, Morel, & Bellassen, 2016). While emissions are falling, progress has been uneven across sectors. The transport and building sector failed to achieve their reduction targets (OECD, 2023a).

In 2007, Germany set in the Integrated Energy and Climate Programme the objective of 40% emissions reduction by 2020 (OECD, 2012). With the Climate Action Programme 2020, sector specific targets were set (BMUB, 2014). The federal structure of Germany makes the federal states important actors in climate policy (Heidrich et al., 2016). Several of them have their own climate legislation. Half of the 16 federal states developed their climate legislation before the adoption of the Climate Change Act on the federal level, with North-Rhine Westphalia being the first in 2013. Differences in the ambition of federal states appear to be related to their reliance on fossil fuels (IRS, 2021).

Climate action on the local level is supported by both federal and state level. Several federal states support municipalities through various mechanisms, such as the provision of funding for projects. States that have a higher reliance on fossil-fuel energy are often less supportive (IRS, 2021). Of particular importance for local climate action is the National Climate Initiative. Since 2008, it has offered funding and guidance to climate action projects. Under the Local Authority Guideline, municipalities are supported with, amongst other things, the development of climate plans (Schumacher, Zell-Ziegler, & Repenning, 2017). Despite the multitude of support measures, the high administrative load from the federal level has been a strain on local administration lacking capacity (OECD, 2023b).

3.2.3 Italy

In 2013, the country had a population of 59.7 million (Eurostat, 2024b). 15.3% of the population lived in municipalities with more than 250,000 inhabitants, while 75.7% of inhabitants were living in highly or medium urbanised areas (Istat, 2015d). Italy is decentralised with a number of urban areas, particularly in the north of the country. In the centre and south, urban areas are distributed more sparsely (Eurostat, 2016). In 2015, 56.3% of the country was living in the north. Due to migration, the population balance was slightly positive. Larger urban areas, in particular Milan and Rome, were experiencing population growth, particularly outside the core municipality (Istat, 2015c).

Economic activity was diversified but also characterised by regional disparity. Industrial activity is primarily concentrated in the north. Economic growth stalled in the aftermath of the 2008 financial crisis, setting the country back compared to other Western European nations (Accetturo, Albanese, Paola, & Torrini, 2024). The financial and subsequent sovereign debt crisis led to an increase in unemployment (Istat, 2015b). As for many indicators, the North-South divide can be observed for unemployment, too, which is particularly persistent in the South (Baussola & Mussida, 2017).

At 36.7%, natural gas was the most important energy source, with fossil fuels together making up 79.1% of the total primary energy supply (IEA, 2016). Following the 2008 crisis, total energy consumption fell. In the early 2010s, Italy saw an increase in renewable energy production, accounting for 16.7% of the energy demand in 2013 (Istat, 2015a).
Its reliance on fossil fuels results in high levels of air pollution in the north of the country. With its concentration of industry and intensive agriculture, the region produces almost half of Italy's GDP. Being surrounded by mountains on three sides, the topographic features of this region result in persistently high levels of air pollution, particularly in the winter months. Due to these conditions, air pollution improvements would require more stringent measures than in regions with similar emission levels (Robotto, Barbero, Cremonini, & Brizio, 2022).

Since 2005, emissions in all sectors have been decreasing. Italy reduced its total emissions (without LULUCF) by 19.8% between 1990 and 2014. However, this can at least partially be attributed to negative GDP growth following the 2008 financial crisis (IEA, 2016; OECD, 2024d). Compared to other Western European countries, Italy has been slow to address climate change. National climate legislation was introduced in 2002 with the Climate Change Action Plan aiming at increasing energy efficiency and fostering renewable energy development. With this plan, the country aimed at aligning with the reduction targets of the Kyoto Protocol. Over the course of the following years, further legislation stipulating a wide variety of mitigation actions followed, ensuring compliance with EU targets. However, legislation lacked comprehension (Alberton, 2023; Gregorio Hurtado et al., 2014).

Climate and energy policy is divided between national and subnational levels. Constitutionally, Italy is a regional state with division of power between four tiers of government: national government, regions, provinces and municipalities (Gregorio Hurtado et al., 2014). Similar to a federal system, regions legislate in matters which are not assigned to the federal state. Authority in matters of energy and environment was largely transferred to the regions from the 1970s onwards. However, the constitutional reform in 2001 started a recentralisation trend leading to tensions between the state and regions regarding the competencies of environmental and related governance (Alberton, 2023).
Italy lacks national-level legislation coordinating climate action on lower levels. For example, commitments under the Kyoto Protocol were not translated into regional legislation. On the regional level, Regional Energy-Environment Plans have been developed, yet comprehensive climate plans are the exception. The national framework also does not actively support cities in climate policy development (Alberton, 2023).
In light of the lack of national-level support, voluntary approaches have become a central pillar of climate action. On a local level, international climate networks play an important role for

supporting climate legislation. Regions, provinces and cities which signed a charter under the coordination of the Italian Local Agenda 21 commit themselves to develop a climate plan for mitigation and adaptation (Agende 21 Locali Italiane, 2010). A significant role plays the CoM. Most Italian cities with a mitigation plan developed the plan as part of the CoM (Reckien et al., 2018). While 23% of the German population lives in municipalities that are CoM signatories, in Italy it is 70% (Kern, 2019). The popularity of the CoM in Italy can be traced back to the "European Sustainable Cities & Towns Campaign", which was particular popular in Spain and Italy (Kern, 2023).

3.2.4 United Kingdom

In 2015, the UK had a population of 65.1 million inhabitants (Eurostat, 2024b). The population is unequally distributed, with England alone accounting for 84% (ONS, 2016). With more than 70% living in predominantly urban areas, the country has the highest share of urban population of any OECD country (OECD, 2016b). 16% of the country's population was living in the capital London. Other large urban areas can be found in the midlands and north of England (Eurostat, 2016).

The UK has a diverse but specialised economy. The service sector is of primary importance and contributed 80.2% to the UK's GDP in 2020. The finance and insurance industry are important pillars of its economy. The importance of industry has been declining, accounting for only 19.2% of the country's GDP. The economic downward trend of the industry has implications on a spatial level, too. A strong regional disparity can be observed between the capital region and the rest of the country. The South-East, including London, is characterised by knowledge intensive services, while other regions have a higher share of manufacturing and low-tech sectors. Cities, except for London, are less productive than the OECD average. This regional disparity can be observed for a range of factors, such as educational attainment and revenue of local authorities (OECD, 2017b).

Greenhouse gas emissions are mostly related to transport, followed by power, and heat and buildings. Emission trends are uneven but negative for all sectors except agriculture. The UK reduced its emissions (without LULUCF) by 39 % by 2016 against a 1990 baseline. Emission reductions were driven by the replacement of coal with natural gas and renewable energy use. Progress was slower in the transport, and heat and building sectors (IEA, 2019). These two sectors are also associated with air pollution. However, emission levels have been declining for most pollutants (Defra, 2018). In 2019, per capita emission intensities of several pollutants were lower than in most OECD countries (OECD, 2022b).

Climate policy has been on the UK's agenda for longer than for most other countries. The 2008 Climate Change Act represents one of the earliest examples of comprehensive legislation strategically addressing climate change. The act set a legally binding target for reaching an 80% decrease in emissions by 2050 with respect to 1990 levels. It also requires setting five-year carbon budgets on which the government has to report regarding progress to parliament. The government is advised on carbon budgets by a specifically established independent advisory body, the Climate Change Committee (CCC). In addition to legislation on the state-level, Scotland, Northern Ireland, and Wales have devolved legislation setting their own goals (Benson & Lorenzoni, 2014; OECD, 2022a).

In contrast to the other countries of this analysis, there is no intermediary level between the national government and local authorities. Planning actions on the municipal level are, therefore, strongly influenced by the national government (RTPI, 2023). The strong centralisation in England leads to sub-national authorities having little revenue and power. Public investment at sub-national levels is considerably lower than in other OECD countries (OECD, 2017b).

Nonetheless, a framework of legislation exists mandating local authorities to actively address climate change in planning. Through the Planning and Compulsory Purchase Act 2008, local authorities are required to align planning policy with mitigation and adaptation to climate change. Furthermore, they have to show how policies contribute to the Climate Change Act. A similar stipulation can be found in the National Planning Policy Framework from 2012. Various other legislations further shape climate action on the local level (RTPI, 2023).

For the sake of completeness, it should be noted that the legislative framework in the devolved countries differs, but for reasons of brevity and clarity will not be further elaborated here. For an overview of relevant policy regarding local climate planning in Scotland, Wales, and Northern Ireland see RTPI (2023).

4. Methodology

As has been elaborated in the literature review section, urban climate action is complex and cannot be explained by single factors. Climate mitigation action is the consequence of various factors interacting. Traditional statistical analysis is only partially suited to address such an issue, making analysis considerably more difficult. While correlation analysis could determine significant correlations for several factors, correlations are weak (Reckien et al., 2015). Moreover, comparative research incorporating larger numbers of cases is still scarce (van der Heijden, 2019a).

In recent years, the use of Qualitative Comparative Analysis (QCA) for research of urban case studies has gained traction (Lamb et al., 2019; van der Heijden, 2018, 2019b). The utility of QCA for urban climate action lies in the ability to identify configurations instead of individual factors. By analysing interactions between factors, a better understanding of the role of individual conditions can be gained. As a result, QCA has found its way into urban climate mitigation research over the past two years, see e.g. Eisenack and Roggero (2022), Roggero, Fjornes, and Eisenack (2023), Habans, Clement, and Pattison (2019), and Kemmerzell and Hofmeister (2019). Accordingly, it represents a suitable methodological choice for this analysis.

4.1. Qualitative Comparative Analysis

4.1.1 Background

QCA was originally introduced by Charles Ragin in 1987, with the intention of formalising comparative analysis and bringing together qualitative and quantitative methodology. He argued that case studies are often rich in details, while this is not the case for quantitative research, which, therefore, is generalisable. In combining elements from these two research methodologies, he aimed to open case-oriented, non-experimental research to quantitative analysis (Ragin, 2000, 2014). It is this dual character that makes QCA a versatile tool for a wide variety of use cases, such as theory building and data analysis. Originally intended for use in the social sciences, it has since found increasing use in other disciplines, too. Since its introduction in 1987, Ragin has further developed the method by expanding it to include fuzzy sets to allow for analysis of non-dichotomous data (Ragin, 2000) and introducing measures of fit to enhance the interpretability of findings (Ragin, 2006).

4.1.2 Set-theoretic Approach

QCA interprets case studies as configurations of multiple conditions. In contrast to conventional variable-oriented approaches, which isolate the effect of individual variables, QCA emphasises the context-dependent nature of variables, understanding the variables of a case as interacting. Patterns of occurring configurations are analysed using Boolean algebra.

Unlike other methodologies, QCA is meant to produce a combination of pathways that can lead to the outcome. By comparing cases based on their configurations, researchers gain insights into pathways leading to the same outcome (Ragin, 2000).

To establish relationships between outcome and conditions, QCA is using set theory to analyse set relations. Fundamental concepts for the analysis of set relations are sufficiency and necessity. If a condition X leads in all cases to an outcome Y, it is deemed sufficient for the outcome. Thus, a sufficient condition X is a subset of the outcome Y. Necessity follows the opposite logic. If, from the occurrence of the outcome Y, the presence of the condition X can be deduced, Y is a necessary condition for X. In practical application, single conditions are rarely found to be either sufficient or necessary. Instead, conditions are generally combined into so called "configurations" through logical AND conjunction (Schneider & Wagemann, 2012).

4.1.3 *Necessity and Sufficiency*

To enhance the interpretability of findings, QCA makes use of parameters of fit (Ragin, 2000). Thus, for the analysis of necessity and sufficiency coverage and consistency are calculated. Coverage describes the size relations of two sets. For necessity, this means that the coverage score is an expression of how much the necessary condition exceeds the size of the outcome (Schneider & Wagemann, 2012). In crisp-set QCA, the coverage of a condition X as necessary condition for Y is calculated according to the following formula:

$$Y = \frac{Number\ of\ cases\ where\ X = 1\ and\ Y = 1}{Number\ of\ cases\ where\ X = 1}$$

Equation 1: Coverage of necessity (Schneider & Wagemann, 2012, p. 130)

The second parameter of fit, the consistency value, is used to account for imperfect subset relations due to noisy data. It describes to which degree the condition observes necessity (Schneider & Wagemann, 2012). Consistency of necessity of a condition X as necessary condition for Y is calculated according to the following formula:

$$Y = \frac{Number\ of\ cases\ where\ X = 1\ and\ Y = 1}{Number\ of\ cases\ where\ Y = 1}$$

Equation 2: Consistency of necessity (Schneider & Wagemann, 2012, p. 124)

Finally, for necessity there is also the Relevance of Necessity (RoN), which is a measure of proportion, indicating how relevant a necessity relation is. With this parameter, a distinction between trivial and non-trivial conditions can be made. Trivial conditions in this context are conditions that are (almost) always present regardless of the outcome (Schneider & Wagemann, 2012).

The parameters of fit of sufficiency are calculated using the same formulas as for necessity, albeit following a reversed interpretation, e.g. equation 1 is used to calculate the consistency of sufficiency and equation 2 for the coverage of sufficiency. This is due to sufficiency representing the mirror image of necessity (Schneider & Wagemann, 2012).
In this context, consistency describes the degree to which a condition is in line with the statement of sufficiency. In set-theoretic terms, it quantifies how much the condition is overlapping with the outcome. Coverage of sufficiency describes how much of the outcome is covered by the condition. It is calculated as the percentage of cases of the outcome that are explained by the condition. In set-theoretic terms, it describes the degree of overlap between two sets. While making use of the same formulas, interpretation differs notably. A threshold is used to account for logically contradictive and simply inconsistent cases (Schneider & Wagemann, 2012).

4.1.4 Characteristics of Set Theory

Based on the basic notions of sufficiency and necessity further characteristics of set theory can be directly derived: equifinality, conjunctural causation and asymmetry. It is these three characteristics that make QCA a valuable tool for addressing causal complexity (Schneider & Wagemann, 2012).

- Asymmetry describes the fact that the occurrence of a condition leading to an outcome does not automatically imply that the non-occurrence of the condition will also result in the non-occurrence of the outcome. For example, if condition X leads to outcome Y this does not mean that ¬X leads to ¬Y can be assumed (Schneider & Wagemann, 2012).
- Equifinality describes various conditions leading to the same outcome. Essentially, in set theoretic terms, different conditions are subsets of the outcome. In the solution term, all configurations sufficient for the outcome are combined by plus signs, with the plus sign denoting a logical OR argument (Schneider & Wagemann, 2012).
- Conjunctural causation describes the phenomenon that an outcome cannot be explained by a single factor. Instead, the interplay of various factors needs to be considered. Conjunctural causation can be observed if the effect of a condition is determined by its combination with other conditions (Schneider & Wagemann, 2012).

These characteristics determine how and in which context the application of QCA is useful. Through the absence of symmetry, QCA differs from correlational statistical methods. While the former only considers cases confirming the outcome, the latter considers all cases. Therefore, set relations should not be equated with correlation. Furthermore, regression analysis aggregates the effects of individual parts to produce a unifinal result. It, therefore, differs from the equifinal results derived from alternative formulations in QCA.

Because of the unique features of set relations, QCA is preferable over other regression-based methods for cases exhibiting causal complexity (Ragin, 2000; Schneider & Wagemann, 2012).

4.1.5 Implementation

A central element of QCA is the construction of truth tables, which essentially summarise statements of sufficiency. A truth table summarises all possible cases with each row representing a possible combination of conditions. Alongside each configuration, the outcome and number of cases exhibiting this combination of conditions are listed (Schneider & Wagemann, 2012).

The findings summarised in the truth table are then logically minimised using Boolean algebra. The minimisation process is making use of the Quine-McCluskey algorithm. Conjunctions in the truth table, called primitive expressions, are compared to determine logically redundant conditions, with a condition being deemed redundant if rows with the same outcome differ only in one condition. In such cases, the differing condition can be eliminated, simplifying the expression. The conjunctions obtained through the minimisation process are called prime implicants. All prime implicants leading to the outcome can be combined using the logical OR operator to produce the solution term (Schneider & Wagemann, 2012).

When constructing the solution term, the treatment of theoretically possible but unobserved truth table rows is of importance and requires careful consideration. Unobserved truth table rows are so-called logical remainders. Assumptions about the outcome of logical remainders can notably alter the solution term and its plausibility (Schneider & Wagemann, 2012).

If, in the minimisation step, no assumptions are made about the outcome of logical remainders, logical remainders are disregarded, and the solution term is based solely on empirically observed configurations. A solution term constructed this way is referred to as complex solution (Schneider & Wagemann, 2012).

As the complex solution is often less generalisable, the inclusion of logical remainders can be warranted to obtain solution terms that are easier to interpret. For this, the dimension of complexity, describing the number of conditions and logical operators that a solution term consists of, has to be considered. The fewer conditions and logical operators are involved in a solution, the less complex it is. The least complex solution formula is called the parsimonious solution (Ragin, 2014).

The parsimonious solution indiscriminately uses all logical remainders as simplifying assumptions. As this may contradict theoretical expectations, it is essential to examine simplifying assumptions. Accordingly, simplifying assumptions can be divided into two categories. Simplifying assumptions that can be justified by both empirical evidence and theory, also called directional expectation, are referred to as easy counterfactuals. In contrast, difficult counterfactuals are based on assumptions contradicting the directional expectation (Schneider & Wagemann, 2012).

By comparing complex and parsimonious solution, while evaluating the assumptions underlying counterfactuals, an intermediate solution can be generated. The intermediate solution only considers easy counterfactuals. It is therefore more complex than the parsimonious solution but less likely to be based on wrong assumptions (Schneider & Wagemann, 2012).

The choice of the solution formula depends on the research context and requires careful consideration. In any case, Schneider and Wagemann (2012) argue they should all be revealed so that the assumptions of an interpretation can be traced back.

4.1.6 Criticism and Limitations of the Method

Generally accepted by now, QCA has not been uncontested. Common criticism concerns its analytical robustness. Variations in the number of cases, changes of calibration thresholds or measurement errors may lead to wrong conclusions. Furthermore, critics argue that it offers little advantage over regression analysis, as it is based on more regressive assumptions and does not account for probabilistic processes (Mello, 2021).

Proponents of the method respond to these criticisms by emphasising the importance of adequate case knowledge, by which the design of the QCA should be informed. Measurements of fit were introduced to quantify the set-theoretic relationships (Ragin, 2006). Ragin (2014) further argues that QCA offers advantages over conventional regression analysis, such as accounting for asymmetric behaviour.

To effectively use QCA, it is vital to be aware of its limitations and acknowledge the importance of appropriate research design and calibration. If used correctly, its flexibility in using both quantitative and qualitative data makes it useful for a wide variety of different research contexts (Mello, 2021).

4.2. Relevance for the Case

As elaborated in the literature review, drivers of urban climate action have primarily been researched in isolation. Increasingly, the configurational nature of factors has been acknowledged. It is this feature that makes using QCA a promising tool for this analysis.

While generally said to work best for small and medium-N case numbers (Ragin, 2000), this analysis follows the argumentation of Schneider and Wagemann (2012) who argue that not the number of cases but rather theoretical considerations regarding the usefulness of set theory for explaining the underlying processes should be underlying the decision of whether to use QCA or not. If it is expected that causal complexity is underlying a phenomenon, so the argument, QCA is a valid methodological choice, regardless of the number of cases.

Previous research (e.g. Eisenack and Roggero (2022), van der Heijden (2019b)) has demonstrated this to be the case for urban climate action. By operationalising drivers of urban mitigation planning, the findings of Eisenack and Roggero (2022) served as a starting point for this analysis. In this analysis, further factors are introduced, including factors that are negatively correlated with the outcome. By doing so, the full potential of QCA will be leveraged.

4.3. Data Sources

Data used for this analysis draws from various openly accessible databases. GDP per capita data stem from the OECD Regions, Cities and Local Areas dataset (OECD, 2024e). Population and unemployment data was obtained from the Eurostat City Statistics (a synthesis of the discontinued Urban Audit and Large City Audit) database (Eurostat, 2017). Originally created to collect information on the quality of life, the database contains a variety of indicators. It covers a geographically dispersed and representative sample of European cities of various sizes with a population of at least 50,000. To ensure representability, in some cases smaller cities were considered, too. Cities included in the dataset were selected to include at least one city from each NUTS3 region and at least 20% of a country’s population (Eurostat, 2004).

4.3.1 Outcome

Before exploring the factors that were chosen for the analysis, it is necessary to define the outcome. Climate action can take on many forms. Accordingly, operationalising climate mitigation necessitates choosing an appropriate outcome. Following Eisenack and Roggero (2022), the existence of climate mitigation plans has been chosen as outcome. Climate plans have the advantage of being readily available. While the mere existence of a climate mitigation plan cannot be equated with actual mitigation effort, the process of drafting a mitigation plan does indicate that the city has taken a first step and acknowledged the need for action (Eisenack & Roggero, 2022).

Information about the presence of a climate mitigation plan was obtained from a dataset of European Local Climate Plans (Reckien, Flacke, & Boer, 2020). It is based on an analysis of the climate plans of 885 Urban Audit cities. The authors systematically searched for plans, and a typology for the type of plan was developed by Reckien et al. (2018). Climate plans are assigned to one of six categories, depending on their focus and integration with other planning documents. For this analysis, only type A plans were considered. Accordingly, local climate plans are considered stand-alone documents with a clear focus on climate change and developed for an urban area. Plans do not have to be officially adopted. Instead, non-binding and expired

documents and drafts were included in the dataset as well, as they were deemed sufficient to indicate that active consideration of climate change was taking place.
It should be noted that defining what constitutes a “local” climate plan is not always straight-forward. In France, for example, plans are available for entire city regions, while in the UK plans exist for various municipalities of a city region. Accordingly, London is divided into its boroughs while Paris is represented as Greater Paris, encompassing administratively separate adjacent cities (Reckien et al., 2018).

The dataset of plans used for this analysis was collected from November 2016 to January 2017. While for each country, a broadly similar number of cities is represented, cities in the UK are overrepresented (see Table 2). However, the smaller number of cities in France and Italy can also be explained by cities being counted towards a metropolitan city, as opposed to the UK, where, as stated before, different boroughs of London are counted individually.

Table 2: Number and share of cities with mitigation plans for each country

Country	**Number of cities**	**Cities with mitigation plan**	**Share of cities with plan**
France	63	56	88.89%
Germany	79	63	79.75%
Italy	59	41	69.49%
UK	86	48	55.81%
Total	287	208	72.47%

4.3.2 Capacity Indicators: GDP per Capita and Population Size

As established before, local authorities differ in terms of resource availability and technical expertise. These factors determine a city’s capacity to implement policies and draft plans. Institutional capacity is commonly connected to proxies, such as GDP per capita and population size. A larger city may have a greater number of stuff, while an affluent city is less restricted by resource constrains (Homsy, 2018b).
However, relations between these proxies and climate planning are less straight-forward and may not suffice to adequately capture the complexity of a city’s capacity (Pitt, 2010). For this reason, this analysis employs three different measures associated with institutional capacity simultaneously. This combination of multiple proxies is expected to better capture the complexity and yield a better understanding of the influence of capacity.
The first proxy used is GDP per capita, whose explanatory power has already been shown by Eisenack and Roggero (2022). Accordingly, this analysis follows their methodology. Data was obtained from the OECD regional statistics dataset. It is available at a TL3 resolution, which for

the most part is equivalent to Eurostat's NUTS3 level (OECD, 2022c). The use of this dataset rather than Eurostat data is justified by its greater coverage.
As data for the existence of climate plans was collected at the beginning of 2017, GDP per capita data from up to two years before was collected. This is meant to cover the conditions of the time when the plans were in development. In the case of GDP per capita, data for the years 2013-2015 was averaged to avoid biases induced by fluctuation (Eisenack & Roggero, 2022).

Population served as the second proxy for capacity. The Eurostat City statistics dataset contains population data for 879 cities. However, the temporal coverage greatly varies. Data for the relevant years is not available for all cities. Therefore, linear interpolation was utilised to fill data gaps for cities with at least two data points between 2010 and 2018. For the subsequent analysis, cities with at least one data point for one of the years 2013-2015 were considered. If more than one data point was available, the mean for the three years was calculated.
Data reflects population according to administrative boundaries. However, in the case of certain larger cities, such as Paris or Milan, the dataset follows the definition of Greater Cities instead. This is to better capture the urban character of the cities extending beyond its administrative borders (Eurostat, 2017). This contradicts the interpretation of population as an indicator of local administrative capacity, as a local government's expenditure will be determined by the size of the population within administrative boundaries. However, the inconsistency introduced this way is deemed negligible as all cities for which this is the case surpass the threshold for population and a similar inconsistency can be observed for planning documents. However, it should be mentioned that this results in the omission of cities that are administratively independent. E.g. the city of Monza counts towards Milan.
In 2015, the four countries analysed had a combined population of 273,089,200, representing 53% of the EU's total population (Eurostat, 2015). Out of the 885 cities included in the City Statistics dataset, 462 cities are located in these countries. However, not for each city data is available for every indicator within the specified timeframe. The dataset of this analysis contains 287 cities accounting for 62% of cities in the city statistics dataset. These cities taken together have a combined population of 80,385,784 representing approximately 29% of the four countries' population and 15.8% of the EU's population at that time. Cities range in size from 34,600 to 10,091,100.

4.3.3 Unemployment

Unemployment was chosen as the third indicator that is primarily associated with capacity. While not as commonly used to proxy administrative capacity as GDP per capita or population, it is believed to be a valuable addition due to its potentially bi-directional effects. It commonly is interpreted as a strain on a city's resources (Reckien et al., 2015). Unemployment, therefore, represents a factor that potentially mitigates existing financial capacity. Its inclusion is expected to better capture the complexity of capacity.

Unemployment rate data was available for a total of 829 cities. However, as is the case for population data, availability for the relevant years was limited. Accordingly, data processing followed the same methodology as for population data.

For some cities, in particular those located in France, unusually high unemployment rates were found, e.g. 43% for the city of Compiègne. While such high values make calculation errors or faulty underlying data seem likely, a compounding factor can be found in a differing definition of unemployment for French cities. The unemployment rate of French cities is calculated based on the population census and deviates from the ILO definition used for other countries, using a wider definition of unemployment, leading to a higher estimate (Eurostat, 2024a).

A potential alternative is the OECD regional statistics database. However, the highest spatial resolution is at TL3 level, which would dilute the city focus. Furthermore, no data is available for Germany. Therefore, Eurostat data offers the most comprehensive data for unemployment at the city level. While the differing definition makes cross-country comparison more complicated, extraordinarily high values were not excluded but manually checked for alternative data. As alternative data led to the same set membership, high values were used regardless. This is an advantage of crisp-set QCA, as the method is not very susceptible to deviations that are not close to the threshold.

4.3.4 *Co-Benefit of Air Pollution Reduction*

In addition to the three capacity-associated factors, this analysis incorporates two additional factors previously used by Eisenack and Roggero (2022). This way, it can be examined how they interact with the factors already presented furthering the understanding of their role.

One of these factors is co-benefits of climate mitigation policies. A variety of possible co-benefits of climate action exist, yet quantification can be challenging. The most commonly addressed type of co-benefits is improved air quality (Ürge-Vorsatz et al., 2014).

Common climate mitigation action is addressing the transport and heating sectors, with measures aimed at replacing fossil fuels (Sethi et al., 2020). Both sectors are also sources of particulate matter (PM), which has adverse health effects. A reduction in the use of fossil fuels would also result in a decrease in urban PM concentrations, providing an incentive for cities with high air pollution levels to implement climate mitigation policies. However, case studies indicate that the role of co-benefits is manyfold and highly context-dependent (Roggero, Gotgelf, & Eisenack, 2023).

Eisenack and Roggero (2022) used air quality co-benefits as indicators in a QCA in which they were part of one configuration. However, it only featured eastern European cities, for which it was concluded that co-benefits had likely no explanatory power. Therefore, shifting the focus to Western European nations, as this analysis does, might unveil interactions previously uncaptured. The data for co-benefits consists of the average level of PM2.5 in µg/m³ experienced by the population. It was obtained from the OECD regional statistics database at TL3 resolution, which was spatially assigned to cities (OECD, 2024c). The different spatial resolution was not deemed relevant, as administrative boundaries are irrelevant for air pollutants. Just like for the other factors, data was averaged for the years 2013-2015.

4.3.5 National-level Legislation Obligating Plan Development

As the final factor of this analysis, the influence of a nation's climate policy was considered. Eisenack and Roggero (2022) operationalised climate policy with it prominently focusing in the solution formula. They used the Climate Change Performance Index (CCPI), an annually published index evaluating countries' climate change mitigation efforts.

However, all four countries of this analysis score relatively close to each other, making it difficult to reliably operationalise the index. Furthermore, two of the four countries, France and the UK, have national legislation mandating for cities to develop climate plans. As both countries also ranked higher than the other two in the CCPI for 2013-2015, it was decided not to use the CCPI but instead use obligation as a condition. Accordingly, French and British cities were assigned the outcome 1 for this condition, while Germany and Italy were assigned the outcome 0. This follows the use of the condition by Eisenack and Roggero (2022), although they used obligation alongside national-level climate policy.

4.4. Operationalisation

4.4.1 Research Design

Since the outcome, plan existence, can only be dichotomous, a crisp-set approach was chosen. In crisp-set QCA, set membership is assigned based on a threshold. The threshold determines whether a condition is considered present or absent. Accordingly, the case membership is assigned to a case (Schneider & Wagemann, 2012).

Aside from plan existence, all other conditions were available as continuous values, which could be translated into fuzzy sets. Fuzzy sets have the advantage of displaying a more nuanced membership. However, translating values into fuzzy sets is complicated by the varying data quality of some of the indicators. This becomes particularly problematic in the face of the different methodologies used for the unemployment rate of French cities. Additionally, some factors are hard to translate to fuzzy sets, despite being continuous. Eisenack and Roggero (2022) argued that conditions like co-benefits lacked the theoretical understanding to translate them into fuzzy sets.

In contrast, crisp sets are not affected by variations of values except for values in the direct vicinity of the threshold. This makes crisp-set appear a more suitable choice for this analysis.

4.4.2 *Calibration*

Calibration is of particular importance for QCA as it forms the basis for establishing qualitative differences between cases. Where possible, calibration should be informed by theoretical knowledge external to the data (Schneider & Wagemann, 2012). In the following, the choice of thresholds and underlying considerations for the setting of thresholds will be explained. An overview of thresholds and the share of cities above said thresholds (share of cities obligated to develop a plan in the case OBL) can be found in Table 3.

Table 3: Thresholds and share of cities above the threshold for each condition

Condition	Abbreviation	Threshold	Share of cities above the threshold
Outcome	OUT	≤2013	72%
Affluence	AFL	40,700	40%
Co-benefits	COB	12.77	40%
Obligation	OBL	-	52%
Population	POP	150,000	40%
Unemployment	UNE	9.5	39%

The literature does not offer a suitable categorisation for GDP per capita, as whether a value is considered high or low is highly context dependent. All four countries are highly developed Western European countries, so the average GDP per capita of Western European countries may provide guidance. However, national data is of only limited suitability as cities are not necessarily indicative of a country's economy. For this reason, it was decided to derive the threshold from the statistical distribution of the cases. To account for the vague nature of this metric, the third quintile was chosen.

Europe has relatively few large cities. This is also reflected by cities in the dataset of which only 10% had a population of over 500,000. Therefore, a focus on large cities would prove difficult to operationalise, in particular with respect to the large number of cities with a set membership in the outcome. As there is a considerable number of second-rank cities it was decided to set the threshold so that second-rank cities and larger cities would be classified as "large". Camagni, Capello, and Caragliu (2015) define second-rank cities in an EU context as those having a population between 200,000 and 1 million inhabitants. Setting the threshold at 200,000 would classify around one third of the dataset as large cities. However, as they apply this categorisation to Larger Urban Zones (LUZ) (now commonly referred to as Functional Urban Areas, FAU) and not cities according to administrative boundaries, a slightly more lenient threshold was chosen, dividing the dataset approximately at the third quintile.

For setting the threshold for co-benefits, the approach from Eisenack and Roggero (2022) was used as a starting point. Informed by the WHO guideline value, they opted to set the threshold to 11.4 µg/m^3. Accordingly, two thirds of all cities were deemed as having co-benefits. However, it remains questionable whether cities would be guided by the WHO guideline value as opposed to the EU air quality standards. The latter, at the time of data collection, defined an annual threshold of 25µg/m^3 for PM2.5. This threshold is considerably higher than the WHO guideline and, in contrast to the latter, also legally binding. Therefore, it appears more likely that cities exceeding the EU air quality standard for PM2.5 value would have reason to implement mitigation measures in order to decrease emissions.

However, while some cities came close to the EU air quality standard, no city was found to exceed the value. In accordance with the other conditions, it was therefore decided also to set the threshold at the third quintile. Accordingly, the threshold was set at 12.77 µg/m^3. While considerably lower than the EU air quality standard, it is considered more likely that cities towards the higher end of the scale would use the advocacy potential of air pollution reduction to justify plan drafting.

Unemployment rates of this dataset are impacted by the aftermath of the 2008 financial crisis and vary considerably between the countries. While the median for cities in Germany and the UK was 6% and 6.25%, respectively, for cities in Italy, it was 10.43% and for French cities even 18%. The literature does not provide a threshold that suits widely differing contexts. Accordingly, statistical analysis was performed, and eventually, here, too, the third quintile was chosen as the threshold.

4.5. Summary and Expectations

A high value of necessity for any of the conditions is not likely to be observed as plan development as an outcome is associated with equifinality. While the four countries do share many features, institutional and other factors differ significantly. Hence, it is unlikely that the outcome can be traced back to one specific condition, which would emerge as a necessary condition.

It is also unlikely that any of the conditions will be individually sufficient. Nonetheless, due to the high number of cases with a positive outcome, it is expected that affluence and population have a high individual sufficiency. For affluence, this has been shown to be the case by Eisenack and Roggero (2022). As population size has been shown to have a strong relationship with plan development, it is likely to follow this pattern, too. The other conditions are expected to have lower sufficiency scores and are only relevant in conjunctions.

Regarding conjunctural causation, affluence and population are likely to lead to positive outcomes in configurations. Neither the presence or absence of either co-benefits or national-level obligation is expected to change their effect. Especially, if both configurations are present in a configuration simultaneously, the outcome will very likely be positive. This leads to the first hypothesis of this study:

> **H1:** Cities that are both affluent and large develop mitigation plans regardless of circumstances.

Conversely, it is unlikely that the absence of either affluence or population in a configuration will be a driver of plan development. However, the presence of unemployment may mitigate the effect of population and particularly GDP per capita, as cities will have to divert funding to social causes. Accordingly, it is unlikely to see the presence of affluence or population simultaneously with unemployment in the same configuration.

> **H2:** Unemployment can offset the effect of affluence or population size.

Additionally, in France and the UK, where national-level obligation mandates local authorities to produce mitigation plans, unemployment is not expected to play a significant role. For these two countries, national-level obligation is expected to be the main driver, particularly for disadvantaged cities. Accordingly, configurations may feature the presence of obligation and unemployment simultaneously.

> **H3:** National-level obligation drives mitigation plan development even in cities with high unemployment levels.

Yet, as explored before, the role of unemployment is also not necessarily unidirectional. It is possible that, in certain circumstances, unemployment may present an incentive for cities to engage in climate action. It might act as a driver of climate action, particularly for non-affluent cities wanting to leverage the growth potential of green sectors.

> **H4:** The presence of unemployment can be related to plan development.

Lastly, co-benefits are likely only to have a noticeable effect on plan development in regions with high air pollution levels. This might be the case, particularly for regions with notoriously high air pollution, like the Po Valley in Italy. This part of the country was characterised by a variety of different city types with respect to size and affluence, while unemployment was generally low. Accordingly, it is likely that a configuration with co-benefits also features a lack of unemployment.

> **H5:** Co-benefits drive mitigation plan development in the absence of unemployment.

5. Results

In the following, the results of the QCA are presented. For the analysis, the R package "QCA" was used. The R script for this analysis can be found in Appendix 5.

5.1. Necessity of Individual Conditions

Before testing configurations, it is common practice to start with individual conditions. For a condition to be necessary, it has to be a superset of the outcome. Therefore, it is useful to start with individual conditions as configurations can only be necessary if all its individual conditions are necessary (Schneider & Wagemann, 2012).

Table 4 summarises consistency, coverage score, and Relevance of Necessity (RoN) for each individual condition. A commonly accepted score for considering a condition necessary is 0.9 (Schneider & Wagemann, 2012). The research context may warrant choosing a different, less stringent threshold, but the highest consistency score is 0.639 for ¬COB (¬ denotes logical negation) and hence noticeably below the threshold. Therefore, choosing a different threshold is out of the question. The analysis shows that no individual condition can be deemed necessary. As no condition passes the consistency score for necessity, high coverage and RoN scores are meaningless.

Table 4: Parameters of fit of necessity for individual conditions (¬ denotes logical negation)

Condition	Abbreviation	Consistency	Coverage	RoN
Affluence	AFL	0.471	0.845	0.905
Co-benefits	COB	0.361	0.658	0.816
Obligation	OBL	0.500	0.698	0.754
Population	POP	0.447	0.816	0.892
Unemployment	UNE	0.399	0.748	0.863
¬ Affluence	¬AFL	0.529	0.643	0.655
¬ Co-benefits	¬COB	0.639	0.769	0.740
¬ Obligation	¬OBL	0.500	0.754	0.814
¬ Population	¬POP	0.553	0.665	0.663
¬ Unemployment	¬UNE	0.601	0.710	0.685

5.2. Sufficiency of Individual Conditions

Relations of sufficiency are fundamental for QCA. As explained in section 4.1.3, a condition is sufficient if its presence leads in every case to the outcome. In set-theoretic terms, such a condition is a subset of the outcome.

The threshold for the consistency of sufficiency is often lower than for necessity. Ragin argues that it should be no lower than 0.75 (Ragin, 2008). The choice of an appropriate threshold should be informed by the research context. Factors such as the number of cases and logical remainders, as well as theoretical expectations, are instrumental in informing the decision for the right threshold. For large-N QCA, a threshold of at least 0.8 is widely accepted (Rubinson, Gerrits, Rutten, & Greckhamer, 2019).

This analysis has a relatively great share of cases with a set membership in the outcome, offering justification for a high threshold. At the same time, there are few logical remainders and calibration of conditions can only, to some extent, be guided by the literature. While blindly following conventions is not advisable, in the face of these considerations, the choice of a threshold of 0.8 appears to be a good compromise.

Consistency ranges from approximately 0.64 to 0.85 (see Table 5). This relatively narrow range is likely linked to the great number of cases with a positive outcome. AFL and POP both can be considered individually sufficient with consistency scores of greater than 0.8. Both conditions also have a similar coverage with 0.471 and 0.447, respectively. As such, each of the two conditions covers just under half of all cases.

Conversely, ¬AFL and ¬POP have the lowest and third lowest consistency, respectively. However, it should be noted that conditions are asymmetric. Notably, also ¬COB and UNE have a relatively high consistency, albeit below the threshold. The former also has the highest coverage of all conditions.

Table 5: Parameters of fit of sufficiency for individual conditions (¬ denotes logical negation)

Condition	**Abbreviation**	**Consistency**	**Coverage**
Affluence	AFL	0.845	0.471
Co-benefits	COB	0.658	0.361
Obligation	OBL	0.698	0.500
Population	POP	0.816	0.447
Unemployment	UNE	0.748	0.399
¬ Affluence	¬AFL	0.643	0.529
¬ Co-benefits	¬COB	0.769	0.639
¬ Obligation	¬OBL	0.754	0.500
¬ Population	¬POP	0.665	0.553
¬ Unemployment	¬UNE	0.710	0.601

5.3. Truth Table

After exploring necessity and sufficiency of individual conditions, the following will examine the sufficiency of configurations. Each row of the truth table stands for a logically possible configuration. The total number of truth table rows is determined by the number of conditions *k*, according to the formula 2^k (Schneider & Wagemann, 2012). This analysis works with five conditions, yielding 32 logically possible configurations.

For each truth table row, the consistency score of sufficiency and the number of occurrences are listed. Whether a configuration is deemed sufficient depends on whether it surpasses the sufficiency score. As case numbers for configurations are all in the small and medium range, in contrast to the analysis of sufficiency of individual conditions, for the truth table, a more lenient threshold of consistency of 0.75 was chosen.

The truth table (Table 6) summarises the results of the sufficiency analysis of configurations. Out of 32 possible configurations, 30 could be observed. Cities are not evenly distributed between configurations. They range between none and 32 observations per configuration. Rows 26 and 30 represent logical remainders as their configurations could not be observed. This phenomenon of non-occurrence of logically possible configurations is normal in QCA and has been termed "limited diversity" (Schneider & Wagemann, 2012).

Configurations that are deemed sufficient are assigned the outcome "1". In total, there are 19 configurations, which are sufficient for the outcome. The great number of configurations with an outcome of 1 is likely connected to the great share of cases with set membership in the outcome. Two configurations, row 4 and row 9, have a consistency value of exactly 0.75. Accordingly, they sit exactly on the threshold. For those two rows, it is advisable to look at the contradictory cases to confirm or reject whether those configurations can be considered sufficient.

Some observations regarding the interplay of conditions can be made. If only one condition is present, the outcome is always positive, with the exception of OBL. Similarly, the presence of four or more conditions at the same time always leads to a positive outcome. For two and three conditions, no clear pattern can be observed. Most cities show configurations with one to three conditions present.

Table 6: Truth table displaying the sufficiency of configurations

Row	AFL	COB	OBL	POP	UNE	OUT	n	Consistency
1	0	0	0	0	0	0	7	0.286
2	0	0	0	0	1	1	7	0.857
3	0	0	0	1	0	1	2	1.000
4	0	0	0	1	1	1	4	0.750
5	0	0	1	0	0	0	13	0.385

Row	AFL	COB	OBL	POP	UNE	OUT	n	Consistency
6	0	0	1	0	1	1	32	0.875
7	0	0	1	1	0	0	15	0.467
8	0	0	1	1	1	1	24	0.875
9	0	1	0	0	0	1	16	0.750
10	0	1	0	0	1	0	17	0.353
11	0	1	0	1	0	1	3	1.000
12	0	1	0	1	1	0	5	0.600
13	0	1	1	0	0	0	12	0.500
14	0	1	1	0	1	0	8	0.500
15	0	1	1	1	0	0	4	0.250
16	0	1	1	1	1	0	2	0.500
17	1	0	0	0	0	1	29	0.793
18	1	0	0	0	1	0	2	0.500
19	1	0	0	1	0	1	14	0.857
20	1	0	0	1	1	1	1	1.000
21	1	0	1	0	0	1	9	0.889
22	1	0	1	0	1	1	1	1.000
23	1	0	1	1	0	1	10	1.000
24	1	0	1	1	1	1	3	1.000
25	1	1	0	0	0	1	7	1.000
26	1	1	0	0	1	?	0	-
27	1	1	0	1	0	1	20	0.950
28	1	1	0	1	1	1	4	1.000
29	1	1	1	0	0	0	13	0.462
30	1	1	1	0	1	?	0	-
31	1	1	1	1	0	1	2	1.000
32	1	1	1	1	1	1	1	1.000

5.4. Solution Formula

To obtain the solution formula, primitive expressions of the truth table are minimised using Boolean algebra. To do this, the "minimize" function of the "QCA" package uses the classical and enhanced Quine-McCluskey and Consistency Cubes algorithms (Dusa & Paduraru, 2024). In essence, the algorithms compare primitive expressions and remove logically redundant formulations to yield the prime implicants (Schneider & Wagemann, 2012).

5.4.1 *Complex, Parsimonious and Intermediate Solution*

As explained in chapter 4, the standard analysis produces three different types of solution formula, depending on the treatment of logical remainders. The choice of the most appropriate solution formula depends on the research context and should be elaborated to reveal underlying considerations (Schneider & Wagemann, 2012). Therefore, in the following, all three solution formulas will be presented.

The complex (sometimes also called conservative) solution minimises the primitive expressions without considering logical remainders (Schneider & Wagemann, 2012). There are six equivalent alternative formulations of the formula (see, for example, Equation 3, showing M6, one of the alternative formulations of the complex solution). All six formulations share three and contain six prime implicants in total. Table 7 shows the prime implicants of the complex solution. Apart from POP, for all conditions, both presence and absence occur in at least one configuration.

$$M6: AFL * POP \ + \ \neg AFL * \neg COB * UNE \ + \ COB * \neg OBL * \neg UNE \ + \ AFL * \neg COB * \neg UNE \ + \ \neg COB * OBL * UNE \ + \ \neg OBL * POP * \neg UNE \ -> \ OUT$$

Equation 3: Alternative formulation M6 of the complex solution

The parsimonious solution formula incorporates logical remainders in the minimisation process, seeking to construct a solution formula with the smallest number of logical operators (Schneider & Wagemann, 2012). The resulting formula is presented in Table 8. As only two logical remainders exist, the parsimonious solution closely resembles the complex solution. It differs only in one regard. Based on truth table row 30, one additional prime implicant has been added. Alternative formulations M1-M4 are shared by both complex and parsimonious solution. M5 and M6 of the parsimonious solution are based on assumptions about row 30.

In both logical remainders, AFL is present. Directional expectation suggests that the presence of AFL or POP would lead to OUT = 1, as both conditions have previously been identified as sufficient. Furthermore, in all other cases where AFL was present together with COB while OBL was absent, the outcome was OUT = 1. The configuration of row 26, AFL*COB*UNE, can therefore be considered a sufficient condition.

A similar reasoning can be used for row 30, though empirical information is less clear. Row 30 differs from row 29 only in the presence of UNE. The configuration of row 29 leads to a positive outcome in less than half of all observed cases. Theoretical guidance would relate the presence of UNE rather to the absence of a plan. Yet, UNE has a relatively high individual sufficiency. Accordingly, there is ground for treating it as a sufficient condition. However, the configuration AFL*OBL*UNE, which it is based on, should be subjected to particular scrutiny.

The intermediate solution (see Table 9) is, in essence, identical to the parsimonious solution. By explicitly declaring row 26 a simplifying assumption, the algorithm adds two further configurations, which, however, do not have any unique coverage even within their alternative formulation and can, therefore, be disregarded.

Due to their small number, logical remainders exert a negligible influence on the solution formula. Therefore, the three solution formulas only differ in the number of alternative formulations. Against the background of weak theoretical evidence for the use of the simplifying assumptions, it seems reasonable to work with the complex solution. Its alternative formulations do not rely on assumptions about logical remainders and instead focus on empirical observations. The following will, therefore, focus on the complex solution.

5.4.2 *Comparing Alternative Solution Formulas*

The solution formula, regardless of formulation, has a total coverage of 79.8% and a consistency of 87.8%. Coverage scores of the configurations range between 0.087 and 0.293. Each of the alternative solution formulas of the complex solution consists of six configurations. Configurations 1-3 are a part of every alternative solution formula. These three configurations explain cases that cannot be explained by any of the other configurations of the solution formula. Accordingly, they are configurations with unique coverages > 0.

The consistency of configurations ranges between 0.855 and 0.957. Configuration 4, AFL*¬COB*OBL, has the highest consistency. It is followed by configuration 1, AFL*POP, which represents the overlap of the two conditions which have been found to be individually sufficient. The two individually sufficient conditions AFL and POP are present in six out of nine conditions.

Formulas M1-M4 attribute the greatest coverage to configuration ¬AFL*¬COB*UNE. This formulation includes truth table row 4, which has a consistency score of 0.75 and, as such, is located right at the consistency threshold. Increasing the consistency threshold to 0.76 leads to the disappearance of this exact formulation (see Appendix 2). Yet, a similar formula ¬AFL*¬COB*¬POP*UNE can be observed, differing from ¬AFL*¬COB*UNE only in the inclusion of ¬POP. While further qualifying the initial configuration, it does not contradict it and suggests that UNE is in fact in some cases related to OUT = 1. In contrast, the configuration COB*¬OBL*¬UNE, which hinges on truth table row 9, also with a consistency score of the threshold level 0.75, disappears if the threshold is increased.

Table 7: Prime implicants of the complex solution. The values indicate their coverage in alternative formulations M1-M6.

Config. Nr	**Formula**	**Consistency**	**Coverage**	**Unique Coverage**	**(M1)**	**(M2)**	**(M3)**	**(M4)**	**(M5)**	**(M6)**
1	AFL*POP	0.945	0.250	0.034	0.034	0.038	0.034	0.038	0.034	0.038
2	¬AFL*¬COB*UNE	0.866	0.279	0.029	0.264	0.279	0.264	0.279	0.029	0.043
3	COB*¬OBL*¬UNE	0.891	0.197	0.058	0.106	0.091	0.072	0.058	0.106	0.091
4	AFL*¬COB*OBL	0.957	0.106	0.000	0.005	0.005	0.043	0.043		
5	AFL*¬COB*¬UNE	0.855	0.255	0.000	0.111	0.111			0.149	0.149
6	AFL*¬OBL*¬UNE	0.871	0.293	0.000			0.111	0.111		
7	¬COB*¬OBL*POP	0.857	0.087	0.000	0.010		0.010		0.010	
8	¬COB*OBL*UNE	0.883	0.255	0.000					0.005	0.005
9	¬OBL*POP*¬UNE	0.923	0.173	0.000		0.010		0.010		0.010

Table 8: Prime implicants of the parsimonious solution. The values indicate their coverage in alternative formulations M1-M6.

Config. Nr.	**Formula**	**Consistency**	**Coverage**	**Unique Coverage**	**(M1)**	**(M2)**	**(M3)**	**(M4)**	**(M5)**	**(M6)**	**(M7)**	**(M8)**
1	AFL*POP	0.945	0.250	0.029	0.034	0.038	0.034	0.038	0.029	0.034	0.034	0.038
2	¬AFL*¬COB*UNE	0.866	0.279	0.029	0.264	0.279	0.264	0.279	0.264	0.279	0.029	0.043
3	COB*¬OBL*¬UNE	0.891	0.197	0.058	0.106	0.091	0.072	0.058	0.106	0.091	0.106	0.091
4	AFL*¬COB*OBL	0.957	0.106	0.000	0.005	0.005	0.043	0.043				
5	AFL*¬COB*¬UNE	0.855	0.255	0.000	0.111	0.111			0.149	0.149	0.149	0.149
6	AFL*¬OBL*¬UNE	0.871	0.293	0.000			0.111	0.111				
7	AFL*OBL*UNE	1.000	0.024	0.000					0.005	0.005		
8	¬COB*¬OBL*POP	0.857	0.087	0.000	0.010		0.010		0.010		0.010	
9	¬COB*OBL*UNE	0.883	0.255	0.000							0.005	0.005
10	¬OBL*POP*¬UNE	0.923	0.173	0.000		0.010		0.010		0.010		0.010

Table 9: Prime implicants of the intermediate solution. The values indicate their coverage in alternative formulations M1-M6.

Config. Nr.	**Solution**	**Consistency**	**Coverage**	**Unique Coverage**	**(M1)**	**(M2)**	**(M3)**	**(M4)**	**(M5)**	**(M6)**	**(M7)**	**(M8)**	**(M9)**	**(M10)**
1	AFL*POP	0.945	0.250	0.010	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014
2	¬AFL*¬COB*UNE	0.866	0.279	0.029	0.264	0.279	0.264	0.279	0.264	0.279	0.264	0.279	0.029	0.043
3	COB*¬OBL*¬UNE	0.891	0.197	0.058	0.106	0.091	0.072	0.058	0.072	0.058	0.106	0.091	0.106	0.091
4	AFL*¬COB*OBL	0.957	0.106		0.005	0.005	0.043	0.043						
5	AFL*¬COB*¬UNE	0.855	0.255		0.111	0.111			0.149	0.149	0.149	0.149	0.149	0.149
6	AFL*COB*¬OBL	0.968	0.144						0.000	0.000				
7	AFL*COB*UNE	1.000	0.024		0.000	0.000	0.000	0.000			0.000	0.000	0.000	0.000
8	AFL*¬OBL*¬UNE	0.871	0.293				0.111	0.111						
9	AFL*OBL*UNE	1.000	0.024						0.005	0.005	0.005	0.005		
10	¬COB*¬OBL*POP	0.857	0.087		0.010		0.010		0.010		0.010		0.010	
11	¬COB*OBL*UNE	0.883	0.255										0.005	0.005
12	¬OBL*POP*¬UNE	0.923	0.173			0.010		0.010		0.010		0.010		0.010

The reliance of conditions without AFL and POP on the calibration of the consistency thresholds warrants a closer look at cases without either of the two conditions that have been found to be individually sufficient. For this reason, further sub-QCAs have been performed featuring only those cities deemed not affluent or large respectively. The thresholds were kept the same as for the main QCA.

As POP has been determined to be sufficient already, only the conditions OBL, COB and UNE were included. The truth table of sub-QCA 1 (without AFL), shown in Table 10, does not feature any logical remainders. As such, only the complex solution is relevant. The prime implicants of the complex solution of sub-QCA 1 (without AFL) are shown in Table 11.

Table 10: Truth table of sub-QCA 1 (without AFL)

Row	COB	UNE	OBL	OUT	n	Consistency
1	0	0	0	0	9	0.444
2	0	0	1	0	28	0.429
3	0	1	0	1	11	0.818
4	0	1	1	1	56	0.875
5	1	0	0	1	19	0.789
6	1	0	1	0	16	0.438
7	1	1	0	0	22	0.409
8	1	1	1	0	10	0.500

Table 11: Prime implicants of sub-QCA 1 (without AFL)

Config. Nr.	Solution	Consistency	Coverage	Unique Coverage
1	¬COB*UNE	0.866	0.527	0.527
2	COB*¬UNE*¬OBL	0.789	0.136	0.136
3	M1	0.849	0.664	

The same procedure was repeated for cases below the threshold for population, resulting in truth table (Table 12). As once again, no logical remainders can be observed, the analysis has only one solution, the complex solution. The prime implicants making up the solution formula are displayed in Table 13.

Table 12: Truth table of sub-QCA 2 (without POP)

Row	COB	UNE	OBL	OUT	n	Consistency
1	0	0	0	0	36	0.694
2	0	0	1	0	22	0.591
3	0	1	0	1	9	0.778
4	0	1	1	1	33	0.879
5	1	0	0	1	23	0.826
6	1	0	1	0	25	0.480
7	1	1	0	0	17	0.353
8	1	1	1	0	8	0.500

Table 13: Prime implicants of sub-QCA 2 (without POP)

Config. Nr.	Solution	Consistency	Coverage	Unique Coverage
1	¬COB*UNE	0.857	0.313	0.313
2	COB*¬UNE*¬OBL	0.826	0.165	0.165
3	M1	0.846	0.478	

Comparing the solution formulas of sub-QCA 1 and 2 shows that they consist of the same configurations in the absence of AFL and POP, respectively. While they differ in coverage they do have similar consistency. The coverage for the configuration ¬COB*UNE is particularly high in both cases. This validates the findings of the main QCA, suggesting that there are indeed cases where UNE is connected to the presence of the outcome. This configuration has, in both sub-QCAs, a relatively great individual coverage.

The configuration COB*¬UNE*¬OBL has also been present in the main QCA. In comparison to configuration ¬COB*UNE, it does have a slightly smaller consistency and a notably smaller coverage. The fact that it is present in all three QCAs validates its importance in the solution formula. Hence, it can be concluded that the two configurations, ¬AFL*¬COB*UNE and COB*¬OBL*¬UNE, are not only a product of the choice of the consistency threshold.

This information is useful for differentiating between the alternative formulas of the main QCA. While total coverage and consistency are the same for all alternative solution formulas, they differ in how much coverage they attribute to the configurations. Alternative solution formulas M1-M4 attribute the greatest coverage to configuration 2, ¬AFL*¬COB*UNE. As the combination of the lack of affluence with simultaneous unemployment is believed to primarily impact plan development negatively, it appears more reasonable to use an alternative formulation attributing less coverage of this configuration.

The coverage of ¬AFL*¬COB*UNE is much smaller for M5 and M6. Instead, M5 and M6 feature configuration 5, AFL*¬COB*¬UNE, as the most important configuration. While this configuration has the lowest consistency score, it is only negligibly less consistent than configuration 2, and the overall consistency for all alternative formulations is the same. Configuration 5 aligns well with expectations due to the high individual sufficiency of AFL and the attributed effect of affluence in the literature. It appears, therefore, logical to work with one of the solution formulas that utilise this configuration. This narrows down the choice to alternative solution formulas M5 and M6. M6 attributes more coverage to configuration 1, AFL*POP, the overlap of the two individually sufficient conditions. Therefore, the following analysis will focus on M6.

The Venn diagram of the chosen solution formula (M6) shows two clusters without overlap (Figure 1). Cluster 1 consists of the configurations ¬AFL*¬COB*UNE and ¬COB*OBL*UNE, which overlap considerably. Cluster 2 is more of an elongated area of overlap of the remaining configurations. Both of the latter configurations also have considerable unique coverage that is not explained by any of the other configurations. The configurations differ in how many cities they cover. With 39 cities, ¬OBL*POP*¬UNE covers the fewest and ¬AFL*¬COB*UNE with 67 the most cities. There are 42 cities with the outcome OUT =1 that are not covered by any configuration.

5.4.3 *Spatial Patterns of the Configurations*

Distinct spatial patterns of the distribution of cities per configuration can be observed (see Figure 2). Configuration AFL*POP includes cities across all four countries. In Germany and the UK, no distinct spatial pattern can be observed. However, in Italy, with the exception of Rome, only cities in the northern part can be found in this configuration, underscoring the economic gradient in the country. In France, only four cities can be found in this configuration.

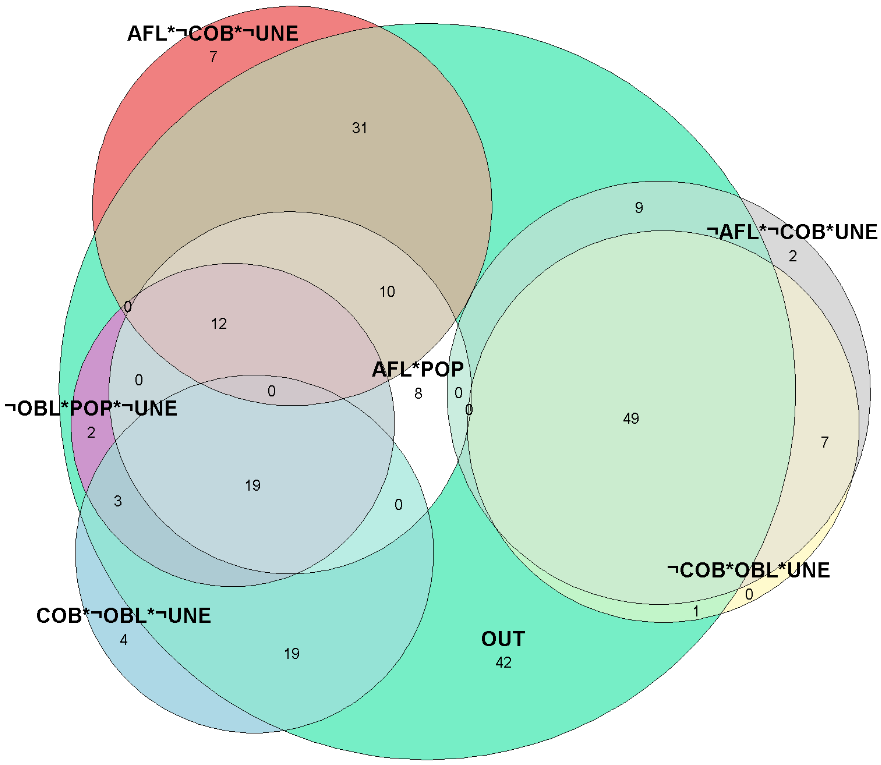

Figure 1: Euler diagram displaying the set relations of alternative solution M6

Most of the cities of the configuration ¬AFL*¬COB*UNE are located in France, emphasising the comparatively high levels of unemployment in the country. Another smaller cluster in southern Italy underscores the spatial patterns of unemployment in Italy. Additionally, a number of cities in the Midlands and Northern England and a single German city, Stralsund, can be found in this configuration.

For the interpretation of OBL and its negation, it needs to be considered that it represents essentially a differentiation between France and the UK on the one, and Germany and Italy on the other side. Thus, OBL should not automatically be equated with the requirement of plan development in the former two countries. Accordingly, the configuration COB*¬OBL*¬UNE, featuring the negation of OBL features cities exclusively in Italy and Germany. There are distinct clusters in northern Italy, the Rhine-Ruhr area and East Germany. The former share the commonality of being industrial and densely populated. More isolated, the two German city states, Bremen and Hamburg, and south Italian cities, Barletta and Salerno, belong to this configuration, too.

AFL*¬COB*¬UNE features almost exclusively cities in Germany and the UK, with no French and only one Italian city, Bolzano, being part of the configuration. Cities in Germany are mostly found in the south and centre and in proximity to the coast. For Germany, this configuration appears to be essentially the complement of the configuration COB*¬OBL*¬UNE. British cities of this configuration are spread across the country, not displaying any patterns. It is the configuration with the greatest number of both German and British cities, likely reflecting their higher GDP per capita compared to France and Italy.

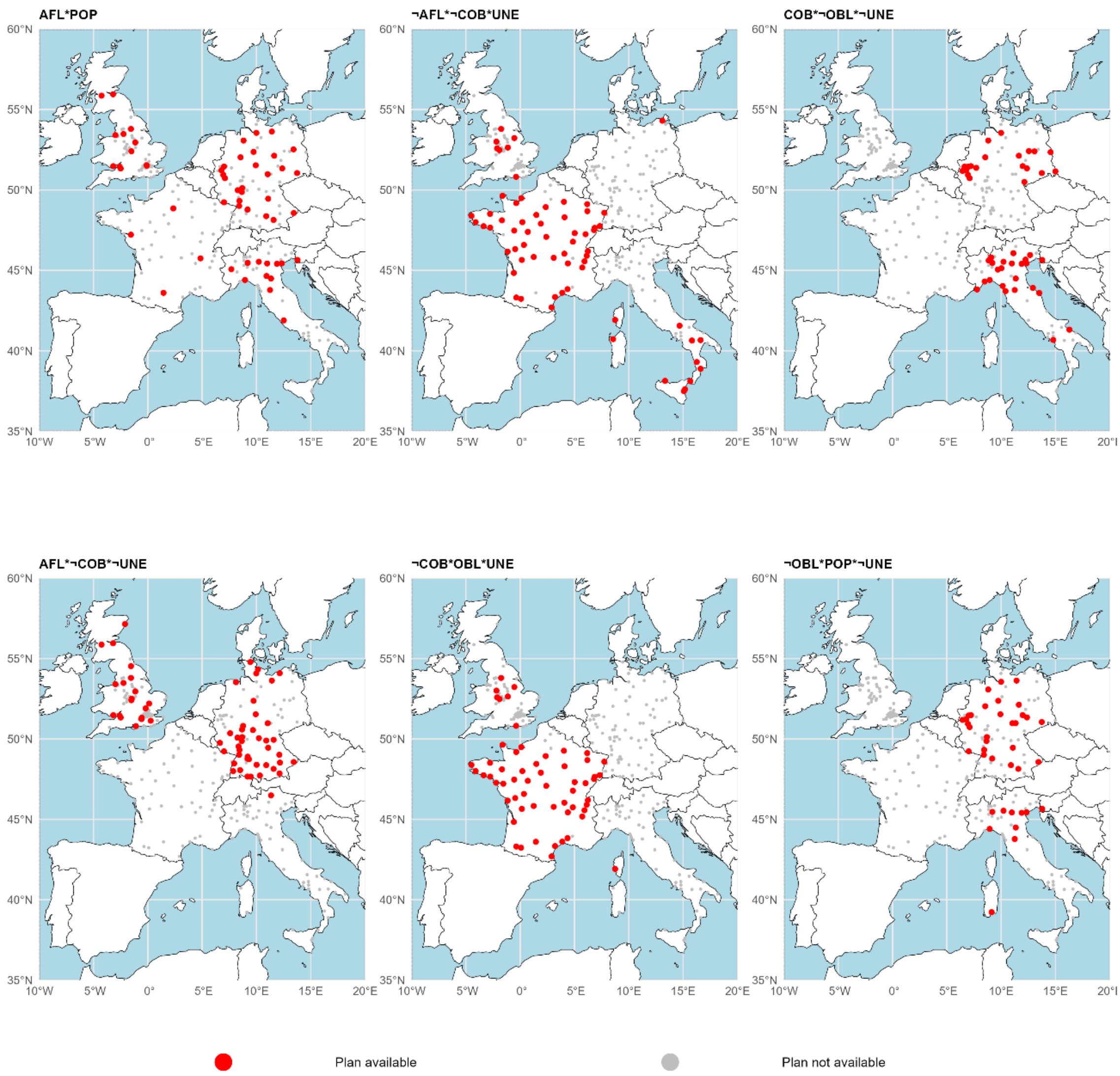

Figure 2: Geographical patterns of cities in the six configurations

Due to the presence of OBL, cities in the configuration ¬COB*OBL*UNE are found exclusively in France and the UK. While in the UK, primarily cities in the Midlands and North belong to this configuration, in France, no patterns can be observed. For both countries, there is a noticeable overlap with cities belonging to the configuration AFL*¬COB*UNE.

Cities in the sixth and final configuration, ¬OBL*POP*¬UNE, are exclusively found in Germany and Italy due to the negation of OBL. Cities in the former do not show clustering, while Italian cities are found almost exclusively in Northern Italy. The only exception is the Sardinian city of Cagliari. This is likely due to the higher population density and lower unemployment patterns in Northern Italy.

6. Discussion

6.1. Discussion of Configurations

The results of the analysis underline the conjunctural nature and complexity of mitigation plan development. Apart from AFL*POP, the conjunction of the two individually sufficient conditions, all configurations feature three conditions. For each condition, both its presence and absence are featured in a configuration at least once, with the exception of population size, for which the logical negation is not part of any configuration.

6.1.1 Configurations Featuring Affluence and Population

The results are consistent with findings in the literature regarding the importance of capacity for mitigation plan development (see e.g. Eisenack and Roggero (2022), Reckien et al. (2015)). The two conditions used to proxy capacity, affluence and population size, are featured in three out of six configurations, hinting at their substantial impact on mitigation plan development. The conjunction of these two conditions occupies a central spot in the analysis. There is a considerable overlap of AFL*POP with three other configurations. This overlap shows that cities that are both affluent and large are capable of developing plans regardless of other circumstances, confirming H1 (Homsy, 2018b). The strength of this configuration is further emphasised by its high consistency. In contrast, the configurations featuring only either affluence, AFL*¬COB*¬UNE, or population, ¬OBL*POP*¬UNE, both require the absence of unemployment, confirming H2.

The largest overlap of AFL*POP can be observed with ¬OBL*POP*¬UNE. As established before, OBL represents essentially a differentiation between France and the UK on the one, and Germany and Italy on the other side. Accordingly, the configuration ¬OBL*POP*¬UNE can be interpreted as large cities in Germany and Italy with low unemployment.
The substantial overlap with AFL*POP suggests that many of the cities covered by the configuration are also affluent. This calls for a closer look at the cases not covered by AFL*POP. The truth table (see Table 6) shows that only five cities in the configuration ¬OBL*POP*¬UNE, those described in rows 3 and 11, are not simultaneously affluent. Yet, this condition has the highest consistency of all. For the five cities not covered by AFL*POP, the consistency is even 100%. These five cities range between 200,000 and 350,000 inhabitants and are, therefore, medium-sized. Accordingly, this condition indicates that medium-sized cities are able to develop mitigation plans so long as social issues such as unemployment are in a controlled range, even in the absence of affluence. This underscores the influence of population on mitigation planning, which is well-documented in the literature (Homsy, 2018a; Otto, Kern, Haupt, Eckersley, & Thieken, 2021).

Nonetheless, the significant overlap between AFL*POP and ¬OBL*POP*¬UNE shows that population size plays a role only in a few cases for cities that are not affluent. In contrast, the influence of affluence appears to be less dependent on population. AFL*¬COB*¬UNE does have a substantial unique coverage. This suggests that affluence is of greater importance for mitigation plan development than population size.

The greater importance of affluence may be influenced by the choice of the alternative solution formula. To validate this theory, it is useful to look at all alternative formulations. For this, a plot of all alternative configurations of the complex solution has been created (see Figure 3). Configurations featuring AFL are indeed a superset of configurations featuring POP. Thus, there appears to be a difference between affluence and population regarding their explanatory power. This might be due to large cities generally being affluent while affluence is not necessarily tied to population size and instead can be achieved by smaller cities, too. However, the dataset contains 61 cities that are affluent and not large and 59 that are not affluent but large. Therefore, there is a noticeable number of large cities that are not affluent, and this theory cannot be substantiated.

It is more likely that the greater explanatory power of affluence compared to population is primarily a result of the relatively low threshold for population used in this analysis. Essentially, the threshold is a distinction between small cities on the one hand and medium- and large-sized cities on the other. The effect of population is likely to be more pronounced if a higher population threshold of 500,000 or 1 million would have been chosen.

In summary, while population size can be an appropriate proxy of plan development, its use diminishes with an increase in the number of smaller cities in a dataset. In research contexts featuring primarily small and medium-sized cities, such as this analysis, affluence is the more appropriate indicator of capacity, as it is more generally applicable.

6.1.2 Configurations of Unemployment and Obligation

The solution formula also indicates that there is a pathway to plan development for cities which are not affluent. The configuration ¬AFL*¬COB*UNE features, besides the absence of co-benefits, also unemployment. It is unlikely that the absence of co-benefits has any explanatory power in this configuration. This is supported by the fact that, for multiple cities of this configuration, the PM2.5 value is close to the threshold. However, cities of this pathway tend to have high unemployment rates, noticeably exceeding the threshold. Through the combination of the absence of affluence and the presence of unemployment, cities of this configuration can be described as disadvantaged.

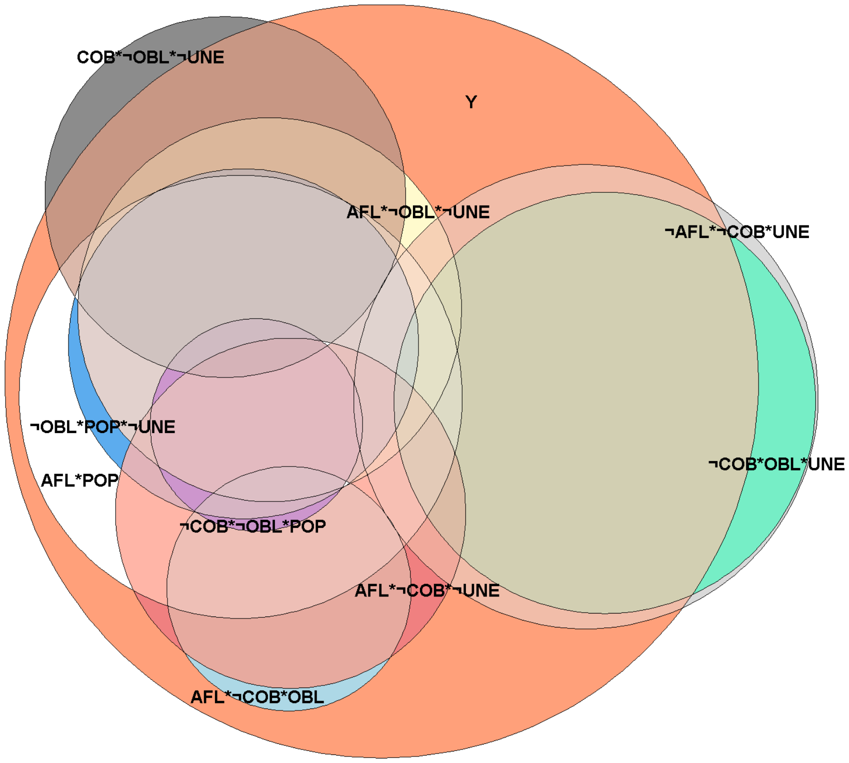

Figure 3: Euler diagram showing the prime implicants of all alternative formulations of the complex solution

French and British cities in this configuration require special attention as they make up the majority of cases. The configuration AFL*¬COB*UNE significantly overlaps with ¬COB*OBL*UNE. The latter can be interpreted in the way that even in the face of high unemployment cities develop plans due to the obligation imposed from the national level, with the absence of co-benefits once again not having any explanatory power. From the notable overlap of the two configurations, it can be reasoned that obligation in France and the UK is the driving factor for disadvantaged cities.

To validate the hypothesis of national-level legislation being the driving factor for plan development in cities of these overlapping configurations, the content of climate plans has been examined. All French cities with an unemployment rate of more than 20% were examined for mentions of "labour market", "employment", and "unemployment", as it was reasoned that the cities with the highest unemployment rates are the most likely to develop plans in an attempt to reduce unemployment. Additionally, the preface or introduction was searched for motivations.

For most French cities, the climate plans on which the dataset was based are no longer available as cities have since updated their plans with only the latest version being available (see Appendix 3). Mitigation plans for six French cities could be found. They differ in their consideration of labour market impacts. Angers, Besançon, and, to a lesser extent, Grenoble acknowledge the positive impact measures can have on the labour market. At the same time, Angers, Besançon and Saint-Etienne also specifically highlight the national context with its requirement for plan development. Lastly, Niort and Tours mention neither any specific motivation/background nor labour market effects.

While there are indications suggesting labour market considerations, it is questionable whether this was a primary reason for the development of the plan. All six cities developed their plans after the Grenelle II law came into force in 2010. Additionally, the French Agency for Ecological Transition (ADEME) lists all plans that were created in accordance with the Grenelle II Act (ADEME, 2024). This includes the plans of the cities featured in this configuration. Thus, climate planning of French cities is likely a response to national-level legislation and not primarily motivated by local drivers. So far, this appears to validate H3.

However, a similar obligation also exists for cities in the UK. Examining the British cities in the configuration indicates that obligation does not have the same impact in both countries. While 3 out of 53 French cities in the configuration ¬COB*OBL*UNE lack a plan, in the UK, it is 4 out of 7. Therefore, in the UK obligation is clearly not as successful in initiating plan development. It appears that the UK's national-level framework is not enough to encourage disadvantaged cities to engage in climate mitigation planning. This stark contrast between France and the UK is not limited to cities found in this configuration. 88.9% of French cities but only 55.8% of British cities in the dataset have a mitigation plan. This aligns with the literature. Reckien et al. (2018) found that only two thirds of British cities complied with the national legislation.

As was the case for French cities, the examination of planning documents of British cities in the ¬COB*OBL*UNE was limited due to plan availability. For only one city, Leicester, a plan could be found. Its Sustainability Action Plan does neither mention national-level obligation nor economic benefits as a motivation. However, Leicester is a unique case. It has a reputation as a frontrunner in terms of sustainability. Lemon, Pollitt, and Steer (2015) observed that Leicester's climate and energy policy positively impacts employment in related sectors. As the city can be described as deprived in a UK context, it might consciously use its climate and energy policy to create employment. However, it is questionable whether its experience is generalisable. The fact that more than half of British cities in this configuration do not have a plan makes it rather unlikely that unemployment serves as a widespread motivation for plan development.

Even the legislative framework seems insufficient in making British develop plans. The overall low number of British cities with a mitigation plan contrasts the findings of Heidrich et al. (2016), according to which the UK was the furthest in terms of both local mitigation and adaptation action. The legislative framework in France is considerably more successful in spurring plan development. The limited number of plans in the UK allows to reject H3.

Turning back to the configuration ¬AFL*¬COB*UNE, a number of Italian and a German city belong to this configuration, too. While cases in France and potentially the UK can be explained by national-level obligation, this is not the case for cities in Italy and Germany. The configuration suggests that high unemployment and being disadvantaged incentivise a city to turn to climate action. This seemingly contradictory finding might be explained by green growth. The concept of green growth postulates that the need to address climate change can be seen as an opportunity to spur economic growth and create jobs. On the city level, this is increasingly incorporated into plans and strategies (Hammer, Kamal-Chaoui, Robert, & Plouin, 2011).

To determine whether green growth was a motivating factor, it is useful to examine the planning documents of cities closer. As for French and British cities, climate mitigation plans were searched for mentions of “labour market”, “employment”, and “unemployment” (see Appendix 3).

Stralsund, the only German city in this configuration, does not mention expected effects on employment but rather cites the influence of the Climate Alliance (Klima-Bündnis), a network of European cities, to have influenced the city’s climate policy.

For the Italian cities, findings are more diverse. Some cities, such as the Sicilian municipalities of Catania and Acireale, explicitly mention in the preface or summary the potential of the plan to create jobs. These cities see the plan as an opportunity to spur development. Accordingly, it is likely that expected economic impulses, including labour market impacts, were a motivation for plan development.

Other cities, such as Palermo, do not explicitly mention labour market aspects in the introduction or motivation but name potential synergies elsewhere in the document. Palermo also links the planning process to its candidate status as the 2019 European capital of culture. It is, therefore, likely that a reason for developing the plan was prestige. Lastly, two other Italian cities, Cosenza and Matera, do not explicitly mention employment effects. These results show that the effects of unemployment, even within this configuration, are varied.

Unemployment can be considered both a negative influence on capacity and its potential reduction a kind of co-benefit. In that sense, some cities might use the advocacy potential of unemployment, particularly in regions with persistently high unemployment levels. Interpreting unemployment reduction as a type of co-benefit might explain the complex findings of its effect. It may behave similarly to co-benefits of air pollution for which Roggero, Gotgelf, and Eisenack (2023) found that effects are context-dependent and cannot be generalised.

Nonetheless, across three countries, there are indications of the consideration of the effect on labour markets of climate policies. Some cities, which can be described as being disadvantaged, seem motivated to engage in climate action by the prospect of green growth. The potential of green growth as a motivation for climate action in cities has been documented in the literature. In a case study of two cities in the UK and Germany, the opportunity for green energy has been a driver of green growth. Facing high levels of unemployment, the port cities of Bremerhaven and

Hull used the potential of offshore wind energy to create jobs (Wurzel et al., 2019). Furthermore, for regions in Spain and Greece which are similar to South Italian cities, both in climatic conditions and in terms of unemployment, energy-related measures were found to have the potential to contribute to the reduction of unemployment (H. Berger & Bendjebbour, 2019).

While the findings within the configuration are not consistent, it nonetheless allows to reject the theory that unemployment always acts as a barrier for mitigation action. Instead, it appears that unemployment can indeed stimulate climate action, validating H4.

It should be noted that there are motivations outside the scope of this analysis. Almost all Italian cities developed their climate plans under the umbrella of international climate networks, specifically the CoM (Pietrapertosa et al., 2019). In particular, the findings for Sicilian cities warrant further examination. The Sicilian regional government very actively encouraged the participation of its municipalities in the CoM (Famoso, Lanzafame, Monforte, & Scandura, 2015; Pietrapertosa et al., 2021). The great number of cities with a plan could therefore primarily be a result of regional support.

Whether unemployment influenced the decision of municipalities to join the CoM is unclear. There are some indications that cities join climate networks to address unemployment. Del Pablo-Romero et al. (2015) found a positive correlation between unemployment and Spanish cities being CoM signatories. Spanish cities are the second largest group of CoM signatories and share many similarities with Italian cities. Given these parallels, it is not unlikely that unemployment acts as a driver for joining the CoM and eventually plan development for Italian cities, too. The link between unemployment and climate networks calls for further investigation.

6.1.3 Configurations Featuring Co-benefits of Air Pollution

The last configuration of the solution formula, COB*¬OBL*¬UNE, has a significant unique coverage that is independent of the choice of the alternative formulation. The direct interpretation of this configuration suggests that co-benefits in the shape of air pollution reduction could be connected to mitigation planning in cities in Germany and Italy as long as unemployment is low. In a more general way, in the absence of more pressing issues, cities may use co-benefits to justify climate planning. This seemingly confirms H5.

The combination of high air pollution and low unemployment hints at industrial areas. The cities of this configuration are primarily found in the Po Valley in northern Italy, the Rhein-Ruhr area and more isolated in Eastern Germany (see Figure 2). The former two regions, in particular, share many features. Both areas are densely populated and were the industrial heartland and major emitters of their respective countries (S. Berger, Musso, & Wicke, 2022). On the surface, these similarities make it likely that there are indeed shared motivations for plan development.

46 cities were found in this configuration, of which five did not have a plan. Among the cities with a plan, 22 were also covered by other configurations. For some of them, it is more likely that size or affluence was the main driver, e.g. Milan, Hamburg and Cologne. Nonetheless, to validate this configuration, the plans of all cities were manually searched for mentions of air pollution. For this, a keyword search for the words "Luftverschmutzung" or "qualità dell'aria" and "inquinamento atmosferico" was conducted. To capture all possible constellations of the words, the plans were searched for the terms "Luft", "l'aria" and "inquin" for German and Italian cities respectively (see Appendix 4).

Air pollution has been mentioned in most mitigation plans. However, plans varied in how prominent the topic was. Air pollution is usually mentioned in one of the following ways. In most plans, mentions of the keywords are limited to isolated occurrences. Many plans refer to specific related legislation like air quality plans. Some cities, such as Bologna, feature a section about the status quo of a range of environmental indicators, including air pollution. Others explicitly mention the synergic effects specific mitigation actions can have on air pollution reduction, particularly in relation to the transport sector. The benefits of policies for reducing road traffic and banning polluting vehicles are often linked to improving air quality. For example, Milan and Cologne explicitly list for each measure co-benefits, with air pollution frequently featured. These cases show that there is awareness about co-benefits.

Nonetheless, it appears unjustified to describe air pollution as a prominent and decisive theme. For it to be considered a motivation for plan development, a plan should place additional emphasis on air pollution. Noteworthy in that sense are Treviso and Genoa, who mention air pollution in the preface. However, in the rest of the respective documents, mentions of air pollution are practically absent for Treviso and mostly limited to other relevant legislation for Genoa.

The fact that many cities refer to specific legislation addressing air quality, such as the Po Valley Agreements, suggests awareness of the interconnected nature of both issues. However, it also indicates that responsibility is shifted to specific legislation. Cities do not use the advocacy potential of air pollution. Mentions of air pollution are too isolated and do not comprehensively deal with synergies. The plans do not provide strong evidence that air pollution played a significant role for plan development. Accordingly, plan examination does not support H5. However, the connection between co-benefits and mitigation planning might not be direct, with more complex connections linking the two (Roggero, Gotgelf, & Eisenack, 2023). For example, it is possible that co-benefits affect the selection of policies in a mitigation plan.

A potential reason for the limited focus on air pollution might be that it becomes only relevant if pollutant levels become directly threatening to health. In this case, co-benefits would only be relevant for cities in the Po Valley. Cities located in the North of Italy appear to be more sensitised towards air pollution. However, measures addressing air pollution rely on public support

(Eckersley, Harrison, & Poberezhskaya, 2023). If public support is not given, linking air pollution and mitigation planning may be counterproductive (Roggero, Gotgelf, & Eisenack, 2023).
Many plans of cities in that region also mention the natural conditions that contribute to high levels of air pollution. In fact, emissions in Northern Italy were found to be lower than in North-Rhine Westphalia, but due to the geographic conditions resulted in higher concentrations (Robotto et al., 2022). Therefore, substantial measures would be necessary to bring down emissions (Colombo et al., 2023). Against this backdrop, the advocacy potential of air pollution as a co-benefit of climate mitigation efforts is limited.
The limited support for air pollution co-benefits as a driver of climate action aligns with the literature. Pitt (2010) found that co-benefits had little effect on the adoption of climate mitigation policies in the US.

In the face of the lack of explanatory power of air pollution, an explanation for this configuration might be that state or regional level legislation was a major factor for promoting plan development. Both regions were particularly active in their respective country. However, while North-Rhine Westphalia was the first German state to develop climate mitigation legislation, most cities developed their plans before the state-level climate protection law was enacted in 2013 (IRS, 2021). Most cities in the Rhein-Ruhr area are also above the threshold for population and are featured in other configurations. Only three cities are considered small. Therefore, it is possible that size acted as the primary driver, with their other characteristics having little explanatory power.
In Northern Italy, most cities in this configuration are located in Veneto and Lombardy. While these two regions do not have regional mitigation plans, they have signed the Under2 MOU, a voluntary commitment to reduce emissions. Yet, as this was done only in 2015, it also cannot explain municipal plan development, as most plans were submitted before (Pietrapertosa et al., 2021). Hence, it appears that for both countries higher-level support was not a decisive factor.

The co-benefits of air pollution reduction are recognised by cities, yet they seem not to be a major motivation to engage in climate mitigation planning. Their advocacy potential is limited. Yet, there are a considerable number of cities found in no other configuration of all alternative formulations of the complex solution. Hence, the considerable unique coverage of this configuration might be a product of the decisions made in the research design, such as the chosen conditions. Climate planning might be explained by other characteristics hidden to this analysis. To produce further insights, a deeper analysis is necessary. Interview materials might help uncover themes that are hidden in planning documents and computer-aided methods such as Thematic Analysis could help to uncover themes inaccessible to surface level analysis.

6.1.4 *Relation to Network Membership*

While the deeper look into some of the configurations highlighted the complexity of cases even within the same configuration, the combined findings of this analysis nonetheless allow to address research question 3: The large coverage and generally high consistency of the configurations of this QCA show that in the absence of network membership as a condition climate planning can be explained. This allowed to highlight some interactions that may have remained hidden had climate network membership been included in this analysis. In comparison, Eisenack and Roggero (2022) found network membership to have a substantial unique coverage. Nonetheless, the findings also highlight that for some of the conditions chosen, namely unemployment, researching the interaction in the context of network membership in different contexts may be a promising next step.

6.2. Limitations

While QCA has been successfully implemented for unravelling patterns of urban climate action, the findings of this study are limited in a number of ways. Limitations primarily arise from the methodology and the data used.

First of all, it should be noted that QCA is descriptive, not inferential. QCA is not suited to identify causal relationships. While examination of mitigation plans was used to validate some of the seemingly more contradictory configurations, case studies should follow to confirm the findings of this analysis. The here employed approach of key word search is highly dependent on the wording used. Case studies, particularly in combination with background information, such as interview materials, may be able to uncover hidden themes.

A further limitation arises from the dichotomous nature of crisp-set QCA, which does not do justice to continuous indicators such as GDP per capita or population. While the impact of these two indicators is clear, using fuzzy-set QCA may help to clarify the influence of some of the mixed results for indicators such as unemployment. However, when doing so, special attention should be paid to the quality of the data source. Naturally, the analysis inherits all limitations from the data sources. This is most evident for the unemployment levels for French cities which were calculated using a different methodology than for the other countries. The usage of data from different sources also introduces distortions, e.g. through different spatial resolution.

Furthermore, the choice of methodology may result in a simplification of the interplay of conditions. Particularly in crisp-set QCA, the choice of thresholds has a significant impact on the analysis. For many of the conditions, no literature-induced guidance exists. Therefore, thresholds are derived from statistical measures which may not align well with functional differences.

Another bias concerns the spatial focus. Focussing on four industrialised Western European countries introduces a bias. This contributes to the homogenisation of background conditions and may have the benefit that patterns are more clearly observable than in a more diverse dataset. However, it also can mean that results may not be applicable to other contexts.

Additionally, while the selection of cities in the City Statistics dataset was meant to fulfil criteria of representability, data availability limited this as for the timeframe of interest, data was available only for certain cities. As this is the case for all Eurostat indicators, this may result in filtering introducing a bias as data availability for larger cities is often better, leading to them being overrepresented. Connected to that, only data from a limited timeframe of three years was used. While data was averaged to even out cycles, in some cases, the analysis relies on one data point only. Averaging of more than three years may help to even out anomalous values, especially in the face of fluctuations in the aftermath of the financial crisis. Furthermore, the focus on the years 2013-2015 may not be suitable for all plans. A range of plans have been developed in the late 2000s and may have been subject to different conditions. While it is unlikely that factors have changed dramatically in the course of a few years, accounting for the individual year of plan development may improve the connection to plan development.

Owing to the reliance on the dataset by Reckien et al. (2018), the data is, in many cases, already outdated. At the same time, 72% of the cities included in this analysis already had a mitigation plan. This is a relatively large share, meaning that a more recent dataset could probably not be operationalised effectively as too few cases would not have mitigation plans. Accordingly, the operationalisation of alternative outcomes may prove more suitable. This may also increase the meaningfulness of results, as mere plan development does not necessarily necessitate concrete action. A shift to emission targets or concrete reductions as implemented by Roggero, Fjornes, and Eisenack (2023) may be a more appropriate outcome.

6.3. Outlook

The results of this analysis highlight the complexity of climate planning. It furthers the understanding of the interactions between some of the many factors involved. Conjunctural causation proved helpful for analysing climate plan development. The findings of this analysis further qualify and generally align with Eisenack and Roggero (2022). Naturally, there is room for further research, and a number of lessons can be drawn for both research and policy.

6.3.1 Further Research

This analysis focused on wealthy Western European countries where a majority of cities have already developed mitigation plans. The focus on the developed world has the advantage of facing fewer data constraints and findings can be useful to explain climate action in less developed countries. Yet, while findings may be value to guide climate action in the global south, they should not be translated in a one-size-fits-all fashion neglecting local institutions. Ultimately, specifically analysing climate action in less developed countries may be valuable.

That being said, the use of QCA for understanding climate action is only at the beginning. A range of changes could be made to the research design. When focussing on western nations, in face of the high number of cities with a plan, it may be equally relevant to invert the focus of the analysis and examine which factors contribute to a city not having a mitigation plan. Alternatively, further, so far not considered factors such as voting behaviour, could be included in comparative analyses. This may shed new light on the factors used in this analysis. For example, the role of unemployment should further be examined in the presence of climate networks which are believed to bridge the lack of capacity. It is unclear whether cities with high unemployment would have been able to develop mitigation plans without climate networks, which may have played a crucial role.

Further attention should also be given to the factor of co-benefits. The role of air pollution could not be confirmed as a motivation for plan development. However, this does not mean that other positive side effects have no explanatory power. As was shown for unemployment, considerations other than mere greenhouse gas emission reductions play a role for municipalities drafting mitigation plans. Potential other co-benefits could be renewable energy potential. Accordingly, it might be useful for future research to consider environmental factors such as solar intensity, which has been shown to relate to plan development, indicating the potential for solar energy. As some cities cite the potential of renewable energy as motivation for plan development, researching whether the presence of municipal mitigation plans has a measurable effect on renewable energy capacity or stimulates other types of positive economic development may produce further insight.

6.3.2 *Implications for Municipalities*

A number of lessons can also be drawn for authorities seeking to increase local climate planning. Focussing on countries that are amongst the front runners of local climate planning naturally means that the findings are less pertinent to these countries as many of the cities in the countries of this analysis do already have mitigation plans, and some more have since developed one. However, even in developed countries there are still municipalities without mitigation plans. Furthermore, this analysis can serve as guidance for cities seeking to engage in climate action in countries where local climate action is less widespread.

This analysis shows that affluence and population play an important role in plan development. While these are factors that cities have little control over, the analysis offers some insights into factors that can be leveraged by cities in conjunction with these two factors.

First of all, the role of national-level policy has been further qualified. It is widely understood that national-level policy can spur plan development. However, as the difference between the UK and France shows, results can vary depending on policy implementation. France's more direct obligation through the Grenelle II Act has been more successful in making cities develop plans. Thus, countries seeking to strengthen local mitigation planning should rather use French national policy as guidance.

The analysis also highlights the ambiguous role unemployment can play. Its presence does not automatically mean that climate planning is impossible. Instead, the need to tackle unemployment can create synergies with sustainable development. Cities, particularly those located in areas suitable for renewable energy production, could leverage this potential to address two issues simultaneously.

Lastly, the advocacy potential of co-benefits appears to be barely recognised by municipalities. While the advocacy potential of air pollution reduction is highly context dependent (Roggero, Fjornes, & Eisenack, 2023), some municipalities may profit from more actively linking mitigation efforts to it.

7. Conclusion

Climate change needs to be addressed on multiple levels. By being cause, victim and solution all at once, cities are in a position of central importance. To enable cities' mitigation efforts, it is crucial to understand what makes cities engage in climate action.

This study has explored interactions of factors associated with mitigation plan development in Western European cities. By utilising crisp-set QCA, six configurations were identified. These results highlight the complexity inherent in urban climate mitigation planning.

While affluence and population size, having been found to be individually sufficient, frequently feature as central drivers in different contexts, they differ in impact. Affluence has been found to be more generally applicable for explaining climate action, suitable for different city contexts. In contrast, while population size also met the requirement for sufficiency, it offered no additional explanatory power, likely due to the relatively low threshold, grouping both large- and medium-sized cities together.

The study also highlighted the nuances of the effects of unemployment, national-level obligation, and co-benefits. While unemployment is primarily understood to be a barrier to plan development, this has been shown not always to be the case. Instead, in the absence of affluence, it may act as a driver, particularly for cities wanting to engage in green growth.

National-level obligation can be useful for stimulating local climate action, even in non-affluent cities, but its effectiveness is highly dependent on the practical implementation. France's legislative implementation has been more effective in stimulating climate planning than the UK's approach.

Co-benefits were found to have little influence on plan development. While some cities consider co-benefits in their climate plans, this analysis could find no concrete evidence that co-benefits motivate plan development. Examination of plans using keyword search could not substantiate air pollution co-benefits as an explicit driver of mitigation action.

These findings contribute to a better understanding of factors influencing climate planning. While the dominant effect of capacity has been confirmed, climate mitigation planning is not reserved exclusively for cities with favourable socio-economic conditions. At the same time, the findings show that the understanding of urban climate planning is still imperfect, with gaps remaining.

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Appendices

Appendix 1: The following cloud folder contains the R scripts, an overview of cities found in each configuration and an overview of all planning documents that were searched for this analysis: https://drive.google.com/drive/folders/1M9CKUysN9tLL69XT8OQTWibk7UH--_W1?usp=drive_link

Appendix 2: Complex solution if threshold of 0.76 is used

Formula	Consistency	Coverage	Unique Coverage	M1	M2
AFL*POP	0.945	0.25	0.038	0.038	0.038
AFL*~OBL*~UNE	0.871	0.293	0.034	0.144	0.034
~COB*OBL*UNE	0.883	0.255	0.101	0.101	0.106
~OBL*POP*~UNE	0.923	0.173	0.024	0.024	0.024
~AFL*~COB*~POP*UNE	0.872	0.163	0.029	0.029	0.029
AFL*~COB*OBL	0.957	0.106	0.0	0.038	
AFL*~COB*~UNE	0.855	0.255	0.0		0.038
M1	0.893	0.726			
M2	0.893	0.726			

Truth table and complex, parsimonious and intermediate solution for the QCA with a threshold of 0.76 can be found in Appendix 1 - QCA_higher_threshold_0_76.

Appendix 3: Cities for which the planning document was searched for mentions of unemployment

City Code	City (Core)	Country	Plan found
DE071C1	Stralsund	Germany	yes
FR011C1	Saint-Etienne	France	yes
FR022C2	*Clermont-Ferrand*	*France*	*no*
FR023C2	*Caen*	*France*	*no*
FR025C1	Besançon	France	yes
FR026C2	Grenoble	France	yes
FR030C1	*Fort-de-France*	*France*	*no*
FR035C2	Tours	France	yes
FR036C2	Angers	France	yes
FR037C1	*Brest*	*France*	*no*
FR043C2	*Perpignan*	*France*	*no*
FR044C2	*Nîmes*	*France*	*no*
FR046C2	*Bayonne*	*France*	*no*

City Code	City (Core)	Country	Plan found
FR051C2	*Troyes*	*France*	*no*
FR060C2	*Chartres*	*France*	*no*
FR061C2	Niort	France	yes
FR063C2	*Béziers*	*France*	*no*
IT005C1	Palermo	Italy	yes
IT010C1	Catania	Italy	yes
IT020C1	Campobasso	Italy	yes
IT023C1	Potenza	Italy	yes
IT026C1	Sassari	Italy	yes
IT048C1	Cosenza	Italy	yes
IT054C1	Matera	Italy	yes
IT056C1	Acireale	Italy	yes
UK005C1	*Bradford*	*Great Britain*	*no*
UK014C1	Leicester	Great Britain	yes
UK019C1	*Lincoln*	*Great Britain*	*no*

The plan of the German city was searched for “Arbeit”. French cities were searched for “marché du travail”, “emploi” and “chômage”. Italian cities were searched for “lavoro” and “disoccupazione”. Furthermore, the preface or introduction was searched for other motives of plan development.
Plans of French and Italian cities were Auto-translated using the build-in translation function in Microsoft Edge and DeepL. An excel-sheet with a short description of the findings for each city can be found in Appendix 1 - cities_unemployment_green_growth.ods.

Appendix 4: Cities for which the planning document was searched for mentions of air pollution co-benefits

City Code	City (core)	Country	Plan found
DE002C1	Hamburg	Germany	Yes
DE004C1	Köln	Germany	Yes
DE006C1	Essen	Germany	Yes
DE008C1	Leipzig	Germany	Yes
DE009C1	Dresden	Germany	Yes
DE010C1	Dortmund	Germany	Yes
DE011C1	*Düsseldorf*	*Germany*	*No*
DE012C1	Bremen	Germany	Yes

City Code	City (core)	Country	Plan found
DE015C1	Bochum	Germany	Yes
DE017C1	Bielefeld	Germany	Yes
DE018C1	Halle an der Saale	Germany	Yes
DE019C1	Magdeburg	Germany	Yes
DE023C1	Moers	Germany	Yes
DE029C1	Frankfurt (Oder)	Germany	Yes
DE034C1	Bonn	Germany	Yes
DE036C1	Mönchengladbach	Germany	Yes
DE041C1	Potsdam	Germany	Yes
DE045C1	Iserlohn	Germany	Yes
DE074C1	Görlitz	Germany	Yes
IT002C1	Milano	Italy	Yes
IT006C1	Genova	Italy	Yes
IT007C1	Firenze	Italy	Yes
IT009C1	Bologna	Italy	Yes
IT011C1	Venezia	Italy	Yes
IT012C1	Verona	Italy	Yes
IT013C1	Cremona	Italy	Yes
IT014C1	Trento	Italy	Yes
IT015C1	Trieste	Italy	Yes
IT017C1	*Ancona*	*Italy*	*No*
IT028C1	Padova	Italy	Yes
IT032C1	Salerno	Italy	Yes
IT033C1	*Piacenza*	*Italy*	*No*
IT038C1	Barletta	Italy	Yes
IT039C1	Pesaro	Italy	Yes
IT041C1	Pisa	Italy	Yes
IT042C1	Treviso	Italy	Yes
IT044C1	Busto Arsizio	Italy	Yes
IT047C1	Massa	Italy	Yes
IT052C1	Savona	Italy	Yes
IT058C1	Pordenone	Italy	Yes

Plans of French and Italian cities were auto-translated using the build-in translation function in Microsoft Edge and DeepL. An excel-sheet with a short description of the findings for each city can be found in Appendix 1 - cities_air_pollution_co-benefits.ods.

Appendix 5: R Script

```
# Script: Urban Climate Plans in Major European Nations
# Analysing Factor Interactions
# This script is based on the script by Eisenack and Roggero (2022)
# Many roads to Paris: Explaining Urban Climate Action in 885
# European Cities, Global Environmental Change

#### 1. INITIALISATION ####
library(QCA)
library(SetMethods)
library(dplyr)

setwd("C:/Users/jr12l/Documents/_Study/Master Thesis/Data/")

#### 2. LOADING DATA ####
# mporting datasets
import <- read.csv("GEC_paper/d_reck_CCPI.csv", sep = ";", dec = ".",
                   stringsAsFactors = F, row.names = 2, fileEncoding = "UTF-8")
source("unemployment.R")
source("population.R")

# Subsetting to include only relevant data
c("City_Code", "city_name", "country_name", "af", "pm25",
  "gpcX2013", "gpcX2014", "gpcX2015", "latitude", "longitude") -> keep_these

d_reck <- data.frame(import[, keep_these], stringsAsFactors = FALSE, row.names =
rownames(import))

# Merging dataframes
d_reck$City_Code <- substr(d_reck$City_Code, 1, 6)
d_reck_ue_pop <- merge(merge(d_reck, population, by = "City_Code", all = TRUE),
                       unemp_r, by = "City_Code", all = TRUE)
# Filtering rows based on specific conditions
```

```
d_reck_ue_pop <- d_reck_ue_pop %>% filter(!is.na(country_name))
d_reck_ue_pop <- d_reck_ue_pop[rowSums(!is.na(d_reck_ue_pop[c("p2013", "p2014",
"p2015")])) >= 1, ]
d_reck_ue_pop <- d_reck_ue_pop[rowSums(!is.na(d_reck_ue_pop[c("ue2013", "ue2014",
"ue2015")])) >= 1, ]

# Keep only specific countries
keep_these <- c("DE", "UK", "IT", "FR")
d_reck_ue_pop$Country_Code <- substr(d_reck_ue_pop$City_Code, 1, 2)
d_reck_ue_pop <- d_reck_ue_pop[d_reck_ue_pop$Country_Code %in% keep_these, ]

# Calculations and cleaning
# Population and unemployment averages (2013-2015)
columns_to_check <- c("p2013", "p2014", "p2015")
d_reck_ue_pop['apop'] <- apply(d_reck_ue_pop[columns_to_check], 1, function(x) mean(x,
na.rm = TRUE))
columns_to_check <- c("ue2013", "ue2014", "ue2015")
d_reck_ue_pop['aune'] <- apply(d_reck_ue_pop[columns_to_check], 1, function(x) mean(x,
na.rm = TRUE))

# Averaging GDP per capita
rowMeans(cbind(d_reck_ue_pop$gpcX2013, d_reck_ue_pop$gpcX2014,
d_reck_ue_pop$gpcX2015),
    na.rm = TRUE) -> d_reck_ue_pop[, "agpc"]

# Removing unused columns
remove_these <- c("gpcX2013", "gpcX2014", "gpcX2015", "p2013", "p2014", "p2015",
"ue2013", "ue2014", "ue2015")
d_reck_ue_pop <- d_reck_ue_pop[, !colnames(d_reck_ue_pop) %in% remove_these]

# Visual inspection of data
## Unemployment
ggplot(d_reck_ue_pop, aes(x = aune)) + geom_histogram(binwidth = .5)
summary(d_reck_ue_pop$aune)
quantile(d_reck_ue_pop$aune, na.rm = T, probs = c(0.4, 0.6))

## Population
```

```
ggplot(d_reck_ue_pop, aes(x = apop)) + geom_density() + xlim(0, 1000000)
summary(d_reck_ue_pop$apop)
quantile(d_reck_ue_pop$apop, na.rm = T, probs = c(0.4, 0.6))

## Co-benefits and GDP per capita
summary(d_reck_ue_pop$pm25)
summary(d_reck_ue_pop$agpc)

#### 3. MAIN ANALYSIS ####
# Calibration
## Setting thresholds
threshold_B <- 12.77
threshold_C <- 40700
threshold_P <- 150000
threshold_U <- 9.5
O_countries <- c("France", "Great Britain")

## Creating sets to assign set membership
Y_OUT <- as.numeric(d_reck_ue_pop$af)
B_COB <- as.numeric(d_reck_ue_pop$pm25 > threshold_B)
A_AFL <- as.numeric(d_reck_ue_pop$agpc > threshold_C)
O_OBL <- as.numeric(d_reck_ue_pop$country_name %in% O_countries)
P_POP <- as.numeric(d_reck_ue_pop$apop > threshold_P)
U_UNE <- as.numeric(d_reck_ue_pop$aune > threshold_U)

## Creating the calibrated data matrix
standard_dataset <- data.frame(A_AFL, B_COB, O_OBL, P_POP, U_UNE, Y_OUT,
                    stringsAsFactors = FALSE, row.names = rownames(d_reck_ue_pop))
standard_dataset <- na.omit(standard_dataset)
colSums(standard_dataset) / nrow(standard_dataset)

# Analysis of necessity
QCAfit(standard_dataset[, -ncol(standard_dataset)],
    standard_dataset[, ncol(standard_dataset)], necessity = TRUE)

# Analysis of sufficiency
QCAfit(standard_dataset[, -ncol(standard_dataset)],
```

```
    standard_dataset[, ncol(standard_dataset)], necessity = FALSE)

# Truth table analysis
truthTable(standard_dataset, outcome = colnames(standard_dataset)[ncol(standard_dataset)],
      conditions = colnames(standard_dataset)[-ncol(standard_dataset)],
      complete = TRUE, incl.cut = 0.75) -> tt
print(tt)

# Logical minimisation
## Complex Solution
minimize(tt, details = TRUE) -> complex_solution
print(complex_solution)

## Parsimonious Solution
minimize(tt, include = "?", details = TRUE) -> parsimonious_solution
print(parsimonious_solution)

## Intermediate Solution (with easy counterfactuals)
tt$tt[tt$tt$OUT == "?" & tt$tt$P_POP == "1" | tt$tt$OUT == "?" & tt$tt$A_AFL == "1", ] ->
easy_counterfactuals
rownames(easy_counterfactuals) -> easy_counterfactuals
"1" -> tt$tt[easy_counterfactuals, "OUT"]
minimize(tt, details = TRUE) -> intermediate_solution
print(intermediate_solution)

# Find cities in configuration
# AFL*POP
standard_dataset$A_AFL == 1 & standard_dataset$P_POP == 1 ->
  these_cities
these_rows <- rownames(standard_dataset)[these_cities]
AFL_POP <- d_reck_ue_pop[these_rows, ]
# ¬AFL*¬COB*UNE
standard_dataset$A_AFL == 0 & standard_dataset$B_COB == 0 & standard_dataset$U_UNE
== 1 ->
  these_cities
these_rows <- rownames(standard_dataset)[these_cities]
afl_cob_UNE <- d_reck_ue_pop[these_rows, ]
```

```
# COB*¬OBL*¬UNE
standard_dataset$B_COB == 1 & standard_dataset$O_OBL == 0 & standard_dataset$U_UNE
== 0 ->
  these_cities
these_rows <- rownames(standard_dataset)[these_cities]
COB_obl_une <- d_reck_ue_pop[these_rows, ]
# AFL*¬COB*¬UNE
standard_dataset$A_AFL == 1 & standard_dataset$B_COB == 0 & standard_dataset$U_UNE
== 0 ->
  these_cities
these_rows <- rownames(standard_dataset)[these_cities]
AFL_cob_une <- d_reck_ue_pop[these_rows, ]
# ¬COB*OBL*UNE
standard_dataset$B_COB == 0 & standard_dataset$O_OBL == 1 & standard_dataset$U_UNE
== 1 ->
  these_cities
these_rows <- rownames(standard_dataset)[these_cities]
cob_OBL_UNE <- d_reck_ue_pop[these_rows, ]
# ¬OBL*POP*¬UNE
standard_dataset$O_OBL == 0 & standard_dataset$P_POP == 1 & standard_dataset$U_UNE
== 0 ->
  these_cities
these_rows <- rownames(standard_dataset)[these_cities]
obl_POP_UNE <- d_reck_ue_pop[these_rows, ]

#### 4. SUB-QCA 1 EXCLUDING CASES WHERE A_AFL = 1 ####
# Subsetting data
dataset_no_aff <- subset(standard_dataset, A_AFL == 0)
keep_these <- c("B_COB", "U_UNE", "O_OBL", "Y_OUT")
dataset_no_aff <- data.frame(dataset_no_aff[, keep_these],
                       stringsAsFactors = FALSE, row.names = rownames(dataset_no_aff))

# Analysis of necessity
QCAfit(dataset_no_aff[, -ncol(dataset_no_aff)],
     dataset_no_aff[, ncol(dataset_no_aff)], necessity = TRUE)

# Analysis of sufficiency
```

```
QCAfit(dataset_no_aff[, -ncol(dataset_no_aff)],
       dataset_no_aff[, ncol(dataset_no_aff)], necessity = FALSE)

# Truth table analysis
truthTable(dataset_no_aff, outcome = colnames(dataset_no_aff)[ncol(dataset_no_aff)],
           conditions = colnames(dataset_no_aff)[-ncol(dataset_no_aff)],
           complete = TRUE, incl.cut = 0.75) -> tt_noaff
print(tt_noaff)

# Logical minimisation
## Complex solution
minimize(tt_noaff, details = TRUE) -> complex_solution_noaff
print(complex_solution_noaff)

## Parsimonious solution
minimize(tt_noaff, include = "?", details = TRUE) -> parsimonious_solution_noaff
print(parsimonious_solution_noaff)
print(parsimonious_solution_noaff$SA)

#### 5. SUB-QCA 2 EXCLUDING CASES WHERE P_POP = 0 ####
# 5.1 Subsetting data
dataset_no_pop <- subset(standard_dataset, P_POP == 0)
keep_these <- c("B_COB", "U_UNE", "O_OBL", "Y_OUT")
dataset_no_pop <- data.frame(dataset_no_pop[, keep_these],
                             stringsAsFactors = FALSE, row.names = rownames(dataset_no_pop))

# 5.2 Analysis of necessity
QCAfit(dataset_no_pop[, -ncol(dataset_no_pop)],
       dataset_no_pop[, ncol(dataset_no_pop)], necessity = TRUE)

# 5.3 Analysis of sufficiency
QCAfit(dataset_no_pop[, -ncol(dataset_no_pop)],
       dataset_no_pop[, ncol(dataset_no_pop)], necessity = FALSE)

# 5.4 Truth table analysis
truthTable(dataset_no_pop, outcome = colnames(dataset_no_pop)[ncol(dataset_no_pop)],
           conditions = colnames(dataset_no_pop)[-ncol(dataset_no_pop)],
```

```
            complete = TRUE, incl.cut = 0.75) -> tt_nopop
print(tt_nopop)

# Logical minimisation
## Complex solution
minimize(tt_nopop, details = TRUE) -> complex_solution_nopop
print(complex_solution_nopop)

## Parsimonious solution
minimize(tt_nopop, include = "?", details = TRUE) -> parsimonious_solution_nopop
print(parsimonious_solution_nopop)
print(parsimonious_solution_nopop$SA)

# Clean up
rm(complex_solution_noaff,
   complex_solution_nopop,
   parsimonious_solution_noaff,
   parsimonious_solution_nopop,
   tt_noaff,
   tt_nopop)

#### 6. EULER DIAGRAMS ####
library("eulerr")

# Without outcome (Y_OUT)
complex_solution$pims -> sets4euler
columns_to_keep <- c("A_AFL*P_POP", "~A_AFL*~B_COB*U_UNE",
"B_COB*~O_OBL*~U_UNE",
                    "A_AFL*~B_COB*~U_UNE", "~B_COB*O_OBL*U_UNE",
"~O_OBL*P_POP*~U_UNE")
sets4euler <- sets4euler[, columns_to_keep]
c("AFL*POP", "¬AFL*¬COB*UNE", "COB*¬OBL*¬UNE",
  "AFL*¬COB*¬UNE", "¬COB*OBL*UNE", "¬OBL*POP*¬UNE") -> colnames(sets4euler)
euler(sets4euler) -> euler_fit
plot(euler_fit)

# With outcome (Y_OUT)
```

```
cbind(complex_solution$pims, standard_dataset$Y_OUT) -> sets4euler
columns_to_keep <- c("A_AFL*P_POP", "~A_AFL*~B_COB*U_UNE",
"B_COB*~O_OBL*~U_UNE",
                    "A_AFL*~B_COB*~U_UNE", "~B_COB*O_OBL*U_UNE",
"~O_OBL*P_POP*~U_UNE",
                    "standard_dataset$Y_OUT")
sets4euler <- sets4euler[, columns_to_keep]
c("AFL*POP", "¬AFL*¬COB*UNE", "COB*¬OBL*¬UNE",
  "AFL*¬COB*¬UNE", "¬COB*OBL*UNE", "¬OBL*POP*¬UNE", "OUT") ->
colnames(sets4euler)
euler(sets4euler, shape = "ellipse") -> euler_fit_Y
plot(euler_fit_Y, quantities = list(fontsize = 10))

#### 7. Maps ####
# Loading packages
library("ggplot2")
library("rnaturalearth")
library("rnaturalearthdata")
library("sf")
library("grid")
library("ggspatial")
library("gridExtra")

# Formatting data
all_cities <- st_as_sf(d_reck_ue_pop[rownames(standard_dataset), ],
                      coords = c("longitude", "latitude"),
                      crs = 4326,
                      agr = "constant")

rich_big_cities <- st_as_sf(d_reck_ue_pop[rownames(standard_dataset), ]
                           [complex_solution$pims[1] == 1, ],
                           coords = c("longitude", "latitude"),
                           crs = 4326,
                           agr = "constant")

disadvantages_cities <- st_as_sf(d_reck_ue_pop[rownames(standard_dataset), ]
                                [complex_solution$pims[2] == 1, ],
```

```
                            coords = c("longitude", "latitude"),
                            crs = 4326,
                            agr = "constant")

rich_wo_benefit_cities <- st_as_sf(d_reck_ue_pop[rownames(standard_dataset), ]
                            [complex_solution$pims[4] == 1, ],
                            coords = c("longitude", "latitude"),
                            crs = 4326,
                            agr = "constant")

obligated_unmployment_cities <- st_as_sf(d_reck_ue_pop[rownames(standard_dataset), ]
                                  [complex_solution$pims[7] == 1, ],
                                  coords = c("longitude", "latitude"),
                                  crs = 4326,
                                  agr = "constant")
co_benefit_cities <- st_as_sf(d_reck_ue_pop[rownames(standard_dataset), ]
                        [complex_solution$pims[8] == 1, ],
                        coords = c("longitude", "latitude"),
                        crs = 4326,
                        agr = "constant")
big_cities <- st_as_sf(d_reck_ue_pop[rownames(standard_dataset), ]
                  [complex_solution$pims[9] == 1, ],
                  coords = c("longitude", "latitude"),
                  crs = 4326,
                  agr = "constant")

# Get the country borders
countries <- ne_countries(scale = "medium", returnclass = "sf")

# Define a plotting function
plot_group_map <- function(group_sf, title) {
  ggplot() +
    geom_sf(data = countries, fill = "white", color = "black") +
    geom_sf(data = all_cities, color = "gray", size = 0.5) +
    geom_sf(data = group_sf, color = "red", size = 1.5) +
    coord_sf(xlim = c(-10, 20), ylim = c(35, 60), expand = FALSE) +
    labs(title = title) +
```

```
  theme_minimal() +
  theme(panel.background = element_rect(fill = "lightblue"),
        plot.title = element_text(size = 10, face = "bold"), axis.text = element_text(family =
"Arial"))  # Change the title size here
}

# Create a plot for each group
plot_rich_big_cities <- plot_group_map(rich_big_cities,
                                       "AFL*POP")
plot_disadvantages_cities <- plot_group_map(disadvantages_cities,
                                            "¬AFL*¬COB*UNE")
plot_co_benefit_cities <- plot_group_map(co_benefit_cities,
                                         "COB*¬OBL*¬UNE")
plot_rich_wo_benefit_cities <- plot_group_map(rich_wo_benefit_cities,
                                              "AFL*¬COB*¬UNE")
plot_obligated_unmployment_cities <- plot_group_map(obligated_unmployment_cities,
                                                    "¬COB*OBL*UNE")
plot_big_cities <- plot_group_map(big_cities,
                                  "¬OBL*POP*¬UNE")

# Adjust position of legend
legend <- gTree(children = gList(
  pointsGrob(0.2, 0.5, pch = 16, gp = gpar(col = "red", cex = 1.5)),
  textGrob("Plan available", x = 0.3, y = 0.5, just = "left", gp = gpar(fontsize = 10)),
  pointsGrob(0.6, 0.5, pch = 16, gp = gpar(col = "gray", cex = 1.5)),
  textGrob("Plan not available", x = 0.7, y = 0.5, just = "left", gp = gpar(fontsize = 10))
))

# Combine the plots
configurations_mapped <- grid.arrange(
  plot_rich_big_cities, plot_disadvantages_cities, plot_co_benefit_cities,
  plot_rich_wo_benefit_cities, plot_obligated_unmployment_cities,
  plot_big_cities, ncol = 3,
  bottom = legend,
  padding = unit(1, "line")
)
```

```
# save as .png file
ggsave("configurations_mapped.png", configurations_mapped, units = "cm", width = 30, height
= 30,
       dpi = 300)
```

Declaration of Originality

I hereby declare that this thesis is the result of my own work and that I have indicated all sources, including online sources, which have been cited without changes or in modified form, especially sources of texts, graphics, tables and pictures.

I confirm that I have not submitted this thesis for any other examination.

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Wageningen, 30/11/24,