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How do local factors shape transformation pathways towards climate-neutral and resilient cities?

Wolfgang Haupt [a], Peter Eckersley [a,b], Janne Irmisch[a] and Kristine Kern [a,c]

[a]Research Group Urban Sustainability Transformations, Leibniz Institute for Research on Society and Space, Erkner, Germany; [b]Department of Accounting and Finance, Nottingham Trent University, Nottingham, UK; [c]Department Public Administration, Åbo Akademi University, Abo, Finland

ABSTRACT

We examine how local socioeconomic, institutional and political factors shape climate transformation pathways in 23 mid-sized German cities. We group our cities into three types: industrial cities (which may have experienced recent structural change), historic cities (in which a significant proportion of the buildings or landscape is under monument protection) and university cities (in which academic or research institutions play a major role in the local community). Drawing on document analysis and expert interviews, we find that budgetary constraints, weaker civil societies and lower levels of political support result in unfavourable structural conditions for successful transformations in industrial cities. Historic cities have often only limited options to change their built environments, but many have identified climate change as a major threat to their built heritage and are therefore keen to take action in climate adaptation. Lastly, university cities are further along the transformation pathways than the other city types, largely due to having more favourable economic conditions as well as greater support from civil society, politics and the local research community.

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1. Introduction

Ongoing and accelerated climate change poses unprecedented challenges for cities. On the one hand, as large energy consumers and emitters of greenhouse gases, cities have to make substantial contributions to mitigate further global warming (United Nations Environment Programme 2021). On the other hand, a lack of greenery and permeable surfaces within urban built environments means that cities are often more vulnerable to climate change than other places and thus need to adapt to impacts such as more frequent heatwaves or heavy rainfall (Intergovernmental Panel on Climate Change 2022). In this context, successful climate policy needs to be more than 'just' the development and adoption of mitigation and adaptation strategies or the implementation of isolated measures. Instead, cities must transform themselves profoundly and comprehensively

CONTACT Wolfgang Haupt wolfgang.haupt@leibniz-irs.de

to become climate-neutral and resilient (which we characterize here as an ideal type). This includes considering climate change mitigation and adaptation as cross-sectoral tasks that are integrated into all major city development processes (e.g. urban and transport planning, green area management, education, etc.).

Previous studies suggest certain structural preconditions (local factors) are closely associated with ambitious local climate policy and climate-neutral and resilient city transformations (Zahran et al. 2008; Homsy 2018; Kern 2019; Haupt, Eckersley, and Kern 2022). Thus, we assume that some cities are (much) more likely to transform into climate-neutral and resilient places than others. Analysing the literature, we identify three distinct 'real-city' types for which we expect varying degrees of success in climate policy and sustainability transformation. The first type are industrial cities in transition (henceforth industrial cities), which may have experienced recent structural change and have the most unfavourable starting conditions for urban transformation. Second, historic cities, in which legal restrictions limit the physical changes that anyone can make to a significant proportion of buildings or landscapes, have to cope with exceptional constraints but also benefit from unique synergies for urban transformation. Third, we have university and science cities (henceforth university cities), in which academic or research institutions play a major role in the local community and which we suggest benefit from conditions that are most likely to facilitate climate-neutral and resilient city transformations.

Our paper draws on document analysis and 57 interviews in 23 mid-sized German cities to examine how local urban structures and sociodemographic, socioeconomic and political factors shape climate policy-making and strategy. Recent studies have found that local climate policies across Europe can vary significantly, although larger cities tend to be more active and set more stringent objectives than smaller municipalities (Salvia et al. 2021; Otto et al. 2021). However, apart from a few forerunners, there has been less research into mid-sized cities, particularly around the local factors and structural preconditions that influence their climate activities. This applies in general (Kern 2019; van der Heijden 2019; Haupt, Eckersley, and Kern 2022) but also specifically for Germany (Häußler and Haupt 2021; Otto et al. 2021), the country our study focusses on. We group our 23 cities into the three categories outlined above to help understand how local conditions may be shaping the approaches of different types of city.

Our article is structured as follows: First, we present and summarize key literature on each city type, starting with the ideal city type of climate-neutral and resilient cities and continuing with the three real types of industrial cities, historic cities and university and science cities. With regards to the latter three types, we then formulate expectations as to the likelihood that they may transform into the ideal type of a climate-neutral and resilient city. We set out our research design (case selection and methods) in the following section, before presenting our key findings on each city type and reviewing our expectations. Lastly, we summarize key findings and pathways for future research in a concluding section.

2. Ideal type – climate-neutral and resilient cities

Many cities have started multifaceted attempts and set up strategies to become green, sustainable, circular, carbon-neutral and resilient. Forerunner cities pursue a comprehensive approach that focuses on various areas of environmental policy, including climate mitigation and adaptation (Madsen and Hansen 2019; Ersoy and Larner 2020). Bibliometric analysis of the trajectory of these concepts revealed two distinct main clusters: sustainable cities that mostly concentrate on eco-economic issues, and smart cities that focus more on socioeconomic issues and rely on the use of information communication technology (De Jong et al. 2015). Other concepts seem to be hybrid forms that combine both approaches (Fu and Zhang 2017; Schraven, Joss, and Jong 2021). International debates have influenced the development of these concepts. Shortly after the Rio Summit in 1992, most of today's leading cities in Europe, such as Copenhagen, Stockholm and Amsterdam, started Local Agenda 21 initiatives, joined city networks, such as ICLEI and the Climate Alliance, set up CO2 reduction targets, developed indicators and established monitoring systems for measuring their emissions (Kern 2019; Otto et al. 2021). Since then, debates on environmental issues have been complemented and replaced by debates on sustainable development and climate governance (see Meijering, Tobi, and Kern 2018). In 2015, the UN adopted Agenda 2030, which contains a specific sustainable development goal for cities. SDG 11 covers 'making cities and human settlements inclusive, safe, resilient and sustainable'. In addition, international organizations such as UNEP, UN Habitat, OECD and the World Bank developed broader concepts of sustainability, which included aspects of economic and social sustainability. Nonetheless, environmental issues are central to the conceptualization of the ideal 'green city'. For example, European rankings such as the Green City Index and the Green Capital Award are based on environmental indicators (Meijering, Kern, and Tobi 2014), including climate mitigation and adaptation, air quality, water, waste & land use, transport, buildings, energy, noise, biodiversity, green growth, sustainable mobility and environmental governance.

In Europe, sustainable cities have sought to reduce car-dependency in favour of cycling-friendly alternatives (Anderberg and Clark 2013) or have established themselves as solar cities (Madsen and Hansen 2019). City administrations have sought to capitalize on these transformations through urban marketing strategies that present them as green and sustainable (Andersson 2016; Haupt 2021), particularly if they have won prizes or performed well in ranking systems (Graczyk 2015; Growe and Freytag 2019). Another aspect of this 'Green City Branding' (Andersson 2016) involves communicating their success through membership of transnational city networks (Kern 2019; Otto et al. 2021).

Case study research has already examined the (ecological) performance and marketing strategies of various green and sustainable cities. This literature focuses mostly on larger and capital cities such as London, Amsterdam (Brilhante and Klaas 2018), Copenhagen (Anderberg and Clark 2013; Brilhante and Klaas 2018; Madsen and Hansen 2019; Hofstad et al. 2022) or Oslo (Røe and Luccarelli 2016; Hofstad et al. 2022). In addition, studies have examined smaller green and sustainable cities such as Vaxjö (Andersson and James 2018), Bristol (Ersoy and Larner 2020) and above all Malmö (Anderberg and Clark 2013; Holgersen and Hult 2021). This also applies to Germany, where scholars have also studied smaller cities, especially two places that also feature in our selection: Freiburg (Kronsell 2013; Growe and Freytag 2019) and Heidelberg (Graczyk 2015; Growe and Freytag 2019).

Recent debates focus less on green and sustainable cities and put more emphasis on the transformation towards climate-neutral and resilient cities (Albert, Rufat, and Kuhlicke 2021; Huovila et al. 2022). In Europe, forerunner cities like Oslo and Copenhagen aim to become climate-neutral by, or even before 2030 (Hofstad et al. 2022). At European level the debates started to change in 2008, when the European Commission, supported by the Committee of the Regions and the EU Parliament, launched the 'Covenant of Mayors'. Signatories committed themselves to reduce their CO2 emissions by at least 20 percent by 2020 and at least 40 percent by 2030. In 2014, the Covenant of Mayors was complemented by Mayors Adapt, a second initiative of the EU Commission. Signatories committed themselves to either develop a comprehensive adaptation strategy for the city or to integrate climate adaptation into already existing plans. In 2015, the Covenant of Mayors and Mayors Adapt merged. Today, new signatories have to commit themselves to develop integrated mitigation and adaptation strategies and reduce their CO2 emissions by at least 55% by 2030. In April 2022, the EU set up two Missions on climate adaptation and climate-neutral cities. Out of the 377 cities that submitted an expression of interest, the Commission selected 100 from all member states, and 12 additional cities from eight non-member states, for its 'Climate-Neutral and Smart Cities Mission'. These cities are supposed to develop strategies to reach climate-neutrality by 2030. The EU Mission on Adaptation to Climate Change will support 150 European regions and communities towards climate resilience by 2030 (European Commission 2022).

Nine German cities feature in the Climate-Neutral and Smart City Mission: Aachen, Dortmund, Dresden, Frankfurt/Main, Heidelberg, Leipzig, Mannheim, Munich and Münster. A recent ranking of 104 German cities according to their climate policy performance shows that Heidelberg and Freiburg also occupy a prominent position in the area of climate policy (Otto et al. 2021). It thus stands to reason that a close connection exists between successful environmental and sustainability policies on the one hand and climate policy on the other. However, even forerunners such as Freiburg and Heidelberg are far from being climate-neutral and resilient cities. Thus, our study departs from the ideal type of a climate-neutral and resilient city and examines the possible transformation pathways to realize these goals over the medium term. Which types of city, and which factors within different city types, might facilitate or hinder such a transformation? We examine these questions for each of the city types introduced below, namely industrial cities, historic cities and university cities.

3. Real types – industrial, historic and university cities

(1) Industrial cities

Central to our study are industrial cities in transition, that can be characterized by a (formerly) heavy reliance on the industrial sector, and many of which have been 'shrinking' as these industries have declined (Rieniets 2009; Haase et al. 2016; Döringer et al. 2020). This shrinkage is frequently accompanied by high rates of unemployment, increasing poverty and a municipal budget that is permanently under strain (Jonas and Wurzel 2021). While in many western German cities the process of shrinkage began in the 1970s (Martinez-Fernandez et al. 2012), this did not really happen in eastern Germany until the 1990s, albeit at a considerably faster pace and over a much shorter timescale (Bontje 2004; Bernt 2009). In post-socialist countries such as the former GDR, former industrial cities experienced a difficult process of economic transformation, deindustrialization and high unemployment (Rieniets 2009; Martinez-Fernandez et al. 2012;

Döringer et al. 2020; Ferenčuhová 2020). At the same time, however, some very wealthy industrial cities, which may rely heavily on a few large employers or a dominant sector, have very low unemployment. For example, studies of Germany's most well-known 'car city', Wolfsburg, show that local industry, and here in particular one dominant company, exerts considerable influence over political decision-making and urban-development processes (Heßler 2013).

With this in mind, we suspect that the dominance of a single, large-scale automotive company or other carbon-intensive industries will have a negative effect on a city's climate policy and its sustainability transformation. Previous studies support this thesis and point to lock-in effects that can arise as a result of high-emission industries, which can slow or even prevent policy change at the local level (Hommels 2005). Recent studies do suggest that individual cities of this type are able to succeed in taking on pioneer roles in the area of climate policy (Eckersley 2018; Haupt, Eckersley, and Kern 2022). In addition, Bristol (Ersoy and Larner 2020) and Malmö (Anderberg and Clark 2013; Holgersen and Hult 2021) provide two outstanding examples of cities that, following a phase of economic decline, have succeeded in setting profound and permanent green city transformation processes in motion. Nonetheless, in shrinking, economically disadvantaged, and fiscally strained industrial cities we expect a comprehensive transformation towards a climate-neutral and resilient city to be less likely than in other city types.

(2) Historic cities

We also investigate historic cities and their potential to transform to climate-neutral and resilient cities. Tourism is often of great importance to the local economy in such places (Canale et al. 2019; Lillevold and Haarstad 2019), and historic heritage or World Heritage status can help to establish a strong sense of identity amongst the local population (Jimura 2016; Eckersley 2017; Lillevold and Haarstad 2019). What clearly distinguishes historic cities from the other city types is that relatively little of their built structure can be changed. Although this appears to make (sustainable) transformation of the city less realistic, previous studies have identified various connections and possible synergies between World Heritage and sustainable urban development (Labadi 2017; Lillevold and Haarstad 2019; Irmisch 2020; Kern et al. 2021a). The built environment in historic cities, unlike in modern cities, for instance, is often created using highly durable construction materials (Lillevold and Haarstad 2019; Kern et al. 2021a). With this in mind, Lillevold and Haarstad (2019, 329) advocate a change of outlook within urban sustainability to a 'deep city' perspective: 'there is also a need to focus on how resources brought from the past – histories, artefacts, and places – may be used for promoting urban sustainability'.

There has been very little research into the relationships between historic preservation, heritage and climate policy and their significance for urban development: most studies in this field focus instead on the risks to heritage assets from climate threats (Fatorić and Seekamp 2017). However, the few available studies show no fundamentally negative influence on climate policy engagement (Lillevold and Haarstad 2019; Irmisch 2020; Kern et al. 2021a). Historic cities nevertheless face the challenge of introducing climate policies that adhere to historic preservation orders or World Heritage guidelines.

For example, energy-efficient building retrofits and the (re)design of public squares and streetscapes are subject to strict guidelines (Kern et al. 2021a). Yet, these restrictions might prevent unsustainable (planning) practices associated with higher energy consumption and private car use, such as the construction of shopping-malls or sprawling suburban landscapes (Lillevold and Haarstad 2019). For example, the intersection of sustainable mobility and World Heritage offers diverse synergies for the city of Bamberg, although they are yet to receive much attention within practice (Irmisch 2020). We assume that comprehensive World Heritage status results in specific obligations and restrictions regarding urban development and building control, which have implications for climate strategies. For historic cities, successful transformations into climate-neutral and resilient cities will largely depend on how they make use of their existing urban form. On the one hand, these constraints and obstacles could make transformations difficult, but – conversely – some historic cities might benefit from existing synergies that make transformations easier than in other (more modern) places.

(3) University cities

Lastly, we investigate the influence of universities and research institutes on local climate policy. Universities are located in 90 German cities; however, for our purposes we only place cities into this category if they have at least one university of supra-regional importance and a certain size, as well as additional research institutes, and a relatively high proportion of students and academic employees among their total population. Previous studies suggest that a supportive research landscape in a city has a positive influence on urban climate policy (Eckersley 2018; Keeler et al. 2019; Bery and Alice Haddad 2022). Of particular significance appear to be research institutes with a focus on climate change or sustainability, and research institutions which support the city in developing and implementing ambitious climate strategies (Kern et al. 2021a; Bery and Alice Haddad 2022). Moreover, university cities normally have growing, younger, educated and affluent populations and rely more on service industries (Kern et al. 2021b; van Raan 2021; Shatilo 2021). This results in a civil society, including environmental and climate-justice groups, that is significantly stronger and more active that in other cities (Zahran et al. 2008; Kern et al. 2021a). Lastly, cities with such sociodemographic and socioeconomic characteristics tend to have a higher share of voters of political parties that prioritize climate and environmental issues (Mann, Briant, and Gibin 2014; Homsy 2018; Kern et al. 2021a). Such factors listed above have all been identified in the literature as conducive conditions for urban climate policy (Zahran et al. 2008; Homsy 2018; Kern 2019; Haupt, Eckersley, and Kern 2022).

Notably, the most prominent cities in Germany with a green image, that is, those that strive towards a comprehensive sustainability transformation (including climate mitigation and adaptation), and have already been able to achieve success, are – without exception – university cities such as Heidelberg or Freiburg (Kronsell 2013; Growe and Freytag 2019; Graczyk 2015). Moreover, a recent study that investigated urban transportation policies in 44 German cities showed that larger metropolitan areas and university cities are most advanced in this area, particularly due to their bike-friendly environment (Holz-Rau et al. 2022). Among the city types we investigate, university cities benefit from the most favourable conditions to set in motion comprehensive transformation processes, and we suggest they are in a better position to advocate ambitious climate policy than industrial or historic cities. Thus, we expect that they would find it easier to transform into climate-neutral and resilient cities.

(4) Summary of assumptions

We adopt several structural conditions as independent variables – the local factors that we assume create the most favourable conditions for climate-neutral and resilient city transformation. Our dependent variable is local climate policy performance (which we assume is strongly influenced by these local factors). Figure 1 illustrates the most important local factors for urban transformation and demonstrates how they tend to feature in the three real types. All of them apply to university cities, and most are present in historic cities. By contrast, none of these factors are prevalent in industrial cities. We expect some overlaps between historic and university cities but see very few similarities between these two real types and industrial cities (see Figure 1). We also suggest that the converse of these local factors contributes towards a more difficult transformation. For example, because we assume the existence of a university has a positive effect on climate policy, the absence of one probably has negative effects. Moreover, cities can still exercise agency within these structural conditions, and therefore climate policy performance may differ from a city's real type. In other words, cities with unfavourable local conditions might nevertheless make progress, due to the activities of key individuals that put climate change on the agenda and increase a city's capacities (Homsy 2018; Haupt and Kern 2022; Haupt, Eckersley, and Kern 2022). Lastly, we are well aware that our real types are a simplified illustration of reality. We do not wish to go backwards in the academic debate and fully agree with Brenner and Schmidt (2015)'s argument that 'the fabric of urbanization is multidimensional' (169) and that 'the urban is a process, not a universal form, settlement type or bounded unit' (165). Nevertheless, the definition of three broad city types allows us to structure and test our assumptions on the importance of local factors for local climate policy-making. We hope that additional studies by other researchers will challenge our assumptions and come up with more nuanced subtype cities.

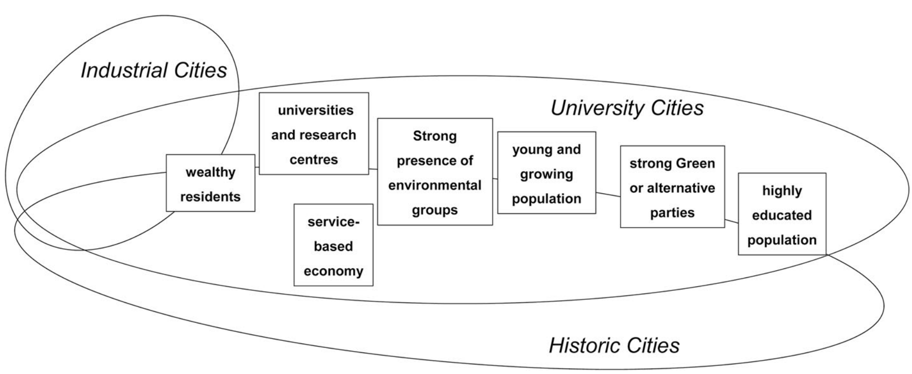

Figure 1. Expected overlaps between industrial, historic and university cities.

4. Case selection and methods

To review our expectations, we identified 23 mid-sized cities in Germany that fitted with our definitions of the three city types. Four of these cities exhibited characteristics of two different types and we thus placed them into both categories. This applied to *Potsdam, Regensburg and Würzburg* (historic and university cities) and *Wuppertal* (industrial and university city). Figure 2 shows the distribution of our case study cities over the

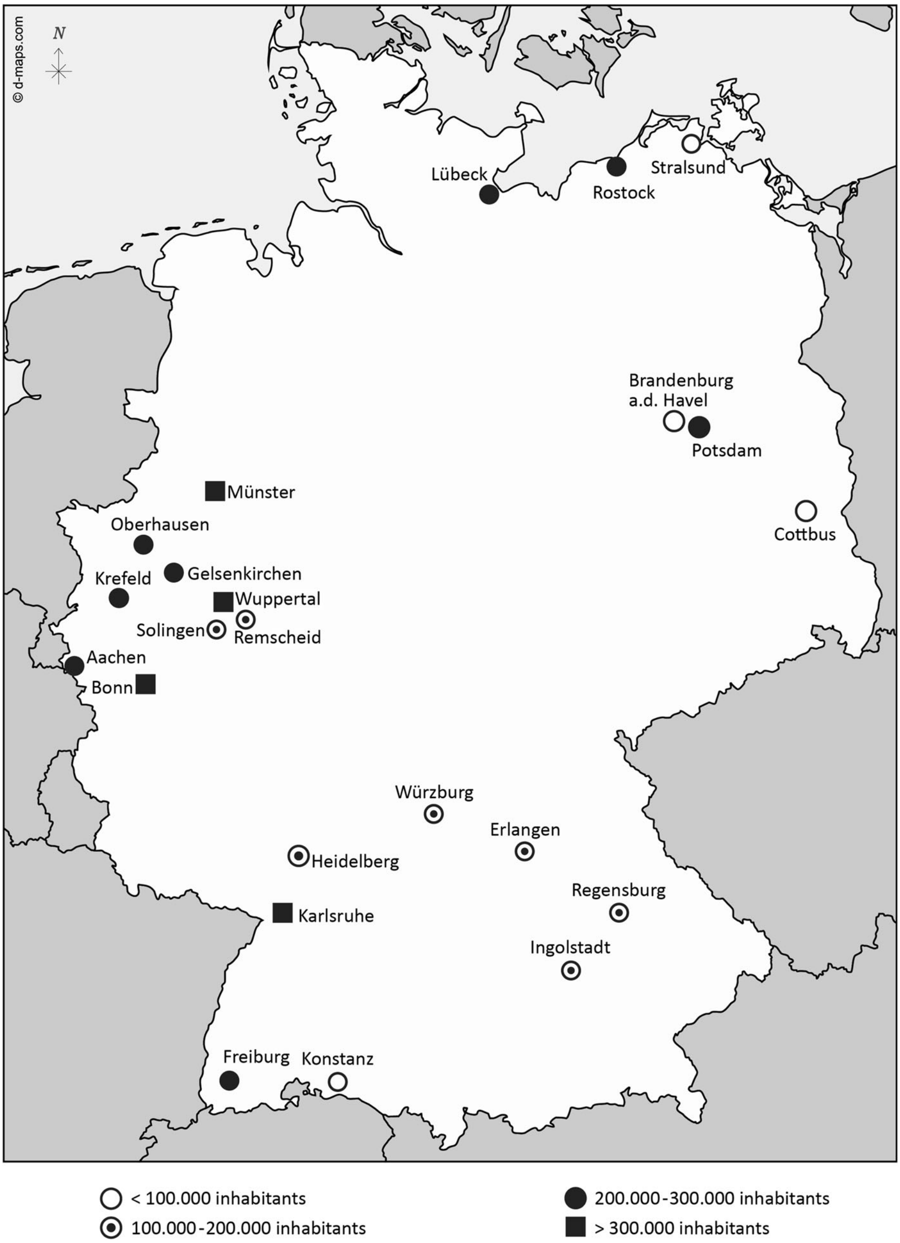

Figure 2. Examined cities.

country. The smallest city we examined was Stralsund (approx. 59,000 inhabitants), and the largest was Wuppertal (approx. 355,000 inhabitants). Many case study cities are located in the West, in Germany's most populous state (*Bundesland*) North Rhine-Westphalia, which is very urbanized and has a high number of mid-sized cities.

We focused on mid-sized cities mainly for two reasons. First, it allowed us to place them into our three categories more easily. Larger cities such as Berlin, Hamburg, Munich or Cologne are, in a way, industrial, historic and university and science all in one. In contrast, the importance of a university, a historic centre or certain industry is probably much higher for mid-sized cities and towns than for larger cities. Second, most research has so far concentrated on larger cities (van der Heijden 2019; Haupt, Eckersley, and Kern 2022) that also tend to be more active in climate policy since they have higher capacities (Kern 2019; Otto et al. 2021; Salvia et al. 2021). Although mid-sized German cities have been quite active (Otto et al. 2021), they do not receive the same attention as larger cities (Häußler and Haupt 2021). At the same time, however, focusing on smaller towns might have proven more difficult, since most of them have not been very active in climate policy in Germany (Otto et al. 2021).

Our sample includes nine industrial cities (see Table 1). We selected cities from regions traditionally characterized by the mineral and steel industries, mining, and fossil-fuel power generation (*Cottbus, Brandenburg, Gelsenkirchen, Oberhausen*), as well as the textile (*Krefeld, Wuppertal*), tool manufacturing (*Remscheid, Solingen*) and car industries (*Ingolstadt*). The populations of several of our case studies have been shrinking for decades. Our sample includes west-German cities, where the shrinkage process began in the 1960s (*Gelsenkirchen, Krefeld, Oberhausen, Remscheid, Solingen, Wuppertal*), and East German cities whose population has decreased drastically since the early 1990s (*Brandenburg, Cottbus*). Several of our case studies underwent a process of extensive deindustrialization (particularly *Brandenburg, Gelsenkirchen, Krefeld*, *Wuppertal, Oberhausen*). Unemployment rates in many of the industrial cities investigated are (sometimes quite considerably) above the German average: *Gelsenkirchen, Krefeld, Oberhausen* and *Wuppertal* are among the 20 German cities with the highest rates of joblessness. At the same time, our sample includes a very wealthy city

Table 1. Selected industrial cities (light grey: highest/best value, dark grey: lowest/ worst value), sources: Federal Statistical Office of Germany (2019); Handelsblatt (2019).

City	Population trend (1992-2019), in %	Municipal dept per capita (2017), in €	GDP per capita (2019), in €	Manufacturing sector (2019), in %	Service sector (2019), in %	Unemployment (2019); in %	Prospected future chances and risks ranking of 401 cities and counties (2019)[a]
Brandenburg	- 26.0	4550	33,053	21.4	77.8	8.2	high risks (370)
Cottbus	- 31.2	6249	35,833	10.9	88.8	7.5	high risks (363)
Gelsenkirchen	- 13.3	6513	31,930	17.4	82.5	12.6	high risks (371)
Ingolstadt	+ 27.2	4363	133,426	43.8	55.9	2.8	best chances (3)
Krefeld	- 8.3	4722	41,132	25.5	74.0	10.2	moderate risks (312)
Oberhausen	- 6.8	9871	27,489	19.0	80.9	9.9	high risks (378)
Remscheid	- 11.5	8110	37,671	35.0	64.9	7.2	moderate risks (323)
Solingen	+ 4.3	6624	32,449	29.9	70.0	7.0	balanced (301)
Wuppertal	- 8.9	7339	37,183	23.0	76.8	8.1	balanced (189)

Note: [a]German-wide study on economic opportunities of all 401 independent municipalities and counties (Kreise).

with very low unemployment (*Ingolstadt*), whose economy is shaped by a single large-scale automobile company (Audi), which is still in its early stages of transformation towards E-mobility.

We also examined five historic cities (see Table 2), all of which have received UNESCO World Heritage status. Most of Germany's 51 UNESCO World Heritage sites are individual buildings or building complexes such as churches or cathedrals. We distinguish between cities in which 'only' individual buildings or building complexes have received World Heritage status and those in which larger areas are subject to UNESCO World Heritage protection. This means there are significantly fewer World Heritage cities in Germany than industrial cities or university cities. The number of cities that 'only' have a historic city centre is probably similar to the number of industrial and university cities. Nevertheless, we decided to focus on World Heritage cities to study particularly clear cases of cities that need to align their urban development and climate strategies with distinct heritage and monument protection obligations and restrictions. The examined cities have received UNESCO World Heritage status either for their medieval historic inner cities (*Lübeck, Regensburg, Stralsund*) or for their large-scale parks (*Würzburg*) or park landscapes (*Potsdam*). The latter two also have historic city centres (baroque in *Potsdam* and medieval in *Würzburg*).

Lastly, we examine 13 university cities (see Table 3). These include numerous older university cities steeped in tradition (*Heidelberg*, *Freiburg*, *Rostock*), cities with a very high proportion of students and academic employees in the total population (*Regensburg*, *Würzburg*, *Potsdam*) and cities with very large, research-oriented universities as well as additional research institutes (*Aachen*, *Bonn*, *Erlangen*, *Karlsruhe*, *Münster* and *Potsdam* again). Moreover, we selected cities that host non-university research institutes with a distinct focus on climate change and sustainability. This includes the *Wuppertal* Institute for Climate, Environment and Energy, The Institute for Applied Ecology in *Freiburg*, the Institute for Energy and Environmental Research in *Heidelberg*, and the *Potsdam* Institute for Climate Impact Research.

Our empirical work is based on an extensive document analysis that was checked and complemented by expert interviews. For all 23 case study cities we first analysed a set of key climate policy documents (mostly climate mitigation and adaptation strategies and related reports) and further material (e.g. media sources, minutes of city council

Table 2. Selected historic cities (light grey: highest/best value, dark grey: lowest/worst value), sources: Federal Statistical Office of Germany (2019); Handelsblatt (2019).

City	Population trend (1992-2019), in %	Municipal dept per capita (2017), in €	GDP per capita (2019), in €	Manufacturing sector (2019), in %	Service sector (2019), in %	Unemployment (2019), in %	Prospected future chances and risks ranking of 401 cities and counties (2019)[b]
Lübeck	+/- 0.0	5,567	45,098	19.2	80.6	7.3	balanced (276)
Potsdam	+ 22.7	5,391	44,596	6.5	93.4	5.3	high chances (92)
Regensburg	+ 23.6	3,273	85,414	23.6	76.2	3.3	very high chances (19)
Stralsund[a]	- 18.8	4,486	26,513	14.6	82.2	7.3	high risks (388)
Würzburg	+/- 0.0	5,634	67,017	9.3	90.4	3.3	very high chances (24)

Notes: [a]Numbers for the administrative district of Vorpommern-Rügen (224,693 inhabitants).
[b]German-wide study on economic opportunities of all 401 independent municipalities and counties (Kreise).

Table 3. Selected university cities (light grey: highest/best value, dark grey: lowest/worst value), sources: Federal Statistical Office of Germany (2019); Handelsblatt (2019).

City	Population trend (1992-2019), in %	Municipal dept per capita (2017), in €	GDP per capita (2019), in €	Manufacturing sector (2019), in %	Service sector (2019), in %	Unemployment (2019), in %	Prospected future chances and risks ranking of 401 cities and counties (2019)[c]
Aachen[a]	+ 2.9	5,900	39,194	20.0	79.7	7.0	moderate chances (101)
Bonn	+ 11.2	6.223	82,081	6.2	93.8	6.3	very high chances (28)
Konstanz[b]	+ 13.8	4,122	35,915	23.4	75.1	2.9	high chances (81)
Erlangen	+ 9.6	5,437	100,095	33.4	66.4	3.5	best chances (6)
Freiburg	+ 19.3	3,815	55,284	11.0	88.7	4.7	high chances (57)
Heidelberg	+ 15.2	5,454	58,209	10.8	88.9	4.0	very high chances (13)
Karlsruhe	+ 12.2	5,743	66,579	15.0	84.9	3.8	very high chances (23)
Münster	+ 18.4	3,677	57,708	9.8	89.7	4.5	very high chance (25)
Potsdam	+ 22.7	5,391	44,596	6.5	93.4	5.3	high chances (92)
Regensburg	+ 23.6	3,273	85,414	23.6	76.2	3.3	very high chances (19)
Rostock	- 15.2	6,217	38,106	13.6	86.2	6.7	balanced (224)
Wuppertal	- 8.9	7,339	37,183	23	76.8	8.1	balanced (189)
Würzburg	+/- 0	5,634	67,017	9.3	90.4	3.3	very high chances (24)

Notes: [a]Figures for the city region Aachen (556,246 inhabitants).
[b]Figures for the administrative district of Konstanz (285,815 inhabitants).
[c]German-wide study on economic opportunities of all 401 independent municipalities and counties (Kreise).

meetings). Next, we conducted 57 expert interviews with local stakeholders from the case study cities between June 2019 and February 2022. We spoke with city practitioners responsible for climate policy (29), local politicians (7) and representatives of civil society (21), particularly environment and climate groups. The semi-structured interviews followed two methodological guidelines, one for city practitioners and politicians and another one for civil society actors. Both interview guidelines focussed on identifying and understanding the cities' climate policies and their overall transformation pathways. The interviews with city practitioners and politicians concentrated more on the integration of climate policy into local government processes, whereas those with civil society representatives were oriented towards the diversity and influence of local civil society actors.

5. Findings and review of expectations

This section presents key findings on the three different city types and discusses and reviews our research expectations that were explained in section 2.

(1) Industrial cities

Our findings confirmed the presumption that it is often difficult for industrial cities (in transition) to achieve climate-policy success (see also Table 4). This was true both for structurally weak cities (*Brandenburg, Cottbus, Krefeld*) and more affluent industrial

Table 4. Key climate policy activities of the selected industrial cities, sources: local policy documents and various (local) media articles.

City	Entry into the Climate Alliance	Other network memberships	First mitigation strategy	Climate neutrality goal by	GHG-emission reduction per capita[c] in %	First adaptation strategy	Climate strike attendance[d]	Declaration of climate emergency[e]
Brandenburg	/	/	2017	/	- 13.5 (2010-2014)	2016	Unknown	/
Cottbus	/	/	2013	/	- 50.3 (1992-2011)	/	Unknown	/
Gelsenkirchen	2008	ICLEI[a]	2011	/	- 18.6 (1990-2007)	2012	~ 500	11 July 2019
Ingolstadt	1992	/	2011	/	- 2 (2008-2012)	/	~ 1.500	/
Krefeld	/	/	2002	2050	- 1.1 (2010-2017)	2020	~ 3.500	4 July 2019
Oberhausen	1998	CoM[b]	2012	2050	- 24.8 (1990-2008)	2013	Unknown	/
Remscheid	1995	/	1999	/	- 28.2 (1990-2017)	2013	Unknown	/
Solingen	1993	/	2002	/	- 14.2 (1990-2009)	2013	~ 1.000	/
Wuppertal	1992	CoM, Mayors Adapt	1996	/	- 30.6 (1990-2017)	2014	~ 3.500	24 March 2019

Notes: [a]Local Governments for Sustainability (ICLEI).
[b]Covenant of Mayors (CoM).
[c]Greenhouse gas (GHG); in brackets the time period considered.
[d]Global climate strike on September 20, 2019.
[e]Dates of climate emergency declarations or comparable resolutions.

cities in which single large-scale enterprises dominate (*Ingolstadt*). Our study also confirms that existing lock-in effects, resulting for instance from local, high-carbon industries, can hinder sustainability transformations (Hommels 2005). For example, the city administration in *Cottbus*, a city strongly characterized by the mining and coal industries, found it difficult to persuade crucial actors in politics and business of the necessity and opportunities provided by climate-oriented urban development (Interview C1). The situation was similar in the car city *Ingolstadt*, where policymakers recoil from ambitious climate mitigation measures in deference to the perceived interests of the Audi Group (Interviews I1, I2, I3). In some respects, however, Audi itself demonstrates greater ambition than the politicians of *Ingolstadt* (Interview I1). The Group has been certified under the Eco Management and Audit Scheme (EMAS), for instance, and plans to achieve climate-neutral production by 2030. In cities such as *Ingolstadt*, but also in *Krefeld, Remscheid* and *Solingen*, it was also clear that lock-in effects can arise not only from high-emission industries, but also from an urban infrastructure strongly biased toward car usage (Interviews Kf1, Rs1, Rs2, So2).

Civil society groups were only able to exert limited pressure on climate policy in almost all of the industrial cities we studied, particularly compared to the other city types (see below). Local Fridays for Future groups, for example, tended to be relatively small and weak, and most policymakers did not treat climate change as a key priority (Interviews Bb2, C1, I1, Kf1, O1, Rs1, So2). In addition, among the selected industrial cities only *Gelsenkirchen* and *Krefeld* had declared a climate emergency (Table 4).

In some industrial cities, the lack of financial and human resources posed the largest challenge for the development and implementation of climate measures (Interviews Bb1, O1, O2, Rs1), particularly where municipalities were affected by budgetary safeguarding measures (e.g. *Oberhausen, Remscheid*). Nevertheless, some of these (former) industrial cities did apply successfully to national or EU programmes for third-party funding in order to develop and implement ambitious climate policies (e.g. *Gelsenkirchen, Oberhausen, Remscheid*). However, focusing too much on acquiring third-party funding comes with the significant risk that climate activities will scale back once the funding ends and short-term staff contracts expire (Haupt and Kern 2022; Haupt, Eckersley, and Kern 2022).

Our findings suggest that structural change plays a key role in shaping urban climate policy. While this began as early as the 1960s in the west-German Ruhr region, including our cities of *Gelsenkirchen, Krefeld* and *Oberhausen,* the east-German cities of *Brandenburg* and *Cottbus* only started to experience deindustrialization from the 1990s onwards, after unification. This process is still currently underway in *Cottbus*, which remains heavily dependent on fossil fuel industries. On the whole, the cities of the Ruhr region have made significantly more climate-policy progress than those in the eastern state of Brandenburg – but they have also had more time to adjust to economic challenges.

Of the industrial cities we investigated, none is on a clear path to becoming a sustainable city. Classic success stories of former industrial cities that have successfully undergone a green transformation, such as Bristol (Ersoy and Larner 2020) or Malmö (Anderberg and Clark 2013; Holgersen and Hult 2021) are – at least in this form – unknown in Germany. Attempts at tackling such a transformation have, however, taken place since the mid-1990s in cities such as *Gelsenkirchen,* which sought to counter the decline of coal mining by encouraging the development of a solar-energy industry. However, despite funding from the EU and the state of North Rhine-Westphalia for a number of high-profile solar energy projects, the city struggled to compete with non-European competitors, especially from China, where photovoltaic plants could be manufactured much more cheaply than in Germany (Interview G1; see also Eckersley 2018).

(2) Historic cities

The historic cities we investigated exhibited a diverse mix of characteristics that might facilitate a sustainability transformation (see also Table 5). The first thing to note is the huge importance of tourism to the local economy for all of our case study cities, as emphasized in the literature (Canale et al. 2019; Lillevold and Haarstad 2019). In line with current research (Jimura 2016; Lillevold and Haarstad 2019), we also found that the cultural heritage of historic cities contributed towards the creation of strong local identities within the urban population.

A crucial point, and one that is likely to become increasingly important in the future, are the threats that climate change pose to World Heritage sites. In *Lübeck* and *Potsdam*, in particular, World Heritage conservators were acutely aware of these risks (Interviews L1, P1). *Lübeck's* historic old town – often dubbed the 'Queen of the Hanseatic League' – is threatened not only by storm tides and rising sea levels, but also torrential rainfall and drought. At the heart of this is the yet unresolved question of how physical measures (e.g. flood barriers) can be installed without damaging the character and charm of the city or even jeopardizing its UNESCO World Heritage status. Potsdam's World Heritage Sites, i.e. its historic gardens and palaces, are threatened above all by rising temperatures and drought. In response, the Prussian Palaces and Gardens Foundation has introduced various mitigation and adaptation measures. It has developed strategies for the sustainable irrigation of the gardens and begun to refurbish historic buildings to reduce energy consumption and protect them from mould formation (Interview P1).

While previous studies suggest that synergies between climate mitigation or adaptation and historic preservation can exist (Labadi 2017; Lillevold and Haarstad 2019; Irmisch 2020; Kern et al. 2021a), we found that they created hurdles and conflicts in the case of *Regensburg* (Interview Rb2). We suggest that this was largely due to the reasons why the city achieved World Heritage status in the first place. As a City of Stone', *Regensburg's* heritage features are much harder to reconcile with many possible climate adaptation measures (e.g. shading and greening) than, for instance, the models present in *Stralsund* or *Potsdam* (in both cases, a 'Green City on the waterfront'). With regard to climate mitigation, however, *Regensburg* has achieved successes. In the historic old town, slender electric buses adapted to the narrow streets now run emission-free on electricity supplied from a local hydroelectric power station. This also fits with previous findings on diverse synergies between sustainable mobility and World Heritage or historic town centres (Irmisch 2020), and distinguishes the historic cities we investigated from several industrial cities. Since historic city centres were not designed around the needs of motorists, car-friendly features were never locked into local transport infrastructures (Hommels 2005). Conflicts can nevertheless arise in historic cities in this area, especially where many tourists arrive by car, as is the case in *Stralsund* (Interview St1). Not only does this have an influence on the city's greenhouse-gas emissions,

Table 5. Key climate policy activities of the selected historic cities, sources: local policy documents and various (local) media articles.

City	Entry into the Climate Alliance	Other network memberships	First mitigation strategy	Climate neutrality goal by	GHG-emission reduction per capita[c] in %	First adaptation strategy	Climate strike attendance[d]	Declaration of climate emergency[e]
Lübeck	1993	/	1994	2040	- 9.7 (2006-2015)	2014	~ 4.000	23 May 2019
Potsdam	1995	/	1999	2050	- 17 (2003-2014)	2010	~ 6.000	14 August 2019
Regensburg	1993	ICLEI[a], CoM[b]	1993	2050	- 9.7 (2012-2018)	2011	~ 4.000	/
Stralsund	2009	/	2010		- 21 (2007-2012)	2010	unknown	/
Würzburg	2008	/	2012	2045	- 39 (1990-2019)	2012	~ 5.000	/

Notes: [a]Local Governments for Sustainability (ICLEI).
[b]Covenant of Mayors (CoM).
[c]Greenhouse gas (GHG); in brackets the time period considered.
[d]Global climate strike on September 20, 2019.
[e]Dates of climate emergency declarations or comparable resolutions.

but impermeable parking areas are also problematic from the perspective of climate adaptation since they reduce urban resilience to torrential rain and heatwaves. Many historic cities are nevertheless further along the path to becoming sustainable cities in comparison with other city types, without any far-reaching transformations having been at all necessary in this area.

We restricted our study to cities with extensive UNESCO World Heritage sites, but our findings have implications for many other places in Germany and elsewhere. This is particularly the case for cities with a historic town centre in which a large number of buildings or groups of buildings are under preservation orders, and where tourism is a key local industry – regardless of their UNESCO World Heritage status. In contrast to the Prussian palaces and gardens that comprise about a third of *Potsdam*'s territory, for example, the 'problem zones' with regard to climate mitigation and adaptation measures are located in its baroque old town, which consists largely of listed buildings, but has no World Heritage status. Planning restrictions have made it difficult to introduce greening, shading and unsealing initiatives in these temperature hotspots, and solar panels are prohibited not only on the rooftops of buildings within World Heritage areas and their buffer zones, but also within certain long vistas (Interviews P1, P2).

(3) University cities

As we suspected, science cities found it much easier to develop ambitious climate policy than our other city types (see also Table 6). Probably the most important reason for this, as already indicated in the literature, is their socio-demographic structure (Homsy 2018; Zahran et al. 2008; Kern et al. 2021b; Shatilo 2021). The university cities we investigated had predominantly young and affluent populations and high proportions of students and academics. These groups are more likely to vote for candidates and parties in local and regional elections that favour action on environmental and climate-related issues (Mann, Briant, and Gibin 2014; Homsy 2018; Kern et al. 2021a). Of the university cities we examined, for instance, Green party city mayors had been in place in *Freiburg* (2002-2018), as well as in *Aachen, Bonn* and *Wuppertal* (all since 2020). Besides this, the Green Party has been strongly represented in the local councils of several university cities, in some cases for quite some time. For example, in *Freiburg* (since 2009), *Karlsruhe, Konstanz* and *Heidelberg* (since 2019), and *Aachen* and *Bonn* (since 2020) the Greens are the largest party on the city council. This means the topic of climate change is often given more attention in local debates, which in turn can be reflected in more ambitious climate mitigation targets (see Table 6) and more generous resource allocations.

Additionally, we found that civil society actors were very prominent in university cities and place urban policymakers under much more pressure than in other city types. Firstly, established environmental protection organizations such as the BUND (German Federation for the Environment and Nature Conservation), NABU (Nature and Biodiversity Conservation Union) or Greenpeace have often been very active and well organized in university cities for several decades, together with other local environmental groups (Interviews A1, Bn1, E1, F1, H1, Ko1; M1). Furthermore, since 2018 and 2019 local Fridays for Future groups have become particularly well represented and powerful (see Table 3; Interviews Bn1, F2, Ka 1, Ko2, M3, Wü1). This contributed

Table 6. Key climate policy activities of the selected university cities, sources: local policy documents and various (local) media articles.

City	Entry into the Climate Alliance	Other network memberships	First mitigation strategy	Climate neutrality goal by	GHG-emission reduction per capita[c] in %	First adaptation strategy	Climate strike attendance[d]	Declaration of climate emergency[e]
Aachen	1991	CoM[a], Mayors Adapt	1993	/	- 22.9 (1990-2017)	2012	~ 6.000	19 June 2019
Bonn	1995	CoM, ICLEI[b]	1995	2035	- 33.3 (1990-2018)	2013	~ 15.000	4 June 2019
Erlangen	1995	CoM	1994	2050	- 35.4 (1990-2019)	2020	~ 5.000	29 May 2019
Freiburg	1993	CoM, ICLEI, Energy Cities	1986	2050	- 37 (1992-2018)	2019	~ 20.000	/
Heidelberg	1994	CoM, ICLEI, Energy Cities	1992	2050	- 30 (1987-2017)	2015	~ 9.000	10 May 2019
Karlsruhe	2011	CoM, ICLEI	1999	2050	- 21 (2007-2015)	2008	~ 9.000	16 July 2019
Konstanz	1992	/	2016	2035	- 5.4 (2010-2017)	/	~ 5.000	2 May 2019
Münster	1995	CoM, ICLEI, Mayors Adapt	1995	2030	- 40 (1990-2019)	2015	~ 20.000	22 May 2019
Potsdam	1995	/	1999	2050	- 17 (2003-2014)	2010	~ 6.000	14 August 2019
Regensburg	1993	ICLEI	1993	/	- 9.7 (2012-2018)	2011	~ 4.000	/
Rostock	1993	CoM, Mayors Adapt	2000	2035	- 53 (1990-2010)	2013	~ 3.000	25 September 2019
Wuppertal	1992	CoM, Mayors Adapt	1996	/	- 30.6 (1990-2017)	2014	~ 3.500	24 March 2019
Würzburg	2008	/	2012	2045	- 39 (1990-2019)	2012	~ 5.000	/

Notes:[a] Local Governments for Sustainability (ICLEI).
[b]Covenant of Mayors (CoM).
[c]Greenhouse gas (GHG); in brackets the time period considered.
[d]Global climate strike on September 20, 2019.
[e]Dates of climate emergency declarations or comparable resolutions.

towards university cities such as *Konstanz, Heidelberg, Münster* and *Erlangen* being among the first German municipalities to declare a climate emergency in May 2019. Indeed, all the university cities we investigated have declared a climate emergency or agreed a similar city council resolution to combat climate change.

We found many examples of ambitious climate and sustainability initiatives in university cities. For example, many have introduced extensive cycling infrastructure. *Münster* has for a long time been perceived as Germany's most prestigious cycling city (Interviews M1, M2), and *Bonn, Münster, Karlsruhe, Freiburg, Potsdam, Heidelberg, Regensburg, Würzburg, Konstanz* and *Erlangen* have all been judged to have a bike-friendly environment (ADFC [Allgemeiner Deutscher Fahrrad-Club, the German Bicycle Club] 2020; Holz-Rau et al. 2022). Several cities have complemented their leadership role in climate mitigation with one in climate adaptation (*Heidelberg, Münster*) – although other first-generation climate pioneers, such as *Freiburg* and *Bonn*, have struggled to fully integrate climate adaptation into existing institutional arrangements (see Otto et al. 2021).

The question arises, however, as to whether the climate pioneering role of several university cities can be attributed exclusively to their socioeconomic composition. One might assume, first of all, that municipalities can usually recruit the specialist staff required for climate policy in university cities directly from their universities, and this was confirmed in our *Heidelberg* and *Münster* fieldwork (Interviews H1, M1, M2). In addition, the physical proximity of universities and research institutions alone offers opportunities for exchange and cooperation that can decisively advance urban climate policy. In 2020 in *Wuppertal*, for instance, the long-standing director of the Wuppertal Institute for Climate, Environment and Energy was elected as Green Party candidate to the position of city mayor. Similarly, a former President of the transnational urban network Local Governments for Sustainability (ICLEI) was mayor of *Bonn* – the city in which this network is headquartered – for several years. The secretariat of the United Nations Framework on Climate Change as well as the vice-rectorate of the United Nations University are also located in *Bonn*, and the Institute for Applied Ecology in *Freiburg*, the Institute for Energy and Environmental Research in *Heidelberg*, and the Potsdam Institute for Climate Impact Research have each played a key role in the development of their respective city's climate strategies (Interviews F1, H1, P1). Potsdam has also launched a city-science partnership for collaboration between the city authorities and local research institutions in the field of climate change (Interview P1). The climate mitigation strategies of the cities we examined contain greenhouse gas reduction targets that are significantly higher than in most other German cities (Otto et al. 2021).

Overall, therefore, our study confirms previous findings that suggest research institutions can help cities with the development of ambitious climate strategies (Kern et al. 2021a; Bery and Alice Haddad 2022). Generally, though, beyond the example of *Potsdam* (Kern et al. 2021a) there have been few studies examining the potential of such collaborations and partnerships, especially with regard to climate policy and broader urban sustainability transformations.

6. Conclusions and pathways for future research

We examined the climate policy pathways of 23 mid-sized German cities and explored how far their transformation to become a climate-neutral and resilient city has progressed. Although some cities have made substantial progress and are much further on their transformation path than others, none of them is close to reaching the ideal type of a climate-neutral and climate resilient city.

As expected, we identified substantial differences between the three investigated real types of industrial, historic and university cities. Most industrial cities operate within unfavourable structural conditions for becoming carbon-neutral and climate resilient. In particular, these include budgetary constraints, weaker civil society organizations, and lower levels of political support. Despite these constraints, however, some of these cities have been able to adopt ambitious climate policies. Results for historic cities, which are limited in terms of the changes they can make to the built environment or the urban form – but might nonetheless view sustainability as an additional tool to preserve monuments and attract tourists, were mixed. However, some of these cities have clearly identified climate change as a major threat to their historic built heritage and thus started to discuss and adopt adaptation measures. Lastly, as expected from the literature, we found that university cities found it much easier to develop far-reaching climate policies, because they had more sympathetic populations (including strong climate action groups) and politicians, and could often rely on support from the local research community.

Our exploratory work has focussed on a relatively high number of cities and thus remains on a rather general level. There is certainly a need for more in-depth single case or comparative small-n studies to further test and develop our expectations on the significance of structural conditions (local factors) for local climate policy. We defined and examined three broad city types, but of course reality is more complex and there is no textbook industrial, historic or university city. Indeed, cities often share the characteristics of several city types: our sample included several historic cities that are university cities at the same time. We suggest that our three city types and the local factors that create the most favourable conditions for climate-neutral and resilient city transformation should rather be seen as a starting point for the definition of more nuanced and specific sub-types, some of which may share characteristics with those that we developed. Moreover, while our study confirmed expectations that university cities are further ahead on their transformation pathways, our findings on industrial and historic cities were more multilayered and less clear. Therefore, we see particular need for further research on climate policy in industrial and historic cities as well in sub-types of these cities. For a start, the timing and speed of (de)industrialization could distinguish multiple sub-categories of industrial city. Additionally, one of our industrial cities was very wealthy and dominated by a single industry sector and enterprise (Audi in *Ingolstadt*). There are fewer examples of such cities, but the fact that *Ingolstadt* performs quite poorly in climate policy might be a good reason to undertake further studies on comparable cities, particularly those that operate within the same multilevel context. Examples from Germany could include other automotive cities such as *Wolfsburg* (Volkswagen), or cities dominated by the chemical industry such as *Ludwigshafen* (BASF) or the pharmaceutical industry such as *Leverkusen* (Bayer). In a recent ranking of climate policy involving 104 German cities, all three performed very poorly (Otto et al. 2021). Future studies might bring more detailed insights on the role of high-emission enterprises on local climate policy and maybe also how cities might be able to break out of such lock-in situations and start making progress towards climate-neutrality and resilience transformations.

Our findings show that the built environment and heritage shaped sustainable development and climate policy in historic places. Nevertheless, immaterial or intangible heritage could also play an important role in urban sustainability and climate policies. Cities in which immaterial heritage is of key importance, which we might term cultural cities, might either be seen a sub-category of historic cities or even as a whole new city type. Cultural cities are often (smaller) cities that are also highly dependent on tourist industry but whose reputations are built on fewer points of reference to sustainability and climate change. This is the case, for instance, with the festival cities *Baden-Baden* and *Bayreuth*, or the city of German classicism *Weimar*, but is also true of significantly larger cities such as *Kassel*, which hosts the Documenta exhibition. All these cities are measurably less active in climate policy than other cities of comparable size (Otto et al. 2021), but limited research means that it remains unclear how this focus on immaterial heritage might affect a climate-neutral and resilient city transformation. Nonetheless, as our other case studies have illustrated, local factors often play a key role in shaping approaches to urban sustainability, and therefore we might expect such factors to be important drivers of climate strategy.

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ORCID

Wolfgang Haupt http://orcid.org/0000-0002-1042-2106
Peter Eckersley http://orcid.org/0000-0001-9048-8529
Kristine Kern http://orcid.org/0000-0001-9923-4621

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