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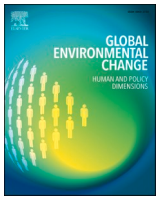

From grey to green? Tipping a coal region incrementally

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ABSTRACT

A rapid and full decarbonisation of both energy and industry is essential to meet the targets in the Paris agreement, which brings coal- and carbon-intensive regions under significant pressure. Some regions have advanced in their transition and can provide insights in the system change processes. In this paper, we investigate the socio-economic transition processes of Essen and Duisburg as part of the wider structural change in the Ruhr Region/ Germany. We explore causes and effects of their trajectories in the last 30 + years and identify differences in outcome as a function of the interventions and/or contextual differences, while investigating whether either city crossed a tipping point in their transition process (yet). Therefore, we specifically evaluate the cities' development trajectories by seeking evidence for "no", "incremental" or "radical or tipping" changes in sets of qualitative and quantitative indicators.

Our analysis shows that both cities experienced incremental changes in their demographic, economic and political trajectories but we found no evidence for either city to have crossed a tipping point in their transition process yet. However, distinct developments in the cities' policy narratives and visions indicate qualitative changes while putting them on different development trajectories potentially leading to tipping points in the future. Our study shows that the sequence of interventions and timing are important factors for the trajectory of a region determining the quality of societal change. It also suggests that radical change and tipping are the exception rather than the rule, especially in the highly complex social systems of cities.

1. Introduction

To meet the temperature targets of the Paris Agreement, both the energy system and the industry sector must be fully decarbonised (IPCC, 2022). This brings coal- and carbon-intensive regions under particular pressure, because the impacts of closing mines, power stations and industries may be especially strong here due to the strong socio-economic, political and cultural path dependencies and lock-in effects that have made them dependent on fossil fuel industries in the first place (Unruh, 2000; Berkhout, 2002).

Yet, some previously coal-dependent regions have already advanced in their transition away from coal and provide insights in the system dynamics and change processes. The conurbation of the Ruhr Region – *Ruhrgebiet* – in North Rhine-Westphalia, Germany, is an example of an old industrial region in which structural change away from coal has been ongoing for about sixty years (Hospers, 2004). There, the two neighbour cities of Essen and Duisburg share a long tradition of coal mining and coal-dependent industry – all of which has come under transformation pressure as coal mining decreased and ultimately stopped. In the process, both cities have seen similar problems of population decline, increased unemployment and growing low-income segments, both in comparison to the coal era and compared to other regions in Germany. Simultaneously, the two cities appear to develop differently, and they are perceived as very differently *good* or *attractive*: in German national city ranking reports (e.g. based on indicators such as dynamics in migration, employment, life expectancy, number of child care facilities etc.) Essen consistently ranks mid-field, well ahead of Duisburg, which sits at the lowest tier of all assessed cities (HWWI, 2019; Prognos, 2019; iwConsult, 2021). Hence, something appears to go better in Essen's transition away from coal than it has so far in Duisburg.

Here, we investigate the socio-economic transition processes of Essen and Duisburg as part of the wider structural change in the Ruhr Region and seek to understand the triggers of local development during and after the coal phase-out and to answer the question of whether either city has crossed a tipping point in their transition process (yet), away from coal towards a low-carbon but still prosperous future, yet?. In the

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two case studies, we explore causes and effects of the cities' development trajectories in the last 30 + years, seeking to identify differences in outcome as a function of the interventions and/or contextual differences. We examine policy interventions and their impacts on socio-economic indicators to identify non-linearities and significant shifts. In addition, we draw on 20 interviews with local stakeholders to better understand the local narrative developments. We discuss our empirical findings in the context of the broader academic discussion about the concept of social tipping points and its applicability and use in societal systems (Milkoreit, 2022).

2. Societal change: Path dependency and tipping points

Regional systems dominated by carbon-intensive industries are (often) locked into specific development pathways, both because they depend on the continuing economic activity but also because social, economic and technical institutions and infrastructures have co-developed with the dominant industry, supporting and entrenching it over a long time. Once an industry has become dominant, reducing or eliminating regional dependence faces strong short- and long-term problems. Such path dependency results from different positive feedbacks among technological infrastructures and political or economic institutions which increase the returns to scale and make change difficult and costly (Unruh, 2000; Berkhout, 2002). In other words, path dependence refers to a process or system "whose outcome evolves as a consequence of the process' or system's own history", associated with a particular spatial component as the "economic landscape inherits the legacy of its own past industrial and institutional development" (Martin and Sunley 2006, p. 399 and p. 408).

Since the seminal papers of David (1985, 1986, 1988) and Arthur (1988, 1989, 1994), societal processes of stability and change have been intensively investigated through the lens of path dependency and lock-in theories. Stability is associated with technological 'lock-in' (technology field to become locked onto a trajectory, despite more efficient alternative), economic "lock-in" (a dynamic of increasing returns) and institutional hysteresis (formal and informal institutions changing slowly over time). Here, processes of change are often related to either incremental endogenous steps or radical shifts induced by exogenous factors conceptualised as critical junctures. According to the path dependence model, external shocks are expected to eventually prompt a "region's economy to 'break free' from its 'locked-in' path of development" (Martin and Sunley 2006, p. 417). Despite the dichotomy, Mahoney and Thelen (2009, p. 2) emphasise not to overlook significant shifts based on "endogenous developments that often unfold incrementally".

The notion of radical change is also associated with social tipping points when systems occasionally shift into fundamentally different trajectories. However, in contrast to critical junctures, they indicate the point when the path enters lock-in (Sydow et al., 2009).

Such social tipping points are limited periods of time in which interventions – both large and small – trigger new self-reinforcing feedbacks that accelerate systemic change in social or economic context (Lenton et al., 2022). These types of interventions we are interested in here seek to trigger a specific effect, but tipping can, at least in principle, also be unintended effects of actions with an entirely different intent. Similar to the natural world (Scheffer et al., 2001; Schellnhuber, 2010; Lenton et al., 2019), social tipping points can become visible in non-linearities of peaks or dips in selected system indicators (Milkoreit et al., 2018). These impacts and disruptions are sought in hard indicators such as demographic, economic and political developments (Tàbara et al., 2018; Otto et al., 2020; Winkelmann et al., 2020; Lenton et al., 2022). For example, the closure of a dominant industry is often followed by increasing unemployment and outward migration, leading to an overall socio-economic decline and drop of GDP in the region. This has happened in many previous coal regions, for example Wales or Appalachia (Carley et al., 2018; Della Bosca and Gillespie, 2018; Sheldon et al., 2018). If this declining trend is reversed, for example through new jobs creation triggered by dedicated policy action to attract new companies, the region may have passed a tipping point – from the decline associated with the disappearance of a dominant industry to a new but still prosperous future.

In addition to such 'hard' indicators, there are softer indicators such as public and policy narratives carrying transformative capacities and agential forces (Schmidt, 2011; Lieu et al., 2020). Narratives are ways of structuring human comprehension of complex environments, helping people interpret the world (Bruner, 1991). They are a crucial element in transformation processes as means for eroding lock-ins and reorienting practices and visions towards desirable alternatives (Robinson and Cole, 2015; Buschmann and Oels, 2019), and so potentially inducing tipping points (Tàbara et al., 2018; Hinkel et al., 2020). Narrative changes may not constitute tipping points in themselves – the mere change of visions does not equal a new development trajectory – but they may be indicative of an upcoming tipping point, because they signify the emergence of a new vision for the region with associated measures to achieve it (Freeman, 1992).

The closure of an industry is an example that follows the (more widely used) negatively connoted or undesired tipping point perception, yet there is a growing literature about 'positive tipping points', which describe a normative perception of a desired trajectory in terms of sustainability transformations (Tàbara et al., 2018, 2020, 2021; Lenton, 2020; Strauch, 2020). A distinctive feature of (positive) social tipping processes is the element of agency: the intention to bring about desired socio-economic trajectories (Winkelmann et al., 2020; Lenton et al., 2022). Interventions are purposeful actions from individual or collective public (e.g. government, civil society) or private (e.g. industry, businesses) actors to accelerate, manage or coordinate a change process in a social system (Westley et al., 2011; Otto et al., 2020; Winkelmann et al., 2020; Lenton et al., 2022). This idea of desirable, radical social change triggered by deliberate interventions emphasises the importance of human agency as a central idea in the social tipping point literature. Local governments may seek to influence the trajectory of their town by initiating new economic activities or partnerships.

In summary, we define tipping processes as fundamental systemic change, leading to a cascade or chain reaction of single changes shifting a system from state A to a qualitatively different state B (Collier and Collier, 2015; Granovetter, 1978; Grodzins, 1957; Lenton et al., 2019; Milkoreit et al., 2018; Pierson, 2004; Scheffer et al., 2009; Winkelmann et al., 2020). The tipping point specifically constitutes the moment when a system moves into lock-in situation and the beginning of a (new) path dependence (Sydow et al., 2009).

There is much discussion about *when* tipping points become observable in the complexity of social systems across times and scales, and whether they can be predicted or not (Nuttall, 2012; van Ginkel et al., 2020). Winkelmann et al (2020) state that "social tipping processes do not have a spatial extent or effective dimensionality that is known ex-ante" (p. 8). The presently dominant view is that tipping points may only be identified retrospectively in reference to the specific historical legacy or systemic change (Pierson, 2000b; Collier and Collier, 2015). While still rare, newer studies suggest that social tipping processes can be predicted, particularly in smaller, sectoral systems. Andreoni et al. (2021) provide evidence from a behaviour threshold model finding that the benefit–cost ratio of norm change is a key determinant of the probability of social tipping points. Others suggest that past stock market bubbles (Diks, Hommes and Wang, 2018) or

electricity grid blackouts showed early warning signs (Ren and Watts, 2015) and would have possibly been predictable. Lieu et al., (2020) find that changes of narratives carry radical transformative forces and can trigger systemic disruptions. Thus, the rise of new discourses or narratives may precede tipping dynamics, making them at least roughly predictable. Here, we examine evidence for past changes, including tipping points, but we also assess ongoing, not yet concluded processes to discuss whether they may constitute tipping points.

However, because the idea of social tipping points is new and empirical study of complex social systems is difficult, there is no clear view in the literature for how to distinguish tipping processes from other forms of structural or social change, resulting in calls for further empirical investigation particularly for systems currently in transformation (Winkelmann et al., 2020). Despite the rapidly growing body of conceptual literature on the topic (Milkoreit et al., 2018), there is a lack of empirical examples. Our study does precisely this by empirically investigating the societal and economic development trajectories of Essen and Duisburg during and after the phase-out of coal mining.

3. Method

To answer our research question, we examine interventions and outcome of regional developments in a case study comparison of Essen and Duisburg. The cities were chosen as two examples of intensive socio-economic transformation processes in close geographical proximity with very similar starting conditions yet diverging perceptions and possible future pathways. This study followed an explorative approach to compare two similar cases aiming to uncover similarities, differences, and social dynamics trajectories for a tipping point analysis. Specifically, we sought to obtain a deeper understanding of how different variables affect outcomes while drawing on the tipping concept. Because Essen and Duisburg are so close, both geographically and historically, but their present trajectories are seemingly different, making them ideal for pairwise comparison.

As illustrated in Fig. 1, for each case study we explore causes and impacts of a system shifting over time. We observe events and interventions in the initial system state and their impacts on the social and economic systems of the two cities at a later point time. Specifically, we evaluate the cities' development trajectories from coal decline to a complete coal phase-out. We seek evidence for "no", "incremental" or "radical/tipping" changes in a set of indicators describing the social and economic development over time. We investigate three types of variables. First, *events* as exogenous factors leading to an industry disappearing; in our case, this is the closing of coal mines. Second, *interventions* as deliberate and targeted policy and industry measures influencing the regional socio-economic trajectories while seeking to address negative effects of the event(s). Third, *impacts* as the long-term changes in socio-economic variables. These variables are where we can observe the outcome of interventions, including a possible tipping point (Fig. 2).

The analysis comprised several steps. The first step focussed on a qualitative analysis: this included a comprehensive review of the literature to understand the historical evolution of the coal sector and to obtain crucial context for our study. Hereby, we also delved into the policies at national, regional, and local level, aiming to identify key interventions relevant to our research question. To this purpose we conducted an extensive primary literature analysis of research articles and historical analyses, national and state parliament protocols (1960 to today), legislative output, press releases and websites of local governments, regional governance organisations and NGOs (e.g. Ruhr Regional Association), and news media articles[1] [and] [2] to examine key interventions in Table 1.

To further contextualise and interpret the data from the literature, we gain additional input in 20 semi-structured interviews with local, regional and national stakeholders (see Table 2 and list in Appendix 5). The interviews were held between March and November 2021 with representatives from government and non-governmental organisations, including regional and local governance authorities, labour unions, local companies, university, media and local NGOs. Interview partners were selected based on a local and regional stakeholder map aiming for multiple voices across political, industry and civil society organisations. The interview questions were concerned with major events, political decisions, and transformation process of the region from the individual's perspective (see appendix for the list of questions).

The analysis of both the literature and interview transcripts underwent a rigorous iterative process aimed at identifying overarching thematic constructs and sub-themes relevant to our research question. Employing a qualitative content analysis methodology, we also delved into the narratives in the broader regional context, elucidating multifaceted perspectives and temporal evolution of the coal-industry as well as the green storylines. The interviews were coded following both an inductive and deductive approach, applying a combination of predetermined codes derived from our research framework as well as emergent codes e.g. interventions, and radical change, slow change, socially acceptable transition, local identity, industry culture and industrial heritage (see Appendix 6 and 7). This analytical approach facilitated the identification and validation of key interventions in the region and the cities, and their further contextual interpretation.

In the second step, we examined the outcomes of these interventions using a range of socio-economic indicators, including statistical data. We analyse **quantitative data** for a set of demographic and economic indicators over timeframes of 20–50 years (depending on data availability) (Table 3). We take this long temporal perspective, because trajectories of and trajectory changes in social systems are specifically visible in demographic dynamics, economic structures and political arrangements across time (Winkelmann et al., 2020).

In the third step, we **examine the relation between interventions**, the **quantitative social and economic data** to determine the potential impacts of the interventions and particularly if they are related to any strong trend shifts. To this purpose, we evaluate the trajectories of the indicators in the data series towards dynamics of *no, incremental or radical change*. In this, '*no change*' is indicated by an indicator remaining roughly constant over time, before and after an intervention. We consider a trend as '*incremental change*' when an indicator changes over time, but only slowly, without discontinuities, such as rapid surges or drops. '*Radical change*', in contrast, is recognised by a sharp and rapid shift in a variable, regardless of the direction. Here, we see radical change as a proxy for a tipping point (see Fig. 1): because radical change signals the departure from an old to a new trend, this is indicative of system tipping. We acknowledge multiple dependencies and interactions exist that in larger and very complex systems and hence the attribution of causalities must be treated with great caution. Hence, there are almost certainly additional actions and developments that we did not capture. Nonetheless, our study mapped the relations within the regional system paying particular attention to the timeline, sequence and scale of events and applied triangulation by using both quantitative (time series of statistical data) and qualitative data (interviews, media articles, website and government documents) sources; particularly the interviews help ensure that we have indeed included all of the most important interventions and developments.

4. Results

4.1. Early events of the transition dynamic

The Ruhr Region is a regional archetype of lock-in and path dependency (Hospers, 2004; Oei et al., 2020). There, the coal and steel

[1] Predominantly local newspapers such as Westdeutsche Allgemeine Zeitung (WAZ; online articles since 2003), and national newspapers such as Zeit Online and Spiegel Online.

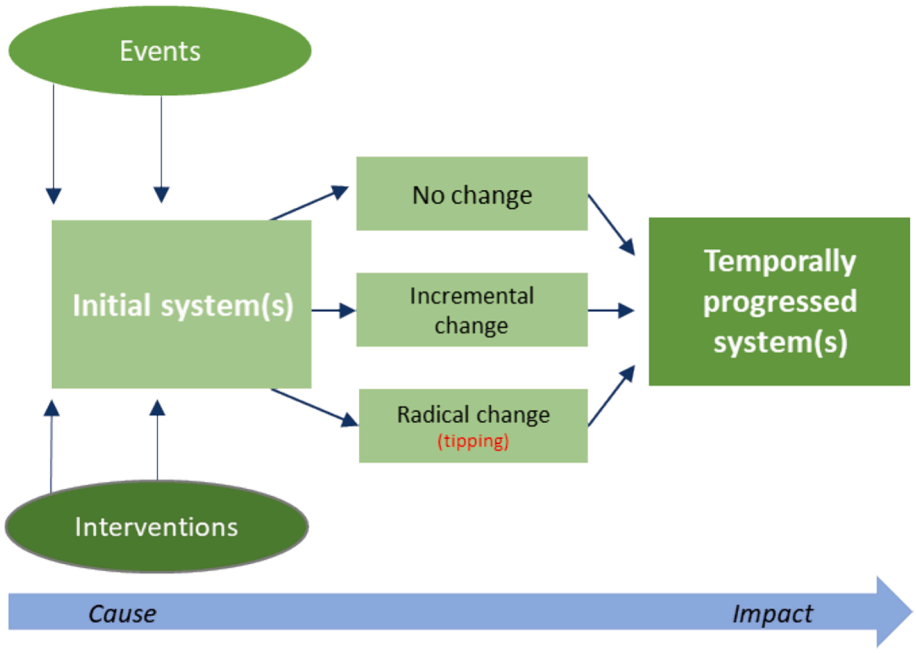

Fig. 1. Analytical framework for case study analysis.

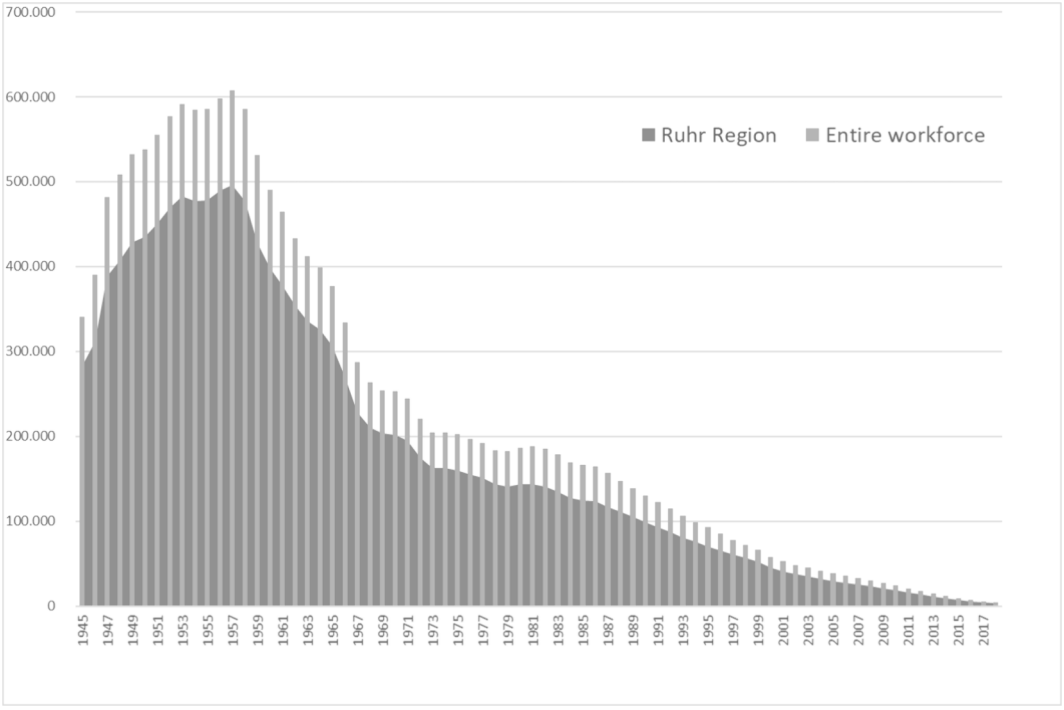

Fig. 2. Development of the workforce in hard coal mining in the Ruhr and Germany (entire workforce) between 1945 and 2018. .
Source: Kohlenwirtschaft (2022)

Table 1
Selected interventions.

NRW (state level)	Essen	Duisburg
IBA (1989–1999)	Cultural Capital 2010	duisport extension at Krupp-Stahlwerk Rheinhausen 1998
Law to end coal subsidies (2007)	Green Capital 2017	New Silk Road – Chinese partnership
Election and government change (2005)		

Table 2
Interviewed stakeholders in at local and region/ state level.

	Essen	Duisburg	Regional/ State Level
Government	2	–	3
Public governance bodies/ Unions	1	1	3
Industry	2	1	1
NGOs	1	2	1
Academia and Media	1	–	1

Table 3
Indicators of socio-economic system state and ultimate change.

Indicators	
Population size	Local population development and migration patterns 1962–2020.
Age	Distribution of different age cohorts 1995–2020.
Education	Share of residents with tertiary education 2005–2020
Election patterns	Local voter turnout and party preferences at local, state and national elections between 1975 and 2020.
Unemployment	Unemployment rates as percentage of all unemployed in relation to all persons in the labour force 2000–2020
Employment	Development of number of employees at locality of work 1976–2020
GDP	Trends in the regional and local economic output measuring GDP at market price and per employed person 1991–2019.
Disposable income	Disposable income per resident in Euro between 1995—2020

Table 4
Selected key figures of German hard coal mining (both Ruhr Region and Saarland) 1957–2018.

Year	Hard coal mining	Employees	Capacity per person and shift	Number of mines	Hard coal imports	Hard coal exports
	in kt [x]	*end of year*	*in kg*		*in kt*	
1957	149,446	607,349	1,585	173	18,936	27,529
1967	112,043	287,270	3,264	81	7,356	25,631
1977	84,513	192,015	3,850	43	7,275	20,837
1987	75,818	156,483	4,559	32	8,974	8,570
1997	45,796	78,101	5,762	17	23,290	789
2007	21,307	32,803	7,071	8	45,891	463
2017	3,669	5,711	8,809	2	42,980	1,065
2018	2,584	4,125	10,041	2	41,107	1,045

Source: Kohlenwirtschaft (2022).

industries have been dominant for many decades dating back to the industrialisation in the 19th century characterised by specific forms of path dependency – a natural-resource based economic lock-in (high dependency on the mining and steel industry) and an institutional hysteresis (network of companies, politicians, and unions) as well as a cognitive lock-in (the belief that the crisis was cyclical, not structural) embedded in a specific regional path dependence (coal seams near the surface) (Martin and Sunley, 2006, Sydow et al., 2009). The coal price crisis in the late 1950s constitute a critical juncture which intensified self-reinforcing processes emerging from the co-evolution of economy and institutions in the region. Specific political choices were made to cushion the impact of these global market shifts, and instead of choosing the more efficient and cost-effective solution (at the time) to obtain cheaper foreign coal, it was decided to establish a system of high subsidies and regulatory coercive measures for domestic coal production. The thick and dense institutional network grown from the long co-evolution of economy and institutions reinforced the region's coal pathway in the following years and perpetuated efforts to modernize existing structures in the Ruhr area, leading to further investments and reluctance to embrace new economic opportunities (Farrenkopf *et al.*, 2019; Hospers, 2004).

The thick and dense institutional structures consisting of coal corporations, unions, parts of civil society and the state government – as well as their coalitions held significant political powers while opposing change for socio-economic reasons. The prospect of high unemployment and social hardship in the region was a constant threat for political leaders at state and national level, and hence coal mining had to continue. In addition, the hard and dangerous work in the mines was a source of workers' (group) identity, social cohesion, and pride – leading to a cultural-cognitive lock-in in the years of crisis and increasing the resistance to change (Oei *et al.* 2019, Brauers *et al.* 2020).

Notwithstanding, the exogenous factors led to the closure of more than 90 mines and consequently to a substantial drop of employment in the sector in the 1960s (Table 4) (Oei et al., 2020; Kohlenwirtschaft, 2022).

5. Usable extraction (water and ash content are also considered)

Although the ramifications of the coal and steel industry decline were felt across the region, the two cities experienced the direct impact much later: The last mine in Essen closed in 1986 (Zeche Zollverein, 2022), in Duisburg in 2008 (RAG Aktiengesellschaft, 2021). The closure of Essen's coal mine *Zeche Zollverein* was an industry's decision as part of the ongoing consolidation measures in the sector. While there were about 8,000 workers at the height of the mining process, the 1,200 remaining in 1986 were covered through social plans (early retirements) and relocation to other mines (Schwalb, 2021). In comparison, the mine in Duisburg was much smaller, with a peak production of 3.4 million

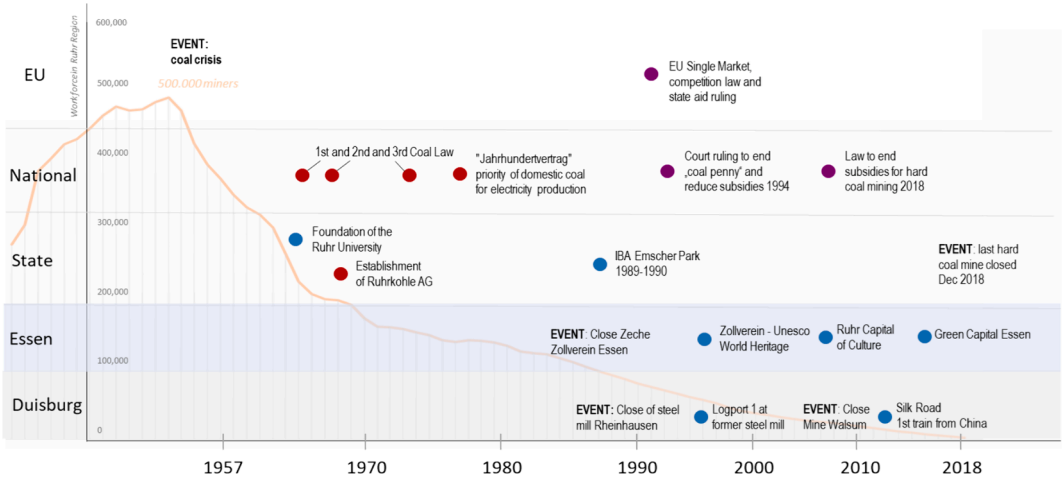

Fig. 3. Events and selected interventions (red dots for measures maintaining the industry, violet for restructuring and ending coal subsidies, blue for measures moving beyond coal) along the timeline illustrating top-down and city-level measures.

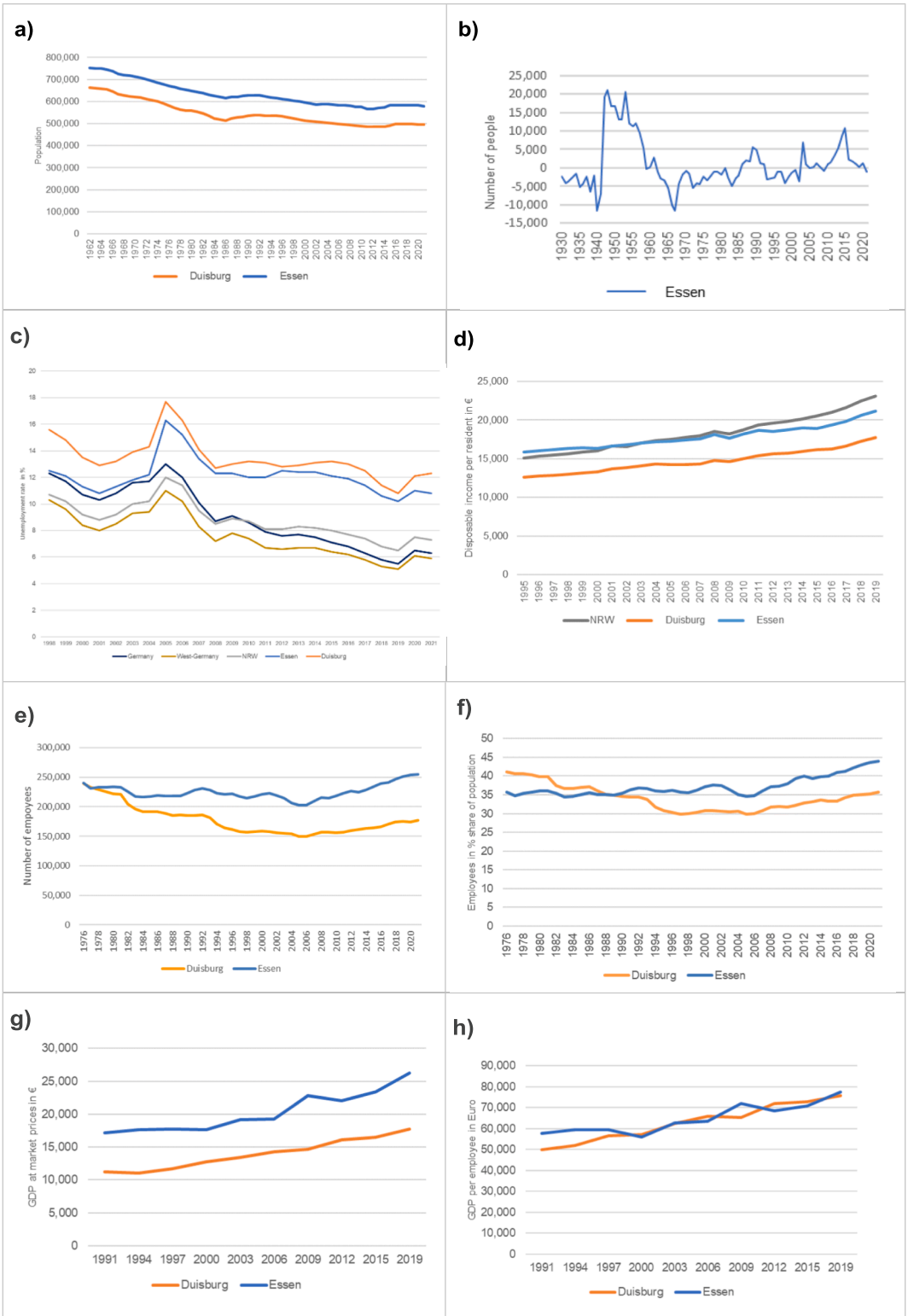

Fig. 4. Socio-demographic trends in Essen and Duisburg, Ruhr and North-Rhine Westphalia (NRW). a) Population – number of local residents; b) Migration (inward (positive) and outward (negative) migration in Essen only); c) Unemployment: share of the unemployed in the working-age population; d) Average personal disposable income in Euro; e) Employment (absolute numbers) f) Employment (share of total population); g) GDP at market prices in € h) GDP per employee in €; i) Students in the Ruhr Region; j) number of university graduates. Sources: www.it.nrw, regionalstatistik.de, www.destatis.de, www.rvr.ruhr and provision of statistical data by the City of Essen and Duisburg and the Regionalverband Ruhr.

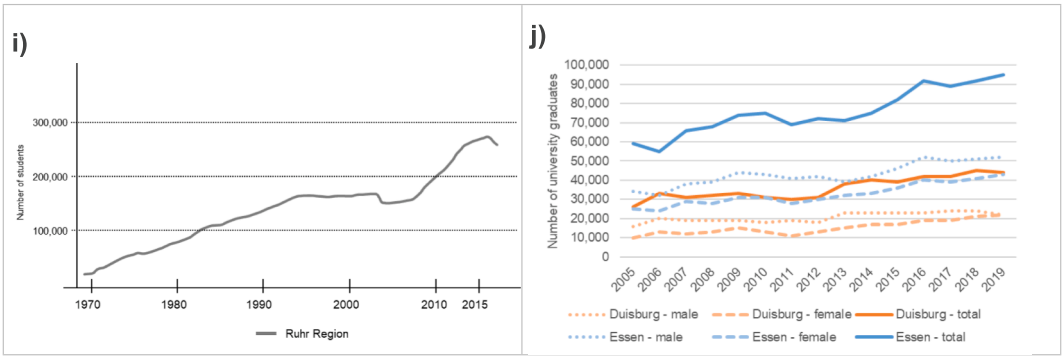

Fig. 4. (*continued*).

tonnes of coal (annually) and 4,600 workers in 1982 (RAG Aktiengesellschaft, 2021). The closure of the mine in Duisburg was much later and came because of an extensive public protest against the expansion of the mine to greater depths, compromising properties of local residents. At this time, about 2,500 miners were still employed (Huske, 2005).

5.1. Top-down interventions to halt and facilitate the coal industry decline

The German coal industry has always been subject to government interventions due to its great importance for national energy security, economic growth and the labour market (Berger et al., 2019). With the demise of the coal sector, a series of top-down interventions intensified firstly to halt the decline and later counteract its negative impacts (Fig. 3 – red dots) (Landesregierung Nordrhein-Westfalen, 1968; Regionalkunde Ruhrgebiet, 2021).

The first coal law was introduced in 1963, establishing an association to rationalise the coal industry issuing mine closure premiums (Bundesgesetzblatt 1963). This federal government intervention also triggered industry measures and ultimately the establishment of the Ruhrkohle AG (later RAG Aktiengesellschaft) in 1968. This new company amalgamated 94 % of the coal production in the Ruhr and eventually integrated all coal mining companies in the region (RAG Aktiengesellschaft, 2018). Subsequent coal laws (2nd, 3rd) in 1966 and 1974 sought to secure the domestic hard coal mining further and involved a steady increase of subsidies (von Fels and Neu, 1980). The so-called century contract ("Jahrhundertvertrag") in 1977 comprised a purchase guarantee for German hard coal by the electricity industry.

As intended, the early interventions to prop up the coal industry conserved the dominance of the coal industry while patching up symptoms of the unwanted yet unavoidable societal transformation process (Arndt et al., 2016; Dahlbeck et al., 2022). These and the measures in the following three decades did not bend the quantitative trajectory. Instead "no one is left behind" became the leitmotif and led to a significant slowing down of the workforce decline and yet also phase-out efforts.

5.2. Incremental shifts following national and state interventions

Although the bulk of policies at state and national level sought to preserve the status quo for many years, some interventions paved way to new developments beyond coal. An important very early milestone was the foundation of the Ruhr Universities which enabled synergies in research and innovation for economic development (Heinze and Hilbert, 1996; Bogumil and Heinz, 2021) (see Fig. 3 – blue dots). State efforts focused on enhancing economic diversification and re-industrialisation (e.g. supporting car manufacturing in neighbouring Bochum) as well as the reduction of environmental pollution. Further state interventions sought to buffer repercussions for the regional economy through investment in local transport and recreational infrastructure and since the 1990 s support for medium-sized enterprises (production industry).

A significant milestone was the Emscher Park International Building Exhibition (IBA) (Fig. 3 – blue dot), put forward by the Head of the Department of Urban Development in the NRW State Ministry of Regional and Urban Development. The IBA was a decade-long program (1989 to 1999) which continues to be widely present in the collective conscious and indeed considered as a threshold event with great symbolic power for the identity development for the region (Interviews Emscher Genossenschaft and City of Essen). The main aims of this regional development measure were an ecological and cultural renewal understood as the imperative for the economic prosperity of the region's future (IBA, 1999; Universität GH Essen, 2021).

Although the transition pressure was particularly felt at the local level, the city governments of Essen or Duisburg did not take a leading role to intervene. The decline of their local industries also did not occur until the mid-1980s. Hence, for a long time, the local socio-economic trajectories remained subject to national and state measures.

Looking at the city level, the trajectories resemble the regional socio-demographic trend with no radical and rapid shifts occurring across a range of different indicators. The measures to secure the domestic hard coal production helped to stop the outward migration and population decline and slowed down the unemployment rate increase. Still, Essen and Duisburg both lost almost one quarter of their population in the early years (see Fig. 4 *a*), in the 1980s the negative trend slowed down and ultimately stabilise it in 2010 s (Regionalverband Ruhr, 2021).

Since the beginning of the structural transformation, the Ruhr Region and so the two cities still experience higher than state average unemployment rates but also show a recent positive trend in the labour market (see Fig. 4 *c*) (Dahlbeck et al., 2022). Across time, Duisburg shows higher unemployment than Essen. In particular, the share of long-term unemployment is greater in Duisburg, where almost 50 % of all unemployed in 2016 had been without work for more than one year (Glock, 2006; Statistikportal, 2022). Since 2005, the unemployment rate has fallen considerably, mirroring state and national developments, though the decline slowed in the last decade in both cities. In 2019, the unemployment rates in Essen and Duisburg still exceeded 10 %, far higher than in other regions and Germany as a whole. The industry decline and loss of well-paid jobs in the coal and steel production is visible in the relatively lower disposable income per resident in the two cities (see Fig. 4 *d*). Dahlbeck et al (2022) found that there was a significant "break" after 1987, when disposable income in the Ruhr Region started to fall behind state and national levels. However, there is no official data for the cities before 1995, and since 1995, both cities show an increase of private household income, albeit at a slower pace than

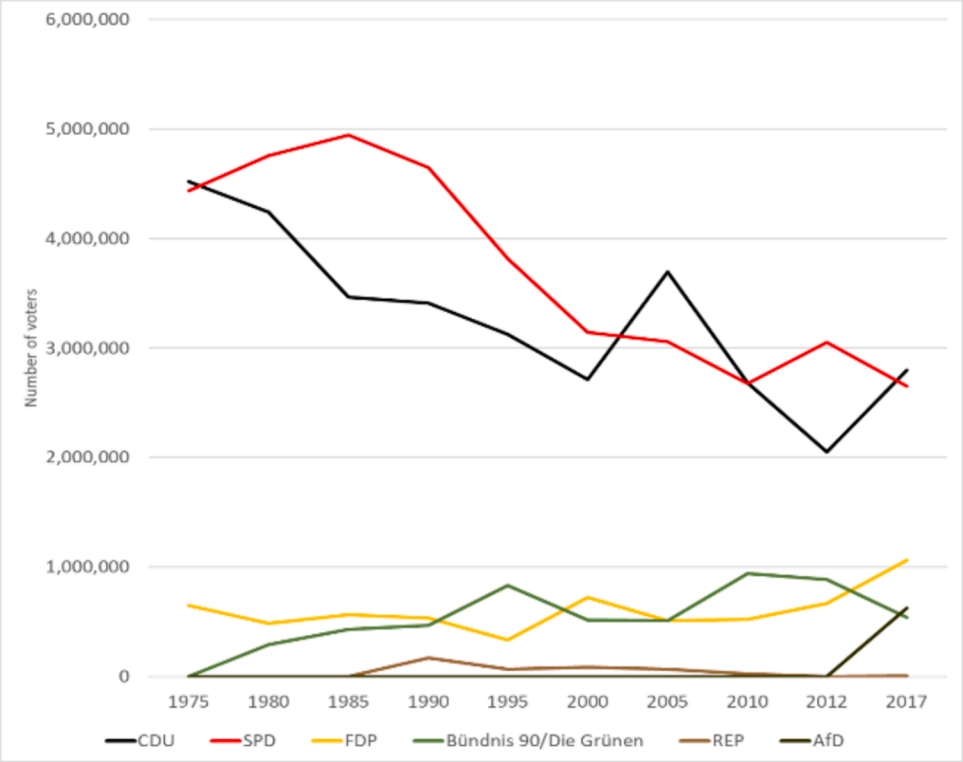

Fig. 5. NRW state election since 1975 in total numbers of voters. Acronyms refer to Social Democrats (SPD), Christian Democrats (CDU), liberals (FDP), Republican nationalists (REP), and Alternative for Germany (AfD).).
Source: (it.NRW, 2022

state level.

Yet, the positive economic development at national level also extends to the region: both cities experienced a rise in GDP (see Fig. 4 *g and h*) and increasing employment levels mainly in the service sector and particularly after the national labour market reform in 2005 (see Fig. 4 *e and f*). Although starting from a higher level, Essen increased its GDP (at market prices) by about 52 % while Duisburg performed slightly better gaining about 58 % (see Fig. 4 *g*). This positive trend is also resembled in the number of students and university graduates (see Fig. 4 *i and j)* which have steadily increased since the foundation of the Ruhr University in Bochum. Today there are more than 260,000 students at five universities, one art college and 13 other higher education institutions in the Ruhr region, as well as over 45,000 employees who depend directly or indirectly on the science and research institutions (Bogumil and Heinz, 2021). The University Essen-Duisburg, a fusion of the previously independent universities in both cities is one of the largest universities in Germany with 42,000 students (UDE, 2022). The main focus is on natural and engineering disciplines, such as nano-tech, biomedical sciences, urban and water systems (UDE, 2022).

5.3. Changing mood, new visions and reframing – From top-down to bottom-up

Although the policy interventions from national and state level did not have a strong observable impact on the quantitative indicators, the substantially increasing subsidies for the sector, the slow decline of miners' workforce and the realisation of "the unavoidable" led to a significant shift in public perception and mood (Interviews City of Essen, non-governmental organisations).

Although the peak for financial aid and fiscal measures to support the hard coal sector was only reached in the mid-1990 s (Meyer, Schmidt and Eidems, 2010), the national public mood already started to change in the 1980s. In 1982, an electricity customer declined to pay the "coal penny" to its power provider RWE, a levy that was introduced in 1974 and constituted a significant part of the subsidies (1/4) (ibid) (Meyer, Schmidt and Eidems, 2010). This dispute initiated a cascade of developments exposing growing discontent with the coal subsidies beyond the Ruhr Region.

The decreasing importance of federal pro-coal policy and the increasing number of closed mines, including the resulting brownfield land, required a new focus of state interventions. The potential of the cities moved into the centre of attention, with regional conferences and regional development plans following a new bottom-up approach and participative governance structures (Arndt et al., 2016). Ecological measures and regional identity building were addressed explicitly, providing impetus for new future visions.

In this context, the IBA was a crucial step. This event was conceived and implemented at a time when the environmental discourse intensified and principles of sustainable development and resource protection were postulated and later adopted at the Rio Conference (WCED, 1987; UN General Assembly, 1992). The aims and measures of the IBA emphasised the environmental theme and were mainly associated with renaturation of the river Emscher, providing access to green spaces for the residents and rejuvenate the Garden City idea[2] in the region. In addition, the local material remains were repurposed and re-valuated as "technical monuments worthy of preservation" and set them up as

[2] Urban planning model by Ebenezer Howard 1898 based on the concept to break up the density of a city by integrating settlement structure interspersed with green spaces, loosened up and divided into neighbourhoods according to plan by radial streets, with spatial separation of important functions, a surrounding green belt, and sufficient provision of jobs and utilities for the population.

Table 5
State governments composition in NRW since 1947. Acronyms refer to Social Democrats (SPD), Christian Democrats (CDU) and liberals (FDP).).

Year	1947	1950	1954	1956	1958	1962	1966	1970	1975	1980	1985	1990	1995	2000	2005	2010	2012	2017
Leading Party	CDU	CDU	CDU	SPD	CDU	CDU	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	CDU	SPD	SPD	CDU
Coalition partner	SPD	Zentrum	FDP	FDP			FDP	FDP	FDP				Greens	Greens	FDP	Greens	Greens	FDP

Source: (Landesregierung Nordrhein-Westfalen, 2022

lighthouse projects of the program including the "Duisburg-Nord Landscape Park" and the "Zollverein Mine Shaft XII" (IBA, 1999; Duisburg, 2022a; Zollverein, 2022).

Ultimately the IBA marked the beginning of more regionally driven interventions from the 2000 s. These were focused on supporting economic clusters in line with the regional and local capacities and resources. This approach was further strengthened by the EU regional development programs and funding indicating a clear break from the old industries. For example, the Cultural Capital *Ruhr 2010* event was held across the Ruhr Region under the motto "change through culture, culture through change" supported by state and EU funding (Kulturhauptstadt-Büro der Stadt Essen, 2011).

These interventions further eroded the acceptance of mining, and hence contributed to a shift in public perception and growing awareness that coal mining will not return to its former economic strength or position in the local economy (Interviews representatives of SPD and Greens – state level). The shift is observable in the electorate behaviour (Fig. 5). Although the social democrat-led (SPD) governments sought to facilitate the structural change process, their efforts did not convince the traditional electorate, which also suffered from demographic shifts (Landtag intern, 1981). A weak national labour market and welfare reforms (Agenda 2010) by the SPD-led national government further deteriorated public legitimacy between 2000–2005.

After 40 years, the SPD-led state government lost power to the CDU in 2005 (Table 5). The new state government broke up institutional ties and ended the paradigm of the indefinitely subsidised hard coal mining in the Ruhr Region, signalling an end of the sector. Hence, the election of 2005 marks the end of the mainstream narrative and focus on coal carried by state government for decades.

The new government's position specifically shaped the next negotiation round for the renewal of coal subsidies in 2006–07. CDU called for the coal mining phase-out by 2014 to relieve the increasing financial burden for the state budget. In contrast, the SPD supported the concept of maintaining a "base mining industry" (Sockelbergbau)[3] also beyond 2018. Hence, the change in state government in 2005 enabled the 2007 decision to end subsidies, which eventually led the phase-out of coal mining (Feist and Hoffmann, 2006). The environmental impacts and concerns over coal-related carbon emissions were secondary arguments (Interviews RAG and NGOs) and only entered the mainstream policy narrative about coal when the phase-out was already agreed (SPD and BÜNDNIS 90/DIE GRÜNEN, 2012).

5.4. Cities building on their new narratives

Whereas the NRW population voted for political change in 2005, this was not the case in the Ruhr Region, or in Essen and Duisburg, despite the SPD losing votes compared to the 1990 s (*see* Table 6, Appendix 3 and 4). Dependent on exogenous factors, the local level did not take a leading role to intervene in the transformation. Yet, since 2000 s the efforts of the local governments in Essen and Duisburg become more visible seeking to influence the internal and external perception of their localities.

5.4.1. Essen: From IBA to cultural and green capital awards

In Essen, the IBA Program coincided with the closure of their local mine and provided an impetus for seeking new opportunities and visions. Instead of demolishing the industrial area (as usually done), the mining plant and buildings were renovated and repurposed for new users predominantly from the cultural scene establishing its status as a model example of industrial transformation (Zeche Zollverein, 2022). The recognition of Zeche Zollverein as UNSECO World Heritage in 2001 marked another milestone for it becoming a nationally and an

[3] Comprising two or three mines with around 10,000 workers are to produce coal on a permanent basis.

Table 6
Social democrat- (SPD, red) or Christian Democrat-led (CDU, black) government and mayors in Duisburg and Essen, 1964–2020. Source: Data obtained from City of Duisburg and City of Essen.

Year	1946	1948	1952	1956	1961	1964	1969	1975	1979	1984	1989	1994	1999	2004	2009	2014	2020
Duisburg	CDU	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD
Essen	CDU	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	SPD	CDU	CDU	SPD	SPD	CDU

internationally acknowledged symbol of the industrial culture as well as the transformation process, creating some 1,300 jobs in culture, start-ups, and gastronomy (Zollverein, 2016).

The industrial culture narrative guided the region's efforts to gain the EU's Cultural Capital Award. Unlike the IBA, which was driven by state government and state-external stakeholders, the Cultural Capital process *Ruhr2010* was driven by several Ruhr municipalities and the Ruhr association, with the city of Essen leading the application process (Kunzmann, 2004; Zentrum für Kulturforschung, 2010; Ebert, 2017) the application was successful and hosted the Cultural Capital in 2010. Essen held a third of the almost 300 event projects and benefited most from the positive images generated (Kulturhauptstadt-Büro der Stadt Essen, 2011).

After the Ruhr2010 and in reference to the IBA, Essen started to actively promote its green pathway (Stadt Essen, 2014). This included the adoption of a local climate protection strategy; the city joining the "Covenant of Mayors" in 2010 and receiving European Energy Award in 2013 (ibid). The management staff at Essen's local government also progressed the opportunity to receive the EU Green Capital Award. The Award is an initiative of European cities to recognise municipal efforts towards environmentally friendly urban living, rewarding and triggering efforts by cities and boosting green awareness within and beyond the city (European Commission, 2021). Essen won the Green Capital Award in 2017, attributing much of its progress to the efforts of previous programs particularly the IBA and the restoration of the river Emscher (Interview Emscher Genossenschaft).

The Award created momentum for other bottom-up initiatives: in 2020 the parliament of the city decided to implement measures to increase safety and attractiveness of cycling and walking in Essen. After a local biking initiative (*Essener Radentscheid*) collected more than 23,000 signatures, the City pledged to support the initiative by developing an implementation strategy, including funding of €232 million and 19 new staff within the municipality over nine years (Schymiczek, 2020b; Radentscheid Essen, 2021; Stadt Essen, 2021). Another example is the Climate Decision (*Klimaentscheid*) that, following the example of other German cities, requests Essen to become carbon–neutral by 2030. It has not (yet) achieved this aim but has pushed the City of Essen to increase its decarbonisation targets to be consistent with 1.5–1.7 degree global warming (Schymiczek, 2020a, 2021b, 2021a; Klimaentscheid-Essen, 2021).

In addition, the 2021 evaluation of the Green Capital Award emphasises the event's success in terms of an increase of employees in the "green sectors". Between 2017 and 2020 the total "green workforce" increased by 21 % to 14,300 making Essen the green leader in the Ruhr Region; this is projected to increase to 20,000 by 2025 (Stadt Essen, 2020).

5.4.2. *Duisburg: Chinese city partnership and logistic hub*

Although the city of Duisburg was also part of the IBA and Ruhr2010, it was not able to capitalise on the events as much as Essen. In particular, the Ruhr2010, did not remain in good memory. The Love Parade, an electronic dance music festival and part of the Ruhr2010 program, ended in disaster with lives lost because of significant safety issues and failure by the authorities (Jacobsen, 2010; Klüpfel, 2012). This stifled Duisburg's efforts associated with the Cultural Capital Award and led to great risk aversion by the local authorities so that Ruhr2010 and subsequently large public events struggled to receive official event approvals (Fischer, 2020).

In contrast, the City of Duisburg's interventions focused on the development of existing and new industrial activities since the late 1990 s. Duisburg still hosts a local steel production and has a port with international connection. However, state interventions initiated the brownfields to become repurposed for the establishment of an international logistic centre linked to the local port and railway. A first milestone was the purchase of land by the state government after the closure of the oldest Krupp steel mill in Rheinhausen in 1998 (Interview with Unions). This was followed by further local land acquisition and the expansion of the Duisport logistic hub, which is partly owned by the city (1/3) and state government (2/3) (Interview with Duisport and Presentation 2021). A second milestone was the intensification of a partnership between Duisburg and the Chinese city Wuhan fostering the development of an international trade route (Stadt Duisburg, 2022b). The "new silk road" initiative was celebrated by national and state government officials from Germany and China with a train arriving from China in the port of Duisburg in 2014 (Verfürden, 2021). With the establishment of a network of business experts, a China Affairs Coordination Unit and the appointed China-representative by the city further institutionalise this pathway.

In addition, new opportunities for the local steel industry are seen in green hydrogen (Müller et al., 2021). A joint collaboration between the energy company STEAG, thyssenkrupp Steel and the electrolysis supplier thyssenkrupp Uhde Chlorine Engineers work on a feasibility study for the construction of a water electrolysis plant with a capacity of up to 500 MW located at site of the former Zeche Walsum (STEAG, 2022). The industry initiatives are accompanied by national and state government funding of €100 million for a Hydrogen Technology and Innovation Centre (Innovations- und Technologiezentrums Wasserstoff) in Duisburg (BMDV, 2021; RP Online, 2021; Stadt Duisburg, 2021).

5.4.3. *Bifurcation in local narratives*

Since the decision to end coal mining in the Ruhr Region, both cities have fostered their individual post-coal narratives. We show that a bifurcation in the local story lines and self-perception manifests from around 2010 (see Table 7 for an overview of the development).

Duisburg was unable to capitalise on the IBA and the Ruhr2010 for creating a local narrative, although it also promotes post-industrial sites as tourist attractions (Duisburg Kontor GmbH, 2020). Instead, the city interventions foster existing policy narratives associated with the growing local logistic industry and green steel, particularly through the expansion of the port: such activities reproduce and revitalise the industrial narrative in the Duisburg.

Essen, in contrast, used the Ruhr2010 as a steppingstone to foster new opportunities and progress a sustainable policy narrative "from a city of coal and steel to the greenest city in North Rhine-Westphalia "(Stadt Essen, 2020). The perception of the Green Capital Award and its related events and activities successfully furthered the city's green

Table 7
Development of Essen and Duisburg.

Timeframe	Essen	Duisburg
1958–1980	Local mining activities and steel production shaping the local economies and social perceptions in both cities against the broader developments in the region. This included e.g. the Development Program Ruhr targeting the modernisation of mining operations, investment in infrastructure particularly local transport and recreational areas as well as attracting new industries.	
1980–1990	1986: close of local mine "Zeche Zollverein"	1987: close of one of the major steel plants Rheinhausen
	IBA started its 10-year program, here initial emphasis on the industrial heritage of Zeche Zollverein	IBA focus on the industrial heritage and access to green space in Duisburg-Nord Landscape Park
1990–2000	Decade of the IBA: regional potential moves into the centre of action, with regional conferences and regional development plans. A new bottom-up approach and governance structures emerged. Local policy interventions had a conserving impact with a focus on economic and social dimension. Yet, ecological measures and regional identity were addressed explicitly for the first time providing a new vision and impetus for new identity building.	
	Seeking for new image and attempts to diversifying local economy.	Continuing the industrial image and seeking and expanding new industries – brownfields repurposed for the establishment of an international logistic centre linked to the local port and railway. This included land purchase 1998 to expand Duisport logistic hub.
	Emergence of industrial culture narrative.	
2000–2010	Zeche Zollverein becomes UNESCO World Heritage 2001 and furthers the perception of the industrial legacy of the mining operations in the city.	Public protest and government-industry compromise to close mine Walsum earlier than anticipated in 2008.
	Industrial cultural narrative led to efforts for applying as the "Cultural Capital Ruhr2010" – which fostered further initiatives.	Involvement in the "Cultural Capital Ruhr2010" event, led to tragic event and aversion of new larger scale cultural activities.
2010-today	Building on success of Ruhr2010 and following the mainstream sustainability narrative in reference to the IBA to establish green image.	Intensification of a partnership between Duisburg and the Chinese city of Wuhan – fostering "new silk road" narrative.
	Participation in „Covenant of Mayors" in 2010 and receiving the European Energy Award 2013	Conserving local steel industry fostering the "new opportunities" through green hydrogen.
	Successful application to the Green Capital Award hosted 2017.	Continuing the industrial image – characterised by leading sectors of metal production and processing, energy supply energy supply, shipping and logistics and warehousing.
	Momentum created for local initiatives e.g. increasing attractiveness of cycling and local climate decision.	

self-image and increased the view that Essen is already quite "green" (Essen is the third greenest city in Germany with a share of 53 % green and open space) (ibid 2020). The local initiatives and activities during the event year were well received (Interview with City of Essen), and more than 7,000 media reports promoted the city's efforts within and beyond its borders. However, some interviewees critically reflected that the efforts were too small so that the Award was mainly an image campaign. For example, Essen remains a shareholder of fossil fuel energy giant RWE and depends on dividends for the municipality budget (Interview with not-for-profit organisations in Essen).

Although it is too soon to determine a lasting impact of the narrative change, different interview partners acknowledged that after the Award, demands regarding environmental issue have greater political power. The city has pledged different future environmental and climate targets – "Once Green Capital, always Green Capital" (Stadt Essen, 2020). Indeed, the city promised to continue its efforts announcing a "Green Decade" across 12 themes including climate protection, water management and mobility which are to be executed through the Green Capital Agency until 2027 (Stadt Essen, 2021). The City's "Green Decade Program" will conclude with the International Garden Exhibition hosted in the Region in 2027.

6. Discussion

We investigated the socio-economic transition process in two neighbouring, previously coal-dependent cities – Essen and Duisburg, Germany. By examining interventions and outcomes, we observed **incremental changes** in their demographic, economic and political trajectories but we found no evidence for either city to have crossed a tipping point in their transition process yet. Although the Ruhr region, and so both cities emerged from a natural-resource based economic lock-in, institutional hysteresis as well as a strong cultural-cognitive connection to the coal industry, new path dependencies are yet to reveal. Still, distinct developments in the cities' policy narratives indicate qualitative changes while putting them on quite different trajectories potentially leading to tipping points in the future.

Both cities are embedded in a wider structural transformation of the Ruhr Region and were subject to state and national interventions as part of the coal phase-down and –out process over decades. Yet, these interventions reinforced the coal-centred path dependency and only sought and allowed for incremental changes. In fact, these national- and state-level structural interventions were meant to *avoid* rapid and significant shifts away from coal, instead intended a long "gliding flight" for the coal phase-out to avoid social hardship.

In Essen, the economic and social trends show the city has coped better than Duisburg in the post-coal transition process and was more pro-active in seeking and shaping a new vision and local narrative. Essen experienced the local industry closure earlier than Duisburg and has thus had more time to adapt to a post coal-mining era, but the socio-economic data shows Essen to perform better also in earlier years. The Essen government successfully leveraged on the major interventions (e.g. IBA and Ruhr2010), ultimately putting forward and promoting the motto "from grey to green" following the contemporary national and European zeitgeist. While new compelling narratives and positive frames have the power to erode lock-ins, reorient practices towards desirable alternatives and ultimately attract new interest (Buschmann and Oels, 2019), the new narrative in Essen has not yet triggered large-scale changes measurable in the socio-economic data. Nevertheless, the new, green agenda may potentially mark the start of a new era of sustainable businesses and practices in the city, and positively influencing

the internal and external perception of the former mining town.

Duisburg has struggled in the post-coal transformation process but has over time increased its efforts to continue down a heavy industry pathway. Although the local mine is closed, the steel industry remains an important local economic factor, furthered by recent plans to foster local green hydrogen production. In addition, state-level interventions were successful to turn the port and the large, decommissioned steel and mining sites into a thriving global logistic sector in the city. Hence the industry activities continue to form the local narrative, which is further enhanced by local government through a city partnership with Wuhan/China putting forward the narrative of "Duisburg at the end of the new silk road".

Consequently, the cities appear at a crossroads. While their socio-economic trajectories still show similar trends, the narratives and policy visions of the cities suggest that their future trajectories will diverge. While Duisburg develops its old narrative of continued and new heavy industry structures, Essen has formulated an alternative vision for the city, departing from the old mining image towards a greener future. Since the transition processes are still ongoing, it remains to be seen which of the two pathways is more successful for the continued economic and social development of the cities. Whereas it seems unlikely that Duisburg will develop in a "greener" way than Essen, the economic success can go both ways. It may be a risky strategy, hinging on the successful development or access to hydrogen resources, but it is certainly conceivable that Duisburg may prosper with its industry pathway utilising and further developing existing capacities and resources from the local port and (green) steel production opportunities. In Essen, policy interventions may have altered the local narrative and hence positively influenced internal and external perception as well as attracting new businesses and innovation. These efforts will likely improve the greenness of the city and may or may not lead to improving social conditions and prosperity in Essen. Success and prosperity are thus uncertain, but the developmental bifurcation is likely already happening: as they embark in different directions, the cities will likely grow increasingly different over time.

In summary, we cannot confirm whether either of the cities has reached a tipping point. While both cities have moved away from their coal-centric economic systems and are no longer reliant on coal, Essen seems to have passed a "narrative tipping point" by articulating a green vision for its future development. However, it remains uncertain whether its efforts toward a sustainable future will be fruitful. In contrast, Duisburg has embarked on a new economic trajectory, particularly in the logistics sector, though it remains predominantly industrial. If Duisburg's strategy proves successful, it may suggest that it has already reached a tipping point. However, the success of industry's decarbonisation efforts will ultimately determine whether this tipping point is positive or not. In contrast, Essen has clearly not passed a positive tipping point in the sustainability transformation, but its progression towards one continues.

Overall, the interventions and impetus for moving away from coal were triggered top down, especially from the national level. But the tipping point in narratives and vision at local level is achieved via a bottom-up decisions and action (changing the future image of the city/creating new opportunities).

In the wider academic discourse, our research contributes to the emerging research domain seeking empirical evidence of social tipping points. Given the (still) limited availability of such evidence (Milkoreit, 2022, Lenton et al., 2023), our case studies represent a valuable addition to the developing theory of social tipping points. We aim to offer three conceptual and methodological considerations to enrich the discourse.

First, our empirical findings suggest that it is difficult to determine tipping dynamics in an ongoing transformation process. The industry lock-in and associated institutional path dependencies have prolonged the phase-out process of coal mining for six decades. We can see some recent initiatives to reshaping the cities' futures, but not yet observe any lasting effects of these interventions. Hence, longer timeframes are required to determine if the transformation process exhibits a radical change. Consequently, this suggests that tipping points in large and complex social systems, such as major cities, are hardly observable ex ante but only ex post.

Second, our study suggests that the *tipping point* lens for investigating societal change may be problematic. Societal transition processes tend to be slow and gradual, and hence dominated by incremental changes that may accumulate to substantial shifts over several decades (North, 1990; Collier and Collier, 2015). Indeed, social systems exhibiting self-reinforcing dynamics can be resilient to change over long periods of time (Pierson, 2000b), while radical shifts and non-linear trajectories appear undesirable, also because they oppose existing power and interest structures and because their success is uncertain. Hence, radical change and *tipping* should be expected to be the exception rather than the rule, especially in the highly complex social systems of cities. We thus suggest studying processes of social transformation in carbon-intensive regions not through a tipping lens but by studying gradual change and its interventions, thereby possibly finding a tipping point without searching specifically for this likely uncommon process.

Third, social systems are highly complex, which makes it challenging to map processes of causes and effects, especially across (governance) scales. Although we focused on the cities' developments, the historical dependence of the coal and steel industry on state and national interventions strongly affected the local trajectories. Consequently, identifying cause and effect along specific variables can indeed be more precise in smaller, sectoral systems than in larger, more society-wide ones. For example, investigating smaller and well-delimited socio-technical systems such as national electric car systems Sharpe and Lenton (2021) or wind and solar power Strauch (2020) can yield more definitive answers about the occurrence of a tipping point than the social-economic system of a city or region. Undoubtedly, more empirical studies on tipping point dynamics are required, and we expect the investigation of smaller-scale social-technical systems to be a fruitful scale.

The findings of this study must be seen considering some limitations. Empirical investigations of radical change in large, complex social systems are still rare (Winkelmann et al., 2020) and hence methods and tools have yet to be further tested for yielding answers to social tipping point processes. For our analysis, we relied on publicly available data but, apart from the interviews, we did not generate further primary data. We would have been particularly interested in (longitudinal) data on local perceptions of the coal phase-out and the appropriateness of the municipal and regional interventions after the mines closed, but such data – e.g. public surveys – were not available at city level and over the required timeframe. Furthermore, a deeper, data-driven investigation of the social, ethnic, and demographic segregation within the cities, on the district level, could have yielded insights not observable on the aggregated city level, for example about development of particularly low-status neighbourhoods, which provide opportunities for further research.

7. Conclusion

This study sought to identify the key triggers of local development and whether Duisburg or Essen have crossed a tipping point in the structural change process. We find marginal social, economic, and demographic differences, in which Essen consistently performs somewhat better than Duisburg, but not dramatically so. Their development trends

are practically parallel, indicating that they are not on different social and economic trajectories, yet. However, we also identify a bifurcation in the cities' visions and their narrative development: whereas Essen envisions a green, sustainable future, Duisburg remains devoted to its industrial storyline. Neither of the cities have crossed a tipping point in the hard quantitative indicators (e.g. unemployment rate, GDP) yet the narrative change may indicate a significant and qualitative shift in the long term: if the cities embark on different trajectories now, this will likely result in stronger social and economic differences in the future.

We have shown empirically that incremental change was the dominant process of change in our two cases, although tipping dynamics may still materialise in the future. We cannot rule out that, seen from a few decades into the future, the period around 2020 can be identified as a tipping period in one or both cities. This also means that the sum of incremental changes when observed ex post may have led to a substantial transformation – supporting the notion of transformative incrementalism – achieving transformative change through long processes and the sum of small interventions. The strategies to influencing the local narrative building as well as focus on local strength and capacities appear as key mechanisms also relevant for other coal communities in their transition process. These interventions, whether they trigger tipping or not, are still necessary and useful steps towards a prosperous future beyond coal.

CRediT authorship contribution statement

Franziska Mey: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. **Arno Weik:** Data curation, Formal analysis. **Johan Lilliestam:** Conceptualization, Funding acquisition, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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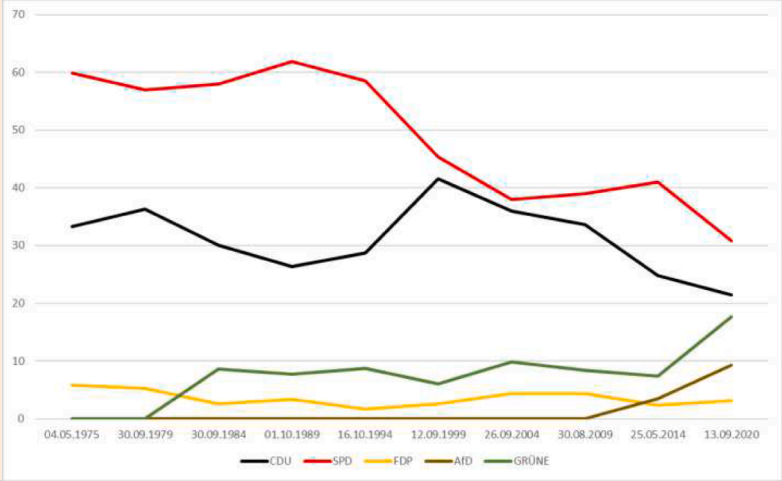
Appendix 1. Major laws and regulation of coal interventions since 1960s

Year	Title of Law	Purpose
1963	Law to support the rationalisation of mining *(Gesetz zur Förderung der Rationalisierung des Bergbaus)*	The mining companies had to join the Rationalisierungsverband (association for consolidation), which aimed at to reduce the number of mines. In the case of closures, the federal government awarded premiums and financial aid.
1965	1st law *to support* the use of hard coal in power stations *(Gesetz zur Förderung der Verwendung von Steinkohle in Kraftwerken)*	The law included tax benefits for the establishment of new coal fired power stations requiring the use of domestic hard coal for electricity production. Increase competitiveness against oil fuel in heating.
1966	2nd law *to secure* the use of hard coal production in the electricity industry *(Gesetz zur Sicherung des Steinkohleneinsatzes in der Elektrizitätswirtschaft)*	Subsidies for the use of domestic coal to ensure competitiveness in the world market – to ensure a reasonable share of domestic coal in the electricity production. It offered the steel industry subsidies and funds in case of redundancies to cushion social hardship, when using domestic coal.
1974	3rd law to *further secure* the use of "community coal" (Gemeinschaftskohle) in the electricity system *Gesetzes zur weiteren Sicherung des Einsatzes von Gemeinschaftskohle in der Elektrizitätswirtschaft (Drittes Verstromungsgesetz)*	Under the Act, the amount of hard coal to be purchased by the electricity industry was determined so that domestic demand for hard coal was stabilised and electricity supply was secured. In return, the electricity industry was granted subsidies to compensate for possible additional costs. These costs were to be covered by households with a levy on the electricity bill (also known as the Kohlepfennig).
1977	Agreement between the coal mining industry and electricity suppliers for the purpose of electricity generation. *Jahrhundertvertrag*	Contract of the century (Jahrhundertvertrag) by which private and public German electricity producers are obliged to purchase stipulated amounts of German coal.
1980	Amendment of the 3rd law to *further secure* the use of community coal *Neufassung des Gesetzes zur weiteren Sicherung des Einsatzes von Gemeinschaftskohle in der Elektrizitätswirtschaft (Drittes Verstromungsgesetz)*	For the purpose of energy security, the use of domestic coal for electricity and heat production receives subsidies for 191 million tonnes 1981 to 1985, 215 million tones 1986 to 1990 and 232,4 million tones 1991 to 1995.
1994 (July)	Law to *secure* the use of hard coal in the electricity production and amendment to the nuclear law and feed-in law *(Gesetz zur Sicherung des Einsatzes von Steinkohle in der Verstromung und zur Änderung des Atomgesetzes und des Stromeinspeisungsgesetzes)*	For the purpose of energy security, a reasonable share of the German hard coal should be secured for electricity production 1996 to 2005.The coal mining industry receives a special fond for subsidising its operations.
1995	Law to *reorient* the hard coal use for electricity from 1996	To secure the support for coal industry after the end of the special coal levy, the subsidies will be provided by federal government budget.
1997	Law to *restructure* the coal subsidies 1997 *(Gesetz zur Neuordnung der Steinkohlesubventionen*)	Subsidies for mining companies will be drawn from the federal budget and provided in a decreasing stagger between 1998 and 2005.
2007	Law *to finance the end* of the subsidised hard coal mining by 2018	The law specifies to end the subsidised extraction of hard coal in Germany at the end of 2018 in a socially acceptable way.
2020	Act to reduce and end coal-fired power generation and to amend other laws (Coal Phase-out Act)	This included the reduction and ultimate end of coal and lignite-fired power generation by 2038 in Germany.

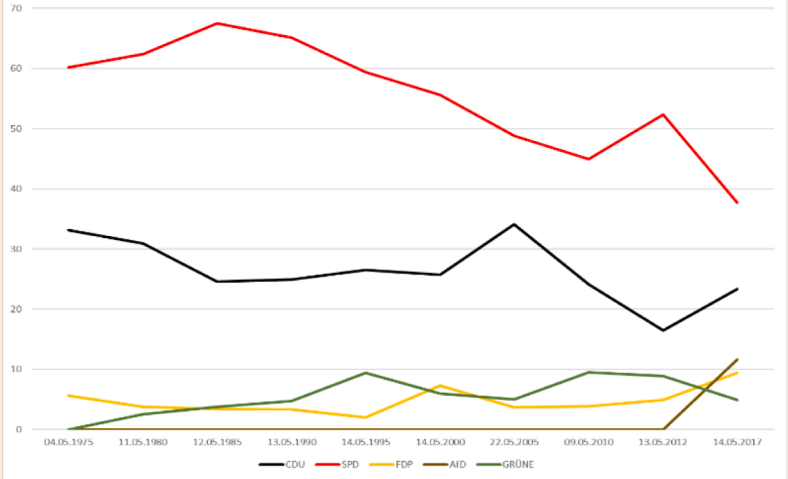
Appendix 2. Election results in Duisburg since 1975 at all government levels

Local government

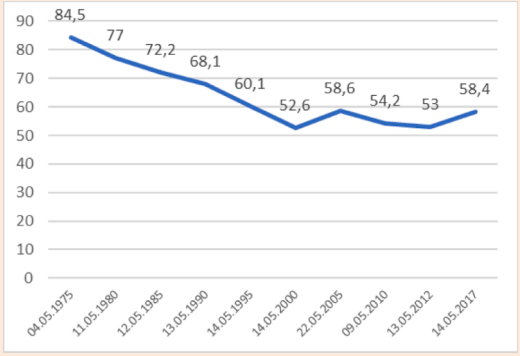


Voters turn out in %

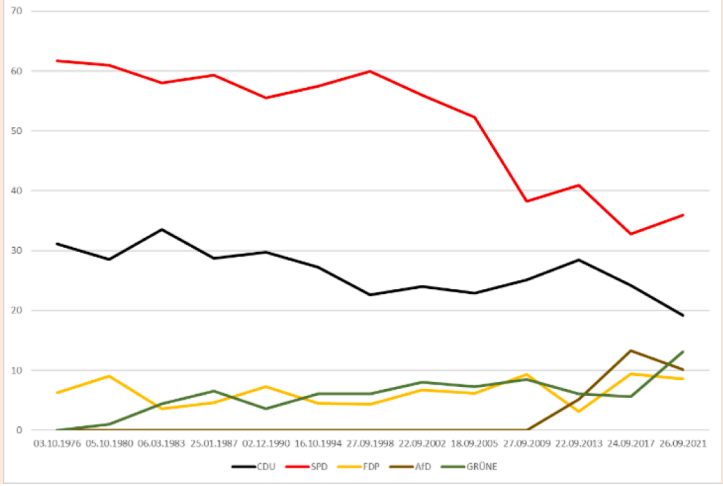
State level



Voters turn out in %

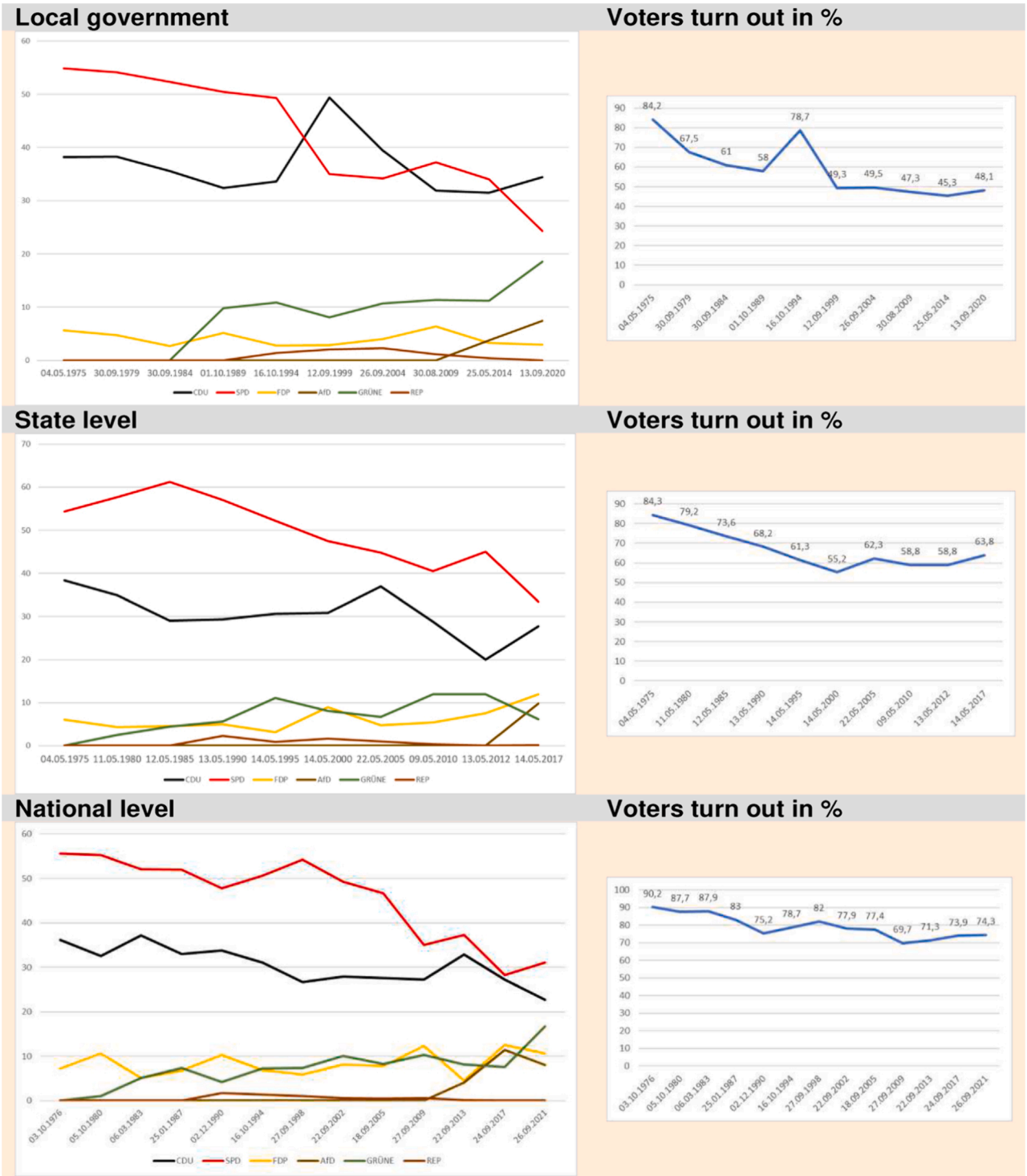


National level



Voters turn out in %

Appendix 3. Election results in Essen since 1975 at all government levels



Appendix 4. Major interview questions

- *In your opinion, what were major events in the city and/or Ruhr Region regarding the coal-phase out process in the last decades?*
- *What were significant political decisions that influenced the local/regional trajectory, and why was this/these measures particularly important for the city?*
- *How did the public (and your) perspective on the dominant industry change over time, and why?*
- *What is the current and future vision of the city/region?*
- *In your opinion, what constituted a tipping point for the locality, and why?*

- *What was the role of your organisation in the local/regional transformation process?*

Appendix 5. Interviewees and organisations

#	Category	Institution/organisation
1	NGO	Bürgerenergiegenossenschaft
2	NGO	StadtwandlerInnen
3	NGO	Emscher Genossenschaft
4	NGO	Emscher Genossenschaft
5	Public governance bodies/Unions – regional level	NRW Energieagentur
6	Public governance bodies/Unions – regional level	Regionalverband Ruhr
7	Public governance bodies/Unions – state level	DGB NRW
8	Public governance bodies/Unions – state level	IG BCE
9	Public governance bodies/Unions – local level	DGB-Region Mülheim-Essen-Oberhausen
10	Government – local level	Grüne Hauptstadt Agentur Essen
11	Government – local level	Stadt Essen
12	Government – state level	The Greens NRW
13	Government – state level	SPD NRW
14	Government – state level	CDU NRW
15	Industry (Regional level)	RAG Stiftung
16	Industry (Essen)	Talpa Solutions
17	Industry (Essen)	Zeche Zollverein e.V.
18	Industry (Duisburg)	Port of Duisburg
19	Academia	University of Bochum
20	Media	WAZ – Westdeutsche Allgemeine Zeitung

Appendix 6. Excerpt from coded themes and description

Predetermined and emerging themes	Description
Quality of change	This refers to any reference or indication of the pace or intensity of change in the cities or region following interventions or decisions from government or industry. This involves both radical and swift changes as well as changes over a longer timeframe.
Political interventions	Any type of deliberate government interventions including policies, regulations or decisions at local, state and national government influencing the socio-economic development in the city and/or region before, during and after coal-phase out.
Industry interventions	Any type of deliberate industry intervention to influence the development of the dominant industry in the region. It also includes efforts to diversify the economy and create new job opportunities in post-coal industries and sectors.
Civil society interventions	Any type of intervention coming from civil society actors, including unions (e.g. protests/conflict and agreements with industry or government). This also includes responses from local communities and stakeholders to the coal phase-out, including resistance, adaptation strategies, and community activism.
Historical Events	Large external event that influenced the development in the city or region.
Economic and social effects	This relates to impacts of the coal phase out on communities and workers in the two cities, including changes in demographics, (un)employment, social cohesion, and quality of life.
Socially acceptable transition	The process of change in the region being widely supported, approved, and embraced by its members.
Conflicts over coal expansion	Conflicts emerging over the expansion/prolonging of coal mining.
Myths of the Ruhr Region	The historical development of the Ruhr from a thriving industrial powerhouse, characterized by its coal and steel production, which played a crucial role in driving Germany's economic growth and development during the 19th and 20th centuries.
Local identity	Specific local identity stemming from the miners community, including reference to cultural elements, symbols, and collective memory, shared stories, traditions, social cohesion, and contemporary dynamics that shaped the sense of belonging and uniqueness of the region.
Industrial heritage/legacy	Dealing with the social and environmental ramifications and impact of the coal phase down and out in the two cities – e.g. industrial heritage, and eternity costs.
Industry culture	

Appendix 7. Excerpt from the codebook for interview analysis

Theme	Emerging sub-theme	Code Description	Example from interviews
Quality of change	Radical/tipping point	This refers to any reference or indication of the pace or intensity of change in the cities or region following interventions or decisions from government or industry. This involves both radical and swift changes as well as changes over a longer timeframe.	„Vielleicht war der Kipppunkt erreicht, als nur noch 6 oder 7 Bergwerke übrig waren, und diese Größenordnung möglicherweise ein Ende möglich machte. Dies illustriert den Größeneffekt, bei dem die Möglichkeit, etwas vollständig zu beenden, mit seiner Verkleinerung zunimmt.“ (Interview 15)
Interventions	Decision and social effects	Any type of deliberate government interventions including policies, regulations or decisions at local, state and national government influencing the socio-economic development in the city and/or region before, during and after coal-phase out.	„Die Entscheidung, den Bergbau vollständig einzustellen, war jedem bewusst, dass dies sehr gezielt in Lebensverhältnisse, Lebensstrukturen, Einkaufsgewohnheiten, kommunale und quartierbezogene Angelegenheiten eingreifen würde. Es gab immer wieder große und teils heftige Diskussionen darüber, warum diese Entscheidung getroffen wurde, was sogar zu Demonstrationen von Bergleuten führte. Die Idee des Sockelbergbaus, bei der die Kernkompetenz erhalten

(*continued on next page*)

(*continued*)

Theme	Emerging sub-theme	Code Description	Example from interviews
			bleibt, wäre aus heutiger Sicht lediglich Symbolpolitik, ohne spürbare Effekte für die Region.“ (Interview 8)
Socially acceptable transition	Nobody is left behind/Niemand fällt ins bergfreie		„Es wird berichtet, dass diese Idee im kleinsten Kreis, einschließlich Werner Müller, dem Leiter der Stiftung, diskutiert wurde, um mehrere Fliegen mit einer Klappe zu schlagen: Wie können wir den Bergbau beenden, ohne die Menschen auf die Straße zu setzen? Es bestand ein hoher Wert auf eine extrem enge Zusammenarbeit mit den Betriebsräten und der Mitbestimmung, wobei solche Veränderungen nicht zu Lasten der Menschen gehen sollten. Dies spiegelte einen sehr hohen sozialpolitischen Anspruch und Grundsatz wider.“(Interview 13)

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