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THE EFFECTS OF ECONOMIC CRISES ON CARBON EMISSION PEAKS AND STRUCTURAL CHANGE IN OECD AND G20 COUNTRIES

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Abstract

Economic disruption associated with the Covid-19 pandemic and the current energy and – potentially economic – crisis related to the war in Ukraine emphasize the importance of understanding and managing crises' immediate and lasting effects on decarbonisation. Theory shows that the expected effects of crises are contested and could be supportive or detrimental to decarbonisation. This article examines the timing and mechanisms for how countries peak emissions and whether such peaks are related to economic crises. We empirically investigate the timing of CO_2 emissions peaks in OECD and G20 countries 1965-2019, and the effects of major economic crises on the activity-related and structural drivers of emissions. We show that in all but two countries that have peaked emissions, the peak occurred just before or during a recession, by the combined effect of lower GDP growth and decreasing energy and/or carbon intensity during and after the crisis. In peak-and-decline countries, crises have typically magnified pre-existing improvements in energy and carbon intensities. Almost all peaking countries have returned to economic growth post-crisis, implying that structural change – not lost economic activity – was the critical driver of emission peaks. In non-peaking countries, the GDP growth was less affected, and structural change effects were weaker or rather increased emissions. Crises do not automatically trigger peaks but may strengthen ongoing decarbonisation trends through several mechanisms.

1. Introduction

The COVID-19 pandemic pushed the global economy into recession in 2020. After a strong recovery in 2021, the current war in Ukraine and the associated energy and food crises create social and economic disruption in many countries and may cause a new global recession in 2023. Because the pandemic and the war hit at a time of increasing concern about environmental sustainability and long-term climate targets, many policy organisations and scholars have argued about their potential effects on the transitions to zero-carbon economies (Engström, Gars et al. 2020, Forster, Forster et al. 2020, Hanna, Xu et al. 2020, Meles, Ryan et al. 2020, Steffen, Egli et al. 2020, Geels, Pereira et al. 2022). Understanding and managing crises' immediate and lasting effects on decarbonisation is key to reaching the Paris Agreement's targets: every country must first peak and then practically eliminate CO_2 and other greenhouse gas (GHG) emissions by mid-century (IPCC 2022) which appear to be highly challenging, especially in times of geopolitical and social disruption. There is a rich literature on decoupling, showing that many countries – particularly in Europe – have peaked their CO_2 emissions and achieved absolute decoupling, both for production- and consumption-based emissions (Naqvi and Zwickl 2017, Cohen, Jalles et al. 2018, Le Quéré, Korsbakken et al. 2019, Lamb, Wiedmann et al. 2021, Lamb, Grubb et al. 2022). Still, this literature does not systematically explain the timing for national emission peaks. Previous research argues that crises have short-lived effects and hardly affect global emissions (Forster, Forster et al. 2020, Le Quéré, Peters et al. 2021). Yet, past and current national crises suggest that crises may trigger long-lasting changes in national economies and energy systems. This article examines the timing and mechanisms for how countries have peaked emissions and whether such peaks are related to economic crises.

Theoretically, there are several reasons to expect a deep economic crisis to support the structural change needed for decarbonisation through complex interactions between political, economic, and social factors. Schumpeterian economists have pointed to "creative destruction" (Mensch and Schnopp 1980) as an essential driver of structural change. During economic crises, the least efficient assets (or even entire industries) may collapse and not come back again during recovery because they are replaced by new, more efficient assets or activities. Since these "creatively destroyed" assets are often also the least energy- or carbon-efficient ones, the effect is structural change and a lasting reduction of emissions. Politically, crises may open windows of opportunity for action and trigger "critical junctures" in energy and climate policy (Dupont, Oberthür et al. 2020), allowing for paradigmatic policy shifts that are hard or impossible during normal times. Crises may also allow the implementation of green recovery packages following a Green Keynesianism approach (Harris 2013, Smulders, Toman et al. 2014, Cömert 2019). From a transition studies perspective, external "landscape" shocks – like economic crises – can destabilize existing socio-technical regimes, thereby enabling regime change and a transition to a new system (Geels 2013). These arguments support the hypothesis that economic crises may, *because* they are so disruptive, be conducive to the type of structural, long-term change needed for decarbonisation.

Other scholars have argued that economic crises can have negative effects on decarbonisation because they increase uncertainty and thus hamper private investments, especially in new and thus risky technologies (Del Río and Labandeira 2009, Antal and van den Bergh 2013). Further, crises can shift political priorities from solving long-term issues like climate change to the immediate socio-economic impacts of the crisis (Ashford, Hall et al. 2012), and to restore the economy as it was before the recession (Loorbach and Huffenreuter 2013). Such effects would thus mainly work to preserve the economy and be detrimental to structural change – a crisis may briefly reduce emissions due to lower economic activity but not trigger lasting effects. Thus, the expected effects of crises are contested and could be supportive or detrimental to decarbonisation.

Empirically, scholars have investigated policy measures implemented in different countries to support people and companies, boosting economy recovery after the pandemic, and particularly the "green" components of recovery packages. In this context, an "opportunity narrative" has emerged, highlighting the fact that "green recovery" has the potential to stimulate the economy in a way that is compatible with the goals of deep decarbonisation through the coming decades (Barbier 2020, Bodenheimer and Leidenberger 2020, Markard and Rosenbloom 2020, Rosenbloom and Markard 2020, Steffen, Egli et al. 2020). A second stream in the climate mitigation literature has assessed the pandemic's impacts on energy consumption and carbon dioxide (CO_2) emissions. Typically, economic downturns lead to a substantial reduction in energy consumption and consequently in GHG emissions, particularly CO_2 (Bertram, 2021). In fact, the growth of global CO_2 emissions since the beginning of the 20th century has *only* been interrupted by major political and economic crises like World War II, the oil shocks in the 1970s, the dissolution of the Soviet Union (1988–1991) and the 2007-09 Global Financial Crisis (GFC) (IEA, 2020). In 2020, the COVID-19 pandemic caused a global recession, with global GDP dropping 3.3% in 2020 (World Bank 2022), leading to 4% less primary energy consumption and energy-related CO_2 emissions falling by 5.9%, the largest absolute decline recorded in the last 50 years (BP 2022). Yet, driven primarily by a strong economic recovery in China and the United States (IEA, 2021), global CO_2 emissions rebounded 5.1% in 2021 (BP 2022). Some studies have suggested that crises` effects are often temporary and that at least the latest two global economic crises may have no long-lasting effects on decarbonisation (Forster, Forster et al. 2020, Le Quéré, Peters et al. 2021).

However, zooming into emissions data for individual countries and sectors (BP 2022) suggests that economic crises may have acted as tipping points for national emissions trajectories: once the economy returns to growth after a crisis-induced drop, energy-related emissions do not always bounce back to pre-crisis levels but remain a permanently lower. This suggests that structural change may have happened: the driving forces of emissions may have changed in a way that results in permanent decarbonisation of the economy. These potential effects of economic downturns on structural change and decarbonisation at the national and sectoral levels, beyond global averages, have received little attention in the literature.

In this paper, we contribute to the empirical climate economics literature by investigating the effects of past crises on national CO_2 emission peaks and their economic (GDP) and structural (reflected here by changes in carbon and energy intensities) drivers. We investigate this in the 45 countries that are part of the OECD and the G20 (or both) in 1965-2019: Are national CO_2 emission peaks associated with economic crises? And if so, which economic and structural mechanisms explain such crisis-related emissions peaks? We assess the effects of crises on national CO_2 emissions using the Kaya identity and Index Decomposition Analysis, both examining countries that have peaked and such that have not, to understand the mechanisms by which economic crises affect emissions. We show that in almost every country that has peaked, the peak occurred just before or during an economic crisis associated with major geopolitical events or financial crashes, through the combined effect of lower GDP growth post-crisis and a lasting structural change leading to decreased energy or carbon intensity, or both. We conclude that crises do not automatically trigger emissions peaks and structural change, but they can be supportive, especially if national decarbonisation processes have already begun.

2. The dynamic interplay between structural change, decarbonisation and crises in economics and transition studies.

In this section, we identify dimensions of structural change that are crucial for the process of decarbonisation (2.1); we revisit the theoretical arguments on the relationship between crises and structural change in the economics and transition studies literature (2.2); we briefly review the scares empirical studies on these topics (2.3).

2.1 Which dimensions of structural change are critical for the process of decarbonisation?

The processes of economic growth, structural change and anthropogenic GHG emissions are intertwined, with structural change occurring at different levels and in different domains. Structural change is understood as a set of interrelated changes in various aspects of the economy, such as the sector compositions of output and employment, the organisation of industry, the financial system, income and wealth distribution, demography, and political and social institutions (Ciarli and Savona 2019). Various dimensions of structural change affect sustainability transitions and, particularly, the process of decarbonisation. In the most compressive review of the empirical evidence on that topic, (Savona and Ciarli 2019) highlighted several dimensions of structural change as particularly important because of their direct impacts on climate change mitigation.

Economic sectors: changes to the sectoral composition of the economy related, mostly, to shifts from manufacturing to services (tertiarisation) of from agriculture to manufacturing and changes between subsectors (e.g., from hard to soft industries). The sectoral composition of an economy influences different aspects of climate change through input/output relations, which differ in terms of technical coefficients, labor coefficients, and energy intensity. Thus, economic sectors contribute differently to GHG emissions. They also differ in terms of abatement costs and in innovative activity.

Industrial organisation: changes in the organisation of production, through national and international value chains, have several direct effects on climate mitigation. First, increased specialisation is usually associated with higher productivity, which may influence energy intensity and innovation capacity. Second, changes in the organisation of production (for ex. firms' decision to make or buy) are also likely to modify the geographic concentration of economic activities and workers, an important factor in the contribution of transportation to GHG emissions. Third, outsourcing may come with increased international trade, which may imply offshoring more polluting activities from some countries to others.

Technical change: it is central to both structural and climate change and includes changes to the energy mix, increased energy efficiency due to technical progress, and development and diffusion of less carbon-intensive goods and services. Innovations in zero-carbon technologies and energy efficiency technologies are crucial in the process of complete decarbonisation. It is important to distinguish between incremental innovations, which improve existing practices and products, and radical innovations, which require changes in large parts of the economy, including consumer behaviour, the production structure, infrastructure and related institutions.

Demand: there are at least three aspects on the demand side of structural change that are critical to decarbonisation. First, income levels (GDP per capita) affect consumption patterns. Second, income distribution shapes the level of final consumption, the distribution of consumption across products, aversion to pollution and a country's capacity to generate innovations. Third, consumers´ preferences change with income and over time. Preferences have been discussed extensively with respect to time: risk aversion and the rate at which individuals discount future generations' consumption and cost of climate change relative to present consumption and costs to reduce emissions.

Employment: it includes employment relocations across industries and geography, as new industries demand for new skills and novel combinations of know-how. The pace of adaptation of the workforces to new industries, geographies, technologies and tasks may induce a more or less efficient transition towards green technologies or impede it.

Institutions: Several aspects of structural change discussed here are influenced by institutions, including energy and climate governance, agency and power, social norms, and the organisation of critical industries for decarbonisation (e.g. electricity markets).

Some dimensions of structural change represent changes in national economies and other in the international configuration of the economic system and influence mutually. The empirical literature uses several variables to investigate the environmental impact of the above-mentioned production and consumption changes (Ciarli and Savona 2019). The most common include energy intensity, which is the ratio of energy inputs to GDP, and is inversely related to energy efficiency, and "quality" of the energy mix, which is related to the share of different fossil fuels, renewables and nuclear and measures the GHG content of energy consumption. In the empirical part of this paper, we use the concepts of energy and carbon intensities as indirect indicators of structural change; we do not investigate specific dimensions such as employment and institutions (see Method).

2.2 What are the theoretical expected effects of crises on structural change and decarbonisation?

Environmental and ecological economists, political scientists, and scholars from other disciplines related to transition studies have theorised this question. Overall, they have pointed out several reasons why crises would positively impact climate mitigation and the transition to a carbon-neutral economy and reasons to expect the opposite adverse effects.

In Schumpeterian economics, some scholars linked the concept of evolutionary processes of creative destruction with economic stagnations. Mensch and Schnopp (1980) argue that most of the "inequilibrium" trends, and specifically the shifts in trend, which have been observed during and since the Industrial Revolution, can be traced to changes in the rate and direction of technological innovation. According to Mensh's analysis, in periods of crises the socio-economic systems become structurally ready for a new spurt of basic innovation leading to a new (and different) cycle of growth. Major innovations would tend to cluster in periods of crises because crises induce firms to examine drastically different technological options (Mensch and Schnopp 1980). Also, crises would accelerate the decline of old and usually less efficient economic industries and support the emergence of new and more efficient ones. Authors in this stream (Perez 2013) tend to consider deep crises as normal stages between the long-wave dynamics of techno-economic paradigm shifts: crises may form the tipping point towards the next (green) technological wave.

More recently, the question was examined by scholars related to "green keynesianism" (Harris 2013), focusing on reorienting fiscal and monetary policies and, more generally, on the green growth paradigm. It refers to the idea of reviving economic growth while resolving the problems of environmental decline and social injustice. The main purpose of green keynesianism is, therefore, to recall the state for an active macroeconomic policy to tackle economic malaise and ecologic damage, channelling public spending toward low-carbon industries and environmentally friendly activities (Cömert 2019). This view frames environmental protection as opportunity and reward rather than punishment or additional costs and looks for strategies to align economic growth and the environment. In the aftermath of an economic crisis, green growth can focus on creating new jobs in clean sectors through public spending on green infrastructure and technologies (Keynesian green stimulus), which stimulates aggregate demand. Thus, given the long lifetime of most energy infrastructures and technologies, countries should not miss the opportunities provided by crises to replace carbon-intensive technologies by cleaner alternatives.

Related to the concept of “critical junctures” from historical institutionalism (Dupont, Oberthür et al. 2020), crises can open up opportunities for new institutional pathways if the forces they unleash give rise to changes in existing norms, regulations and institutions. While institutional and policy processes are path-dependent and ‘locked’ into a certain policy pathway characterised by self-reinforcing feedback effects, an exogenous shock or crisis may trigger a shift away from existing paths toward new trajectories (Fioretos, Falleti et al. 2016). In fact, given the greater competition for scarce resources, economic downturns should strengthen the case for a suitable design of climate policies which lead to cost-effective emissions reductions in an intertemporal perspective. Proponents of this view then call for clear, long-term and stable policy frameworks and more international cooperation.

However, scholars also have highlighted expected negative effects of crises on the process of decarbonisation. By making access to capital more difficult, economic recessions may hinder emissions reduction efforts through their discouraging effects on investments in general, including investments in low- or zero-carbon technologies (Del Río and Labandeira 2009). Moreover, lower energy prices in times of crisis, reduce the economic viability for the development and operation of cleaner technologies (Jalles 2019). Political priorities may also shift again decarbonisation: as both governments and the private sector focus on the recovery and on adapting their respective budgets, they may shift priorities away from climate policies. In this sense, crises tend to lead to deferment and postponement of environmental projects and investment as surviving the crisis and recovering becomes the aim, rather than becoming a “green” company or economy. Indeed, governments are likely to avoid burdening businesses and industries with extra costs and regulations when the economy is fragile, and jobs may be at risk (Jalles 2019). On the consumers´ side, lower economic capacity may encourage the consumption of goods with an inferior environmental quality (and lower prices). Thus, weaker environmental policies, reduced economic capacity for investments and depressed demand for greener products during crises may intensify carbon lock-in. This assumes, nonetheless, a low political will to implement climate policy in the short term, which may not be the case in many countries.

Scholars from transition studies also have examined the impacts of crises on sustainability transitions (Geels 2013, Loorbach and Huffenreuter 2013, Geels, Pereira et al. 2022) . Geels (2013) highlighted the difficulty of the topic, because crises are, by definition, confusing and contested phenomena, which challenge existing ways of doing and understanding. Indeed, crises can disrupt existing institutions and cause uncertainty about future directions, which offers opportunities for substantial change that deviates from locked-in trajectories. Whether or not these opportunities are taken depends on how crises are interpreted (the dominant narrative) and the policy responses. In terms of the well-known multi-level perspective (Geels and Schot 2007), crises can be seen as a shock at the landscape level. This shock creates pressures on regimes in concrete empirical domains (mobility, energy, etc.), where it may affect investor behaviour, availability of capital, public concerns, and the political will to act in favour of sustainability. At the niche level, many green innovations struggle against existing regimes. The wider diffusion of these niche innovations may require changes in the socio-technical regime: changes in consumer practices, changes in public policies to favour green options, reorientations of incumbent firms and investors, and changes in public discourse (Geels 2013). Some or all these changes can emerge or intensify during periods of crisis.

2.3 What do we know empirically about the effects of past economic crises on (de)carbonisation?

It is well established that GHG emissions follow economic growth and that recessions lead to a substantial reduction in energy consumption and consequently in GHG emissions, particularly CO_2 (Bertram, Luderer et al. 2021). In the last 50 years, global CO_2 emissions have steadily increased, punctuated by small dips in the curve during severe and often global economic and political crises. These events, such as the two oil crises (1973-75 and 1979-81), the collapse of the Soviet Union (1989-1991), and the Global Financial Crisis (GFC) (2007-09), did affect the global emissions curve, but only as short-lived dents, suggesting that economic crises do not have an important effect on global CO_2 emissions.

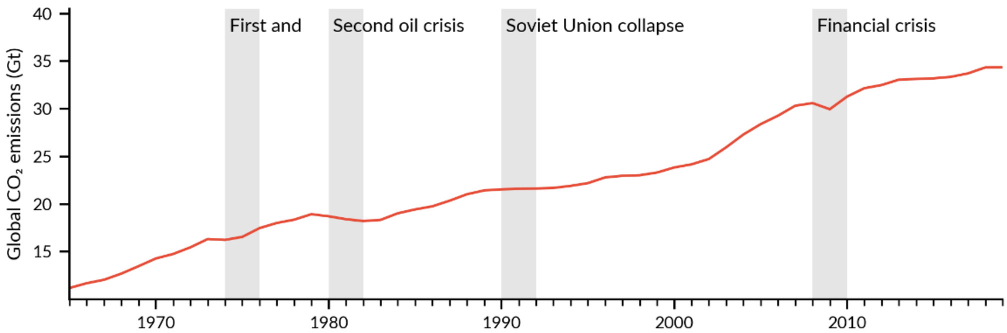


Figure 1: Global fossil CO_2 emissions 1965-2019 (BP 2021)

Previous analyses of such events showed that the short-term effects (1-2 years) could be substantial, but global emissions quickly bounce back, often overcompensating the crisis-related decrease (Peters, Marland et al. 2012). For example, after the 2.1% decrease in 2009, global CO_2 emissions grew by 4.4% in 2010 (BP 2021). Further, even in "global" crises, not all countries and their emission levels are equally affected: whereas effects are severe in some countries, most countries are less or not at all affected. Even the GFC, the then largest global economic crisis since the 1930s, triggered a recession "only" in 100 countries (World Bank 2022), and as most of these countries returned to a growth path quickly, the crisis did not substantially alter the global trajectory of CO_2 emissions. In 2020, the COVID-19 pandemic caused a global recession, with global GDP dropping 3.3% in 2020 (World Bank 2022), leading to a fall in energy-related CO_2 emissions of 5.9%[1], the largest absolute decline recorded in the last 50 years (BP 2022); however CO_2 emissions rebounded 5.1% in 2021 (BP 2022). Because this crisis did not affect the fossil fuel-based energy system architecture, some studies argue its effects are likely temporary (Forster, Forster et al. 2020, Le Quéré, Peters et al. 2021). These analyses suggest that economic crises have no long-standing effects on decarbonisation.

However, zooming into emissions data for individual countries and sectors (BP 2022) suggests that economic crises may have acted as turning points for national emissions trajectories: after a crisis-induced drop, along with reduced economic activity, energy-related emissions do not bounce back to pre-crisis levels once the economy returns to growth but remain on a permanently lower level. This suggests that in those cases, structural change may have happened: the driving forces of emissions may have changed in a way that results in permanent decarbonisation of the economy. Using a sample of 68 countries for the period 1960 to 2014 Alsamara, Mimouni et al. (2021) found that the GFC has had permanent effects on CO_2 emissions and that these effects vary by countries` income level and depending on the severity of the crisis at the national level. Applying the "local projection method", Jalles (2019) investigated a sample of 31 advanced and 55 emerging and low-income countries between 1980 and 2012. Their results suggest that financial crises, in general, led to a statistically significant fall in CO_2 and methane emissions; however, the effects can vary depending on the type of crisis and on the monetary and fiscal situation before the crisis hits.

Here we complement and extend these analyses focusing not only on the crises ´impacts on emissions but on structural change; we use a different method, which allows us to account for changes in energy and carbon intensity before and after major economic crises. To our knowledge, it is the first paper examining the relationship between crises and the structural change toward decarbonisation in a large sample of countries.

[1] In the period 2009-19, primary energy consumption and CO_2 emissions increased by 1.9% and 1.4% per year, respectively.

3. Method

3.1 Scope: Countries investigated.

Our analysis includes the 45 countries which are part of the OECD, the G20 or both. Together, this group of countries accounted for 77% of global CO_2 emissions in 2019 (BP 2021), holding all large emitters. The group comprises 37 OECD member countries and eight G20 countries that are not OECD members.

Table 1: Countries included in the analysis. Countries in *italic* are low- and middle-income countries, all others are high-income countries, according to the World Bank classification in 2021(World Bank 2022).

OECD members	**OECD members (continued)**	**G20 but not OECD members**
Austria	Korea	*Argentina*
Australia	Latvia	*Brazil*
Belgium	Lithuania	*China*
Canada	Luxembourg	*India*
Chile	*Mexico*	*Indonesia*
Colombia	Netherlands	*Russia*
Czech Republic	New Zealand	*South Africa*
Denmark	Norway	Saudi Arabia
Estonia	Poland	
Finland	Portugal	
France	Slovakia	
Germany	Slovenia	
Greece	Spain	
Hungary	Sweden	
Iceland	Switzerland	
Ireland	*Turkey*	
Israel	United Kingdom	
Italy	United States	
Japan		

3.2 Data sources

We base our CO_2 and energy consumption data on statistics from BP (BP 2021). The carbon emissions data reflect only emissions from combustion-related activities of oil, gas, coal and natural gas flaring and are based on 'Default CO_2 Emissions Factors for Combustion' listed by the IPCC in its Guidelines for National Greenhouse Gas Inventories (IPCC 2006). In this, we consider territorial emissions, but not 'consumption-based' emissions, because we are interested in the effect of crises on national economies – and one such effect could in principle be the "outsourcing" of emissions (e.g. shift of manufacturing industry abroad).

We use economic data -GDP in US Dollar (2015 constant)- and population data for 1965-2019 from the World Bank statistics (World Bank 2022). GDP per capita data for countries that were part of the Soviet Union and Poland was taken from Maddison Project Database (Maddison Project Database 2020). The GDP data for the post-Soviet sphere is thus different from the rest of our sample, but because our analysis is concerned with relative, not absolute, changes in GDP, this does not lead to an error or misleading comparison.

3.3 Identification of CO_2 emissions peaks.

For each country, we first identified the year with the highest absolute value in CO_2 emissions in 1965--2019. This metric may be biased by extreme weather conditions or other events that may have affected emissions in a particular year, but without being particularly relevant for the *process* of decarbonisation. To reduce the impact of such short-term fluctuations, we base our analysis on a 5-years moving mean (the unweighted mean of the previous 5 data points). Because emissions can temporarily decrease and then increase again, we apply a second condition for identifying countries with sustained emissions reductions: We identify a 5-year rolling average as peak only if it occurred at least ten years before the end of our data series in 2019. For potential peaks after 2009 it is still too early to know whether they were sustained or temporary peaks. Our data indicates that Australia, Israel, and South Africa may have peaked in 2011-12, and Argentina, Brazil and Mexico in 2015-17, connected to national crises, but we do not yet know whether this is lasting or just a temporary dip in emissions.

We associate an economic crisis with an emission peak if it happens ±2 years around the crisis' onset. This way, we identify the peak-and-decline countries and especially the peak-and-decline countries where the peak is temporally connected to an economic crisis.

3.4 Decomposition of CO_2 emissions.

To study how CO_2 emissions were affected by economic crises, we perform a Kaya decomposition analysis for each country (Kaya 1989). Decomposition analysis is a technique used to identify the contribution of different components of a specific variable. In environmental science and economics, it has been applied to investigate the main factors contributing to the carbon dioxide emissions and the mechanisms influencing energy consumption (Andreoni and Galmarini 2012). Kaya analysis is a common method applied across the climate mitigation literature (Lamb, Wiedmann et al. 2021), which expresses emissions (tCO_2) as a function of population (persons), GDP (2015 US$) and primary energy (J), with the respective terms C, P, G and E:

$$C = P(\frac{G}{P})(\frac{E}{G})(\frac{C}{E}) \qquad (1)$$

where G/P is GDP per capita, E/G in the energy intensity (EI) of GDP and C/E is the carbon intensity (CI) of energy.

We apply Index Decomposition Analysis (IDA) based on aggregate information at the country level, commonly used to perform cross-country comparisons and Kaya time-series analysis (Ang 2005, Ang 2015). There are two variants of IDA: additive decomposition and multiplicative decomposition. In additive decomposition analysis, the arithmetic change of an aggregate indicator such as total CO_2 emissions is decomposed, while in multiplicative decomposition the ratio change of an aggregate indicator is decomposed (Ang 2015). Here, we apply multiplicative decomposition based on the Kaya identity, resulting in:

$$\Delta C = \frac{C^t}{C^0} = \Delta P * \Delta G * \Delta EI * \Delta CI \qquad (2)$$

$$\Delta P = \frac{P^t}{P^0} \qquad (3)$$

$$\Delta G = \frac{G^t}{G^0} \qquad (4)$$

$$\Delta EI = \frac{EI^t}{EI^0} \qquad (5)$$

$$\Delta CI = \frac{CI^t}{CI^0} \qquad (6)$$

To estimate the contribution to emissions of the four Kaya factors in the periods before and after each crisis associated with an emissions peak, we assess trends ten years before the first year and after the last year of the crisis, defining the "crisis" as years with negative GDP growth. For the Global Financial Crisis, the pre-crisis period is 1998-2007, as the crisis started in 2007 although its impacts on GDP manifested in 2008-09 in most countries; its end date is 2019, the last year of our time series. The 10-year period is shorter when data is unavailable or when the post-crisis period overlaps with the next crisis, as occurred between the first (1973-75) and second (1979-80) oil crises. We derive the growth rates of emissions trends and Kaya factors over the pre- and post-crisis periods as:

$$r = \left(\frac{K\ (t+n)}{K\ (t)}\right)^{1/n} - 1 \qquad (7)$$

where *K* is the emissions value or Kaya factor in year *t* (Lamb, Wiedmann et al. 2021).

In our decomposition analysis we call the combined contribution of GDP per capita and population on CO_2 emissions "*GDP effect*" and the combined contribution of carbon intensity and energy intensity "*structural change effect*". Carbon intensity captures decarbonisation of energy supply systems, for example, fuel switching within fossil fuels (e.g., coal to gas) or switching from fossil fuels to renewables or nuclear. Economy-wide energy intensity represents changes that reduce the energy used per unit of GDP, such as energy conservation, increased energy performance of technologies, structural change of economy, and development of efficient urban infrastructure. The impacts of energy and climate policy are reflected in the changes of carbon and energy intensities (IPCC 2022).

4. Results

4.1 Absolute decoupling: the temporality of carbon emissions peaks

Of the 45 OECD and G20 countries we investigate, 28 have passed their national energy-related CO_2 emissions peaks, with the first peaks happening in the early 1970s. Because all but two countries have also experienced GDP growth since the peak emissions year, this shows that absolute decoupling is possible, even over very long periods of up to 50 years. This is neither new nor surprising (Cohen, Jalles et al. 2018, Lamb, Wiedmann et al. 2021). Our results however also show that the emissions generally peak just before an economic crisis (Figure 2), especially the four large global crises: of the 28 countries that have peaked, 26 did so just before (0-2 years) or during an economic crisis. Only Denmark (1998) and Switzerland (2001) have peaked seemingly unrelated to a deep crisis.

During the First Oil Crisis in 1973/75, which triggered an economic crisis especially in Western economies, the first countries peaked, all of them among the hardest-hit western European countries (the UK, Belgium, and Luxembourg). Five further countries (Germany, France, Sweden, Hungary, and Czech Republic) peaked during the second oil crisis and kept decreasing emissions post-crisis. The crisis related to the dissolution of the Soviet Union (1989-1991) coincided with emission peaks in most ex-Soviet and some eastern European countries. Finally, several industrialised countries, especially in Europe but also the US and Japan, peaked just before the onset of the GFC.

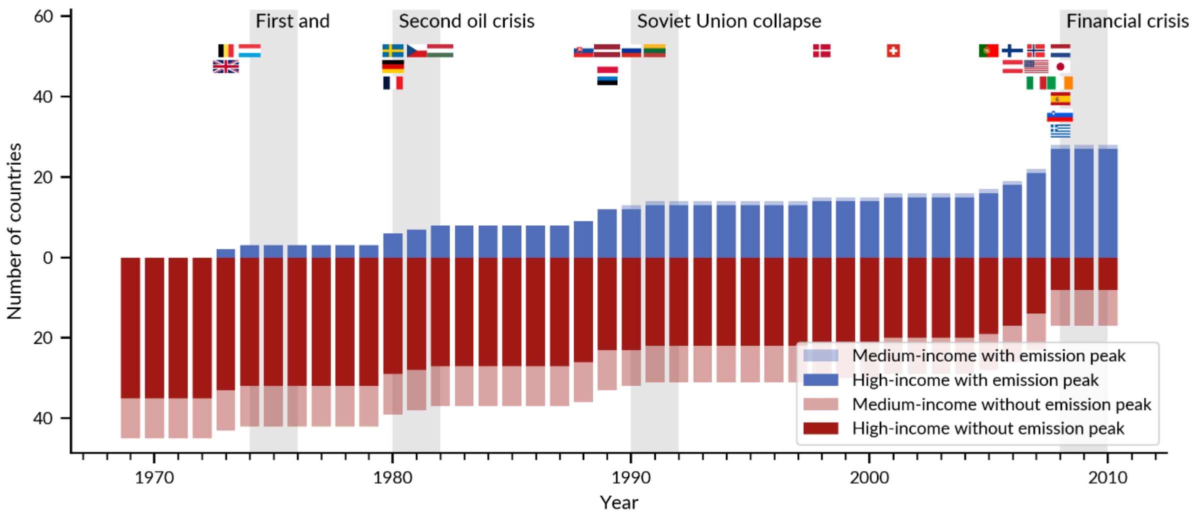


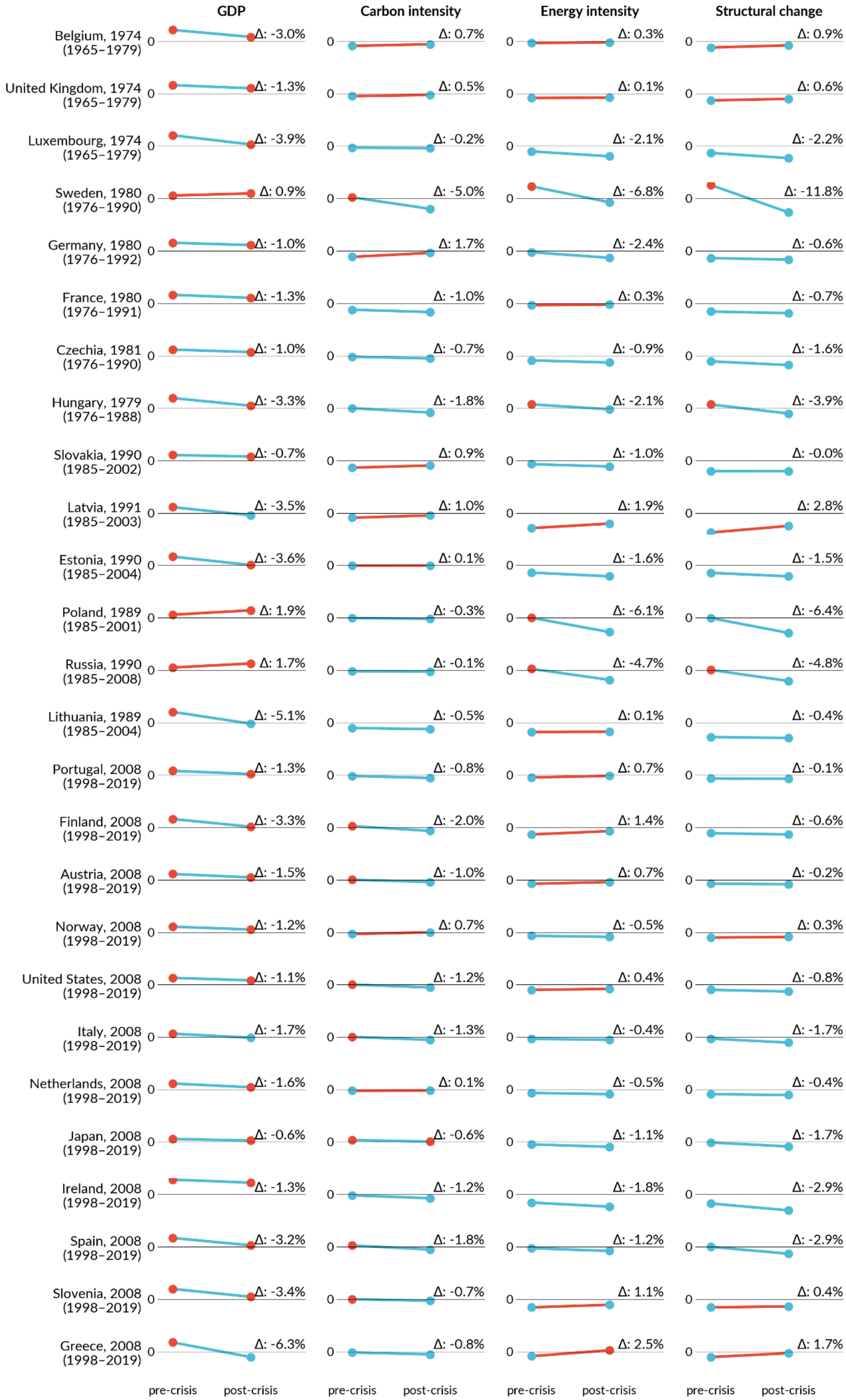
Figure 2: Emissions peaks and economic crises. Number of countries that have and have not peaked CO_2 emissions (the year with the highest rolling average of the five past years). OECD and G20 countries. The flag indicates the peak year of the respective country. Source: (BP 2021).

There is thus a clear temporal connection between economic and geopolitical crises and national peak emissions. In the following, we decompose carbon emissions before and after the peak-related crisis in each country, accounting consequently by the relative contribution of GDP per capita and population (GDP effect), and energy intensity and carbon intensity (structural change effect). We do this for peak-and-decline countries and for non-peaking countries.

4.2 The impact of crises in peak-and-decline countries

The decomposition analysis (Figure 3) shows two different effects explaining the peak timing. First, in 23 of 26 peaking countries, the contribution of the GDP effect to CO_2 emissions was lower post-crisis than before. However, all countries eventually returned to economic growth, meaning that GDP continues to increase emissions, but slower than before (-1.9 percentage points average difference pre- and post-crisis). Only in Lithuania, Latvia (Soviet crisis), Greece and Italy (GFC), which experienced deep and long recessions, did the GDP effect work to slightly decrease emissions in the post-crisis period.

Second, the 26 countries have seen a structural change towards a sustained lower level of emissions. In most cases (17 of 26), pre-existing structural change effect trends intensified during and after crises, leading to faster reduction in energy intensity, carbon intensity or both. In 3 cases, these trends bent, meaning that they were increasing emissions before the crises and decreased them after. In 6 countries, the path of technological change deteriorated post-crises, even if it continued reducing emissions. Hence, in countries that have peaked, structural changes intensified by or coinciding with an economic crisis, not negative GDP, explain the peak and lasting effect of absolute decoupling in all but two countries.



GDP
Carbon intensity
Energy intensity
Structural change
Belgium, 1974 (1965–1979)
Δ: -3.0%
Δ: 0.7%
Δ: 0.3%
Δ: 0.9%
United Kingdom, 1974 (1965–1979)
Δ: -1.3%
Δ: 0.5%
Δ: 0.1%
Δ: 0.6%
Luxembourg, 1974 (1965–1979)
Δ: -3.9%
Δ: -0.2%
Δ: -2.1%
Δ: -2.2%
Sweden, 1980 (1976–1990)
Δ: 0.9%
Δ: -5.0%
Δ: -6.8%
Δ: -11.8%
Germany, 1980 (1976–1992)
Δ: -1.0%
Δ: 1.7%
Δ: -2.4%
Δ: -0.6%
France, 1980 (1976–1991)
Δ: -1.3%
Δ: -1.0%
Δ: 0.3%
Δ: -0.7%
Czechia, 1981 (1976–1990)
Δ: -1.0%
Δ: -0.7%
Δ: -0.9%
Δ: -1.6%
Hungary, 1979 (1976–1988)
Δ: -3.3%
Δ: -1.8%
Δ: -2.1%
Δ: -3.9%
Slovakia, 1990 (1985–2002)
Δ: -0.7%
Δ: 0.9%
Δ: -1.0%
Δ: -0.0%
Latvia, 1991 (1985–2003)
Δ: -3.5%
Δ: 1.0%
Δ: 1.9%
Δ: 2.8%
Estonia, 1990 (1985–2004)
Δ: -3.6%
Δ: 0.1%
Δ: -1.6%
Δ: -1.5%
Poland, 1989 (1985–2001)
Δ: 1.9%
Δ: -0.3%
Δ: -6.1%
Δ: -6.4%
Russia, 1990 (1985–2008)
Δ: 1.7%
Δ: -0.1%
Δ: -4.7%
Δ: -4.8%
Lithuania, 1989 (1985–2004)
Δ: -5.1%
Δ: -0.5%
Δ: 0.1%
Δ: -0.4%
Portugal, 2008 (1998–2019)
Δ: -1.3%
Δ: -0.8%
Δ: 0.7%
Δ: -0.1%
Finland, 2008 (1998–2019)
Δ: -3.3%
Δ: -2.0%
Δ: 1.4%
Δ: -0.6%
Austria, 2008 (1998–2019)
Δ: -1.5%
Δ: -1.0%
Δ: 0.7%
Δ: -0.2%
Norway, 2008 (1998–2019)
Δ: -1.2%
Δ: 0.7%
Δ: -0.5%
Δ: 0.3%
United States, 2008 (1998–2019)
Δ: -1.1%
Δ: -1.2%
Δ: 0.4%
Δ: -0.8%
Italy, 2008 (1998–2019)
Δ: -1.7%
Δ: -1.3%
Δ: -0.4%
Δ: -1.7%
Netherlands, 2008 (1998–2019)
Δ: -1.6%
Δ: 0.1%
Δ: -0.5%
Δ: -0.4%
Japan, 2008 (1998–2019)
Δ: -0.6%
Δ: -0.6%
Δ: -1.1%
Δ: -1.7%
Ireland, 2008 (1998–2019)
Δ: -1.3%
Δ: -1.2%
Δ: -1.8%
Δ: -2.9%
Spain, 2008 (1998–2019)
Δ: -3.2%
Δ: -1.8%
Δ: -1.2%
Δ: -2.9%
Slovenia, 2008 (1998–2019)
Δ: -3.4%
Δ: -0.7%
Δ: 1.1%
Δ: 0.4%
Greece, 2008 (1998–2019)
Δ: -6.3%
Δ: -0.8%
Δ: 2.5%
Δ: 1.7%
0
pre-crisis
post-crisis

Figure 3: Emission driver decomposition in peak-and-decline countries. Changes in growth rates (%/year) of contribution factors to carbon emissions before (first point) and during and after (last point) the economic crisis associated to the CO_2 peak, based on the Kaya identity and multiplicative decomposition. Red (blue) circles mean that the factor increased (reduced) emissions; red (blue) lines indicate that the change from pre- to post-crisis was negative (positive) for decarbonisation. The "year" after the country name denotes the first year of recession and the period below the country name denotes the entire analysis period. Source: (Maddison Project Database 2020, BP 2021, World Bank 2022).

4.3 Mechanisms explaining structural change during crises.

Our results show that crises have intensified structural change in peaking economies, either by magnifying already ongoing improvement trends in energy and/or carbon intensity, or by shifting trends from increasing to decreasing intensities. These changes result from three interrelated mechanisms.

The first mechanism consists of energy efficiency measures taken by governments and firms to respond to higher energy prices or deteriorating economic conditions. This can be seen during the First and Second Oil Crises. The countries that peaked in that period experienced significant improvement trends in energy intensity (Figure 4). Responding to supply constraints and price hikes, governments implemented policy measures to reduce the consumption of expensive imported fuels and address industrial efficiency specially across export-oriented sectors (Ikenberry 1986, Geller, Harrington et al. 2006). Beyond public policies, firms also respond to crises and trigger new market trends, such as the shift towards smaller and more efficient cars during the oil crises, especially in the Western European and Japanese automotive industries (Catalan Vidal 2017, Candelo 2019). Similar positive effects on energy efficiency also occurred in several countries that peaked during the GFC, supported by pre-existing policies and (modest) green recovery funds dedicated to energy efficiency measures (IEA 2020).

The second mechanism, also affecting energy intensity, comprises changes in economic structure due to the decline of energy/carbon-intensive industries and the rise of less energy-intensive ones post-crisis, driven by economic forces. When the economy recovers, it does not recover to its previous state but sees a shift to less energy- or carbon-intensive assets (e.g. modern, efficient production lines) or activities (e.g. service sector instead of manufacturing). In Soviet countries, energy intensity decreased substantially during the 1990s and early 2000s (Figure 4) due to economic transformation; for example, Russia experienced a long recession in the 1990s followed by a booming recovery in the 2000s, during which the GDP share of industry fell from 45% to 30% (1990-2008) (World Bank 2022). In Spain, among the hardest-hit countries during the GFC and the following Euro crisis, the effects on industry were strong, with the sectoral share of GDP falling from 26% in 2007 to 20% in 2015; particularly the construction industry collapsed and never recovered to pre-crisis levels (Royo 2020). The Spanish return to growth thus happened in other, less carbon- and energy-intensive sectors.

The third mechanism is fuel switch, leading to reduced carbon intensity, triggered by new market conditions or policy changes. The First Oil Crisis had a long-lasting effect on the energy mix particularly in Western Europe, for example through large-scale deployment of nuclear power in several countries; this crisis also triggered interest in nascent renewable energy technologies, leading to the first larger-scale R&D programmes, although initially little deployment (Ikenberry 1986). The Second Oil Crisis, some years later, provided new reasons to confirm those developments. The French Messmer nuclear programme implemented in response to the First Oil Crisis put France on a path to largely CO_2-free electricity from the late 1970s (Guillaumat-Tailliet 1987), and the resulting fuel switch from oil to nuclear led to the French emission peak in 1980. Similar energy policy developments explain the Swedish emissions peak in 1979, resulting in a shift from oil to bioenergy and nuclear power (Millot, Krook-Riekkola et al. 2020). Furthermore, during the GFC, most (10 of 12) peaking countries improved their carbon intensity trends during and after the crisis, especially as coal power was pushed out of power systems due to changing market conditions and dedicated policy. The GFC recovery packages did not have a major effect on the energy mix, as they were focused on end-use efficiency and the car sector (IEA 2020). Further, the deployment of renewable energy continued through and after the crisis, and accelerated in some countries, such as the US and Italy. Despite the deterioration of the fiscal situation during the GFC, most governments continued to support renewable energy, which also benefited from lower interest rates resulting from expansive monetary policy following the crisis (Cukierman 2013, Schmidt, Steffen et al. 2019).

However, previously improving trends in carbon or energy intensity can also *worsen* during and after crises: in six cases, “structural change” slightly slowed down (Figure 3) but continued to decrease emissions complemented by meagre or zero GDP growth. This effect was particularly notable in Greece during the GFC and Euro-crisis: the GDP fell substantially, temporarily reversing previous improvements in energy intensity. As carbon intensity continues to decrease, the Greek economy is decarbonising, and emissions continue to drop after economic growth returned in 2017 (Figure 4). These degrading effects are much more common in non-peak countries (Figure 5), where the recovery tends to come with an increase in fossil fuel consumption and increasing energy intensity.

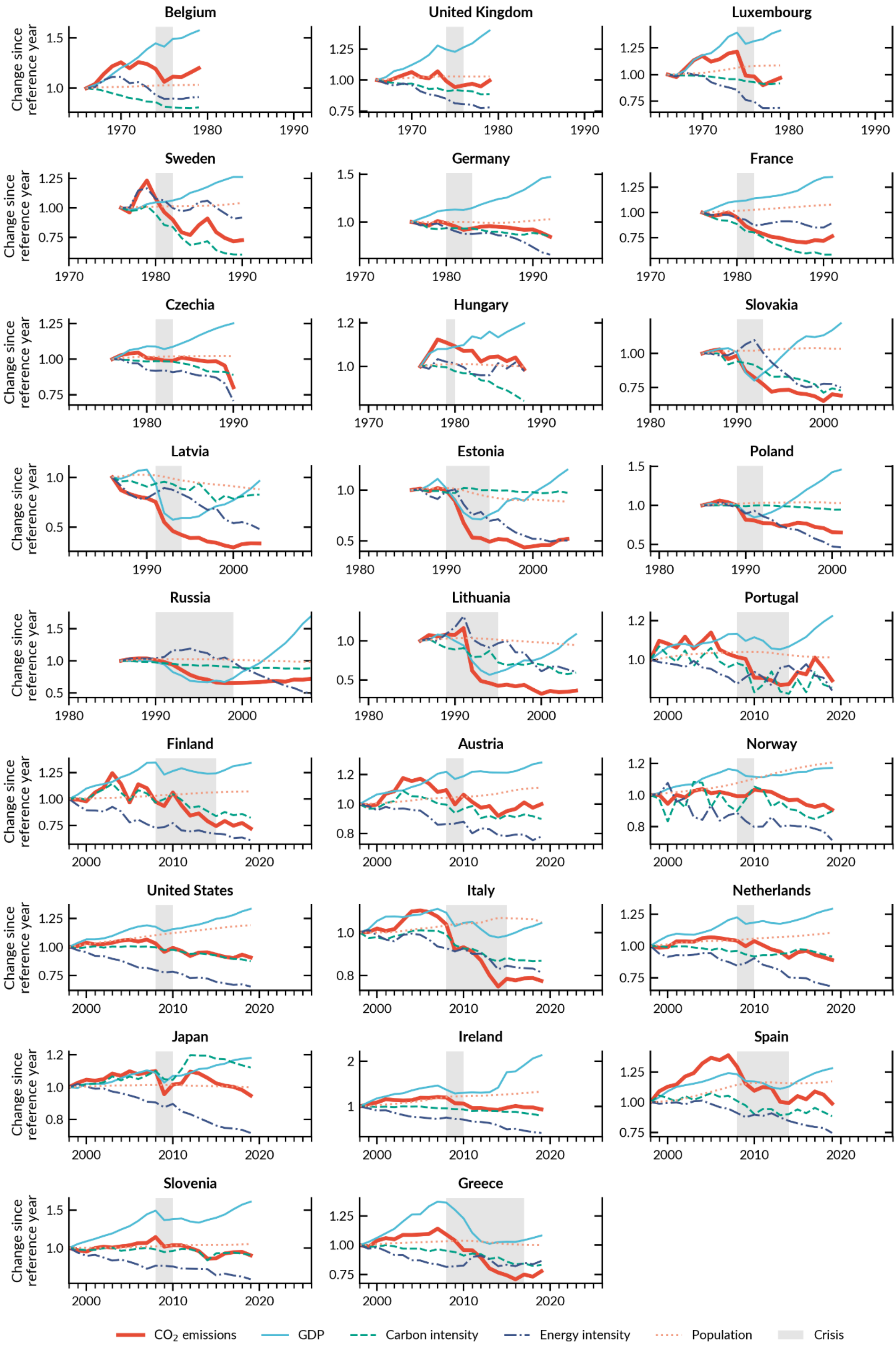

Change since reference year
Belgium
United Kingdom
Luxembourg
Sweden
Germany
France
Czechia
Hungary
Slovakia
Latvia
Estonia
Poland
Russia
Lithuania
Portugal
Finland
Austria
Norway
United States
Italy
Netherlands
Japan
Ireland
Spain
Slovenia
Greece
CO_2 emissions
GDP
Carbon intensity
Energy intensity
Population
Crisis

Figure 4: Crises & national emissions peaks. CO_2 emissions and decomposed emission drivers from the Kaya identity; 26 countries that peaked emissions around economic crises. Charts for all countries and years in Supplementary Note 3. Sources: (Maddison Project Database 2020, BP 2021, World Bank 2022).

4.4 The impact of crises in non-peak countries

GDP growth in non-peak countries was less severely or not affected by the investigated crises. Consequently, emissions weakly decreased during the crises years but rebounded rapidly and kept increasing, triggered by a large GDP effect (generally growing both population and GDP per capita) and weak or emission-increasing structural change effect. Most countries in this group are emerging economies, where energy consumption has increased rapidly in the last decades.

During the first and second oil crises, both the GDP and structural change effects explained rapid emissions *increase* in all non-peak countries. During the Soviet Union Collapse, these countries were hardly economically affected, and GDP continued to increase emissions by more than 3% per year (median value) (Figure 5). Because the contribution of structural change was extremely weak or positive, emissions keep rising in all these countries.

Again, non-peak countries were not hit hard by the GFC, and the GDP effect continued to increase emissions rapidly in the post-crisis period. The structural change effect deteriorated in some countries and improved in others but still was too weak to compensate for the stronger GDP effect. Structural and GDP effects worsened after the GFC in Colombia and India, resulting in higher CO_2 emissions rates. Australia and South Africa are two exceptions: they are the only two cases in this group where emissions slightly decreased in the post-GFC period, and these countries may have peaked in 2011/12. Canada, Israel, and Mexico also show a level of structural change sufficient to compensate for economic growth, indicating that these countries are approaching the national peak.


GDP
Carbon intensity
Energy intensity
Structural change
Argentina, 1990 (1980–2001) Δ: 3.9% Δ: -0.7% Δ: -2.2% Δ: -2.9%
Australia, 1990 (1980–2001) Δ: -0.2% Δ: 0.1% Δ: 0.4% Δ: 0.5%
Brazil, 1990 (1980–2001) Δ: 0.3% Δ: 2.6% Δ: -0.4% Δ: 2.2%
Chile, 1990 (1980–2001) Δ: 3.1% Δ: -1.8% Δ: -0.2% Δ: -2.0%
China, 1990 (1980–2001) Δ: 0.3% Δ: 0.1% Δ: -1.5% Δ: -1.5%
Colombia, 1990 (1980–2001) Δ: -0.7% Δ: 1.5% Δ: -1.3% Δ: 0.1%
Indonesia, 1990 (1980–2001) Δ: -1.4% Δ: 2.0% Δ: 1.1% Δ: 3.2%
India, 1990 (1980–2001) Δ: -0.0% Δ: -0.7% Δ: -1.8% Δ: -2.5%
South Korea, 1990 (1980–2001) Δ: -3.1% Δ: 0.7% Δ: 1.6% Δ: 2.4%
Mexico, 1990 (1980–2001) Δ: 1.6% Δ: 1.3% Δ: -2.6% Δ: -1.3%
New Zealand, 1990 (1980–2001) Δ: 1.0% Δ: 1.7% Δ: -0.9% Δ: 0.8%
Saudi Arabia, 1990 (1980–2001) Δ: 5.9% Δ: 6.1% Δ: -10.6% Δ: -3.6%
Turkey, 1990 (1980–2001) Δ: -2.0% Δ: -0.2% Δ: -1.1% Δ: -1.3%
South Africa, 1990 (1980–2001) Δ: 0.2% Δ: 0.2% Δ: -3.7% Δ: -3.5%
Australia, 2008 (1998–2019) Δ: -1.0% Δ: -1.0% Δ: -0.4% Δ: -1.4%
Israel, 2008 (1998–2019) Δ: 0.0% Δ: -1.2% Δ: -1.1% Δ: -2.3%
South Africa, 2008 (1998–2019) Δ: -2.7% Δ: -0.6% Δ: 0.6% Δ: 0.0%
Argentina, 2008 (1998–2019) Δ: -1.8% Δ: 0.1% Δ: -0.2% Δ: -0.1%
Brazil, 2008 (1998–2019) Δ: -2.0% Δ: 0.0% Δ: 1.5% Δ: 1.5%
Mexico, 2008 (1998–2019) Δ: -0.5% Δ: -0.3% Δ: -1.7% Δ: -2.0%
Saudi Arabia, 2008 (1998–2019) Δ: -0.0% Δ: 0.8% Δ: -1.5% Δ: -0.8%
Turkey, 2008 (1998–2019) Δ: 0.4% Δ: -1.2% Δ: -0.3% Δ: -1.5%
South Korea, 2008 (1998–2019) Δ: -3.2% Δ: 0.2% Δ: 1.1% Δ: 1.3%
Iceland, 2008 (1998–2019) Δ: -3.1% Δ: 3.6% Δ: -1.0% Δ: 2.7%
Chile, 2008 (1998–2019) Δ: -1.5% Δ: -0.2% Δ: 0.1% Δ: -0.1%
China, 2008 (1998–2019) Δ: -2.4% Δ: -1.3% Δ: -3.1% Δ: -4.3%
Colombia, 2008 (1998–2019) Δ: 0.1% Δ: 1.5% Δ: 2.2% Δ: 3.7%
Indonesia, 2008 (1998–2019) Δ: 0.8% Δ: -0.1% Δ: -1.8% Δ: -1.9%
India, 2008 (1998–2019) Δ: 0.0% Δ: 0.0% Δ: 0.1% Δ: 0.1%
Canada, 2008 (1998–2019) Δ: -2.4% Δ: -0.1% Δ: 1.4% Δ: 1.2%
New Zealand, 2008 (1998–2019) Δ: -1.2% Δ: -2.4% Δ: 1.8% Δ: -0.5%
pre-crisis post-crisis

Figure 5: Emission driver decomposition in non-peaking countries following the GFC and Soviet crisis. Changes in growth rates (%/year) of contribution factors to carbon emissions before (first point) and during and after (last point) the economic crisis associated to the CO_2 peak, based on the Kaya identity and multiplicative decomposition. Red (blue) circles mean that the factor increased (reduced) emissions; red (blue) lines indicate that the change from pre- to post-crisis was negative (positive) for decarbonisation. The "year" after the country name denotes the first year of crisis and the period below the country name denotes the entire analysis period. Time series figures for the GFC in Supplementary Note 4; Emission decomposition for all crises in Supplementary Note 5. Source: (Maddison Project Database 2020, BP 2021, World Bank 2022).

5. Discussion and conclusion

We have shown that peaks in CO_2 emissions are associated with periods of economic crisis: of the 28 OECD and G20 countries that peaked emissions in the last 50 years, 26 did so just before or during an economic crisis resulting from geopolitical events or financial crashes. The peaks are explained by the combination of a lower GDP effect during and after the crisis and accelerated structural change, resulting in faster improvements in carbon and/or energy intensity. After the peak, GDP continued to increase emissions in peaking countries, but at a lower level than before the crisis, making structural change improvements triggered during the recession or recovery the key post-crisis emission reduction driver. In all peak cases, the structural change effect reduced emissions post-crisis, and in 20 of 26 cases the effect strengthened or bent from positive to negative. This suggests that crises do not automatically trigger structural change, but they can be supportive, especially if work to improve energy and carbon intensity has already started. By contrast, non-peak countries were marginally or not affected by crises, and structural change effects were too weak to compensate for the strong GDP growth post-crisis, resulting in growing emissions.

These results have important implications for understanding when and why emission peaks occur, which is a necessary (but not sufficient) condition to achieve the Paris Agreement goals. Most countries that have peaked did so not by "waiting for a crisis to come" but had already been implementing policies to improve energy efficiency or to develop less carbon-intensive energy: they were already improving energy or carbon intensity, or both, and this trend was strengthened in the crisis. The intensification of positive trends during crises suggests that some governments take advantage of times of economic instability to deepen support for policy reforms and green Keynesianism programs. This is a key difference between peaking and non-peaking countries, visible especially in the 1970s (as crisis-induced nuclear programmes intensified) and during the GFC (e.g. green recovery programmes in the US, Japan and EU). Also, in some cases, deep recessions -such as the ones in Russia and in the Baltic states in the 1990s or in Spain and Ireland during the GFC- destabilised entire economic sectors, favouring the deployment of new technologies and less emitting economic activities.

Our findings also have important implications for the green growth versus degrowth debate (Weiss and Cattaneo 2017, Kallis, Kostakis et al. 2018, Meckling and Allan 2020): is degrowth necessary or desirable to reach a peak in emissions and eventually zero emissions? Our results show that absolute decoupling have occurred in a limited group of countries: GDP continued to grow while domestic CO_2 emissions decreased in the peak and decline group, but with three important caveats. First, the rates of improvements in carbon and energy intensity rarely go below -4% per year, which implies that GDP growth must be moderate, not surpassing a certain limit, if emissions are to be reduced. Second, reaching an absolute peak in emissions does not necessarily mean reaching zero emissions quickly: even the first economies to peak in the 1970s (e.g. Belgium, the UK and Germany) still have a long way to go to fully decarbonize their economies. Third, transformative change on the supply side is not always accompanied by equivalent change on the demand side, potentially resulting in emissions leakages toward other economies.

In line with previous research (Jalles 2019), our findings do not mean that the effects of crises on decarbonisation are always or *necessary* positive. During the recovery period, countries can just build back the pre-crisis economy or step back to an even more carbon-intensive economy, such as the coal-based recovery in China and other countries after the Asian financial crisis of 1997 (Parker and Bhatti 2020). In such cases, emissions do not peak post-crisis, but the emissions curve may even bend up. Policies supporting energy efficiency and clean energy must start before a crisis hits, so countries can have the opportunity to support already emerging cleaner industries during the recovery phase. In addition, our findings do not mean that peaks will necessarily happen during recessions, as shown by the cases of Denmark and Switzerland, but they suggest that crises speed up the process making it possible to peak earlier.

Our approach has some limitations that call for more research. First, we worked with production- and not consumption-based emissions, as we investigate the effects of crises on national economies and their energy systems. Previous research has pointed to the transfer of emissions from developed to emerging economies as a potential driver of industrialised country climate progress, although that effect seems to have stopped or clearly slowed down in the last 15 years (Pan, Peters et al. 2017, Le Quéré, Korsbakken et al. 2019). Future research should address the possible impact of economic crises on demand and thus on consumption emissions. A second limitation refers to explanations of why emission peaks happened in some countries and not in others and the exact effects on peaking countries' economic structure and energy systems. The observed structural change results from combinations of market forces and dedicated public policies, but the case-specific proportion was not investigated here. Further country-specific case study analysis would be required to answer questions about the root causes of each peak (and non-peak).

It is still too early to know which countries achieved a peak in carbon emissions during the Covid-19 economic crisis now combined with the energy related crisis, and what their effects on structural, lasting change will be – if any. The drop in GDP was very deep in the first half of 2020 but also short, with recovery starting quickly partly explained by a rapid policy response in all major economies through expansive fiscal and monetary policy. On the one hand, the short duration of the GDP fall suggests that this crisis' "creative destruction" effects could be limited. On the other hand, we also observe disruptions in global supply chains with impulse to re-localise production, which may alter previous globalisation trends and emission trajectories worldwide. Politically, the Covid-19 crisis also differs from previous ones. Since the signature of the Paris Agreement, there has been a growing consensus on the necessity to decarbonise the global economy as soon as possible. Therefore, many countries make their recovery packages "green", explicitly seeking to build back better and use the crisis as leverage for green investments, thus helping accelerate technological change. This trend is strong in the industrialised countries that are already climate leaders, whereas climate laggard countries do not have green recovery packages or focus their recovery efforts on fossil fuel sectors (Quitzow, Bersalli et al. 2021). Finally, at the time of writing, the war in Ukraine is a major disruption of the global energy system, similar in many respects to the oil crises in the 1970s. Again, in times of crisis, strategic decisions are being taken by governments and firms whose effects will be crucial for the objective of net-zero emissions before 2050.

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7. References

Alsamara, M., K. Mimouni, Z. Mrabet and A. Temimi (2021). "Do economic downturns affect air pollution? Evidence from the global financial crisis." Applied Economics **53**(35): 4059-4079.
Andreoni, V. and S. Galmarini (2012). "Decoupling economic growth from carbon dioxide emissions: A decomposition analysis of Italian energy consumption." Energy **44**(1): 682-691.
Ang, B. W. (2005). "The LMDI approach to decomposition analysis: a practical guide." Energy policy **33**(7): 867-871.
Ang, B. W. (2015). "LMDI decomposition approach: a guide for implementation." Energy Policy **86**: 233-238.
Antal, M. and C. J. M. van den Bergh (2013). "Macroeconomics, financial crisis and the environment: strategies for a sustainability transition." Environmental Innovation and Societal Transitions **6**(March 2013): 47-66.
Ashford, N. A., R. P. Hall and R. H. Ashford (2012). "The crisis in employment and consumer demand: Reconciliation with environmental sustainability." Environmental Innovation and Societal Transitions **2**: 1-22.
Barbier, E. B. (2020). "Greening the post-pandemic recovery in the G20." Environmental and Resource Economics **76**(4): 685-703.
Bertram, C., G. Luderer, F. Creutzig, N. Bauer, F. Ueckerdt, A. Malik and O. Edenhofer (2021). "COVID-19-induced low power demand and market forces starkly reduce CO2 emissions." Nature Climate Change **11**(3): 193-196.
Bodenheimer, M. and J. Leidenberger (2020). "COVID-19 as a window of opportunity for sustainability transitions? Narratives and communication strategies beyond the pandemic." Sustainability: Science, Practice and Policy **16**(1): 61-66.
BP (2021). Statistical Review of World Energy 2021 | 70th edition.
BP (2022). Statistical Review of World Energy, 71st Edition.
Candelo, E. (2019). The First Oil Shock: A Turning Point in Production and Marketing. Marketing Innovations in the Automotive Industry, Springer**:** 81-93.

Catalan Vidal, J. (2017). "The stagflation crisis and the European automotive industry, 1973–85." Business History **59**(1): 4-34.
Ciarli, T. and M. Savona (2019). "Modelling the evolution of economic structure and climate change: a review." Ecological economics **158**: 51-64.
Cohen, G., J. T. Jalles, P. Loungani and R. Marto (2018). "The long-run decoupling of emissions and output: Evidence from the largest emitters." Energy Policy **118**: 58-68.
Cömert, M. (2019). "Revival of Keynesian Economics or Greening Capitalism:"Green Keynesianism"." Sosyoekonomi **27**(42): 129-144.
Cukierman, A. (2013). "Monetary policy and institutions before, during, and after the global financial crisis." Journal of Financial Stability **9**(3): 373-384.
Del Río, P. and X. Labandeira (2009). "Climate change at times of economic crisis." Economía **5**: 09.
Dupont, C., S. Oberthür and I. von Homeyer (2020). "The Covid-19 crisis: a critical juncture for EU climate policy development?" Journal of European Integration **42**(8): 1095-1110.
Engström, G., J. Gars, N. Jaakkola, T. Lindahl, D. Spiro and A. A. van Benthem (2020). "What policies address both the coronavirus crisis and the climate crisis?" Environmental and Resource Economics **76**(4): 789-810.
Fioretos, O., T. G. Falleti and A. Sheingate (2016). "Historical institutionalism in political science." The Oxford handbook of historical institutionalism: 4-28.
Forster, P. M., H. I. Forster, M. J. Evans, M. J. Gidden, C. D. Jones, C. A. Keller, R. D. Lamboll, C. Le Quéré, J. Rogelj and D. Rosen (2020). "Current and future global climate impacts resulting from COVID-19." Nature Climate Change **10**(10): 913-919.
Geels, F. W. (2013). "The impact of the financial–economic crisis on sustainability transitions: Financial investment, governance and public discourse." Environmental Innovation and Societal Transitions **6**: 67-95.
Geels, F. W., G. I. Pereira and J. Pinkse (2022). "Moving beyond opportunity narratives in COVID-19 green recoveries: A comparative analysis of public investment plans in France, Germany, and the United Kingdom." Energy Research & Social Science **84**: 102368.
Geels, F. W. and J. Schot (2007). "Typology of sociotechnical transition pathways." Research policy **36**(3): 399-417.
Geller, H., P. Harrington, A. H. Rosenfeld, S. Tanishima and F. Unander (2006). "Polices for increasing energy efficiency: Thirty years of experience in OECD countries." Energy policy **34**(5): 556-573.
Guillaumat-Tailliet, F. (1987). "La France et l'énergie nucléaire: réflexions sur des choix." Revue de l'OFCE **19**(1): 189-227.
Hanna, R., Y. Xu and D. G. Victor (2020). After COVID-19, green investment must deliver jobs to get political traction, Nature Publishing Group.
Harris, J. M. (2013). Green Keynesianism: Beyond standard growth paradigms.
IEA (2020). Green stimulus after the 2008 crisis, International Energy Agency.
Ikenberry, G. J. (1986). "The irony of state strength: comparative responses to the oil shocks in the 1970s." International Organization **40**(1): 105-137.
IPCC (2006). Guidelines for National Greenhouse Gas Inventories.
IPCC (2022). Working Group III contribution to the Sixth Assessment Report (AR6): Mitigation of Climate Change.
Jalles, J. T. (2019). "Crises and emissions: New empirical evidence from a large sample." Energy Policy **129**: 880-895.
Kallis, G., V. Kostakis, S. Lange, B. Muraca, S. Paulson and M. Schmelzer (2018). "Research on degrowth." Annual Review of Environment and Resources **43**: 291-316.
Kaya, Y. (1989). "Impact of carbon dioxide emission control on GNP growth: interpretation of proposed scenarios." Intergovernmental Panel on Climate Change/Response Strategies Working Group, May.
Lamb, W. F., M. Grubb, F. Diluiso and J. C. Minx (2022). "Countries with sustained greenhouse gas emissions reductions: an analysis of trends and progress by sector." Climate Policy **22**(1): 1-17.
Lamb, W. F., T. Wiedmann, J. Pongratz, R. Andrew, M. Crippa, J. G. Olivier, D. Wiedenhofer, G. Mattioli, A. Al Khourdajie and J. House (2021). "A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018." Environmental Research Letters.

Le Quéré, C., J. I. Korsbakken, C. Wilson, J. Tosun, R. Andrew, R. J. Andres, J. G. Canadell, A. Jordan, G. P. Peters and D. P. van Vuuren (2019). "Drivers of declining CO 2 emissions in 18 developed economies." Nature Climate Change **9**(3): 213-217.
Le Quéré, C., G. P. Peters, P. Friedlingstein, R. M. Andrew, J. G. Canadell, S. J. Davis, R. B. Jackson and M. W. Jones (2021). "Fossil CO 2 emissions in the post-COVID-19 era." Nature Climate Change **11**(3): 197-199.
Loorbach, D. and L. Huffenreuter (2013). "Exploring the economic crisis from a transition management perspective." Environmental Innovation and Societal Transitions **5(**March 2013): 35-46.
Loorbach, D. A. and R. L. Huffenreuter (2013). "Exploring the economic crisis from a transition management perspective." Environmental Innovation and Societal Transitions **6**: 35-46.
Maddison Project Database (2020). Maddison style estimates of the evolution of the world economy. A new 2020 update.
Markard, J. and D. Rosenbloom (2020). "A tale of two crises: COVID-19 and climate." Sustainability: Science, Practice and Policy **16**(1): 53-60.
Meckling, J. and B. B. Allan (2020). "The evolution of ideas in global climate policy." Nature Climate Change **10**(5): 434-438.
Meles, T. H., L. Ryan and J. Wheatley (2020). "COVID-19 and EU Climate Targets: Can We Now Go Further?" Environmental and Resource Economics **76**(4): 779-787.
Mensch, G. and R. Schnopp (1980). Stalemate in Technology, 1925-1935: The Interplay of Stagnation and Innovation, Klett-Cotta.
Millot, A., A. Krook-Riekkola and N. Maïzi (2020). "Guiding the future energy transition to net-zero emissions: Lessons from exploring the differences between France and Sweden." Energy Policy **139**: 111358.
Naqvi, A. and K. Zwickl (2017). "Fifty shades of green: Revisiting decoupling by economic sectors and air pollutants." Ecological Economics **133**: 111-126.
Pan, C., G. P. Peters, R. M. Andrew, J. I. Korsbakken, S. Li, D. Zhou and P. Zhou (2017). "Emissions embodied in global trade have plateaued due to structural changes in China." Earth's Future **5**(9): 934-946.
Parker, S. and M. I. Bhatti (2020). "Dynamics and drivers of per capita CO2 emissions in Asia." Energy Economics: 104798.
Perez, C. (2013). "Unleashing a golden age after the financial collapse: Drawing lessons from history." Environmental Innovation and Societal Transitions **6**: 9-23.
Peters, G. P., G. Marland, C. Le Quéré, T. Boden, J. G. Canadell and M. R. Raupach (2012). "Rapid growth in CO 2 emissions after the 2008–2009 global financial crisis." Nature climate change **2**(1): 2-4.
Quitzow, R., G. Bersalli, L. Eicke, J. Jahn, J. Lilliestam, F. Lira, A. Marian, D. Süsser, S. Thapar and S. Weko (2021). "The COVID-19 crisis deepens the gulf between leaders and laggards in the global energy transition." Energy Research & Social Science **74**: 101981.
Rosenbloom, D. and J. Markard (2020). A COVID-19 recovery for climate, American Association for the Advancement of Science. **368:** 447-447.
Royo, S. (2020). From boom to bust: The economic crisis in Spain 2008–2013. Why banks fail, Springer**:** 119-140.
Savona, M. and T. Ciarli (2019). "Structural changes and sustainability. A selected review of the empirical evidence." Ecological economics **159**: 244-260.
Schmidt, T. S., B. Steffen, F. Egli, M. Pahle, O. Tietjen and O. Edenhofer (2019). "Adverse effects of rising interest rates on sustainable energy transitions." Nature Sustainability **2**(9): 879-885.
Smulders, S., M. Toman and C. Withagen (2014). "Growth theory and 'green growth'." Oxford review of economic policy **30**(3): 423-446.
Steffen, B., F. Egli, M. Pahle and T. S. Schmidt (2020). "Navigating the clean energy transition in the COVID-19 crisis." Joule **4**(6): 1137-1141.
Weiss, M. and C. Cattaneo (2017). "Degrowth–taking stock and reviewing an emerging academic paradigm." Ecological Economics **137**: 220-230.
World Bank (2022). World Development Indicators. W. Bank.