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Growth, Coal and Carbon Emissions:
Economic Overheating and Climate Change

Emanuel Kohlscheen, Richhild Moessner and Elői Takáts[1] [2]

Abstract

We use a comprehensive database of 121 countries over the 1971-2016 period to study how macroeconomic factors drive carbon (carbon-dioxide) emissions. For this purpose, dynamic panel regressions are estimated. Carbon emissions rise with economic development, manufacturing activity, urbanization and increasingly with economic growth. In electricity generation, the use of coal, and to a lesser degree of oil, is associated with higher carbon emissions, while renewable energy use is already associated with lower national emissions in advanced economies. We also uncover a non-linearity: economic overheating is particularly harmful when coal use is more intensive. The results suggest that mitigating economic cycles might also reduce carbon emissions.

JEL Classification: O40; O44; Q00; Q40; Q50

Key words: carbon dioxide; climate change; coal; emissions; energy; environment; growth; pollution; urbanization

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[2] We are grateful for comments from Dubravko Mihaljek, Nikola Tarashev, Egon Zakrajšek, an anonymous reviewer and seminar participant at the Bank for International Settlements. All remaining errors are our own. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank for International Settlements.

1. Introduction

Climate change is perhaps the most pressing challenge of our time. There is overwhelming evidence on the unprecedented risks it poses to our economies and to our lives. The main climate change scenarios, assuming the continuation of current policies, suggest a roughly 3 degree Celsius increase in global temperatures from pre-industrial levels by the end of the century (Group of 30, 2020). The considerable uncertainty around the climate change process means that even sharper temperature increases are also plausible. Therefore, our current economic development path is unsustainable. To avoid a climate catastrophe we need to reduce the emission of greenhouse gases – chiefly that of carbon-dioxide (CO_2) – that drive climate change (Stern, 2007, 2008). Economic policy cannot avoid considering climate change anymore.

Hence, a key question for policymakers is how to map macroeconomic variables into carbon emissions. A more precise understanding could help to devise the right structural and cyclical policies towards a more sustainable economy. This understanding could also help decision makers to factor in the carbon emission impact of various policies, such as economic stabilisation.

This paper provides such mapping between key macroeconomic variables and carbon emissions. We use comprehensive data from a panel of 121 countries over the 1971-2016 period to establish the link between per capita carbon emissions and macroeconomic variables, such as GDP growth, the level of urbanization and the mix in the use of energy, including the role of coal, oil and renewable energy sources. We study our panel both across advanced and emerging economies – and also across different time periods.

We find both linear and non-linear carbon emission drivers. On the linear side, we obtain three main findings. First, carbon emissions increase with the level of economic development. Higher income countries have higher emissions, both across advanced and emerging economies. Second, economic growth is replacing urbanization as a major driver of carbon emissions across countries. While the sensitivity of carbon emissions has increased, particularly across emerging markets, the sensitivity to urbanization has diminished. Third, we confirm that reliance on coal in the energy mix greatly increases carbon emissions throughout. Conversely, relying on renewable energies significantly lowers carbon emissions. Encouragingly, the effect of renewables has become economically and statistically significant in advanced economies during the last decades. Throughout the paper, our inference is based on standard errors computed according to Driscoll and Kraay (1998), which are robust to general cross-sectional and temporal dependence.

We also uncover a non-linear link between economic activity and carbon emissions. This fourth finding is, to the best of our knowledge, new. We follow the hypothesis that overheating economies might use a less efficient mix of resources: capital, labour and the energy mix might deviate from the optimal one as capacity becomes scarce. Indeed, we find that electricity generation relies more heavily on coal, the dirtiest energy source, during overheating episodes. Overall, we find that the interaction between economic growth and coal use is significant and positive for carbon emissions. The results suggest that booms can disproportionally increase the use of carbon heavy coal and thereby contribute to additional emissions.

The findings are policy relevant. Our linear models results provide broad support for structural policies aimed at greening the energy mix. They clearly highlight the very negative role of coal, and to a lesser extent of oil – and the positive impact of renewable energy sources. Here, our new finding that the sensitivity of carbon emissions to growth is increasing seems particularly relevant. Our non-linear results are particularly relevant for cyclical economic policies. In particular, central banks might find it relevant that economic stabilisation, which is within most central bank mandates, could also mitigate carbon emissions, and thereby lessen the risks of climate change.

The rest of the paper proceeds as follows. Section 2 discusses the related literature. Section 3 summarizes the data. Section 4 presents the methodology. Section 5 presents our structural estimates. Section 6 discusses our cyclical estimates. The final section concludes with policy implications and suggests possible directions for future research.

2. Literature

Our study relates to a rapidly growing empirical literature on the effects of economic growth on carbon emissions and climate change. We do not aim to provide a full review of this literature here, but rather link our study to selected relevant studies.

The result that emissions grow in tandem with the rise in per capita GDP aligns well with earlier findings by Raupach et al (2007). These authors had already pointed to the increasing role of emerging markets and less developed countries in emission growth.[3] More broadly, our findings in this respect also tend to align well with the long held conclusion of Holtz-Eakin and Selden (1995) that CO_2 emissions will continue to grow because of rapid output growth in emerging countries. Absent major policy interventions, increased energy efficiency is unlikely to match the negative environmental impacts coming from GDP growth.

The finding that urbanization increases per capita carbon emissions in a significant way contrasts with that of Sadorsky (2014), who used a selection of 16 emerging economies. That study had found a positive, but statistically insignificant effect of urbanization. Our findings on the effects of urbanization are likely to be more significant in part because our study covers a much larger set of countries and a longer time period. With respect to urbanization, our conclusions resonate more with Kasman and Duman (2015). Further, we find that the contribution of urbanization has been weakening more recently, as the process may have run its course in many countries.

As to what regards the energy mix, our most striking result is the very negative implications of coal use for CO_2 emissions per capita. This in itself is not new (see, for instance, the International Energy Agency (2019) report). However, to the best of our knowledge, we are the first to show that this effects has increased recently. Furthermore, we do find that greater use of renewables is associated with lower CO_2 emissions in advanced economies. This adds new evidence to our understanding as earlier studies, such as Menyah and Wolde-Rufael (2010), concluded that renewable energy use had not yet reached a critical mass that would allow it to reduce emissions in a meaningful way. Our results suggest that for some key countries renewable energy has reached the development level, where its impact is already visible even at the macro level.

Our findings on coal also support other work that highlights coal's oversized role in carbon emissions. An interesting theoretical study in this area is worth mentioning: Harstad (2012) shows that the best way to address free-riding in international climate coalitions might be simply to buy all coal reserves and conserve them. Coal is so harmful for climate change, that directly

[3] Interestingly, Wang (2012) finds that, when it comes to oil related CO_2 emissions, economic data do not support the environmental Kuznets curve hypothesis.

blocking coal use through market operations might be more efficient than international trade restrictions or tariffs on polluters (Nordhaus, 2015). Empirically, the recent paper of Coglianese et al. (2020) examines the factors behind a reduction in coal production in the United States from 2008-2016. In turn, Hassler et al. (2018) use an integrated assessment model with two fossil fuels and green energy and find that the largest policy error arises when climate policy is overly passive, whereas a high carbon tax should be applied when climate changes. They argue that its negative impacts on the economy are very limited since there is considerable substitutability between fossil and non-fossil energy sources.

We also present new results on the increased linkage between GDP growth and CO_2 emissions. Gonzalez-Sanchez and Martin-Ortega (2020) also find a positive relation between emissions and GDP growth in a recent study for a group of ten euro area countries since the 1990s. They, however, do not track the evolution of this relation over time. Our results also resonate for instance with Feng et al (2015), who had found that the main driver of emissions growth in the case of the United States prior to the global financial crisis was GDP growth. They also concluded that the reduction in emissions in the immediate aftermath of the crisis was linked to weak economic activity, and not to any change in the fuel mix. Earlier, also Peters et al (2012) had noted that global CO_2 emissions resumed their pre-crisis trend quite rapidly after the global financial crisis. A similar pattern could be likely in the post-Covid-19 recovery. The International Energy Agency (2020) estimates an unprecedented fall in CO_2 emissions of around 8% in 2020 arising mainly due to the economic slowdown of the Covid crisis. However, their analysis suggests that the rebound in CO_2 emissions after the crisis may be even larger than the decline, unless the investment to restart the economy is dedicated to cleaner energy.

Our approach links carbon emissions not only to the structural developments, but also to the cyclical evolution of the macroeconomy. To the best of our knowledge, the systematic association of overheating economic activity and greater coal use, with the correspondent larger detrimental effects for emissions, is original. The closest study in this respect is that of Doda (2014), who finds that emissions are procyclical and that, if anything, procyclicality increases with the level of income. Furthermore, our conclusions are also broadly consistent with a strong reduction in CO_2 emissions during the Covid-19 crisis (International Energy Agency, 2020).

3. Data

We compile our data from two sources in order to assess the empirical drivers of carbon dioxide emissions. First, we collect demographic, economic and energy use data from the World Bank: GDP per capita, GDP growth, the urbanization rate, share of manufacturing in GDP and share of coal, oil and renewables in electricity generation. Second, we collect carbon dioxide (CO_2) emission per capita, as measured in metric tons, from the Carbon Dioxide Information Analysis Center (CDIAC) at the U.S. Department of Energy's Oak Ridge National Laboratory in Tennessee.

Our joint dataset spans the 1971-2016 period and 121 countries. The country selection is based solely on data availability. We retain only countries for which all the variables were available for at least 10 years in the sample. This leaves us with an unbalanced panel with 3,895 country-year observations. The full list of variables, including their mean and standard deviations, are listed in Table 1.

Table 1: Summary statistics

variable	observations	mean	std. dev.
CO2 per capita (in metric tons)	3,895	4.633	6.252
GDP per capita (log)	3,895	8.443	1.447
GDP growth	3,895	0.039	0.054
urbanization rate	3,895	0.565	0.221
manufacturing / GDP	3,895	0.152	0.063
share of electricity from oil	3,895	0.218	0.284
share of electricity from coal	3,895	0.150	0.251
share of electricity from renewables	3,895	0.028	0.062

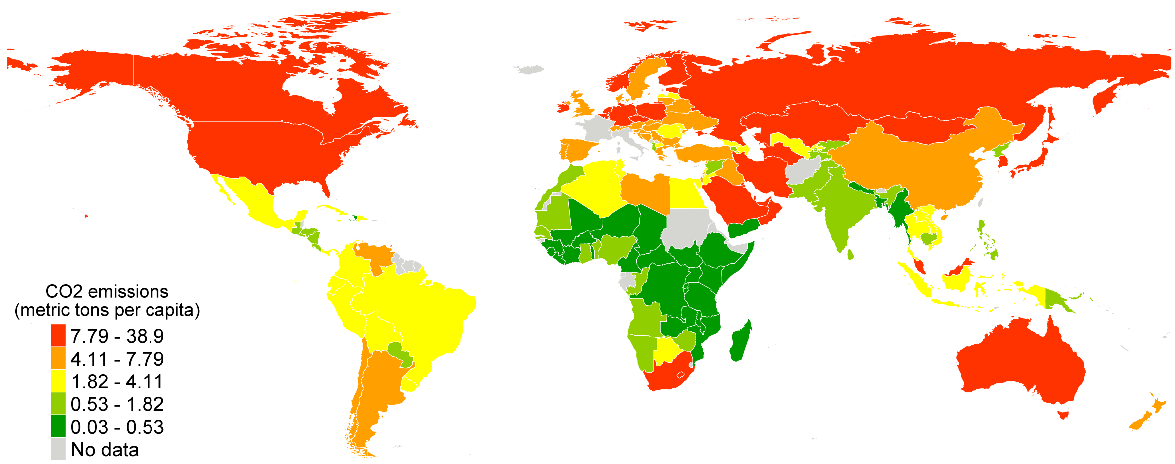
Our main variable of interest is carbon emissions. These emissions emanate mostly from the burning of fossil fuels (to heat, transport goods and people or generate electricity) and the manufacture of steel and cement.

The level of carbon emissions, following that of economic development, is highly uneven across countries. Highly developed advanced economies tend to emit large quantities of carbon per capita, while less developed economies, particularly in Africa or India, tend to emit less (Figure 1). However, there is no definite advanced-emerging economy divide: due to fast economic development many emerging market economies (including energy producers and fast developing East Asian economies) already have high carbon emission levels per capita. This is very different from the start of the sample: in 1971 advanced economies dominated per capita carbon emissions (Figure A1 in the Appendix). This largely reflects both decreasing per capita carbon emissions in Europe and, to lesser degree, in North America, and increasing emissions in East Asia and, to a lesser degree, in North Africa and the Middle East (Figure A2 in the Appendix).

Carbon emissions per capita

2016

Figure 1

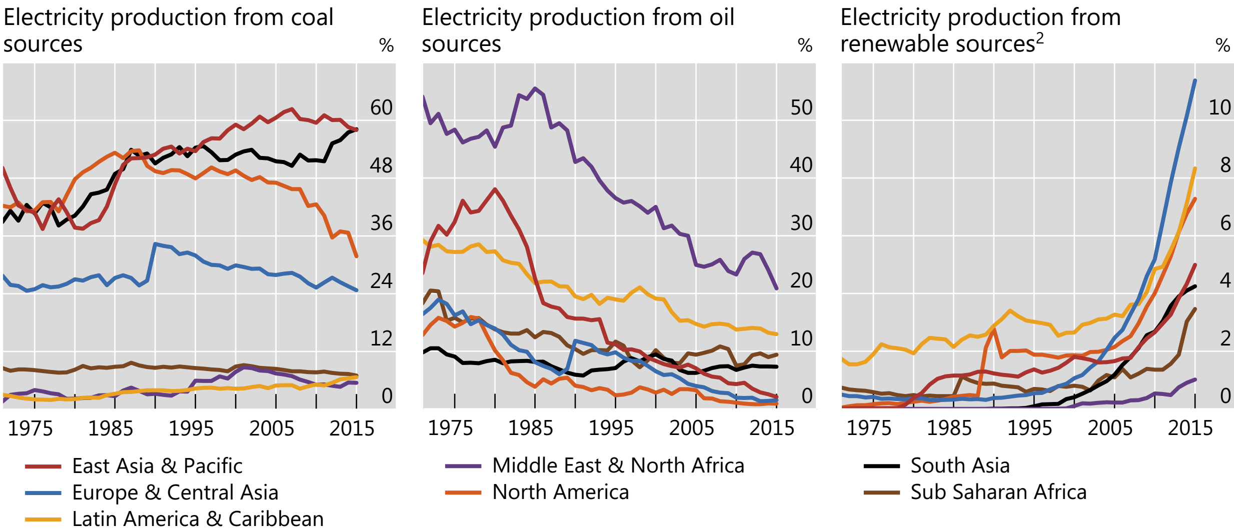


When we disentangle the drivers of emissions, our main explanatory variables are economic development (GDP per capita, valued at 2010 US dollars, and real economic growth) and economic structure (the urbanization rate and share of manufacturing in GDP). Over the sample period, real GDP per capita has grown fast, averaging 3.9%. Overall, we observe a convergence in the urbanization rate: Latin America converged to North American levels, and East Asia to European levels (right-hand panel, Figure A3 in the Appendix). The initially stark differences in urbanization have been much attenuated in the recent sample. We also control for the share of manufacturing in domestic output – as larger reliance on manufacturing might be associated with larger emissions.

Furthermore, we utilise information on the energy mix used to produce electricity, including the share of coal, oil and renewables (Figure 2). One striking observation is the still large role of coal, which is the dirtiest energy source (left-hand panel). More than one-half of Asian electricity generation relies on coal today, up from slightly more than one-third in the early 1970s. Coal use has also increased in North America as electricity generation moved from oil to coal (centre panel), and the coal share declined only recently due to the increased use of shale gas and renewables. The share of oil, partly reflecting rising oil prices, has receded throughout our sample in all regions, albeit with some heterogeneity (centre panel). In contrast, renewable energy has started to increase spectacularly after the 2000s (right-hand panel). Renewables are particularly widely used in advanced economies, in Europe and North America and also in many Latin American countries.

Electricity production

In percent of total[1] Figure 2



[1] Population-weighted averages. [2] Excluding hydroelectric power. Source: IEA Statistics.

In addition, we expand our analysis with several robustness checks. For these checks, we extend our sample to include further relevant variables for carbon emissions, such as the motorisation rate (see Table A2 in the Appendix). However, the motorisation rate does not seem to affect our results – yet, it constrains our sample. The motorisation rate is only available for a broad set of countries after 2000. Therefore, we focus on the baseline specification without it, and include it only in robustness checks later.

4. Methodology

We investigate the evolution of carbon emissions in a dynamic panel model as carbon emissions tend to be highly persistent. Formally, we explore the potential drivers of carbon-dioxide emissions (denoted by CO2) along the lines of equation (1) below:

$$\begin{aligned} \mathrm{CO2}_{i,t} = {} & \alpha_i + \beta_t + \delta\, \mathrm{CO2}_{i,t-1} + \gamma\, \mathrm{GDPpc}_{i,t} + \theta\, \mathrm{growth}_{i,t} \\ & + \omega\, \mathrm{urbanization}_{i,t} + \vartheta\, \mathrm{manufacturing}_{i,t} + \mu_1 \mathrm{share}_{oil,i,t} \\ & + \mu_2\, \mathrm{share}_{coal,i,t} + \mu_3\, \mathrm{share}_{renewables,i,t} + \varepsilon_{i,t} \end{aligned} \tag{1}$$

Besides the lagged dependent variable, we include a number of explanatory variables. Throughout, our models include country fixed effects to capture unobserved heterogeneities across countries that might affect the rate of carbon dioxide emissions. These include institutional factors like enforcement of environmental laws and also natural factors such as average median temperatures correlating with heating needs. In our baseline specification we also include the full set of yearly time dummies to control for global factors. These subsume for instance technological advances that may reduce environmental effects, as well as other global trends or global shocks.

We also include key economic variables that could explain the evolution of carbon emissions. Our baseline model includes GDP per capita (GDPpc), real GDP growth (growth), the urbanization rate (urbanization), the manufacturing/GDP ratio (manufacturing) and the share of oil, coal and renewables in electricity generation (share_{oil}, share_{coal} and $\mathrm{share}_{renewables}$, respectively).

In order to understand the potential non-linear drivers of carbon emissions, we expand our structural model of equation (1) with an interaction term between the demeaned share of coal used for electricity generation ($\overline{\mathrm{share}_{coal,i,t}}$) on the one hand and demeaned GDP growth ($\overline{\mathrm{growth}_{i,t}}$) on the other hand. For demeaning we use the country-specific means in order to capture country-specific deviations from trend. Formally, we estimate a variation of equation (1) as follows:

$$\begin{aligned} \mathrm{CO2}_{i,t} = {} & \alpha_i + \beta_t + \delta\, \mathrm{CO2}_{i,t-1} + \gamma\, \mathrm{GDPpc}_{i,t} + \theta\, \mathrm{growth}_{i,t} \\ & + \omega\, \mathrm{urbanization}_{i,t} + \vartheta\, \mathrm{manufacturing}_{i,t} + \mu_1\, \mathrm{share}_{oil,i,t} + \mu_2\, \mathrm{share}_{coal,i,t} \\ & + \mu_3\, \mathrm{share}_{renewables,i,t} + \omega\, \overline{\mathrm{share}_{coal,i,t}} * \overline{\mathrm{growth}_{i,t}} + \varepsilon_{i,t} \end{aligned} \tag{2}$$

A positive interaction term in equation (2) would signal that above trend growth in coal intensive economies increases carbon emissions non-linearly, i.e. more than what one would normally expect based on GDP growth and the share of coal alone. Economic overheating could lead to additional carbon emissions, if economic actors, observing a relative scarcity of various inputs - including energy, start resorting to less efficient and dirtier energy sources.

Throughout we use fixed effect panel estimations and apply Driscoll-Kraay (1998) standard errors to ensure robustness to both cross-sectional and temporal dependence.

5. Linear Model Estimates

5.1 Baseline model

We first turn to estimate our linear dynamic panel equation (Table 1). The baseline specification can describe the country-specific evolution of carbon emissions relatively well (Model 1). The lagged dependent variable has a coefficient of 0.8 and is highly statistically significant, which confirms that a dynamic panel specification is indeed appropriate.[4] Also, the Pesaran (2015) CD-test clearly rejects the null hypothesis of cross-section independence for some models, suggesting that using Driscoll-Kraay standard errors are indeed appropriate.

Table 2
Dynamic model of CO2 emissions

Dependent variable: CO2 emissions per capita (in metric tons, log)

		model	
	(I) - BASELINE	(II)	(III)
	global model with time dummies	global model with time trend	global model with Brent price
previous year CO2 per capita	0.806***	0.806***	0.741***
	0.028	0.027	0.027
GDP per capita (log)	0.072***	0.068***	0.094***
	0.013	0.012	0.007
GDP growth	0.210***	0.222***	0.176***
	0.040	0.041	0.054
urbanization rate	0.186***	0.186***	0.205***
	0.037	0.037	0.054
manufacturing / GDP	0.124***	0.136***	0.136***
	0.030	0.031	0.047
share of electricity from oil	0.045***	0.045***	0.082***
	0.010	0.011	0.011
share of electricity from coal	0.148***	0.154***	0.197***
	0.019	0.020	0.025
share of electricity from renewables	-0.103***	-0.120***	-0.207***
	0.035	0.034	0.035
oil price in USD (deflated by PCE, log)			-0.007***
			0.003
time trend		-0.046***	
		0.017	
observations	3886	3886	2889
number of countries	121	121	121
country fixed effects	yes	yes	yes
time fixed effects	yes	no	no
CD-test	0.199	10.726	7.828
p-value of CD-test	0.842	0.000	0.000
R2	0.882	0.879	0.802

Note: Sample period: from 1971 to 2016, annual data. Standard errors reported in brackets are computed according to Driscoll and Kraay (1998). ***/**/* denote statistical significance at the 1%/5%/10% level.

The baseline model explanatory variables also tend to be statistically significant. First, per capita emissions clearly rise in tandem with economic development (as captured by GDP per

[4] Also, the CD-test clearly rejects the null hypothesis of cross-section independence for some models, suggesting that using Driscoll-Kraay standard errors are indeed appropriate.

capita). The second observation is that not only the level of GDP per capita matters, but also the pace of economic growth. Higher GDP growth is associated with higher emissions. Third, higher urbanization is systematically associated with a higher rate of emissions per head. The effects of higher congestion do not appear to be matched by a possibly higher awareness of environmental issues in urban areas.

Our results for the share of energy highlight the negative role of coal and the positive effect of renewables. A greater usage of coal clearly increases carbon emissions. Based on the baseline specification, a one standard deviation increase in coal reliance increases per capita log CO2 emissions by 0.037 in the short-run on average. In the long-run, the effect increases to 0.191 (i.e. 0.251*0.148/(1-0.806)). Usage of oil typically has a much lower coefficient. Finally, the use of renewable energy is significantly associated with lower emissions. This result may be an indication that such use has already reached a critical mass, so as to produce a beneficial impact on overall emissions.

We investigate unobserved energy efficiency through the time trend. In doing so, we replace the time fixed effects with a time trend (Table 2, Model 2). The time trend variable has a negative sign, signalling a modest trend towards less emissions per capita *ceteris paribus*.

In the third specification we control for the effect of oil prices on carbon emissions (Table 2, Model 3). Here we include the USD price of a Brent barrel, deflated by the personal consumption expenditures (PCE) price index in the United States. The underlying hypothesis is that higher energy prices would increase energy efficiency and thereby reduce carbon emissions. Indeed, we find that a higher international oil price tends to dampen emissions. One explanation for the relative weakness of the effect is the potential substitution between coal and oil, i.e. higher oil prices might induce a higher use of carbon-intensive coal.

5.2 Heterogeneity across time and countries

To further our understanding of broad drivers of emission trends, we re-estimate the baseline model for several sub-samples both across time and across different groups of countries.

First, we focus on different time periods (Table 3). In the first half of the sample (that is, between 1971 and 1993) rapid urbanization and growth in manufacturing drove carbon quite emissions strongly (Model 2). In contrast, in the second half of the sample (1994-2016), these effects weaken considerably, while the effect of GDP growth grows in magnitude. In fact, the point estimate of its coefficient increases by about 50%.

Furthermore, the energy mix starts to have a much clearer effect on per capita emissions in the more recent sample. Throughout, the most negative environmental impact comes from the use of coal. Importantly, the short-run impact of the reliance on coal nearly triples in the most recent part of the sample. At the same time, the beneficial effect of reliance on renewable sources has also increased substantially, and become statistically significant.

Table 3
Dynamic model of CO2 emissions: selected subsamples

Dependent variable: CO2 emissions per capita (in metric tons, log)

	model		
	(I)	(II)	(III)
	1971-2016	1971-1993	1994-2016
previous year CO2 per capita	0.806***	0.727***	0.746***
	0.028	0.046	0.026
GDP per capita (log)	0.072***	0.097***	0.100***
	0.013	0.02	0.007
GDP growth	0.210***	0.151**	0.224***
	0.040	0.064	0.051
urbanization rate	0.186***	0.383***	0.232***
	0.037	0.085	0.061
manufacturing / GDP	0.124***	0.210***	0.148**
	0.030	0.061	0.061
share of electricity from oil	0.045***	0.021	0.087***
	0.010	0.014	0.014
share of electricity from coal	0.148***	0.075***	0.223***
	0.019	0.019	0.028
share of electricity from renewables	-0.103***	-0.011	-0.187***
	0.035	0.034	0.035
observations	3886	1362	2524
number of countries	121	86	121
country fixed effects	yes	yes	yes
time fixed effects	yes	yes	yes
CD-test	0.199	141.8	225.7
p-value of CD-test	0.842	0.000	0.000
R2	0.882	0.767	0.787

Note: Sample period: from 1971 to 2016, annual data. Standard errors reported in brackets are computed according to Driscoll and Kraay (1998). ***/**/* denote statistical significance at the 1%/5%/10% level.

Next, we turn to examine the differences between advanced and emerging economies (Table 4). Here we classify all countries with GDP per capita above $15,000[5] as advanced economies (left-hand panel) and classify all other countries in our sample as emerging economies (right-hand panel). The models explain between 69% and 90% of the variation in CO_2 emissions. The CD-test rejects cross-sectional independence in all cases.

[5] In fixed 2010 dollars.

Table 4
Dynamic model of CO2 emissions: Advanced vs Emerging Market Economies

Dependent variable: CO2 emissions per capita (in metric tons, log)

	advanced economies			emerging market economies		
	(I)	(II)	(III)	(IV)	(V)	(VI)
	1971-2016	1971-1993	1994-2016	1971-2016	1971-1993	1994-2016
previous year CO2 per capita	0.776***	0.686***	0.694***	0.820***	0.722***	0.758***
	0.031	0.043	0.054	0.03	0.057	0.031
GDP per capita (log)	0.045**	0.070*	0.098***	0.077***	0.107***	0.094***
	0.02	0.037	0.032	0.012	0.026	0.009
GDP growth	0.244***	0.204*	0.224**	0.202***	0.129*	0.216***
	0.076	0.115	0.098	0.048	0.069	0.056
urbanization rate	0.157**	0.568**	0.162**	0.140***	0.294***	0.194**
	0.075	0.201	0.074	0.033	0.076	0.078
manufacturing / GDP	0.226**	0.111	0.409**	0.098***	0.177***	0.069
	0.111	0.344	0.181	0.032	0.044	0.047
share of electricity from oil	0.088**	0.052	0.116**	0.022**	0.014	0.078***
	0.036	0.054	0.052	0.009	0.013	0.011
share of electricity from coal	0.132***	0.070*	0.260***	0.097***	0.109***	0.178***
	0.032	0.034	0.033	0.019	0.024	0.042
share of electricity from renewables	-0.173***	-0.134	-0.282***	-0.005	-0.019	-0.067
	0.044	0.305	0.058	0.025	0.028	0.042
observations	945	257	688	2941	1105	1836
number of countries	38	18	37	92	70	90
country fixed effects	yes	yes	yes	yes	yes	yes
time fixed effects	yes	yes	yes	yes	yes	yes
CD-test	53.7	137.4	231.8	6.4	38.2	16.9
p-value of CD-test	0.000	0.000	0.000	0.000	0.000	0.000
R2	0.776	0.687	0.738	0.903	0.797	0.809

Note: Sample period: from 1971 to 2016, annual data. Standard errors reported in brackets are computed according to Driscoll and Kraay (1998). ***/**/* denote statistical significance at the 1%/5%/10% level.

The effect of GDP growth on CO_2 emissions has increased in the recent sample, relative to the early sample, for both advanced and emerging economies (compare Model 2 with 3 and Model 5 with 6). The increase is particularly pronounced for emerging countries. In terms of magnitude, the coefficient for poorer countries seems to have converged to that of advanced ones. Furthermore, the coefficient of the coal share in electricity generation has clearly increased significantly in both cases.

5.3 Robustness

We undertake a number of robustness checks. First, we extend our energy mix with information on the use of hydroelectric, gas and nuclear power (Table A1 in the Appendix). These variables have coefficients that overall are still not significantly different from zero at the 5% level. Furthermore, their inclusion does not materially change the coefficient estimates for the other variables.

We also extend our model with the motorisation rate (Table A2 in the Appendix). That is we include the number of vehicles per 1,000 people as an explanatory variable. Albeit data availability shrinks the sample by around two-thirds, controlling for the motorisation rate in each country does not change the broad pattern of our results. Furthermore, the motorisation variable itself is not found to be significant, when we also control for GDP level and growth. The insignificance and the large drop in sample size lead us not to include motorisation in our main specification.

6. Non-linear estimates: Overheating and Coal

Next, we turn to investigate the non-linear relationship between economic activity and carbon emissions. The underlying hypothesis that we test is whether carbon emissions increase due to overheating economies. We posit that red-hot economies may strain energy resources within a country and lead to increased use of more carbon intensive sources, such as coal.

Table 5
Dynamic model of CO2 emissions: with interaction term (coal use * GDP growth)
Dependent variable: CO2 emissions per capita (in metric tons, log)

	1971-2016	1971-1993	1994-2016
previous year CO2 per capita	0.806***	0.727***	0.744***
	0.028	0.046	0.027
GDP per capita (log)	0.072***	0.097***	0.097***
	0.012	0.020	0.009
GDP growth	0.227***	0.152**	0.266***
	0.041	0.064	0.037
urbanization rate	0.188***	0.382***	0.241***
	0.038	0.086	0.063
manufacturing / GDP	0.129***	0.211***	0.157***
	0.030	0.061	0.058
share of electricity from oil	0.045***	0.022	0.086***
	0.010	0.014	0.014
share of electricity from coal	0.146***	0.075***	0.216***
	0.019	0.019	0.026
share of electricity from renewables	-0.103***	-0.012	-0.190***
	0.035	0.034	0.037
demeaned share of coal * demeaned GDP growth	0.818**	0.164	1.258***
	0.323	0.260	0.264
observations	3881	1357	2524
number of countries	121	86	121
country fixed effects	yes	yes	yes
time fixed effects	yes	yes	yes
CD-test	0.2	141.3	224.7
p-value of CD-test	0.851	0.000	0.000
R2	0.883	0.767	0.789

Note: Sample period: from 1971 to 2016, annual data. Standard errors reported in brackets are computed according to Driscoll and Kraay (1998). ***/**/* denote statistical significance at the 1%/5%/10% level.

To test this hypothesis, we expand our baseline model with an interaction term between GDP growth and coal use (see equation (2) in the section on Methodology). To assure that the variable relates to the pattern observed in each country and to variations at the margin, we first demean GDP growth and coal use by their respective country-specific means.

We obtain a positive and statistically significant coefficient estimate for the interaction term in the full sample and the most recent sample (Table 5). All the other coefficient estimates are consistent with previous results, suggesting that the interaction term does not subsume their explanatory power. The positive sign of the interaction term indicates that emissions increase particularly when GDP growth and coal use are both above their historical norms in a given country (Model 1). We take this as prima facie evidence of greater reliance on dirty energy when GDP growth is higher. Moreover, while the point estimate of the interaction term was also positive in the early part of the sample (Model 2), it became much larger and statistically significant in the recent sample (Model 3). This suggests that the relation between economic overheating and coal use has intensified.

We also test the hypothesis directly. Specifically, we estimate a parsimonious dynamic panel model of the drivers of coal use in the energy matrix (Table 6). To assert global significance, we focus on the 11 G-20 member countries where coal accounted for more than 30% of electricity production. This group includes all six largest economies of the world. First, the results confirm the persistence of coal use: the lagged dependent variable is consistently significant in all specifications. Furthermore, while higher GDP growth did not generally lead to larger reliance on coal before 2000, it clearly has done so since the turn of the millennium. In the post-2000 sample, increased economic growth is associated with a higher share of coal in the energy mix.[6] Particularly in East and South Asia, economic growth and the share of coal have tended to move hand-in-hand (Figure A4 in the Appendix).

Table 6
Intensity of coal use in electricity production and GDP growth

Dependent variable: Share of coal in electricity production (in %, demeaned)

	1980-1999	2000-2016
Share of coal in electricity (lagged)	0.887***	0.910***
	0.082	0.048
GDP growth (lagged, demeaned)	-0.059	0.225***
	0.095	0.058
observations	220	176
number of countries	11	11
CD-test	44.2	40.9
p-value of CD-test	0.000	0.000
R2	0.769	0.726

Note: Estimated on yearly data. Included countries are all G-20 countries where the share of coal exceeded 30% at least once after 2000 (i.e. Australia, China, Germany, India, Indonesia, Japan, South Africa, South Korea, Turkey, United Kingdom and the United States). Standard errors reported in brackets are computed according to Driscoll and Kraay (1998). ***/**/* denote statistical significance at 1/5/10% confidence level.

All in all, these results point to potentially damaging effects of running overly heated economies. This is because the increased use of coal in the energy mix significantly worsens carbon emissions. Therefore, they suggest that cyclical stabilisation policies might also offer positive environmental impact.

[6] Very similar results to those obtained in Table 6 are also obtained when we include the full set of country specific time trends.

7. Conclusion

We use comprehensive data from a panel of 121 countries over the 1971-2016 period to link per capita carbon emissions to key macroeconomic variables, such as GDP growth, the level of urbanization and the energy mix, including the role of coal, oil and renewable energy sources. As we show, the linkage between emissions and GDP growth has been strengthening over time, with higher point estimates in the most recent sample.

We also uncover novel non-linear links between the economy and carbon emissions. We follow the hypothesis that overheating economies might use a less efficient energy mix as capacities become scarce. We find evidence that indeed during economic booms the use of coal increases. Overall, the interaction between economic growth and coal use is significant and positive for carbon emissions: i.e. booms disproportionally increase the use of carbon heavy coal and thereby contribute to additional CO_2 emissions.

The findings are policy relevant. Our linear model findings provide broad support for structural policies to green the energy structure. They highlight the negative role of coal, and to a much lesser extent that of oil – and the positive impact of renewable energy sources. The consistently negative impact of coal provides clear support for policy efforts to steer away from coal. Our new finding that the carbon intensity of economic growth is increasing also underscores the urgency of the ongoing climate change reforms.

Perhaps even more policy relevant are the non-linear model findings. They might matter especially for central banks, which have the mandate to maintain stable economic conditions over time. Our results suggest that carbon emissions can rise disproportionately during booms. Therefore, mitigating the boom-bust cycle might also contribute to reducing carbon emissions. This finding might be particularly relevant as central banks assess what role they can play in mitigating climate change within their mandates.

We hope that our analysis will pave the way for future research about the relationship between the economy and climate change. While our large panel helped to identify global trends, using more granular, country level data could nuance our findings with relevant country specifics. Of particular interest is the level at which GDP growth tips the energy mix into more carbon intensive sources in each country.

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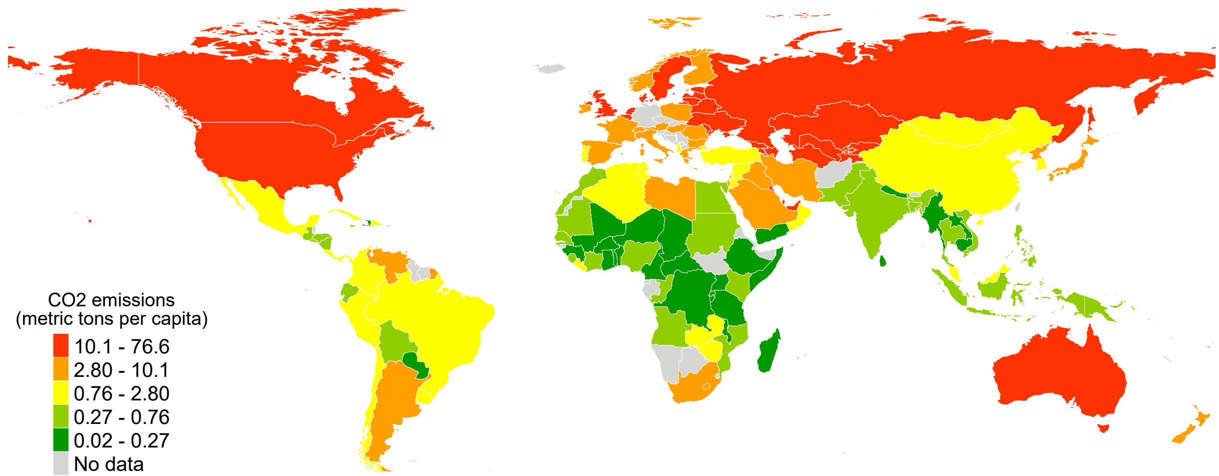
Appendix

Carbon emissions per capita

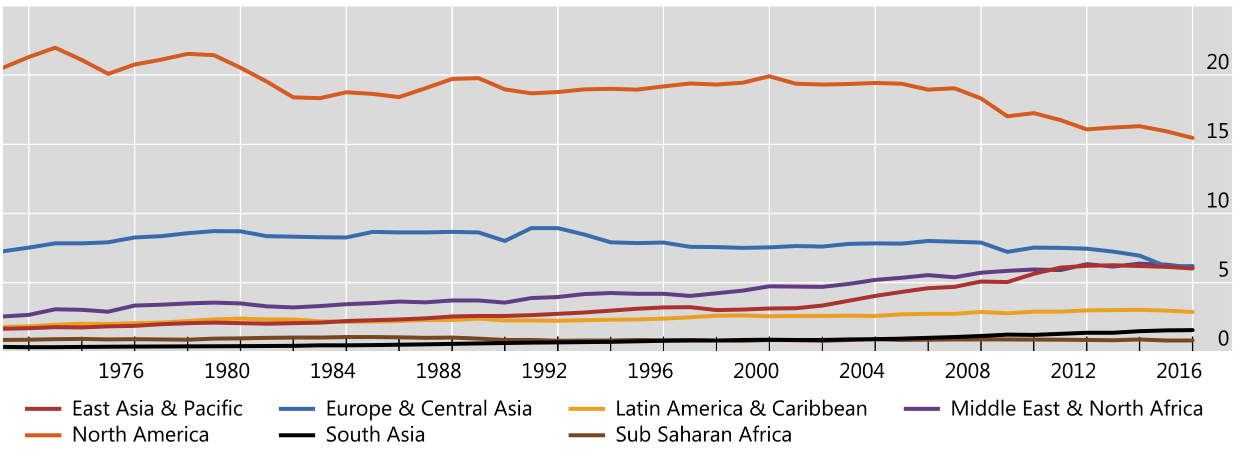
1971 Figure A1



For Soviet union countries, data of Russia are applied.

CO_2 emissions

Metric tons per capita[1] Figure A2

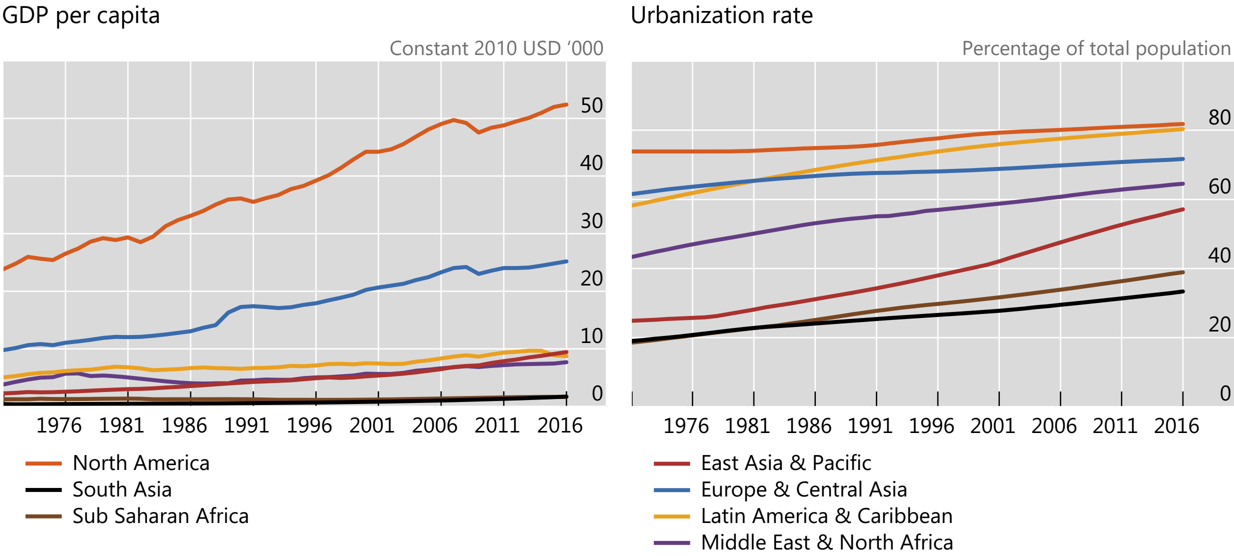


[1] Population-weighted averages.

Source: Carbon Dioxide Information Analysis Center (CDIAC) at the U.S. Department of Energy's Oak Ridge National Laboratory.

Urbanization and economic growth across regions

Figure A3



Population-weighted averages.

Share of coal versus GDP growth by region (in %)

Figure A4

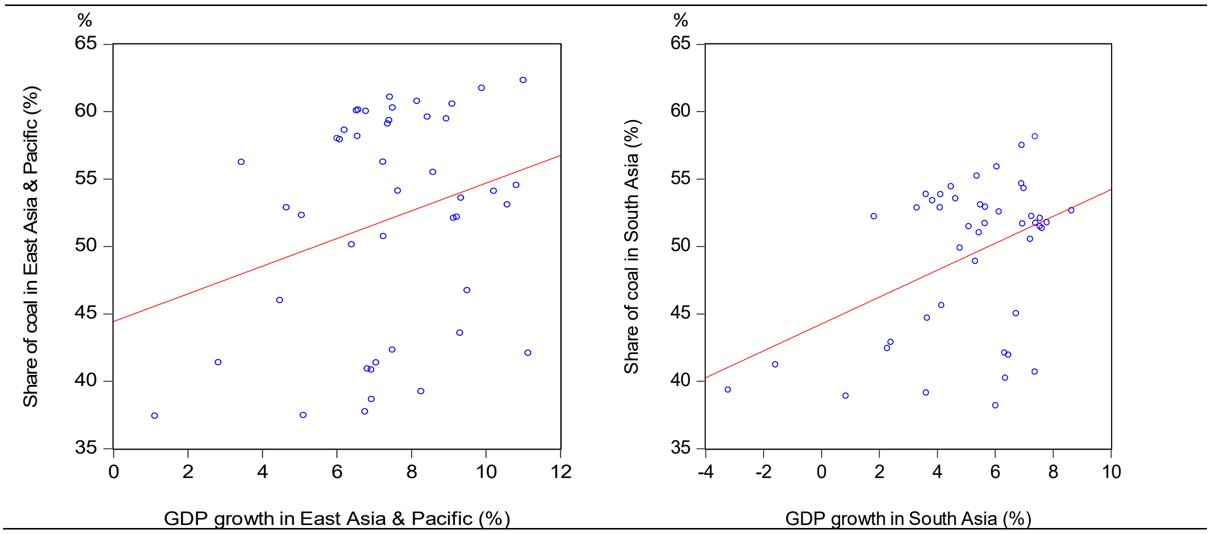


Table A1
Robustness check: with all energy sources

Dependent variable: CO_2 emissions per capita (in metric tons, log)

	model	
	(A3.I)	(A3.II)
	1971-2016	1971-2016
previous year CO2 per capita	0.795***	0.794***
	0.029	0.029
GDP per capita (log)	0.074***	0.074***
	0.013	0.012
GDP growth	0.201***	0.218***
	0.040	0.040
urbanization rate	0.204***	0.206***
	0.037	0.038
manufacturing / GDP	0.100***	0.104***
	0.032	0.032
share of electricity from oil	0.084**	0.085**
	0.037	0.037
share of electricity from coal	0.172***	0.172***
	0.035	0.033
share of electricity from renewables	-0.098	-0.098
	0.061	0.061
share of electricity from hydro	0.005	0.007
	0.041	0.042
share of electricity from natural gas	0.073*	0.074*
	0.038	0.038
share of electricity from nuclear	-0.019	-0.018
	0.038	0.039
demeaned share of coal * demeaned GDP growth		0.799**
		0.340
observations	3802	3802
number of countries	121	121
country fixed effects	yes	yes
time fixed effects	yes	yes
CD-test	0.248	0.230
p-value of CD-test	0.804	0.818
R2	0.881	0.881

Note: Standard errors reported in brackets are computed according to Driscoll and Kraay (1998). ***/**/* denote statistical significance at 1/5/10% confidence level.

Table A2
Model with motorisation (since 2000)

Dependent variable: CO2 emissions per capita (in metric tons, log)			
		model	
	(I) - BASELINE	(II)	(III)
	global model with time dummies	global model with time trend	global model with Brent price
previous year CO2 per capita	0.744***	0.743***	0.749***
	0.033	0.033	0.029
GDP per capita (log)	1.111***	1.051***	0.854***
	0.304	0.301	0.237
GDP growth	1.382**	1.708***	1.780***
	0.599	0.521	0.560
urbanization rate	2.340***	2.325***	1.195
	0.842	0.847	0.969
manufacturing / GDP	4.262	4.336	4.480
	2.935	3.033	2.880
share of electricity from oil	-0.059	-0.036	-0.009
	0.306	0.307	0.280
share of electricity from coal	0.629*	0.649**	0.653**
	0.338	0.324	0.327
share of electricity from renewables	-0.332	-0.431	-0.979*
	0.517	0.499	0.506
motorisation (vehicles per 1000)	-0.006	-0.091	-0.032
	0.104	0.108	0.108
oil price in USD (deflated by PCE, log)			-0.188**
			0.072
time trend		-0.037***	
		0.012	
observations	1485	1485	1485
number of countries	108	108	108
country fixed effects	yes	yes	yes
time fixed effects	yes	no	no
CD-test	-0.158	7.122	8.390
p-value of CD-test	0.875	0.000	0.000
R2	0.730	0.726	0.725

Note: Standard errors reported in brackets are computed according to Driscoll and Kraay (1998). ***/**/* denote statistical significance at the 1%/5%/10% level.

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