Drivers for the renaissance of coal

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Edited by M. Granger Morgan, Carnegie Mellon University, Pittsburgh, PA, and approved June 11, 2015 (received for review November 27, 2014)

Coal was central to the industrial revolution, but in the 20th century it increasingly was superseded by oil and gas. However, in recent years coal again has become the predominant source of global carbon emissions. We show that this trend of rapidly increasing coal-based emissions is not restricted to a few individual countries such as China. Rather, we are witnessing a global renaissance of coal majorly driven by poor, fast-growing countries that increasingly rely on coal to satisfy their growing energy demand. The low price of coal relative to gas and oil has played an important role in accelerating coal consumption since the end of the 1990s. In this article, we show that in the increasingly integrated global coal market the availability of a domestic coal resource does not have a statistically significant impact on the use of coal and related emissions. These findings have important implications for climate change mitigation: If future economic growth of poor countries is fueled mainly by coal, ambitious mitigation targets very likely will become infeasible. Building new coal power plant capacities will lead to lock-in effects for the next few decades. If that lock-in is to be avoided, international climate policy must find ways to offer viable alternatives to coal for developing countries.

climate change mitigation | Kaya decomposition | developing countries | coal

Despite the goal outlined by the United Nations Framework Convention on Climate Change (UNFCCC) to limit and reduce greenhouse gas emission to prevent dangerous anthropogenic interference with the climate system (1), global emissions have continued to rise steadily. Since 1971 global annual energy-related CO_2 emissions have more than doubled (Fig. 1*A*). In recent years emission growth has accelerated further, interrupted only briefly during the recent economic crisis. Assessments of the factors driving these developments using the Kaya* identity have identified growing per-capita incomes, especially in developing and newly industrializing countries, as the dominant reason for rising emissions (2, 3). [The Kaya* identity decomposes changes in emissions into changes in population, per-capita income, the energy intensity of gross domestic product (GDP), and the carbon intensity of energy production. See Steckel et al. (2) for further information.] However, the growing carbon intensity of energy production (i.e., the amount of emissions generated to produce one unit of energy) also has played an important role, and the increased use of coal has been particularly important (2). Coal consumption not only has risen in line with a growing global economy but has outpaced the growth of total energy use. Although coal was central to the industrial revolution (4), it increasingly was superseded by oil and gas in the 20th century. With these recent developments, however, coal again has become the most important source of energy-related emissions on the global scale (Fig. 1*B*).

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (5) identifies the replacement of coal-fired power plants by less carbon-intensive energy technologies as one of the most cost-efficient options to reduce global emissions. In recent years, however, the previous trend of declining carbon intensity in energy production has been reversed because of the increasing share of coal in the energy mix (5). This increase raises the question of whether we currently are witnessing a “renaissance of coal” on the global scale, in which the global energy system will become dominated by coal. Because coal is the most carbon-intensive fossil fuel, such a development would have serious implications for climate change-mitigation strategies. The observation that numerous countries, such as China and India, seem to meet their growing appetite for energy to a large part with coal raises serious concerns about whether current development trajectories are compatible with climate change mitigation. It also raises the question of whether high rates of economic growth were fueled, at least in some part, by a more-than-proportional increase in coal use and whether one can expect other countries to follow this highly carbon-intensive pathway in the future.

Fig. 1 *C* and *D* shows the development of carbon intensity (CO_2 per unit of primary energy) and energy intensity (primary energy per unit of GDP) across the different world regions in the last decades. Energy intensity generally has decreased in all regions of the world except in the Middle East and Africa, where it increased (particularly in the 1980s and 1990s) in parallel with economic decline (Fig. 1*C*). In contrast, the global and regional developments of carbon intensity show a qualitatively different behavior (Fig. 1*D*). On the global level, carbon intensity decreased steadily until the late 1990s. This historic trend has been reversed by a sharp increase in carbon intensity since then, and this increase was interrupted only briefly by the onset of the economic crisis. The global trend is not generally replicated in all the world regions. Rather, it follows the sharply increasing carbon intensity in Asia, a region that also witnessed high rates of economic growth throughout almost the entire observation period. Most other developing regions also paired an increase in carbon intensity with high rates of economic growth (the Latin American countries, which experienced economic growth without increasing their carbon intensity, are an exception).

Significance

The current carbonization of the global energy system poses a severe challenge for efforts to reduce carbon emissions. Here we show that the increase in the carbon intensity of energy production is caused mainly by the increased use of coal, not only in China and India but also across a broad range of developing countries, especially poor, fast-growing countries mainly in Asia. The (relatively) low coal prices are an important reason countries choose coal to satisfy their energy needs. This result underlines the importance of cheaply available energy for economic growth and suggests that viable alternatives to cheap coal will be required to ensure the participation of developing countries in global climate change mitigation.

Author contributions: J.C.S., O.E., and M.J. designed research; J.C.S., O.E., and M.J. performed research; J.C.S. and M.J. analyzed data; and J.C.S. and M.J. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1422722112/-/DCSupplemental.

*Kaya Y (1990) Impact of carbon dioxide emission control on GNP growth: Interpretation of proposed scenarios. Paper presented to the Intergovernmental Panel on Climate Change Energy and Industry Subgroup, Response Strategies Working Group, Paris (mimeo).

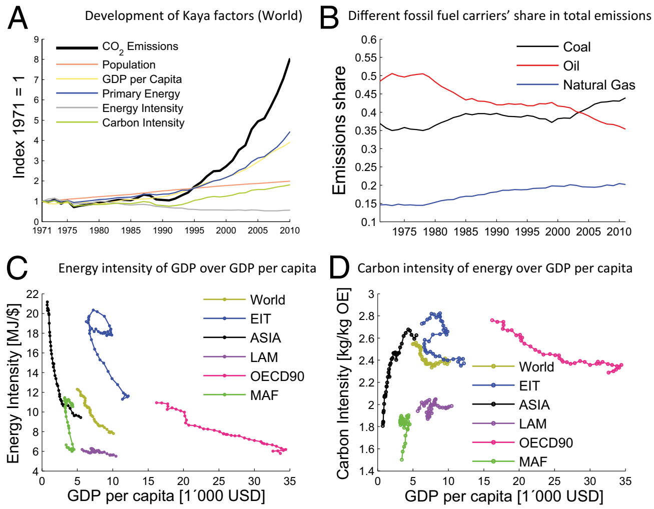

Fig. 1. (*A*) Development of the factors of the Kaya identity over time normalized to 1971. (*B*) Share of emissions from fossil fuel energy carriers over time. (*C* and *D*) Energy intensity over GDP per capita (*C*) and carbon intensity of energy over GDP per capita (*D*) for five aggregated world regions and the global total from 1971–2011. The regions are OECD 1990 countries (OECD90), economies in transition (EIT), Latin American countries (LAM), countries of the Middle East and Africa (MAF), and other Asian countries (ASIA). Data are from refs. 33 and 34.

Fig. 2 shows the development of emissions from solid fuels since 1901 to demonstrate long-term trends in coal use and related emissions (note that from the beginning of industrialization to 1900 the share of coal was nearly 100%). Fig. 2*A* shows total emissions from solid fuels on a double-logarithmic scale. Fig. 2*B* shows the share and development of coal in total energy-related emissions from 1901–2010 for UNFCCC Annex I and non-Annex I countries and the global average. Three observations are particularly striking: First, total emissions of solid fuels have increased significantly faster than absolute emissions since the year 2000 (Fig. 2*A*). Second, although the share of coal in total emissions decreased globally until the 1970s, it then stabilized at ~40% and only very recently has increased to levels higher than 45% (Fig. 1*B*). Third, although industrialized countries on average have decarbonized their energy systems since the 1980s, the share of coal has increased in non-Annex I countries. These data are in line with the observation that economic convergence is closely related to a convergence in energy-use patterns (6).

In the following sections we systematically analyze the impact and drivers of carbon-intensity increases, with a particular focus on coal. Previous literature has argued that China, whose coal-intensive energy system has not changed structurally for decades (2, 7), has been a driving factor behind the increase of global carbon emissions. In this respect, most recent data from China implying that emissions and coal use have decreased in 2014 (8) might be seen as a ray of hope. [Note, however, that the accuracy of the underlying data might be questioned. In the past, statistics of Chinese coal consumption have been subject to large adjustments after their initial publication (see ref. 9 and energyandcarbon.com/chinas-carbon-emissions-fall-2014/).] Similarly, the agreement between the United States and China (10), in which China announced it will peak CO_2 emissions around 2030 and will increase its share in low-carbon energy to 20% until 2030, has been seen as a major step towards ending the impasse in international climate negotiations (www.carlocarraro.org/en/topics/climate-policy/on-the-recent-us-china-agreement-on-climate-change/). Our results, however, show that the coal renaissance is not restricted to a few particular cases but instead is a general phenomenon occurring in a broad set of countries. We further show that especially poor, fast-growing countries have used coal systematically (because it is cheap and/or widely available) to fuel their hunger for energy. If this trend continues, countries such as India and Vietnam can be expected soon to reach per-capita emissions comparable to those in China or the countries that are members of the Organization for Economic Cooperation and Development (OECD).

Decomposition of Global and Regional Emissions

In this section we first analyze global and regional emission drivers along the lines of the Kaya* identity, which attributes the change of total emissions to four factors: changes in (*i*) population size, (*ii*) income per capita, (*iii*) energy intensity of the economy (i.e., energy per GDP), and (*iv*) carbon intensity (i.e., CO_2 emissions per unit of energy). To decompose drivers of carbon intensity changes explicitly, we make use of an extended decomposition method developed by Steckel et al. (2) that allows the contribution of individual energy carriers to be identified. Finally, we assess the relative importance of individual factors.

Fig. 3 compares developments in different world regions (for both developing and developed countries) in terms of percentual annual increase. On the global scale, annual emissions have grown nearly every year, except in times of economic crises. For the last four decades, economic growth has been the dominant driver of global emissions. The influence of population growth, which translated into 2% of annual emission growth in the early 1970s, has slowed to an increase of ~1% in recent years. Historically, increasing emissions driven by economic and population growth have been slowed down by decreasing energy and carbon intensities. Although energy intensity has decreased constantly, carbon intensity alone has increased global carbon emissions by roughly 1% per annum since 2003.

In OECD countries, emission growth generally has been slower than the global average and has been mostly negative in the last decade. [Note that we look at emissions that have been accounted for in the borders of a specific country and/or region (i.e. production-based). Studies that account for emissions differently (i.e. consumption-based) find that OECD emissions have increased, rather than remained constant, because of increased imports of emission-intensive goods that have been produced elsewhere. See Jakob et al. (11) for a discussion of both accounting mechanisms.] After the downfall of the Soviet Union, economies in transition (EITs) have managed to balance economic growth with improvements in carbon and energy intensity, with slight variations from this general trend in very recent years.

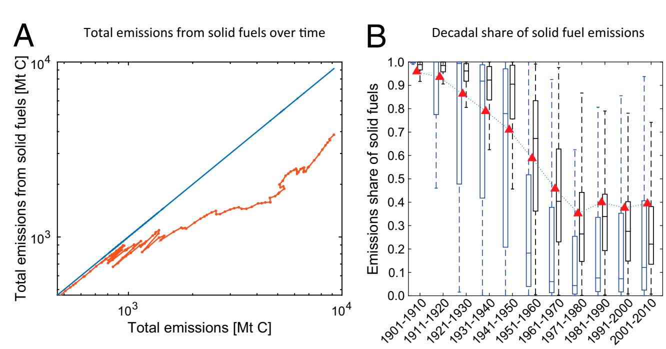

Fig. 2. (*A*) Total emissions from solid fossil fuels (including coal, lignite, and peat) relative to total emissions on a double logarithmic scale from 1901–2010 (red line). Markers indicate different years. (*B*) Median decadal solid fossil fuels' share in total emissions since 1901 for Annex I (black boxes) and non-Annex I countries (blue boxes) to the UNFCCC. The median value is indicated by horizontal lines, boxes show the 25th to 75th interquartile range, and whiskers show maximum and minimum values. Red triangles indicate the global average. Data are from ref. 33.

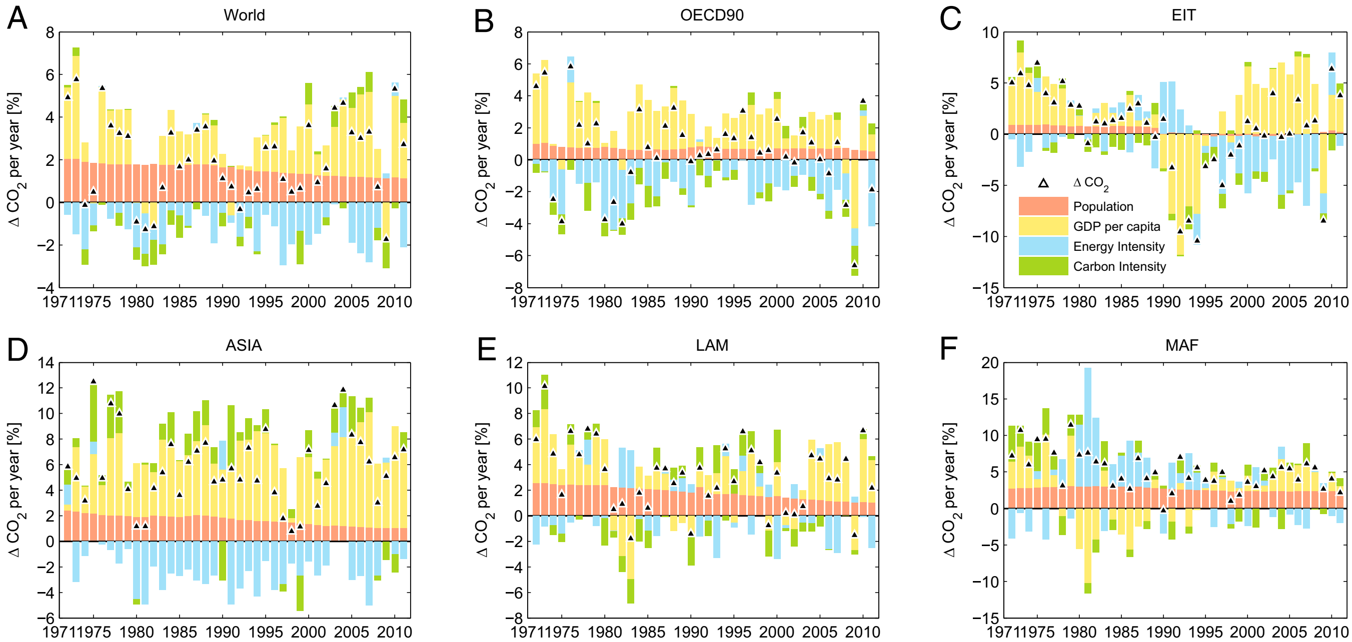

Fig. 3. Drivers of increasing emissions by Kaya factors for the world (*A*) and for five different world regions (*B*–*F*): OECD 1990 countries (*B*); economies in transition (EIT) (*C*); other Asian countries (*D*); Latin American countries (LAM) (*E*); and countries of the Middle East and Africa (MAF) (*F*). Please note different scales. Analyses are based on data from refs. 34 and 35.

The emission growth per year generally is higher in Asia, Latin America, and the Middle East and Africa than in developed regions or the global average. Asia in particular has experienced high rates of emission growth triggered by high rates of economic growth and, in contrast to most other regions, a constant carbonization of the energy system. In the Middle East and Africa, emission growth has long been driven by population growth, with widely fluctuating contributions of economic growth before the 2000s. Identifying constant patterns is more difficult in Latin America. Although carbonization contributed to an annual emission growth of ∼1% in the 1980s and 1990s, in the last decade carbonization has not played a major role in emission growth in Latin America. Rather, increased economic growth has been the major contributor (more than 5% per year) to emission growth. The influence of population growth on rising emissions has declined significantly over the past 40 y.

Making use of an extended Kaya decomposition method developed in Steckel et al. (2), Fig. 4 shows how different energy

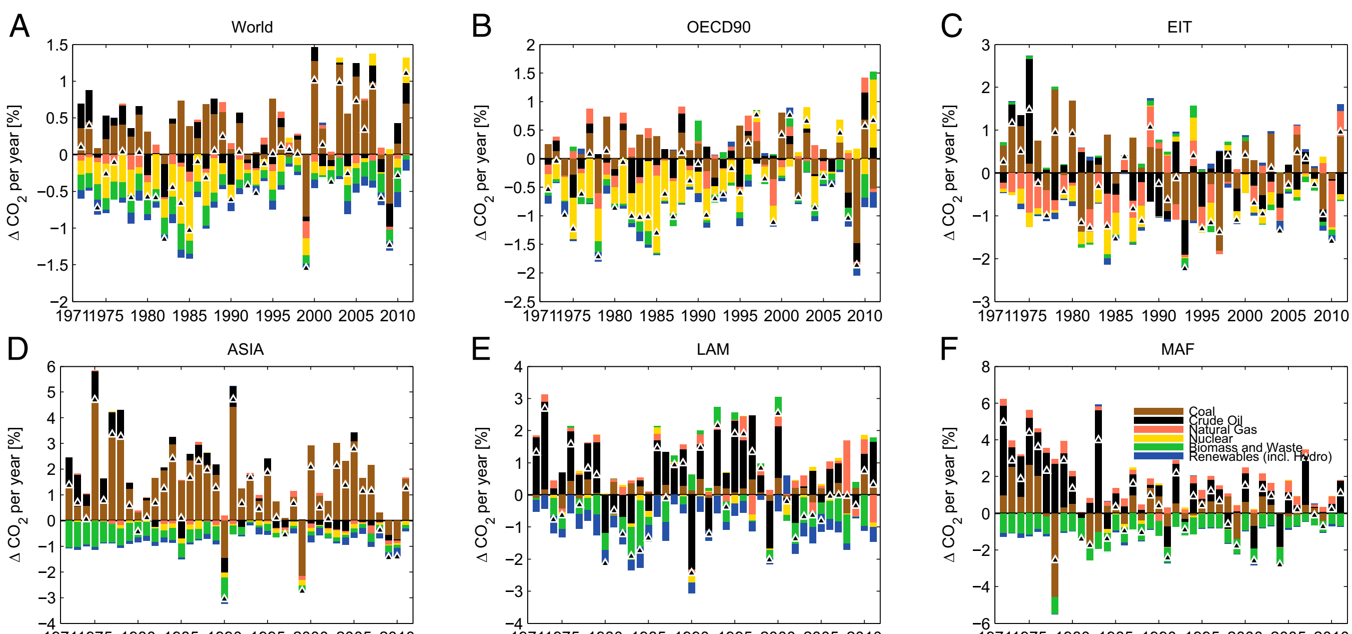

Fig. 4. Factors contributing to changing carbon intensity by energy carrier for the world (*A*) and for five different world regions (*B*–*F*). Please note different scales. Analyses are based on data from refs. 34 and 35.

carriers have contributed to changes in carbon intensity. This methodology (see *SI Appendix* for details) performs a secondary decomposition to assess changes in total emissions caused by changed shares of primary energy carriers in overall energy use. Hence, an increasing share of an energy carrier with a carbon intensity above the average of the current energy mix will have a positive contribution, and a decreasing share of an energy carrier with a carbon intensity below average would have the opposite effect. On the global level, increasing shares of nuclear energy (particularly driven by OECD countries) have balanced the increasing influence of coal and, to a lesser extent, oil on emissions. Since the 1990s most developing regions, in particular Asia, have increased their carbon intensities by using a higher proportion of coal in the energy mix. In Latin America the increases in carbon intensity in the 1980s and 1990s were driven not by coal but by oil, and the decreases, particularly in the 2000s, were driven by higher shares of hydro energy and energy from renewable and waste sources. As in Asia, nuclear energy has played only a small role in decarbonization. In the Middle East and Africa all fossil energy carriers, including coal, contributed to the carbonization of the energy system in the last decade.

Fig. 5 summarizes the results for the global perspective for the periods 1971–1999 and 1999–2011. To make these two periods of different length comparable, average annual effects are displayed in the figure. In absolute terms, global energy-related emissions have increased by 17.3 gigatonnes (Gt) between 1971 and 2011. Of this increase, 12.7 Gt can be attributed to population growth, and 15.4 Gt can be attributed to increases in per-capita income. Decreasing energy intensity has saved 9.8 Gt. The reduced carbon intensity accounts for 1 Gt of emission savings. Interestingly, the contribution of different factors varies across time. Although population growth had quite similar effects in the periods before and after 2000, the annual effect of economic growth more than doubled and has been the dominant factor in the latter period. This increase in GDP per capita has not been compensated by the less-than-proportional decrease in energy intensity. Finally, carbon intensity trends have reversed. That is, although decreasing carbon intensity contributed to emission savings of 1.7 Gt in the period from 1971–2000, 0.7 Gt of the increase in emissions can be attributed to increasing carbon intensity since then. Of this increase, 1.6 Gt can be attributed to coal; i.e., the average annual emission growth that can be attributed to coal has more than doubled in the last decade compared with the foregoing three decades. However, an increased use of biomass and renewable energy sources has offset more than half of the increase attributable to coal. Nuclear energy, in contrast, which saved ~1.5 Gt of emissions up to 2000, has not contributed to decarbonization since that time.

Coal and Economic Development

This section presents a statistical analysis to explain the increases in coal-induced emissions obtained with the Kaya* analysis. In the baseline specification, we regress k_{cf}, i.e., the percentual increase in energy-related CO_2 emissions that can be attributed to a rising share of coal in the energy mix, on the rate of economic growth and per-capita GDP, using a robust fixed-effects estimator and time-specific fixed effects (see *SI Appendix* for details). In this specification, our dataset includes data for 73 countries (51 non-OECD and 22 OECD) for the time period 1972–2011. The results of these estimates are shown in Fig. 6 in time intervals of 10 y and for the entire observation period.

For the rate of economic growth there are positive coefficients for non-OECD as well as OECD countries, indicating that the share of coal in the energy mix indeed has grown faster for countries with higher economic growth. Interestingly, for non-OECD countries this coefficient has increased steadily over time, with a value of 0.17 for the period 2002–2011. All else being equal, a non-OECD country that has a 5% higher annual growth rate of per-capita GDP during this period displays an additional 0.85% increase in emissions per year. Because this effect captures only the impact of a growing share of coal in the energy system, but not the general expansion of the energy system (i.e., increased coal use that increases as the energy system expands, although the share of coal in the energy mix remains constant), this effect is substantial. Results for the coefficient of per-capita GDP are mostly statistically insignificant, a notable exception being non-OECD countries for the period 2002–2011. For this period, a country with an annual per-capita income of US$5,000 or lower displays about 0.8% higher emissions because of changes in k_{cf} (i.e., the effect on emission growth that can be attributed to coal). It also is interesting that this coefficient decreases steadily over time; i.e., the effect by which poorer countries show larger relative increases in k_{cf} becomes more pronounced over time.

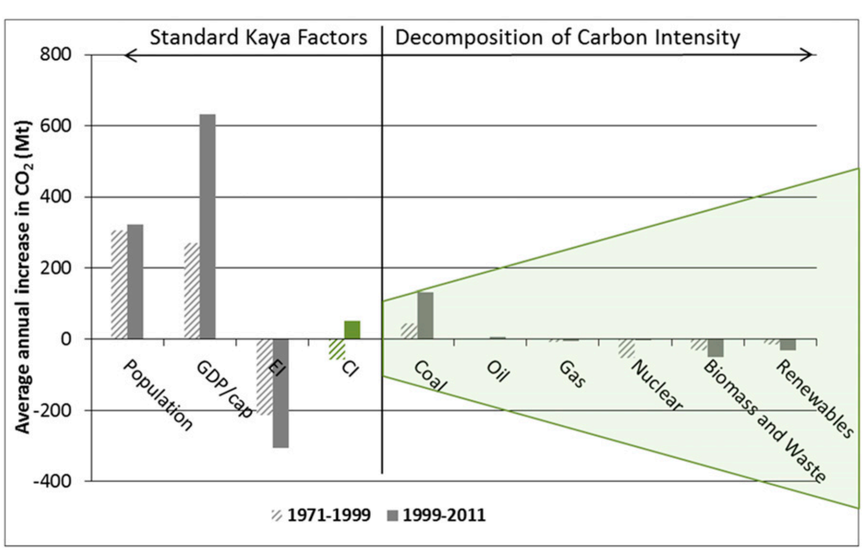

Fig. 5. Average annual emissions attributed to particular effects during two periods for a standard Kaya decomposition (*Left*) and based on the extension that additionally decomposes carbon intensity into different energy carriers (*Right*). CI, carbon intensity; EI, energy intensity.

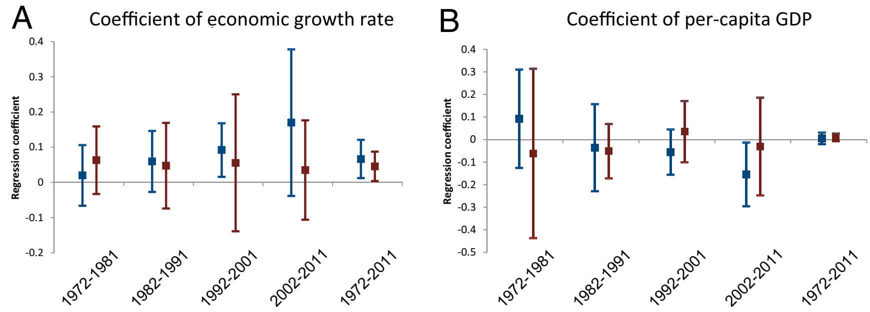

Fig. 6. Regression coefficients for the variables economic growth rate (*A*) and per-capita GDP (*B*) for non-OECD (blue) and OECD (red) countries, respectively. Squares indicate point estimates, and lines indicate the 90% confidence interval.

In summary, in recent years non-OECD countries have relied increasingly on coal to meet their energy needs. The poorer a country is and the higher its rate of economic growth, the stronger is this effect. Both effects become more pronounced over time, suggesting that increasing coal use is a general trend among poor, fast-growing countries and is not restricted to a few specific countries. These results confirm the hypothesis of a global renaissance of coal. This conclusion is strengthened by the fact that excluding China and India from the regression hardly affects the results (see *SI Appendix* for details), indicating that these two countries are not driving the results but rather are representative for the global sample.

We extend this basic regression in two dimensions. Because both extensions yield very similar estimates for the coefficients of the rate of economic growth and per-capita GDP, we report only the coefficients for the additional variables (see *SI Appendix* for all coefficients).

To assess the influence of fossil fuel prices, we include price indices for coal, oil, and natural gas, in addition to the explanatory variables of our baseline specification. Because of data availability, the size of our sample is reduced to 18 countries (6 non-OECD and 12 OECD) for a shorter time-span that ranges from 1978–2011. The results shown in Fig. 7*A* confirm that countries (non-OECD as well as OECD) with lower coal prices have experienced more rapid increases in emissions resulting from changes in k_{cf}. The effect of prices is significant, indicating that a lower coal price of 1 SD corresponds to an annual increase of emissions caused by a rise in k_{cf} of 0.9%.

To control for the role of endowments with fossil fuel resources, we add a measure of per-capita reserves of coal, oil, and natural gas (measured in physical units; see *SI Appendix* for details) to our baseline specification. Because there are insufficient time-series data for coal reserves, we add only the respective endowment in the year 2011 as a proxy. Because this variable remains constant over time, we use a robust random-effects estimator. For some countries, our data indicate zero resources, which could suggest reporting errors. For this reason, we run the regression in three different specifications: (*i*) including all countries; (*ii*) excluding countries for which all reserves are reported as zero; and (*iii*) excluding all countries for which at least one reserve is reported as zero. The first specification corresponds to the full sample of 73 countries, the second contains 43 countries (30 non-OECD and 13 OECD), and the third contains 14 countries (nine non-OECD and four OECD). The results are displayed in Fig. 7*B*. Perhaps surprisingly, the point estimates for non-OECD countries are negative, although they are not statistically significant, suggesting that non-OECD countries with larger coal reserves have experienced a lower increase of emissions because of changes in k_{cf}. In contrast, the estimates are positive for OECD countries and, except for the case in which all zero observations are excluded, are statistically significant. The effect is relatively small, however, with 1 standard deviation (SD) in coal reserves corresponding to an increase in emissions of only 0.06%.

Discussion

It is evident that coal use and related emissions have increased dramatically in the last decade. Although the global energy system showed a decarbonizing trend before the turn of this century, we have observed a constant carbonization of the global energy system since then, driven mainly by coal use in Asia. This development is in stark contrast to expectations formed a decade ago. For instance, the International Energy Agency (IEA) (12) had forecast that the share of coal in global energy use in 2030 will be slightly lower than it was in 2004. Odell (13) regarded a high growth rate in coal use as "unrealistic," assuming a maximum contribution of coal to fossil fuel supplies of 30%. From Fig. 8, which contrasts historic shares of coal in primary energy

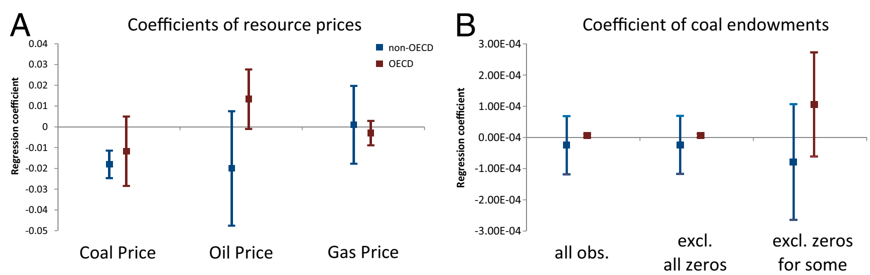

Fig. 7. (*A*) Regression coefficients for the price index of coal, oil, and natural gas for non-OECD (blue) and OECD (red) countries for the time period 1978–2011. (*B*) Regression coefficients for endowments with coal for non-OECD (blue) and OECD (red) countries. Specifications include all countries (all obs.), excluding those for which all reserves are zero (excl. all zeros), and those for which some but not all reserves are zero (excl. zero for some) for the time period 1972–2011. Squares indicate point estimates, and lines indicate the 90% confidence interval.

use against scenario results from large-scale integrated assessment models as used by the IPCC, it becomes evident that the current share of coal in primary energy use (~30%) cannot be sustained in ambitious scenarios of climate-change mitigation. Instead, the construction of coal-fired power generation facilities [at least those not equipped with carbon capture and sequestration (CCS)] must be phased out almost immediately to avoid the lock-in of carbon-intensive energy infrastructures (14). This effect is more pronounced in non-Annex I countries, where coal use today plays an even larger role than expected for business-as-usual scenarios (see also *SI Appendix*).

To understand the relevance of these results for future climate policy, we need a detailed understanding of the reasons underlying the observed coal renaissance. In this paper we show that increasing reliance of coal as a source of energy is not restricted to a few individual countries; rather, it constitutes a global phenomenon, especially among poor and fast-growing countries. This renaissance of coal has even accelerated in the last decade; this acceleration can be explained by the low prices of coal relative to other energy sources. It is interesting that the availability of domestic coal resources does not seem to have a major influence on this result for poor countries, perhaps because coal can be imported in countries with low endowments (15). Such global integration of regional coal markets might be accelerated and facilitated by major coal exporters investing massively in coal-export capacity, with respect to both mining and coal-terminal capacity (15).

The attractiveness of coal in developing countries also could be related to the relatively low capital costs of coal-fired power plants (16). However, McNerney et al. (17) argue that fuel prices, not capital costs, drive generation costs, not only for coal, but for all fossil fuel-based generation technologies. Thus, our approach focusing primarily on the relative difference in fuel prices seems to be reasonable.

Our results raise the more general question of the role of developing countries in climate-change mitigation. Developing economies now account for such a large share of global energy use that the trend toward higher carbon intensity in these countries

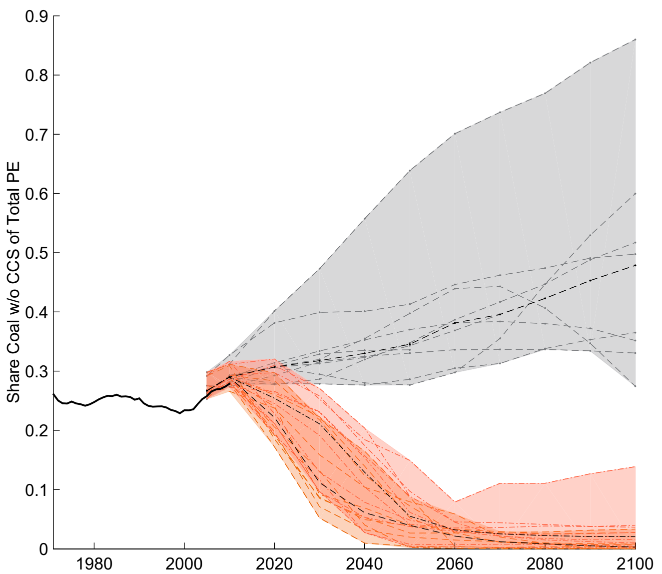

Fig. 8. Share of coal in global primary energy use from 1971–2011 [historic data, based on ref. 30 and scenario data from 2005–2100 (36)]. Gray lines indicate the use of coal without CCS in business-as-usual scenarios, red lines show 500-ppm scenarios, and orange lines show 450-ppm scenarios. Black dashed lines indicate median values for different scenario categories.

cancels out the effect of decreasing carbon intensities in industrialized countries. If the future economic convergence of poor countries is fueled to a major extent by coal, i.e., if current trends continue, ambitious mitigation targets likely will become infeasible. Recent modeling studies that analyze cost-efficient transformation pathways of the global energy system agree that coal use without CCS must be phased out in the near future to ensure that the goal of keeping global warming below 2 °C remains attainable, at least if the possibility of achieving negative emissions (i.e., sequestering greenhouse gases that already have been emitted from the atmosphere) in the future is limited (5). Furthermore, building new coal power plants, mining operations, and transport networks for long-distance coal trade arguably would result in further lock-in of this highly carbon-intensive energy carrier and would make future emission reductions even more difficult to achieve. Because it seems unlikely that without intervention coal use will decline drastically in the near future, it is advisable to develop measures that ensure that newly constructed coal-fired power plants are "capture-ready," i.e., that they can be retrofitted with CCS to avoid emissions to the atmosphere. In the longer run, such a scheme could be complemented with subsidies for CCS to constitute a cost-efficient second-best alternative to measures such as carbon pricing that may be more politically contentious (14).

In consideration of decarbonization efforts, two recent publications (18, 19) propose schemes to restrict the supply of coal. However, given their severe distributional impacts, these approaches are unlikely to be more politically acceptable than quantitative emission caps, than a carbon tax to curb emissions (combined with a transfer mechanism to compensate poor countries for their incremental abatement costs), or than incentivizing developing countries to participate in a global climate agreement. Integrating a coal moratorium in a mix of other policy instruments, including lower-than-optimal carbon prices and support for low-carbon technology, seems to be more promising in this respect (20). Although in the long and medium term low-carbon technologies such as wind or solar energy might become competitive on the large scale (21), these longer-term trends are unlikely to influence investment decisions in countries that are rapidly increasing their energy-generation capacity today. If investments in high-carbon technologies are to be avoided, international climate policy must find ways to make the use of coal unattractive for developing countries, either by increasing the price of coal or by lowering the costs of low-carbon alternatives, while at the same time ensuring that those countries' development prospects are not hampered by the use of low-carbon alternatives.

An incentive for switching to alternative sources of energy could lie in policy objectives other than climate policy, such as those addressing local air pollution, energy security, and energy access (22). In a meta-analysis of air quality cobenefits, Nemet et al. (23) found that emission reductions would yield mean health cobenefits of US$49 per ton of CO_2 (tCO_2) (with a range of US$2–196 per tCO_2, the highest cobenefits being seen in developing countries). In a similar vein, using a global chemical transport model, West et al. (24) found that health cobenefits of climate measures would largely exceed the associated mitigation costs. Finally, McCollum et al. (25) focus on synergies between climate policy and other policies. They point out that ambitious climate measures would reduce the costs of clean air policies and energy security measures by US$100–600 billion (0.1–0.7% of GDP) annually by 2030. The generation of revenues by carbon pricing could be an additional motivation for countries to foster climate policy. Those revenues could be used for infrastructure investment or tax or debt reduction (26, 27).

However, measures that would discourage coal use and encourage the use of low-carbon technologies as a cobenefit of other policies would require identifying country-specific policy goals and the opportunities to further them. A salient example of a policy that serves objectives that are not directly climate related but that nevertheless could reduce coal use is China's recent implementation of the Action Plan for Air Pollution Prevention and Control. Even though it is aimed at improving ambient air quality, this policy could lead to declining CO_2 emissions from 2020 onwards (28). Other examples include Vietnam's recent Green Growth policies that include a reform of implicit fossil fuel subsidies in the power sector (29) and India's climate discourse, which largely revolves around energy security (30).

Materials and Methods

The influence of coal on emissions growth has been calculated using an extended Kaya decomposition. Please see *SI Appendix* for a detailed description of the method.

Here we describe the data and methods used for the econometric analysis. The variables are summarized in *SI Appendix*, Table S1. Data sources are listed in *SI Appendix*, Table S2.

The dependent variable k_{cf} denotes the percentual increase in CO_2 emissions that can be attributed to an increased share of coal in the energy mix. The explanatory variables gdp_cap and g denote the per capita GDP in constant year 2005 US dollars at purchasing power parity and its annual growth rate, respectively. The variables i_oilpr, i_natgas, and i_coal are end-use price indices for oil, natural gas, and coal, respectively (the aggregation of prices for different kinds of oil, gas, and coal into one composite index is carried out via the Paasche formula, using physical quantities consumed as weights; see ref. 31). The variables oil_cap, coal_cap, and gas_cap indicate per-capita proved reserves of oil, coal, and natural gas, respectively (i.e., the estimated quantities of fossil fuels recoverable under current economic conditions; see ref. 32). Because there are considerable observations of fossil fuel reserves that are zero, we define two dummy variables to be able to exclude these observations and assess the robustness of our results: first, reserves_all_zero identifies cases in which there is an entry of zero for all kinds of three reserves (i.e., oil_cap = coal_cap = gas_cap = 0). Second, reserves_some_zero denotes all observations for which at least one type of reserves is zero.

The results of all regressions reported in the paper are reported in *SI Appendix*, Table S3.

Fig. 6 shows results for the coefficients of (*i*) per capita GDP and (*ii*) its growth rate for non-OECD and OECD countries for the time periods 1972–1981, 1982–1991, 1992–2001, 2002–2011, and 1972–2011. These respective regressions are contained in *SI Appendix*, Regressions 1–5. Likewise, results for OECD countries for the same time-spans are included in *SI Appendix*, Regressions 5–10.

Data for price indices of coal, oil, and natural gas are available only from 1978 onwards. Because of the rather small number of countries for which price data are available (6 non-OECD and 12 OECD countries), the regressions were carried out only for the full time period to avoid econometric problems related to small samples. The reports for non-OECD and OECD countries are reported in *SI Appendix*, Regressions 11 and 12, respectively.

Finally, for the reserves of fossil fuels three specifications were run for each country type to account for the fact that a reported value of zero could reflect a reporting error and thus would result in biased estimates of the respective coefficients. First, we include all observations (ALL). Second, we excluded countries in which all reserves were reported to be zero (EXCL_ALL_ZERO). Third, we excluded all countries for which at least one type of reserve was reported to be zero (EXCL_SOME_ZERO). There are no reliable time-series data on fossil fuels reserves, and changes across time likely reflect changes in reporting rather than real changes in resource endowments resulting from depletion. Furthermore, it seems unlikely that such a time series would show sufficient temporal variation to yield statistical power. For this reason, only reserve data for the year 2013 were included, and a random effects estimator was used.

All estimates were carried out using time-specific fixed effects to account for idiosyncratic effects that have an identical influence on all countries in a given year. The respective coefficients have been omitted from *SI Appendix*, Table S3 for the sake of readability. They are available from the authors upon request.

ACKNOWLEDGMENTS. We thank Nicolas Koch, Alexander Radebach, Hans Joachim Schellnhuber, and Kristin Seyboth for comments and fruitful discussions and Mia Burger for excellent research assistance. O.E. and J.C.S. received support from Deutsche Forschungsgemeinschaft Collaborative Research Center 1026.

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Drivers for the renaissance of coal

Supplementary Material

I) Extended Kaya decomposition

This part of the SI aims to explain the underlying calculations that lead to results presented in Figures 3 and 4 of the main text. This text is based on (1).

In order to come up with a detailed analysis of energy related carbon emissions, we break up emissions-growth along the factors of the Kaya identity (2), which expresses carbon emissions *F* as a product of the underlying factors GDP *G*, primary energy *E*, and population *P*:

$$F = P\left(\frac{G}{P}\right)\left(\frac{E}{G}\right)\left(\frac{F}{E}\right) =: P\,a\,e\,k\,, \tag{S.1}$$

The right-hand-side refers to the relative variables per-capita GDP (affluence) $a = G/P$, energy intensity $e = E/G$, and carbon intensity of energy $k = F/E$. Using the Laspeyres index method (3), a change over time in emissions ΔF can be expressed as the joint contribution of the four underlying effects (indicated by subscript *f*),

$$F(t+\Delta t) - F(t) = \Delta F = P_f + a_f + e_f + k_f\,, \tag{S.2}$$

where each effect can be derived from multiplication, as done here exemplarily for population,

$$P_f = \Delta P \cdot a_t \cdot e_t \cdot c_t + \Delta P \cdot \left[\begin{array}{l} +\frac{1}{2}\cdot\left[(\Delta a)\cdot e_t \cdot c_t + a_t \cdot (\Delta e)\cdot c_t + a_t \cdot e_t \cdot (\Delta c)\right] \\ +\frac{1}{3}\cdot\left[(\Delta a)\cdot(\Delta e)\cdot c_t + (\Delta a)\cdot e_t \cdot (\Delta c) + a_t \cdot (\Delta e)\cdot(\Delta c)\right] \\ +\frac{1}{4}\cdot(\Delta a)\cdot(\Delta e)\cdot(\Delta c) \end{array} \right]. \tag{S.3}$$

Note that different methods can be used to decompose the Kaya identity into additive effects, see, e.g. (3) for a review of different approaches. The first part of Eq (C.3) ($\Delta P \cdot a_t \cdot e_t \cdot c_t$) can be interpreted as the partial effect of the population component on the change of CO_2 emissions between time step *t'* and the preceding step *t*. The following parts capture interactions between the remaining variables and form the so called residual term.

In order to get a better understanding of the specific dynamics of the carbon intensity, we subject its time-series to an extended decomposition that allows expressing the change in carbon-intensity as a sum of changes in the supply from specific energy carriers. Namely, carbon intensity $k_{t'}$ at time *t'* can be expressed relative to a preceding time step *t* as

$$k_{t'} = k_t \frac{E_t}{E_{t'}} + \sum_j \left(\frac{k_{jt'} E_{jt'} - k_{jt} E_{jt}}{E_{t'}} \right), \tag{S.4}$$

where j indexes the different energy carriers, e.g. natural gas, coal etc., and k_{jt} represents the specific carbon intensity of energy carrier *j* at time *t*, which supplies carrier-specific energy E_{jt}. Changing specific carbon intensity over time might be confusing at first sight. However, the composition of energy carriers, e.g. coal, changes over time, as for example lignite is replaced by hard coal or vice-versa. Given that by definition we have

$$E_t = E_{t'} - \sum_j \left(\Delta E_j \right), \tag{S.5}$$

where ΔE_j denotes the change between *t* and *t'* in energy supply E_j, one can write

$$k_{t'} = k_t \frac{E_{t'} - \sum_j \left(\Delta E_j \right)}{E_{t'}} + \sum_j \left(\frac{k_{jt'} E_{jt'} - k_{jt} E_{jt}}{E_{t'}} \right).. \tag{S.6}$$

The first part of the expression can be interpreted as the energy carrier's changing contribution to the overall energy mix, while the second term of the expression indicates the change of the energy carriers' specific carbon intensity. This can be reformulated to express the change Δk in carbon intensity between t and t' as a sum over contributions from all energy carriers:

$$\Delta k = \frac{1}{E_{t'}} \sum_j \left(k_{jt'} \cdot E_{jt'} - k_{jt} \cdot E_{jt} - \Delta E_j k_t \right) \tag{S.7}$$

Δk so far only captures the partial effect. In a complete Laspeyres decomposition, all residuals are taken into account, implying that the effect of carbon intensity k_f can be written as $k_f = \Delta k \cdot R$, where *R* represents the residual (compare also Eq C.3). *R* can then be written as:

$$\begin{aligned} \mathrm{R} &= (\mathrm{P_t} \cdot \mathrm{a_t} \cdot \mathrm{e_t}) + \frac{1}{2} \cdot (\Delta\mathrm{P} \cdot \mathrm{a_t} \cdot \mathrm{e_t} + \Delta\mathrm{a} \cdot \mathrm{P_t} \cdot \mathrm{e_t} + \Delta\mathrm{e} \cdot \mathrm{P_t} \cdot \mathrm{a_t}) \\ &+ \frac{1}{3}(\Delta\mathrm{P} \cdot \Delta\mathrm{a} \cdot \mathrm{e_t} + \Delta\mathrm{P} \cdot \Delta\mathrm{e} \cdot \mathrm{a_t} + \Delta\mathrm{e} \cdot \Delta\mathrm{a} \cdot \mathrm{P_t}) + \frac{1}{4} \cdot \Delta\mathrm{P} \cdot \Delta\mathrm{a} \cdot \Delta\mathrm{e}) \end{aligned} \tag{S.8}.$$

In order to adapt the decomposition of carbon intensity, i.e. the effect k_f of carbon intensity on the change of emissions, we need to multiply Δk (Eq. C.7) by R on both sides. This leads to the graphs shown in Figure 5, which allow to directly observe the influence of specific changes in the energy mix on emissions.

II) Regression Analysis

As dependent variable of our regression analysis, we take k_{cf}, i.e. the increase of carbon emissions from one year to the next that can be attributed to a rising share of coal in the energy mix. In our baseline specification, we use per-capita GDP and its growth rate as explanatory variables (regressions 1-10). We run regressions using a robust panel data estimator on panels of 10 years, as well as the entire observation period (1972-2011).

Additional analysis includes the domestic end-user prices for oil, coal, and natural gas in the years 1978 - 2011 (Regressions 11-12) and the estimated reserves of these fossil fuels (Regressions 13-18). As data for fossil fuel reserves are not available as a time-series, we carried out Regressions 13-18 without fixed effects.

Summary statistics are provided in SI Table 1, data sources in SI Table 2. SI Table 3 and SI Table 4 give the results of the regression analysis reported in the paper. SI Table 5 and SI Table 6 report the same specifications, but for the data set excluding China and India.

As price indices for coal, gas, and oil are only available for 18 countries, we also perform a sensitivity analysis. We use prices (in US$) for steam coal and natural gas (prices in the industrial sector for both) as well as prices for household diesel or unleaded gasoline. Even though this does not increase our sample size, the countries included in this sample are different from the ones in our benchmark estimates. The fact that our analysis is robust against this alternative specification strengthens our confidence in our results (reported in SI Table 7 for the sample of all countries over the entire period).

Variable	N	mean	stand. dev.	min	max
kcf	160	0.0815	1.054	-3.582	4.112
g	160	1.827	2.066	-4.581	7.016
gdp_cap	160	27.87	6.905	15.54	43.57
i_oilpr	136	79.30	16.26	48.30	122.1
i_natgas	136	89.93	22.42	55	162.6
i_coal	68	72.08	14.95	49.40	107.5
oil_cap	160	11114	18331	275.6	52788
coal_cap	160	28911	37647	86.73	117121
gas_cap	160	3203	3307	152.9	10933
reserves_all_zero	160	.405	.491	0	1
reserves_some_zero	160	.811	.392	0	1
oecd	160	.297	.457	0	1

SI Table 1: Summary Statictics

Variable	Data source	Time period
gdp_cap, population	(4)	1972-2011
i_oilpr, i_natgas, i_coal	(5)	1978-2011
p_industry_steam_coal, p_industry_gas, p_hh_diesel, p_hh_leaded_gasoline	(6)	2007
oil_cap, gas_cap, coal_cap	(7)	2013

SI Table 2: Data Sources

VARIABLES	(1) DC_1972-1981	(2) DC_1982-1991	(3) DC_1992-2001	(4) DC_2002-2011	(5) DC_1972-2011	(6) IC_1972-1981	(7) IC_1982-1991	(8) IC_1992-2001	(9) IC_2002-2011	(10) IC_1972-2011
g	0.0198	0.0595	0.0921**	0.170	0.0664**	0.0629	0.0474	0.0552	0.0348	0.0456**
	(0.0429)	(0.0431)	(0.0381)	(0.104)	(0.0270)	(0.0461)	(0.0586)	(0.0935)	(0.0679)	(0.0200)
gdp_cap	0.0919	-0.0360	-0.0559	-0.155**	0.00519	-0.0615	-0.0517	0.0352	-0.0310	0.00959
	(0.108)	(0.0963)	(0.0499)	(0.0704)	(0.0128)	(0.180)	(0.0579)	(0.0654)	(0.104)	(0.00807)
i_oilpr										
i_natgas										
i_coal										
coal_cap										
oil_cap										
gas_cap										
Constant	-0.476	0.175	1.126**	2.037***	0.507*	0.505	1.520	-1.221	-0.147	-0.638*
	(0.858)	(0.438)	(0.488)	(0.724)	(0.262)	(2.939)	(1.187)	(1.614)	(3.684)	(0.368)
Observations	520	520	520	520	2080	220	220	220	220	880
R-squared	0.013	0.019	0.048	0.115	0.030	0.084	0.046	0.100	0.103	0.094
Number of country_id	52	52	52	52	52	22	22	22	22	22

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

SI Table 3: Output of regression analysis reported in the paper (continued on next page). Time-specific fixed effects are omitted from the table.

VARIABLES	(11) DC_1978-2011	(12) IC_1978-2011	(13) DC_1972-2011_ALL	(14) DC_1972-2011_EXCL_ALL_ZERO	(15) DC_1972-2011_EXCL_SOME_ZERO	(16) IC_1972-2011_ALL	(17) IC_1972-2011_EXCL_ALL_ZERO	(18) IC_1972-2011_EXCL_SOME_ZERO
g	0.0813**	0.103**	0.0714***	0.0743***	0.0379	0.0470*	0.0371	0.111
	(0.0287)	(0.0461)	(0.0170)	(0.0188)	(0.0310)	(0.0250)	(0.0289)	(0.0745)
gdp_cap	0.0924	-0.0391	-0.0114	-0.0327*	-0.198***	-0.0176**	-0.0116	-0.0339
	(0.0576)	(0.0299)	(0.00943)	(0.0193)	(0.0401)	(0.00827)	(0.0164)	(0.0677)
i_oilpr	-0.00911	0.00702						
	(0.00919)	(0.00724)						
i_natgas	0.00183	-0.0106**						
	(0.00754)	(0.00437)						
i_coal	-0.0142*	-0.00915						
	(0.00558)	(0.00748)						
coal_cap			-2.46e-05	-2.39e-05	-7.86e-05	5.70e-06**	5.71e-06**	0.000106
			(4.75e-05)	(4.75e-05)	(9.45e-05)	(2.77e-06)	(2.88e-06)	(8.51e-05)
oil_cap			9.07e-07	1.74e-06	0.000147**	2.59e-06	2.23e-06	6.84e-05
			(1.54e-06)	(1.60e-06)	(7.20e-05)	(2.93e-06)	(3.38e-06)	(5.29e-05)
gas_cap			-1.41e-05	-1.49e-05*	-0.00130**	3.38e-06	3.63e-07	-0.00104
			(9.38e-06)	(8.07e-06)	(0.000650)	(9.92e-06)	(1.30e-05)	(0.000912)
Constant	1.282	1.924	0.146	0.196	1.532**	-0.588	-0.629	0.0756
	(1.901)	(1.356)	(0.259)	(0.405)	(0.699)	(0.451)	(0.637)	(2.402)
Observations	187	365	2080	1240	400	880	520	160
R-squared	0.355	0.175	0.029	0.063	0.112	0.092	0.095	0.301
Number of country_id	6	12	52	31	10	22	13	4

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

SI Table 4 (cont'd): Output of regression analysis reported in the paper. Time-specific fixed effects are omitted from the table.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
VARIABLES	DC_1972-1981	DC_1982-1991	DC_1992-2001	DC_2002-2011	DC_1972-2011	IC_1972-1981	IC_1982-1991	IC_1992-2001	IC_2002-2011	IC_1972-2011
g	0.0158	0.0541	0.0876**	0.178	0.0660**	0.0629	0.0474	0.0552	0.0348	0.0456**
	(0.0462)	(0.0445)	(0.0394)	(0.107)	(0.0283)	(0.0461)	(0.0586)	(0.0935)	(0.0679)	(0.0200)
gdp_cap	0.108	-0.0599	-0.0597	-0.113	0.00582	-0.0615	-0.0517	0.0352	-0.0310	0.00959
	(0.136)	(0.121)	(0.0514)	(0.0808)	(0.0148)	(0.180)	(0.0579)	(0.0654)	(0.104)	(0.00807)
i_oilpr										
i_natgas										
i_coal										
coal_cap										
oil_cap										
gas_cap										
Constant	-0.673	0.236	-0.325	1.463*	0.506*	0.505	1.520	-1.221	-0.147	-0.638*
	(1.050)	(0.529)	(0.354)	(0.783)	(0.272)	(2.939)	(1.187)	(1.614)	(3.684)	(0.368)
Observations	470	470	470	470	1880	220	220	220	220	880
R-squared	0.018	0.015	0.052	0.120	0.031	0.084	0.046	0.100	0.103	0.094
Number of country_id	47	47	47	47	47	22	22	22	22	22

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

SI Table 5: Regression Results without China and India. Time-specific fixed effects are omitted from the table.

VARIABLES	(11) DC_1978-2011	(12) IC_1978-2011	(13) DC_1972-2011_ALL	(14) DC_1972-2011_EXCL_ALL_ZERO	(15) DC_1972-2011_EXCL_SOME_ZERO	(16) IC_1972-2011_ALL	(17) IC_1972-2011_EXCL_ALL_ZERO	(18) IC_1972-2011_EXCL_SOME_ZERO
g	0.0813**	0.103**	0.0668***	0.0736***	0.0553	0.0470*	0.0371	0.111
	(0.0287)	(0.0461)	(0.0181)	(0.0195)	(0.0385)	(0.0250)	(0.0289)	(0.0745)
gdp_cap	0.0924	-0.0391	-0.0124	-0.0216	-0.172**	-0.0176**	-0.0116	-0.0339
	(0.0576)	(0.0299)	(0.0102)	(0.0187)	(0.0698)	(0.00827)	(0.0164)	(0.0677)
i_oilpr	-0.00911	0.00702						
	(0.00919)	(0.00724)						
i_natgas	0.00183	-0.0106**						
	(0.00754)	(0.00437)						
i_coal	-0.0142*	-0.00915						
	(0.00558)	(0.00748)						
coal_cap			-2.60e-05	-2.65e-05	-6.77e-05	5.70e-06**	5.71e-06**	0.000106
			(4.71e-05)	(4.20e-05)	(9.53e-05)	(2.77e-06)	(2.88e-06)	(8.51e-05)
oil_cap			1.12e-06	1.43e-06	0.000102	2.59e-06	2.23e-06	6.84e-05
			(1.56e-06)	(1.45e-06)	(9.71e-05)	(2.93e-06)	(3.38e-06)	(5.29e-05)
gas_cap			-1.03e-05	-1.15e-05	-0.000897	3.38e-06	3.63e-07	-0.00104
			(9.51e-06)	(7.09e-06)	(0.000868)	(9.92e-06)	(1.30e-05)	(0.000912)
Constant	1.282	1.924	-0.0662	-0.369	0.0349	-0.235	0.0815	-0.782
	(1.901)	(1.356)	(0.480)	(0.427)	(1.005)	(0.297)	(0.371)	(1.308)
Observations	187	365	1880	1160	320	880	520	160
R-squared	0.355	0.175						
Number of country_id	6	12	47	29	8	22	13	4

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

SI Table 6: Regression Results without China and India. Time-specific fixed effects are omitted from the table.

VARIABLES	(1) ALL_DIESEL	(2) ALL_LEADED_GASOLINE
gdp_cap	-0.0124	-0.215
	(0.0749)	(0.145)
g	3.953	1.642
	(5.663)	(2.989)
p_industry_steam_coal_	-0.0108**	-0.00946**
	(0.00433)	(0.00422)
p_industry_gas_	-0.00309	0.000599
	(0.00284)	(0.00405)
p_hh_diesel_	7.98e-05	
	(0.000622)	
p_hh_leaded_gasoline_		-5.80e-05
		(0.000742)
Constant	1.594	4.022
	(1.383)	(2.387)
Observations	237	199
R-squared	0.180	0.274
Number of country_id	17	17

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

SI Table 7: Regression results using prices for diesel (1) and leaded gasoline (2) as the price for oil products. For gas, prices for natural gas for industry are used, and for coal prices for steam coal for industry

III) The 25 countries with the highest average annual emission increase due to coal

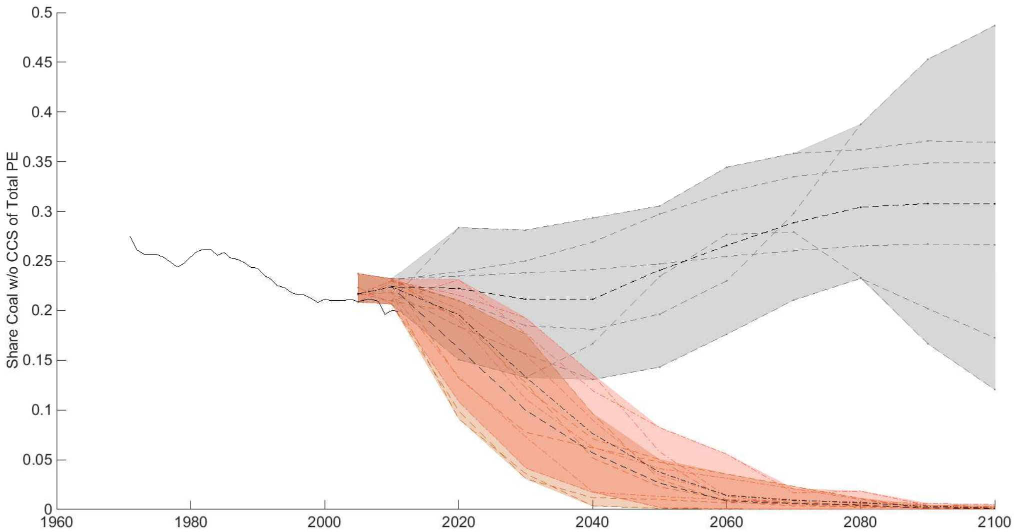
	Average 1972-2011 (% per year)	Average 2000-2011 (% per year)	Average 1972-2011 ($MtCO_2$ per year)	Average 2000-2011 ($MtCO_2$ per year)
Nepal	3.42	0.80	0.02	0.02
India	1.90	1.50	11.32	18.23
Vietnam	1.83	2.51	0.75	1.90
Peop. Rep. China	1.28	0.96	26.75	41.74
Thailand	0.90	0.72	0.83	1.47
Indonesia	0.86	1.01	1.80	3.34
Chinese Taipei	0.83	0.64	1.07	1.38
Philippines	0.83	1.12	0.43	0.77
Turkey	0.78	0.61	0.85	1.19
Hong Kong	0.75	0.73	0.20	0.31
Korea	0.73	1.03	2.23	4.62
Zimbabwe	0.72	-1.04	0.03	-0.16
Israel	0.52	0.13	0.17	0.07
Malaysia	0.50	0.87	0.47	1.23
Australia	0.48	0.27	1.08	0.86
Chile	0.47	0.25	0.17	0.19
Finland	0.45	0.24	0.14	-0.04
Iceland	0.40	0.44	0.01	0.01
Greece	0.37	0.27	0.17	0.21
Dem. Rep. Congo	0.35	1.65	0.01	0.04
Brazil	0.32	0.33	0.71	1.01
Pakistan	0.31	0.45	0.20	0.45
Morocco	0.31	0.29	0.06	0.08
Colombia	0.26	0.07	0.08	0.04
Myanmar	0.24	1.06	0.02	0.08

SI Table 8: The 25 countries with the largest average annual increase of emissions due to the increase of coal in percent during the period 1972-2011 (fist column) and 2000-2011 (second column). The third and fourth columns give the average increase in absolute annual emissions over the respective time-span.

Non-OECD	**Albania, Algeria, Argentina, Bangladesh, Brazil, Bulgaria, Chile, China, Chinese Taipei, Colombia, Cuba, Cyprus, Czech Republic, Democratic Peoples' Republic of Korea, Democratic Republic of Congo, Dominican Republic, Egypt, Hong Kong, Hungary, India, Indonesia, Ireland, Islamic Republic of Iran, Israel, Kenya, Korea, Malaysia, Mexico, Morocco, Mozambique, Myanmar, Nepal, Nigeria, Pakistan, Panama, Peoples' Republic of China, Peru, Philippines, Poland, Romania, Singapore, Slovak Republic, South Africa, Sri Lanka, Syrian Arab Republic, Thailand, Tunisia, Turkey, Venezuela, Vietnam, Zambia, Zimbabwe**
OECD	**Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, USA**

SI Table 9: List of the 25 countries that have shown the highest increases in emission growth between 1972 and 2011 clustered into OECD and non-OECD countries

IV) Extended analysis – PE share of coal in IAM scenarios for Annex I and non Annex I countries



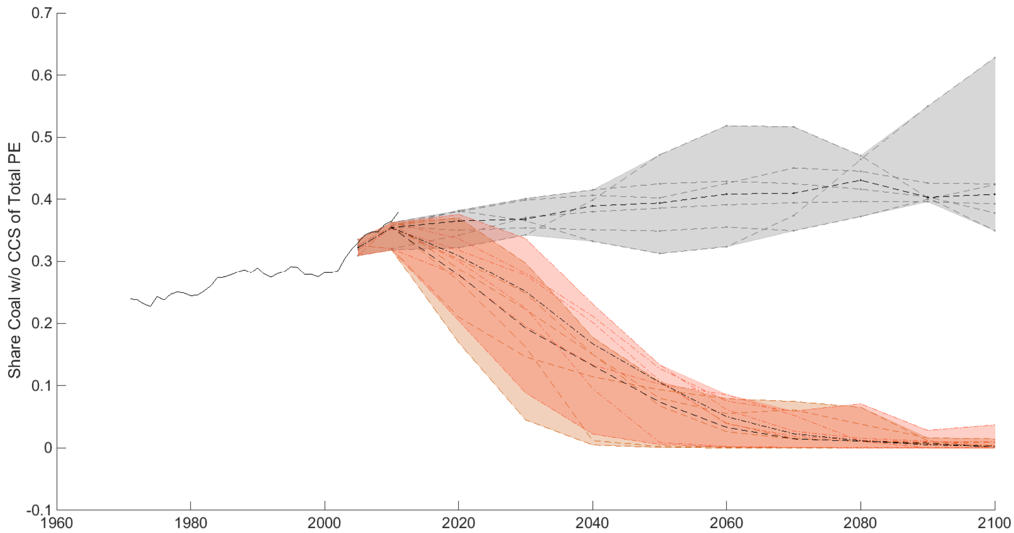


Figure S1: PE by coal in relation to overall total primary energy supply for Annex I countries (above) and non-Annex I countries lower picture). Historic data from 1971 to 2011 are taken from (8); scenario data from the LIMITS model intercomparison exercise (9). Grey shades indicate Business as usual scenarios (without climate policies), red shadings indicate 500 ppm stabilization scenarios, orange shadings indicate 450 ppm stabilization scenarios. Black solid line shows historic data, dotted lines indicate the median of scenarios for respective stabilization categories.

V) VII – Extended analysis: Energy- and carbon intensity over time excluding China and India from the region "ASIA"

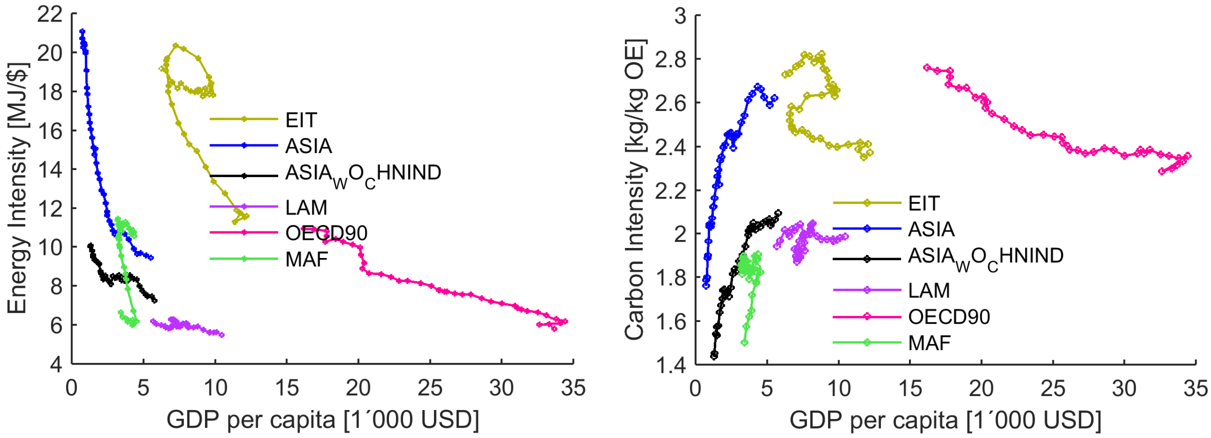
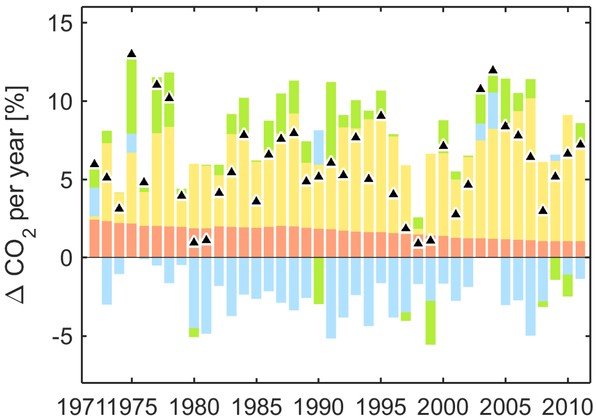


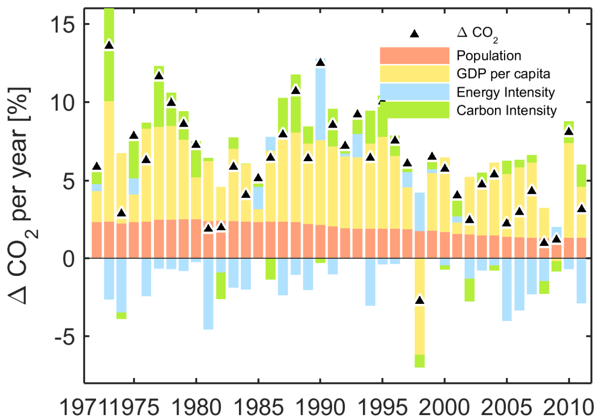
Figure S2: Energy- and carbon intensity excluding China and India from the Asia region.

VI) Extended analysis – Kaya analysis of Asia w/o China and India

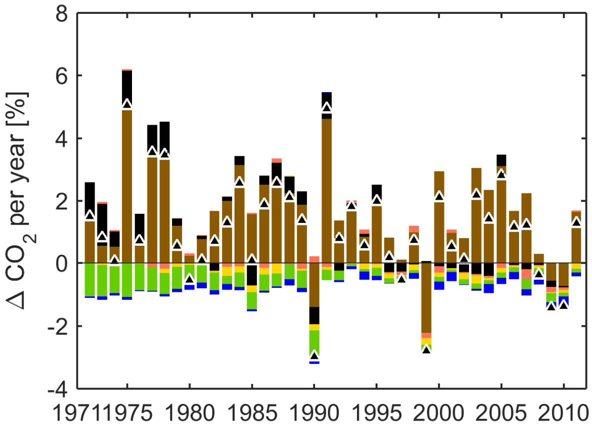
a) Kaya factors: ASIA with China and India



b) Kaya factors: ASIA w/o China and India



c) Carbon intensity: ASIA with China and India



d) Carbon intensity: ASIA w/o China and India

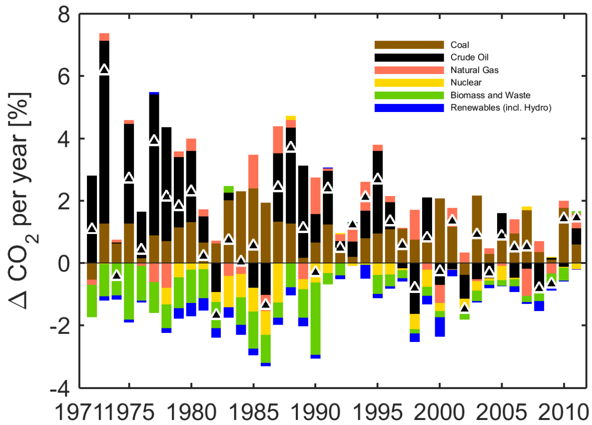


Figure S3: Drivers of emissions along the lines of the Kaya identity (upper row) and contributing factors to changing carbon intensity (lower row) for the ASIA region (compare Figure 3 and 4 in the main text) compared to the ASIA region with China and India being excluded.

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