

1 **Drivers of declining CO₂ emissions in industrial countries**

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24 **Global emissions of carbon dioxide (CO₂) from fossil fuels and industry increased by 2.2%**
25 **per year on average between 2005 and 2015¹. Global emissions need to peak and decline**
26 **rapidly to limit climate change to well below two degrees Celsius of warming^{2,3}, one of the**
27 **goals of the Paris Agreement⁴. Untangling the reasons underlying recent changes in**
28 **emissions trajectories is critical to guide efforts to attain those goals. Here we analyse the**
29 **drivers of decreasing CO₂ emissions in a group of 18 industrial countries that have**
30 **decarbonized over the period 2005-2015. We show that within this group, the**
31 **displacement of fossil fuels by renewable energy and decreases in energy use explain**
32 **decreasing CO₂ emissions. However the decrease in energy use can be explained at least in**
33 **part by a lower growth in GDP. Correlation analysis suggests that policies on renewable**
34 **energy are supporting emissions reductions and displacing fossil fuels in these 18**
35 **countries, but not elsewhere, and that policies on energy efficiency are supporting lower**
36 **energy use in these 18 countries as well as more widely. Overall, the evidence shows that**
37 **efforts to reduce emissions are underway in many countries, but they need to be**
38 **maintained and enhanced by more stringent policy actions to support a global peak in**
39 **emissions followed by global emissions reductions in line with the goals of the Paris**
40 **Agreement³.**

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1 Fossil fuel CO₂ emissions are the main cause of human-induced climate change⁵. Historically,
2 they have increased over timescales of many decades in all countries⁶. However, since the
3 mid-1970s, emissions have peaked and subsequently declined consistently in several
4 European countries, initially because of energy resource substitutions from coal to oil, gas
5 and nuclear power. Since the early 1990s, transfers of emissions through international trade
6 have also contributed to emission reductions in some countries^{7,8}, although this effect
7 stabilized around 2005 in most developed economies¹. In the period since 2000, global fossil
8 fuel emissions have increased rapidly driven by the rapid industrialization of China^{1,9}. Yet,
9 emissions in the USA and in Europe have decreased for over a decade, reducing the rate of
10 increase globally⁹.

11 Understanding the drivers of emissions trends in countries where emissions are consistently
12 decreasing could indicate whether efforts to decarbonise energy systems and tackle climate
13 change are truly in motion, or whether they are simply reflecting secular trends in national
14 and global economies. In addition, despite significant attention given to policies and
15 measures to tackle climate change^{4,10}, it is not clear if they have significantly influenced
16 national emission trends consistently across all countries¹⁰⁻¹³. The scale of government and
17 non-government led actions to reduce emissions has grown in recent years, but a broad
18 assessment of their overall effect is largely missing.

19 In this analysis, we use national CO₂ emissions from fossil fuel combustion from the
20 International Energy Agency (see Methods). We isolate a ‘peak-and-decline’ group of 18
21 countries where emissions have significantly decreased over the period 2005-2015
22 considering both territorial and consumption emissions (Fig. 1; Supplementary Figure S1).
23 The peak-and-decline group represents 28% of global emissions. We also select two control
24 groups for reference. Both control groups include countries where emissions have not
25 significantly decreased, but distinguish low GDP growth (group A, 30 countries) and high
26 GDP growth (group B, 31 countries; see Methods).

27 Emissions in the peak-and-decline group decreased by –2.4% [–2.9% to –1.4%] per year on
28 average during 2005-2015 (Table S1-S2; numbers indicate the median and 25-75 percentile;
29 see Methods). To understand why, we decompose country-level emissions trends among
30 four contributing factors representing physical drivers (Table 1; see Methods): (1) energy use
31 – changes in final energy, attributable to changes in the efficiency with which energy
32 services are provided and consumed; (2) fossil share – changes in the share of fossil fuels in
33 final energy (including electricity and heat generated from fossil fuels), reflecting the
34 displacement of fossil fuels by non-fossil energy including renewables and nuclear; (3) fossil
35 utilisation rate – changes in the ratio of fossil final energy over fossil primary energy,
36 representing energy consumed or lost in energy extraction, conversion and transmission;
37 and (4), fossil CO₂ intensity – changes in the carbon intensity of fossil energy, reflecting the
38 proportion and fuel quality of coal, oil and gas in the overall fossil fuel mix.

39 Results show that the largest contribution to emissions decreases in the peak-and-decline
40 group for 2005-2015 was from decreases in the fossil share of final energy, accounting for a
41 median of 47% [36 to 73%] of the decrease in emissions (Fig. 2), and decreases in energy
42 use, accounting for 36% [18% to 56%]. There was no substantial contribution at the group
43 level from changes in fossil utilisation rate or from changes in fossil CO₂ intensity (Fig. 2).
44 Outsourcing of emissions through trade was small relative to these four physical drivers and
45 does not account for their substantial contribution to CO₂ reductions (Fig. 2). Results were
46 similar across available datasets (Table S3).

47 Some country-level variation within the peak-and-decline group is notable (Table S3-S4).
48 First, contributions to emissions decreases in the USA were more evenly distributed across

1 the four drivers, with the largest single contributor coming from the switch from coal to gas
2 driven by the availability of shale gas. Second, the contribution of decreases in the fossil
3 share of energy alone dominated emissions decreases in Austria, Finland, and Sweden,
4 consistent with a rising market share of renewables in power generation and/or heat.
5 Finally, the contribution of reductions in energy use dominated emissions decreases in
6 France, Ireland, Netherland, Spain, the United Kingdom, as well as the EU28, despite the
7 economies growing.

8 These drivers of emissions in the peak-and-decline group were distinct from those of the
9 control groups, where changes in emissions are dominated by changes in energy use alone.
10 In group A (low GDP growth), increases in energy use accounted for 75% [-11 to 130%] of
11 the increase in CO₂ emissions, with no substantial contributions from the three other factors
12 (Table S5; Fig. S2). In group B (high GDP growth), increases in energy use accounted for 79%
13 [58 to 90%] of the increase in CO₂ emissions, with an additional contribution of 16% [2
14 to 29%] from the rising share of fossil energy in final energy. Many rapidly growing economies
15 are seeing coal and oil's share rising faster than renewable or other low-carbon energy.

16 Changes in CO₂ emissions in the peak-and-decline group differ from previous changes
17 observed since 1960 (Fig. 3). During the 1960s and 1970s, CO₂ emissions grew rapidly, driven
18 by a large increase in energy use. This was partly offset by reductions in fossil CO₂ intensity
19 due to a switch from coal to oil and gas following market forces (e.g., economically
20 exploitable natural gas resources) and environmental regulations (e.g., air pollution
21 controls). From the early 1980s to the early 2000s, CO₂ emissions grew more slowly. The
22 effect of continuing increases in energy use was partly offset by reductions in the fossil share
23 of energy due to the expansion of nuclear power with a smaller contribution from changes in
24 fossil CO₂ intensity in the 1990s. Changes in CO₂ emissions in the decade 2005-2015 are a
25 break from historical trends in that they are supported by the largest decreases in the fossil
26 fuel share observed since 1960, and by the only decrease in energy use sustained over a
27 decade.

28 We further examine the decrease in energy use during 2005-2015 by decomposing the
29 drivers of energy use into the associated growth in GDP, and the energy intensity of that
30 GDP which also captures structural change in the economy (see Methods). The decrease in
31 energy use in the 2005-2015 period is associated with low growth in GDP of around 1% per
32 year in the peak-and-decline group, and reductions in the energy intensity of GDP of around
33 -1% to -2% per year (Fig. S3). These reductions in energy intensity of GDP in 2005-2015 do
34 not stand out compared to similar reductions observed since the 1970s (Fig. S3), indicating
35 that decreases in energy use in the peak-and-decline group could be explained at least in
36 part by the lower growth in GDP.

37 To gain insights into the likely persistence of the 2005-2015 trends, we compare the drivers
38 of decreasing CO₂ emissions in 2005-2015 in the peak-and-decline group to the drivers of
39 decarbonization in six global Integrated Assessment Models (IAMs)¹⁴ used to explore future
40 energy transformation pathways consistent with limiting climate change to two degrees of
41 warming (Fig. S4). The IAMs project emission decreases over the period 2010 to 2020 in the
42 EU and USA driven primarily by decreases in the fossil share of energy and by changes in the
43 fossil CO₂ intensity (including carbon capture and storage in some models), with a smaller
44 contribution from improvements in fossil utilisation rate. Changes in energy use do not
45 contribute systematically to emissions reductions in these near-term IAM projections (Fig.
46 S4; Table S6). However, the IAMs also assume annual GDP growth of 2.4% which is over
47 double that observed in the past decade in the peak-and-decline group. For a fixed GDP
48 growth¹⁵, one widely-used IAM sees reductions in energy use make a growing contribution
49 to emission decreases as climate targets become more stringent (Fig. S4). Although the IAM

1 simulations are not designed for short-term analysis¹⁶, this comparison suggests that if GDP
2 returns to strong growth in the peak-and-decline group, reductions in energy use may
3 weaken or be reversed unless strong climate and energy policies are implemented.

4 Finally, we examine the role of climate and energy policies as drivers of emissions reductions
5 during 2005-2015. We separate policies broadly into three types according to whether they
6 promote (1) renewable energy, (2) energy efficiency, or (3) climate change mitigation and
7 adaptation (referred to below as 'climate policy frameworks'; see Methods). We use the
8 numbers of policies adopted in law per country between 2005 and 2015, as a general
9 indicator of the political commitment of a government to promote or restrict activities
10 affecting carbon emissions¹⁷. Although a simple measure, numbers of policies are a useful
11 first-order proxy of policy influence with precedent in the literature¹⁸, as supported by a
12 detailed study of the US states¹⁹ and a comparative study among industrial countries²⁰.

13 In the peak-and-decline group, there were 35 [27-51] and 23 [15-35] policies per country in
14 place by 2015 that promoted energy efficiency and renewable energy respectively (Table 2).
15 This is substantially more than in either of the control groups (Table 2). Numbers of climate-
16 change mitigation policies were also higher but more similar amongst the groups, with 10 [8-
17 12] framework policies per country in the peak-and-decline group, compared to 7 [5-8] and
18 8 [5-10] respectively in control groups A and B.

19 In the peak-and-decline group, correlations between the drivers of emission decreases and
20 the numbers of relevant policies were all of the expected sign. Decreases in energy use
21 were correlated with the number of energy-efficiency policies ($r=-0.54$). Decreases in the
22 fossil share of energy were correlated with policies on renewable energy ($r=-0.75$).
23 Decreases in total emissions were correlated with the number of climate policy frameworks
24 ($r=-0.54$; Table 2). Negative correlations indicate that larger reductions in emissions take
25 place when more policies are in place. Decreases in energy intensity of GDP (see Methods)
26 were also correlated with policies on energy efficiency ($r=-0.42$) but with significance only at
27 the 90% level (Table 2).

28 In both control groups, the numbers of policies on energy efficiency were not significantly
29 correlated with trends in energy use. However they were significantly correlated with trends
30 in energy intensity of GDP. This suggests that policies have an effect on energy efficiency,
31 but that effect is hidden by the effect of GDP growth on energy demand. For control group B
32 (high GDP), trends in the fossil share of energy correlated positively with the number of
33 policies on renewable energy ($r=0.51$). Renewables growth in these rapidly-expanding
34 economies is adding additional capacity rather than displacing fossil fuels. Finally, in both
35 control groups, there was a positive correlation between the trends in emissions and the
36 number of climate-policy frameworks, which could reflect actions on climate change
37 adaptation rather than mitigation. The number of climate policy frameworks was too small
38 to test the effects of adaptation and mitigation policies separately.

39 These correlations provide indirect evidence that policies on energy efficiency may be
40 playing an important role in driving emission reductions across countries, and that policies
41 on renewable energy act to displace fossil fuel energy in the peak-and-decline group, but not
42 elsewhere. Climate policy frameworks also appear to support emissions reductions but only
43 in the peak-and-decline group, perhaps due to the larger number of policy frameworks in
44 place. Although it is possible that the correlations could be due to other factors, the more
45 mature implementation of a larger number of policies in the peak-and-decline group
46 compared to the two control groups have a clear interpretation that energy and climate
47 policies support emissions reductions.

1 Looking forward, the persistence of the decreases in emissions over the coming decades will
2 depend primarily on structural decreases in energy use and in the share of fossils in the
3 energy mix. To maintain and enhance decreases in energy use in the peak-and-decline
4 group, policy support needs to be enhanced, particularly if GDP growth increases. Further
5 support for reductions in energy use could tackle consumption^{21,22} or the efficiency of
6 energy-service provision as well as energy-conversion efficiencies in end-use technologies²³
7 (Table 2). More detailed representation of the policy and non-policy drivers of energy use in
8 models should also help further explore the solution-space for deep mitigation²⁴. The large-
9 scale deployment of renewable energy is not sufficient by and of itself to lead to durable
10 emissions decreases; it needs to be delivered within a framework of strong and supportive
11 climate policies.

12 Finally, as significant as they have been, the emissions reductions observed and analysed in
13 the 18 countries of the peak-and-decline group fall a long way short of the deep and rapid
14 global decarbonisation of the energy system implied by the Paris Agreement temperature
15 goals³, especially given the increases in global CO₂ emissions in 2017 and 2018, and the
16 slowdown of decarbonisation in Europe since 2014²⁵. To limit climate change well below two
17 degrees Celsius, global emissions in 2030 need to be about 25% below 2018 levels²⁶. Recent
18 acceleration in the deployment of renewable energy worldwide will only translate in to
19 emissions reductions if accompanied by extensive measures to phase out the use of fossil
20 fuels²⁷.

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2 Table 1. Description of the drivers of emissions changes as represented in Equation (2). The
3 examples describe factors that could lead to decreases in emissions.

Description	Short name	Examples of factors contributing to <i>declining</i> emissions
<i>FE</i> : Final energy, representing energy at the point of use	Energy use	<ul style="list-style-type: none">• lower quantities of energy services consumed (e.g., less heating or mobility)• improved efficiency of energy services (e.g., insulated homes or higher occupancy vehicles)• improved energy-conversion efficiency of end-use technologies (e.g., more efficient boilers or cars)• electrification of heat engines (e.g., replacing internal combustion engines or gas- or diesel-powered mechanical equipment by electric motors)
<i>C_f</i> : Fossil final energy/Final energy, representing the share of fossil fuels in final energy	Fossil share	<ul style="list-style-type: none">• decrease in direct use of fossil energy (e.g., gas for heating or coal for industrial processes)• increase in share of non-fossil low-carbon energy for electricity/heat generation or final use, including nuclear and renewables (e.g., wind, solar, hydro, biomass)
<i>C_p</i> : Fossil primary energy/Fossil final energy, representing aggregated energy use and losses from extracting fossil energy and converting it to fuels, electricity or heat for final consumption	Fossil utilisation rate	<ul style="list-style-type: none">• improved thermal conversion efficiency (e.g., fossil power generation or refining)• lower transmission & distribution losses• lower fossil industry own use, including in extraction such as mining and in energy used by power plants and refineries (other than energy losses in conversion or refining processes themselves)• less use of refined/transformed fossil products (e.g., switch from electric to gas heating if the electricity is fossil-generated)

C_i : CO ₂ /Fossil primary energy, representing the carbon content of the fossil fuel mix	Fossil CO ₂ intensity	<ul style="list-style-type: none"> fuel switching towards lower-carbon fossil resources (e.g., gas) and away from higher-carbon fossil resources (e.g., coal) reduction in the carbon content of coal and other fuels more use of carbon capture and storage
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3 Table 2. Correlations between numbers of policies and national trends in related CO₂
 4 emission drivers during 2005-2015. Policies on energy efficiency are correlated with changes
 5 in energy use (adjusted for GDP growth in parenthesis, see Methods). Policies on renewable
 6 energy are correlated with changes in non-fossil energy. Climate framework policies are
 7 correlated with total changes in CO₂. Bold numbers are statistically significant at the 95%
 8 level.

	Energy efficiency	Renewable energy	Climate
<i>Peak-and-decline group</i>			
Number of countries with available data	18	18	18
Median [25-75 percentile] number of policies	35 [27-51]	23 [15-35]	10 [8-12]
Correlation with related CO ₂ trend	-0.54 (-0.42 ^a)	-0.75	-0.54
<i>Control group A</i>			
Number of countries with available data	24	30	30
Median [25-75 percentile] number of policies	10 [3-28]	11 [7-19]	7 [5-8]
Correlation with related CO ₂ trend	-0.14 (-0.61)	-0.07	0.56
<i>Control group B</i>			
Number of countries with available data	13	31	31
Median [25-75 percentile] number of policies	2 [1-15]	6 [5-12]	8 [5-10]
Correlation with related CO ₂ trend	0.55 ^a (-0.66)	0.51	0.30

9 ^aStatistically significant at the 90% level

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1 **Data and Methods:**

2 **CO₂ emissions and energy data:** CO₂ emissions are from fossil fuels only and are from the
3 IEA Reference approach²⁸, which estimate CO₂ emissions using supply-side data of energy
4 production. The final and primary energy data used in the decomposition come from IEA's
5 World Energy Balances database [accessed July 2018]²⁹. Total primary and final energy are
6 reported directly in the database, and we define the fossil share of final energy as direct final
7 consumption of fossil fuels plus final consumption of heat and electricity derived from fossil
8 sources. We also use four other sources of emissions to check the robustness of our analysis
9 (see Supplementary Information): the Sector approach of the IEA; the national reports
10 submitted to the United Nations Framework Convention on Climate Change (UNFCCC); BP;
11 as well as emissions based on consumption accounting^{7,30}.

12 The 'peak-and-decline' group is selected based on those countries where emissions
13 decreased significantly over the period 2005-2015 in at least three of the four databases,
14 and where emissions also decreased significantly when accounted for on a consumption
15 basis (Table S2; see also Supplementary information). It excludes Greece whose economy
16 contracted severely during this period, and Jamaica because of suspected issues with the
17 data. The two control groups include countries where emissions do not significantly
18 decrease, with group A and B separated by their GDP growth rate below (group A) or above
19 (group B) 3.5% per year.

20 **GDP data** are from the International Energy Agency, national currencies.

21 **Policy data:** We synthesized data on the cumulative number of policies promoting: (1) the
22 use of renewable energy and (2) energy efficiency; and the cumulative number of (3) climate
23 framework policies. Energy policy data is from the IEA/IRENA (International Renewable
24 Energy Agency) Joint Policies and Measures database [accessed May 2018]. A climate
25 framework policy is a legal act that seeks to provide a unifying basis for climate change
26 mitigation and/or adaptation policy. We identified climate policies as frameworks if they
27 were indicated accordingly by the Global Climate Legislation database, which is also the
28 source for this data¹⁰. Given their broad scope, climate framework policies include a
29 substantial share of measures targeting energy issues. However, the key difference between
30 a climate framework policy and policies promoting the use of renewable energy and energy
31 efficiency is that the latter were adopted as stand-alone pieces of legislation and exclusively
32 target these two issues. In this analysis, policies such as the fraction of renewable energy
33 target would be considered an energy policy under (1), even if the incentive for the policy is
34 from addressing climate change. Many policies that encourage the deployment of
35 renewable energy also encourage energy efficiency, so that (1) and (2) are themselves
36 correlated. These variables include the total number of legal acts adopted nationally by
37 2015. Data were available for at least two of three policy drivers for countries in groups A
38 and B.

39 **Correlation analysis:** All correlations presented use the Spearman ranked correlation so that
40 each country has the same weight. Significance is assessed with a two-tailed t-test. We
41 present the median and 25-75 percentile as a measure of the general trends found in most
42 countries. Note that the sum of the medians of the energy decomposition does not
43 necessarily add up to 100%.

44 **Emission drivers:** We separate different contributions to territorial CO₂ emissions (C)
45 between final energy (FE); the fraction (C_f) of that final energy from fossil fuels (FE_{ff}/FE); the
46 ratio (C_r) of fossil fuel primary energy over fossil fuel final energy (PE_{ff}/FE_{ff}); and the carbon
47 intensity (C_i) of that fossil fuel primary energy (C/PE_{ff}), as follows:

$$C = FE \times \frac{FE_{ff}}{FE} \times \frac{PE_{ff}}{FE_{ff}} \times \frac{C}{PE_{ff}} = FE \times C_f \times C_r \times C_i \quad (1)$$

1 Examples of what these terms represent are provided in Table 2. The change in ΔC between
 2 two given years t_2 and t_1 is decomposed exactly using the Logarithmic Mean Divisia Index
 3 (LMDI) approach³¹ as follows:

$$\Delta C = \Delta C_{FE} + \Delta C_{C_f} + \Delta C_{C_r} + \Delta C_{C_i} \quad (2)$$

4 where

$$\Delta C_X = \frac{C^{t_2} - C^{t_1}}{\ln C^{t_2} - \ln C^{t_1}} \ln \left(\frac{C_X^{t_2}}{C_X^{t_1}} \right) \quad (3)$$

5 We also further decompose FE of Eq. (1) into a contribution from GDP , and the energy
 6 intensity of GDP (E_i) to better understand the drivers of changes in energy demand:

$$7 \quad FE = GDP \times \frac{FE}{GDP} = GDP \times E_i \quad (4)$$

8 Which extends Eq. (2) into:

$$\Delta C = \Delta C_{GDP} + \Delta C_{E_i} + \Delta C_{C_f} + \Delta C_{C_r} + \Delta C_{C_i} \quad (5)$$

9 The energy intensity of GDP includes all reductions in energy use per unit of GDP produced,
 10 and therefore includes energy intensity as well as structural changes in the economy (e.g.
 11 structural change from the production of goods to the production of services). See
 12 Supplementary Information for detailed results.

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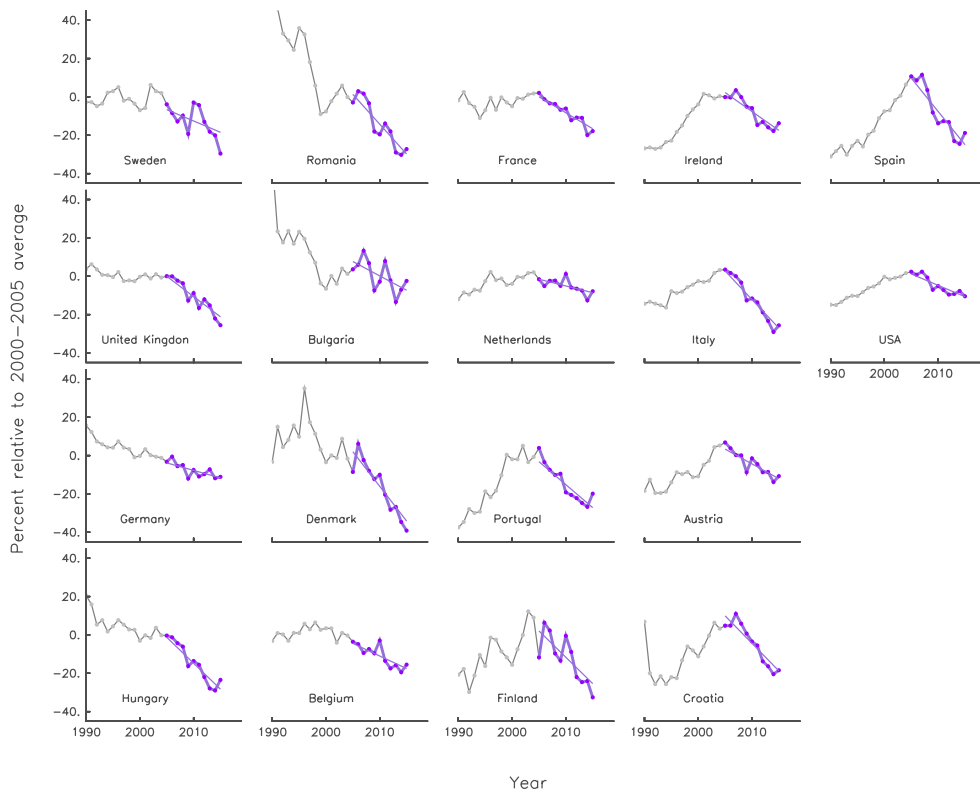
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1 **Figures:**

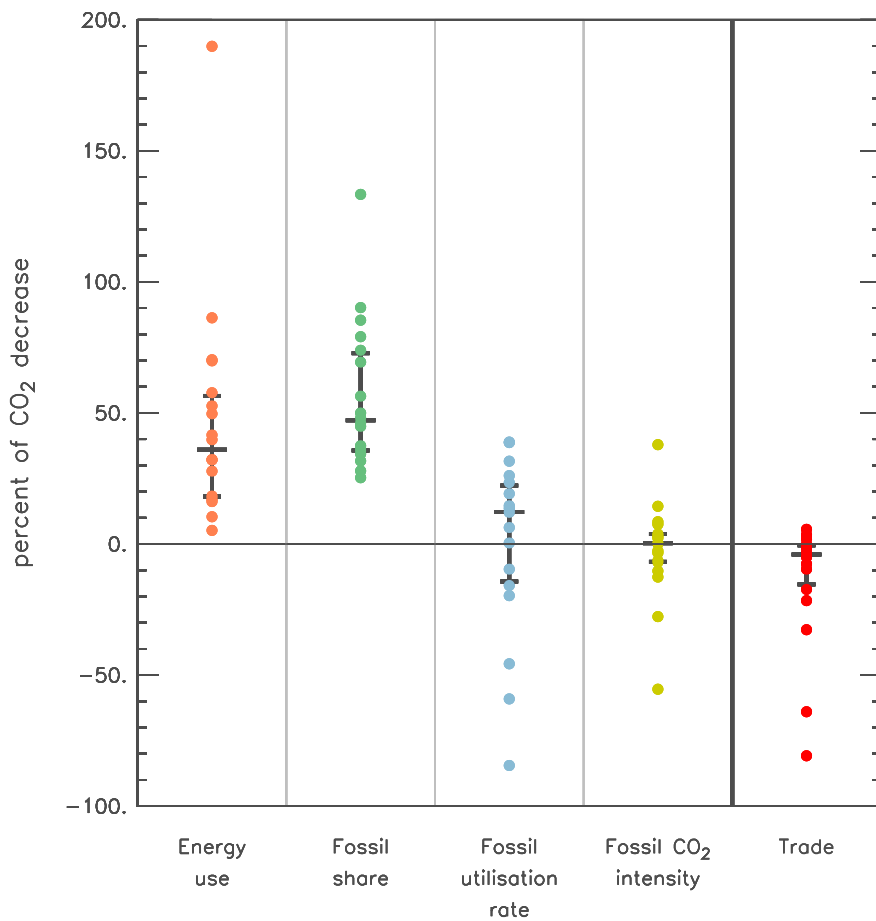


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3 **Figure 1.** Change in CO₂ emissions from fossil fuel combustion for the 18 countries in the
4 'peak-and-decline' group (in percent). The 2005-2015 time period analysed here is
5 emphasized in purple, with the linear trend shown for each country. Emissions are from the
6 IEA reference approach²⁹. The countries are generally presented in order of their
7 approximate peak date, with some permutations for clarity. Change is relative to the 2000-
8 2005 average.

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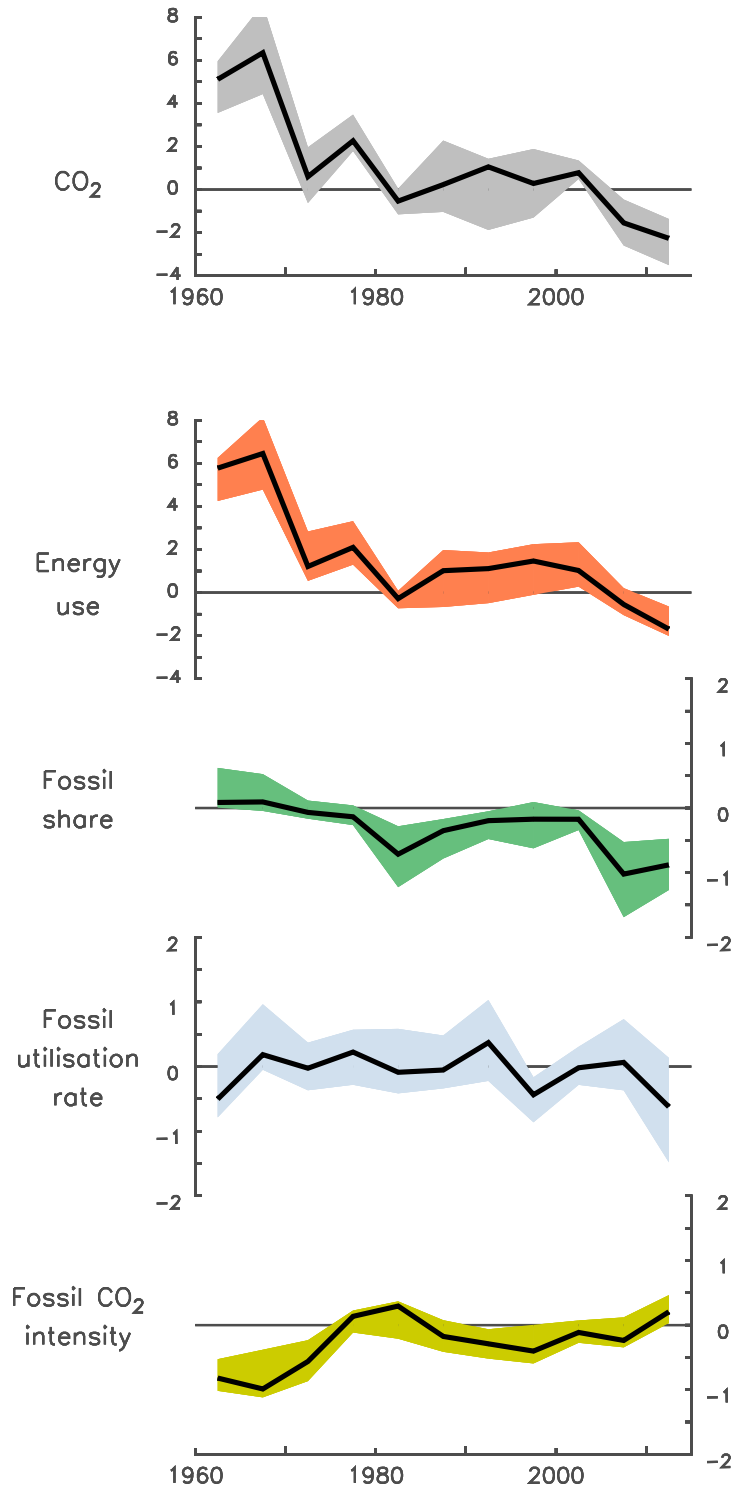


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3 **Figure 2.** Contributions to the decrease in national CO₂ emissions from four physical drivers
 4 of change in energy production and use, as well as international trade, during 2005-2015.
 5 Each dot shows data for one country. Contributions are from changes in energy use
 6 (orange), fossil share of energy (green), fossil utilisation rate (blue), and fossil CO₂ intensity
 7 (yellow; the four right-hand terms of Eq. 2; Table 2). The transfer of emissions due to
 8 outsourcing consumption through trade is also shown (red). Energy data are from the IEA
 9 Reference approach²⁹. Data are for the 18 countries in the peak-and-decline country group,
 10 with the median and 25-75 percentile (bars). See Supplementary Table S3.

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2 **Figure 3.** Time-series of changes in CO₂ emissions (top) and the contributions from changes
 3 in energy systems (percent per year). Contributions are from changes in energy use, the
 4 fossil share of energy, the fossil utilisation rate, and the fossil CO₂ intensity (Table 1). Data
 5 are for the peak-and-decline group as in Fig. 2, analysed in increments of 5 years from 1960
 6 to 2015, showing the median and 25-75 percentile range.

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1 References

- 2 1 Le Quéré, C. *et al.* Global Carbon Budget 2017. *Earth Syst. Sci. Data* **10**, 405-448,
3 doi:10.5194/essd-10-405-2018 (2018).
- 4 2 Stocker, T., Qin, D. & Plattner, G.-K. *Climate Change 2013 The Physical Science Basis*.
5 (Cambridge University Press, 2013).
- 6 3 van Vuuren, D. P. *et al.* Carbon budgets and energy transition pathways.
7 *Environmental Research Letters* **11**, doi:10.1088/1748-9326/11/7/075002 (2016).
- 8 4 Jordan, A. *et al.* Going beyond two degrees? The risks and opportunities of
9 alternative options. *Climate Policy* **13**, 751-769, doi:10.1080/14693062.2013.835705
10 (2013).
- 11 5 IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II*
12 *and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate*
13 *Change*. 151 pages (2014).
- 14 6 Boden, T. A., Marland, G. & Andres, R. J. Global, Regional, and National Fossil-Fuel
15 CO₂ Emissions, available at: http://cdiac.ornl.gov/trends/emis/overview_2014.html,
16 last access: July 2017. (Oak Ridge National Laboratory, U.S. Department of Energy,
17 Oak Ridge, Tenn., U.S.A. , 2017).
- 18 7 Peters, G. P., Minx, J. C., Weber, C. L. & Edenhofer, O. Growth in emission transfers
19 via international trade from 1990 to 2008. *Proceedings of the National Academy of*
20 *Sciences of the United States of America* **108**, 8903-8908,
21 doi:10.1073/pnas.1006388108 (2011).
- 22 8 Davis, S. J. & Caldeira, K. Consumption-based accounting of CO₂ emissions.
23 *Proceedings of the National Academy of Sciences* **107**, 5687-5692,
24 doi:10.1073/pnas.0906974107 (2010).
- 25 9 Peters, G. P. *et al.* Key indicators to track current progress and future ambition of
26 the Paris Agreement. *Nature Clim. Change* **7**, 118-123, doi:10.1038/nclimate3202
27 (2017).
- 28 10 Fankhauser, S., Gennaioli, C. & Collins, M. Do international factors influence the
29 passage of climate change legislation? *Climate Policy* **16**, 318-331,
30 doi:10.1080/14693062.2014.1000814 (2015).
- 31 11 Bernauer, T. & Böhmelt, T. National climate policies in international comparison: The
32 Climate Change Cooperation Index. *Environmental Science & Policy* **25**, 196-206,
33 doi:10.1016/j.envsci.2012.09.007 (2013).
- 34 12 Dubash, N. K., Hagemann, M., Höhne, N. & Upadhyaya, P. Developments in national
35 climate change mitigation legislation and strategy. *Climate Policy* **13**, 649-664,
36 doi:10.1080/14693062.2013.845409 (2013).
- 37 13 Lachapelle, E. & Paterson, M. Drivers of national climate policy. *Climate Policy* **13**,
38 547-571, doi:10.1080/14693062.2013.811333 (2013).
- 39 14 Riahi, K. *et al.* Locked into Copenhagen pledges — Implications of short-term
40 emission targets for the cost and feasibility of long-term climate goals. *Technological*
41 *Forecasting and Social Change* **90**, 8-23,
42 doi:<https://doi.org/10.1016/j.techfore.2013.09.016> (2015).
- 43 15 van Vuuren, D. P. *et al.* Alternative pathways to the 1.5 degrees C target reduce the
44 need for negative emission technologies. *Nature Climate Change* **8**, 391-+,
45 doi:10.1038/s41558-018-0119-8 (2018).
- 46 16 van Vuuren, D. P. *et al.* What do near-term observations tell us about long-term
47 developments in greenhouse gas emissions? A letter. *Climatic Change* **103**, 635-642,
48 doi:10.1007/s10584-010-9940-4 (2010).
- 49 17 Marcinkiewicz, K. & Tosun, J. Contesting climate change: mapping the political
50 debate in Poland. *East European Politics* **31**, 187-207,
51 doi:10.1080/21599165.2015.1022648 (2015).

1 18 Tosun, J. Environmental monitoring and enforcement in Europe: a review of
2 empirical research. *Environmental Policy and Governance* **22**, 437-448 (2012).

3 19 Dietz, T., Frank, K. A., Whitley, C. T., Kelly, J. & Kelly, R. Political influences on
4 greenhouse gas emissions from US states. *Proceedings of the National Academy of
5 Sciences* **112**, 8254-8259, doi:10.1073/pnas.1417806112 (2015).

6 20 Knill, C., Schulze, K. & Tosun, J. Regulatory policy outputs and impacts: Exploring a
7 complex relationship. *Regulation & Governance* **6**, 427-444, doi:10.1111/j.1748-
8 5991.2012.01150.x (2012).

9 21 Girod, B., van Vuuren, D. P. & Hertwich, E. G. Climate policy through changing
10 consumption choices: Options and obstacles for reducing greenhouse gas emissions.
11 *Global Environmental Change-Human and Policy Dimensions* **25**, 5-15,
12 doi:10.1016/j.gloenvcha.2014.01.004 (2014).

13 22 Grubler, A. *et al.* A low energy demand scenario for meeting the 1.5 degrees C target
14 and sustainable development goals without negative emission technologies. *Nature
15 Energy* **3**, 515-527, doi:10.1038/s41560-018-0172-6 (2018).

16 23 Wilson, C., Grubler, A., Gallagher, K. S. & Nemet, G. F. Marginalization of end-use
17 technologies in energy innovation for climate protection. *Nature Climate Change* **2**,
18 780-788, doi:10.1038/NCLIMATE1576 (2012).

19 24 Grubler, A. *et al.* A low energy demand scenario for meeting the 1.5 °C target and
20 sustainable development goals without negative emission technologies. *Nature
21 Energy* **3**, 515-527, doi:10.1038/s41560-018-0172-6 (2018).

22 25 Le Quéré, C. *et al.* Global Carbon Budget 2018. *Earth Syst. Sci. Data* **10**, 2141-2194,
23 doi:10.5194/essd-10-2141-2018 (2018).

24 26 Masson-Delmotte, V. *et al.* in *Global warming of 1.5°C. An IPCC Special Report on the
25 impacts of global warming of 1.5°C above pre-industrial levels and related global
26 greenhouse gas emission pathways, in the context of strengthening the global
27 response to the threat of climate change, sustainable development, and efforts to
28 eradicate poverty* 32 (World Meteorological Organization, Geneva, Switzerland).

29 27 Figueres, C., Whiteman, G., Le Quéré, C. & Peters, G. P. Carbon emissions rise again.
30 *Nature* (2018).

31 28 OECD/IEA. CO2 emissions from fuel combustion © OECD/IEA,
32 www.iea.org/statistics, Licence: www.iea.org/t&c, accessed July 2017.,
33 (International Energy Agency/Organisation for Economic Cooperation and
34 Development, Paris, 2017).

35 29 OECD/IEA. Based on IEA World Energy Balances database © OECD/IEA,
36 www.iea.org/statistics, Licence: www.iea.org/t&c, accessed July 2018 (2018).

37 30 Le Quéré, C. *et al.* Global Carbon Budget 2016. *Earth Syst. Sci. Data* **8**, 605-649,
38 doi:10.5194/essd-8-605-2016 (2016).

39 31 Ang, B. W. The LMDI approach to decomposition analysis: a practical guide. *Energy
40 Policy* **33**, 867-871, doi:10.1016/j.enpol.2003.10.010 (2005).

41