Reduction in greenhouse gas emissions by national climate legislation

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Abstract

The international response to climate change has been inadequate, but not zero. There are 1,800 climate change laws worldwide. We use panel data on legislative activity in 133 countries over the period 1999-2016 to identify statistically the short-term and long-term impact of climate legislation. Each new law reduces annual CO2 emissions per GDP by 0.78% nationally in the short-term (during the first three years) and by 1.79% in the long term (beyond three years). The results are driven by parliamentary acts and by countries with a strong rule of law. In 2016, current climate laws were associated with an annual reduction in global CO2 emissions of 5.9 GtCO2, more than the US CO2 output that year. Cumulative CO2 emissions savings from 1999 to 2016 amount to 38 GtCO2, or one year's worth of global CO2 output. The impact on other greenhouse gases is much lower.

The international community is not on track to meet the climate change objectives of the Paris Agreement[1]. According to UN estimates, global greenhouse gas emissions in 2030 will be some 15 $GtCO_2e$ higher than required under a 2ºC stabilisation path[2].

Yet countries are taking action against climate change. The *Climate Change Laws of the World* database records 1,800 climate change laws and policies worldwide, covering both mitigation and adaptation[3]. There is no country in the world that does not have at least one climate change law[4].

In this paper we estimate statistically what this body of legislation has collectively achieved. Presumably the law making has had some impact, and global emissions would have been even higher in its absence. But by how much?

The *Climate Change Laws of the World* dataset is uniquely suited to answer this question. The database aspires to be comprehensive, tracking the legislation activities of every country in the world over the past 30 years or more.

The database adopts a fairly broad definition of climate legislation, including parliamentary acts, executive orders and policies of equivalent importance. For simplicity, we refer to all these interventions as "laws".

The database includes both laws that are aimed explicitly at climate change and laws that have an impact on climate change. It covers the full range of interventions that is relevant to reducing greenhouse gas emissions, from framework laws (such as, the UK *Climate Change Act*) and dedicated climate measures (e.g., New Zealand's *Climate Change Response (Emissions Trading) Amendment*) to sector policies on energy (e.g., Germany's *Renewable Energy Sources Act*), transport (e.g., Brazil's *Mandatory Biodiesel Requirements*) and forestry (e.g., the Democratic Republic of Congo's *Law on Protection of the Nature*). Other laws deal with adaptation, either exclusively (e.g., Japan's *Climate Change Adaptation Act*) or in conjunction with wider climate or environmental objectives (e.g. the *2050 Climate Strategy* of the Marshall Islands). The breadth and richness of these measures means that the statistical relationships we find are average associations, but that they reflect the impact of law making on emissions, rather than a spurious correlation.

So far, *Climate Change Laws of the World* has mostly been used to assess global progress in adopting climate policies [5–9], understand the political economy of passing climate laws[10–12] and identify good practice in climate change governance[13]. These explorations are part of a wider literature on international, national and sub-national climate change governance[14–16], on the drivers of emission reductions[17] and on the political economy of environmental protection[18–22].

The evaluation of public policy is interested in the effectiveness with which policy goals are met, but also in the political context in which measures are implemented and their impact on policy processes, institutions and the political discourse[23–25]. Applications are emerging that look climate legislation from these angles[26–29]. However, the merit of a climate change law ultimately depends on its ability to reduce emissions (or climate risks, in the case of adaptation laws).

Statistical methods provide a powerful, reduced-form way of ascertaining the link between legislation and emissions. There is a notable tradition of using statistical techniques to estimate the impact of socio-political factors on the environment, including studies on the political economy of urban air quality[30], energy intensity[31] and the lead content of petrol[32]. In relation to climate change there have been attempts to explain greenhouse gas emissions as a function of socio-economic and political factors like fuel exports and the level of democracy[33,34].

This analysis is in the same vein. We use panel data regression to statistically identify the link between adopting new climate laws and greenhouse gas emissions per GDP in the country that passes the law. We are interested both in the short-term effect of a new law (its impact on emissions within three years) and its cumulative effect, in conjunction with earlier laws, over several years. Although some countries had to be dropped for data reasons, we paint a global picture of climate change legislation and its aggregate impact on global greenhouse gas emissions.

Trends in climate change legislation

Climate Change Laws of the World documents climate change legislation over several decades and across the world. While the database is comprehensive, our analysis is restricted, by the availability of emissions data, to the legislative activities of 133 countries over the period 1999–2016. We also exclude laws solely dedicated to adaptation, which leaves a body of 1,092 mitigation laws that are the subject of our analysis.

About 40 percent of database entries are legislative acts, passed by parliaments, and about 60 percent are executive orders, issued by governments. A prominent example of the latter is US President Barack Obama's *Clean Power Plan* of 2015. Chinese climate policy also relies heavily on executive orders, including pertinent provisions in the 12th and 13th five-year plans. We are interested in the combined effect of all these interventions, although we will test whether there is a difference between parliamentary acts and executive orders.

Most climate change laws were passed in the last 20 years (Figure 1a). By the end of 1999, there were only 145 such laws worldwide. Some of them were dedicated climate change acts, such as Sweden's *Carbon Tax Act* of 1991, but many early laws had wider objectives, such as energy conservation. After 1999, the number of climate laws began to rise rapidly. Law making reached a peak in the period 2009-13, when over 120 new laws were passed each year[4].

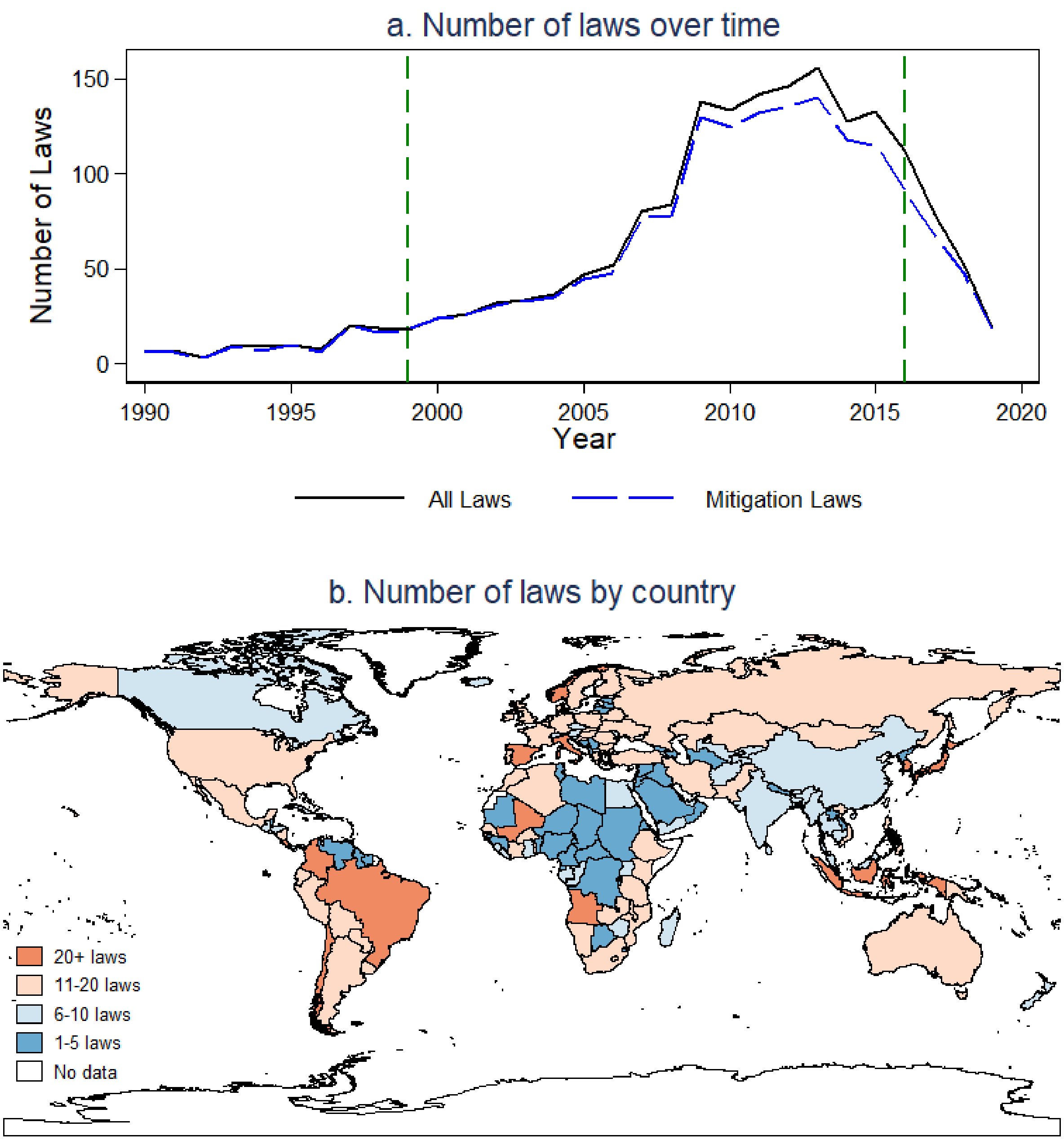

Figure 1: Climate laws. a. the number of climate laws in use 1990-2019, b. climate laws in individual countries, as of 31 December 2019. Panel (a) shows all climate laws (black solid line) and all mitigation laws (blue dashed line) for 1990-2019. The green dashed lines identify the period 1999-2016, which is the focus here. Panel (b) shows the stock of climate laws in individual countries at the end of 2019. All data are from *Climate Change Laws of the World*.

Climate change laws differ in scope and ambition. Three out of four countries have overarching framework laws, specifically aimed at creating an institutional framework to reduce greenhouse gas emissions. A good example is Mexico's *General Law on Climate Change 2012*. Sometimes, these frameworks are couched in a wider sustainable development or green growth narrative, such as Ethiopia's *Growth and Transformation Plan* 2016 and South Korea's *Framework Act on Low-Carbon Growth* of 2010.

However, the majority of climate laws concern sector-specific interventions, in particular on energy. Over half of all climate laws contain provisions about energy supply, such as the promotion of renewable energy. Over 40% of laws deal with demand-side energy efficiency, among other provisions. Since most laws deal with more than one issue and energy interventions tend to have economy-wide effects, we think of both overarching and sector-specific laws as economy-wide interventions.

On average countries have nine climate laws, of which five to six deal with mitigation, but in some cases this number can rise to well over 20 (Figure 1b). For example, Brazil has 28 climate-related laws and policies and Spain has 38.

Our focus on national climate policy means ignoring important initiatives at the sub-national level and by non-state actors. State, province and city-led initiatives are particularly important in countries with federal structures or where national engagement with climate change has been intermittent, such as Australia, Brazil, Canada and the United States. In many of these countries, climate policy at sub-national level is ahead of the national discourse. Conversely, in EU member states a focus on national climate policy would ignore the important role of the European Union in national climate policy. The EU passed no fewer than 31 mitigation laws between 1999 and 2016, including legislation to set up an EU-wide emissions trading scheme and establish ambitious targets on renewable energy, which are legally binding for its member states. To reflect this, all EU laws are added to the tally of member states.

A potential problem with *Climate Change Laws of the World* is that when laws are amended the database only records the latest version, thus omitting earlier activities. Legal provisions are often tightened over time (as for example Switzerland did when revising its *CO_2 Act* in 2013), but there are also cases of reversal (such as the repeal of Canada's *Kyoto Implementation Act* in 2012 and Australia's *Clean Energy Act* in 2014). In each case, these events supersede earlier database entries.

Climate legislation and emissions intensity

Our climate legislation data constitute a panel of 2,394 country-year observations (133 countries over 18 years). We are interested in annual greenhouse gas (CO2 and non-CO2) emissions per unit of economic output (mtCO2e/GDP), a ratio known as emissions intensity, and how it is affected by the passage of climate change laws. We use emissions intensity, rather than absolute emissions, to reduce the impact of confounding factors like country size and economic performance.

The hypothesis is that climate change laws codify a country's policy ambitions with respect to greenhouse gas emissions. After a law is passed it will start to affect national emissions. Some laws may kick in immediately, others more gradually or with a delay. This suggests that in the most general model emissions intensity in year t is a function of the laws passed in year $(t-1)$, $(t-2)$, $(t-3)$ and so on, each lag with a different weight. We aggregate these annual effects into

(i) a short-term impact (related to the stock of laws passed in the previous three years), and (ii) a long-term impact (related to the stock of laws that are more than three years old).

The impact of laws on emissions also depends on the discipline with which they are implemented. For example, Brazil and Indonesia both have extensive rules on deforestation, but their implementation has been patchy[35,36]. We control for differences in implementation effectiveness through a time-variant indicator on the rule of law, which is taken from the Worldwide Governance Indicators[37].

The statistical model is completed by a set of control variables on economic factors, weather fluctuations and other governance features. We add a country fixed effect to control for time-invariant factors such as different socio-economic contexts, political cultures and renewable energy potentials (e.g. solar irradiance). A time fixed effect controls for inter-temporal trends that are uniform across countries, such as the global fall in clean technology costs. Further details are provided in the Methods.

We conduct separate regressions for CO2 and non-CO2 greenhouse gases. The current body of climate laws has a strong focus on energy and energy-related emissions. There has been much less policy attention on agriculture and land use, the main sources of non-CO2 emissions. We hypothesise that this difference in legislative emphasis is reflected in the emissions performance of CO2 and non-CO2 gases.

The results suggest that passing a climate change law has a statistically significant, negative effect on CO2 emissions per GDP over both the short and long term (Table 1). As anticipated, there is less of an effect on non-CO2 gases, where the impact of laws is statistically significant only over the long term.

Table 1 - Climate laws and their effect on emissions

VARIABLES	(1) Other GHGs	(2) CO2 Emissions
(L1) Stock of Recent Mitigation Laws	-0.0012	-0.0078***
	(0.0017)	(0.0021)
(L1) Stock of Older Mitigation Laws	-0.0065***	-0.0179***
	(0.0013)	(0.0014)
(L1) Rule of Law	-0.3162***	-0.6164***
	(0.1137)	(0.1168)
(L1) HP Filter	0.2229	0.3679*
	(0.2307)	(0.2124)
(L1) ln(GDP per-capita PPP)	-0.2349	1.1623***
	(0.1938)	(0.2570)
(L1) ln(GDP per-capita PPP) Square	-0.0135	-0.0840***
	(0.0105)	(0.0138)
(L1) Import share (% of GDP)	0.0001	0.0018***
	(0.0004)	(0.0006)
(L1) Services share (% of GDP)	0.0025**	-0.0029**
	(0.0010)	(0.0012)
(L1) Temperature (Deviation)	0.0042	-0.0123*
	(0.0058)	(0.0067)
Federal Systems	-0.0141	0.0059
	(0.0159)	(0.0407)
Constant	1.6213*	-4.5877***
	(0.8967)	(1.2092)
Observations	2,394	2,394
Country FE	YES	YES
Year FE	YES	YES
R2(within)	0.195	0.214

Notes: Robust standard errors are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are defined as Ln(kg per-$ other GHG Emissions) and Ln(kg per-$ CO2 Emissions), respectively.

As the dependent variable is in logarithmic form, the regression coefficients in Table 1 have a straightforward interpretation. Passing a new climate law reduces annual CO2 emissions per GDP in that country by 0.78% in the short term (during the first three years) and by 1.79% in the long term (after three years). The impact on non-CO2 gases is insignificant in the short term and about a third of the CO2 effect (0.65%) in the longer term.

It is worth to briefly discuss the main control variables. We find that a strong rule of law – our proxy for implementation effectiveness – affects both CO2 and non-CO2 emissions, an issue that is explored further below. There is an inverted u-shaped relationship between (the log of) greenhouse gas intensity and (the log of) GDP per capita, similar to an environmental Kuznets curve[38].

There is a positive correlation between carbon intensity and the cyclical component of GDP (labelled the HP filter, after the decomposition method we use, see methodology section). This is consistent with the literature, which has found carbon emissions to be more cyclically volatile than economic output[39]. Emissions grow faster than GDP during upswings and fall more rapidly during downturns. Accordingly, a country's emissions intensity falls when economic activity flat-lines and rises when the economy is picking up. We find no cyclical relationship in the case of non-CO2 gases, which are associated with less volatile activity.

Air temperatures above the long-term average are associated with a lower CO2 emissions intensity. This suggests that the effect of air temperature on winter heating, which is important for the large emitters of the northern hemisphere, dominates the effect of air temperature on summer cooling. We do not find a significant relationship between non-CO2 emissions and fluctuations in air temperature. This is as expected, since temperature fluctuations primarily affect energy demand and therefore CO2 emissions.

Legislative quality

The impact of climate legislation on emissions depends substantively on the strength of a law and the rigour with which it is implemented. To gain further insights into these questions, we experiment with two additional model specifications. The focus is on CO2 emissions.

First, we analyse the importance of implementation capacity. Implementation capacity is proxied by a rule-of-law indicator, which in the main model enters the regression directly. As an alternative, we now interact the rule-of-law variable with the number of laws passed in each year. We can think of the resulting variable as the effectiveness-weighted stock of climate laws: each law has a weight between 0 and 1 that reflects implementation capacity in the year it was passed.

The new specification allows us to explore the impact of good or bad implementation on CO2 emissions (Table 2, column 1). For countries with a middling rule of law score of 0.5 (the mean value of the sample, see table S1 in the Supplementary Information), the estimated effect of new climate legislation is similar to the main results: A long-term reduction in CO2 emissions of 1.35% (0.0270×0.5).

However, for a country with a strong rule-of-law score of 0.9 (the maximum value observed in the sample) the effect is stronger: a 2.43% (0.0270×0.9) fall in emissions in the long run. In countries with weak implementation capacity emissions could fall by as little as 0.27% (0.0270×0.1, the lowest rule-of-law score in the sample).

A second specification explores the difference between legislative acts and executive orders. There is a suspicion that legislative acts are a more powerful way to cut emissions. While *Climate Change Laws of the World* only includes policies that are of equivalent status to an executive order, many of them are primarily aspirational.

To explore this question, we run regressions where parliamentary acts and executive orders are entered separately (Table 2, columns 2,3). The empirical results confirm our suspicion. Most of the estimated emission reductions can be credited to legislative acts. In the specification where legislative acts and executive orders are tested simultaneously, we find no significant effect of executive orders on CO2 intensity.

Table 2 – Legislative quality results

	(1) Implementation quality	(2) Legislative Acts vs Executive Orders	(3)
VARIABLES		Both types	Leg. Acts only
(L1) Stock of Recent Mitigation Laws × (L1) Rule of Law	-0.0132***		
	(0.003)		
(L1) Stock of Older Mitigation Laws × (L1) Rule of Law	-0.0270***		
	(0.002)		
(L1) Stock of Recent Parliamentary Mitigation Acts		-0.0122***	-0.0125***
		(0.0029)	(0.0029)
(L1) Stock of Older Parliamentary Mitigation Acts		-0.0249***	-0.0254***
		(0.0017)	90.0017)
(L1) Stock of Recent Executive Mitigation Orders		-0.0019	
		(0.0036)	
(L1) Stock of Older Executive Mitigation Orders		-0.0034	
		(0.0032)	
(L1) Rule of Law		-0.5333***	-0.5179***
		(0.1159)	(0.1159)
(L1) HP Filter	0.4357**	0.4067*	0.4135*
	(0.2136)	(0.2144)	90.2152)
(L1) ln(GDP per-capita PPP)	0.8515***	0.8756***	0.8432***
	(0.2695)	(0.2544)	(0.2557)
(L1) ln(GDP per-capita PPP) Square	-0.0716***	-0.0700***	-0.0686***
	90.0143)	(0.0136)	90.0136)
(L1) Import share (% of GDP)	0.0020***	0.0020***	0.0020***
	(0.0006)	(0.0006)	(0.0006)
(L1) Services share (% of GDP)	-0.0021*	-0.0025**	-0.0025**
	(0.0012)	(0.0012)	(0.0012)
(L1) Temperature (Deviation)	-0.0136**	-0.0108	-0.0107
	(0.0067)	(0.0067)	(0.0067)
Federal Systems	0.0328	0.0371	0.0421
	(0.0382)	(0.0363)	(0.0353)
Constant	-3.1774**	-3.2331***	-3.0749**
	(1.2699)	(1.2006)	(1.2066)
Observations	2,394	2,394	2,394
Country FE	YES	YES	YES
Year FE	YES	YES	YES
R2 (within)	0.214	0.225	0.225

Notes: Robust standard errors are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are defined as Ln(kg per-$ other GHG Emissions) and Ln(kg per-$ CO_2 Emissions), respectively.

The aggregate effect of climate policy and legislation

The statistical results at the country-year level can be used to estimate the historical impact of the current body of climate laws on global emissions, as detailed the Methods. The difference between observed actual emissions (which include the effect of climate legislation) and estimated counterfactual emissions (which assume no climate legislation) are initially small (Figure 2), For CO2, the two curves begin to deviate from about 2004, when legislative activity starts to pick up particularly in advanced (EU/OECD) countries. For non-CO2 gases, the two curves remain close throughout, reflecting the moderate impact on other greenhouse gases we found in the panel

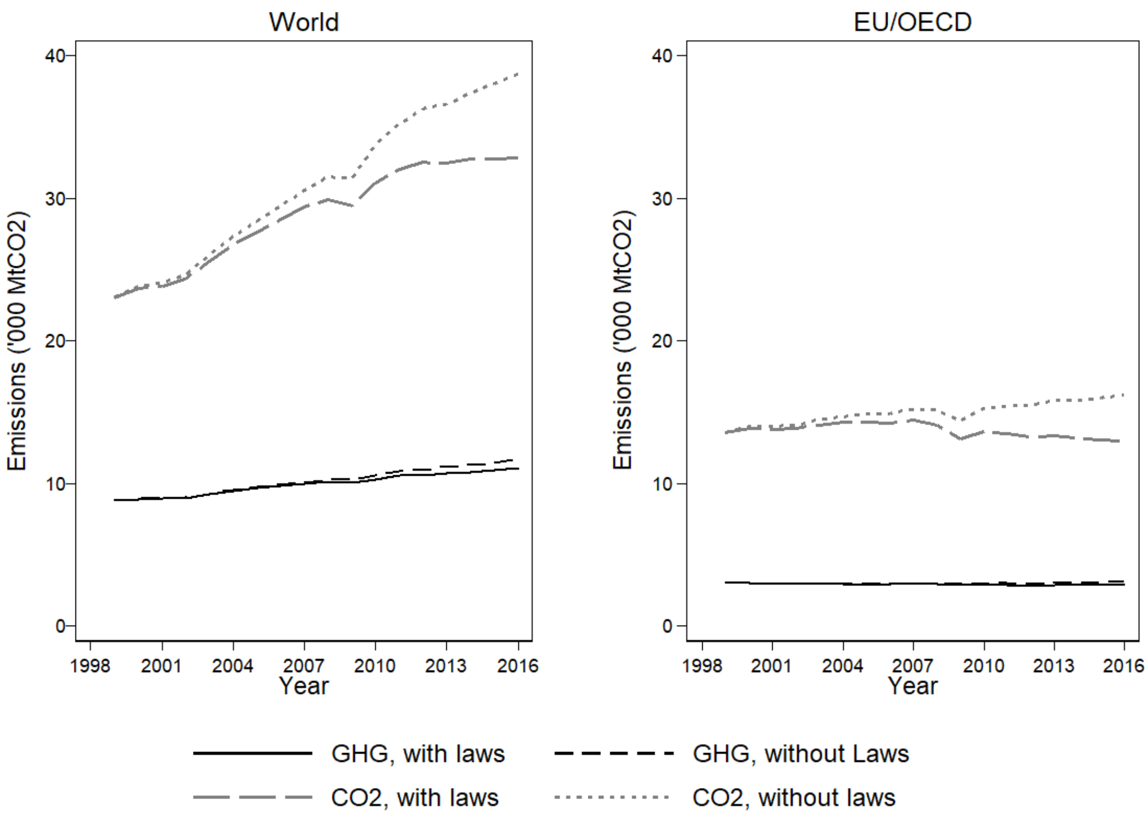

Figure 2: Emissions path with and without laws. Emissions of CO_2 (grey) and other greenhouse gases (black) are shown for 1998-2016 for the World and EU/OECD countries. Observed emissions (solid lines) include the impact of all legislative activity to date. Counterfactual emissions (dashed lines) were constructed by estimating a hypothetical emissions trajectory in which there was no legislative activity.

regressions.

By 2016 the difference between actual CO_2 emissions and the estimated "no legislation" counterfactual is 5.9 $GtCO_2$ (Figure 3). This equates to a legislation-induced cut in annual emissions of about 15% from a "no legislation" baseline. By comparison, the United States, the world's second largest CO_2 emitter, releases 5.2 $GtCO_2$ a year. Avoided non-CO_2 emissions are much smaller, amounting to 0.6 $GtCO_2e$.

Two thirds of the estimated CO_2 reduction and close to half of the non-CO_2 cuts were achieved in advanced (OECD and EU) countries, where there are more climate laws and government effectiveness is higher. In those countries, climate legislation has succeeded in stabilising carbon emissions at 1999 levels. However, globally climate legislation has offset only about a third of CO_2 emissions growth since 1999 (Figure 3).

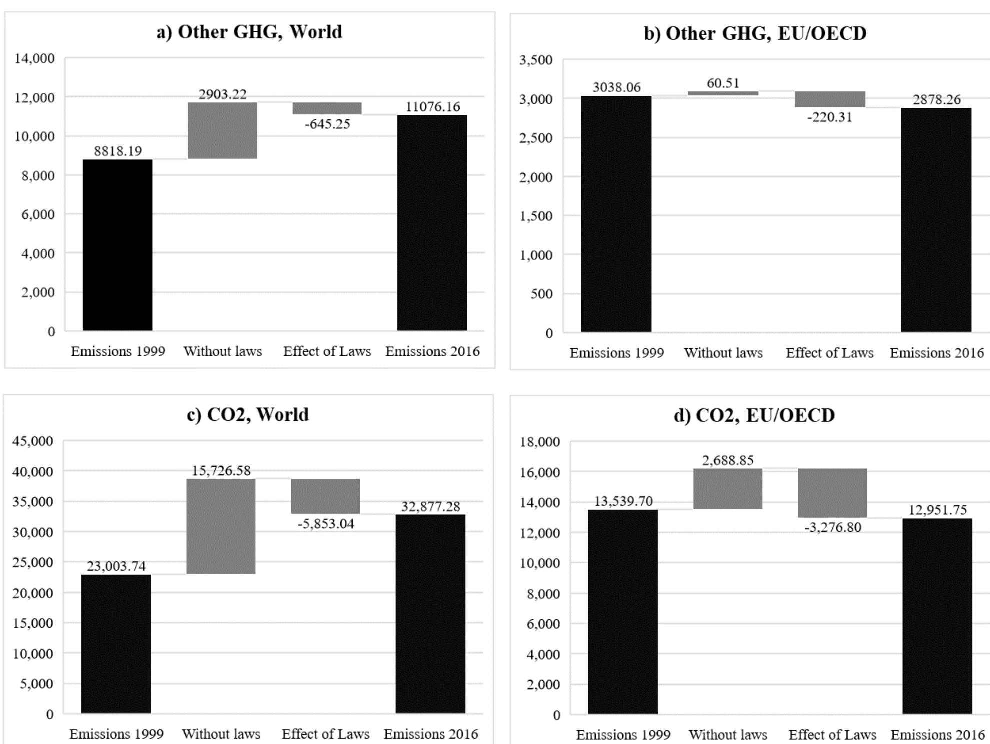

Figure 3: Change in emissions by gases and region (1999 to 2016). Emissions for 1999 and 2016 are the observed emissions for each country group and gas. Emissions "without laws" are calculated from the estimated counterfactual emissions path. The "effect of laws" is calculated as the difference between observed actual emissions and estimated counterfactual emissions.

The difference in area underneath the two emissions trajectories measures the cumulative emissions savings between 1999 and 2016 (Table 3). Since 1999, climate change legislation has saved 37.7 GtCO2 in CO2 emissions, or about one year's worth of carbon output. By comparison, the remaining carbon budget that is consistent with 1.5ºC is between 420 GtCO2 and 770 GtCO2, depending on assumptions[40]. Without existing climate laws, the remaining carbon headroom would be between 5% (37.7/770) and 9% (37.7/420) lower. A further 3.9 GtCO2e was avoided in cumulative non-CO2 emissions.

The results are robust to the alternative specifications reported in Table 2 (aggregate CO2 avoidance of 36.4 – 39.2 GtCO2) and in the supplementary materials (aggregate CO2 avoidance of 27.4 – 37.7 GtCO2).

Table 3: Total emissions savings by gas and region (1999-2016)

	Other GHG avoidance (GtCO2e)	CO2 avoidance (GtCO2)
World (133 Countries)	3.9	37.7
EU/ OECD (41 Countries)	1.5	22.9

Notes. Emissions avoidances are calculated as the total avoided emissions due to laws as percentage of total emissions occurred during 1999-2016 for the selected country groups.

Conclusions

As countries ratchet up their contributions to the Paris Agreement, it is important to understand how effective existing climate legislation has been in reducing greenhouse gas emissions. We find that the body of 1,092 mitigation laws that we studied (out of a total stock of 1,800 climate laws and policies) has made some difference. Passing a new climate law is associated with a reduced emissions intensity both in the short term (within the first three years after their adoption) and cumulatively in the longer term.

Our results therefore underline the importance of a solid legal framework in tackling climate change. They also speak to the crucial role of parliaments: Emission reductions have been driven by legislative acts, much more than executive orders. They further emphasise the importance of disciplined implementation: The impact of climate laws is significantly higher in countries with a strong rule of law, where legal provisions are more likely to be followed.

The aggregate emissions reductions from the current body of climate laws is sizeable in absolute terms: CO2 savings of 38 GtCO2 over the period 1999 to 2016 and a further 4 GtCO2e in non-CO2 emissions. However, to those who are concerned about the scale of the climate challenge, these aggregate cuts will feel like a modest reward for years of negotiation, campaigning and concerted global effort. It has increased the remaining carbon space to stay within 1.5°C by just 5-9%.

Carbon policy must clearly be tightened to meet the objectives of the Paris Agreement. It is safe to assume that this means improvement both at the extensive margin (the number of laws) and the intensive margin (stronger, better implemented laws). Our reduced-form analysis can shed light only on the overall relationship between climate legislation and emissions. It is silent about the political, institutional and societal processes through which legislation is turned into environmental outcomes.

There is an emerging literature that begins to study climate legislation in those practical terms[26,28]. Students of climate change legislation have also begun to identify elements of good practice that constitute effective climate change governance and the best policies to incentivise emission reductions[13,41]. If policy makers adopt these lessons, there should over time be a stronger relationship between climate change legislation and greenhouse gas emissions than the one identified here.

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Methods

The econometric model

Our hypothesis is that the level of greenhouse gas emissions is a function of, among other factors, legislative history. A country's climate change ambitions need to be codified in policies or laws. In the most general model, emissions intensity (that is, greenhouse gas emissions per GDP) in year t would be a function of the laws passed in year $(t-1)$, $(t-2)$, $(t-3)$ and so on, each lag with a different weight.

However, to avoid excessive lags we aggregate legislative history into two time periods: A short-term variable which consists of the stock of laws passed during the past three years, and a long-term variable which aggregates the number of laws that are older than three years. This is equivalent to assuming identical coefficients for lags in each of these time periods. We are interested in emissions intensity, rather than absolute emissions, to control for confounding factors related to population and the economy.

Formally, we estimate different versions of the following equation using a two-way fixed effect panel regression model:

$$y_{it} = \alpha + \beta_1 S_{it}^S + \beta_2 S_{it}^L + \gamma \boldsymbol{X}_{it} + \theta_i + \nu_t + \varepsilon_{it} \qquad (1)$$

where y_{it} represents the log of emissions intensity in country i at year t, that is $y_{it} \equiv ln\left(\frac{E_{it}}{GDP_{it}}\right)$. $S_{it}^S \equiv \sum_{k=1}^{3} L_{i(t-k)}$ is the stock of laws passed in the previous three years, which measures the short-term effect of legislation, and $S_{it}^L \equiv \sum_{k=1}^{t-4} L_{ik} + S_{i0}$ is the stock of laws at the end of year $(t-4)$, which measures the long-term effect of legislation. S_{i0} is the stock of laws at the outset.

In one of our specifications, the stock of laws is further split into legislative acts (passed by parliaments) and executive orders and policies (issued by governments), each stock with the structure described above.

Vector $\boldsymbol{X}_{it}$ contains a set of control variables, described in more detail below. The model is completed by a full set of country and year fixed effects (θ_i and v_t) and a random error term ε_{it}. The country effect controls for time-invariant factors such as different socio-economic contexts, political cultures and renewable energy potential (e.g. solar irradiance). The time fixed effect controls for inter-temporal trends that are uniform across countries, such as the global fall in renewable energy costs and developments in climate science.

Data

The climate legislation data come from *Climate Change Laws of the World.* The database includes information for 198 jurisdictions (197 countries plus the European Union) until early 2020. Data gaps in some of the control variables means we are focusing on 133 countries over the period 1999-2016, with the lagged variables going back to 1996. We are also excluding climate laws that exclusively deal with adaptation, leaving a total of 1,092 laws over 2,394 country-year observations (133 countries × 18 years).

The 1,092 laws cover a wide range of policy measures and ambitions. Tangible initiatives include carbon pricing schemes (either taxes or emissions trading systems), support for renewable energy, incentives for or regulation on energy conservation, support for low-carbon transport (e.g. emissions standards or subsidies for clean cars) and measures to combat deforestation. Many laws include sector or economy-wide emissions targets, often aspirational, sometimes legally binding. Other laws set up new processes and institutions to monitor, report and verify emission reduction progress. Together with the lag structure, the richness of these measures gives us confidence that the relationships we find reflect the impact of laws on emissions, rather than a spurious correlation.

Climate Change Laws of the World includes the European Union as a separate entity, and we add EU laws to the tally of member states, since they have legal force among members (starting from the date of EU accession in the case of new member states).

The vector of control variables, $\boldsymbol{X}_{it}$, has several components. The first component is an indicator of government effectiveness, which controls for differences in the rigour with which laws are implemented. Our chosen indicator is the Rule of Law variable from the *Worldwide Governance Indicators*, which captures "perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the court"[37]. The original scale was converted into a [0,1] range as follows: $g_{it} = \frac{g_{it}^{orig} - g_t^{min}}{g_t^{max} - g_t^{min}}$. See data availability statement for on access to these data.

In one of our specifications, the rule-of-law variable is interacted with the number of laws, so that the stock of law variables take the alternative form $\breve{S}_{it}^{S} \equiv \sum_{k=1}^{3} L_{i(t-k)} g_{i(t-k)}$ and $\breve{S}_{it}^{L} \equiv \sum_{k=1}^{t-4} L_{ik} g_{ik} + \breve{S}_{i0}$.

The next set of controls are economic variables. GDP per capita controls for the possibility of an environmental Kuznets curve[38]. Two further variables, import share and the size of the service sector, control for changes in economic structure that may affect the emissions profile. All three variables are taken from the World Bank's *World Development Indicators* database. See data availability statement for on access to these data. We note in passing that empirical studies of low-carbon competitiveness have identified no substantial impact of climate policy on economic performance[42]. This gives us confidence that the climate legislation and GDP per capita variables are independent.

Greenhouse gas emissions are subject to annual fluctuations, related in particular to the business cycle and weather. We control for this by including two variables that measure, respectively, the cyclical component of economic activity and deviation from average air temperature. The cyclical component of GDP is based on a Hodrick-Prescott (HP) decomposition, an established tool in macroeconomics, which is calculated by standard statistical packages[43]. Fluctuations in air temperature are the difference between annual average temperatures and the long-term (1980-2015) average. Both temperature records come from the World Bank's *Climate Knowledge Portal*. See data availability statement for on access to these data.

The final control variable is a dummy, taken from the *Database of Political Institutions* 2017 (see data availability statement for weblink).[44] The variable takes the value of 1 for countries with a federal system, where states or provinces have strong legislative powers It controls for the possibility that national climate legislation may be complemented by policies at the sub-national level and that these competencies may shift over time. (Time invariant arrangements are picked up by the country fixed effect).

Supplementary Table S1 contains summary descriptions of all variables.

The total impact of climate legislation

We use the statistical relationships estimated through equation (1) to calculate a counterfactual "no legislation" emissions path, which estimates what global greenhouse gas emissions would have been in the absence of any climate change legislation.

We start by setting all legislation terms in the estimated equation (1) equal to zero. We then subtract this expression from the full estimated equation (1). Using the superscript $\sim$ for "no legislation" terms and $\frown$ to denote estimated values, this yields

$$\hat{y}_{it} - \tilde{y}_{it} = \hat{\beta}_1 S_{it}^S + \hat{\beta}_2 S_{it}^L \qquad (2).$$

Recalling the definition of y_{it} as the logarithm of emissions intensity, we can rewrite the left-hand side of equation (1) as:

$$\hat{y}_{it} - \tilde{y}_{it} = \ln\left(\hat{E}_{it}/GDP_{it}\right) - \ln\left(\tilde{E}_{it}/GDP_{it}\right) = \ln\left(\hat{E}_{it}/\tilde{E}_{it}\right) \qquad (3).$$

Combining equations (2) and (3) yields

$$\tilde{E}_{it} = \hat{E}_{it} \,.\, exp\left(-\hat{\beta}_1 S_{it}^S - \hat{\beta}_2 S_{it}^L\right) \qquad (4).$$
$$\approx E_{it} \,.\, exp\left(-\hat{\beta}_1 S_{it}^S - \hat{\beta}_2 S_{it}^L\right)$$

The last step replaces estimated with observed emissions. Global "no legislation" emissions are then calculated by aggregating the country-level emissions estimates over countries and time:

$$\tilde{E}_{global} = \sum_i \sum_t \tilde{E}_{it} \qquad (5).$$

Data availability statement

All data used in this study are in the public domain as follows.

- Climate legislation data are from *Climate Change Laws of the World*, available at https://climate-laws.org/.

- Data on the rule of law are from the *Worldwide Governance Indicators*, available at www.govindicators.org and https://databank.worldbank.org/source/worldwide-governance-indicators.
- Economic data are from World Bank's *World Development Indicators* database, available at https://databank.worldbank.org/source/world-development-indicators.
- Data on political systems are from the *Database of Political Institutions 2017*, available at https://publications.iadb.org/en/database-political-institutions-2017-dpi2017.
- Temperature data come from the World Bank's Climate Knowledge portal, available at https://climateknowledgeportal.worldbank.org/download-data.

Code availability statement

The full computer code is available on GitHub (https://github.com/).[45] The analysis was carried out using STATA.

Supplementary information

The supplementary information contains an overview and summary statistics of all variables used in the analysis. It also describes the results of robustness checks, which were carried out to ascertain the strength of our econometric results. We split the sample, introduce different specifications of the dependent variable and experiment with different ways to measure legislative activity. The sensitivity checks confirm that our main results are robust, but they add additional insights on the relative performance of industrialised and emerging countries.

Variables Description and Summary Statistics

Information on the datasets that were used and how to access them is contained in the Online Methods. To complement this information, Table S1 contains summary descriptions of all variables.

Industrialised countries vs the rest of the world

In a first round of sensitivity tests we split the sample into an industrialised country panel and a developing country panel. The former group comprises all countries that are members of the Organization for Economic Cooperation and Development (OECD) and the European Union (EU).

The hypothesis is that advanced countries, responding to their obligations under the UN Framework Convention on Climate Change (UNFCCC), have put in place more stringent legislation. We also note that interventions in developing countries are often in the form of policy documents, rather than acts of parliament, which have less legal force (see results in Table 2 of the main manuscript).

The results confirm that climate laws in industrialised countries have had a stronger impact on emissions, particularly in the short-term and with respect to non-CO2 gases. The long-term impact on CO2 is broadly the same (Table S2).

Further robustness checks

The remaining robustness checks concern changes to the definition or in measurement of some key variables (Table S3). The adjustments are made to the regressions for CO2 only.

The first definitional change concerns the dependent variable. Instead of using emissions intensity as the dependent variable, we regress emissions per capita against the effect of climate legislation. The results are similar for the variables of interest, confirming the robustness of our main results.

The second definitional change concerns the way climate legislation in EU member states is counted. In the main results, climate laws passed at the EU level are added to the tally of EU member states at the time of their accession to the EU. The argument is that those laws are binding on member states. However, as a robustness check we explore what would happen if no such adjustment was made. The results are robust to this change.

The third change introduces an additional control variable to measure clean technical progress. The rapid fall in the costs of renewable energy technologies like solar PV could be an important driver of energy-related CO2 emissions. In the main regressions we rely on country and time fixed effects to capture these trends. The former controls for differences in countries' renewable energy potential (e.g. solar irradiance or wind speeds), while the latter picks up global changes in renewable energy costs.

As a robustness check we introduce an additional variable, the share of renewable energy in total energy generation, which serves as a proxy for technical progress. There are alternative proxies of technical progress, such as patent data, but they are not sufficiently granular to cover all 2,394 country-years. There is a possibility that this variable is endogenous (i.e., determined, among other factors, by the provisions in climate laws), but the variable is significant, and our main results remain intact.

Table S1 - Variables Description and Summary Statistics

VARIABLES	Description	Mean	Standard Deviation	Minimum	Maximum
GHG emissions	Other GHG emissions (mtCO2) per 2011 PPP $1 GDP in year *t* in country *i*	0.347	0.653	0.00670	12.00
CO2 emissions	CO2 emissions (mtCO2) per 2011 PPP $1 GDP in year *t* in country *i*	0.262	0.181	0.0332	1.803
Laws	Number of climate change laws passed in year *t* in country *i*	0.575	1.031	0	12
Mitigation Laws	Number of mitigation climate change laws passed in year *t* in country *i*	0.539	0.985	0	12
Legislative Acts	Number of legislative climate change laws passed in year *t* in country *i*	0.293	0.716	0	12
Stock of Laws	Number of climate change laws passed in country *i* until year *t*	4.336	5.303	0	45
Stock of Mitigation Laws	Number of climate change mitigation laws passed in country *i* until year *t*	4.142	5.139	0	43
Rule of law	Index of rule of law	0.507	0.200	0.0965	0.920
GDP per-capita	GDP per capita, PPP (constant 2011 international $)	16,937	18,076	545.7	102,635
GDP HP filter	GDP HP filter	-0.000264	0.0206	-0.181	0.188
Import share	Imports of goods and services (% of GDP)	45.69	24.46	8.397	210.4
Services share	Services, value added (% of GDP)	52.99	11.48	12.44	93.72
Temperature Variation	Difference between the yearly average temperature and the long-term (1980-2015) average temperature	0.306	0.453	-1.726	2.763
Federal System	1 if states/provinces have legislative powers	0.187	0.390	0	1

Notes. Summary statistics are restricted to the estimating sample of 133 countries over 18 years (1999-2016).

Table S2 –Industrialised countries vs rest of the world

	(1)	(2)	(3)	(4)
	EU/OECD Countries		Non-EU/OECD Countries	
VARIABLES	Other GHG	CO2	Other GHG	CO2
(L1) Stock of Recent Mitigation Laws	-0.0042***	-0.0046**	-0.0019	0.0013
	(0.0016)	(0.0019)	(0.0033)	(0.0037)
(L1) Stock of Older Mitigation Laws	-0.0127***	-0.0083***	-0.0069***	-0.0097***
	(0.0012)	(0.0012)	(0.0024)	(0.0032)
(L1) Rule of Law	-0.9832***	-0.2051	-0.2479*	-0.4998***
	(0.1703)	(0.2685)	(0.1379)	(0.1336)
(L1) HP Filter	0.5337**	-0.0110	0.2054	0.4448*
	(0.2311)	(0.2305)	(0.2789)	(0.2542)
(L1) ln(GDP per-capita PPP)	2.8691***	-0.2547	-0.2482	0.5396*
	(0.7800)	(1.0765)	(0.2873)	(0.3108)
(L1) ln(GDP per-capita PPP) Square	-0.1755***	-0.0065	-0.0110	-0.0535***
	(0.0408)	(0.0578)	(0.0157)	(0.0168)
(L1) Import share (% of GDP)	-0.0002	-0.0013*	0.0002	0.0034***
	(0.0007)	(0.0007)	(0.0005)	(0.0007)
(L1) Services share (% of GDP)	0.0041*	-0.0073**	0.0021*	-0.0015
	(0.0024)	(0.0031)	(0.0011)	(0.0012)
(L1) Temperature (Deviation)	0.0005	-0.0101*	0.0042	-0.0072
	(0.0062)	(0.0060)	(0.0102)	(0.0118)
Federal Systems	-0.0103	0.0196		
	(0.0181)	(0.0325)		
Constant	-13.0959***	2.6982	1.7172	-2.1101
	(3.6938)	(4.9767)	(1.2791)	(1.4224)
Observations	738	738	1,656	1,656
Country FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
R2 (within)	0.391	0.234	0.165	0.190

Notes: Robust standard errors are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are defined as Ln(kg per-$ other GHG Emissions) and Ln(kg per-$ CO2 Emissions), respectively.

Table S3 – Further robustness checks

VARIABLES	(1) Per-capita CO2	(2) Excluding EU laws	(3) Clean Tech
(L1) Stock of Recent Mitigation Laws	-0.0070***	-0.0049*	-0.0057***
	(0.002)	(0.0027)	(0.002)
(L1) Stock of Older Mitigation Laws	-0.0182***	-0.0161***	-0.0138***
	(0.0014)	(0.0021)	90.0014)
(L1) Rule of Law	-0.5821***	-0.6321***	-0.4050***
	(0.1155)	(0.119)	(0.1101)
(L1) HP Filter	-0.4924**	0.3459	0.3862*
	(0.1998)	(0.2161)	(0.2002)
(L1) ln(GDP per-capita PPP)	2.3226***	1.3908***	0.409
	(0.2529)	(0.2577)	(0.2635)
(L1) ln(GDP per-capita PPP) Square	-0.0941***	-0.0954***	-0.0471***
	-0.0136	-0.0139	-0.0139
(L1) Import share (% of GDP)	0.0022***	0.0015**	0.0017***
	(0.0006)	(0.0006)	(0.0006)
(L1) Services share (% of GDP)	-0.0037***	-0.0034***	-0.0030***
	(0.0012)	(0.0012)	(0.0011)
(L1) Temperature (Deviation)	-0.0150**	-0.0148**	-0.0047
	(0.0067)	(0.007)	(0.0062)
Federal Systems	-0.0289	-0.0142	0.0218
	(0.0404)	(0.0437)	(0.0353)
(L1) Renewable energy % of total			-0.0112***
			(0.001)
Constant	-5.1556***	-5.6668***	-0.5557
	(1.1875)	(1.2054)	(1.2578)
Observations	2,394	2,394	2,394
Country FE	YES	YES	YES
Year FE	YES	YES	YES
R2 (within)	0.309	0.184	0.277

Notes: Robust standard errors are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are defined as Ln(kg per-$ other GHG Emissions) and Ln(kg per-$ CO2 Emissions), respectively.