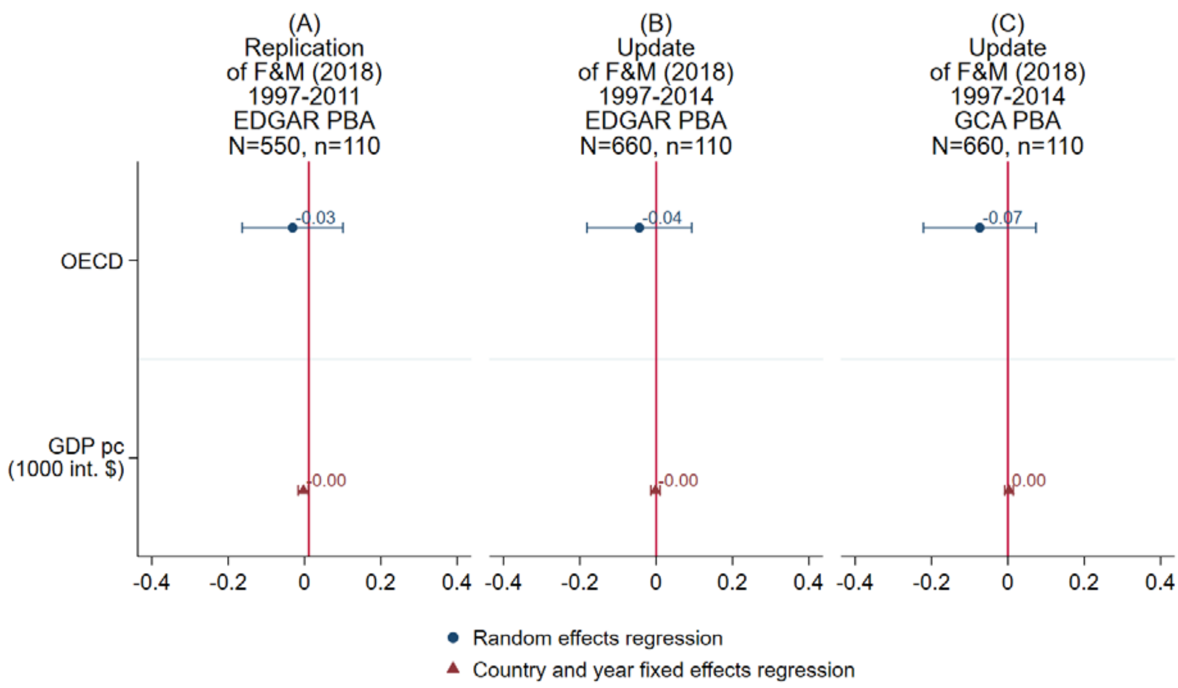
Environmental Science & Policy 104 (2020): 52-54

Reply to the comment by Zhang and Fang (2019) on consumption-based versus production-based accounting of CO_2 emissions

Zhang and Fang (2019) criticize our finding (Franzen and Mader 2018) that there is (on average) no carbon leakage from developed to developing countries. In the paper we show that countries' GDP per capita is statistically not related to the ratio of consumption-based (CBA) to production-based (PBA) accounting of CO_2 emissions. Hence, the ratio of the two accounting schemes does not differ between richer and poorer countries or, put differently, does not depend on a country's GDP per capita. Zhang and Fang (2019) have two concerns with our paper: First, they believe that we should have used the Global Carbon Atlas (GCA) for both CBA and PBA and should not have mixed the data with the Emissions Database for Global Atmospheric Research (EDGAR); we used the EDGAR to obtain countries' PBA and the GCA to obtain their CBA. Second, the authors argue that we should not have used the ratio of CBA to PBA but the difference of CBA – PBA for our analyses. In what follows, we respond to both concerns.

The answer to Zhang and Fang's first concern is straightforward: The main results of the regression analysis of the CBA/PBA ratio on OECD membership (or GDP) are not affected by the data source. This is shown in Figure 1, which displays the differences between members and non-members of the OECD in terms of the CBA/PBA ratio obtained from random effects regression using the 110 countries for which the data is available. Furthermore, Figure 1 displays the within effects of GDP per capita obtained from fixed effects panel regressions that only take into consideration the countries' within variance. Panel A of Figure 1 is a replication of our earlier model using the newest updates of EDGAR (Janssens-Maenhout et al. 2017) for PBA and GCA (Peters et al. 2011) for CBA. Panel B extends the models by using the data that includes the newest available year, 2014. Finally, we analyze the effect using the data of GCA for both PBA and CBA (Panel C). The results always indicate that OECD membership is not related to the CBA/PBA ratio. This also holds true for a between (not shown in Figure 1) and a within analysis of the CBA/PBA ratio on GDP per capita. Hence, the results do not depend on taking the data from EDGAR or GCA for PBA.

Figure 1: Regressions of the ratio of CBA to PBA of CO_2 emissions



Note: Unstandardized regression coefficients with 95% confidence intervals. All models contain dummy variables for each year to control for overall time-trends. All standard errors are clustered by country, and therefore robust with respect to heteroscedasticity and autocorrelation. CBA = consumption-based accounting. PBA = production-based accounting. F&M = Franzen and Mader. EDGAR = Emissions Database for Global Atmospheric Research. GCA = Global Carbon Atlas. n = number of countries. N = number of observations (n multiplied by the number of years). Robustness checks comprise fixed effects (FE) panel regressions with country-specific constants and slopes (FEIS) (Brüderl and Ludwig 2015), and penalized splines FE models (Ruppert et al. 2003) to test the parameter of gross domestic product (GDP) for linearity. Furthermore, we ran 110 regressions dropping one country each time to test for statistical outliers. In addition, the robustness of standard errors was checked using non-parametric bootstrapping. Moreover, we reran all six models controlling for energy intensity, trade balance, and the shares of the industry and service sector of the GDP (data from World Bank 2019). Likewise, we tested for the influence of omitted variables using the method suggested by Frank (2000). Finally, the robustness of the GDP effect was checked by substituting the purchasing power parity-corrected GDP per capita (PPP GDP p.c.) as gathered from the International Monetary Fund (2019) by the PPP GDP p.c. as provided by the World Bank (2019). None of these checks had any substantial influence on the estimates. All models and all the robustness checks were calculated using the statistical software package STATA 16.0. See also Table S1 in the supplement for the exact regression results of all six models. Table S2 describes all variables and Table S3 lists all countries included in the models.

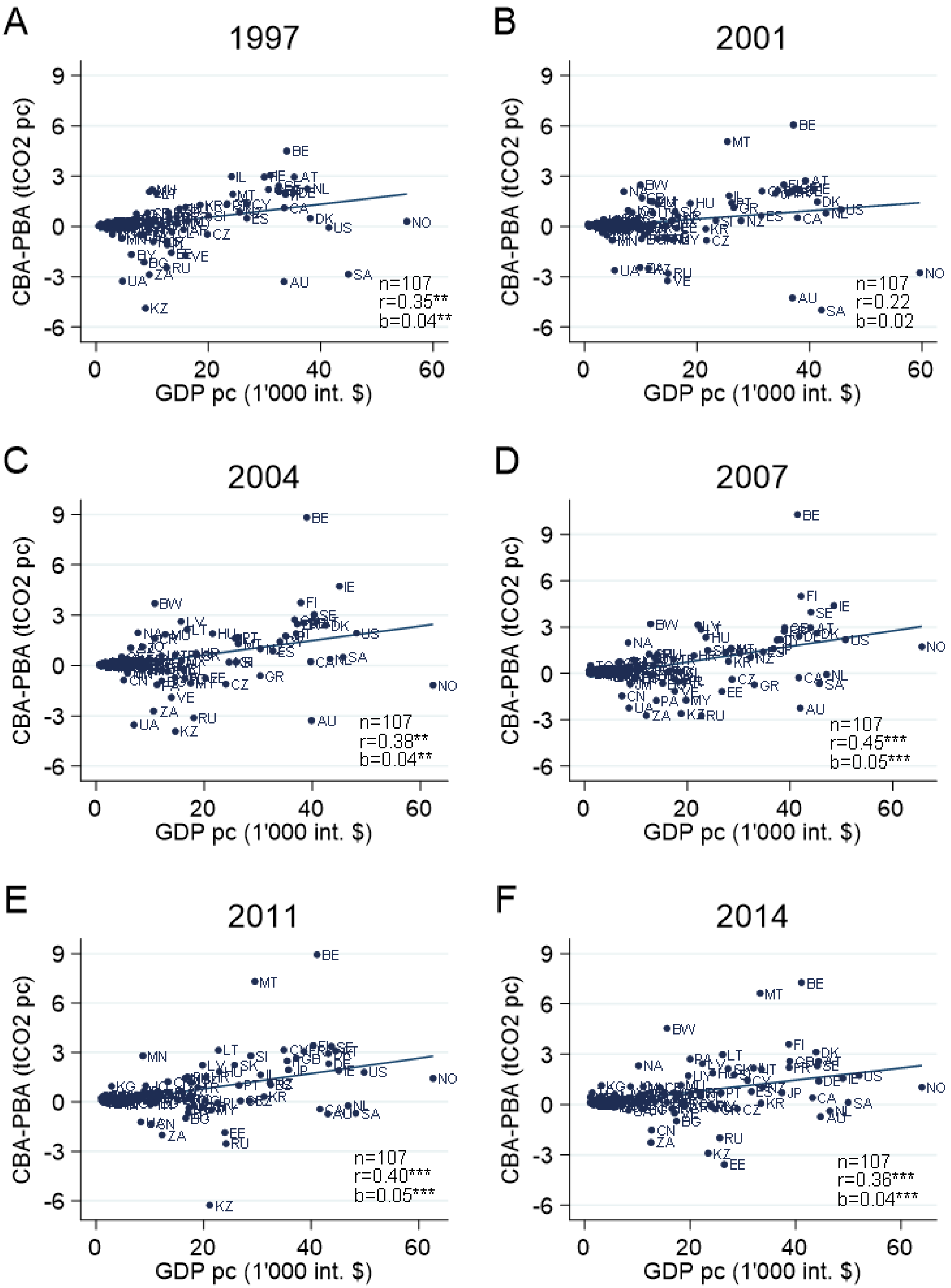
This does not come as a surprise since both data sources use the same definition of PBA. Also, the correlation of EDGAR and GCA PBA is 0.99. Hence, both data sources are almost identical with respect to the PBA data, and are compatible.

The second argument refers to taking the ratio of CBA/PBA versus the absolute difference of CBA-PBA. Whether one uses the relative or the absolute differences is more a matter of perspective than a question of right or wrong. Let's for example take two countries. One has 5 tons of PBA CO_2 emissions per capita and the other 10 tons. Let's assume that the absolute difference of CBA-PBA for the first is 0.5 and for the second 1 ton, then the relative differences are the same (10%) but the absolute difference is bigger for the country with the higher PBA. Since PBA is strongly associated with GDP (e.g. Franzen and Mader 2016), an analysis of GDP on the ratio would result in a zero effect, but an analysis of the absolute difference would result in a positive effect of GDP.

This is exactly what we see in the data. Figure 2 displays the simple OLS between country regressions of GDP on the absolute differences for the six available years. The average zero-order correlation is 0.36 and the regression coefficient 0.04. Hence, for every $1000 increase of purchasing-power-adjusted GDP, the increase in CBA-PBA difference is 40kg of CO_2 per capita. Therefore, Zhang and Fang do have a point, taking the absolute difference instead of the ratio changes the results. However, Figure 2 also reveals that the correlation did not change substantially over the last 18 years (from 1997 to 2014). This fact is also reflected by a fixed effects regression analysis which only takes into account the countries' within variation of the absolute difference. The effect of GDP is statistically not significant (see Figure 3). Hence, if we take the absolute difference of CBA-PBA into account, we do find GDP-related differences, but these did not change over the last 18 years; i.e. further changes in GDP did not increase the absolute difference. This finding is not compatible with the carbon leakage hypothesis. If richer countries displace CO_2-intensive industries into poorer countries then one would expect this process also to have occurred during the last 18 years. Instead the differences we observe were already present in 1997 and have not increased since then.

One way of avoiding the problem of taking relative differences or absolute differences is to dichotomize countries into those with a positive difference (CBA > PBA) and those with a negative difference (no country has exactly zero). In this way, both measures, ratio and difference, assign the countries into identical groups.

Figure 2: Between-countries correlations of GDP per capita and the CBA-PBA difference, 1997-2014

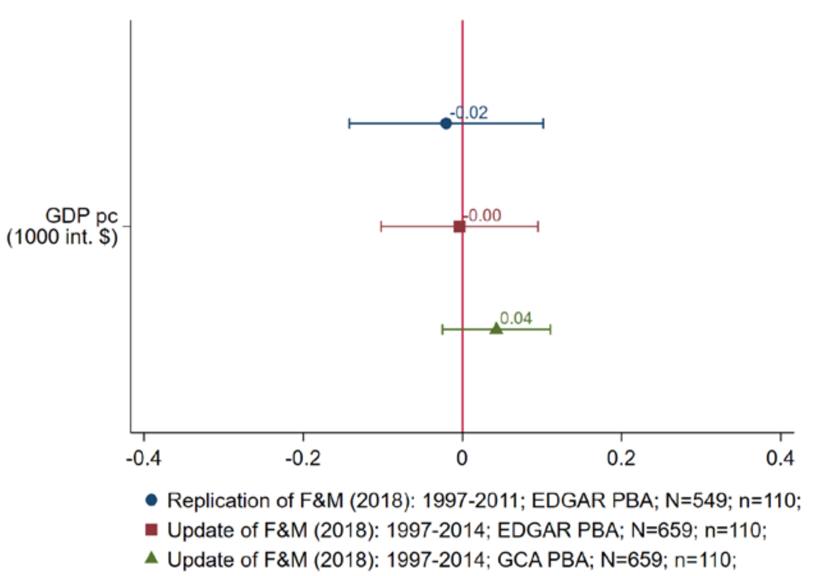


Note: Scatterplots and linear ordinary least squares (OLS) regression lines of the bivariate correlation of GDP p.c. and the difference between CBA and PBA of CO_2 emissions by year. r = Pearson's correlation coefficient. b = beta coefficient of the bivariate linear OLS regression between GDP p.c. and CBA-PBA (see Table S4 in the supplement for details). * = *p*<0.05, ** = *p*<0.01, *** = *p*<0.001. The countries corresponding to the depicted country codes can be obtained from Table S3. The number of countries in the scatterplots is reduced from 110 to 107, because Cook's D identified Singapore, Bahrain, and Switzerland as influential cases (Cook's D > 0.5). Data sources: CBA: Global Carbon Atlas (GCA); PBA: Emissions Database for Global Atmospheric Research (EDGAR). Robustness checks for the OLS regressions comprise penalized splines FE models (Ruppert et al. 2003) to test the parameter of gross domestic product (GDP) for linearity. Furthermore, we ran 107 regressions dropping one country each time to test for statistical outliers. In addition, the robustness of standard errors was checked using non-parametric bootstrapping. Moreover, we reran all six models controlling for energy intensity, trade balance, and the shares of the industry and service sectors of the GDP (World Bank 2019). Likewise, we tested for the influence of omitted variables using the method suggested by Frank (2000). Additionally, the robustness of the GDP effect was checked by substituting the purchasing power parity-corrected GDP per capita (PPP GDP p.c.) as gathered from the International Monetary Fund (2019) by the PPP GDP p.c. as provided by the World Bank (2019). Finally, we replaced the PBA emissions from the EDGAR by the PBA emissions from the GCA. None of these checks had any substantial influence on the estimates.

Countries in the negative group would profit from a change of accounting schemes from PBA to CBA, and countries in the positive group would have a disadvantage. An analysis of this dichotomized variable (random effects logit model see model 8 of Table S4 in the supplement) shows that GDP is not related to it. The average GDP per capita of the negative difference group is 16 825 international dollars and 16 298 in the positive group. This difference is statistically not significant ($t = 0.39$, $p = 0.70$). Hence, changing the accounting scheme from PBA to CBA would not benefit the poorer countries per se, and adhering to the established PBA schemes does not put them into a worse position. From this perspective a change does not seem meaningful, and this confirms the conclusion of our paper (Franzen and Mader 2018).

Our research question was the following: If countries changed from PBA to CBA how big would this change be in relative terms from the perspective of a given country. This relative perspective is often used in comparative research. For instance, changes in GDP or unemployment are usually presented in percentages and not in absolute numbers. A relative perspective also makes sense when it comes to CO_2 emissions. For example let's assume that Switzerland decreased its production-based CO_2 by one ton per capita, would that mean that Switzerland reduced it a lot, or a little? Whether one ton is a large or a small change for a given country depends on the level it started at. One ton means a lot for a country with low levels of CO_2 and it means a relatively small change for a country with high emission levels. Suppose representatives from every country were to sit around a (very) large table and decide between two different reduction schemes: In one scenario, all countries are required to reduce the same absolute amount of CO_2, and in the other scenario the same relative amount. The same absolute amount for every country would probably be judged as very unfair. The same relative amount might still be unfair but is much fairer than the same absolute amount. In the long run (this century) we estimate (Franzen and Mader 2016) that CO_2 emission levels have to be reduced to 3 tons per capita for every individual on earth in order to reach the 2-degree target. Given that the earth can cope with about 30Gt of CO_2 emissions per year, and given that the world population increases to 10 billion in the near future, the 3 tons per inhabitant of the world provides a helpful political goal. This is an absolute goal. But the way to get there can of course be expressed in relative reduction targets. In order to get there, the relative reduction goals must be much larger for rich countries as compared to poor countries. We do not debate this position. We only debate the position that changing the accounting schemes from PBA to CBA is a helpful method to reach the 2-degree target. Instead, we believe that a change of the accounting schemes is rather complicated and distracts from the real problem of reducing CO_2 emissions to sustainable levels.

Figure 3: Country and year fixed effects regressions of the difference between CBA and PBA of CO_2 emissions



Note: Unstandardized regression coefficients with 95% confidence intervals. All models contain dummy variables for each year to control for overall time-trends. All standard errors are clustered by country, and therefore robust with respect to heteroscedasticity and autocorrelation. CBA = consumption-based accounting. PBA = production-based accounting. F&M = Franzen and Mader. EDGAR = Emissions Database for Global Atmospheric Research. GCA = Global Carbon Atlas. n = number of countries. N = number of observations (n multiplied by the number of years). All robustness checks mentioned in the caption of Figure 1 were also applied here. None of these checks had any substantial influence on the estimates. See also Table S5 in the supplement for the exact regression results of all three models.

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Supplement of the “Reply to the comment by Zhang and Fang (2019) on consumption-based versus production-based accounting of CO_2 emissions”

Table S1: Regressions of the ratio of CBA to PBA of CO_2 emissions

Model	(1)	(2)	(3)	(4)	(5)	(6)
	Replication of Franzen and Mader (2018)		Update of Franzen and Mader (2018)			
	RE	FE	RE	FE	RE	FE
Dependent variable	CBA/PBA ratio					
Data source for CBA	GCA	GCA	GCA	GCA	GCA	GCA
Data source for PBA	EDGAR	EDGAR	EDGAR	EDGAR	GCA	GCA
Years covered	1997, 2001, 2004, 2007, 2011		1997, 2001, 2004, 2007, 2011, 2014			
OECD membership	-0.03		-0.04		-0.07	
	(0.07)		(0.07)		(0.08)	
GDP p. c.		-0.00		-0.00		0.00
		(0.01)		(0.01)		(0.01)
2001	0.02	0.03	0.02	0.03	0.04	0.04
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
2004	0.02	0.03	0.02	0.03	0.06	0.06
	(0.03)	(0.04)	(0.03)	(0.04)	(0.04)	(0.04)
2007	0.07	0.09	0.07	0.09	0.14**	0.13*
	(0.04)	(0.06)	(0.04)	(0.06)	(0.04)	(0.05)
2011	0.10**	0.11*	0.10**	0.11*	0.13***	0.12**
	(0.03)	(0.05)	(0.03)	(0.05)	(0.03)	(0.04)
2014			0.15***	0.17**	0.19***	0.17**
			(0.04)	(0.06)	(0.04)	(0.05)
n x T	550	549	660	659	660	659
n	110	110	110	110	110	110
R^2 within	0.03	0.03	0.06	0.06	0.07	0.07
theta	0.72		0.75		0.75	

Note: * = p<0.05, ** = p<0.01, *** = p<0.001. Unstandardized regression coefficients with standard errors in brackets. All models contain dummy variables for each year in order to control for overall time-trends. All standard errors are clustered by country, and therefore robust with respect to heteroscedasticity and autocorrelation. CBA = consumption-based accounting. PBA = production-based accounting. RE = random effects regression. FE = Country and year fixed effects regression. GCA = Global Carbon Atlas. EDGAR = Emissions Database for Global Atmospheric Research. Table S2 in the supplement describes all variables and Table S3 lists all countries included in the models.

Table S2: Variable description

Variable	mean/ share		within ($\bar{x}_i$)		between ($x_{it} - \bar{x}_i + \bar{\bar{x}}$)			N (n x T)	n	Description	Data Source
		sd	min.	max.	sd	min.	max.				
PBA of CO_2 p. c. (metric tons)	3.98	0.73	-0.58	8.22	4.47	0.04	25.02	1002	167	PBA CO_2 emissions p. c. of fossil fuel use and industrial processes (cement production, carbonate use of limestone and dolomite, non-energy use of fuels and other combustion) attributed to the country in which goods and services are produced. Excluded are: short-cycle biomass burning (such as agricultural waste burning) and large-scale biomass burning (such as forest fires).	EDGAR
PBA of CO_2 p. c. (metric tons)	3.97	0.85	-1.52	10.21	4.48	0.03	23.56	1026	171		GCA
CBA of CO_2 p. c. (metric tons)	5.49	1.16	-2.31	13.30	5.31	0.07	24.22	666	111	CBA CO_2 emissions p. c. of fossil fuel use and industrial processes attributed to the country in which goods and services are consumed (CBA CO_2 = PBA CO_2 – CO_2 exports + CO_2 imports).	GCA
CBA/PBA ratio	1.26	0.22	0.07	2.55	0.38	0.61	2.48	660	110	Ratio of CBA to PBA (CBA/PBA).	GCA (CBA), EDGAR (PBA)
CBA/PBA ratio	1.29	0.24	-0.07	3.25	0.42	0.65	2.88	660	110		GCA (CBA), GCA (PBA)
CBA-PBA difference	0.58	0.72	-2.98	5.54	2.26	-9.61	13.77	660	110	Difference between CBA and PBA (CBA-PBA). Unit: metric tons p. c..	GCA (CBA), EDGAR (PBA)
CBA-PBA difference	0.64	0.66	-3.33	4.15	2.23	-8.15	14.55	660	110		GCA (CBA), GCA (PBA)
OECD Member-ship	0.20		0.20	0.20		0	1	1044	174	Dummy variable for OECD membership (1) and non-membership (0)	OECD
GDP p. c. (1000 internatio-nal dollars)	14.11	2.68	-7.56	31.64	14.77	0.57	83.23	1003	170	Gross domestic product (GDP) p. c. based on purchasing power parity (PPP). PPP GDP is GDP converted to international dollars using PPP rates. Data are in international dollars based on the 2011 International Comparison Program (ICP) round.	IMF

Note: EDGAR = Emission Database for Global Atmospheric Research, GCA = Global Carbon Atlas, IMF = International Monetary Fund, OECD = Organisation for Economic Co-operation and Development, WB = World Bank; All variables in the models are included in the units reported above.

Table S3: Countries included in the analyses

AL	Albania	CR	Costa Rica	IN	India	MA	Morocco	SK	Slovak Republic
AR	Argentina	CI	Cote d'Ivoire	ID	Indonesia	MZ	Mozambique	SI	Slovenia
AM	Armenia	HR	Croatia	IR	Iran, Islamic Rep.	NA	Namibia	ZA	South Africa
AU	Australia	CY	Cyprus	IE	Ireland	NP	Nepal	KR	South Korea
AT	Austria	CZ	Czech Republic	IL	Israel	NL	Netherlands	ES	Spain
AZ	Azerbaijan	DK	Denmark	IT	Italy	NZ	New Zealand	LK	Sri Lanka
BH	Bahrain*	DO	Dominican Rep.	JM	Jamaica	NI	Nicaragua	SE	Sweden
BD	Bangladesh	EC	Ecuador	JP	Japan	NG	Nigeria	CH	Switzerland*
BY	Belarus	EG	Egypt, Arab Rep.	JO	Jordan	NO	Norway	TZ	Tanzania
BE	Belgium	SV	El Salvador	KZ	Kazakhstan	PK	Pakistan	TH	Thailand
BJ	Benin	EE	Estonia	KE	Kenya	PA	Panama	TG	Togo
BO	Bolivia	ET	Ethiopia	KG	Kyrgyz Republic	PY	Paraguay	TN	Tunisia
BW	Botswana	FI	Finland	LA	Lao PDR	PE	Peru	TR	Turkey
BR	Brazil	FR	France	LV	Latvia	PH	Philippines	UG	Uganda
BG	Bulgaria	GE	Georgia	LT	Lithuania	PL	Poland	UA	Ukraine
BF	Burkina Faso	DE	Germany	MG	Madagascar	PT	Portugal	GB	United Kingdom
KH	Cambodia	GH	Ghana	MW	Malawi	RO	Romania	US	United States
CM	Cameroon	GR	Greece	MY	Malaysia	RU	Russia	UY	Uruguay
CA	Canada	GT	Guatemala	MT	Malta	RW	Rwanda	VE	Venezuela, RB
CL	Chile	GN	Guinea	MU	Mauritius	SA	Saudi Arabia	VN	Vietnam
CN	China	HN	Honduras	MX	Mexico	SN	Senegal	ZM	Zambia
CO	Colombia	HU	Hungary	MN	Mongolia	SG	Singapore*	ZW	Zimbabwe

Note: We only considered countries that are members of the United Nations. All the models in Figures 1 and 3 include all 110 countries. The models in Figure 2 are based on 107 countries, since three countries as indicated by (*) are influential cases according to Cook’s D.

Table S4: Between-countries regressions of the difference between CBA and PBA of CO_2 emissions

Model	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) RE	(8) Logistic RE
Years covered	1997	2001	2004	2007	2011	2014	1997, 2001, 2004, 2007, 2011, 2014	
Dependent variable				CBA-PBA difference				Dummy CBA>PBA
GDP p. c.	0.04**	0.02	0.04**	0.05***	0.05***	0.04***	0.04***	-0.00
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)
2001							-0.01	-0.49
							(0.08)	(0.55)
2004							0.06	-0.22
							(0.09)	(0.58)
2007							0.14	-0.08
							(0.10)	(0.63)
2011							0.21*	0.81
							(0.09)	(0.66)
2014							0.18	1.14
							(0.11)	(0.72)
Constant	-0.25	-0.05	-0.23	-0.28	-0.14	0.03		
	(0.16)	(0.17)	(0.17)	(0.15)	(0.14)	(0.13)		
n x T							641	641
n	107	107	107	107	107	107	107	107
R^2	0.12	0.04	0.14	0.20	0.15	0.12		
R^2 within							0.09	
theta							0.79	
Log Pseudolikelihood								-221.00

Note: * = p<0.05, ** = p<0.01, *** = p<0.001. Unstandardized regression coefficients with standard errors in brackets. The models 7 and 8 contain dummy variables for each year in order to control for overall time-trends. All standard errors of the models 7 and 8 are clustered by country, and therefore robust with respect to heteroscedasticity and autocorrelation. The models 1-6 include robust standard errors. Table S2 in the supplement describes all variables and Table S3 lists all countries included in the models.

Table S5: Country and year fixed effects regressions of the difference between CBA and PBA of CO_2 emissions

Model	(1)	(2)	(3)
	Replication of Franzen and Mader (2018)	Update of Franzen and Mader (2018)	
Dependent variable		CBA-PBA difference	
Data source for CBA	GCA	GCA	GCA
Data source for PBA	EDGAR	EDGAR	GCA
Years covered	1997, 2001, 2004, 2007, 2011	1997, 2001, 2004, 2007, 2011, 2014	
GDP p. c.	-0.02	-0.00	0.04
	(0.06)	(0.05)	(0.03)
2001	-0.02	-0.04	-0.01
	(0.10)	(0.09)	(0.10)
2004	0.13	0.09	0.08
	(0.14)	(0.13)	(0.13)
2007	0.32	0.25	0.18
	(0.21)	(0.17)	(0.17)
2011	0.43	0.35	0.21
	(0.24)	(0.18)	(0.15)
2014		0.36	0.21
		(0.24)	(0.17)
n x T	549	659	659
n	110	110	110
R^2 within	0.04	0.05	0.09

Note: * = p<0.05, ** = p<0.01, *** = p<0.001. Unstandardized regression coefficients with standard errors in brackets. All models contain dummy variables for each year in order to control for overall time-trends. All standard errors are clustered by country, and therefore robust with respect to heteroscedasticity and autocorrelation. Table S2 in the supplement describes all variables and Table S3 lists all countries included in the models.