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Testing for the economic and environmental impacts of EU Emissions Trading System: A panel GMM approach

1. Introduction

The first in the world and largest installation-level 'cap-and trade' system for reducing greenhouse gas (GHG) emissions to date is the European Union's Emissions Trading Scheme (EU ETS). The system is meant to help the EU attain its immediate and longer-term goals in terms of emissions reduction by promoting reductions of emissions in cost-efficient and economically efficient processes. The major element of EU ETS is its emission cap and also the EU emission allowances (EUAs) trading market. The cap ensures that total emissions do not exceed a fixed level in the period the cap is defined for. Since 2005 the system has controlled GHG emissions in approximately 11,000 installations. Compliance is ensured through the penalty and social control structure as high fines are imposed on those companies which emit too high amount of pollutant. In addition, firms face an obligation to surrender the allowances owed. Thus, the cap (i.e. the environmental target) is maintained effectively (EU, 2015). The EU ETS is organised in trading periods (or phases), of which four are currently decided and more may follow. Currently the system is in its third phase.

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The revised EU ETS Directive, which will apply for the fourth period from 2021 to 2030, was designed to meet the reduction target for 2030 by reducing emissions by 43% compared to 2005 levels. Up to now the actual emissions were below the target path, i.e. the cap was not being binding. Depending on economic activity as measured by GDP, this unintended situation might continue over the next years. Figure 1 gives some basic insights on the performance of the EU ETS in recent years with projections on the next decade.

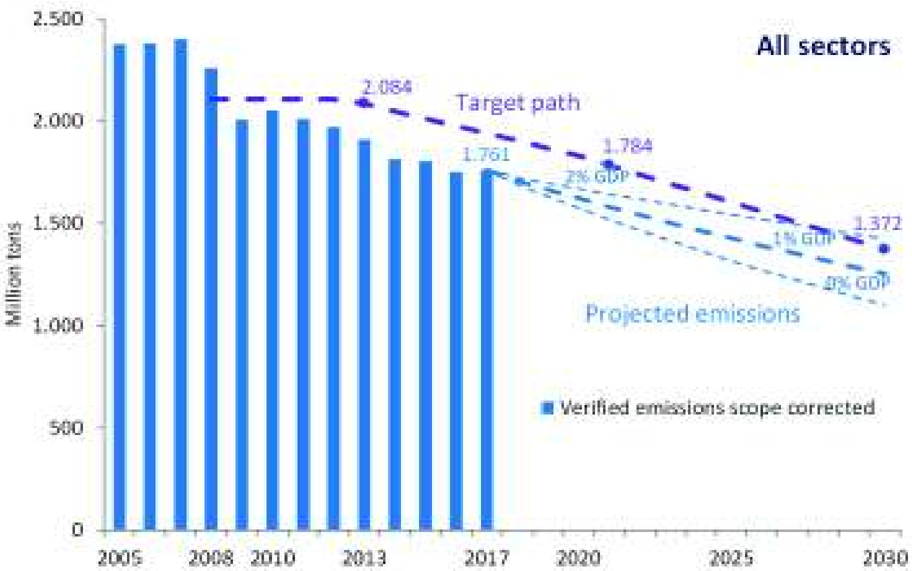

Figure 1. Verified emissions, target path and projected emissions

Source: Wegener Center elaborations on EEA, 2018 and EU TL, 2018

Verified emissions have been under the target path since the start of Phase 2 of the EU ETS. As underlined by Marcu et al. (2018, 2020) the relationships between changes in GDP and changes in emissions depicted in Figure 1 have created a corridor of potential future emission levels depending on GDP growth rates between 0 and 2 percent per year (current GDP growth trends fluctuates around 2 percent, in contrast to a stagnation in Phase 2). This suggests that in the Phase 4 of EU ETS actual emissions might exceed the target path only if GDP growth rates remain high. This conclusion, however, does not take into account various policy changes (including renewables deployment), that may have an impact on the GDP-emission links. In this context, an important research problem arises: How much of the result observed in Figure 1 and discussed in this paragraph is due to an actual decrease in CO_2 intensity, and how much is due to a decrease in the level of economic activity? This paper aims to shed some light on this crucial issue.

The COVID-19 pandemic has had a great impact on the European Union economies in many aspects, also with regard to the discussion on the future of EU climate policy. The plan to rebuild and support the European Union's economy, which is currently under discussion at European government summits, seems to place less emphasis on environmental issues since the main focus is being placed on a quick recovery of EU economy in the realms of global competition. One of the issues discussed in the EU's recovery plan following the COVID19 epidemic is the continued operation of the EU ETS. One of main challenges for Germany's 6-month EU Council presidency in the second half of 2020 is the discussion on making European Union climate neutral by 2050. In this context, a first big step is setting the final shape of European economic recovery programme. Germany supports the European Commission's proposal to increase the target to −50 to −55 percent. However, the general attitude to increasing ambitions of the EU climate policy in the upcoming years seems to be getting less enthusiastic. In other words, the very-needed debate on concrete climate policy tools might not get enough attention in the upcoming months.

The meeting of Special European Council held in Brussels between 17–21 July 2020 led to several initial conclusions, including EU climate policy. EU leaders agreed a recovery package and the 2021–2027 budget that is aimed at supporting the economic recovery after the COVID19 pandemic and increasing investment in the green and digital transitions. When it comes to climate action, it was announced that 30% of the total expenditure from the MFF and Next Generation EU will support climate-related projects. Expenses under the MFF and Next Generation EU will comply with the EU's objective of climate neutrality by 2050, the EU's 2030 climate targets and the Paris Agreement. By the end of 2022, the Commission plans to come back with a revised proposal on the EU ETS, possibly extending it to the aviation and maritime sectors.

The aim of this paper is to make a preliminary assessment of the effectiveness of the EU ETS in terms of reducing the actual emissions to the air while preserving economic growth of EU member states. The extensive empirical analysis is focuses on examining the issues in question for different phases of the EU ETS and various groups of EU economies that differ in terms of economic development and the overall air pollutant emission.

2. Main research hypotheses

The data presented in Figure 1 suggests that verified emissions have been under the target path since the start of EU ETS Phase 2. One may claim that this process was driven (at least to some extent) by the policy of EU ETS. This, in turn, suggests the formulation of the initial research hypothesis:

Hypothesis 1. Lowering the level free allowances in EU ETS had a statistically significant impact on reducing the level of actual emissions. This impact was especially strong in highly polluting EU economies.

From a global perspective coal combustion is not only the largest source of CO_2 emissions, but also a major threat to public health. At the same time about 80% of EU coal power plants (and all Polish coal power plants) do not comply with EU regulations on emissions standards. This feature of the combustion sector in EU leads to formulation of the second hypothesis:

Hypothesis 2. The impact of lowering allowances in EU ETS on reducing the level of actual emissions was much weaker for installations listed in combustion sector compared to other EU sectors.

In order to enable learning and refinement the EU ETS is designed to operate in phases. Burke (2006) underlines that the release of the very first verified emissions data in Phase 1 of EU ETS indicated that permits had been over-allocated by around ninety-five megatons while Alberola (2006) shows the EU ETS market was not as short as expected, particularly with regard to power producers needing fewer EUAs. However, based on lessons learnt from Phase 1 in later phases certain regulators refined the EU ETS in an attempt to provide a more robust and efficient market operation (Niblock and Harrison, 2011). Thus, it rapidly became evident that markets and economies managed to adjust to the scheme regulations. One may expect that this process of conforming to the new provisions should have a positive impact on general environmental effectiveness of EU ETS and the following hypothesis should hold true:

Hypothesis 3. The positive impact of lowering the level free allowances in EU ETS on reducing the level of actual emissions intensified during the later stages of EU ETS in all sectors and all EU countries.

As shown in Figure 1, levels of verified emissions and GDP growth seem to be correlated which directly stems from the fact that higher levels of air pollution are to some extent induced by increased economic activity. However, the ongoing process of shifting EU economy toward services and other activities characterized with low GHG emission levels, installation of new eco-efficient technologies and the impact of EU ETS system of penalties for extensive pollutants seem to support the final hypothesis of this paper:

Hypothesis 4. Lowering the level free allowances in EU ETS did not have a statistically significant impact on reducing GDP growth rates of EU economies.

The hypotheses listed above will be verified using detailed dataset described in Section 3 and the methodology described in Section 4.

3. The dataset

In this paper we use the detailed data on EU ETS provided by the Wegener Center for Climate and Global Change (WCCGC).[1] The database stems from EUTL and contains all monitored installations. The EEA-database also originates from EUTL but in contrary to WCCGC database is aggregated in (about 40) activities. In addition, the estimates of aggregates on WCCGC database are derived from a comparison of the intersection of installations in previous years, which gives a much better approximation compared to EEA database in which the missing values are not considered. Although the role of EU ETS in shaping the environmental policy of EU is obvious, current economic literature lacks any econometric analyzes devoted to the issues in question that would apply the reliable Wegener Center for Climate and Global Change database. Thus, the originality of this study follows from the fact that in contrary to existing studies (comp. e.g. Anderson and di Maria (2011), Jaraite and di Maria (2014), Martin et al. (2014), Borghesi and Flori (2018), Teixidó et al. (2019), Cañón-de-Francia and Garcés-Ayerbe (2019), Lin et al. (2019), Wildgrub et al. (2019), Verde et al. (2019), Bayer and Aklin (2020), Bruyn et al. (2020), among others) this paper provides results of a very first thorough empirical analysis of the detailed WCCGC database. Two main variables listed in Wegener Center for Climate and Global Change database will be used in empirical investigations. The first one is **free allocations** which are determined ex ante (widely) independent of production activity by installations, namely based on a so-called benchmark procedure. The basic idea is to give the installations with top technology the highest share of free allowances and others less, depending on their performance in a (outdated) reference period. The second one is **verified emissions** that reflect EU ETS policies as well as general economic conditions and international competitiveness. Table 1 presents the list of variables used in the empirical part of the study.

[1] Wegener Center for Climate and Global Change is an interdisciplinary, internationally oriented institute of the University of Graz (School of Environmental, Regional and Educational Sciences, with partner institutes also in the Faculties of Natural Sciences, Business, Social and Economic Sciences, and Arts and Humanities), which serves as core research center for pooling the competences of the University in the areas "Climate, Environmental, and Global Change".

Table 1
Variables examined in the empirical analysis

Symbol	Definition	Unit	Data source
Variables defined for individual installations			
$A_{i,t}$	Allowance in installation i in period t	Tons[2] of CO_2	Wegener Center for Climate and Global Change
$A_{i,t}^{phase2}$	If period t belongs to EU ETS Phase 2 this is equal to allowance in installation i in period t (i.e. $A_{i,t}$), otherwise this is equal to zero	Tons of CO_2	Wegener Center for Climate and Global Change
$A_{i,t}^{phase3}$	If period t belongs to EU ETS Phase 3 this is equal to allowance in installation i in period t (i.e. $A_{i,t}$), otherwise this is equal to zero	Tons of CO_2	Wegener Center for Climate and Global Change
$E_{i,t}$	Verified emissions in installation i in period t	Tons of CO_2	Wegener Center for Climate and Global Change
Aggregated variables defined for groups of installations across EU countries			
$\overline{A}_{c,t}$	Average allowance in installations in country c in period t, technically $\overline{A}_{c,t} = \frac{1}{n}\sum_{i \in c} A_{i,t}$, where n is the number of instalations in country c in period t	Tons of CO_2	Wegener Center for Climate and Global Change
$\overline{A}_{c,t}^{phase2}$	If period t belongs to EU ETS Phase 2 this is equal to allowance in country c in period t (i.e. $\overline{A}_{c,t}$), otherwise this is equal to zero	Tons of CO_2	Wegener Center for Climate and Global Change
$\overline{A}_{c,t}^{phase3}$	If period t belongs to EU ETS Phase 3 this is equal to allowance in country c in period t (i.e. $\overline{A}_{c,t}$), otherwise this is equal to zero	Tons of CO_2	Wegener Center for Climate and Global Change
$GDP_{c,t}$	GDP growth in country c in period t	%	Eurostat

A complete dataset was available for 22 European countries and covered the period 2005–2018. In the case of other countries, there were incomplete records

[2] Or the equivalent amount of a different greenhouse gas.

in the dataset because of delays in joining the European Union or the EU ETS program. We not only decided to estimate models for individual countries, but also to split the data into smaller groups, which allows to create aggregate data for GDP-focused calculations[3] as well as to compare the results between different groups of economies. Table 2 presents details of the country groups examined in this paper.

Table 2

Groups of countries examined in the empirical analysis

Group of countries	Composition of the group
Western Europe[4]	Austria [AT], Belgium [BE], Spain [ES], France [FR], United Kingdom [GB], Ireland [IE], Netherlands [NL], Portugal [PT]
High renewable energy[5]	Sweden [SE], Finland [FI], Lithuania [LT], Denmark [DK], Austria [AT], Portugal [PT], Estonia [EE]
Low renewable energy[6]	United Kingdom [GB], Netherlands [NL], Belgium [BE], Ireland [IE], Poland [PL], Slovakia [SK], Hungary [HU]
High air pollution[7]	Czech Republic [CZ], Lithuania [LT], Hungary [HU], Latvia [LV], Poland [PL], Slovakia [SK], Hungary [HU]
Low air pollution[8]	Sweden [SE], Finland [FI], Ireland [IE], Spain [ES], Portugal [PT], Denmark [DK], Estonia [EE]
High HDI index[9]	Ireland [IE], Germany [DE], Sweden [SE], Netherlands [NL], Denmark [DK], Finland [FI], United Kingdom [GB], Belgium [BE]
Medium HDI index[10]	Austria [AT], Slovenia [SI], Spain [ES], Czech Republic [CZ], France [FR], Italy [IT], Estonia [EE]
Low HDI index[11]	Greece [GR], Poland [PL], Lithuania [LT], Slovakia [SK], Latvia [LV], Portugal [PT], Hungary [HU]

[3] Note that GDP growth data is only available on the country level.
[4] These are the countries which are globally recognized as Western and highly developed in terms of economic development.
[5] Based on Eurostat data – https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics/pl.
[6] Based on Eurostat data – https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics/pl.
[7] Based on data on healthy life years lost as a result of air pollution per hundred inhabitants provided by WHO – http://gamapserver.who.int/gho/interactive_charts/phe/aap_mbd/atlas.html.
[8] Based on data about healthy life years lost as a result of air pollution per hundred inhabitants provided by WHO – http://gamapserver.who.int/gho/interactive_charts/phe/aap_mbd/atlas.html.
[9] Based on UN Development programme data – http://hdr.undp.org/en/data.
[10] Based on UN Development programme data – http://hdr.undp.org/en/data.
[11] Based on UN Development programme data – http://hdr.undp.org/en/data.

To give a brief overview of the statistical properties of the dataset on the examined variables, we abandon any attempt to supply descriptive statistics in tabular form, but instead focus on analysing a set of plots depicted in Figures 2–4 that give insights on the main trends observed in the database. In the further parts of this paper, we divide the installations listed in WCCGC database into three groups: the group covering all installations, the group covering combustion-related installations, and the group covering other (non-combustion) installations.

As can be seen in Figure 2, the level of free allowances was lower in the countries with high level of social development, in which the median of free allowances was about 25,000 tons of greenhouse gas, but in medium and low developed countries the median was higher than 50,000 tons of greenhouse gas almost in every EU ETS phase. In general, there was a slightly lower level of free allowances in EU ETS Phase 3 compared to previous phases. The levels of actual emissions did not seem to depend on the level of social development of examined countries. One can notice that the ratio of free allowances to actual emissions decreased significantly below unity during Phase 3 of EU ETS.

In this context an interesting research problem would be to test what the trends depicted in Figure 2 would look like if the combustion sector was examined separately among the installations. This interesting problem is tackled in Figure 3. The boxplots presented in Figure 3 confirm that allowance levels seem to be similar in the case of medium and high developed countries. These levels are significantly higher for low developed countries. On the other hand, actual emissions are much lower in countries with high level of social development than in the other groups. Compared to previous phases allowance allocation during Phase 3 was visibly lower, however actual emissions remained almost unchanged. Ratio of free allowances to actual emissions was higher than unity during the first two phases of EU ETS, and dropped below 1 during the Phase 3.

In the case of other sectors (comp. Figure 4), there seem to be more outliers than in the case of the data depicted in Figure 2 and 3, especially countries with a low level of social development. In these sectors there was almost no significant difference between the levels of free allowances and actual emissions during the EU ETS phases. In case of countries with a low and medium level of social development, the ratio of free allowances to actual emissions stayed high even in Phase 3. This suggests that no significant improvement in reducing emissions was reported during EU ETS Phase 3 for other sectors.

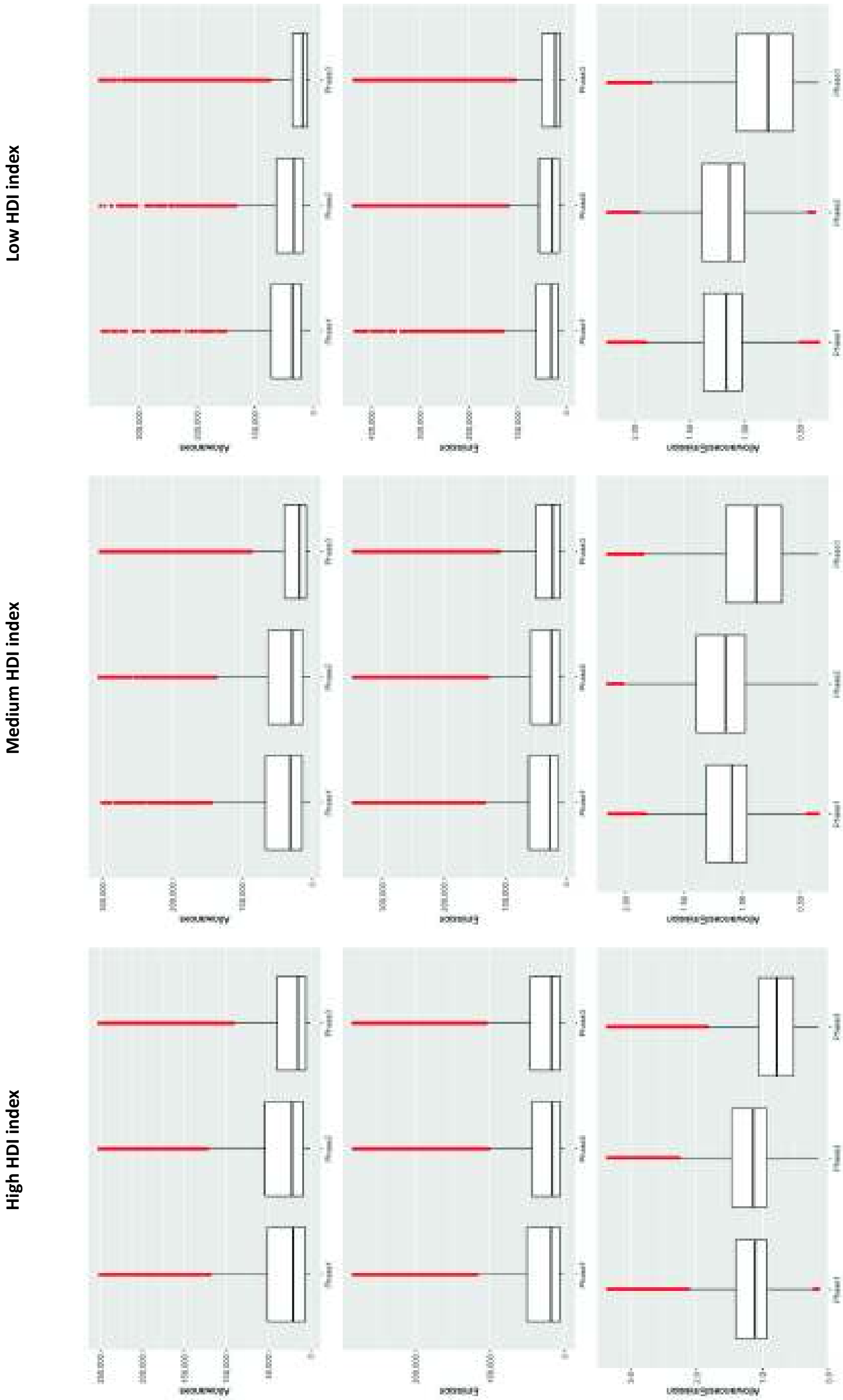

Figure 2. Comparison of boxplots on free allowances and verified emissions for all sectors during the three EU ETS phases

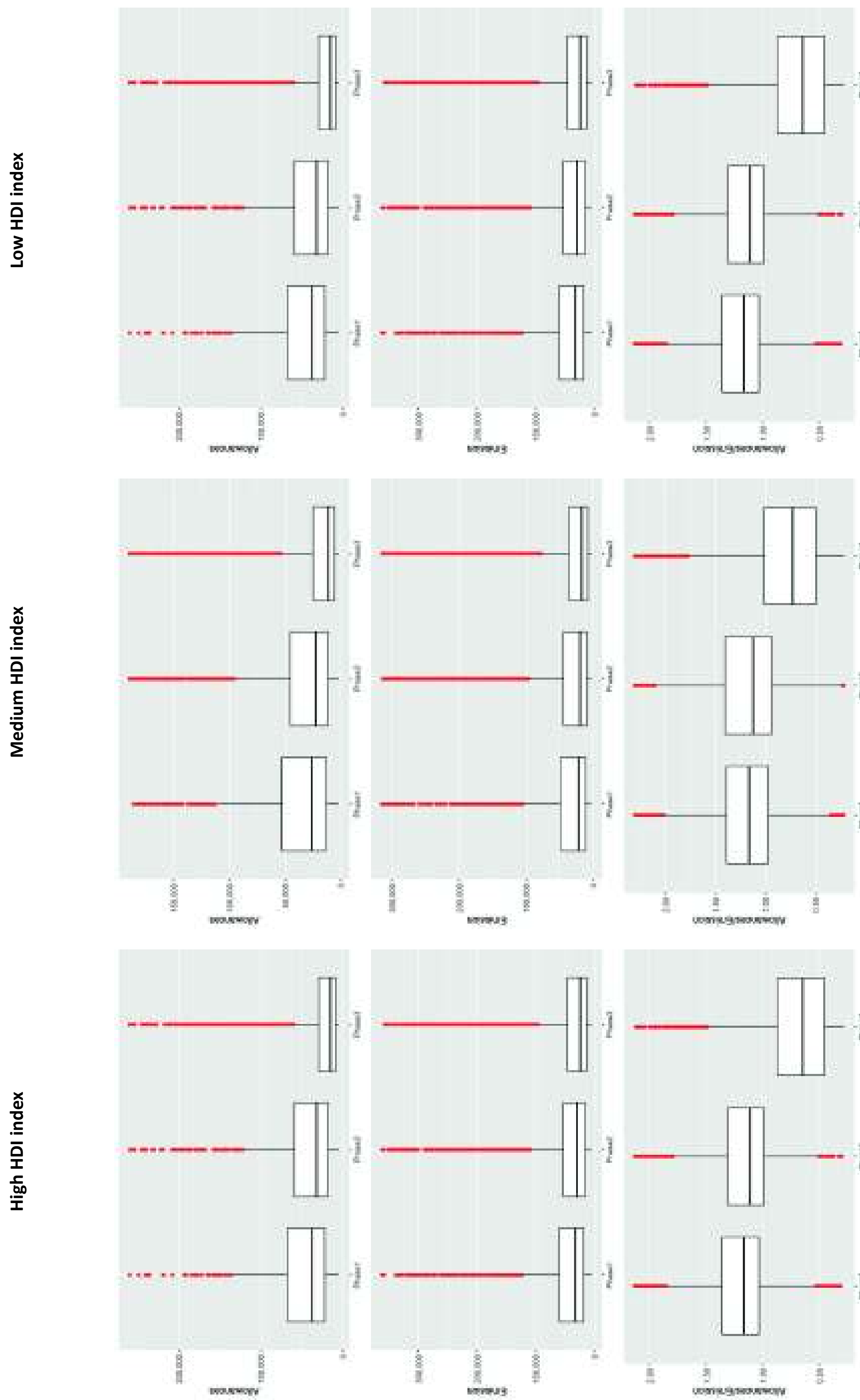

Figure 3. Comparison of boxplots on free allowances and verified emissions for combustion sectors during the three EU ETS phases

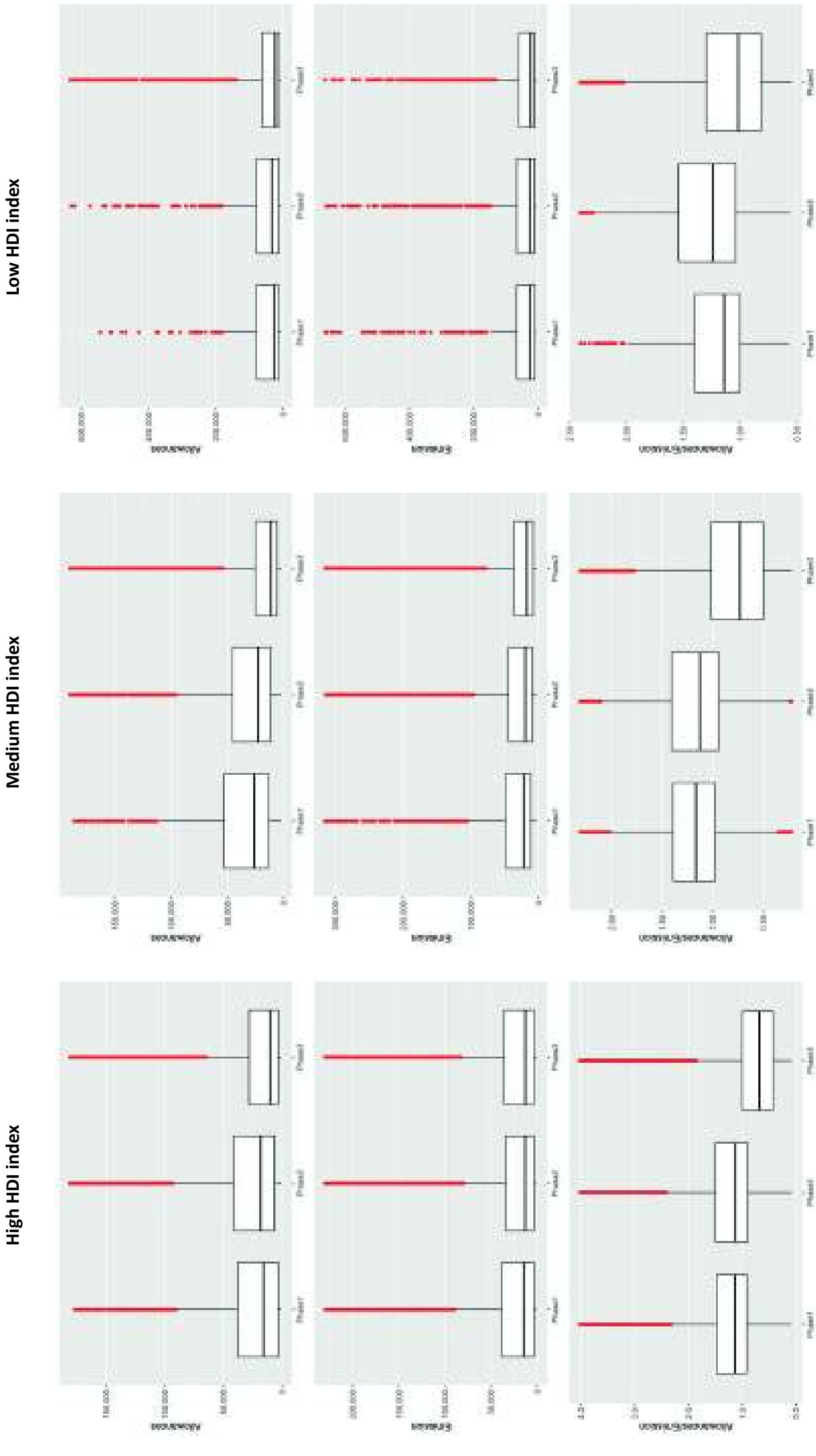

Figure 4. Comparison of boxplots on free allowances and verified emissions for other sectors during the three EU ETS phases

It is also worth illustrating how the actual emissions were distributed over the three phases of EU ETS program. The division was made with regard to the level of development of the countries and the types of groups of sectors. Details are presented in Figure 5.

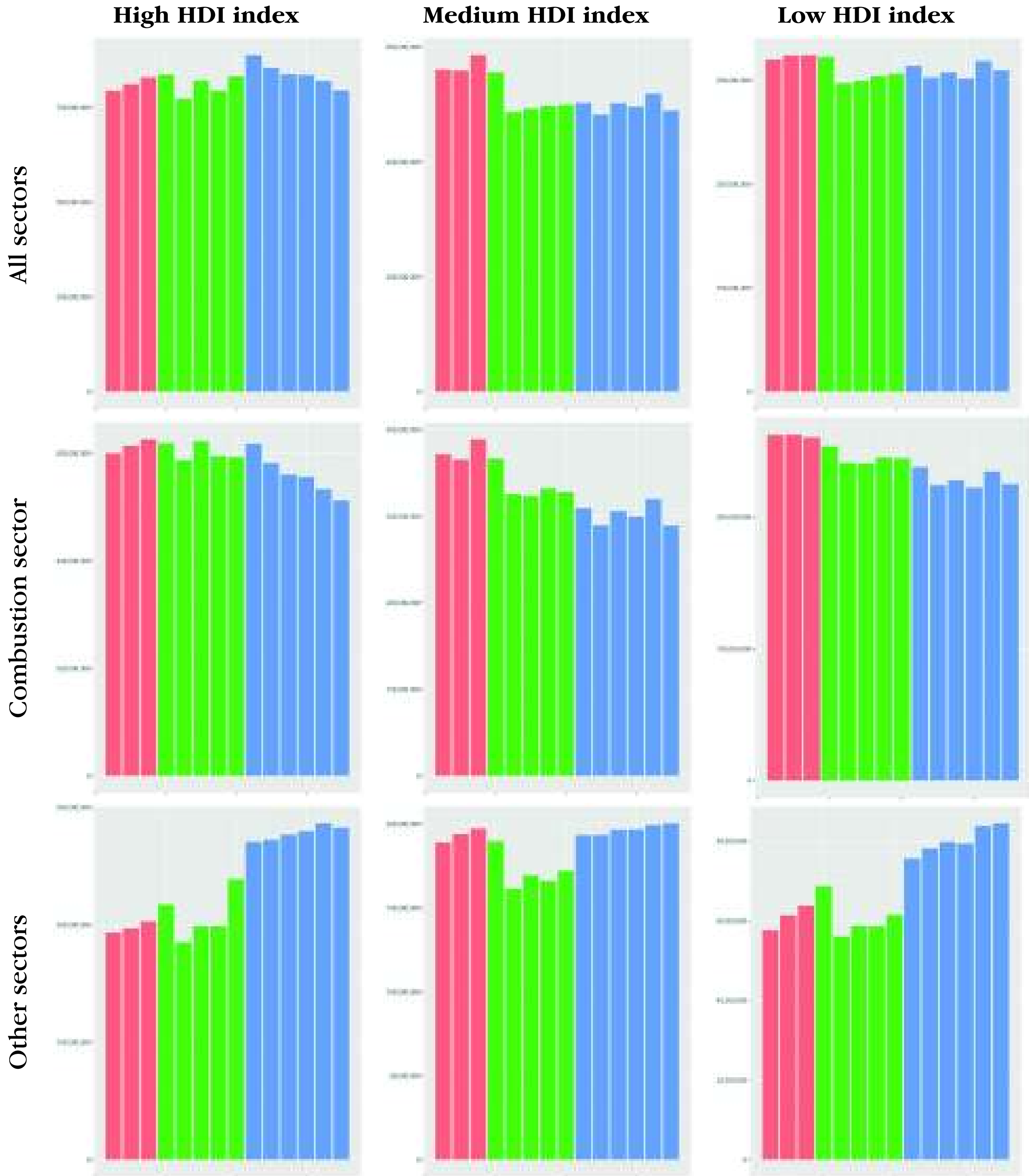

Figure 5. Actual emissions with respect to the level of HDI and types of sectors

Source: Own elaboration. The red colour indicates the pilot phase, the second phase is in green and the third Phase of EU ETS is in blue

As can be concluded from Figure 5, there was a drop in actual emissions in combustion sector and a rise of actual emissions in other sectors during the operating of EU ETS in all groups of countries. In later phases of the programme, one could notice higher levels of emissions in other sectors.

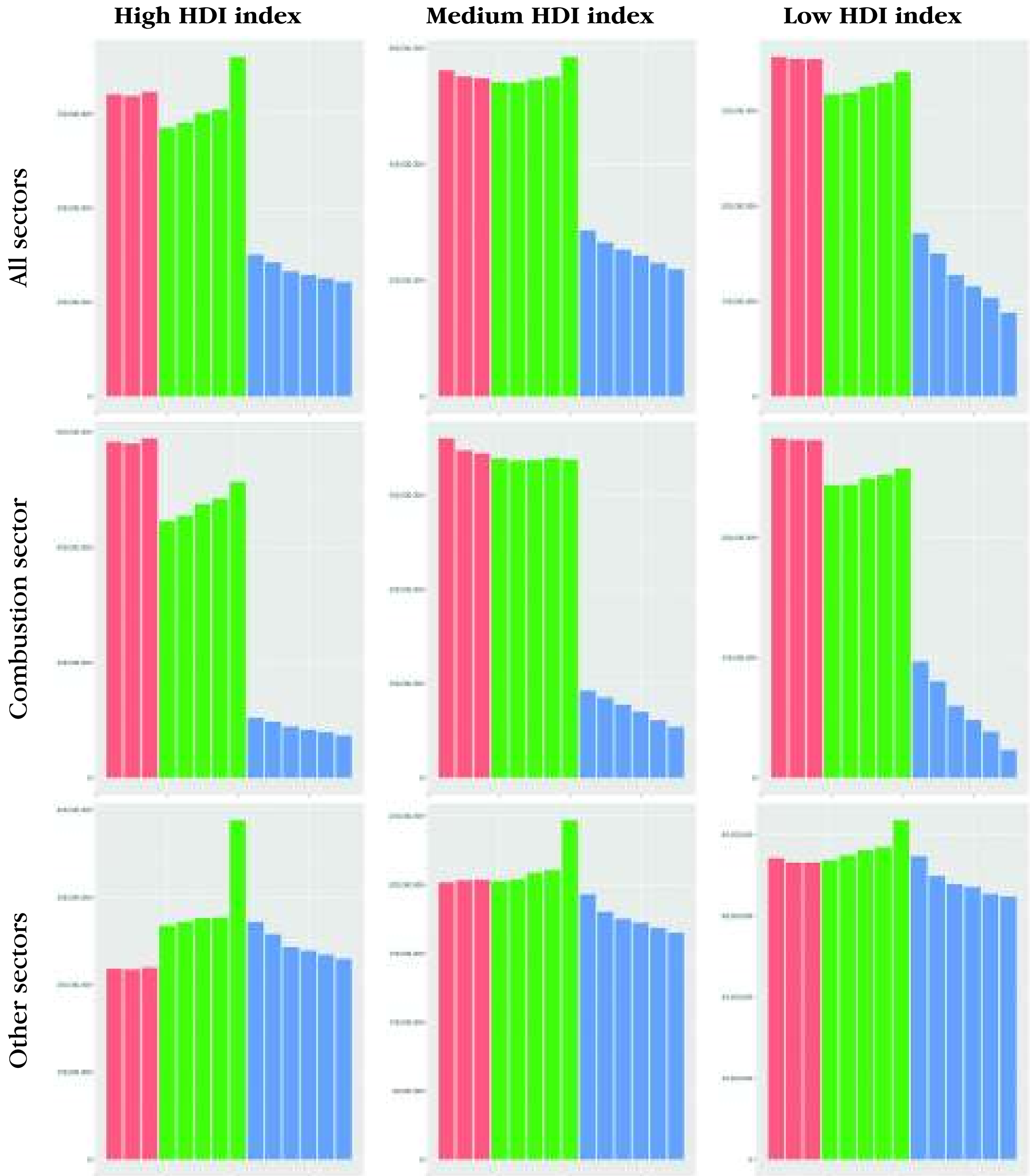

Figure 6. Allowance allocation with respect to level of HDI and types of sectors

Source: Own elaboration. The red colour indicates the pilot phase, the second phase is in green and the third Phase of EU ETS is in blue

In turn, the data presented in Figure 6 proves that there was very meaningful drop of allowance allocation in the combustion sector during the EU ETS Phase 3. Because of that, the summarised allowance allocation also reduced significantly. Interestingly, in 2012 there was a significant peak in the level of allocation in other sectors.

Figure 7. GDP growth with respect to level of social development

Source: Own elaboration. The red colour indicates the pilot phase, the second phase is in green and the third Phase of EU ETS is in blue

As can be seen in Figure 7, the financial crisis of 2009 had a strongest impact on the countries with the highest HDI in EU. The moderately developed countries had experienced 3 years with negative GDP growth. The highest values of growth were recorded in low developed countries during EU ETS Phases 1 and 3.

The analysis of the plots presented in Figures 2–4 leads to an important conclusion with respect to econometric modelling of the WCCGC data. Namely, it suggests that in the formal econometric analyses one should use a dummy variable capturing the effects of 2009 crisis that significantly hit GDP and verified emission (comp. Figure 5 and 7) but did not had a similar impact on free allowances (comp. Figure 6). Thus, when constructing respective panel models we will use a dummy variable (denoted d_{2009}) equal to 1 for the year 2009 and zero otherwise.

4. Methodology

In order to verify the main research hypotheses listed in Section 2, one should use dynamic panel models with fixed effects to examine the dataset discussed in Section 3. The setting examined in this study is rather typical for dynamic panel models as we focus on large cross-sectional dimension and short time dimension. As shown by Nickell (1981), classical OLS-based regression methods cannot be applied in such a case because of endogeneity bias that does not disappear asymptotically if cross sectional dimension rises and time dimension is kept fixed. A typical solution is to use generalized method of moments (GMM) estimators (comp. Hansen, (1982), Anderson and Hsiao (1982), Holtz-Eakin et.al (1988), Arellano and Bond (1991), Arellano and Bover (1995), Blundell and Bond (1998), among others). GMM estimators are usually applied in two variants: difference GMM estimator (Arellano and Bond,1991; Holtz-Eakin et al., 1988) in which lags of the endogenous variables are used as instruments and the system GMM estimator (Blundell and Bond, 1998) that uses additional moment conditions (Sigmund and Ferstl, 2019).

In order to verify Hypotheses 1–3, we will estimate a set of linear dynamic panel-data models of the form:

$$E_{i,t} = a_i + a_0 E_{i,t-1} + a_1 A_{i,t} + a_2 A_{i,t}^{phase2} + a_3 A_{i,t}^{phase3} + a_{2009} d_{2009} + \varepsilon_{i,t} \quad (1)$$

where $\varepsilon_{i,t}$ stands for the idiosyncratic errors with no autocorrelation, i belongs to the set of installations examined and t is the time point. The element a_i captures time-independent individual effects across the examined set of installations while a_0 allows taking into account autoregressive nature of time series of verified emissions.[12] The a_1 coefficient gives insights on the impact of level of free allowances on the level of actual emissions in the Phase 1 of the EU ETS. The sum $a_1 + a_2$ captures the impact of free allowances on the level of actual emissions in the Phase 2 of EU ETS, while $a_1 + a_3$ measures the intensity of this impact in the third phase of EU ETS. Finally, the coefficient a_{2009} captures the effects of 2008–2009 crisis that significantly hit verified emission but had only a minor impact on free allowances (comp. Figures 4 and 5).

In order to verify Hypothesis 4 we will move onto analysing the aggregated emission data and estimating a set of linear dynamic panel-data models of the form:

$$GDP_{c,t} = b_c + b_X X_{c,t} + b_0 GDP_{c,t-1} + b_1 \bar{A}_{c,t} + b_2 \bar{A}_{c,t}^{phase2} + b_3 \bar{A}_{c,t}^{phase3} + b_{2009} d_{2009} + \eta_{c,t} \quad (2)$$

where $\eta_{c,t}$ stands for the idiosyncratic errors with no autocorrelation, c is the member of the country group examined, and t is the time point. Further, $X_{c,t}$ denotes a set of control variables. The coefficient b_c captures time-independent individual effects across the countries, while b_0 allows the autoregressive nature of time series of GDP to be taken into account.[13] The b_1 coefficient gives insights on the impact that the level of free allowances in EU ETS has on the current year

[12] We did not find any statistically significant evidence to consider more than one lag in equation (1).

[13] Similarly to model (1) also in the case of equation (2) the respective inclusion tests provided no support for considering more than one lag.

GDP growth rate. Analogically to (1) the sums $b_1 + b_2$ and $b_1 + b_3$ capture the impact of free allowances on current GDP growth rate in Phase 2 and Phase 3 of EU ETS, respectively. Finally, the coefficient b_{2009} captures the effects of 2008–2009 crisis that significantly hit GDP in EU countries (comp. Figure 7).

5. Empirical results

In this chapter we present results of the estimation of the respective GMM models given in (1) and (2).[14] Table 3 presents the results of estimating models (1) for groups of countries listed in Table 2. Similar results for GDP-focused GMM models are given in Table 4.

Hypothesis 1 stated that assigning fewer free allowances had a statistically significant impact on lowering the level of actual emissions in the EU ETS. Moreover, according to Hypothesis 1, this effect should be especially strong in countries with high air pollution. The results presented in Table 3 (more precisely the data on coefficient a_1 that is responsible for measuring the effect described in Hypothesis 1) prove the hypothesis is true in countries with high usage of renewable energy sources, countries with low air pollution and the countries with high and moderate level of social development. In low air polluting countries, as well as in countries with high usage of renewable energy sources, lowering the level of free allowances had very meaningful effect in reduction of greenhouse gas emissions.

A comparison of the results obtained for combustion and other sectors allows for the claim that it does not matter in which group of installations the reduction of free allowances takes place. In case of installations listed in the combustion sector, lowering allowances was statistically significant for reducing actual emissions for Western Europe countries, high renewable energy countries as well as high and medium HDI index countries. The cases of high statistical significance are almost exactly identical in case of models constructed for all installations and combustion-related installations.

Lowering the level of free allowances in the installations listed in other sectors had a significant impact on lowering actual emissions in the case of countries with a high and low usage of renewable energy, high air pollution and low HDI index. In other words, the groups of countries in which lowering free allowances had a significant impact on lowering actual emissions are slightly different for models constructed for installations listed in the combustion sector and models constructed for other sectors. Anyhow, these results provide no evidence supporting Hypothesis 2.

[14] We used a first difference GMM estimator with the Windmeijer (2005) correction for the two-step covariance matrix.

Table 3

Results of GMM estimation of models (1) for different groups of countries

		a_0		a_1		a_2		a_3		a_{2009}		Hansen test	
		coef.	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**stat.**	**pval.**
Western Europe	All	0.60	**0.00**	0.12	0.13	–0.06	**0.01**	0.03	0.70	–0.01	0.00	24.93	**0.01**
	Combustion	0.45	0.00	0.15	**0.04**	–0.07	0.06	–0.18	0.22	0.00	0.41	23.17	**0.01**
	Other	0.80	**0.02**	0.08	0.43	–0.04	**0.00**	0.01	0.92	–0.03	**0.00**	2.40	0.30
High renewable energy	All	0.10	0.49	0.30	0.00	–0.08	0.01	0.22	0.16	–0.01	0.00	23.36	**0.00**
	Combustion	0.07	0.73	0.31	**0.00**	–0.09	0.07	0.25	0.06	0.00	0.00	18.00	**0.02**
	Other	–0.45	0.01	0.49	**0.02**	–0.03	0.14	0.33	0.00	–0.01	**0.00**	3.42	0.18
Low renewable energy	All	0.98	**0.02**	0.03	0.75	0.00	0.98	0.02	0.66	–0.03	**0.00**	1.60	0.45
	Combustion	1.06	0.51	0.00	0.98	0.05	0.67	0.08	0.40	–0.02	0.28	4.24	0.12
	Other	–0.35	0.65	0.33	**0.02**	–0.05	0.41	–0.06	0.25	–0.01	0.32	3.22	0.20
High air pollution	All	–0.12	0.36	0.13	0.36	–0.03	0.34	0.11	0.12	–0.02	**0.01**	3.28	0.19
	Combustion	0.21	0.54	0.03	0.63	–0.04	0.07	0.00	0.96	–0.01	0.00	6.05	0.20
	Other	–0.17	0.41	0.39	**0.00**	0.03	0.23	0.20	0.13	–0.01	**0.00**	0.20	0.91
Low air pollution	All	0.32	0.03	0.13	0.01	–0.13	**0.00**	–0.04	0.34	–0.01	**0.01**	1.47	0.48
	Combustion	0.38	**0.00**	0.11	0.13	–0.18	**0.00**	0.12	0.23	0.00	0.77	1.72	0.42
	Other	0.12	0.77	0.02	0.85	–0.06	0.08	–0.07	0.48	–0.01	0.00	27.77	**0.00**
High HDI index	All	0.33	0.22	0.10	**0.00**	–0.01	0.83	0.04	0.25	–0.02	**0.00**	0.74	0.69
	Combustion	0.44	0.11	0.11	**0.00**	0.01	0.71	0.24	0.05	–0.02	**0.00**	1.54	0.46
	Other	0.17	0.56	0.05	0.33	–0.05	**0.01**	–0.07	0.11	–0.02	**0.00**	10.11	0.12
Medium HDI index	All	0.71	0.00	0.15	0.00	–0.07	**0.00**	–0.02	0.86	–0.02	**0.00**	2.56	0.28
	Combustion	0.69	0.00	0.14	0.00	–0.08	**0.00**	–0.17	0.22	–0.02	**0.00**	2.52	0.28
	Other	0.75	0.06	0.12	0.41	–0.06	**0.00**	0.01	0.89	–0.03	**0.00**	0.73	0.69
Low HDI index	All	0.43	0.45	0.03	0.53	0.02	0.63	0.06	0.06	–0.02	**0.00**	3.81	0.15
	Combustion	0.70	0.20	0.05	0.37	0.01	0.61	0.05	0.27	–0.01	0.06	1.58	0.45
	Other	–0.19	0.36	0.36	**0.00**	–0.03	0.39	–0.02	0.71	–0.02	**0.00**	2.44	0.29

Hypothesis 3 stated that in the later phases of EU ETS the actual-emission-reducing effect of free allowances became stronger. This expectation was motivated by the fact that in the first phase of EU ETS the allowances were not distributed optimally, a factor which was later significantly corrected. Although in later stages of EU ETS programme the levels of free allowances were significantly reduced, the empirical results presented in Table 3 provide evidence to claim that during the Phase 3 this reduction did not have almost any effect on lowering actual emissions. Only in the case of installations listed in other sectors in countries which use relatively large amounts of renewable energy did coefficient a_3 turn out to be statistically significant at 1% level. To some extent, this questions the validity of a further reduction of free allowances, which seem to have a sagging effect on reducing air pollution within the EU ETS program.

The levels of free allowances set in the Phase 2 of EU ETS turned out to be partially important in reducing actual emissions in Western Europe (with the exception of the combustion sector), in high renewable energy countries (this was confirmed only in the models covering all installations), low air polluting countries (in the case of the model constructed for all installations and the model for installations listed in the combustion sector) and countries at a high level of social development (a model constructed for installations listed in other sectors). On the other hand, the results presented in Table 3 prove that during Phase 2 of EU ETS the levels of free allowances had a very strong and statistically significant impact on reducing actual emissions in countries with a moderate HDI index. To summarize, it can be seen that the pilot and second phase of EU ETS were periods in which the levels of free allowances played a crucial role in reducing actual emissions. In this context, Phase 3 had virtually no effect, which suggests the rejection of Hypothesis 3.

Results outlined in Table 3 were obtained using data for selected groups of countries. Therefore, only eight GMM dynamic panel models were presented and discussed. We also estimated the same types of dynamic panel models for the 22 individual EU countries covered in the WCCGC database. Detailed results can be found in the Appendix placed at the end of this paper (comp. Table A2). To the best of our knowledge, there are no similar thorough analyses of EU ETS database in the current literature that would provide detailed results obtained for installations in individual countries and selected groups of countries. Moreover, one of the biggest advantages of this study is the provision of the R script included in the Appendix that allows not only a replication of the presented results but also a straightforward regular update of the empirical outcomes (e.g. by reorienting the scope of the analysis towards different groups of countries/industries, by using the data on EU ETS Phase 4, etc.). The latter makes the included R code a flexible tool that opens a way for a wide range of EU-ETS-focused quantitative analyses.

Table 4

Results of GMM estimation of models (2) for different groups of countries

	b_0		b_1		b_2		b_3		b_{2009}		**Hansen test**	
	coef.	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**stat.**	**pval.**
Western Europe	–0.43	**0.00**	32.75	0.13	12.25	0.51	61.70	0.27	–4.41	**0.00**	3.82	0.97
High renewable energy	0.07	0.69	24.11	**0.01**	–8.33	0.17	–4.75	0.21	–10.85	**0.00**	4.91	0.94
Low renewable energy	–0.42	0.58	–52.41	0.47	–24.27	**0.04**	–113.38	0.16	–6.63	**0.01**	1.02	1.00
High air pollution	0.05	0.79	11.34	0.57	–11.01	0.65	–3.77	0.63	–10.29	**0.00**	3.62	1.00
Low air pollution	–0.36	0.12	25.21	0.27	–11.82	0.38	–0.57	0.88	–7.48	**0.00**	4.24	0.96
High HDI index	–0.27	**0.00**	10.27	0.46	–5.22	0.47	–3.30	0.54	–5.75	**0.00**	6.39	0.85
Medium HDI index	0.05	0.89	–6.82	0.84	–22.76	0.60	–58.90	0.74	–6.18	**0.01**	4.27	1.00
Low HDI index	0.14	0.59	0.12	1.00	–2.02	0.90	0.19	0.99	–7.92	0.08	4.03	1.00

Note: Set of control variables in models (2) contains only a constant

The fourth hypothesis stated that the level of free allowances did not have a statistically significant effect on GDP growth rate. Referring to the results of estimation of the respective dynamic panel models (comp. Table 4), it can be seen that this hypothesis turned out to be true in the case of almost every examined group of countries. Only for countries that use relatively large amounts of energy from renewable sources was a statistically significant coefficient corresponding to the level of free allowances noticed.

The level of free allowances in Phase 2 of EU ETS had a statistically significant impact on GDP growth rate for those EU countries which use relatively low amounts of energy from renewable sources. On the other hand, the financial crisis of 2008 had a very meaningful impact on lowering GDP growth rate in 2009 for every group of countries, except for countries characterized by a low level of social development.

For every model estimated we conducted a Sargan-Hansen[15] test to check the validity of instrument subsets. In every case the null hypothesis was not rejected, thus one may assume a correct specification of the GMM estimators. In the case of model (2) adding control variables such as **Foreign Direct Investment or Labour Supply** (both these variables were taken from World Bank Database)[16] did not have a noticeable influence on the estimation results compared to the benchmark variant presented in Table 4. Therefore, we do not present these additional results in the main text.

6. Conclusions

The goal of this paper was to add value to the current economic literature that lacks any econometric analyzes devoted to examining free allowances-verified emissions-GDP linkages in the reliable and detailed Wegener Center for Climate and Global Change database on EU ETS emission levels. We made a preliminary assessment of the effectiveness of the EU ETS in terms of reducing the actual emissions to the air while preserving the economic growth of EU member states. The extensive empirical analysis was focused on examining the issues in question for three phases of the EU ETS and various groups of EU economies that vary in terms of economic development and the overall air pollutant emission.

In general, the empirical results provided solid evidence to claim that lowering the level of free allowances in EU ETS had a statistically significant impact

[15] This test allows checking for over-identifying restrictions. Null hypothesis states that the restrictions are valid. In other words, the test verifies if the GMM model specification is correct (Hansen, 1982).

[16] https://data.worldbank.org/

on reducing the level of actual emissions. Moreover, this impact was found to be especially strong in low polluting EU economies.

At the same time, we rejected the hypothesis that the impact of lowering allowances in EU ETS on reducing the level of actual emissions was much weaker for combustion sectors compared to other EU sectors. We also did not find solid statistical evidence to claim that the positive impact of lowering the level free allowances in EU ETS on reducing the level of actual emissions intensified during the later stages of EU ETS in all sectors and countries.

However, we found solid support for claiming that lowering the level free allowances in EU ETS did not have a statistically significant impact on reducing the GDP growth rate of EU economies. The latter may be partly driven by the ongoing process of shifting the EU economy toward services and other activities characterized by low GHG emission levels and installation of new eco-efficient technologies. Last but not least, this also proves that the overall framework of EU ETS, including the system of penalties for extensive pollutants, seems to work (nearly) as planned.

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Appendix

Part 1. Online resources

- Visit https://github.com/PiterCidry/EU_ETS_Article to download the complete R script that allows the replication of all the outcomes discussed in the main text as well as a straightforward regular update of the empirical outcomes (e.g. by reorienting the scope of the analysis towards different groups of countries, by using the data on EU ETS Phase 4, etc.). The dataset provided in the link is generated randomly merely to show the structure of the desired data file. In order to get access to real data about emissions, please contact Wegener Center for Climate and Global Change (https://wegcenter.uni-graz.at/de/).
- Visit https://1drv.ms/u/s!AqWMx9MoY65Rk2iY-F6sq-hC_hLa?e=IzfIEa to download the detailed empirical results. These were obtained using both the full

panel dataset on EU ETS installations as well as the datasets for individual countries, and various combinations of sectors and groups of countries. In addition to the benchmark estimation technique (i.e., a two-step difference GMM) also pooled/FE/RE panel models were estimated and verified. In general, using the attached R script we estimated and examined 1,404 different specifications of panel models. Table A1 summarizes the statistics on the number of different models examined.

– Visit https://1drv.ms/u/s!AqWMx9MoY65Rk2nzyxNhejHpIXOe?e=YnNyvM to find more plots and visualisations of the dataset.

Table A1

Number of panel models examined

Dataset	Dependent variable	Pooled regression	One-way FE (individual effects)	One-way FE (time effects)	Two-way FE	RE	PVAR	Total
Full dataset	Emission	3	3	3	3	3	3	18
	GDP	3	3	3	3	3	3	18
Groups (countries)	Emission	24	24	24	24	24	24	144
	GDP	24	24	24	24	24	24	144
Groups (installations)	Emission	24	24	24	24	24	24	144
	GDP	24	24	24	24	24	24	144
Countries	Emission	66	66	66	66	66	66	396
	GDP	66	66	66	66	66	66	396
Total		234	234	234	234	234	234	1404

Part 2. Results obtained for individual countries

Results of GMM estimation of models (1) for individual countries are presented in Table A2.

Table A2

Results of GMM estimation of models (1) for individual countries

		a_0		a_1		a_2		a_3		a_{2009}		**Hansen test**	
		coef.	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**stat.**	**pval.**
AT	All	–0.61	0.00	0.41	0.00	–0.02	0.38	0.57	0.00	–0.01	**0.01**	1.05	0.59
	Combustion	0.93	**0.00**	0.01	0.95	0.11	0.10	0.21	0.32	–0.02	**0.04**	3.98	0.14
	Other	–0.28	0.00	0.71	**0.00**	0.02	0.34	0.52	0.00	–0.01	0.17	1.43	0.49
BE	All	1.27	**0.00**	–0.05	0.62	0.05	0.44	0.02	0.81	–0.01	0.15	0.78	0.68
	Combustion	1.05	**0.00**	0.03	0.86	–0.15	0.22	–0.18	0.16	0.01	0.13	4.66	0.10
	Other	–1.19	0.54	–0.10	0.09	0.13	0.04	0.15	**0.03**	0.00	0.94	1.79	0.41
CZ	All	0.61	0.00	0.16	0.04	–0.10	**0.00**	–0.04	0.56	–0.02	0.06	0.12	0.94
	Combustion	0.56	0.01	0.18	0.03	–0.10	**0.00**	–0.01	0.88	–0.02	0.16	0.17	0.92
	Other	0.38	**0.02**	0.07	0.27	0.00	0.74	–0.02	0.17	–0.01	0.06	3.60	0.17
DE	All	–0.16	0.46	0.07	**0.04**	–0.01	0.82	0.03	0.45	–0.02	**0.00**	0.62	0.73
	Combustion	–0.12	0.59	0.08	**0.03**	0.00	0.90	0.46	0.01	–0.02	**0.00**	0.63	0.73
	Other	–0.06	0.73	0.17	0.03	–0.08	**0.02**	–0.03	0.28	–0.02	**0.00**	0.86	0.65
DK	All	0.94	**0.02**	–0.13	0.70	–0.19	0.17	–0.20	0.34	0.00	0.99	4.04	0.13
	Combustion	0.91	**0.04**	0.05	0.89	–0.15	0.43	0.19	0.73	0.00	0.68	4.17	0.12
	Other	0.57	0.00	–0.24	0.01	–0.21	0.00	–0.30	**0.00**	–0.02	0.29	0.00	**0.00**
EE	All	–0.96	0.00	0.20	0.03	0.22	0.02	0.93	**0.00**	–0.10	0.11	0.00	**0.00**
	Combustion	–1.06	0.00	0.20	0.04	0.25	0.01	1.01	**0.00**	–0.13	0.12	0.00	**0.00**
	Other	0.40	0.31	0.29	**0.01**	–0.16	0.50	–0.24	0.43	–0.09	0.34	0.00	**0.00**
ES	All	0.36	0.00	0.24	0.05	–0.26	**0.00**	–0.17	0.09	–0.01	0.31	13.86	**0.03**
	Combustion	0.55	**0.00**	–0.19	0.41	–0.35	0.00	–0.50	**0.00**	0.00	0.72	10.47	**0.03**
	Other	0.46	**0.02**	0.16	0.23	–0.08	**0.00**	–0.06	0.42	–0.02	**0.00**	1.11	0.57

Table A2 cont.

		a_0		a_1		a_2		a_3		a_{2009}		**Hansen test**	
		coef.	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**coef.**	**pval.**	**stat.**	**pval.**
FI	All	–0.46	0.01	0.30	**0.02**	–0.12	0.18	–0.16	0.20	–0.01	**0.00**	4.54	0.10
	Combustion	–0.22	0.10	0.49	**0.01**	–0.13	0.07	0.30	0.38	–0.01	**0.02**	4.38	0.11
	Other	2.38	0.19	–0.20	0.22	0.02	0.31	0.16	0.06	–0.02	0.01	1.66	0.44
FR	All	0.34	**0.04**	0.19	0.20	–0.07	0.00	–0.18	0.03	–0.01	**0.03**	0.90	0.64
	Combustion	0.11	0.59	0.40	**0.00**	–0.01	0.89	–0.21	**0.02**	0.00	0.93	1.74	0.42
	Other	0.33	**0.00**	0.07	0.54	–0.15	**0.00**	–0.19	0.07	–0.01	**0.00**	6.16	0.19
GB	All	0.97	**0.00**	–0.10	0.47	–0.02	0.61	0.12	0.06	–0.06	**0.00**	3.62	0.16
	Combustion	0.52	0.08	0.69	**0.00**	–0.01	0.97	0.30	0.13	–0.02	0.01	13.03	**0.01**
	Other	1.30	**0.02**	–0.04	0.82	–0.05	**0.01**	0.07	0.39	–0.06	0.26	1.30	0.52
GR	All	0.58	0.00	0.21	0.00	0.04	0.50	0.19	**0.05**	–0.03	0.24	3.08	0.21
	Combustion	0.28	0.03	0.22	**0.00**	–0.02	0.68	1.29	**0.00**	0.01	0.89	0.00	**0.00**
	Other	0.79	0.00	0.60	0.02	–0.07	**0.04**	0.04	0.67	–0.04	0.03	0.00	**0.00**
HU	All	–0.04	0.97	0.16	0.25	0.03	0.70	–0.05	0.29	–0.01	0.56	3.82	0.15
	Combustion	0.18	0.70	0.15	0.08	–0.01	0.51	–0.08	0.11	0.00	0.24	4.96	0.08
	Other	2.17	0.28	0.22	0.34	0.01	0.93	–0.17	0.37	–0.06	0.36	0.00	**0.00**
IE	All	1.18	0.10	–0.16	0.47	0.07	0.20	–0.08	0.71	–0.02	0.09	2.41	0.30
	Combustion	0.35	0.23	0.30	0.05	–0.11	0.04	0.30	**0.00**	0.00	0.54	1.77	0.41
	Other	2.07	**0.00**	–0.18	0.32	–0.12	0.00	–0.58	0.00	–0.18	0.04	0.00	**0.00**
IT	All	1.05	**0.00**	0.03	0.20	0.02	0.56	0.01	0.78	–0.03	**0.00**	0.89	0.64
	Combustion	1.06	**0.00**	0.02	0.43	0.05	0.17	0.54	0.03	–0.04	**0.03**	1.24	0.54
	Other	0.43	**0.04**	0.11	0.06	–0.06	0.01	–0.13	0.00	–0.02	0.00	9.68	**0.05**

Table A2 cont.

LT	All	1.38	0.29	–0.09	0.75	0.34	0.28	0.45	0.44	–0.02	0.28	0.00	**0.00**
	Combustion	0.39	0.07	0.09	**0.00**	0.14	0.22	–0.26	0.00	–0.01	0.25	0.00	**0.00**
	Other	0.38	0.93	0.77	0.92	–0.13	0.99	–0.24	0.99	0.33	0.99	0.00	**0.00**
LV	All	0.16	0.56	–0.19	0.12	0.01	0.67	–0.08	**0.03**	–0.01	0.09	0.00	0.00
	Combustion	1.53	0.24	–0.65	**0.05**	0.02	0.61	0.06	0.37	0.00	0.54	0.00	**0.00**
	Other	0.53	0.10	0.17	0.22	–0.05	0.00	–0.11	**0.00**	–0.02	0.06	0.00	**0.00**
NL	All	0.43	0.30	0.32	**0.00**	0.01	0.79	–0.01	0.87	–0.01	0.18	7.05	0.13
	Combustion	0.48	0.40	0.28	**0.03**	–0.04	0.48	–0.90	**0.00**	0.01	0.82	3.55	0.17
	Other	–0.10	0.74	0.38	**0.02**	0.02	0.39	0.03	0.12	–0.02	**0.03**	1.66	0.44
PL	All	0.45	0.27	–0.02	0.71	–0.02	0.65	0.02	0.68	–0.01	**0.00**	4.93	0.30
	Combustion	0.43	0.39	–0.04	0.62	–0.01	0.73	0.02	0.57	–0.01	0.31	5.62	0.23
	Other	–0.59	0.04	0.34	**0.00**	–0.02	0.75	–0.17	0.00	–0.02	**0.04**	1.42	0.49
PT	All	0.99	0.00	–0.26	**0.00**	0.03	0.49	0.20	0.13	–0.01	0.26	1.00	0.61
	Combustion	0.61	0.08	–0.11	0.36	–0.01	0.95	0.29	0.38	0.08	0.34	0.00	**0.00**
	Other	0.75	**0.04**	–0.05	0.88	–0.05	0.49	–0.03	0.91	–0.01	0.26	4.12	0.13
SE	All	0.05	0.49	0.21	**0.01**	–0.02	0.55	0.02	0.81	0.00	**0.03**	4.33	0.11
	Combustion	0.54	0.18	0.01	0.97	0.27	0.43	0.31	0.34	0.00	0.81	3.49	0.17
	Other	–0.01	0.89	0.05	0.40	–0.01	0.69	–0.03	0.67	–0.01	**0.05**	4.20	0.12
SI	All	0.71	0.00	0.07	0.00	–0.06	0.00	–0.13	**0.00**	–0.01	0.14	0.00	**0.00**
	Combustion	0.69	0.00	0.08	0.00	–0.06	0.00	0.01	0.45	–0.01	0.41	0.00	**0.00**
	Other	2.77	**0.01**	–0.27	0.59	–0.06	0.72	–0.18	0.52	–0.03	0.06	0.00	**0.00**
SK	All	0.68	**0.00**	0.15	0.13	–0.10	**0.02**	–0.08	0.24	–0.03	**0.01**	1.46	0.48
	Combustion	0.64	**0.00**	0.04	0.63	–0.11	0.01	–0.22	**0.00**	–0.01	0.29	2.44	0.30
	Other	0.86	0.07	0.22	0.51	–0.03	**0.00**	0.25	0.06	–0.07	0.07	0.00	**0.00**

Note. Abbreviations of country names were set according to Table 2