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Ex-post assessment of the Kyoto Protocol – quantification of CO_2 mitigation impact in both Annex B and non-Annex B countries-

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HIGHLIGHTS

- Mitigation effect by the Kyoto Protocol was observed in Annex B non-EIT countries.
- Small EIT countries had perverse effects on CO_2 emission reductions by the Kyoto Protocol during the commitment period.
- In total, 951 $MtCO_2$ emission reduction was achieved by the Kyoto Protocol, mainly in non-Annex B countries.
- The results in this paper contribute the discussion of international cooperation mechanisms under the Paris Agreement.

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ABSTRACT

The Kyoto Protocol implemented the first international top-down mechanisms and provided mitigation incentives for both Annex B and non-Annex B countries. An assessment of the Kyoto Protocol would contribute to the fundamental discussion on designing future mitigation mechanisms under Article 6 of the Paris Agreement, while the use of a top-down approach that includes an emission trading scheme appears important for achieving the 2 °C target. This paper summarizes the existing literature and quantifies the effects of greenhouse gas (GHG) emission reduction impacts from the Kyoto Protocol using the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) approach for Annex B countries and 'additionality' assessment of Clean Development Mechanisms (CDM) projects for non-Annex B countries. We found that the Kyoto Protocol brought about 951 Mt CO_2e of real emission reductions in all over the world, mainly from implementing non-energy-related GHG emission reduction projects in non-Annex B countries. For the Annex B countries, 76 Mt CO_2e of mitigation occurred during the preparation stage of the first commitment period (2005–2007), but no further effects were observed during the first commitment period (2008–2012). The following important lessons were learned from the implementation of the Kyoto Protocol: (1) insufficient emission caps did not provide any mitigation incentives; rather, they resulted in perverse effects amounting to 12 Mt CO_2e, which increased emissions in certain Annex B countries with economies in transition; and (2) since 42% of energy-related projects in non-Annex B countries were assessed as non-additional projects, more attention needs to be paid to the design of international cooperation mechanisms.

1. Introduction

The Kyoto Protocol was adopted on 11 December 1997 as a result of the United Nations Framework Convention on Climate Change (UNFCCC) negotiations. It included the commitments to reduce the emission of six greenhouse gases (GHGs) by 5.2% during the first commitment period of the Kyoto Protocol (KP-CP1: 2008–2012) by Annex B countries, most of which were industrialized countries in the 1990s. The Kyoto Protocol took a top-down approach and used international negotiation at the third session of the Conference of the Parties (COP) under the UNFCCC to determine the emission reductions to be pledged by each country. The Kyoto Protocol introduced flexible mechanisms (the "Kyoto Mechanisms"), which enabled the Annex B countries to fulfil their commitments in a cost-efficient manner through an international cooperation mechanism such as International Emission Trading, Joint Implementation: JI, and Clean Development Mechanism: CDM) and this seemingly efficient approach is not fully examined. A review of the Protocol is thus essential to achieve the 2 °C target adopted under the Paris Agreement.

The Kyoto Protocol has the following two fundamental essences,

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which are relevant for the Paris Agreement. First, Article 6 of the Paris Agreement decides the cooperation mechanism that allows each country to conduct emission reduction overseas. The experience of the Kyoto Mechanisms, including CDM, could be helpful for the negotiation related to international cooperation mechanism [1]. Second, the Kyoto Protocol was the first international commitment to GHG emission reductions imposed by ta top-down approach, to promote domestic GHG emission mitigation actions. In this regard, the current level of countries' mitigation ambitions is so insufficient that there may be more pressure to create a top-down approach [2,3] under the process of Article 4 of the Paris Agreement require countries to develop and submit their nationally determined contribution every five years in a progressive manner.

Therefore, a review of the Kyoto Protocol should be based not only on the domestic emission reductions of a country, but also on Annex B countries' contribution to emission reduction activity in other countries, including non-Annex B countries.

In this paper, we report the results of the analysis on the effects of the Kyoto Protocol on emission reductions by Annex B countries during KP-CP1. These were estimated using panel-data analysis of the data from Annex B countries and using each state in the United States as a control country. Second, we also investigated the environmental integrity of emission reduction outside Annex B countries through international mechanisms to provide an overall assessment of the Kyoto Protocol. Section 2 presents a literature review of the mitigation impacts from the Kyoto Protocol from the viewpoints of overall mitigation impacts by domestic action in Annex B countries, issues associated with over-allocation of emission caps in economy-in-transition (EIT) countries, and mitigation impacts in non-Annex B countries by CDM. Section 3 describes the methodology and data for the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model and the development of additional criteria for CDM projects. Section 4 includes the results and discussion, and the conclusions are presented in Section 5.

2. Literature review for assessing the mitigation impact of the Kyoto Protocol

Since the Kyoto Protocol employed emission trading schemes that provided incentives for both domestic and international emission reduction activities, this study includes a literature review in three parts. The first part summarizes past studies that mainly focus on the domestic impact of the Kyoto Protocol in Annex B countries. The second part focuses on the effects of the Kyoto Protocol on the EIT countries, including JI projects, since those countries can have unique issues of "hot-air",[1] that refers to the concern that some governments will be able to meet their targets for greenhouse-gas emissions under the Kyoto Protocol with minimal effort and could then flood the market with emissions credits, reducing the incentive for other countries to cut their own domestic emissions [4]. The third part shows the emission reduction impact in the Annex B countries where CDM projects were implemented. A number of studies addressed "additionality", which is the aspect to secure real emission reductions through the implementation of mitigation projects.

For identifying the domestic mitigation impact of the Kyoto Protocol, several studies have been conducted using both econometric [5–7] and non-econometric analyses from the perspective of ex-post assessment [8,9]. Among the studies using econometric analysis, most studies focused only on the effect of emission reduction by domestic actions before the completed assessment of the commitments of the Annex B countries during KP-CP1. Grunewald and Martinez-Zarzoso [6] investigated the effects of the Kyoto Protocol on CO_2 emissions based on a sample of 170 countries over the period 1992–2009 using a difference-in-difference estimator. Aichele and Felbermayr [7] evaluated the effects of ratification of binding Kyoto commitments using instrumental variables. Almer and Winkler [5] recently accounted for CO_2 emissions outside 15 countries for 2002 to 2011 using country-level and U.S. state-level panel data while employing synthetic control method. However, additional data available during the period of fulfilling commitments (i.e., the true-up period) was not used. Also, the study did not cover the emission reduction impacts for all Annex B countries. Thus, the number of emission reductions assessed in their study was less than the amount covered under the Kyoto Protocol during KP-CP1.

Regarding the studies pertaining to effects after the end of the first commitment period, Grubb [8] summarized the outcomes of the Kyoto Protocol with respect to international law, effects, and implications of the Paris agreement. The existence of flexible mechanisms such as CDM was analyzed, allowing some countries with a substantial emission cap such as Japan to maintain their compliance. Shishlov et al. [9] documented full compliance of the parties to the Kyoto Protocol during KP-CP1 based on data from the true-up period report, which contains the results of all transactions of Kyoto Protocol units (Kyoto units)[2] through the end of 2015. However, none of them applied an econometric analysis to assess the impact of the Kyoto Protocol.

Indeed, there is criticism that the Kyoto Protocol caused carbon leakage where regulations in some countries allowed them to charge relatively high carbon prices and thus shift production of CO_2-intensive goods to the places that are exempt from such regulation [10]. Nonetheless, it is worthwhile to assess emission reduction impacts of the Kyoto Protocol since it imposes emission reduction efforts for both companies relocating overseas (such as energy-intensive industries), and also a wider range of sectors, such as transportation and building [11]. Then, the quantified mitigation effects of the Kyoto Protocol can be compared with the calculated amount of carbon leakage.

Regarding the effects of the Kyoto Protocol on EIT countries, one significant criticism relates to the regulation of "hot air." Many consider the EIT country emission allowances to be over-allocated, which raises several issues regarding environmental integrity [12,13]. First, this does not provide any incentive for domestic mitigation actions, as those countries can achieve their emission reduction targets without any mitigation measures. In EIT countries, more than 800 of JI projects were implemented in addition to mitigation commitments by the Kyoto Protocol [14]. However, Kollmuss and Schneider [15] quantitatively found that three-quarters of the emission reduction units (ERUs) based on Kyoto units from JI projects were unlikely to represent additional emissions reductions. They also identified negative impacts from those mechanisms (i.e., a "perverse effect"). All projects abating HFC-23 and SF_6 under JI in Russia increased waste gas generation to unprecedented levels once they could generate ERUs by producing more waste gas [16]. Such perverse effects could happen not only with industrial waste gas but also with other energy-related projects, such as the installation of renewable energy and energy efficiency projects [17]. Second, the surplus allowances caused by over-allocation could be sold to other Annex B countries. The surplus of emission allowances also decreased the emission reduction incentives for Annex B countries, and/or allowed a shift to higher CO_2 emission-intensity fuel sources such as coal [12]. On the other hand, some studies shows Green Investment Schemes (GIS) provide incentives to mobilize emission reduction in EIT countries. Karásek and Pavlica [18] reported that the Green Savings Programme that involved the sale of Assigned Amount Units (AAUs) contributed to reducing the payback period of solar systems and heat

[1] Type of hot air includes surplus allowances from emission trading system, double counted emission reductions, non-additional carbon credits and non-permanent carbon offsets [76].

[2] A unit equal to 1 metric tonne of CO_2 equivalent and are used for the compliance with Annex B countries' commitments. Kyoto Protocol units consists of assigned amount units (AAUs), certified emission reductions (CERs) and emission reduction units (ERUs) and removal units (RMUs) generated by LULUCF activities [77].

Table 1
Groups of Annex B countries for the analysis.

Group	Annex B countries	Analytical approach
Annex B non-EIT countries	Germany, Japan, Spain, Italy, UK, France, Netherlands, New Zealand, Austria, Belgium, Norway, Denmark, Finland, Greece, Portugal, Ireland, Luxembourg, Switzerland, Sweden	STIRPAT Model
Small Economies in Transitions*	The Czech Republic, Bulgaria, Slovakia, Romania, Lithuania, Hungary, Slovenia, Latvia,	STIRPAT Model
Large Economies in Transitions	Russian Federation, PolandUkraine	STIRPAT Model
Non-Annex B countries	The countries that host CDM projects with CER issuance and transaction to Annex B countries. There are 59 Annex B countries.	Additionality assessment for each project

* Estonia is excluded from the groups because it has missing values on CO_2 emission from fossil fuel combustion.

pumps to four years, which resulted in the wide diffusion of CO_2 mitigation technology. Ürge-Vorsatz et al. [19] argued that the GIS could play a significant mitigation role until 2012 owing to the significant revenue generated by selling AAUs to other Annex B countries.

For the real emission reduction impacts from CDM projects, the issue of "additionality" is important. Additionality is the concept of "Reductions in emissions that are additional to any that would occur in the absence of the certified project activity" as described in the Article 12 of the Kyoto Protocol [20]. Therefore, if a mitigation project occurs in a country where no mitigation commitments have been imposed, the project would cause no reduction in GHG emissions. Ellis and Kamel [21] stated that the revenue of Certified Emission Reductions (CERs), which are Kyoto units from CDM projects, is not a critical factor for most projects. The result means that such projects have economic advantages even in the absence of CDM, and these CDM projects are considered non-additional. Also, Schneider [22] claims that the review criteria on additionality by the CDM Executive Board before 2008 was more relaxed than it is currently. As a consequence, there is a high probability that a large number of projects may be non-additional. Gillenwater and Seres [23] pointed out that there is information asymmetry between project participants and the CDM Executive Board. Hence, it is likely that CDM projects have been registered based on biased or insufficient information provided by project participants.

On the other hand, it should be noted that there are supportive findings on the CDM additionality issues, depending on the project type. Lütken [24] showed that projects involving manure and industrial gases such as HFC and N_2O are more likely to be driven by carbon investments. In the waste management sector, Bufoni et al. [25] pointed out that a landfill gas project exhibited an average negative internal rate of return (IRR), which shows that some projects are not attractive without CER revenue. Barton et al. [26] indicated that those in the market expect income from the CERs, which offer significant incentives for attracting investment. Moreover, Tanwar [27] insisted that stand-alone electricity generation using small hydro projects in rural mountainous regions is not financially attractive. Purohit [28] points out that small hydropower projects in India seem to be "additional" because they face the barrier of the instability of government policies in addition to hydrologic, geologic, capacity, and transmission risks, along with lack of infrastructure.

In summary, the existing empirical studies on the impact of emission reductions by the Kyoto Protocol were mainly conducted before the end of KP-CP1. Even though some studies include an assessment of mitigation impact after KP-CP1, they focus on domestic actions without assessing the impact in non-Annex B countries, while the mitigation impacts in non-Annex B countries are also mobilized by the mitigation efforts of Annex B countries. Within the Annex B countries, some studies focus on the EIT countries, where there are many criticisms on additional emission reduction, but there also studies to support positive mitigation impact through GIS.

As the contribution and innovation of this study based on the literature reviews, it is worth conducting an empirical analysis to determine whether the Kyoto Protocol provides real emission reduction impacts in Annex B countries, considering the issue of over allocation of AAU, i.e. emission allowance. For the mitigation effect in non-Annex B countries by the CDM projects, most studies address the issue of additionality, but there have been no studies that quantify the amount of real emission reduction with additionality.

Therefore, in this paper, we first assessed the domestic emission reduction effects of the Kyoto Protocol using robust heterogeneous panel estimates based on data after the completion of KP-CP1 for the three groups of Annex B countries. Second, we also assessed the mitigation effect in non-Annex B countries using data that include all the registered CDM project by the end of true-up period. Finally, we quantified the net mitigation impacts of the Kyoto Protocol using the results from both Annex B and non-Annex B countries.

3. Methods and data

Since the Kyoto Protocol included various countries with heterogeneous economic situations, it is necessary to develop an analytical framework that can capture the different circumstances of the countries. As shown in Table 1, this paper employs the STIRPAT model using panel data analysis to identify the mitigation impact of the Kyoto Protocol by the Annex B countries. The Annex B countries were divided into EIT countries and Annex B non-EIT countries, as several studies have noted that the over-allocation of emission allowances for EIT countries did not provide sufficient incentive [29,30] while Annex B non-EIT countries had more or less emission reduction incentive by the following reasons. For Japan, New Zealand, Norway and Switzerland, the initial emission allowance for KP-CP1 were less than GHG emissions during KP-CP1 when Kyoto Protocol entered into force in 2005 [31]. Thus, those countries had to promote domestic GHG emission reductions. For EU15,[3] Massai [32] reviewed GHG emissions scenario in the EU regarding the Kyoto Protocol's first commitment period developed and presented by the European Environment Agency from 1996 to 2009. It showed that neither business-as-usual scenario nor mitigation policies scenario could fulfil the emission reduction commitment without the use of international cooperation mechanism, which implies that EU15 had additional mitigation incentive during KP-CP1. Australia was excluded from the Annex B non-EIT countries because the country did not transact any Kyoto units. Iceland, Liechtenstein and Monaco were also omitted due to the data availability. Annex B EIT countries are divided into small EITs, with less than 1 Bt CO_2 of initial assigned units during the CP1, and large EITs, with more than 1 Bt CO_2 of initial assigned units during the CP1. This is because the amount of surplus emission allowances in the Large EIT countries such as Russia and Ukraine are more than five times that for the Small EIT countries, which could provide different incentives for emission reduction.

[3] The 15 States who were EU members in 1997 when the Kyoto Protocol was adopted, took on that 8% target that will be redistributed among themselves, taking advantage of a scheme under the Protocol known as a "bubble", whereby countries have different individual targets, but which combined make an overall target for that group of countries. The EU has already reached agreement on how its targets will be redistributed [78].

For the non-Annex B countries, we used a different approach to identify the emission reduction effects of the Kyoto Protocol, because the STIRPAT model could not be used due to the following data limitations. First, there are no control countries for non-Annex B countries to conduct panel data analysis by the STIRPAT model, since most developing countries have joined the Kyoto Protocol. Second, the largest part of the mitigation effect from the Kyoto Protocol in Annex B countries is related to reductions in industrial gases. Country-level emission data is limited to CO_2 emissions from fossil fuel combustion and does not cover GHG emissions. Hence, for non-Annex B countries, each mitigation project was assessed by setting additionality criteria, rather than by using panel data analysis.

3.1. Annex B countries

3.1.1. Empirical model – The IPAT and STIRPAT models

To identify the key impact factor for carbon emissions in different countries, many studies apply the Impact, Population, and Technology (IPAT) method. While the environmental Kuznets Curve/carbon Kuznets Curve (EKC/CKC) framework seeks to determine whether there are inverted U-relations between GDP per capita and emissions or other environmental impact measures per capita [33–35], the STIRPAT model found that population, affluence, and technology are significant drivers. Hence, the major difference between STIRPAT and the EKC/CKC framework is that the EKC effectively assumes that population's elasticity is unity and correspondingly converts the dependent variable into per capita terms [34]. Since Ehrlich and Holdren [36] and Commoner et al. [37] initially introduced the IPAT approach, there has been much discussion and research regarding analyses of the impacts on population and the development of the main environmental indicators like CO_2 emissions. The IPAT equation can be represented as follows:

$$I = P*A*T \tag{1}$$

where P represents population, A represents affluence per capita, and T denotes technology, which is often treated with an intensity-of-use variable. Using the model as a basis, Dietz and Rosa [38] developed a STIRPAT model able to overcome the unit elasticity assumption within the IPAT model and to add randomness for empirical analysis:

$$I_{it} = aP_{it}^{b}A_{it}^{c}T_{it}^{c}e_{it} \tag{2}$$

Under the STIRPAT model, the constant, as well as the exponents b, c, and d, are estimated. The subscript i denotes cross-sectional units (e.g., countries), t denotes period, and e is the residual effort term. Table 2 summarizes the indicator for each variable to apply the STIRPAT model in existing studies [31,35,39–42].

The variable for I is expressed by CO_2 or GHG emissions in most studies. Population and GDP per capita are commonly used for the variables P and A, respectively. While several indicators are used to denote the variable T, energy intensity and renewable energy shares are widely used. [34,39,40,41,42,43]

We employ CO_2 emissions from fossil fuel combustion for I, population for P, real GDP per capita for A, and energy intensity and share of primary supply from non-fossil fuels for T. Hence, the model in this paper is specified as shown in Eq. (3):

$$lnCO2_{i,t} = \beta_0 + \beta_1*lnPOP_{i,t} + \beta_2*lnGC_{i,t} + \beta_3*lnEI_{i,t} + \beta_4*lnNF_{i,t} + \beta_5*KPpre_{i,t} + \beta_6*KPimp_{i,t} + \beta_7*Cr_{i,t} + \epsilon_{i,t} \tag{3}$$

where t denotes year t, i denotes the country samples, CO_2 represents CO_2 emissions from fossil fuel combustion, POP_{it} denotes population, GC_{it} represents GDP per capita (constant 2010 USD), EI_{it} represents energy intensity, NF_{it} represents the share of non-fossil fuel energy sources in the primary energy supply, and $KPpre_{it}$ represents a dummy variable for the Kyoto Protocol, and takes 1 for Annex B countries during 2005–2007. Here, $KPimp_{it}$ represents a dummy variable for the Kyoto Protocol, and takes 1 for Annex B countries during 2008–2012.

Table 2
Application of STIRPAT model.

	I	P	A	T	Others
Liddle [34]	Carbon emissions	Population	Real GDP per capita	Industrial energy intensity, share of primary energy consumption from non-fossil fuel	–
Shuai et al. [39]	CO_2 emissions	Urban population	GDP per capita	Energy intensity	
Iwata & Okada [40]	GHG emission	Total population or Urbanisation	Real GDP per capita	Energy intensity and manufacture ratio	Dummy variables for the Kyoto Protocol
de Alegría et al. [41]	GHG emission	Population	GDP per capita	Energy Intensity, Renewable energy consumption per total primary energy consumption	Dummy variables for crisis
Knight et al. [42]	Total ecological footprint, Carbon footprint,Carbon emission	Population	GDP per capita	Manuf. %GDP/, Service %GDP	Urbanization
Sadorsky [43]	CO_2	Population	Real GDP per capita/work hours, GDP per hour, employment to population ratio	Manufacturing as a percentage of GDP, services as a percentage of GDP	Urbanization

Table 3
Summary statistics and correlations (all variables in natural logs).

Variable	Obs	Mean	Std. Dev.	Min	Max
lnCO2	1980	10.4	2.4	3.3	15.6
lnPOP	2040	16.0	1.7	12.5	21.0
lnGC	2040	10.0	1.0	6.4	12.0
lnNF	2040	−2.0	1.0	−6.5	−0.1
lnEI	2040	5.4	0.7	3.7	7.9
Correlations	lnCO2	lnPOP	lnGC	lnNF	lnEI
lnCO2	1				
lnPOP	−0.1599	1			
lnGC	0.6326	−0.569	1		
lnNF	−0.0397	0.2143	−0.1398	1	
lnEI	−0.2025	0.0516	−0.605	−0.0847	1

We used the augmented mean group (AMG) estimator by Eberhardt and Teal [44], which accounts for cross-sectional dependence by including in the regression a common dynamics process. (Appendix A.1 shows the basic formula of AMG estimator)

One feature of the AMG approach is that the set of unobservable common factors is treated as a common dynamic process with useful interpretations, while other heterogeneous or mean group type estimators approaches, such as the Common Correlated Effects Mean Group (CCEMG), treat the set of unobservable common factors as a nuisance [43]. In fact, Everhardt [45] pointed out that the slope parameters estimated by the CCEMG have not an easy interpretation. On the other hand, the AMG estimator is robust to non-stationary variables, whether co-integrated or not [44]. Thus, arguably, they do not require pre-testing to identify the existence of co-integration or to confirm that all variables are of the same order of integration [34]. Also, the estimators are robust to serial correlation [34,44,46] . While the Kyoto Protocol covers all GHG, we used CO_2 emissions from fossil fuel combustion as the dependent variable due to a limitation on the availability of U.S. state-level GHG emission data.

Based on the estimation result from Eq. (3), the mitigation effect from the Kyoto Protocol was identified by the estimation result of both the elasticity approach as shown in Eq. (4):

$$\text{EMI} = \sum_{i} \sum_{t}^{2005-2007} ems_{i,t} * \widehat{\beta}_5 + \sum_{i} \sum_{t}^{2008-2012} ems_{i,t} * \widehat{\beta}_6 \tag{4}$$

where EMI represents the estimated mitigation impact by the elasticity based on log-log estimation models, ems defines the CO_2 emissions from fossil fuel combustion for country i, and the terms β_5 and β_6 stand for the coefficient of the impact of the Kyoto Protocol with statistically significance during the preparation period and the commitment period, respectively.

3.1.2. Data for Annex B countries

The data on CO_2 emissions were retrieved in the Common Reporting Format that Annex I countries to the UNFCCC use to submit reports to the UNFCCC Secretariat every year, and from the U.S. Environmental Protection Agency for U.S. state-level emission data. For all Annex B countries, this study focused on CO_2 emissions due limited available data, however, it can be a proxy for mitigation impact of those countries because the energy sector contributed most of the GHG emission reductions [47]. GDP and population data were extracted from the World Bank database for Annex B countries and the Bureau of Economic Analysis for U.S. state-level data. The data on the total primary energy supply, energy supply from renewables, and energy supply from nuclear power was retrieved from the International Energy Agency (IEA) database for Annex B countries and the U.S. Energy Information Administration (EIA) for U.S. state-level data. Table 3 shows a summary of the statistics[4].

For the analysis of Annex B countries, U.S. state data are used for hypothetical control countries to identify the impact of CO_2 emissions. The corresponding U.S. state for each Annex B country group was identified by cluster analysis, using data from 2005. The aim of cluster analysis is to identify groups of similar objectives based on selected variables [48]. While the basic approaches are agglomerative hierarchical clustering and k-means clustering, hierarchical clustering was also applied for the following reasons. First, the most common clustering method in economics is agglomerative hierarchical cluster analysis, which provides a powerful tool for relatively small data files [48]. Second, one problem associated with the application of the k-means method is that the researcher has to pre-specify the number of clusters to retain in the data, not suitable for this work [49].

Among the hierarchical clustering approaches, we employed Ward's method, which finds at each stage two clusters of which the merger gives the minimum increase in the total within group effort sum or square (that is, the distance between the centroids of the merged clusters) [50]. The data used for the cluster analysis were CO_2 emissions from fossil fuel combustion, GDP per capita, population, share of zero-emitting energy sources, and energy intensity in 2005.

Table 4 shows the result of the selection of U.S. states as control countries. It identified the 22 U.S. states used as control the Annex B non-EIT countries, 15 for the Annex B Small EIT countries, and 13 for the Annex B Large EIT countries. Also, the cluster analysis results suggest that the large and small economic countries can be separated into different groups.

To test the cross-sectional dependence, the Pesaran [51] cross-sectional dependence test, which employs the correlation coefficients between the time-series for each panel member, was conducted as shown in Table 5. The null hypothesis of cross-sectional independence was rejected for each variable for all groups.

As shown in Table 6, we employ unit root test developed by Im, Pesaran, and Shin (IPS) for the panel datasets since IPS unit root test performs better than traditional test such as Levin-Lin (LL) test [52,53] . (Appendix A.2 shows the basic formula of IPS unit root test) The results of these tests suggest that CO_2 emissions, GDP per capita, energy intensity, and share of zero-emitting sources are first-order integrated. The population data shows the presence of a unit root for the data without time trend, as Liddle [54] pointed out that the coefficient of population in the STIRPAT model is unstable because: (1) the likelihood that the elasticity of population is not different from unity, (2) the lack of robustness in estimating the population elasticity, and (3) the difficulty in establishing a population's integration properties in the absence of very long-term dimensioned data. On the other hand, the population data in the first difference with time trend does not show the presence of unit root, which can be interpreted as stationarity. Therefore, this study applies the data with consideration of the time trend.

3.2. Identifying the amount of CERs without additionality

3.2.1. Additionality criteria for CDM projects

This report assesses the additionality of CDM projects by developing three criteria as discussed in Section 2, and the issues of CDM additionality derived for various reasons. In this chapter, we establish two criteria for investment analysis and one criterion for the project and country-specific condition based on literature reviews.

The first criterion of non-additionality issues comes from an ex-ante assessment of investment analysis. Several studies have pointed out that a large number of projects estimated that their IRR was increased 2–3% by CER revenue [24,55–57] . However, their values were too small to make valid claims of additionality. Furthermore, Schneider [22] stated that the information to be utilized in investment analysis lacked transparency, and Haya [58] noted that the information used in the investment analysis described in the Project Design Document (PDD) was inconsistent with the information submitted to financial institutions. Michaelowa [59] also indicated that the value of the benchmark

[4] The data used for this paper is available from the link below. http://dx.doi.org/10.17632/342mfrmv4k.1.

Table 4
List of reference states in U.S.

Group	Reference U.S. states
Annex B non-EIT	Alabama, Arizona, Arkansas, California, Connecticut, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, New Jersey, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, Washington, West Virginia, Wisconsin
Small EIT	Alabama, Tennessee, South Carolina, Arizona, Washington, Connecticut, Oregon, Arkansas, Mississippi, Iowa, Kansas, Maryland, Minnesota, Wisconsin, Massachusetts, Missouri, New Hampshire, Idaho, Maine, South Dakota, Montana, Nebraska, Vermont
Large EIT	California, Florida, New York, Georgia, Michigan, North Carolina, New Jersey, Virginia, Illinois, Pennsylvania, Indiana, Ohio, Texas

Table 5
Cross-sectional dependence: absolute value mean correlation coefficients and Pesaran test.

	lnCO2	lnPOP	lnGC	lnNF	lnEI
Annex B non-EIT	0.52 (65.9)	0.93 (152.3)	0.97 (158.9)	0.85 (139.6)	0.40 (39.8)
Annex B small EIT	0.51 (23.3)	0.92 (41.2)	0.97 (98)	0.97 (98.1)	0.39 (20.6)
Annex B large EIT	0.59 (14.3)	0.90 (20.1)	0.83 (43.7)	0.95 (49.8)	0.44 (11.9)

Notes: CD-test statistic is in parentheses. Null hypothesis is cross-sectional independence. Statistical significance indicated by < 0.01. Group1 shows countries with substantial emission cap. Group2 shows small EIT countries. Group3 shows large EIT countries.

Table 6
Panel unit root test.

		Constant w/o trend		Constant w/ trend	
		In Levels	In first differences	In Levels	In first differences
Annex B non-EIT	lnCO2	0.614	0.000	1.000	0.000
	lnPOP	0.366	0.753	1.000	0.000
	lnGC	0.046	0.000	1.000	0.000
	lnNF	1.000	0.000	0.000	0.000
	lnEI	0.818	0.000	0.000	0.000
Small EIT	lnCO2	0.042	0.000	1.000	0.000
	lnPOP	0.305	0.232	0.995	0.000
	lnGC	0.382	0.000	0.536	0.000
	lnNF	1.000	0.000	0.000	0.000
	lnEI	0.013	0.000	0.000	0.000
Large EIT	lnCO2	0.600	0.000	1.000	0.000
	lnPOP	0.000	0.164	0.985	0.019
	lnGC	0.335	0.000	0.996	0.000
	lnNF	1.000	0.000	0.001	0.000
	lnEI	0.236	0.000	0.001	0.000

was not always appropriately claimed.

The second criterion is based on an ex-post assessment related to investment analysis. Kuriyama and Koakutsu [60] pointed out that there are some projects at operation status, even though the CER price was well below the assumption in the PDDs.

The third category of non-additionality issues addresses project and country-specific conditions. He and Morse [61] pointed out that the renewable energy projects in many developing countries were often implemented for political reasons, regardless of project profitability.

Several studies assess CDM projects that employ hydropower and wind power technologies in China as non-additional since those technologies are too mature to be supported by CDM [62–67]. Lazarus and Chandler [68] stated that it is highly unlikely that a significant portion of the coal-fired power projects is truly additional, considering both the pressure to build efficient technology due to ongoing coal price increases, as well as Indian and Chinese government policies. Waste heat recovery projects have also been assessed as non-additional, since the waste recovery process at a production site is already economically reasonable compared to utilizing fossil fuel [67].

Based on a literature review for the non-additionality of CDM projects, this paper develops the following additionality criteria.

- **Additionality Criterion A:** The data on investment analysis shows that the difference between IRR with revenue from CERs, and the benchmark IRR in the PDD, is more than 3%.
- **Additionality Criterion B:** The data on investment analysis shows that the difference between 'CER price (USD/t CO_2e) that was used for assessing additionality in the PDD' and 'CER price (USD/t CO_2e) at the ECX (European Climate Exchange) on the date of publication of monitoring report' is more than 3 USD/t CO_2e.
- **Additionality Criterion C:** The project is other than 'Hydro and wind power projects in China and India' and 'fuel switch to natural gas for power plants and waste heat recovery in iron and steel sector in all the countries.'

3.2.2. Data for non-Annex B countries

The data for mitigation impact from the Kyoto Protocol in non-Annex B countries were taken from monitoring reports that have been verified by the designated operation entities under the CDM and approved by the CDM Executive Board. The CER for KP-CP1 can be assumed to be mobilized by Annex B country investments since there was little demand to purchase CERs other than the fulfilment of emission reduction targets under the Kyoto Protocol.

Based on the monitoring period in each monitoring report, we calculated the amount of CER issuance by the end of KP-CP1. Using the CDM project reference number of each monitoring report, this report identifies the project type and the assumption of investment information using the Institute for Global Environmental Strategies (IGES) CDM project database [69] and IGES CDM Investment Analysis database [70].

4. Results and discussion

4.1. Mitigation impact by the Kyoto Protocol from Annex B countries

Table 7 displays the regression results from the AMG panel estimators. The estimated coefficients of population, GDP per capita, and energy intensity were positive for all groups. While all coefficients ranged from 1.04 to 1.33, population was the most influential factor among the three independent variables for all countries. On the other hand, the share of zero-emitting energy sources is negative for Annex B non-EIT countries and Small EIT countries, but not significant for Large EIT countries. Furthermore, the coefficient for zero-emitting energy sources is lower than the coefficients for population, GDP per capita, and energy intensity. This result implies that population, GDP growth, and improving energy intensity, including a change in economic structure and energy efficiency, had mainly influenced CO_2 emissions by the end of first commitment period of the Kyoto Protocol. The coefficients for the economic crisis were negative and statistically significant for all three groups. This result represents well the fact that the economic crisis had an impact on CO_2 emissions reductions.

Table 7
STIRPAT estimations with US state-level reference emission.

	Annex B non-EIT		EIT small		EIT Large	
lnCO2						
lnPOP	1.04***	[0.32,	1.11**	[0.23,	1.33**	[0.26,
	(2.84)	1.77]		1.99]		2.4]
			(2.46)		(2.43)	
lnGC	0.78***	[0.64,	0.80***	[0.62,	1.06***	[0.88,
	(12.41)	0.92]		0.97]		1.24]
			(8.89)		(11.75)	
lnEI	0.71***	[0.6,	0.74***	[0.59,	0.88***	[0.74,
	(13.53)	0.82]		0.88]		1.03]
			(10.15)		(12.01)	
lnNF	−0.17***	[−0.23,	−0.12***	[−0.15,	−0.08	[−0.19,
	(−5.93)	−0.12]		−0.08]		0.03]
			(−6.2)		(−1.38)	
KPpre	−0.004**	[−0.01,	0.003	[−0.01,	−0.001	[0, 0]
	(−2.33)	0]		0.01]		
			(0.71)		(−0.49)	[−0.01,
						0.01]
KPimp	−0.000	[−0.01,	0.007*	[0, 0.01]	0.008	
	(−0.09)	0.01]	(1.84)		(1.08)	
Crisis	−0.04***	[−0.06,	−0.15**	[−0.21,	−0.11***	[−0.21,
	(−4.88)	−0.03]		−0.09]		−0.01]
			(−4.73)		(−2.17)	
trend	0.00	[−0.01,	0.00	[−0.01,	0.00	[−0.02,
	(−1.38)	0]		0.01]		0.01]
			(−0.06)		(−0.77)	
cons	−16.72***	[−27.9,	−17.53***	[−30.66,	−25.82***	[−44.7,
	(−2.93)	−5.55]		−4.4]		−6.95]
			(−2.62)		(−2.68)	
Obs	1196			695		368
Groups	52		31		16	
RMSE	0.0143		0.0200		0.0136	
CD	−1.18		−2.31		−1.58	
CIPS	−4.78		–		−4.74	

* Statistical significance at the 10% level.
** Statistical significance at the 5% level.
*** Statistical significance at the 1% level.

The treatment effects of the Kyoto Protocol, i.e. KPpre and KPimp, which are the most interesting coefficient in this study, had a negative impact on domestic CO_2 emissions only in Annex B non-EIT countries during the preparation period. This result implies that Annex B non-EIT countries had enough mitigation incentives by the sufficient emission cap for KP-CP1 that mitigation effort was mobilized during the preparation period. But the coefficient of the Kyoto Protocol during the commitment period for the non-EIT countries was not significant. It shows that mitigation effort for non-EIT countries during this period were weakened since it reveals a surplus of Kyoto units around this period. This result is consistent with the situation where project participants purchase Kyoto units from other entities that overachieved emission reduction targets rather than conduct emission reduction activities by themselves due to the low price of Kyoto units during the KP-CP1.

The estimated coefficient of the Kyoto Protocol during the commitment-period was positive for Small EIT countries. This result implies that the Kyoto Protocol had a perverse effect on CO_2 emission reduction for Small EIT countries. This fact is consistent with previous studies that argue that the existence of hot air resulted in a negative incentive for carrying out mitigation actions in those countries. For Large EIT countries, even though the coefficient was not statistically significant, the coefficient of the Kyoto Protocol during the commitment period was 0.008. This result provides the possibility of perverse effects in the same manner as for Small EIT countries.

4.2. Emission reduction in non-Annex B countries

Fig. 1 shows the result of the CER additionality assessment by the three criteria. HFC and N_2O projects have issued 500 Mt CO_2e and 260 Mt CO_2e respectively, the first and second largest share among all project types. CERs issued from HFC and N_2O projects strongly show additionality, since all the CERs satisfied the three criteria.

On the other hand, the amount of CERs issued from hydropower projects and wind power projects have the third and fourth share largest among all project types. But 60% of CERs from hydropower

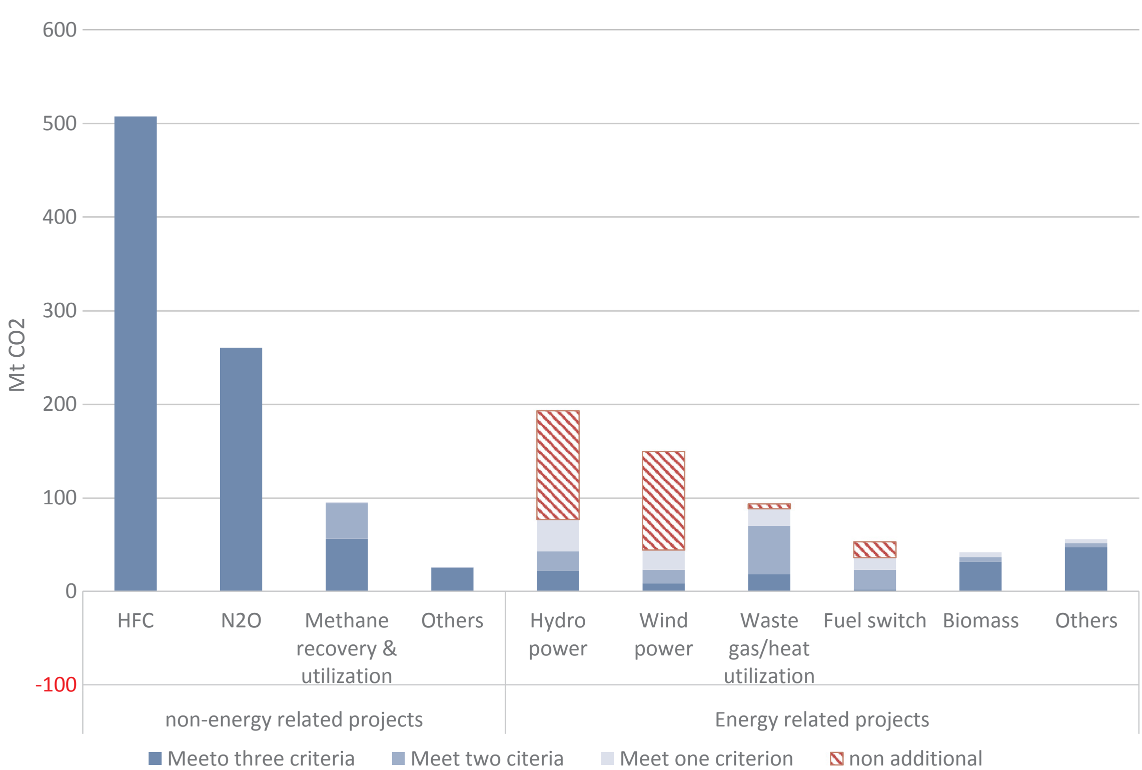

Fig. 1. The result of additionality assessment of CER by project types.

Table8
Quantified mitigation impacts by the Kyoto Protocol.

Country	Mitigation impacts
Annex B non-EIT	76 $MtCO_2e$ of mitigation effect during preparation period of the Kyoto Protocol.
Annex B small EIT	12 $MtCO_2e$ of negative (i.e. perverse) effect during the commitment period of the Kyoto Protocol.
Annex B large EIT	Neither mitigation nor perverse impact was observed. But the coefficient of mitigation effect of the Kyoto Protocol during the commitment period was negative without statistically significance.
Non-Annex B countries	246 $MtCO_2e$ of mitigation impact by CO_2 emission reduction from energy-related projects 887 $MtCO_2e$ of mitigation impact including all GHGs
Total	310 $MtCO_2e$ of mitigation impact by CO_2 emission reduction from energy-related projects 951 $MtCO_2e$ of mitigation impact including all GHGs

projects and 71% of CERs from wind power projects did not meet any additionality criteria, and were, thus assessed as "non-additional." For hydro and wind power projects, the amount of CERs that satisfy all the three additionality criteria was just 11% and 6%, respectively. Interestingly, among energy-related projects, the CERs from biomass projects and other projects, including photovoltaics (PV) and energy efficiency projects, met the three additionality criteria.

In a summary of emission reductions in non-Annex B countries, the CERs that meet the more than or equal to additionality criteria accounted for 1134 Mt CO_2e. Among those CERs, the CERs from the non-energy projects accounted for 887 Mt CO_2e, while the CERs from energy-related projects accounted for 246 Mt CO_2e. From this result, the Kyoto Protocol mobilized real emission reduction activities in Annex B countries that were mainly achieved by non-CO_2 related projects.

4.3. Summary of results

The results of the mitigation effect are summarized in Table 8. The Annex B non-EIT countries had 76 Mt CO_2e positive mitigation effects, achieved during the preparation period. On the other hand, Small EIT countries had 12 Mt CO_2e of perverse effect during the commitment period. For the non-Annex B countries, the results show that the emission reductions that satisfy one or more environmental eligibility criteria total 246 Mt CO_2e for emissions reductions from fossil fuel combustion and 887 Mt CO_2e for emission reductions including all GHGs. In the end, the net mitigation effect by the Kyoto Protocol was determined to be 951 Mt CO_2e, including non-CO_2 GHGs in non-Annex B countries, and 310 Mt CO_2e of mitigation effect, excluding non-CO_2 GHGs.

5. Conclusions

During KP-CP1, the Kyoto Mechanisms played an important role in promoting emission reduction activities for the three types of countries: Annex B non-EIT countries that have substantial emission caps, EIT countries that had a surplus of emission allowances, and non-Annex B countries without emission caps but with mitigation incentives by the mitigation mechanisms. Therefore, a review of the current emission trading scheme could further the discussion on how to promote mitigation activities globally. Indeed, Article 6 of the Paris Agreement introduces international cooperation mechanisms that promote mitigation activities outside a country. Furthermore, there are many views to enhance mitigation targets using not only bottom-up and but also top-down approaches, including emission trading systems to achieve the 2 °C targets of the agreement. This paper quantified the overall mitigation impact of the Kyoto Protocol led by Annex B countries, not only within Annex B countries, but also in non-Annex B countries through the CDM.

In this analysis, Annex B countries were divided into three groups based on the results of Kyoto units acquisition: Annex B non-EIT countries, Small EIT countries, and Large EIT countries. For the Annex B non-EIT countries, the Kyoto Protocol had 76 Mt CO_2e of a positive effect on domestic CO_2 mitigation actions during the preparation period (2005–2007) but no mitigation impact during the commitment period (2008–2012). This result is logical, since Annex B non-EIT countries were keen to reduce CO_2 emissions at the domestic boundary to avoid purchasing Kyoto units during the preparation period. However, during the commitment period, the option of purchasing Kyoto units was economically reasonable, owing to the existence of surplus emission allowances.

Regarding the Small EIT countries that had surplus emission allowance during KP-CP1, we observed 12 Mt CO_2e of perverse effects by the Kyoto Protocol during the commitment period due to the following reasons. First, due to the existence of so-called "hot air" in those countries, Small EIT countries did not have any incentive to work on mitigation actions. Second, even though some JI projects were implemented in those countries, the mitigation impact of those projects was not significant, because most of the JI projects were assessed as non-additional and had the potential to increase CO_2 emissions using higher CO_2 emission intensity fuel sources.

For the emission reduction effect in non-Annex B countries, the total mitigation effect by energy-related projects that reduced fossil fuel combustion was calculated to be 246 Mt CO_2e. When considering emission reductions by industrial gases and methane avoidance, the number increases to 887 Mt CO_2e. Considering the Kyoto Protocol's mitigation effect during KP-CP1 for all groups, we identified at least 951 Mt CO_2e of net mitigation effect, including non-CO_2 GHGs in Annex B countries, and 310 Mt CO_2e, excluding non-CO_2 GHGs.

This study has some limitations, summarized as follows. This study does not deal with identifying carbon leakage from the Annex B countries to the non-Annex B countries, as some studies, such as Aichele and Felbermayr [71] Bernard et al. [72] had previously identified. Therefore, further studies need to provide more overall assessment, including domestic contribution, carbon offset, and carbon leakage, to quantify the emission reduction impacts by the Kyoto Protocol.

The implications of this study are, first, that implementing offsetting schemes, such as baseline and credit, has great potential to promote emission reductions outside of countries with a substantial emission cap through international cooperation mechanisms. But, at the same time, we reemphasized that those mechanisms should ensure a framework to secure real emission reductions as discussed in Article 6, paragraph 4, of the Paris Agreement. Second, setting emission reduction targets by a top-down approach brings real emission reduction impacts. This result encourages the current negotiation of the Paris Agreement that request all countries to enhance their mitigation ambitions. Third, it reveals that setting appropriate emission targets is also important to facilitate emission reductions. The insufficient emission caps did not provide any mitigation incentives, thus leading to perverse effects that increased emissions.

The lessons learned from the Kyoto Protocol contribute to design a mitigation mechanism that results in net emission reduction effects, possibly by using the international framework under Article 6 of the Paris Agreement.

Appendix A

A.1. Augmented mean group model

The Augmented Mean Group (AMG) is one of heterogeneous common factors panel data models that can account for slope heterogeneity and cross-section dependence. The AMG is extracted from the year dummy coefficients of a pooled regression in first differences and represents the levels-equivalent evolution of unobserved common factors across all countries [44]. Provided the unobserved common factors from the part of the country-specific cointegrating relation [73], the augmented country regression model encompasses the cointegrating relations, which is allowed to differ across i.

Stage 1 $\Delta y_{it} = b'\Delta x_{it} + \sum_{t=2}^{T} C_t \Delta D_t + e_{it} \quad \Rightarrow \hat{c_t} \equiv \hat{\mu}_t$

Stage 1 represents a standard first difference regression with T-1 year dummies in first differences. In this paper, y_{it} represents CO_2 emissions from fossil fuel combustion and x_{it} is a vector of observable inputs including GDP per capita, energy intensity and the share of non-fossil fuel energy sources in the primary energy supply. Dt represents time dummies (starting from the second period as they are differenced). The coefficients to the time dummies, c_t, are turned into a variable shared across panel units $\hat{\mu}_t$.

Stage 2 $y_{it} = a_i + b'x_{it} + c_i t + d_i\hat{\mu}_t^{\cdot} + e_{it} \quad \hat{b}_{AMG} = N^{-1}\sum_i \hat{b}_i$

The time dummy coefficient variable included in Stage 2 approximates the unobserved common factors that are potentially driving the variables in each panel unit [74]. Also, in stage 2 $\hat{\mu}_t$is included in each of the N standard country regressions which also include a linear trend term to capture omitted idiosyncratic process evolving in a linear fashion over time [44].

A.2. Unit root test (Im-Pesaran-Shin Test)

Consider a sample of N cross sections (industries, regions or countries) observed over T time period. The Im-Pesaran-Shin (IPS) Test can be expressed as follows;

$y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \epsilon_{i,t}$

t=1,2,...,T

The null and alternative hypotheses are defined as:

$H_0: \quad \rho_i = 1 \; for \; all \; i$

Against the alternative

$H_1: \quad \rho_i < 1 for \; at \; least \; one \; i$

IPS test uses separate unit root tests for the N cross-section units. Their test is based on the Augmented Dickey-fuller (ADF) statistics averaged across groups [75]. After the estimation of the separate ADF regressions, t-statistic for testing $\rho_i = 1$ is computed.

ADF regression:

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^{p_i} \theta_{ij}\Delta y_{i,t-j} + \epsilon_{i,t}$$

Let $t_{i,T}$ (i = 1,2,…,N) denotes the t-statistic for testing unit roots in individual series I, and let E ($t_{i,T}$) = μ and V ($t_{i,T}$) = σ.

$$\bar{t}_{N,T} = \frac{1}{N}\sum_{i=1}^{N} t_{i,T} \text{ and } \sqrt{N}\frac{(\bar{t}_{N,T}-\mu)}{\sigma} \overset{N}{\Rightarrow} \text{N}(0,1)$$

The t-bar is then standardized and it is shown that the standardized t-bar statistic converges to the standard normal distribution as N and T → ∞

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