CONVERGENCE IN CARBON EMISSIONS AND CONVERGE CLUBS

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Abstract

Paris Agreement (2016) brings hundreds of countries together under an international intention to limit global warming. Currently (December 2021), 193 parties submitted their first long-term trajectories to take action against climate change known as nationally determined contributions (NDCs). The agreement does not put forward a direct action plan but rather leave it to the parties. The agreement is successful in achieving the ultimate aim of creating awareness and setting global and local barriers against emissions. The domestic policies to comply with this supranational agreement to mitigate emissions create new economic challenges hence, NDCs, i.e., emission reduction aims, and the realizations vary according to the Parties. In the light of these developments, this paper analyzes whether there is a convergence in the emissions globally, regionally and according to income levels. Empirical findings suggest convergence in per capita emissions within income groups but divergence globally and regionally except for the EU, which is at the forefront of international agreements to fight with climate change. Lastly, certain dates of international agreements do not reflect dramatic changes under treatment effect using difference-in-differences technique.

Keywords: CO2 Emissions, convergence

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1. Introduction

By 2021, hundreds of world leaders come together on behalf of their nations to share a common ideal taking action to reduce greenhouse gas emissions and to restore nature at COP-26 in Glasgow, the UK. Conference of the Parties (COP) is the ultimate authority of United Nations Framework Convention on Climate Change (UNFCCC) (hereinafter, the Convention) with the first meeting, namely as COP-1, held in Berlin by 1995. However, the first conference on the environmental issues (held by United Nations Conference on Environment in Stockholm) dates back to 1972 highlighting the growing evidence of man-made harm on the earth such as pollution in water, air, earth; disturbances to the ecological balance of the biosphere; destruction and depletion of irreplaceable resources (United Nations, 1972). First World Climate Conference (WCC-1), on the other hand, is the first conference to recognize climate change as a serious *global issue* by 1979 in Geneva, Switzerland. 20 years after this conference, the Earth Summit (The United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil in 1992) brings the representatives of 179 countries together and UNFCCC is adopted[1] currently with 197 countries to ratify to become Parties to the Convention. This is the first agreement on the environmental issues with this global scale and that specify certain goals for the all Parties however with differentiated responsibilities based on their social and economic conditions. Industrialized countries (named as Annex 1 countries) are given the highest responsibilities to take actions on climate change. Several countries (especially the EU[2]) are successfully applying policies and setting long-term targets by allocating a large share from their budget. However, the Convention can establish a more prudent system by setting the highest targets for the countries the most responsible for the climate change, which would be fitting to the differentiated responsibilities declared by UNFCCC.

COP-21 held in Paris by 2015 sets a target, under Paris Agreement currently with 193 Parties, to limit global warming below 2 degrees Celsius above pre-industrial levels and to set further limits to the temperature increase by 1.5 degrees Celsius. In the fight with climate change, reductions in the CO2 emissions come as the main global target. Paris Agreement is the first legally binding and universal treaty to achieve this aim by obliging the Parties submit their nationally determined contributions (NDCs). Some countries have not ratified yet or late-ratified[3] with complaints over the economic burden the climate targets carry. On the other hand, developed countries are economically more eligible to pursue higher concerns over environmental and social issues in line with environmental Kuznets curve (EKC). Accordingly, the EU countries implement further environmental policies under energy and climate change objectives such as Energy 2020 strategy for competitive, sustainable and secure energy (COM/2010/0639[4]) or 2030 Climate Target Plan (COM/2020/562[5]). Setting high targets for countries with different development levels may lower motivation and interest to fight with climate change. Hence, NDCs by Paris Agreement are reasonable as countries do set their own

[1] UNFCCC is adopted in New York by 1992 and is put into force by 1994.
[2] The EU agreed to allocate a minimum 20% share of EU budget on climate action for 2014-2020 budget and proposed a minimum 25% for the 2021-2027 budget (European Commission Climate Action, 2021). Retrieved from https://ec.europa.eu/clima/eu-action/funding-climate-action/supporting-climate-action-through-eu-budget_en, Accessed by 5.11.2021.
[3] Only Eritrea, Libya, Yemen and Iran (last three are Middle Eastern countries) have signed but not ratified. Iraq, Turkey, South Sudan ratified and the US accepted Paris Agreement within the year 2021. Retrieved from https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en, Accessed by 25.12.2021.
[4] https://ec.europa.eu/energy/topics/renewable-energy/directive-targets-and-rules/renewable-energy-targets_en#2020-targets, Accessed by 25.12.2021.
[5] https://ec.europa.eu/clima/eu-action/european-green-deal/2030-climate-target-plan_en, Accessed by 25.12.2021.

targets according to their individual economic conditions. Most of the countries[6] ratified to Paris Agreement by 2016. Therefore, CO2 emissions can be examined whether countries achieve mitigation.

In this study, we scrutinize the existence of global convergence of CO2 emissions in several aspects such as income, regional. There are several methodologies to analyze convergence such as cointegration, unit root testing which are prone to result in false negative regarding the existence of convergence due to their limitations in detecting asymptotic co-movement between the series. Regression analysis may suffer from omitted variable or endogeneity problems that are hard to tackle with. We employ Phillips and Sul (2007, 2009) test, which overcome these limitations and do not require any control for integration order of the variables. It is a sigma convergence test, which examines whether variance declines over time. Phillips and Sul (2007, 2009) also identifies convergence clubs endogenously using clustering algorithm. There are several studies employing convergence methodology for the per capita CO2 emissions (Panopoulou and Pantelidis, 2009; Robalino-López et al., 2016; Payne and Apergis, 2021). This study contributes to the literature in terms of having: (i) the largest dataset in terms of the number of countries; (ii) analyzing convergence in an extensive way by taking income, regional groups and specific periods into account; (iii) the recent dataset that is crucial to examine the period after Kyoto commitments and Paris agreement and whether these dates are causing any significant changes for the committed countries (Annex 1 or Annex B). In a nutshell, empirical findings suggest that regarding per capita emissions, countries converge within their income groups and international environmental agreements do not reflect a dramatic role in the per capita emissions.

The structure of the paper is as follows. Section 2 provides the empirical literature in details under a table. Section 3 describes the econometric methodology. Section 4 describes the dataset and presents the empirical findings. Last section concludes the paper.

2. Literature

There is an enormous literature on the CO2 emissions convergence such that there are also several papers on the literature survey on the topic (Payne, 2020; Pettersson et al., 2014). In a similar pattern, below table summarizes the revised empirical literature by expressing the dataset, the econometric technique and the key findings. The literature reflects mixed empirical findings depending on the econometric methodology, the country group and the time horizon utilized. However, the literature seems to be consistent in the importance of division of the dataset with respect to income and/or regional dimension.

Table 1: Empirical Literature

Authors	Sample Period	Sample Group	Variable(s)	Method	Key Finding
Aldy (2006)	1960-2000	23 OECD countries, 88 non-OECD countries	Log of per capita CO2 emissions	Unit root testing	Convergence for OECD, divergence for the rest
Kounetas (2018)	1970-2010	23 European countries	CO2 emission per GDP and several additional variables	σ and β convergence and stochastic Kernel distribution	No convergence

[6] Out of 193 ratified countries, 120 countries have ratified within 2016, 51 countries within 2017, 12 countries within 2018. Only 10 countries ratify after 2018.

Tiwari and Mishra (2017)	1972-2010	18 Asian countries	Log of CO2 emissions per capita	σ and β convergence and stochastic Kernel distribution	convergence
Lin et al. (2018)	1950-2013	G18 countries	CO2 emissions per capita	Unit root testing	No convergence
Panopoulou and Pantelidis (2009)	1960-2003	128 countries	Log of CO2 emissions per capita and per GDP	Phillips and Sul (2007) convergence methodology	Convergence clubs according to income and region
Robalino-López et al. (2016)	1980-2010	10 South American countries	CO2 emissions per capita and Kaya components[7]	Phillips and Sul (2007) convergence methodology	Convergence clubs
Westerlund and Basher (2008)	1870-2002	16 developed and 12 developing countries	Log of CO2 emissions per capita	Unit root testing	convergence
Ezcurra (2007)	1960-1999	87 countries	Spatial distribution per capita CO2 emissions	Non-parametric approach	Convergence for industrialized countries
Romero-Ávila (2008)	1960-2002	23 OECD countries	Log of per capita CO2 emissions	Unit root testing	Convergence
Li and Lin (2013)	1971-2008	110 countries	per capita CO2 emissions	β convergence controlling for GDP per capita under GMM methodology	Convergence according to income levels
Jobert et al. (2010)	1971-2006	22 European countries	per capita CO2 emissions	Absolute and conditional convergence under Bayesian shrinkage estimation	Convergence controlling for income
Criado and Grether (2011)	1960-2002	166 countries	CO2 emissions in total, per capita and relative	Non-parametric approach	Mixed results depending on the form of data and groups of income, geography and politics
Churchill et al. (2018)	1900-2014	44 developed countries	Log of relative per capita CO2 emissions	Unit root testing	Stochastic convergence
Barassi et al. (2008)	1950-2002	21 OECD countries	Log of per capita CO2 emissions	Unit root testing	No convergence
Rios and Gianmoena (2018)	1970-2014	141 countries	Log of per capita CO2 emissions	Non-parametric approach	Lowest and the highest polluters converge
Payne and Apergis (2021)	1972-2014	65 developing countries	Per capita CO2 emissions	Unit root testing under income groups and Phillips and Sul (2007) convergence methodology	Stochastic convergence and club convergence within each country group
Churchill et al. (2020)	1921-2014	17 emerging markets	Log of relative per capita CO2 emissions	Unit root testing	Mixed evidence for stochastic convergence
Herrerias (2013)	1980-2009	162 countries	Log of per capita CO2 emissions	Unit root testing and Phillips and Sul (2007) convergence methodology	Divergence overall but convergence within groups
Bhattacharya et al. (2020)	1990-2014	70 countries	CO2 emissions per GDP and several control variables	Phillips and Sul (2007) convergence methodology	Club convergence
Matsuki and Pan (2021)	1907-2011	7 Asian countries	Log of per capita CO2 emissions	Unit root testing	Convergence to the US
El-Montasser et al. (2015)	1990-2011	G7 countries	Log of per capita GHG emissions	Unit root testing	Convergence
Lee and Chang (2009)	1950-2002	21 OECD countries	Relative per capita CO2 emissions	Unit root testing	Convergence

[7] According to Kaya identity, CO2 per capita is decomposed into GDP per capita, energy intensity and CO2 intensity.

Presno et al. (2018)	1902-2002	28 OECD countries	Absolute and relative per capita CO2 emissions	Unit root testing and β convergence	Convergence
Yavuz and Yilanci (2013)	1960-2005	G7 countries	per capita CO2 emissions	Unit root testing	Conditional convergence
Solarin (2019)	1961-2003	27 OECD countries	Log of per capita CO2 emissions and carbon&ecological footprint	Unit root testing and σ and β convergence	conditional convergence for several countries
Lee and Chang (2008)	1960-2000	21 OECD countries	Relative per capita CO2 emissions	Unit root testing	Divergence
Acaravci and Erdogan (2016)	1960-2011	seven regions	per capita CO2 emissions	Unit root testing	Stochastic convergence
Nazlioglu et al. (2021)	1960-2016	13 OPEC and 18 non OPEC countries	Log of per capita CO2 emissions	Unit root testing	Absence of convergence
Magazzino (2019)	1960-2013	19 MENA countries	Relative per capita CO2 emissions	Unit root testing	Mixed results
Barassi et al. (2011)	1870-2004	18 OECD countries	per capita CO2 emissions	Unit root testing	Convergence except for highest polluters
Apergis et al. (2020)	1971-2014	6 Central American countries	CO2 emissions intensity, energy intensity and carbonization index	Phillips and Sul (2007) convergence methodology	Convergence clubs
Ahmed et al. (2017)	1960-2010	162 countries	per capita CO2 emissions	Wavelet based unit root testing	divergence
Camarero et al. (2013)	1960-2008	23 OECD countries	CO2 emissions intensity	Phillips and Sul (2007) convergence methodology	Convergence clubs
Apergis and Payne (2020)	1971-2014	NAFTA countries	CO2 emissions intensity energy intensity and carbonization index	Unit root testing	convergence
Runar et al. (2017)	1985-2010	124 countries	CO2 emissions per capita and several control variables	Non-parametric approach	β convergence
Acar and Lindmark (2017)	1973-2010	28 OECD countries	CO2 emissions per capita	β convergence	Mixed results depending on the period and the sources of emission

3. Methodology

3.1. Phillips and Sul (2007) convergence analysis

In the case of panel data where *i* denotes the cross sectional unit and *t* denotes the time unit, we can decompose X_{it} as the time-varying common component across cross sectional units (μ_t) and the time-varying transition parameter (δ_{it}). Hence, $X_{it} = \delta_{it} + \mu_t$

The common component (μ_t) can be removed by scaling to obtain relative transition parameter (h_{it}) which measures the individual trajectory of *i* relative to the average at time *t* (deviation from the common component), i.e., relative transition path:

$$h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}}$$

Under the assumption that cross sectional average of transition parameter and its limit to infinity is different from zero, cross sectional average of h_{it} is unity by definition; and h_{it} converge to unity if δ_{it} converge to δ for all *i*. Hence, cross sectional variance of h_{it}, which is symbolized as H_t, converges to zero in the long run.

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2$$

Phillips and Sul (2007) use a semiparametric model for the transition coefficients that allows for heterogeneity over *t* and *i* as

$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha}$, where $t \geq 1$, $\sigma_i > 0$ for all *I*

where δ_i is fixed, ξ_{it} is iid(0,1) across *i* but may be weakly dependent over *t*, $L(t)$ is a slowly varying function[8], i.e., log t , for which $L(t) \to \infty$ as $t \to \infty$. α is the decay rate for the cross section variation. With this formulation, δ_{it} converges to δ_i for all $\alpha \geq 0$, which is the null hypothesis of convergence against the alternative hypothesis of divergence

H_0: $\delta_i = \delta$ and $\alpha \geq 0$

H_1: $\{\delta_i = \delta$ for all i and $\alpha < 0\}$ OR $\{\delta_i \neq \delta$ for some i with $\alpha \geq 0$ or $\alpha < 0\}$

In other words, there exists relative convergence (not absolute convergence) when $H_{it} \to 0$ as $t \to \infty$ which is tested running the following log *t* regression,

$log\left(\frac{H_1}{H_t}\right) - 2logL(t) = a + blogt + u$, for $t = T_0, \ldots, T$

Phillips and Sul (2007) recommends starting the regression with the initial observation $T_0 = [rT]$ for some $r > 0$, where the first *r* % of the data is trimmed[9]. $L(t) = log(t)$, $b = 2\alpha$, where b is the speed of convergence parameter of δ_{it} and α is the rate at which the cross-section variation over the transitions decays to zero over time. The convergence test is one-sided with standard normal critical value, which is -1.65 for 5% significance level, i.e., $\widehat{t_b} < -1.65$.

If $b \geq 2$, i.e., $\alpha \geq 1$, and the common component, μ_t , is random walk, then b implies convergence in level form of the data; if $2 > b \geq 0$, then the speed of convergence corresponds to conditional convergence, growth rates of the data converge over time.

3.2. DID methodology

Difference-in-differences (DID) is a methodology proposed by Card and Krueger (1994) to examine the effect of treatment over time considering the control group. In the case of a treatment to a specific group, the change over time in the treatment group can only be measured after filtering the change over time without the treatment and the change over time attributable to factors other than the treatment. Hence, DID compares the changes over time in treatment and control outcomes.

$$Y_{igt} = \alpha_g + \theta_t + B_1 G + B_2 t + B_3 G t + U_{igt} + \varepsilon_{igt}$$

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[8] $L(t)$ can be $\log(t)$, $log^2(t)$, $log\{\log(t)\}$. Phillips and Sul (2007) reflects that the prior function has the best test under Monte Carlo simulations.

[9] According to Phillips and Sul (2007), r = 30% is recommended for small sample case, where T≤50.

where Y_{igt} is the outcome for the cross sectional unit i at time t in the group g (treatment or control group); α_g and θ_t are fixed effects for group level and period, successively; G and t are the indicator variables for treatment or control groups (equals to 1 if treatment, 0 if control group) and for baseline and endline measurements (equals to 1 if endline, 0 if baseline over the time period); U_{igt} is the factors that vary over time and across groups; ε_{igt} is the error term. To measure DID impact, the following difference in differences is constructed:

$$(Y_{i11} - Y_{i10}) - (Y_{i01} - Y_{i00}) = B_3 + (U_{i11} - U_{i10}) - (U_{i01} - U_{i00}) + (\varepsilon_{i11} - \varepsilon_{i10}) - (\varepsilon_{i01} - \varepsilon_{i00})$$

$$ATE = B_3 + U^* + \varepsilon^*$$

If we assume that the error term is equal to zero, i.e., $E(\varepsilon^*) = 0$, and the time variant difference over time in the treatment and control group are equal, i.e., $E(U^*) = 0$, then B_3 becomes the average treatment effect on the treated (ATET) or DID effect. ATET is estimated by fitting a linear model with time and panel fixed effects. The treatment time is the endline, which is the start date when the new procedure is implemented.

4. Data and Empirical Findings

4.1. Dataset

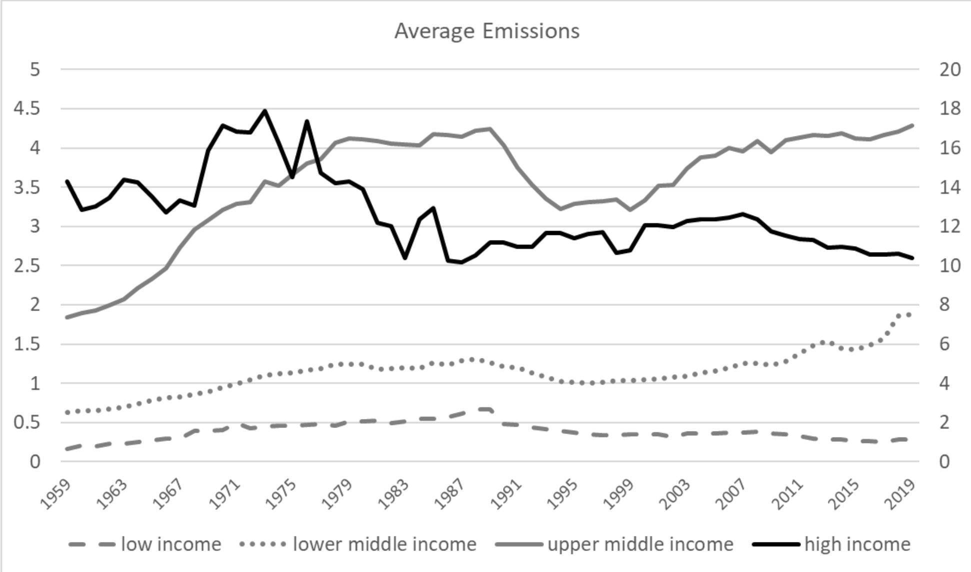
This study covers all countries with CO2 emissions data available over the time horizon 1959-2019. Per capita fossil CO2 emissions (tonnes of CO2 per capita) dataset is obtained from Global Carbon Budget 2020 (Friedlingstein et al., 2020). The data includes emission from coal, oil, gas, cement, flaring and others for 185 countries. Besides the inspection over the whole countries, the study constructs subgroups according to income groups (using 2020 GNI) and regions defined by World Bank. Moreover, Annex I and B countries[10] are scrutinized as the industrialized countries with the highest responsibility by Kyoto or Paris agreements. Crucial subperiods are also examined such as agreement or ratification years. The CO2 per capita data is employed in levels form rather than in logarithmic version not to lose the fluctuation of the original dataset since smoothing the dataset may falsely result in convergence result.

4.2. Findings

Figure 1 and 2 reflect the arithmetic average and the standard deviation of per capita emissions according to income groups, successively. It is observed that the higher the income level, the higher both average and volatility of emissions. For low income countries, both average and volatility is declining after late 1980s; for lower middle income countries, both are increasing in the recent years; for upper middle income countries, both are increasing in the last 20 years; whereas for high income countries, over time, both are decreasing from enormously high numbers. Moreover, international crisis periods reflect their impact on emissions such as East Asian crisis of 1997-2001, Russian crisis of 1992-1997, Latin American crisis of 1994-2002, global financial crisis of 2008-2009.

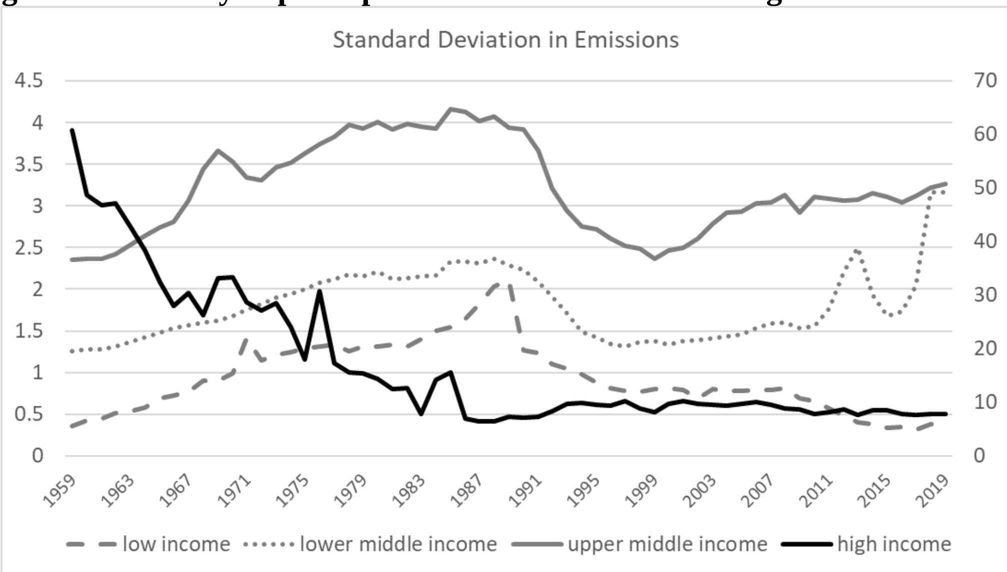
[10] Details are given in the Appendix.

Figure 1: Average per capita CO2 Emissions According to Income Groups



Note: Per capita CO2 emissions are calculated for 59 high income, 48 upper middle income, 48 lower middle income, 26 low income countries according to World Bank (2020) GNI specifications. Bonaire, Saint Eustatius and Saba, Saint Pierre and Miquelon, Taiwan and Venezuela is not clustered according to income by World Bank (2020). High income is depicted on the right-hand-side axis.

Figure 2: Volatility of per capita CO2 Emissions According to Income Groups



Note: Same notes as in Figure 1.

Table 2 shows the top 10 polluters in total CO2 emissions and in per capita terms. Two of the greatest polluters, China and India, does not take place in the per capita terms list due to their high population. However, the US takes place in both lists as one of the major responsibles of climate change. There two developed countries in the per capita list, namely as Australia and Luxembourg. There are two Asian countries in the per capita list, name as Mongolia and Kazakhstan with very low population compared to their lands. Finally, half of the top ten per capita emissions list are from Middle East countries, namely as Qatar, Kuwait, Bahrain, United Arab Emirates and Saudi Arabia, all of which are either OPEC or OPEC plus[11] countries. This

[11] Non-OPEC countries that export crude oil are referred as OPEC plus countries such as Bahrain in the top 10 per capita emissions list.

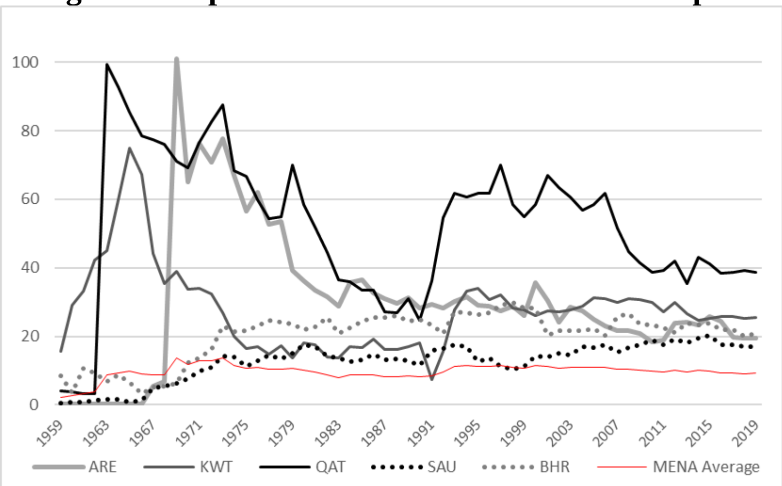
list reflects that a specific attention must be paid for Middle Eastern countries under the CO2 emissions and environmental issues topic. Time series figure of the recent greatest per capita Middle Eastern emitters (Figure 3) reflects that they are performing way above the MENA average with Qatar standing out as the highest per capita emitter globally. Moreover, except for Qatar, none of the top Middle Eastern polluters depicts a decline over time, which may suggest a call for environmental awareness by oil exporting countries.

Table 2: Top 10 Polluters in Total and in Per Capita in 2019

Country	Total CO2 Emissions	Country	Per capita CO2 Emissions
China	10174.68	Qatar	38.61
USA	5284.70	Kuwait	25.56
India	2616.45	Bahrain	20.93
Russia	1678.37	Mongolia	20.31
Japan	1106.66	United Arab Emirates	19.52
Iran	779.53	Saudi Arabia	16.99
Germany	701.96	Kazakhstan	16.92
Indonesia	617.51	Australia	16.31
South Korea	611.26	USA	16.06
Saudi Arabia	582.15	Luxembourg	15.89

Note: Countries with total emissions less than 1 million tonnes are excluded from the per capita emissions list.

Figure 3: Top 5 Middle East Polluters in Per Capita



Tables from 3 to 6 report the estimations for conditional convergence analysis for the overall countries, Annex 1 or B countries, subgroups according to income and region, successively. Empirical findings suggest that for overall countries, given in Table 3, there is divergence in the overall period or subperiods of Kyoto Protocol, Kyoto first commitment and adoption of Paris Agreement. As Annex I or B countries are referred as the major responsibles for the past and current emissions, they are also examined for convergence for the full period and subperiods of Kyoto Protocol, Kyoto first commitment all of which reflect divergence, given in Table 4. Findings are also in line with the graphical inspection in Figures 1 and 2 since income groups have distinct paths over the time horizon. For Annex categories, convergence clubs are reported, an algorithm proposed by Phillips and Sul (2007), which aims to detect country groups with similar convergence speeds to the average. Figure A1.1, in the Appendix, plots the relative transition paths of the three convergence clubs within Annex 1 countries after

Kyoto Protocol. The first club does not converge but reflect phase B characteristics, referring to a transitional divergence and turn around. The second and the third clubs converge and the prior one with a high speed[12]. In the second club, Turkey and Lithuania are converging from below with a rise in the relative emissions over time.

Table 3: Overall countries

	$\hat{b}$ (s.e.)	t-stat	Result
Overall and full period T: 1959-2019 N: 185	-0.0606 (0.1366)	-0.4437	Phase B characteristics
Overall after Kyoto T: 1998-2019 N: 185	-0.5541* (0.0313)	-17.721	No convergence
Overall after Kyoto 2008 commitment T: 2008-2019 N: 185	-0.9053* (0.0604)	-14.9940	No convergence
Overall after Paris adopted T: 2016-2019 N: 185	-2.0461* (0.1290)	-15.8657	No convergence

Note:. The term $\hat{b}$ is the coefficient of logt; moreover, t-stat is one-sided t-test with a critical value of −1.65.

Table 4: Annex 1 and B countries

		$\hat{b}$ (s.e.)	t-stat	Result
Annex 1 and full period T: 1959-2019 N: 40		-0.2064* (0.0349)	-5.9079	No convergence
Club1 N=24	AUS, USA, LUX, CAN, RUS, EST, ISL, NLD, JPN, BEL, NOR, AUT, NZL, IRL, FIN, SVN, GRC, CYP, ITA, ESP, TUR, PRT, HRV, MLT	0.4527 (0.0877)	5.159	Conditional convergence
Club2 N=8	CZE, POL, DEU, BGR, DNK, GBR, FRA, CHE	-0.0571 (0.1445)	-0.395	Phase B characteristics
Club3 N=8	BLR, SVK, UKR, HUN, LTU, LVA, SWE, ROU	-0.3149 (0.2612)	-1.206	Phase B characteristics
Annex 1 after Kyoto T: 1998-2019 N: 40		-0.7245* (0.0382)	-18.964	No convergence
Club 1 N=14	AUS, USA, LUX, CAN, RUS, EST, ISL, CZE, NLD, JPN, POL, DEU, NOR, BLR	-0.0596 (0.0493)	-1.2085	Phase B characteristics
Club 2 N=10	BEL, AUT, NZL, IRL, FIN, SVN, SVK, BGR, LTU, TUR	0.5511 (0.1042)	5.2897	Conditional convergence
Club 3 N=16	GRC, CYP, ITA, DNK, GBR, ESP, UKR, HUN, FRA, PRT, CHE, LVA, HRV, SWE, ROU, MLT	0.1039 (0.1261)	0.8236	Conditional convergence
Annex B after Kyoto 2008 commitment [a] T: 2008-2019 N: 34		-0.8076* (0.0477)	-16.9266	No convergence
Club 1 N=2	AUS, LUX	1.6225 (1.3613)	1.1919	Conditional convergence
Club 2 N=10	EST, RUS	-0.0508 (1.0902)	-0.0466	Phase B characteristics
Club 3 N=16	CZE, NLD, POL	0.8313 (0.4478)	1.8563	Conditional convergence
Club 4 N=14	AUT, BEL, DEU, IRL, JPN	0.3555 (0.2720)	1.3071	Conditional convergence
Club 5 N=10	BGR, FIN, HUN, NOR, NZL, SVK	0.0428 (0.1863)	0.2296	Conditional convergence
Club 6 N=16	ESP, GRC, LTU, LVA, PRT, SVN	0.2935 (0.1477)	1.9875	Conditional convergence

[12] As observed in Table 4, the convergence rate is 0.55.

Club 7 N=14	DNK, FRA, GBR, HRV, ITA, ROU	0.2490 (0.1869)	1.3323	Conditional convergence
Club 8 N=10	CHE, SWE, UKR	0.4084 (0.7444)	0.5486	Conditional convergence

Note: ([a]) ISL is non-convergent.

Investigating the convergence analysis according to income levels, on the other hand, reflects existence of conditional convergence for all country groups, given in Table 5. $\hat{b}$ is not statistically significant from zero for high, middle (upper middle plus lower middle) and lower middle income countries which suggests slow convergence. Upper middle and low income countries reflect significant $\hat{b}$ suggesting high speed of convergence. In other words, over time, per capita emissions of countries with similar income levels approach to each other with upper middle and low income countries converging each other faster compared to high and lower middle income countries. Last but not least, G20 and OECD countries are examined which do not reflect convergence. Table 6 reports convergence analysis according to regional groups. Except for EU, Sub-Saharan Africa and Latin America & Caribbean country groups, convergence is not detected for any of the regional groups. Out of the three regional groups, it is only the EU country group that reflects significant $\hat{b}$ suggesting high speed of convergence. This finding is no surprise considering the European Commission's additional environmental policies such as target for renewable energy resources (for the year 2030, a minimum target of 32% share for renewable energy)[13], circular economy and waste and recycling policies under European Green Deal[14].

Table 5: Country Groups According to Income Level

Full period (T: 1959-2019)		$\hat{b}$ **(s.e.)**	**t-stat**	**Result**
High-income N: 59		0.0144 (0.2169)	0.0666	Conditional convergence
Middle income N: 96		0.0164 (0.0534)	0.3068	Conditional convergence
Upper middle income N: 48		0.0908 (0.050)	1.834	Conditional convergence
Lower middle income N: 48		0.1426 (0.1641)	0.869	Conditional convergence
Low income N: 26		0.7183 (0.1730)	4.1519	Conditional convergence
G20 N: 19[$]		-0.1168* (0.0501)	-2.3308	No convergence
Club 1 N=18	SAU, AUS, USA, CAN, KOR, RUS, JPN, DEU, ZAF, CHN, ITA, GBR, TUR, ARG, MEX, IDN, BRA, IND (FRA divergence)	-0.0284 (0.0595)	-0.4766	Phase B characteristics
OECD countries N: 38		-0.004 (0.045)	-0.0821	Phase B characteristics

Note: [$] The EU is omitted as it is a country group.

[13] https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy-framework_en, Accessed by 24.12.2021.
[14] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, Accessed by 24.12.2021.

Table 6: Country Groups According to Regions

Full period (T: 1959-2019)		$\hat{b}$ (s.e.)	t-stat	Result
MENA N: 19		-0.146 (0.1153)	-1.266	Phase B characteristics
OPEC N: 14		-0.175 (0.151)	-1.158	Phase B characteristics
EU N: 27		0.148 (0.072)	2.0471	Conditional convergence
South Asia N: 6		-0.5870* (0.0977)	-6.0104	No convergence
Club 1 N=2	IND, LKA	-0.3434 (0.4073)	-0.8433	Phase B characteristics
Club 2 N=4	PAK, BGD, NPL, AFG	0.0997 (0.204)	0.4888	Conditional convergence
Europe & Central Asia N: 50		-0.5788* (0.0909)	-6.3710	No convergence
Club 1 N=32	KAZ, LUX, FRO, TKM, RUS, EST, ISL, CZE, GRL, NLD, BEL, POL, DEU, BIH, NOR, AUT, IRL, FIN, SVN, GRC, SRB, CYP, ITA, DNK, GBR, ESP, FRA, TUR, PRT, CHE, HRV, MNE	0.3933 (0.1045)	3.7637	Conditional convergence
Club 2 N=8	BLR, SVK, BGR, UKR, HUN, SWE, MKD, UZB	0.0803 (0.1628)	0.4934	Conditional convergence
Club 3 N=4	LTU, LVA, AZE, ROU	0.0008 (0.3761)	0.0022	Conditional convergence
Club 4 N=6	GEO, ARM, ALB, KGZ, MDA, TJK	-0.3011 (0.3135)	-0.9606	Phase B characteristics
East Asia & Pacific N: 26		-0.0557 (0.0984)	-0.5654	Phase B characteristics
Sub-Saharan Africa N: 43		0.0068 (0.1387)	0.0493	Conditional convergence
Latin America & Caribbean N: 35		0.0424 (0.3176)	0.1336	Conditional convergence

Besides convergence, this study examines whether there are significant changes after Kyoto Protocol (ratification and commitment) and Paris Agreement for the most responsible countries. To apply this, DID methodology is applied to examine whether Annex I (or Annex B) countries significantly reduce their emissions effective by the ratification or commitment year, given in Table 7. Compared to the analyses for Annex 1, analysis on Annex B is more plausible as Kyoto Protocol sets binding emission reduction targets[15] for 38 countries and the EU in its Annex B classification, which does not set targets for Belarus, Cyprus, Malta and Turkey[16]. Hence, the starting year of the first commitment to Kyoto Protocol (2008-2012 period is the first commitment and 2013-2020 period is the second commitment period) is determined as the endline in the treatment effect analysis. We observe that the treatment has negative but not significant effect for all cases with t-statistics less than the critical values. As depicted in Figure 4, the treatment groups lower their emissions following the treatment year (2008 for the upper graphs, 2016 for the lower graphs). However, parallel-trends tests reported in the footnote of Table 7 reflect that we fail to reject that prior to the treatment time, the linear trends of Annex (treatment) and non-Annex (control) are parallel. In fact, Figure 4 reflect that carbon emissions gap between Annex and non-Annex are widening especially after 1970s and closing during 2000s. Put it differently, the countries argued to be the most responsible from carbon emissions (classified as Annex I or Annex B) lower their emissions following the agreements however, the dates do not significantly stand out as a treatment date.

[15] UNFCCC Kyoto Protocol (1997). Retrieved from https://unfccc.int/sites/default/files/resource/docs/cop3/l07a01.pdf#page=24 , Accessed by 28.11.2021.

[16] These 4 countries take place in Annex 1 classification.

Table 7: DID methodology

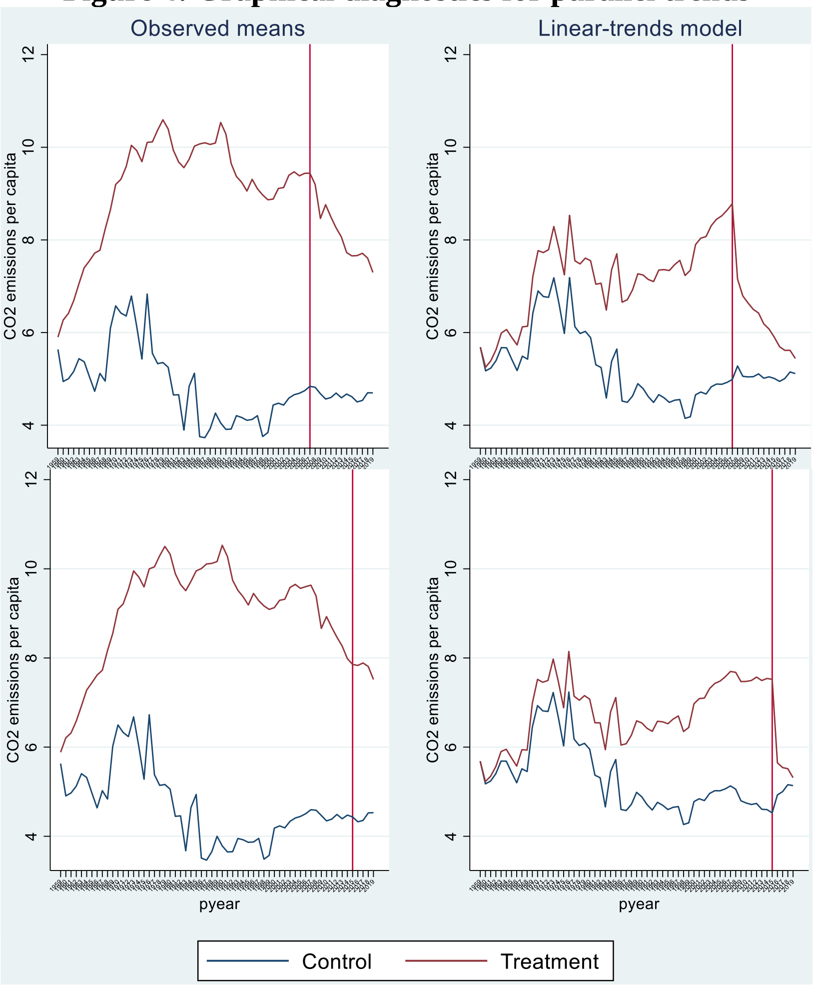
Treatment group	Treatment time	ATET	No of units in both groups	Coefficient (st.err.)	t-stat	No. of obs.
Kyoto ratification years for Annex I*	Treatment time varies according to the ratification year	(DID) (1 vs 0)	Control = 147 Treatment = 38	-0.0873 (0.8827)	-0.10	11,285
Kyoto 2008 commitment for Annex B**[17]	2008 is the treatment time	(DID2008) (1 vs 0)	Control = 151 Treatment = 34	-0.7963 (0.8163)	-0.98	11,285
Paris Agreement for Annex 1 countries	2016 is the treatment time	(DID2016) (1 vs 0)	Control = 145 Treatment = 40	-1.049 (0.7414)	-1.41	11,285

Note 1: ATET estimate adjusted for panel effects and time effects. xtdidregress command is used via STATA 17. Critical value is ∓1.645 at 10% significance level. (*) There are 42 countries and the EU in Annex I. However, the US and Canada have not ratified and Monaco and Liechtenstein are excluded due to lack of data. Hence, 38 countries take treatment at varying periods according to their ratification dates.

(**) There are 38 countries and the European Community in Annex B of 1997 Kyoto Protocol document, the US never ratified and Canada withdrew by 2011. Moreover, Monaco and Liechtenstein are excluded due to lack of data. Hence, 34 countries take treatment. Standard errors are robust error terms.

Note 2: For Annex B and Annex 1 after Paris, parallel-trends test (pretreatment time period) is applied under the null hypothesis that the linear trends are parallel prior to the treatment. The F-test statistics are obtained as $F(1, 184) = 2.12$ and $F(1, 184) = 1.41$ with p-values, 0.1469 and 0.2364, successively.

Figure 4: Graphical diagnostics for parallel trends



Note: Upper figures belong to Annex B countries after Kyoto 2008 commitment, lower figures belong to Annex 1 countries after Paris Agreement 2016.

[17] In order to ensure the validity of DID models, parallel trend assumption should hold. The null hypothesis of parallel trends test assumes that the control and treatment group have parallel trends before the treatment, i.e., the difference between control and treatment group is constant overtime in the absence of treatment.

5. Conclusion

This study analyzes the emissions convergence at the overall level and by time and cross sectional clusters to control for the importance of time, income and regional specifications. The results reflect divergence in the global manner controlling for subperiods, which is consistent with environmental Kuznets curve (EKC). Moreover, subgroup of Annex I or B countries are also found to have no convergence regarding CO2 emissions. Subgroups are utilized to examine whether emissions converge within income and/or regional dimensions. It is observed that emissions converge inside each income group but regional aspect is found to be irrelevant regarding the convergence of emissions except for the EU, which converges with a high rate. This finding is consistent with the active environmental policies within EU, as the region at the forefront of international agreements on climate change. Lastly, Kyoto ratification, commitment and Paris agreement dates are investigated for a structural change under DID methodology. None of the dates suggest a treatment effect for the per capita emissions for the major responsible countries (Annex).

There are several studies highlighting that decline in emissions does not necessarily hamper economic growth (or negligible effects) under general equilibrium models (Roberts et al., 2018; Victor, 2012) or empirical analysis (Piłatowska et al, 2018; Hubacek et al., 2021; Shan et al. 2021) generally for developed countries. On the other hand, analysis for developing countries or oil-exporting countries do not prove absolute decoupling of economic growth and climate mitigation (Hilmi et al, 2018; Tenaw and Hawitibo, 2021) in line EKC. It is apparent that governments will not voluntarily reduce their emissions below a certain level that may shrink growth rate and labor market. Hence, international agreements are of utmost importance to determine specific threshold emission levels for each country conditional on their income or any another macro indicator such as cumulative pollution levels over time. The reference to the main responsible countries in Kyoto Protocol regarding the highest commitment is highly reasonable. However, withdrawal of Canada and no ratification by the US as Annex B countries during Kyoto commitments reflect that these agreements must be fully legally binding with no political escape.

The literature on sustainable development, degrowth, green growth, circular economy is extending considering the unambiguous environmental disasters. Considering the emphasis of growth in the mainstream theory and even the inclusion of income level (hence growth rate) in HDI (human development indicator) calculation, degrowth seems to be standing out as a marginal position arguing the redundancy of economic growth as a necessary condition for well-being (Latouche, 2009). At this point, technical limits of economic growth and hence degrowth should be reconsidered as an opposition to the mainstream theories especially for the developed countries. Investment of renewable energy and nuclear energy are also discussed as remedies for climate change (Saidi and Omri, 2020; Abbasi et al, 2021; Li and Haneklaus, 2021; Wolde-Rufael and Mulat-Weldemeskel, 2021; Khezri et al, 2022). However, considering the continuous rise in the global temperatures, it is unambiguous that current policies that countries determine their determined levels for climate action are not sufficient, hence, radical policies should be implemented with the developed countries taking place as the pioneer players in the international agreement with no escape route.

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Appendix 1: Analysis on Annex countries

Figure A1.1: Relative Transition Paths for Annex 1 after Kyoto Protocol

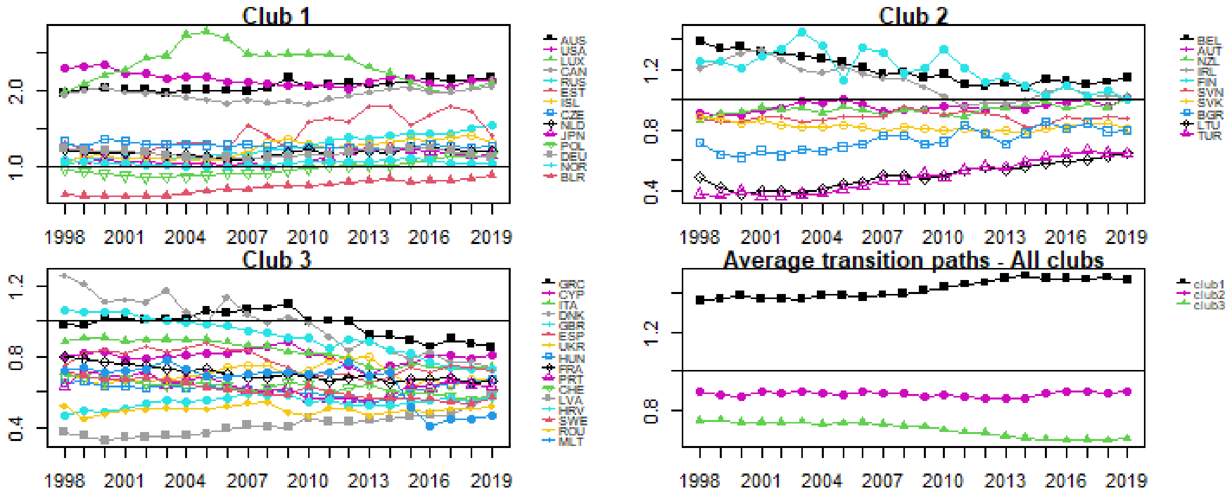

Table A1.2: Descriptive Statistics on Annex I and Annex B countries

Countries	CODES	Kyoto signed	Kyoto ratified	Mean co2	Stdev co2	gdppc	income status	Annex B
Australia	AUS	29-Apr-98	12-Dec-07	18.01	0.96	58,923	H	+
Austria	AUT	29-Apr-98	31-May-02	8.37	0.66	46,718	H	+
Belgium	BEL	29-Apr-98	31-May-02	10.66	1.55	42,888	H	+
Bulgaria	BGR	18-Sep-98	15-Aug-02	6.43	0.46	8,340	UM	+
Belarus	BLR		26-Aug-05	6.30	0.45	6,266	UM	
Canada	CAN	-	-	16.12	2.07	44,958	H	+
Switzerland	CHE	16-Mar-98	9-Jul-03	5.56	0.69	88,413	H	+
Cyprus	CYP		16-Jul-99	7.05	0.75	32,517	H	
Czechia	CZE	23-Nov-98	15-Nov-01	11.26	1.11	20,202	H	+
Germany	DEU	29-Apr-98	31-May-02	10.35	0.77	43,312	H	+
Denmark	DNK	29-Apr-98	31-May-02	8.87	2.08	57,553	H	+
Spain	ESP	29-Apr-98	31-May-02	6.77	1.05	28,091	H	+
Estonia	EST	3-Dec-98	14-Oct-02	12.66	1.36	20,400	H	+
Finland	FIN	29-Apr-98	31-May-02	10.71	1.86	46,173	H	+
France	FRA	29-Apr-98	31-May-02	6.25	0.80	38,897	H	+
The UK	GBR	29-Apr-98	31-May-02	8.17	1.53	46,612	H	+
Greece	GRC	29-Apr-98	29-Apr-98	8.67	1.24	18,993	H	+
Croatia	HRV	11-Mar-99	30-May-07	4.72	0.48	13,792	H	+
Hungary	HUN		21-Aug-02	5.45	0.56	15,042	H	+
Ireland	IRL	29-Apr-98	31-May-02	9.93	1.63	75,113	H	+
Iceland	ISL		23-May-02	10.66	0.65	57,819	H	+
Italy	ITA	29-Apr-98	31-May-02	7.33	1.14	32,044	H	+
Japan	JPN	28-Apr-98	4-Jun-02	9.70	0.41	36,362	H	+
Liechtenstein*	LIE	29-Jun-98	3-Dec-04	5.91	1.12	-	H	+
Lithuania	LTU	21-Sep-98	3-Jan-03	4.33	0.44	17,186	H	+
Luxembourg	LUX	29-Apr-98	31-May-02	20.48	3.40	104,584	H	+
Latvia	LVA	14-Dec-98	5-Jul-02	3.59	0.32	15,967	H	+
Monaco	MCO	29-Apr-98	27-Feb-06			183,245	H	+
Malta	MLT	17-Apr-98	11-Nov-01	5.88	1.32	27,489	H	
Netherlands	NLD	29-Apr-98	31-May-02	10.37	0.66	48,424	H	+
Norway	NOR	29-Apr-98	30-May-02	9.16	0.55	76,085	H	+
New Zealand	NZL	22-May-98	19-Dec-02	8.22	0.54	40,315	H	+
Poland	POL	15-Jul-98	13-Dec-02	8.54	0.34	14,987	H	+
Portugal	PRT	29-Apr-98	31-May-02	5.57	0.71	21,568	H	+
Romania	ROU	5-Jan-99	19-Mar-01	4.41	0.48	11,215	UM	+
Russia	RUS	11-Mar-99	18-Nov-04	10.90	0.57	12,123	UM	+

Slovakia	SVK	26-Feb-99	31-May-02	7.28	0.71	18,128	H	+
Slovenia	SVN	21-Oct-98	2-Aug-02	7.78	0.72	24,062	H	+
Sweden	SWE	29-Apr-98	31-May-02	5.46	0.85	53,490	H	+
Turkey	TUR		28-May-09	4.23	0.63	11,956	UM	
Ukraine	UKR	15-Mar-99	12-Apr-04	6.20	0.70	3,225	LM	+
The USA	USA	-	-	19.12	1.93	60,837	H	+
The EU		29-Apr-98	31-May-02					+

Note: The USA have signed but not ratified Kyoto Protocol. Canada ratified but withdrew by 2011. Both countries ratified Paris Agreement. Liechtenstein and Monaco are excluded from the analysis due to unavailability of CO2 data (per capita fossil CO2 emissions, tonnes of CO2 per capita) and/or GDP per capita.(*) Liechtenstein CO2 data is available between 1990-2019.

Appendix 2: Overall country list

Country Name	Code	Income	Country Name	Code	Income
Afghanistan	AFG	L	Jordan	JOR	UM
Burkina Faso	BFA	L	Kazakhstan	KAZ	UM
Burundi	BDI	L	Kosovo	XKX	UM
Central African Republic	CAF	L	Lebanon	LBN	UM
Chad	TCD	L	Libya	LBY	UM
Congo, Dem. Rep.	COD	L	Malaysia	MYS	UM
Eritrea	ERI	L	Maldives	MDV	UM
Ethiopia	ETH	L	Marshall Islands	MHL	UM
Gambia, The	GMB	L	Mauritius	MUS	UM
Guinea	GIN	L	Mexico	MEX	UM
Guinea-Bissau	GNB	L	Moldova	MDA	UM
Korea, Dem. People's Rep.	PRK	L	Montenegro	MNE	UM
Liberia	LBR	L	Namibia	NAM	UM
Madagascar	MDG	L	North Macedonia	MKD	UM
Malawi	MWI	L	Panama	PAN	UM
Mali	MLI	L	Paraguay	PRY	UM
Mozambique	MOZ	L	Peru	PER	UM
Niger	NER	L	Romania	ROU	UM
Rwanda	RWA	L	Russian Federation	RUS	UM
Sierra Leone	SLE	L	Serbia	SRB	UM
Somalia	SOM	L	South Africa	ZAF	UM
South Sudan	SSD	L	St. Lucia	LCA	UM
Sudan	SDN	L	St. Vincent and the Grenadines	VCT	UM
Syrian Arab Republic	SYR	L	Suriname	SUR	UM
Togo	TGO	L	Thailand	THA	UM
Uganda	UGA	L	Tonga	TON	UM
Yemen, Rep.	YEM	L	Turkey	TUR	UM
Algeria	DZA	LM	Turkmenistan	TKM	UM
Angola	AGO	LM	Tuvalu	TUV	UM
Bangladesh	BGD	LM	Andorra	AND	H
Belize	BLZ	LM	Antigua and Barbuda	ATG	H
Benin	BEN	LM	Aruba	ABW	H
Bhutan	BTN	LM	Australia	AUS	H
Bolivia	BOL	LM	Austria	AUT	H
Cabo Verde	CPV	LM	Bahamas, The	BHS	H
Cambodia	KHM	LM	Bahrain	BHR	H
Cameroon	CMR	LM	Barbados	BRB	H
Comoros	COM	LM	Belgium	BEL	H
Congo, Rep.	COG	LM	Bermuda	BMU	H
Cote d'Ivoire	CIV	LM	British Virgin Islands	VGB	H
Djibouti	DJI	LM	Brunei Darussalam	BRN	H
Egypt, Arab Rep.	EGY	LM	Canada	CAN	H
El Salvador	SLV	LM	Cayman Islands	CYM	H
Eswatini	SWZ	LM	Channel Islands	CHI	H
Ghana	GHA	LM	Chile	CHL	H
Haiti	HTI	LM	Croatia	HRV	H
Honduras	HND	LM	Curacao	CUW	H
India	IND	LM	Cyprus	CYP	H
Indonesia	IDN	LM	Czech Republic	CZE	H
Iran, Islamic Rep.	IRN	LM	Denmark	DNK	H
Kenya	KEN	LM	Estonia	EST	H
Kiribati	KIR	LM	Faroe Islands	FRO	H
Kyrgyz Republic	KGZ	LM	Finland	FIN	H
Lao PDR	LAO	LM	France	FRA	H
Lesotho	LSO	LM	French Polynesia	PYF	H
Mauritania	MRT	LM	Germany	DEU	H

Micronesia, Fed. Sts.	FSM	LM	Gibraltar	GIB	H
Mongolia	MNG	LM	Greece	GRC	H
Morocco	MAR	LM	Greenland	GRL	H
Myanmar	MMR	LM	Guam	GUM	H
Nepal	NPL	LM	Hong Kong SAR, China	HKG	H
Nicaragua	NIC	LM	Hungary	HUN	H
Nigeria	NGA	LM	Iceland	ISL	H
Pakistan	PAK	LM	Ireland	IRL	H
Papua New Guinea	PNG	LM	Isle of Man	IMN	H
Philippines	PHL	LM	Israel	ISR	H
Samoa	WSM	LM	Italy	ITA	H
Sao Tome and Principe	STP	LM	Japan	JPN	H
Senegal	SEN	LM	Korea, Rep.	KOR	H
Solomon Islands	SLB	LM	Kuwait	KWT	H
Sri Lanka	LKA	LM	Latvia	LVA	H
Tajikistan	TJK	LM	Liechtenstein	LIE	H
Tanzania	TZA	LM	Lithuania	LTU	H
Timor-Leste	TLS	LM	Luxembourg	LUX	H
Tunisia	TUN	LM	Macao SAR, China	MAC	H
Ukraine	UKR	LM	Malta	MLT	H
Uzbekistan	UZB	LM	Monaco	MCO	H
Vanuatu	VUT	LM	Nauru	NRU	H
Vietnam	VNM	LM	Netherlands	NLD	H
West Bank and Gaza	PSE	LM	New Caledonia	NCL	H
Zambia	ZMB	LM	New Zealand	NZL	H
Zimbabwe	ZWE	LM	Northern Mariana Islands	MNP	H
Albania	ALB	UM	Norway	NOR	H
American Samoa	ASM	UM	Oman	OMN	H
Argentina	ARG	UM	Palau	PLW	H
Armenia	ARM	UM	Poland	POL	H
Azerbaijan	AZE	UM	Portugal	PRT	H
Belarus	BLR	UM	Puerto Rico	PRI	H
Bosnia and Herzegovina	BIH	UM	Qatar	QAT	H
Botswana	BWA	UM	San Marino	SMR	H
Brazil	BRA	UM	Saudi Arabia	SAU	H
Bulgaria	BGR	UM	Seychelles	SYC	H
China	CHN	UM	Singapore	SGP	H
Colombia	COL	UM	Sint Maarten (Dutch part)	SXM	H
Costa Rica	CRI	UM	Slovak Republic	SVK	H
Cuba	CUB	UM	Slovenia	SVN	H
Dominica	DMA	UM	Spain	ESP	H
Dominican Republic	DOM	UM	St. Kitts and Nevis	KNA	H
Ecuador	ECU	UM	St. Martin (French part)	MAF	H
Equatorial Guinea	GNQ	UM	Sweden	SWE	H
Fiji	FJI	UM	Switzerland	CHE	H
Gabon	GAB	UM	Trinidad and Tobago	TTO	H
Georgia	GEO	UM	Turks and Caicos Islands	TCA	H
Grenada	GRD	UM	United Arab Emirates	ARE	H
Guatemala	GTM	UM	United Kingdom	GBR	H
Guyana	GUY	UM	United States	USA	H
Iraq	IRQ	UM	Uruguay	URY	H
Jamaica	JAM	UM	Virgin Islands (U.S.)	VIR	H

Note: H, UM, LM, L denote high, upper middle, lower middle, low income, successively.