Advanced Panel Data

Impact of Common Economic Trends on Greenhouse Gas Emissions in European Countries

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1 Introduction and Motivation

This work is inspired from a work I have been working on named "Oil price and Greenhouse gas emissions : an investigation on the maritime transport sector" that consists in measuring the impact of OPEC oil prices on Greenhouse Gas Emissions in the maritime transportation sector. In this new paper, I want to assess how efficiently European countries are decreasing their Greenhouse Gas Emissions and if the main economic trend they are following is going in the same direction as the zero carbon objective policymakers want to tend to. In other words, we want to state if the trend, that will be composed by some covariates that most people are considering as being *the main determinants of GHG emissions*, is well distributed enough to make countries able to decrease efficiently their GHG emissions. The results are very inspiring because we can clearly distinguish three groups of countries that are decreasing more or less strongly their GHG emissions depending on the trend they follow. This paper studies only European countries in order to avoid bigger sources of heterogeneity that can be found if incorporating countries in other continents in addition to European countries. Data collected is in a period of a bit more than 2.5 decades. The method to extract the trends is the Principal Component Analysisc (PCA) and will be further expanded in **subsection 3.1**. Afterward, a Within estimation is conducted to determine how each country reacts to its principal trend regarding the said *main determinants* of GHG emissions and if there exists similarities between countries having the same effect.

Trend Definition

What we will call *trend* corresponds to the mutual comovements of some variables, considered as the ones that are varying the most over time for a given country.

GHG definition

Shorter word for *Greenhouse Gas Emissions*.

2 Data

Data is extracted from various sources including Eurostat, World Bank and the 'Our World in Data' website, project of the 'Global Change Data Lab', that collaborates with researchers at the University of Oxford. The variables of interest in this project are :

- GDP in 2015 constant US$ (World Bank)[1]
- Greenhouse Gas Emissions across eight different sectors, later aggregated, in Million tonnes of CO2 equivalent per year (Eurostat)[2]
- Global Oil Consumption in Thousand tonnes (Eurostat)[3]

[1] https://data.worldbank.org/indicator/NY.GDP.MKTP.KD
[2] https://edgar.jrc.ec.europa.eu/emissions_reports
[3] https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_oil__custom_15548999/default/table?lang=en

- Crude Oil Price in constant 2023 US$ per cubic meter (Our World in Data)[4]
- Population in unit (World Bank)[5]
- Population Density in people per square kilometer of land area (World Bank)[6]
- Share of Industry in % of GDP (World Bank)[7]

In order to make the results easier to read, we converted the following variables in the following units of measure :

- GHG emissions in **tonnes** of CO2 equivalent per year
- Global Oil Consumption changed to **tonnes**

Our dataset uses data from the indicators previously stated for 18 European countries (see **table 1** for the list of countries) from 1995 to 2020 (26 annual periods).

3 Analytic Methods

3.1 PCA on each country

We first conduct a Principal Component Analysis (PCA) on the time series covariate matrices (Oil Price, Oil Consumption per Capita, GDP per Capita, Share of Industry in the GDP and Urban Density) of each European country to use the principal components (capturing the principal trend shared by our economic indicators) in a Within Panel Data regression. The goal here is to extract the factors F_i ($T \times P$ matrix) also called *trend* for each country i because it summarizes how covariates of interest vary over time in each country.

The PCA solves the following maximization problem:

$$\max_{A_i} \quad \mathrm{tr}\left[A_i' \Sigma_i A_i\right] \quad \text{s.t.} \quad A_i' A_i = I_p \tag{1}$$

where Σ_i is the covariance matrix of X, and A_i ($P \times P$ matrix) is the matrix of eigenvectors, in the country i.

The solution A_i is the matrix containing the first p eigenvectors of Σ_i. It then follows from the following decomposition :

$$\Sigma_i = A_i \Lambda_{i,p} A_i' + Errors_i \tag{2}$$

where $\Lambda_{i,p}$ is the diagonal matrix of the top p eigenvalues in country i.

The eigenvectors A_i are extracted from the PCA, and the factors F_i representing the common trend of the economic indicators are computed as:

[4] https://ourworldindata.org/grapher/oil-prices-inflation-adjusted?v=1&csvType=full&useColumnShortNames=false
[5] https://data.worldbank.org/indicator/SP.POP.TOTL
[6] https://data.worldbank.org/indicator/EN.POP.DNST
[7] https://data.worldbank.org/indicator/NV.IND.TOTL.ZS

$$F_i = X_i A_i \tag{3}$$

This process is repeated separately for each country, as previously stated. At the end, we will collect in a single table the first Factor only, with T elements (one value of factor for each period), for the N countries in our Panel Data.

3.2 Econometric Analysis

In a second and last step, we will perform a Within estimation of Greenhouse Gas Emissions on the first principal component. The model will be expressed as follows :

$$GHGperCapita_{i,t} = \alpha_i + \sum_{q}^{N} \gamma_q \cdot Factor_1 \times (Country_q = i) + \sum_{s=1996}^{2020} \beta_s \cdot (Year_t = s) + \epsilon_{i,t} \tag{4}$$

where the year 1995 is the year of reference.

Interactive effects fo "Country" with factor 1 have been incorporated in the model because we are suspecting that each country has different distribution of variables' contributions to each dimension since countries are too different in terms of social-economic structure, providing too big source of heterogeneity for the model. Hence, the model will be more accurate since it will measure the impact of factor 1 on Greenhouse Gas Emissions per Capita separately for each. In other words, contributions of variables in factor 1 will be different from a country to another, meaning that depending on the country, factor 1 will not capture the same variations, making interpretation harder if we do not include the interaction term.

Contribution Definition

Determines the level of importance of a variable X_j in defining the Principle Component F_p (Factor F_p) and is computed as follows :

$$\text{Contribution}(X_j, F_p) = \frac{v_{jp}^2}{\sum_{j=1}^{P} v_{jp}^2} \times 100,$$

where P is the total number of variables, v_{jp} is the coordinate of the variable X_j in the eigen-vector p associated to the principal component F_p. This measure goes from 0 to 100.

Coordinate (or loading) Definition

$j-th$ coordinate or loading of an eigen-vector p corresponds to the $j-th$ element of the eigen-vector A^p. Its sign tells the direction of correlation the variable j has with the principal component p (factor p). For example, if sign(a_{13}) is negative, then this means that variable 1 moves in opposite direction with the principal component 3. However, if the sign is positive, this means that variable 1 moves with in the same direction as the principal component 3. Coordinate is given by :

$$\text{Coordinate}(X_j, F_p) = a_{jp}$$

Moreover, the magnitude of the coordinate tells also about the contribution of variable j to principal component p.

4 Results

Table 2 presents the estimates of model **(1)** described in **subsection 3.2**. We identify three groups of countries: those where Factor 1 has a significant positive effect on GHG per capita, those where Factor 1 has a significant negative effect, and those where Factor 1 has no significant effect. **Tables 3, 4, and 5** classify these countries and present the contribution and coordinate of each variable to Factor 1 in each country, allowing us to understand the principal trends shaping each country's emissions.

Furthermore, we observe that most "Year" estimates are significant, particularly from 2009, suggesting that variations in Greenhouse Gas Emissions are strongly influenced by time. This indicates that policies implemented during these years have been effective in gradually reducing emissions. The increasing absolute magnitude of the "Year" estimates over time with respect to the reference year 1995 highlights the growing importance of environmental concerns and the urgency for further reductions in GHG emissions.

Table 2 shows that Czechia, Denmark, Ireland and Sweden exhibit a significant negative relationship between Factor 1 and their emissions. When their principal trend increases by one unit, their GHG emissions per capita decrease. These countries are widely recognized for their environmental commitment, and the sign of their estimate suggests that when their economic trend strengthens, it leads to lower emissions. Since Factor 1 represents the principal trend in each country, the regression results suggest that, for these countries, an increase in Factor 1 consistently leads to a decrease in GHG emissions per capita, regardless of the specific variables that drive this trend. This confirms that their economic trajectory is aligned with emission reductions.

On the other hand, Austria, Bulgaria, Estonia, Greece, Hungary, North Macedonia, Poland and Slovenia display a significant positive effect, meaning that as their trend increases, their emissions per capita also increase. This suggests that in these countries, the variables contributing the most to Factor 1, such as GDP per capita and population density, are positively correlated with emissions, explaining the observed increase in GHG per capita.

Since Factor 1 is composed of the variables that fluctuate the most over time in each country, an increase in Factor 1 implies that these variables evolve in a correlated manner. **Table 4** presents the contributions and PCA loadings for each country. For instance in Sweden and Denmark, an increase in Factor 1 is associated with an increase in GDP per capita and population density, while oil prices and industrial share decrease. We will describe each pattern in the following paragraphs.

Figure 1 illustrates the evolution of Factor 1 and GHG per capita over time. Countries where Factor 1 has a negative effect tend to show a sharp decline in emissions, likely driven by structural economic shifts and sustainable policies. Indeed, the slope of GHG emissions per Capita is much sharper than the other groups of countries and could be due to economic shifts and efficient sustainable policies that managed to foster this decline in emissions. In fact, Denmark and Sweden show decreasing levels of Oil Consumption and Share of Industry in GDP, with higher levels of Oil

Price, GDP per Capita and Population Density. In Ireland, we see the same patterns except that Share of Industry in GDP is not part of the principal trend, and Czechia has the same pattern, except that Consumption per Capita is increasing over time which is quite suprising when we know that GHG emissions are drastically decreasing. The decrease in GHG emissions could be due to a proper use of these energy sources in a more sustainable way. This country has been for a long time dependent to coal, more polluting than oil, but numerous coal power plants have been closed and the use of oil has been a substitute for inhabitants, CO2 quotas have been put in place and Industries could have seen an evolution in their technologies giving less polluting production means.

We also note that countries classified as "developed" on a global scale but still in an economic development phase within Europe, such as Austria, Bulgaria, Estonia, Greece, Hungary, North Macedonia, Poland and Slovenia, show a trend where increasing Factor 1 is associated with higher emissions. Indeed, these countries show an increasing level of GDP per Capita and Population density, and for some an increasing level of Oil Consumption, but all these changes in economic and demographic structure do not seem to be ecologically friendly. These countries need urgently to make a shift in their economic structure to respond to the infrastructural and economic requirements fixed by policymakers such as the European Union or the European Commission, that aim to drastically reduce countries' GHG emissions.

Conversely, the most developed European countries, such as France, Germany, the Netherlands, and Portugal, or countries like Romania and Ukraine exhibit no significant relationship between Factor 1 and GHG emissions per capita. For the first group of countries, this can be explained by their diversified energy mix and investments in sustainable technologies, allowing them to maintain emission reductions regardless of the trajectory of their economic trends. For Ukraine, this decrease in GHG emissions could be due to an economic decline over year implying a lower level of industrialization (as factor 1 decreases in **figure 1**, Share of Industry in GDP evolves in the same direction as factor 1) and an increasing political stability. In contrast, Romania is more stable economically and politically, but this country has been restricted by directives put in place by the EU that foster energetic transition to renewable energies. Consequently, factor 1 does not have any effect on GHG emissions for these countries only because there exists other trends composed by other variables that are not necessarily as evident as the ones used in this study, but that are more significant for these given economies in decreasing emissions.

Overall, our results highlight that while economic trends significantly impact emissions, the nature of this impact varies across countries. For some, reduction of GHG emissions is more drastic because their principal trend is composed by factors that directly influence them, while for others, hardly decrease their emissions because of an economic and industrial development that is still too much polluting.

5 Conclusion and Contribution

In conclusion, this study managed to distinguish countries having an efficient environmental policy regarding the main determinants of GHG emissions defined earlier in the paper. For some, their policy is drastically lowering their emissions because the environmental concern is purely implemented in their economic structure, others that are moderately decreasing their GHG emissions either because their GHG level is already low, or because of other political factors or economic reasons, and finally countries that have GHG emission levels that are stagnating or increasing in some periods of time because their economic expansion depends on sectors that are very consuming in Oil for instance, as we can see in **table 4** with some countries that have increasing levels of Oil Consumption, with increasing levels of GDP.

In this paper, I provided a different way of assessing in what extent countries' policies are efficient and what could explain these reductions, risings or stagnation in GHG emissions by defining their economic trend through a country specific Principal Component Analysis, and finally evaluating their effect on emissions.

Limits of this work could be that the concept of *trend* and its effect on GHG emissions could be hardly interpretable as it comes from a PCA that is originally a method to decrease dimensions in a high dimensional framework, and used here to extract the principle sources of variation over time for a given country. Moreover, we could incorporate additional determinants of GHG emissions to make this study even more accurate, or we could expand this work in assessing how the "global" countries' economic behavior, by including other factors than only the ones that have an impact on emissions, and see the impact of their global economy structure on GHG emissions.

6 Appendix

Country	Country	Country
Austria	Bulgaria	Czechia
Germany	Denmark	Estonia
France	Greece	Hungary
Ireland	North Macedonia	Netherlands
Poland	Portugal	Romania
Slovenia	Sweden	Ukraine

Table 1: List of countries included in the project

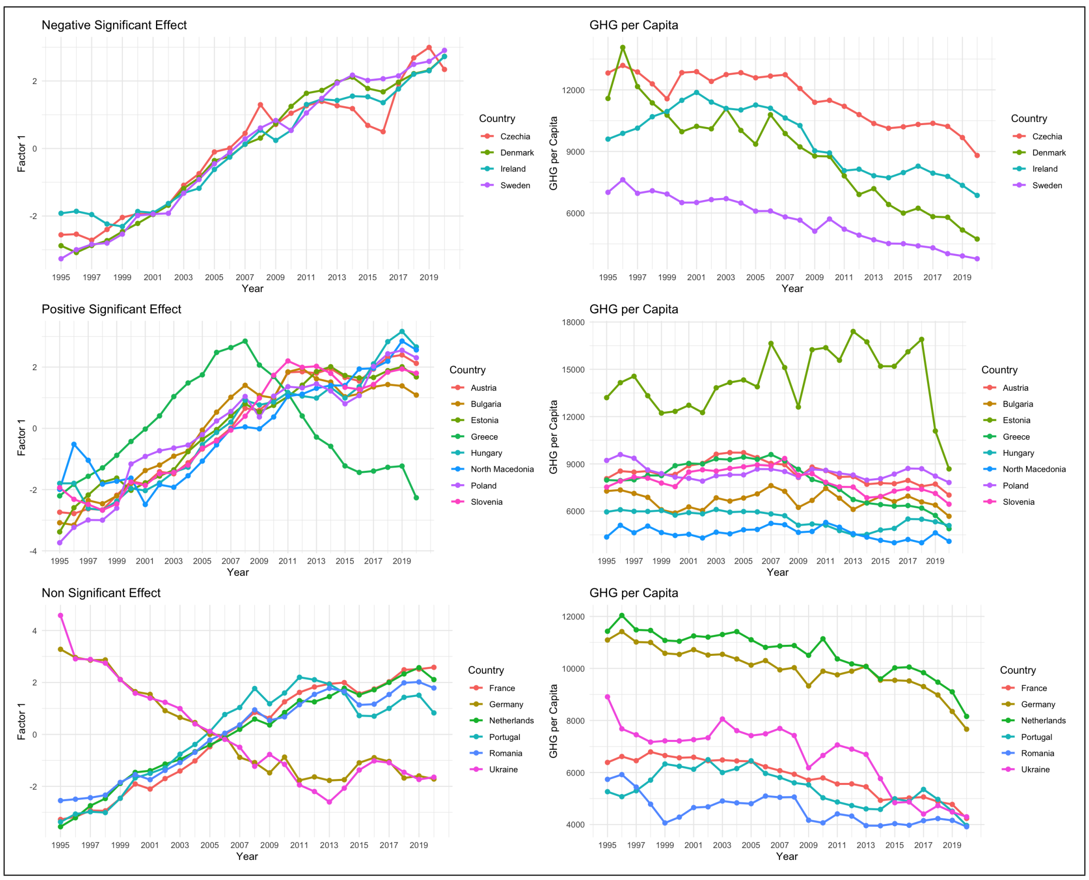

Figure 1: Factor 1 and GHG per Capita over Time

Table 2: Robust Within Model (HC0 Heteroskedasticity Correction).
Country specific factor 1 effect and time dummies.

Variable	Estimate	Std. Error	t value	Pr(> $\|t\|$)
Austria	169.72	91.08	1.86	0.063 .
Bulgaria	317.60	96.96	3.28	0.001 **
Czechia	-212.25	95.26	-2.23	0.026 *
Denmark	-809.74	86.02	-9.41	$< 2.2 \times 10^{-16}$ ***
Estonia	815.07	99.38	8.20	3.14×10^{-15} ***
France	-0.73	83.78	-0.01	0.993
Germany	65.59	94.82	0.69	0.490
Greece	402.40	36.74	10.95	$< 2.2 \times 10^{-16}$ ***
Hungary	171.72	93.26	1.84	0.066 .
Ireland	-406.40	102.11	-3.98	8.16×10^{-5} ***
Netherlands	-50.86	93.32	-0.55	0.586
North Macedonia	358.60	98.26	3.65	0.0003 ***
Poland	214.62	89.79	2.39	0.017 *
Portugal	96.35	86.77	1.11	0.268
Romania	157.85	105.91	1.49	0.137
Slovenia	178.16	93.53	1.90	0.058 .
Sweden	-213.62	83.62	-2.55	0.011 *
Ukraine	125.58	84.78	1.48	0.139
Year1996	309.91	153.58	2.02	0.044 *
Year1997	38.63	116.98	0.33	0.741
Year1998	-97.76	171.87	-0.57	0.570
Year1999	-406.57	243.78	-1.67	0.096 .
Year2000	-400.37	259.51	-1.54	0.124
Year2001	-177.77	278.45	-0.64	0.524
Year2002	-300.92	306.85	-0.98	0.327
Year2003	33.06	272.13	0.12	0.903
Year2004	-83.68	305.60	-0.27	0.784
Year2005	-140.76	358.92	-0.39	0.695
Year2006	-147.03	405.18	-0.36	0.717
Year2007	-93.35	375.95	-0.25	0.804
Year2008	-373.05	444.45	-0.84	0.402
Year2009	-1085.34	445.09	-2.44	0.015 *
Year2010	-721.21	430.15	-1.68	0.094 .
Year2011	-881.56	441.78	-2.00	0.047 *
Year2012	-1163.42	450.89	-2.58	0.010 *
Year2013	-1244.77	464.40	-2.68	0.008 **
Year2014	-1561.99	461.96	-3.38	0.0008 ***
Year2015	-1588.19	462.99	-3.43	0.0007 ***
Year2016	-1577.10	470.20	-3.35	0.0009 ***
Year2017	-1469.72	504.92	-2.91	0.0038 **
Year2018	-1577.49	521.70	-3.02	0.0027 **
Year2019	-2155.53	633.08	-3.40	0.0007 ***
Year2020	-2710.84	667.53	-4.06	5.86e-05 ***
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
R^2	0.748	Adjusted R^2: 0.711		

Table 3: Contributions and Coordinates of First Eigen-Vector of Variables for Countries Having Negative Significant Factor 1 Effect on GHG per Capita

Country	Variable	Contribution	Coordinates (Loading)
Ireland	OilPrice	13.74	0.60
	ConsPerCapita	23.12	-0.78
	GDPperCapita	26.15	0.83
	ShareIndustry	0.31	0.09
	PopulationDensity	36.68	0.98
Denmark	OilPrice	11.14	0.65
	ConsPerCapita	25.60	-0.98
	GDPperCapita	19.92	0.86
	ShareIndustry	19.20	-0.85
	PopulationDensity	24.15	0.95
Sweden	OilPrice	9.07	0.60
	ConsPerCapita	23.54	-0.97
	GDPperCapita	23.10	0.96
	ShareIndustry	22.99	-0.96
	PopulationDensity	21.29	0.92
Czechia	OilPrice	14.21	0.65
	ConsPerCapita	13.61	0.64
	GDPperCapita	31.39	0.97
	ShareIndustry	18.87	-0.75
	PopulationDensity	21.92	0.81

Table 4: Contributions and Coordinates of First Eigen-Vector of Variables for Countries Having Positive Significant Factor 1 Effect on GHG per Capita

Country	Variable	Contribution	Coordinates (Loading)
Austria	OilPrice	13.42	0.67
	ConsPerCapita	5.05	-0.41
	GDPperCapita	27.12	0.95
	ShareIndustry	28.43	-0.97
	PopulationDensity	25.97	0.93
Bulgaria	OilPrice	22.94	0.79
	ConsPerCapita	0.01	-0.01
	GDPperCapita	29.72	0.90
	ShareIndustry	15.88	0.66
	PopulationDensity	31.46	-0.93
Estonia	OilPrice	15.76	0.66
	ConsPerCapita	1.48	0.20
	GDPperCapita	32.89	0.95
	ShareIndustry	15.70	-0.66
	PopulationDensity	34.17	-0.97
Greece	OilPrice	11.78	0.54
	ConsPerCapita	16.43	0.63
	GDPperCapita	35.07	0.93
	ShareIndustry	3.29	0.28
	PopulationDensity	33.44	0.91
Hungary	OilPrice	10.59	0.57
	ConsPerCapita	10.97	0.58
	GDPperCapita	28.69	0.95
	ShareIndustry	21.25	-0.81
	PopulationDensity	28.51	-0.94
North Macedonia	OilPrice	9.05	0.48
	ConsPerCapita	18.66	0.69
	GDPperCapita	36.03	0.96
	ShareIndustry	0.05	0.04
	PopulationDensity	36.21	-0.96
Poland	OilPrice	12.37	0.64
	ConsPerCapita	25.91	0.93
	GDPperCapita	26.24	0.93
	ShareIndustry	7.82	-0.51
	PopulationDensity	27.66	-0.96
Slovenia	OilPrice	17.68	0.73
	ConsPerCapita	1.93	-0.24
	GDPperCapita	25.23	0.87
	ShareIndustry	25.54	-0.87
	PopulationDensity	29.62	0.94

Table 5: Contributions and Coordinates of First Eigen-Vector of Variables for Countries Having Non Significant Factor 1 Effect on GHG per Capita

Country	Variable	Contribution	Coordinates (Loading)
France	OilPrice	11.24	0.67
	ConsPerCapita	17.83	-0.84
	GDPperCapita	21.76	0.93
	ShareIndustry	24.51	-0.99
	PopulationDensity	24.66	0.99
Germany	OilPrice	19.42	-0.75
	ConsPerCapita	30.77	0.94
	GDPperCapita	27.80	-0.90
	ShareIndustry	21.22	0.78
	PopulationDensity	0.78	0.15
Netherlands	OilPrice	11.67	0.61
	ConsPerCapita	0.41	-0.11
	GDPperCapita	29.60	0.97
	ShareIndustry	28.05	-0.94
	PopulationDensity	30.26	0.98
Portugal	OilPrice	22.01	0.84
	ConsPerCapita	14.51	-0.68
	GDPperCapita	17.96	0.76
	ShareIndustry	28.87	-0.96
	PopulationDensity	16.64	0.73
Romania	OilPrice	19.82	0.70
	ConsPerCapita	1.37	-0.18
	GDPperCapita	36.40	0.95
	ShareIndustry	3.36	-0.29
	PopulationDensity	39.05	-0.98
Ukraine	OilPrice	16.82	-0.77
	ConsPerCapita	13.16	0.68
	GDPperCapita	21.96	-0.88
	ShareIndustry	22.40	0.89
	PopulationDensity	25.67	0.95