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Fair and Efficient Allocation of EU Emission Allowances

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Abstract Under the European Union Emission Trading System (EU ETS), the European Union issues and allocates emission allowances (EUA) to the member states to cap the total volume of Greenhouse Gas (GHG) emissions. Since the first years of operation, the EU ETS allocation procedure has undergone multiple changes in an attempt to both fix over-allocation issues and balance surplus as well as to protect firms from carbon leakage. This is partially done through the means of grandfathering emission permits, auctioning or benchmark-based allocation. In this work, we study the allocation methods applied by the EU throughout the years, and we establish a notion of fairness based on the goals that the EU aims to achieve. Aiming to reach a balance between fairness and efficiency, we collect a series of indicators that describe the economic conditions and the energy intensity of each member state, and we perform a cluster analysis to categorize the countries. We then perform a regression analysis to examine whether our selected indicators best describe the free allowance allocation of the EU ETS throughout the years and observe similarities between countries in the same clusters. Finally, we provide a simple yet flexible allowance allocation optimization problem which can incorporate various fair allocation principles proposed by the literature.

Keywords: EU ETS, Cap-and-Trade, Emission Trading System, Allowance Allocation, Individual Fairness

1. Introduction

The European Union Emission Trading System (EU ETS) is the main instrument of the EU's climate and energy policy and the largest international cap-and-trade system. Each year, the EU allocates emission allowances to participating firms, which subsequently they can exchange via the EU ETS market in order to cover for their annual emissions. Since the beginning of its operation, the EU ETS has attracted global scientific interest and many studies have focused on the allocation procedure (see e.g. Buchner et al., 2006, Ellerman et al., 2016, and Martin et al., 2016). Besides, one of the greatest criticisms especially in the first phase of the EU ETS operation was the overallocation of EUAs and the competitive issues that arose between the Member states due to different allocation rules (Ellerman et al., 2016).

Initial allocation of EUAs plays a key role in the stability and efficiency of the system, as it determines the overall shortage of the market (Verde et al., 2019). A challenging step in allocating emission allowances is to determine the allocation principle and consequently the responsibility sharing of CO2 emissions between different member states. Equity in the distribution procedure is important, since unfair allocation of free allowances may impact the economic development of the countries. Generally, the discussion of fair distribution revolves around the definition of fairness and it can be summarized in four principles of distributive justice: (1) *compensation*, where involuntary differences in individual characteristics justify the unequal shares of a resource, (2) *reward*, where voluntary differences in individual characteristics are being rewarded and hence resulting in unequal resource sharing, (3) *exogenous rights*, where individual characteristics are exogenous to the person's claim to the resource (e.g. basic rights such as ability to vote, freedom of speech etc.) and (4) *fitness*, where resources are allocated to the one that makes best use of them (Moulin, 2004).

Many studies on emissions allocation over the years have advocated a variety of different allocation criteria that can be summarized in two main principles (1) fairness in terms of distributive justice and (2) economic efficiency in terms of minimizing abatement costs (Zhou & Wang, 2016). Focusing on the first phase of EU ETS operation, the authors in (Chiu et al., 2015) argue that the allocation is unfair and propose a method for the equitable reallocation of emission permits to member states. The authors in (Ju et al., 2021) propose axioms based on population, historical and business-as-usual emissions to establish equal-per-capita allowance allocation rules that reward developing countries with large populations over developed countries with large historical emissions. Aiming to balance economic activity and production of renewable energy, the authors in (Moretti & Trabelsi, 2021) introduce a Double-Weighted Constrained Equal Awards Rule, to allocate emission allowances, and they investigate similarities in the resulting allocation by using an unsupervised clustering approach. By examining China's Emission Trading System, the authors in (Qin et al., 2017) propose a multi-criteria model that aims to balance equity and efficiency in the allocation of carbon allowances.

A key aspect to the majority of the studies in allowance allocation is the trade-off between fairness and efficiency to either improve existing allocation methods, or to develop new. Furthermore, it is important to incorporate multiple criteria into the allocation procedure so that the allocation results become widely acceptable and economically feasible. In this work, we focus on the allow- ance allocation procedure of the EU ETS in Phase I, II and III. In EU ETS Phase I and II, Grandfathering was the main allocation rule that was being applied, while in Phase III Benchmarking replaced it.

Following the literature in allowance allocation, by selecting multiple complementary criteria as features that describe the EU Member States in terms of size, economic health and energy intensity, we aim to observe whether equity and efficiency are guaranteed in the EU ETS allocation procedure. Using a clustering approach, we first categorize the Member States based on the selected features, and then we compare each cluster in terms of free allocation. Cluster analysis has been used by the previous literature mainly to group EU countries in terms of GHG emissions (Kijewska & Bluszcz, 2016 and Stuhlmacher et al., 2019)) or in terms of allowance transfer patterns in the EU ETS (Betz & Schmidt, 2016). To the best of our knowledge, our work is the first to incorporate various indicators to cluster the member states. We then perform a Regression analysis to examine the relationship between the free allowance allocation and the selected indicators throughout the EU ETS Phases. Finally, in contrast with the Benchmarking allocation rule used in the EU ETS, which tends to reward sectors' best performance, we provide a country oriented optimization problem for the allowance allocation. Our model is simple and flexible and can incorporate various different features and principles proposed in the literature for the fair and efficient allowance allocation.

2. Understanding Free Allowance Allocation through Clustering

In this section, we present the procedure to identify the clusters of the Member States as it occurred by the feature selection. We consider 25[1] EU ETS Member states and the annual data series of 10 indicators for each country. For our analysis we consider data from 2005 up to 2020, which correspond to the first three Phases of EU ETS operation (Phase I: 2005-2007, Phase II: 2008-2012, Phase III: 2013-2020). Aiming to understand the free allowance allocation, we first perform a cluster analysis of the EU Member States by taking into consideration various economic and energy indicators that best express fairness and economic efficiency (Zhou & Wang, 2016). Then we perform a Regression Analysis on a representative subset of these indicators to investigate their relationship with the free allowance allocation.

2.1. Indicators Selection

Aiming to characterize the countries in terms of size, economic conditions and energy consumption we follow the indicator approach of (Zhou & Wang, 2016) and we select indicators that represent the two main allocation principles - *Fairness* and *Economic Efficiency*. To extend our analysis, we include inflation as an indicator that reflects the ability to purchase and therefore further enhance the fairness principle. The Nominal GDP sector composition for all EU Member States was also included, so as to consider a more detailed representation of vertical equity and ability to pay criteria. The list of the selected indicators as well as the corresponding allocation principle can be seen in Table 1.

Table 1. List of Indicators along with the Allocation Principles of (Zhou & Wang, 2016)

Indicators	Principle	Data Source
Population	Fairness	https://data.worldbank.org/indicator/SP.POP.TOTL
GDP per capita	Fairness	https://data.worldbank.org/indicator/NY.GDP.PCAP.CD
Inflation	Fairness	https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG
Agriculture	Fairness	http://wdi.worldbank.org/table/4.2#
Industry	Fairness	http://wdi.worldbank.org/table/4.2#
Manufacturing	Fairness	http://wdi.worldbank.org/table/4.2#
ToEnergy Supply	Fairness	https://ec.europa.eu/eurostat/databrowser/view/nrg_bal_s/
Energy Intensity	Econ. Efficiency	https://ec.europa.eu/eurostat/databrowser/view/NRG_IND_EI
Verified Emissions	Fairness	https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1
Free Allocated Emissions	-	https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

2.2. Cluster Analysis of EU countries

For our cluster analysis, we consider the 10 indicators as seen in Table 1 for the 25 EU Member States. As a first step, we normalize our data by dividing each country's indicator with the corresponding average. To categorize the EU countries into clusters based on the indicators of Table 1, we use the k-means Algorithm. We determine the best number of clusters k by using the NbClust Package in R (*NbClust Function*, version 3.0.1). However, due to the fact that the number of countries examined is 25, we restricted the range of possible clusters between 3-5. The number of clusters occurred is 3 and the categorization of the EU member states that emerge from our analysis can be seen in Figure 1.

2.2. Regression Analysis between the selected Indicators and the Free Allocation

After determining the EU countries clusters, we then perform a Regression analysis to investigate the relationship between our indicators (Table 1) and the number of freely allocated allowances for each member state. Our goal is to understand whether the selected indicators describe the free allocation in all the three operation Phases of the EU ETS.

Since some of the indicators listed in Table 1 are highly correlated, to avoid multicollinearity issues we consider only the Population, the GDP per capita, along with a composite indicator consisting of the Total Energy Supply multiplied by the Energy Intensity. For the best interpretation of the regression results, we divided the time horizon in three parts to correspond to Phase I, II and III of EU ETS respectively. Due to space limitations, we present

[1] Slovakia, Czech Republic and Croatia were not considered, due to lack of data.

the results that correspond only to Phase III of the EU ETS operation.

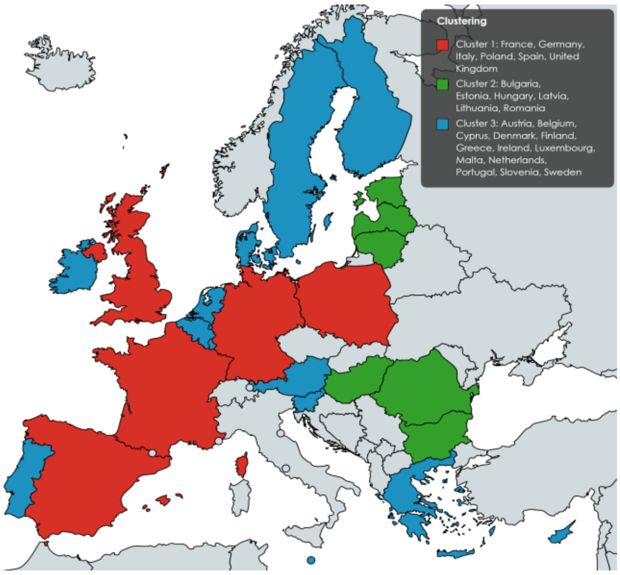

Figure 1. The 3 Clusters of the Member States

Table 2. Regressions R^2 of free allowances against energy supply and verified Emissions of Phase III respectively

R^2	Cluster 1	Cluster 2	Cluster 3
Energy Supply	0.433	0.689	**0.970**
Verified Emissions	**0.822**	**0.824**	0.785

Clusters 1 and 2 depend significantly on verified emissions, while cluster 3 aligns better with energy supply, based on Table 2. Table 2 includes the regression results of each cluster and each indicator with respect to free allocation.

In Figure 2 one can see the results of the four individual regression models, taking into consideration the Population (Figure 2a), the GDP per capita (Figure 2b), the Energy Supply (Figure 2c) and the composite indicators of Energy Supply and Energy Intensity (Figure 2d), for Phase III of the EU ETS. It is clear that the GDP per capita solely fails to explain the free allowance allocation of Phase III. In contrast, the composite indicator "Energy Intensity times Energy Supply" seems to be the best out of the four individual indicators.

Finally, in Table 3, we present a summary of the multiple linear regression results for Phase III. For our model we consider the Population, the GDP per capita and the composite indicator of Energy Supply and Energy Intensity. Once again, it is clear that the GDP per capita is the least significant determinant in the multiple linear regression model for the free allowance allocation of Phase III of the EU ETS.

3. Allowance Allocation Optimization Problem

Considering the indicators approach presented in Section 2, our goal is to find an allocation scheme that balances

Table 3. Multiple Linear Regression of Free Allocation

Free ~ Population + GDPpc + Ener_supply*Ener_intensity					
Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)	Signif.
(Intercept)	4.472e+06	2.042e+06	2.190	0.0297	*
Population	5.876e-01	1.042e-01	5.642	5.82e-08	***
GDPper capita	-3.378e+01	4.424e+01	-0.764	0.4461	
Ener. Supply * Ener. Intensity	2.313e+00	2.815e-01	8.215	2.83e-14	***
Residual stand.err.: 14140000 on 196 DF, Mult. R^2: 0.8564, Adj. R^2: 0.8542					
F-stat: 389.8 on 3 and 196 DF, p-val: < 2.2e-16					

both the individual fairness and the economic efficiency principles. Next, we introduce an optimization problem for the allocation of free allowances in each sector and each country. In our Allowance Allocation Optimization problem, we seek to distribute free allowances to reward sectors and countries that are more efficient in transforming allowances to Purchasing Power Standards (PPS). Due to the fact that each sector may differ in terms of emissions intensity, we also include the ratio of sector's GDP to the sector's verified emissions as a correction factor to describe the sector's performance.

$$max \sum_i (\sum_j v_{ij} \frac{GDP_{ij}}{e_{ij}}) GDP_i^{pps} \quad (1)$$

Where, v_{ij} is the fraction of the total free cap of country i in sector j, GDP_{ij} corresponds to the GDP of sector j in country i, e_{ij} is the verified emissions of sector j in country i and GDP_i^{pps} is the GDP per capita expressed in PPS, i.e. in relation to the EU average.

$$\sum_i \sum_j v_{ij} \leq 1 \quad (2)$$

$$v_i = \sum_j v_{ij} \quad (3)$$

$$a_3 v'_i \leq \sum_j v_{ij} \leq a_4 v'_i \quad (4)$$

$$a_1 v'_j \leq \sum_i v_{ij} \leq a_2 v'_j \quad (5)$$

(2) expresses that the total amount of allocated emissions does not exceed the cap. (3) expresses that the total amount of freely distributed permits per sector j in a country i equals v_i. (4) and (5) express that the amount of freely distributed allowances per country and per sector of the current year does not deviate more than a factor a from the amount of freely distributed allowances of the previous year (denote by v'_i and v'_j per country *i* and sector *j*, respectively).

Our model can incorporate additional constraints that express various fair and efficient criteria proposed by the literature. Herein, we consider an additional constraint aiming for fairness regarding population, ensuring that the percentage of the allowances allocated to each country cannot drastically deviate from its population percentage.

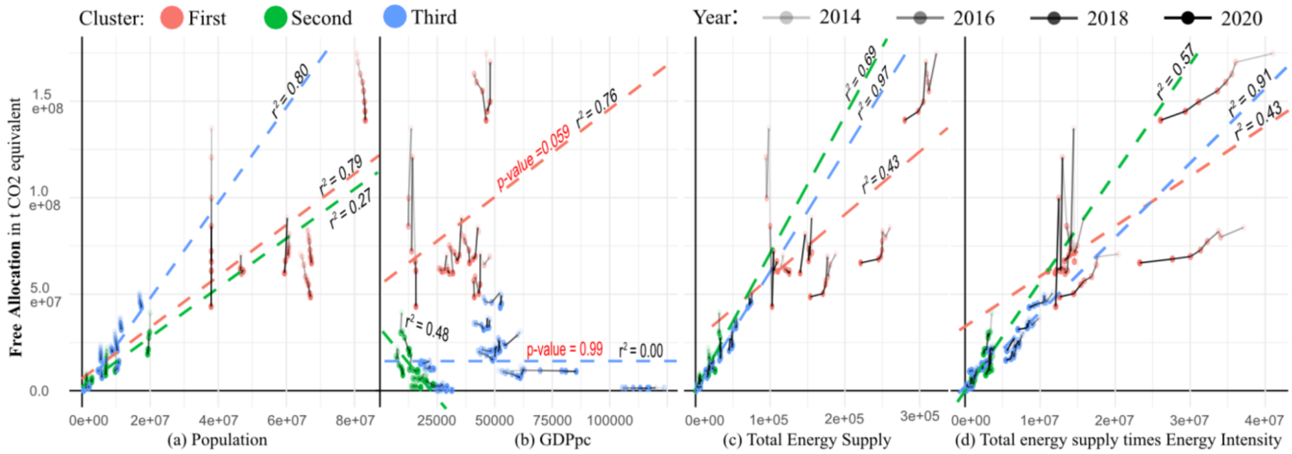

Figure 2. Regressions of Free Allocated Allowances against various Indicators

We demonstrate 2 different deviations of constraint (3): (ex. 1) factor a_1= 0.5 and a_2= 2 and (ex. 2) $a_1 = min(0.8, \frac{avg(GDP^{PPS})}{GDP_i^{PPS}})$, $a_2 = max(1.2, \frac{avg(GDP^{PPS})}{GDP_i^{PPS}})$.

Indicatively, in Table 4, we mention the change in the allocated allowances of two countries based on the variations (ex.1) and (ex.2).

Table 4. Changes in the allocation of two countries according to the two variations in factor a

Country	Ex. 1	Ex. 2	Country	Ex. 1	Ex. 2
Hungary	-30%	51%	Italy	36%	50%
Germany	-50%	-12%	Denmark	100%	50%

4. Conclusions

In this work, we first categorize the EU member states in three clusters based on indicators that express their population, economic activity and energy intensity. Clusters differ in terms of free allocation, as their amount of freely distributed permits depends on different indicators. Finally, we provide a simple and flexible allowance allocation problem that can incorporate various fair and efficient criteria from the literature as constraints.

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