# Decarbonization of Power Markets and Fairness: An Application of Cooperative Game Theory

Christoph Weissbart, ifo Institute, Phone +49 89 9224 1256, Email weissbart@ifo.de

## Overview

Market integration is seen as one complementary tool to decarbonize energy markets. In terms of power markets, this means the creation of a single market in order to keep the cost of transformation at a bearable level. This corresponds to the first-best solution from economic theory. If a group of players is subject to a market-wide and binding constraint, coordination allows to reach the cost-efficient allocation. Meaning, if players can coordinate and share information, they are able to reach the first-best outcome. In the context of power markets this translates into regions that try to maximize their welfare in the power market with respect to a climate (carbon) target. Regions coordinate their abatement efforts until marginal abatement costs across all regions equal. If regions fail to coordinate, average abatement costs increase, which results in a welfare loss.

Yet, the maximization of overall welfare through cooperation leads to redistribution and can result in a reduction of a region's welfare compared to the case without cooperation. This reflects the trade-off between economic effciency and redistribution that is often referred to in climate and energy economics. Hence, this paper tries to quantify why cooperation in the European power market is not rational from the perspective of single regions per se and identifies the importance of transfer payments for reaching the grand coalition, i.e. full cooperation.

This paper is organized in the following: it starts off with a literature overview on the representation of national interests in energy system models. This is followed by a presentation of the model and scenario set-up. Finally, results and policy implications are presented.

## Methods

This paper applies the EU-REGEN model to fnd the future equilibrium outcome of the European power market under a cooperative cost-sharing game. The model regions are assumed to be the set of players *N*. The discounted system cost of each region are interpreted as the payoff function of each player under different coalitions *S*. These underly the individual gain from cooperation, which is the reduction in discounted system cost. Gains are understood as the saving in system costs compared to the case when each player constitutes a singelton coalition. This analysis looks at $2^n - (n - 1)$ possible coalitions with $(n - 1)$ correcting for the singleton coalitions. The grand coalition N represents the first-best outcome with full cooperation and, thus, the cost-efficient market equilibrium.

The analysis is conducted in the framework of the EU-REGEN model (Weissbart, Blanford 2017). The model aggregates the countries of the EU28 plus Norway and Switzerland into 13 regions and considers the north and south of Germany separately. It also disaggregates generators and intra-annual time segments with sufficient resolution to capture dispatch, power flow between regions, and the implications of increased penetration of intermittent renewable energy sources. The model is solved as an intertemporal optimization through 2050 with 5-year time steps with the intention of simulating a competitive equilibrium.

The solution to this is found by solving the cost-minimization problem of the EU-REGEN model for all decisions variables simultaneously. Here, transmission capacity investment, generation capacity additions, and dispatch are optimized. This solution approach is applied to each possible coalition. Based on the framework of the EU-REGEN model with $|N| = 13$ model regions, this results in *8,180* possible coalitions between regions. In terms of climate policy, this paper assumes a 98 % $CO_2$-emission reduction target by 2050. Shared carbon-budgets are assumed for regions constituting a coalition. Each region outside the coalition is subject to its own carbon budget. These regional carbon budgets assume a 98 % reduction target for each region by 2050. The shared carbon budget for coalitions is the sum of regional carbon-budgets of all regions forming a coalition.

## Results

Model results for the future generation path under a 98 % $CO_2$-emission reduction target and the grand coalition are depicted in Fig. 1. Wind power is the dominating technology for the EU decarbonization path. The low substitution elasticity with dispatchable technologies is compensated by the interplay of, still, $CO_2$-emitting and flexible gas power technologies and bioenergy with CCS (BECCS), which is characterized by a negative carbon-intensity. The in-depth analysis of regional wind power market values reveals the importance of cooperation. In terms of wind power investment, regions with high wind power market values can not outcompete regions with a higher resource quality . Hence, regions with access to wind offshore potential bear higher system cost in the cost-efficient path. In return, regions with low-quality wind resources get access to electricity at low marginal abatement cost.

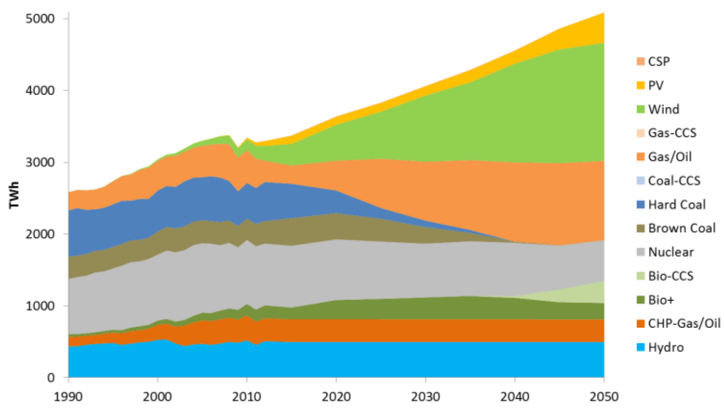


**Fig. 1.** Generation-Mix with Grand Coalition

Moreover, results show that the worth of the grand coalition (in comparison to singleton coalitions only) is a 4 % reduction in total system cost. Under the assumption of non-transferable utility and, hence, the absence of transfer payments only a 1,5 % reduction in totals system costs can be maintained. The underlying nash solution to the cooperative game reveals that a coalition comprising six regions is found to be stable. Contrasting the system cost of each region in the grand coalition case with the cost occurring when each region constitutes a singleton coalition shows that only five regions (out of 13) experience reduced system cost. Therefore, transfer payments (under the assumption of transferable utility) towards the direction of disadvantaged regions are necessary to put the grand coalition in a state of stability. Beyond that, this paper shows that cost allocations have to take uncertaintiy of future cost and non-binding commitments into account.

## Conclusions

This study shows that, in the case of the grand coalition, the interplay between wind power, gas power, and BECCS is the cost-effective equilibrium for the decarbonization of Europe's power sector. The total system costs under the this first-best outcome decrease by 4 % compared to the case without cooperation. Neglecting the possibility of transfer payments disminshes this cost reduction to 1,5 %. Concerning policy implications, this analysis shows the value of cooperation and the importance of thinking about potential transfer payments. This raises the question of how to implement a system of transfer payments and which institutions would be required. Moreover, with respect to future market-designs, it is of great importance to identify potential path-dependencies that arise from smaller coalitions. These results can be valuable when thinking about second-best solutions for reaching the decarbonization of the EU power market.

## References


Weissbart, C. and G. Blanford (2017): “Modeling the Dynamics of the Future European Power Sector – The EU-REGEN Model”, forthcoming.