Assessing incentives for multinational cooperation towards a North Sea Offshore Grid using allocation methods from coalitional game theory

Simon Risanger, Norwegian University of Science and Technology, simon.risanger@gmail.com
Martin Kristiansen, Norwegian University of Science and Technology
Francisco Munoz, Universidad Adolfo Ibáñez
Magnus Korpås, Norwegian University of Science and Technology

Overview

The North Sea Offshore Grid (NSOG) is recognized as a priority project by the European Commission (European Union, 2013) as it serves the twofold purpose of integrating both renewable generation and markets, resulting in environmental and economic benefits. Despite these aggregate benefits for the system as a whole, a major challenge is the underlying incentives for multinational cooperation among countries (Egerer, 2013). There is no supra-national planner to decide system optimal investments or guarantee fair allocation of costs and benefits (Lumbreras, 2016), meaning that cost-efficient system designs are dependent on cooperation among surrounding countries.

This paper presents two prominent allocation methods from cooperative game theory that can be utilised to study fair and stable allocations for multinational projects. The two methods, Shapley value and nucleolus, are compared with the natual allocation that arise by doing no adjustments after projects are built. Hence, three concepts representing different principles of fairness is explored to properly represent features and qualities of the parties. For instance, the level of contribution or bargaining power a country represent in a cooperative solution (i.e. a multinational project). Each method comprise the following characteristics:

1. The natural allocation: Efficient markets will themselves achieve an optimal operating point. However, the allocation might be asymmetric and unstable.

2. The nucleolus: The maximum dissatisfaction that any country experience is minimized. That is, incentives to deviate from the allocation is minimized for all contries yielding a stable solution.

3. The Shapley value: The allocation is distributed with respect to the marginal contributions from each country. This is considered a “fair” allocation, but not necessarily stable.

Methods

A deterministic mixed-integer linear programming (MILP) problem is used for transmission expansion planning (TEP). An aggregated representation of the bordering countries Belgium, Germany, Denmark, Great Britain, the Netherlands and Norway are presented by open source data from ENTSO-E vision 4 and WindEurope. The already planned lines from Great Britain to Norway (North Sea Link), Germany to Norway (NordLink), and Denmark to Great Britain (Viking) are explored as multinational projects in the context of cost-benefit allocations. Each country is a player in a cooperative game. If two countries connected by a corridor are present in a coalition, capacity expansion becomes possible in the TEP model.

Necessary assumptions for establishing a cooperative game are explored. These are mainly internal stability, treatment of externalities, and transferable utility. The three allocation methods are checked for stability by utilising the concept of presence in the game core. The natural allocation is the outcome from full cooperation TEP, while algorithms are estabished to calculate the Shapley value and nucleolus. Both require a proper game representation. The latter is solved by a lexicographically extended linear minmax problem (Fromen, 1997).

Results

The three possible allocations were found to be stable. However, their magnitudes differs significantly due to their respective properties, as shown in Figure 1. Denmark and Norway are worse off in the natural allocation and correspondingly compensated by both the Shapley value and nucleolus. An interesting finding is the high nucleolus allocation to Norway. This is a result of her presence in the two most beneficial corridors, providing flexible hydropower capacity to the system. Consequently, Norway has multiple options between beneficial coalitions, which will affect the dissatisfaction the nucleolus tries to minimise. This means that Norway possess a relatively high bargaining power as, e.g., Germany and Great Britain are more dependent on Norway for their beneficial corridors, and is consequently awarded less by the nucleolus. Even less than what the Shapley value deem to be their contribution to the welfare.

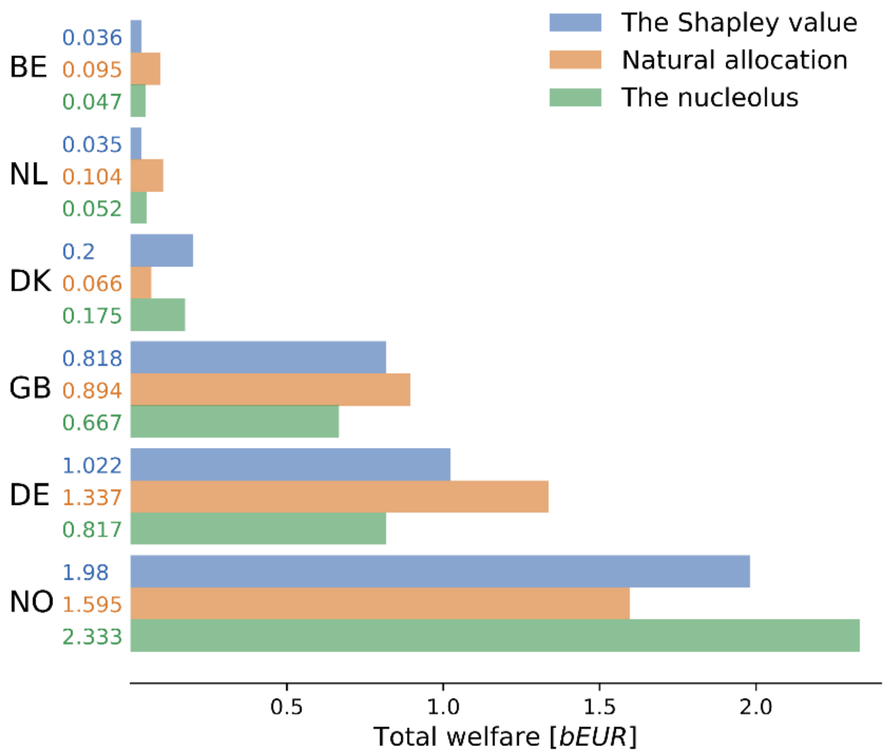

Figure 1 - Comparison of different allocation methods.

The allocations provide interesting results and insights regarding multinational projects for a NSOG. However, there are some weaknesses. Most prominently, the producer surplus decreases significantly for most countries compared to no expansion. This can result in strategic behaviour to counteract their outcomes and produce internal instability which can alter system results. Consumer surplus, which is defined in terms of intangible utility rather than economic profit, also provide challenges when allocating benefits where total welfare is used as payoff metric. However, the results show considerable welfare as congestion rent. This is economic profit available to the TSO for compensating producers or side payments to establish allocations.

Conclusions

The use of cooperative game theory can greatly increase the information and understanding of multinational projects, most notably through techniques to check for stability and fairness of different allocation principles. The most fair allocation will always be a question of subjective normative judgement. However, the different principles provide insight for both involved parties and regulators to perform well considered decisions.

References

B. Fromen, Reducing the number of linear programs needed for solving the nucleolus problem of n-person game theory, European Journal of Operational Research 98 (3) (1997) 626–636. doi: https://doi.org/10.1016/0377-2217(95)00341-X.

J. Egerer, F. Kunz, C. von Hirschhausen, Development scenarios for the north and Baltic seas grid a welfare economic analysis, Utilities Policy 27 (Supplement C) (2013) 123 – 134. doi: https://doi.org/10.1016/j.jup.2013.10.002.

S. Lumbreras, A. Ramos, The new challenges to transmission expansion planning. survey of recent practice and literature review, Electric Power Systems Research 134 (Supplement C) (2016) 19 – 29. doi: https://doi.org/10.1016/j.epsr.2015.10.013.

European Union, Regulation (eu) no 347/2013 (2013). URL: http://eur-lex.europa.eu/eli/reg/2013/347/oj