Modelling Complex Systems: The North Seas Offshore Grid and Future Research

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Overview

The North Seas offshore grid (NSOG) in Europe is a future offshore transmission system connecting offshore wind power and power systems in the North Seas. Such a grid is a priority corridor for the European Comission and will contribute to the 2030 Climate and Energy Policy framework goals, to the completion of the Internal Energy Market and to technological and industrial policy goals (European Commission, 2014).

Several research projects in the last years studied the NSOG, such as OffshoreGrid, Synergies at Seas, North Sea Transnational Grid or the collaboration between E3G and Imperial College. Despite these, there is still high uncertainty on the NSOG development drivers, governance form and how the multiple actors affecting it will coordinate investments and operation. Additionally, national policies, regulations and markets for investment and operation of offshore wind power, interconnectors and European power systems are far from adequate harmonization or coordination, with further research required.

As a complex system, studying and modelling the NSOG requires considering its many characteristics, choosing the correct model and assumptions according to the focus of research, and making and justifying those choices explicitly. This is necessary in order to provide relevant results, since a model of a complex system cannot represent all its aspects simultaneously (Mikulecky, 2001).

Reviews of energy systems modelling tend to classify them by method (top-down or bottom-up) and approach (optimization, equilibrium or simulation) (Pfenninger et al., 2014; Ventosa et al., 2005; Herbst et al., 2012). This research analyses challenges for future research for a NSOG by studying its characteristics, and listing and reviewing the recently published (from 2010 on) bottom-up modelling studies and results, asking therefore how the scientific community can contribute to the NSOG development.

Methods

First, characteristics of electricity transmission systems and the NSOG are presented. Then, a categorization framework is developed and used to review the NSOG bottom-up model studies, considering relevancy for research challenges, and the NSOG characteristics. Finally, this allows the identification of main future research areas.

Categories for the framework are derived from a preliminary analysis of the studies and of published reviews of energy systems. Additional sources include best practices for the development of wind integration studies from Holttinen (2013) and the NERC (2009), and the review of proposals up to 2009 for the NSOG of De Decker and Woyte (2013).

Results

The NSOG presents economies of scale, is lumpy and capital intensive, and path- and geography-dependent. It also requires unproven technology (multiterminal control strategies and DC breakers) with uncertain costs to connect variable and uncertain offshore wind power generation to multiple power markets, each with different characteristics and regulations. Studies of the NSOG must consider these characteristics to choose an adequate methodology.

The main research questions of the reviewed studies are investment & planning and policy & regulation, while an operation & reliability or technological focus is less frequent. This reflects the regulatory complexity and diversity of North Seas power systems and the influence they will have on the NSOG development, but there is an adequate balance between the main research questions of the studies.

Another important point is the methodology concerning the creation of the grid topology, given the geodependence of any NSOG modelling results. In this regard, approximately half the studies develop a NSOG through a transmission expansion analysis, identifying optimal transmission invesments through specified criteria and algorythms. On the other hand, the remaining studies source their NSOG transmission topology from 3rd party studies. Future studies of the NSOG must consider carefully the choice of the grid topology, and use of available topologies must be justified.

This review indicates almost all modelling uses mathematical optimization with the maximization of net social benefits, usually considering CO_2 emissions costs. This contrasts with the balanced approach to research questions, and since individual actor decisions will influence the NSOG development more research using equilibrium and simulation models is required.

Actor resolution is a significant gap in the presentation of study results, with only a third presenting net welfare detailed by producers, consumers and congestion rent. Future research should strive to always present results detailed per actor, especially since studies that did so found that welfare is unequally distributed not only at a national level, but also on an actor level, including net losers on both.
Finally, studies should improve the accessibility of data and assumptions used, a frequent finding in energy modelling literature reviews. Another improvement area for NSOG studies is considering a greater number of scenarios and parameters for sensititity analysis.

Conclusions

There is a wide body of research on NSOG modelling, which demonstrated the renewables and market integration benefits of more meshed grid topologies and analysed a range of policy and regulatory challenges, focusing investment & planning issues through bottom-up optimization methods.
However, consideration of impact of regulation such as support schemes, connection charges and transmission tariffs or permitting in the model parameters is rare and punctual, even though these are central questions to policy makers. Research on these more often than not uses other methods, such as top-down models, real and abstract case studies or legal analises.
Most reviewed studies focus on the optimal NSOG transmission investments considering scenarios of offshore wind power, then drawing descriptive recommendations for energy policy. Modelling and simulation can indeed be powerful economic and policy analysis tools, but this study indicates the NSOG is a very complex system with specific characteristics, and future research needs to use other modelling methods comprehensively.
Of the other available methods, bottom-up equilibrium and simulation models are underrepresented and can contribute to model development drivers by considering actor decisions and differences in regulations and markets endogenously. By doing so, they will also contribute to the planning theory of international restructured and complex power systems.
Besides the gap in model utilization, this review also indicates a number of best practices for future NSOG research. The most important are explicitation of data, assumptions and grid topology choice (and relevance to the research focus), and consideration of sensitivity analysis and multiple scenarios. These best practices are essential to allow the comparison of bottom-up energy model results and to drive research on the NSOG.
To conclude, the richness of results indicates the adopted methodology of comparing NSOG characteristics to studies characteristics and future research areas is an adequate one. The complexity of the NSOG, its current relevance and the many available studies contribute to this outcome.

References

De Decker, J., and A. Woyte (2013): “Review of the Various Proposals for the European Offshore Grid.” *Selected Papers from World Renewable Energy Congress - XI* 49 (0): 58–62.
European Commission (2014): “*A Policy Framework for Climate and Energy in the Period from 2020 to 2030”*.
Herbst, A., F. Toro, F. Reitze, and E. Jochem (2012): “*Introduction to Energy Systems Modelling”*.
Holttinen, H. (2013): “*Expert Group Report on Recommended Practices: 16. Wind Integration Studies”*. IEA Wind.
Mikulecky, D. C. (2001): “The Emergence of Complexity: Science Coming of Age or Science Growing Old?” *Computers & Chemistry* 25 (4): 341–48. doi:10.1016/S0097-8485(01)00070-5.
NERC, North American Electric Reliability Corporation (2009): “*Accommodating High Levels of Variable Generation”*.
Pfenninger, S., A. Hawkes, and J. Keirstead (2014): “Energy Systems Modeling for Twenty-First Century Energy Challenges.” *Renewable and Sustainable Energy Reviews* 33 (May): 74–86.
Ventosa, M., Á. Baíllo, A. Ramos, and M. Rivier (2005): “Electricity Market Modeling Trends.” *Energy Policy* 33 (7): 897–913. doi:10.1016/j.enpol.2003.10.013.