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Expansion planning of the North Sea offshore grid: Simulation of integrated governance constraints

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ABSTRACT

The development of offshore transmission and wind power generation in the North Sea of Europe is advancing fast, but there are significant barriers to an integrated offshore grid in the region. This offshore grid is a multi-level, multi-actor system requiring a governance decision-making approach, but there is currently no proven governance framework for it, or for the expansion planning of the European power system in general. In addition, existing offshore expansion planning models do not endogenously include governance considerations, such as country vetoes to integrated lines. We develop a myopic Mixed-Integer Linear Programming model of offshore generation and transmission expansion planning to study the effect of integrated governance constraints. These constraints limit investments in integrated lines: non-conventional lines linking offshore wind farms to other countries or to other farms. Each constraint affects the system (including the main transmission corridors), transmission technologies and welfare distribution differently. We apply our model to a long-term case study of the 2030–2050 offshore expansion pathways using data from the e-Highway2050 project. Results confirm that the offshore grid is beneficial to society. Integrated governance constraints induce a modest loss of social welfare, but do not change significantly the existing welfare distribution asymmetry between countries and actor groups. They do strongly affect the interaction of line technologies and types (conventional or integrated), so the impact of the integrated governance constraints is more visible on the grid topology than on welfare levels and distribution. We highlight the need to consider technology and type interactions in expansion planning, especially between multiterminal HVDC and integrated transmission lines. Also, an offshore governance framework should address the use of multiterminal HVDC in a non-integrated grid, but this is a second-best option compared to an integrated grid.

1. Introduction

We study the impact of integrated governance constraints on the generation and transmission expansion planning of the European North Sea offshore grid from 2030 to 2050. Governance is a main barrier to the expansion of the grid using integrated transmission lines (Dedecca et al., 2017a; Flament et al., 2015; Konstantelos et al., 2017), but was generally not addressed in the formulation of expansion planning models. In this introduction, to justify our research gap and objective we first present the following concepts: the integrated offshore grid, expansion planning, and governance.

1.1. The integrated North Sea offshore grid

A major driver for the offshore grid are the recent significant cost reductions for offshore wind, apparent in several competitive offshore auction results. Turbine technology and scale, innovation in supply chain processes, business models which reduced risks to developers and reduced financing costs all drove these cost reductions (IEA RETD TCP, 2017; WindEurope, 2017a). We define the North Sea offshore grid as the power system in the North Sea combining offshore power generation (particularly from renewable sources), offshore loads and transmission lines of different technologies.

Offshore conventional generation from fossil fuels and offshore loads (especially oil and gas platforms) may participate but are not as important a driver for the offshore grid as offshore generation from renewable sources (WEC, 2017). Thus, the focus of this study is the expansion of the latter, particularly offshore wind power. Offshore wind and transmission expansion bring economic, environmental and security of supply benefits to the European power system.

The North Sea offshore grid has two main functions: to interconnect offshore wind power plants to onshore systems, and to interconnect these national power systems among them (Dedecca and Hakvoort, 2016). Traditionally, conventional lines perform these functions separately: they either connect offshore farms to an onshore system, or

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interconnect two onshore power systems. In contrast, an integrated line performs both functions simultaneously. We define it as a line that directly connects an offshore wind farms to another wind farm or to an onshore node belonging to another country. While many studies use this nomenclature, these lines can also be called hybrid in the literature (EC and North Seas Countries, 2017; Konstantelos et al., 2017; PROMOTioN, 2017; PwC et al., 2016).

Fig. 1 presents illustrates offshore conventional and integrated lines between two countries. Using the concept of integrated lines, we define an integrated grid as a grid where the generation and transmission expansion planning considers both conventional and integrated lines, leading to the deployment of the two types.

An integrated offshore grid was recently supported by multiple European actors (Belet et al., 2016; EC and North Seas Countries, 2017). Several studies have demonstrated that this may be beneficial to society (Dedecca and Hakvoort, 2016; Konstantelos et al., 2017). Potential benefits include increased system reliability, more efficient generation dispatch, better exploitation of renewable resources, reduced environmental impacts, and reduction of onshore congestions. However, governance aspects such as regulatory differences, the distribution of costs and benefits and the planning of integrated lines are central barriers to an integrated grid (Dedecca et al., 2017a; Flament et al., 2015; Konstantelos et al., 2017).

Since the Dedecca and Hakvoort (2016) review, new studies appeared on the offshore grid, on offshore wind and on HVDC transmission, including Houghton et al. (2016), Konstantelos et al. (2017) and Kristiansen et al. (2017b). Rodrigues et al. (2015) overview the status of offshore wind worldwide, while WindEurope (2017b, 2017a) provide updated statistics and forecasts for offshore wind development. The European Network of Transmission System Operators for Electricity (ENTSO-E, 2016a) has published its latest European development plan, with an analysis of offshore grid projects. Finally, Van Hertem et al. (2016) review the aspects of planning, operation and modelling of HVDC grids.

1.2. Governance in expansion planning models

The expansion planning of power systems is defined as the process of identifying the most adequate investments in generation and

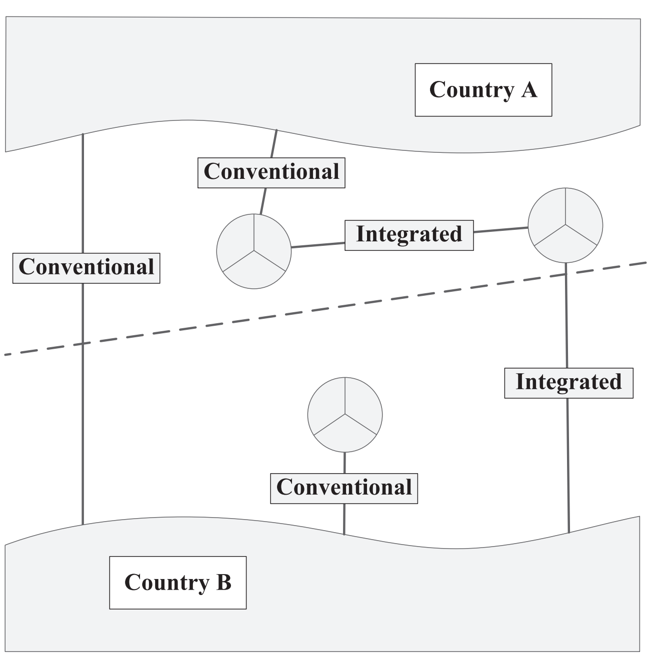

Fig. 1. Integrated and conventional offshore transmission lines.

transmission to guarantee the future system reliability given certain energy and climate policy objectives.

Lumbreras and Ramos (2016) list liberalization, increased penetration of renewable energy sources (RES), large-scale generation projects, long permitting times, and increased market integration and regional planning as new challenges to transmission expansion planning in Europe. To Conejo et al. (2016), the generation and transmission expansion planning in liberalized markets are conducted separately, being the responsibility of different actors. Nonetheless, 'generation and transmission expansion plans are clearly interrelated', which has spurred a number of works on joint expansion planning in liberalized markets.

These aspects and challenges of joint expansion planning make a new paradigm of decision-making necessary: governance (Scott and Bernell, 2015). We define governance as the combination of heterarchical (non-hierarchical) and possibly hierarchical institutions (formal and informal) that guide decision-making in a networked multi-level, multi-actor system, following Bevir (2011).

This form of decision making is also necessary for the expansion planning of the offshore grid, for the offshore grid is also a dynamic, multi-level, networked multi-actor system. Currently, offshore generation and transmission expansion planning is an individual prerogative of European countries, being conducted mainly at the national level (Saguan and Meeus, 2014; Tangerås, 2012). Regional transmission investment plans are non-binding and based on national transmission expansion plans. Moreover, neither the Energy Union nor cooperation initiatives in the North Seas alter this significantly or in a binding manner (EC, 2016a; EC and North Seas Countries, 2017).

One of the main barriers to an integrated grid is the distribution of costs and benefits among countries and actors, as for power systems in general. Thus, Konstantelos et al. (2017) identify "significant imbalances" in the distribution of benefits among consumers and producers and of investment costs among North Sea countries. To Delhaute et al. (2016) 'the distribution of costs and benefits is seen as one of the largest barriers for the development of multi-national assets like interconnectors in meshed structures'.

De Clercq et al. (2015) also indicate the distribution of costs and benefits as a major building block to a governance framework, indicating there is still not an agreed-upon redistribution methodology. Moreover, an integrated European planning process is best suited to assess the interaction and impact of multiple transmission lines, but may increase the complexity of the planning process and face the resistance of national authorities.

Hence, while governance at the regional and European levels of expansion planning is beneficial, the current governance frameworks are not adequate to address it. The distribution of costs and benefits and the complexity of the expansion planning process are particular issues for the North Sea offshore grid, but the majority of studies on offshore grid models of Dedecca and Hakvoort (2016) do not address these governance barriers endogenously. That is, these barriers constrained the models externally (e.g. through investment candidate portfolios) and not internally, through the models' formulation.

1.3. Integrated governance constraints

In summary, European expansion planning mainly occurs at the national level and does not consider integrated lines. The networked, multi-level and multi-actor aspects of European expansion planning argue for decision-making through governance, but there is no specific and tested governance framework for the offshore grid. Moreover, modelling studies have largely left the governance barriers for integrated lines unaddressed.

These barriers are modelled using integrated governance constraints, which represent governance barriers to the expansion planning of integrated lines. We include two types, the novel Pareto welfare and integration constraints described in Section 2.2. This is the first application of integrated governance constraints on a more detailed system