Energy Policy 51 (2012) 605–617

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Optimal interconnection and renewable targets for north-west Europe ☆

Muireann Á. Lynch [a,e,*], Richard S.J. Tol [b,c,d], Mark J. O'Malley [a]

[a] Electricity Research Centre, University College Dublin, Dublin, Ireland
[b] Department of Economics, University of Sussex, Brighton, East Sussex, UK
[c] Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands
[d] Department of Spatial Economics, Vrije Universiteit, Amsterdam, The Netherlands
[e] School of Electronic, Electrical and Communications Engineering, University College Dublin, Belfield, Dublin 4, Ireland

HIGHLIGHTS

- ▸ We use mixed-integer linear programming to determine optimal interconnection locations for given renewable targets.
- ▸ The model is applied to a test system for eight regions in Northern Europe.
- ▸ Interconnection reduces costs only when there is a renewable target.
- ▸ Wind integration costs affect the interconnection portfolio.

ARTICLE INFO

Article history:
Received 6 January 2012
Accepted 1 September 2012
Available online 23 September 2012

Keywords:
Electricity interconnection
Renewable generation
Mixed-integer linear programming

ABSTRACT

We present a mixed-integer, linear programming model for determining optimal interconnection for a given level of renewable generation using a cost minimisation approach. Optimal interconnection and capacity investment decisions are determined under various targets for renewable penetration. The model is applied to a test system for eight regions in Northern Europe. It is found that considerations on the supply side dominate demand side considerations when determining optimal interconnection investment: interconnection is found to decrease generation capacity investment and total costs only when there is a target for renewable generation. Higher wind integration costs see a concentration of wind in high-wind regions with interconnection to other regions.

1. Introduction

1.1. Context

Cross-border electricity transmission, which in a European context is referred to as interconnection[1] , is often presented as a panacea for various challenges that surface in electricity systems. Traditionally, electricity systems evolved in a relatively isolated manner, frequently with one dominant player for generation, supply and transmission. As liberalisation of electricity markets has become a policy aim in many jurisdictions, interconnection has been frequently proposed as the primary, if not only, means of increasing market integration across borders and mitigating market power (Gilbert et al., 2004; Brunekreeft et al., 2005; Neuhoff and Newbery, 2006). Interconnection between regions with a diverse demand profile could also serve to bring about a reduction in the range of the total demand curve. This can reduce generation costs by facilitating a proportional increase in cheaper inflexible generation plant, such as coal and nuclear, and reducing dependence on flexible high-cost peaking plant. Indeed, this is a primary rationale behind large scale power systems—that by meeting demand at an aggregate level, larger and cheaper generation plant can be built which can meet large portions of demand at lower cost. The reliability of the system could also be improved. Finally, as concerns over climate change and energy supply security lead to investment in renewable electricity, interconnection is proposed as a means of facilitating such investment by enabling a country or region with a significant level of intermittent renewable generation to export their surplus electricity and import when supply is low (De Jonghe et al., 2011; European Wind Integration Study, 2010; Eastern Wind integration and Transmission

☆ This work was funded by and conducted in the Electricity Research Centre, University College Dublin, Ireland, which is supported by the Commission for Energy Regulation, Bord Gáis Energy, Bord na Móna Energy, Cylon Controls, EirGrid, Electric Ireland, Energia, EPRI, ESB International, ESB Networks, Gaelectric, Intel, SSE Renewables, and UTRC.

* Corresponding author at: School of Electronic, Electrical and Communications Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
Tel.: +353-1-7161857.
E-mail address: muireann.lynch@ucdconnect.ie (M.Á. Lynch).

[1] Interconnection can also refer to generators connecting to the grid (for example in electricity systems in the USA). For the purposes of this paper interconnection is taken to mean cross-border transmission.

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.09.002

Study, 2011; Ostergaard, 2003). Thus the potential for interconnection to smooth both the supply and demand of electricity, particularly as intermittent renewable generation is increased, is seen as one of the major reasons for interconnection investment.

An increase in renewable energy is a stated aim of the European Commission (1996a,b) with targets in place which aim to source 20% of electricity from renewable sources by 2020 European Commission (2009a). Under Directive 2009/28/EC, this is to be achieved by imposing specific national targets for each individual country within the EU. Aune et al. (2012) find that a policy of differentiated national targets is not a cost-effective way to reach a certain renewable share, even if there is a market for renewable certificates. However, they do not consider the effect of increased interconnection on meeting renewable targets. The question of differentiated targets for individual regions as opposed to a global target is of relevance to other jurisdictions such as the USA, where many states have individual targets for renewable generation (Wiser and Bolinger, 2011).

1.2. Literature

Much of the literature on interconnection considers the effect of building a specific interconnector between two countries or between two regions within a country. Examples include Kanagawa and Nakata (2006), who use the META-Net economic modelling system to conclude that the utilisation of interconnection between Japan and Korea is largely determined by the generation plant mix and emissions or by nuclear energy policy. Schroder et al. (2010) use the WILMAR model to examine the implications of interconnecting Sweden, Germany and Denmark while incorporating an offshore wind farm in the North Sea and the Baltic Sea. Malaguzzi Valeri (2009) examines interconnection between Great Britain and Ireland and concludes that the socially optimal level of interconnection is higher than the level of interconnection likely to be delivered by market forces. This is due to the fact that interconnection tends to harmonise prices in the two connected markets, and so interconnection erodes its own value as an investment opportunity.

Interconnection also features in some generation resource planning models. De Jonghe et al. (2011) use a linear programming model to determine the optimal electricity plant mix with a high level of wind generation. They include existing interconnection in the model but do not examine the effects of adding more interconnection. Neuhoff (2008) includes wind variation and transmission constraints in an expanded investment-planning model, and calculates the additional cost savings from expansions in transmission capacity. Most studies in this area, however, consider interconnection levels as an exogenous variable and do not consider the effects of constructing new interconnection.

Unsihuary-Vila et al. (2011) use a multi-objective model to identify optimal generation and interconnection investments while attempting to find the best compromise between three objectives: minimise cost, minimise greenhouse gases and maximise diversification of the electricity generation mix. They find that no one objective produces a solution which satisfies the other two objectives and so use a weighted average of all three objectives to obtain the optimal solution. Their model is one of the few to include transmission as an endogenous variable, however specific results relating to interconnector investments are not reported, with the authors concentrating more on fuel mix and carbon emissions. The shortcomings of this paper include the fact that demand is included as three load-blocks of low, medium and peak demand over the planning horizon, and as such does not fully capture the variable nature of demand or renewable generation and any correlations between demand and renewable generation, which may constitute a major component of interconnector value.

Some of the more general work in this area studies the economic impacts of interconnection in terms of regulator and generator behaviour, and implications for markets. Brunekreeft et al. (2005) concludes that deep connection charging as well as locational marginal pricing (LMP) may be required to signal efficient investment locations, and that merchant interconnection, while raising new regulatory issues, may still be a suitable means of increasing interconnection. Neuhoff and Newbery (2006) find that integrated electricity markets lead to the highest social welfare, but consumer prices may increase in the short run. Brunekreeft (2005) addresses the regulatory issues pertaining to the regulation of merchant interconnection and concludes that competition law is sufficient to justify refraining from sector-specific arrangements. The optimal ownership and operation of interconnectors is also a well-developed strand in the literature. Brunekreeft and Newbery (2006) find that a regulatory decision to prohibit capacity withholding decreases welfare if the capacity withholding is due to uncertainty and demand growth, and increases welfare if the withholding is due to pre-emptive investment. Kristiansen and Rosellon (2006) propose a mechanism to incentivise investment in merchant transmission using long-term financial transmission rights (FTRs). Buijs et al. (2007) claim that under-investment in transmission in Europe is due to regulatory failures and that merchant interconnectors provide an acceptable alternative to regulated investments in transmission by TSOs.

1.3. Model

There has been little investigation of methods for determining optimal locations for specific interconnectors, other than in specific case studies examining the construction of a particular interconnector such as those mentioned above Kanagawa and Nakata (2006), Schroder et al. (2010), Malaguzzi Valeri (2009). Furthermore, the interaction between interconnection expansion and renewable generation has not been modelled extensively in the literature. Here we present a model which includes interconnector locations as an endogenous variable, thus solving for optimal interconnection for a given renewable target in an objective manner. Thus the impact of renewable targets on optimal interconnection expansion can be examined.

The model determines the optimal amount of investment in new generation capacity as well as optimal investment in interconnection. As such, the model captures the interdependent nature of generation capacity and interconnection rather than attempting to solely identify optimal interconnection investment for a given generation portfolio. This is accomplished by means of an iterative approach in which a linear program and then a mixed integer program are run for each year under investigation, with the linear program determining the optimal generation capacity and the mixed integer program determining optimal interconnection investment.

The model captures the increased capacity to balance supply and demand afforded by interconnection by including demand and renewable generation at an hourly resolution. The model can be used to examine the interchangeable nature of investment in generation capacity or interconnection. By including constraints in the model which require certain proportions of electricity generation to come from renewable sources, the complementary nature, if any, of interconnection and intermittent renewable generation can also be investigated. This is done by applying the model to a test system of eight Northern European countries from the year 2011 to the year 2030. Differentiated renewable targets for each country and a global renewable target are imposed, and the various effects on interconnection are identified.

The paper is structured as follows. Section 2 presents the model. Section 3 outlines the test system to which the model was applied. Section 4 presents the results and discussion. Section 5 concludes.