

# INTERCONNECTION INVESTMENT IN EUROPE

## Optimizing capacity from a private or a public perspective?

Hanneke de Jong\*, Rudi Hakvoort\*\*

\*[h.h.dejong@tbm.tudelft.nl](mailto:h.h.dejong@tbm.tudelft.nl)

\*\* [r.a.hakvoort@tbm.tudelft.nl](mailto:r.a.hakvoort@tbm.tudelft.nl)

\*/\*\* Faculty of Technology, Policy and Management, Delft University of Technology,  
Jaffalaan 5, NL–2628 BX Delft, the Netherlands.

\*\* E-Bridge Consulting, P.O. Box 173, NL–8330 AD, Steenwijk, the Netherlands.

### ABSTRACT

Scarcity of interconnection capacity between neighbouring electricity systems has been identified as one of the reasons for hampering market integration in Europe. This observation combined with the lack of much new public interconnection investment has induced the European legislator to opt for commercial alternatives. However, private investments in interconnection capacity are not straightforward. A public cost-benefit analysis for interconnection significantly differs from a private cost-benefit analysis. Consequently, the optimal investment capacity from a public perspective and a private perspective significantly differs which is shown in this paper by a quantitative analysis. Although it is true that in the short term a merchant interconnection increases the (physical) coupling of different electricity markets, the parties involved have a considerable interest to keep separate markets since the merchant investment must be recouped from exploitation of the trade potential across the link. A merchant interconnection could, thus, have the character of a Trojan horse, yielding more interconnection capacity in the short term, but proving an obstacle to real market integration in the long term. European policymakers need to be aware of that in their quest for European electricity market integration. There seems to be a need for creative alternatives that allow for merchant participation in interconnection investment while at the same time securing the long-term social welfare objective.

### 1. INTRODUCTION

The success of the European electricity market depends to a significant extent on the successful integration of the individual national markets. Due to market concentration in many of these markets, only international trade may give sufficient competitive pressure in the respective systems. For international electricity trade sufficient interconnection capacity needs to be available. For this reason, the European Commission intends to stimulate new investments in interconnection capacity and even opened the way for private parties to invest in new interconnection.

This paper analyses the difference between the public and private cost-benefit analysis regarding (European) interconnection investment. First, we reflect upon the role of interconnections in the

process of market integration and the introduction of merchant (private) investment. Section 3 shortly discusses the existing regulatory framework for both regulated and merchant investment. After this, we will focus on the various steps of the investment process both for regulated and merchant investments. In section 5, the interconnection cost-benefit analyses from public and private perspective are expanded by means of a quantitative analysis. Based on this analysis a case study is performed (in section 6) which points out the difference between the ‘optimum’ interconnection capacity to maximize private profit and the ‘optimum’ interconnection capacity to maximize social value. To conclude, some final remarks are made regarding monopolistic merchant investment.

### 2. INTERCONNECTION INVESTMENT

#### 2.1 Interconnections’ role in establishing the IEM

The ultimate goal of the European process of electricity market liberalisation is the creation of a single European electricity market (IEM). The integration of the present 25 more or less liberalised national markets into a single European market, or even in several regional markets, is however hampered by several factors, such as the existing differences among the Member States in organisation and regulation of the electricity industry, a high degree of concentration in many national generation markets, insufficient coordination and collaboration between regulated entities and regulatory authorities, and a limited amount of available interconnection capacity between neighbouring national electricity systems [1]. Before liberalisation, most European electricity networks were interconnected for the purpose of mutual assistance and in some cases with a view to carrying out long term import/export contracts for electricity [2]. However, in today’s liberalised electricity markets, the role of interconnections has been extended. By providing the physical connection between electricity markets, interconnections form the key to international trade. Recently, the European Commission concluded once again that more interconnection is needed to facilitate companies extending their activities into other regions outside their traditional areas in order to increase competition [3].

## 2.2 Introduction of merchant investment

Investments in interconnection capacity are part of the more general issue of transmission investment. In Europe, the high-voltage electricity transmission networks are owned and operated by ‘transmission system operators’ (TSOs). The costs incurred by a TSO, which may include investment in interconnection capacity, are normally recovered through regulated transport tariffs. These transport tariffs are separated from any charges for electricity as a commodity [2]. When interconnection capacity is limited, the available transmission capacity is allocated through market based congestion management mechanisms. Article 6 (6) of the Regulation 1228/2003 (hereafter: ‘the Regulation’) states that revenues resulting from the allocation of congested interconnection capacity shall be used for:

- (a) *guaranteeing the actual availability of the allocated capacity;*
- (b) *network investments maintaining or increasing interconnection capacities, or;*
- (c) *as an income to be taken into account by the regulatory authorities when approving the methodology for calculating network tariffs, and/or in assessing whether tariffs should be modified.*

In its Sector Enquiry the European Commission concluded that only about one quarter of the congestion revenues is used to build new interconnection or to reinforce existing grid elements [3]. This trend of limited interconnection investment combined with the priority of the EC policy objective of increasing interconnection capacity had induced the European legislator to offer a commercial alternative.

In particular where lasting price differences between markets exist, market parties might be interested themselves to invest in new interconnection capacity in order to capture the congestion rents or use the interconnection directly themselves. These ‘private’ interconnections are commonly referred to as ‘merchant interconnections’. In European context merchant interconnections differ on two main points from regulated interconnections. First, merchant investments are not regained through regulated (transport) tariffs but from revenues from future use of the investment, e.g. revenues induced by the price difference between two ends of the transmission line. The merchant investor therefore takes a commercial risk. Second, merchant interconnections can be developed by other parties than TSOs [2].

## 2.3 Merchant investment rationale

A justified question is why governments should allow merchant investment at all. After all, electricity transmission is generally considered to be a natural monopoly requiring regulation to secure efficient distribution of electric power through the system, open access for generators, traders and end consumers and quality of service. The main reason

for opening transmission investment to profit-motivated investors is that this may address the perceived problem of under-investment in transmission [4]. For example, merchant initiatives may be necessary in markets where vertically integrated incumbents may have poor incentives to invest in new transmission capacity [5]. A second motive concerns the situation where a (new) interconnection connects a high-price and a low-price market. The authorities at the side of the low-price market might be reluctant to agree, since the local market price is likely to increase (cf. [6]). A lack of political willingness to invest in a particular transmission line may form third motive; if other priorities are defined considering the usage of network revenues and there is insufficient political support to raise the regulated tariffs, only a merchant initiative may result in transmission capacity expansion [7].

## 3. REGULATORY FRAMEWORK

### 3.1 Framework for regulated interconnections

Investments in interconnection<sup>1</sup> capacity are part of the more general issue of transmission investment. The main sector-specific legislation has been elaborated in the Electricity Directives 96/92/EC and 2003/54/EC and the Electricity Regulation (EC) No. 1228/2003. For those issues for which no sector-specific legislation has been provided for, general EC law (the EC Treaty) is applicable [2].

Under the Electricity Directives, electricity networks are considered to be natural monopolies. Therefore, network operation remains an exclusive (‘monopolistic’) activity. However, power generation and supply of electricity to so-called eligible customers have become competitive activities. The Directive requires Member States or the owners of transmission networks to designate one or more TSOs. The TSO is not only charged with the task of operating and maintaining transmission networks, but also with the task of investing in (new) transmission capacity, including interconnection capacity. Normally, a TSO convinces its regulatory authority that a new interconnection is beneficial after which the investment costs are included in the rate base for the regulated tariff [2].

The new regime of the new Directive and the Regulation (2003) is also clear on third party access (tpa) which includes, in principle, also access to the interconnections of that network with other networks. Only if congestion exists on an interconnection, a congestion management method must be applied in order to determine the allocation of interconnection capacity. The use of revenues resulting from the allocation of interconnection capacity is regulated as elaborated in section 2.2.

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<sup>1</sup> The European Union defines an interconnection as ‘a transmission line which crosses or spans a border between Member States and which connects the national transmission systems of the Member States’.

### 3.2 Framework for merchant interconnections

Merchant DC interconnections<sup>2</sup> may, upon request, be exempted from third party access and/or concerning the use of the collected congestion rents. These exemptions can only be granted by the national ‘regulatory authority’ on a case-by-case basis [2]. After that, the exemption decision must be notified to the European Commission, which may request that the regulatory authorities concerned amend or withdraw the decision. The exemptions can only be granted under the conditions listed in Article 7(1) of the Regulation. These conditions state that the project should enhance competition in electricity supply, and that exempting it from regulation should not adversely affect the efficient functioning of the electricity market or the regulated transmission system [4].

#### First European merchant interconnection

On 27 april, 2004, the European Commission gave green light to the Estlink submarine cable project, connecting Estonia and Finland. The Estlink is in fact the first, and up till now the only, European merchant interconnection for electricity. The Estlink project was granted an exemption both from the general rules of tpa and the use of collected congestion rents but under some conditions concerning the duration of the exemption, the use of the cable capacity, tpa, transparency and unforeseen effects (see De Jong *et al.*, 2006).

With regard to access to a merchant interconnection a wide range of options is possible. A ‘full’ exemption of the obligation to provide tpa to the interconnection can be granted for the total capacity of the interconnection, without any further conditions. In this case, only general competition law applies [2]. The other extreme case is when no exemption is granted from the obligation to provide tpa. Without this exemption, the access regime for the merchant interconnection concerned must be in accordance with the general framework for tpa. (In this case, an exemption from Article 6(6) of the Regulation, concerning the use of the congestion rents, could still be granted). Between those two extremes, many ‘configurations’ are possible. In addition, a specific exemption granted may cover all or part of the new interconnection [2]. Conditions can be imposed regarding the duration of the exemption, and non-discriminatory access to the interconnection. When granting an exemption, the relevant authority may (even) approve or fix the rules and/or mechanisms on the management and allocation of capacity.

<sup>2</sup> A significant increase of capacity in existing interconnections or, in exceptional cases, alternating current (AC) interconnections can also be eligible for the exemptions provided for in Article 7 of the Regulation.

## 4. INVESTMENT PROCESS

### 4.1 Regulated vs. merchant investment process

One may conceptually distinguish four stages in the process of making an investment decision for interconnections, viz. the economic, financial, regulatory and decisive steps (see Figure 1).

#### Economic stage

Generally, a transmission investment can be initiated both by a merchant and a regulated investor. A merchant investor will perform a first assessment comparing the expected revenues with the expected investment cost. A regulated investor may perform a cost-benefit analysis on a higher level namely that of the social costs and benefits. However, the regulated party may also choose to start with a simple cost-benefit analysis.

#### Financial stage

If the first cost-benefit analysis turns out positively the merchant investor may now perform a more extended analysis in which uncertainty is included. Unpredictable events such as regulatory changes, long-term price developments, and possible additional parallel investments are carefully identified, analysed and accounted for in terms of a risk premium. A regulated party also has to take into account possible risk. Given the social perspective, the risks identified here may differ from those identified by the merchant party.

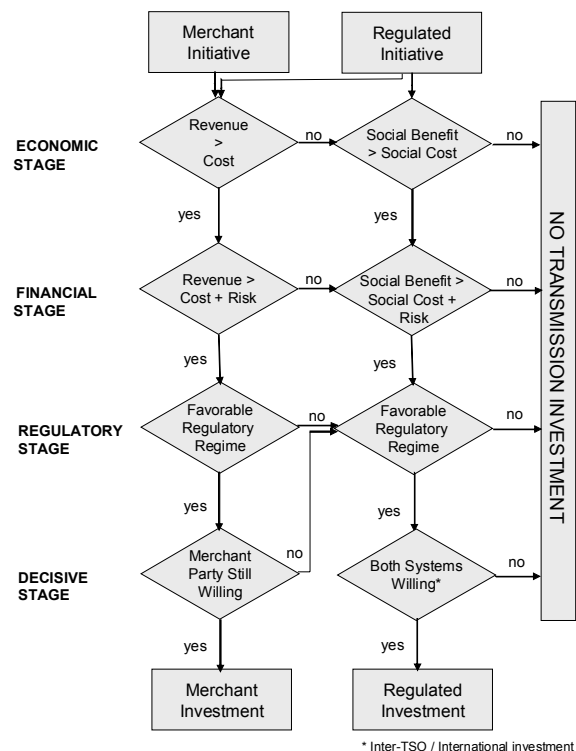


Figure 1: Conceptual representation of the interconnection investment process.

### Regulatory stage

If the extended cost-revenue analysis still turns out to be positive a merchant party needs regulatory approval to be exempted from the obligation to use the collected congestion rents for the purposes listed in European legislation and/or from the obligation to provide regulated tpa (see section 3.2). If a TSO proposes a regulated investment and is convinced that the social benefits of the investment exceed the social cost and risk, it also requires (national) regulatory approval. The relevant regulatory authority has to decide whether the proposed investment — to be recovered by regulated tariffs — is justified.

### Decisive stage

A regulatory authority may attach certain conditions to its approval of a merchant interconnection. The merchant investor should evaluate whether it is still willing to proceed under these new circumstances. If the merchant party abandons the project one could consider converting the merchant project into a regulated project.

With respect to a new regulated interconnection, both connected systems must be in favour of the new investment. Connecting a low price area with a high price area normally implies that the price in the low price area will increase [4]. If the authorities on both sides of the new connection have to give permission, the authorities on the low-price side may hesitate to agree. Here, the authorities may enter into negotiations on the fair distribution of the project cost and benefits. If no agreement is reached, this may imply that the investment is not made although it might be a valuable investment on overall welfare grounds.

### 4.2 Cost-benefit analysis: commercial or socio-economic analysis

A cost-benefit analysis of an interconnection investment consists of three main components: cost, revenues and risk. The cost, revenues and risk from a private perspective may differ from the ones from a public perspective. To illustrate this, table 1 categorizes the costs, revenues and risks related to the NorNed project<sup>3</sup>.

Table 1: Cost, revenue and risk for NorNed.

	Both commercial and social relevance	Only social relevance
<b>Cost</b>	<ul style="list-style-type: none"> <li>▪ Investment</li> <li>▪ O&amp;M</li> <li>▪ Connection cost</li> <li>▪ Interest cost</li> </ul>	Effect on: <ul style="list-style-type: none"> <li>▪ market liquidity</li> <li>▪ price stability</li> <li>▪ security of supply</li> <li>▪ prosperity</li> </ul>
<b>Revenue</b>	Operational revenue	
<b>Risk</b>	<ul style="list-style-type: none"> <li>▪ Actual operational revenue</li> <li>▪ Overrun construction cost</li> <li>▪ Project delay</li> <li>▪ Availability</li> </ul>	Additional cost for electricity system as a whole (extra operational cost or effect on other borders)

(source: De Jong *et al.* [7])

<sup>3</sup> 700 MW DC regulated submarine cable between Norway and the Netherlands (regulatory approval in December 2004).

For this project, a distinction has been made between cost, revenue and risk aspects that are relevant both from a private (commercial) and a public (social) perspective and cost, revenue and risk aspects that are additionally relevant from public perspective. Based on this overview one may expect that the commercial and socio-economic cost-benefit analysis respectively will result in a different choice of the optimum capacity. Consequently, taken into account the economies of scale in transmission investment projects [4], merchant investment may lead to significant underinvestment relative to the welfare optimum [8]. In the remainder of the paper this issue will be discussed based on a quantitative analysis.

## 5. COST-BENEFIT ANALYSIS: QUANTITATIVE ANALYSIS

### 5.1 Analysis of the social benefit

The objective of a regulated interconnection investment is to optimize social welfare. Apart from possible other effects (as mentioned in table 1), the main social benefit will consist of change in consumer and producer surplus in the markets involved. Consider a two-node network in which perfect competition exist in the generation supply market. Generation in node A is assumed to be relatively expensive with respect to generation in node B. On  $t=0$  there is no interconnection while on  $t=1$  the two nodes are connected by a line with capacity  $K$ .

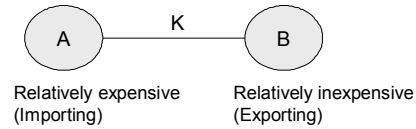


Figure 2: Two nodes connected by interconnection.

Demand ( $D$ ) and supply ( $S$ ) curves (price  $p$  versus quantity  $q$ ) are assumed to be linear and their slopes independent from available capacity deviations resulting from additional import or export.

### Analysis of importing node A

Assumptions for demand and supply curves:

$$D_A(q) = \alpha_d q + b \quad (1)$$

$$S_A(q) = \alpha_s q + c \quad t=0 \quad (2)$$

$$S'_A(q) = \alpha_s q + c - \alpha_s K \quad t=1 \quad (3)$$

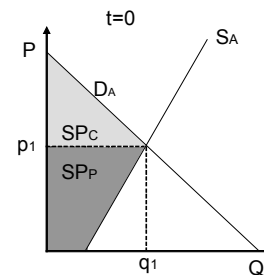


Figure 3: node A at  $t=0$ .

Consumer and producer surplus at t=0

Consumer surplus (SPc) at t=0:

$$SP_{c_{t=0}} = \int_0^{q_1} D_A(q) dq - p_1 q_1$$

$$= \frac{-\alpha_d (b^2 - 2bc + c^2)}{2(\alpha_s - \alpha_d)^2}$$
 (4)

Producer surplus (SPp) at t=0:

$$SP_{p_{t=0}} = \int_0^{p_1} S_A(p) dp$$

$$= \frac{\alpha_s^2 b^2 - 2\alpha_s^2 bc - \alpha_d^2 c^2 + 2\alpha_s \alpha_d c^2}{2\alpha_s (\alpha_s - \alpha_d)^2}$$
 (5)

Consumer and producer surplus at t=1:

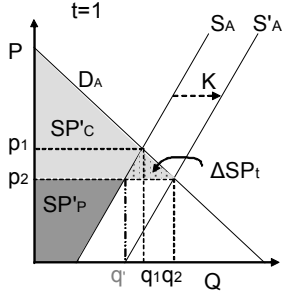


Figure 4: node A at t=1.

Consumer surplus (SPc) at t=1:

$$SP_{c_{t=1}} = \int_0^{q_2} D(q) dq - p_2 q_2$$

$$= \frac{-\alpha_d (b^2 - 2bc + c^2 + 2\alpha_s bK - 2\alpha_s cK + \alpha_s^2 K^2)}{2(\alpha_s - \alpha_d)^2}$$
 (6)

Producer surplus (SPp) at t=1:

$$SP_{p_{t=1}} = \int_0^{p_2} S_A(p) dp =$$

$$\frac{\alpha_s^2 b^2 - 2\alpha_s^2 bc - \alpha_d^2 c^2 + 2\alpha_s \alpha_d c^2 + 2\alpha_s^2 \alpha_d bK - 2\alpha_s^2 \alpha_d cK + \alpha_s^2 \alpha_d^2 K^2}{2\alpha_s (\alpha_s - \alpha_d)^2}$$
 (7)

Change in consumer surplus (ΔSPc) due to inter-connection K:

$$\Delta SP_C = SP_{c_{t=1}} - SP_{c_{t=0}} = \frac{-\alpha_s \alpha_d K (2b - 2c + \alpha_s K)}{2(\alpha_s - \alpha_d)^2}$$
 (8)

Change in producer surplus (ΔSPp) due to inter-connection K:

$$\Delta SP_p = SP_{p_{t=1}} - SP_{p_{t=0}} = \frac{\alpha_s \alpha_d K (2b - 2c + \alpha_d K)}{2(\alpha_s - \alpha_d)^2}$$
 (9)

Change in total consumer and producer surplus in node A (ΔSPt) due to interconnection K:

$$\Delta SP_t = \Delta SP_c + \Delta SP_p = \frac{-\alpha_s \alpha_d K^2}{2(\alpha_s - \alpha_d)^2}$$
 (10)

**Analysis of exporting node B**

Assumptions for demand and supply curves:

$$S(q) = \beta_s q + e$$
 (11)

$$D_B(q) = \beta_d q + d$$
 (12)

$$D'_B(q) = \beta_d q + d - \beta_d K$$
 (13)

Consumer and producer surplus at t=0:

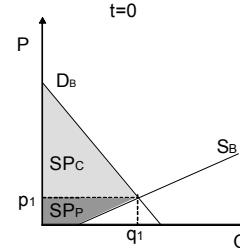


Figure 5: node B at t=0.

Consumer surplus (SPc) at t=0:

$$SP_{c_{t=0}} = \int_0^{q_1} D_B(q) dq - p_1 q_1$$

$$= \frac{-\beta_d (d^2 - 2de + e^2)}{2(\beta_s - \beta_d)^2}$$
 (14)

Producer surplus (SPp) at t=0:

$$SP_{p_{t=0}} = \int_0^{p_1} S_B(p) dp$$

$$= \frac{\beta_s^2 d^2 - 2\beta_s^2 de - \beta_d^2 e^2 + 2\beta_s \beta_d e^2}{2\beta_s (\beta_s - \beta_d)^2}$$
 (15)

Consumer and producer surplus at t=1:

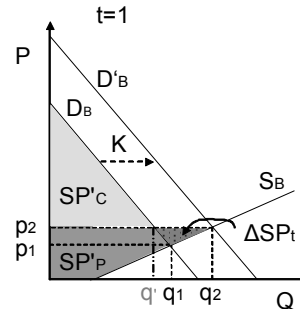


Figure 6: node B at t=1.

Consumer surplus (SPc) at  $t=1$ :

$$SP_{c,t=1} = \int_0^{q'} D_B(q) dq - q' p_2 \quad (16)$$

$$= \frac{-\beta_d(d^2 - 2de + e^2 - 2\beta_s dK + 2\beta_s eK + \beta_s^2 K^2)}{2(\beta_s - \beta_d)^2}$$

Producer surplus (SPp) at  $t=1$ :<sup>4</sup>

$$SP_{p,t=1} = \int_0^{p_2} S_B(p) dp \quad (17)$$

$$= \frac{\beta_s^2 d^2 - 2\beta_s^2 de - \beta_d^2 e^2 + 2\beta_s \beta_d e^2 - 2\beta_s^2 \beta_d dK + 2\beta_s^2 \beta_d eK + \beta_s^2 \beta_d^2 K^2}{2\beta_s(\beta_s - \beta_d)^2}$$

Change in consumer surplus ( $\Delta SP_c$ ) due to inter-connection  $K$ :

$$\Delta SP_C = SP_{c,t=1} - SP_{c,t=0} = \frac{\beta_s \beta_d K(2d - 2e - \beta_s K)}{2(\beta_s - \beta_d)^2} \quad (18)$$

Change in producer surplus ( $\Delta SP_p$ ) due to inter-connection  $K$ :

$$\Delta SP_p = SP_{p,t=1} - SP_{p,t=0} = \frac{-\beta_s \beta_d K(2d - \beta_d K - 2e)}{2(\beta_s - \beta_d)^2} \quad (19)$$

Change in total consumer and producer surplus node B ( $\Delta SP_t$ ) due to interconnection  $K$ :

$$\Delta SP_t = \Delta SP_c + \Delta SP_p = \frac{-\beta_s \beta_d K^2}{2(\beta_s - \beta_d)} \quad (20)$$

### Total social benefit

Based on the aggregated supply- and demand curves the import- and export price dependency curves (PDC) can be constructed. These curves depict how the price changes as a function of additional import or export (due to adding a new interconnection with capacity  $K$ ). Because the additional import for node A equals the additional export for node B the curves can be plotted in one figure. The total value of the new interconnection from a social perspective is also represented in Figure 7 ( $SP_E$ ).

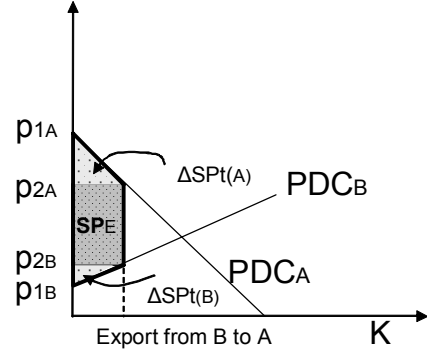


Figure 7: Import-export price dependency curves.

In Figure 7,  $PDC_A$  represents the price dependency curve in importing node A.  $PDC_B$  represents the price dependency curve of exporting node B. The area within the bold lines (stippled area) represents the total value of the new interconnection from a social perspective. Thus, the total value of the interconnection from social perspective equals the sum of  $\Delta SP_t(A)$  and  $\Delta SP_t(B)$  plus  $K*(P_{2A}-P_{2B})$ , as capacity  $K$  is not sold in node B (as the calculation above assumes [see formula 17]) but exported and sold in node A. These terms can be expanded as follows:

$$\Delta SP_{t(A+B)} = \Delta SP_{t(A)} + \Delta SP_{t(B)} \quad (21)$$

$$= \left( \frac{-\alpha_s \alpha_d}{2(\alpha_s - \alpha_d)} - \frac{\beta_s \beta_d}{2(\beta_s - \beta_d)} \right) K^2$$

$$K*(P_{2A} - P_{2B}) \quad (22)$$

$$= K \left( \frac{\alpha_s b - \alpha_d c + \alpha_s \alpha_d K}{\alpha_s - \alpha_d} - \frac{\beta_s d - \beta_d e - \beta_s \beta_d K}{\beta_s - \beta_d} \right)$$

$$= \left( \frac{\alpha_s \alpha_d}{\alpha_s - \alpha_d} + \frac{\beta_s \beta_d}{\beta_s - \beta_d} \right) K^2 + \left( \frac{\alpha_s b - \alpha_d c}{\alpha_s - \alpha_d} - \frac{\beta_s d - \beta_d e}{\beta_s - \beta_d} \right) K$$

Formula 23 then gives for the social value (benefit) of the interconnection  $B_{social}$ :

$$B_{social} = \Delta SP_{t(A+B)} + K(P_{2A} - P_{2B}) \quad (23)$$

$$= \left( \frac{\alpha_s \alpha_d}{2(\alpha_s - \alpha_d)} + \frac{\beta_s \beta_d}{2(\beta_s - \beta_d)} \right) K^2 + \left( \frac{\alpha_s b - \alpha_d c}{\alpha_s - \alpha_d} - \frac{\beta_s d - \beta_d e}{\beta_s - \beta_d} \right) K$$

Additional social benefits may be identified – such as a positive effect on price stability, security of supply or market liquidity – but quantification of these may turn out to be problematic in practice [9].

### 5.2 Analysis of the commercial benefit

The benefit for a merchant investor consists of the profits resulting from the price differences between the connected markets. A merchant investor may either directly profit from this price difference by

<sup>4</sup> In the analysis the assumption is made that producers are selling the extra capacity  $K$  in node B (see figure 5) while they actually export this capacity and sell it in node A. This assumption has to be taken into account when calculating the total social benefit resulting from the interconnection.

purchasing electricity at the cheap side and selling it into the expensive market, or indirectly by selling the interconnection capacity to market parties. The revenues of the interconnection are therefore given by the available interconnection capacity times the value of that capacity (which equals the price difference, cf. [8]; see Figure 8).

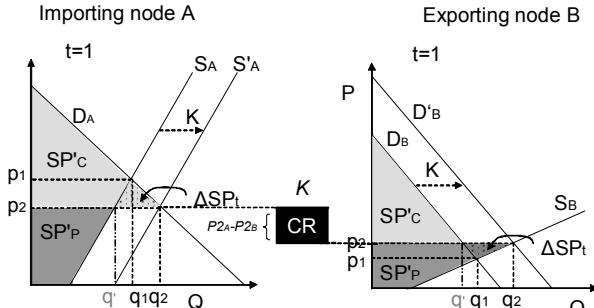


Figure 8: The commercial benefits of an interconnection consisting of congestion rents (CR).

The commercial benefits (congestion rents)  $B_{private}$  from investing in a new interconnection with capacity  $K$  are therefore (see also formula 22):

$$B_{private} = CR = K * (P_{2A} - P_{2B}) = \left( \frac{\alpha_s \alpha_d}{\alpha_s - \alpha_d} + \frac{\beta_s \beta_d}{\beta_s - \beta_d} \right) K^2 + \left( \frac{\alpha_s b - \alpha_d c}{\alpha_s - \alpha_d} - \frac{\beta_s d - \beta_d e}{\beta_s - \beta_d} \right) K \quad (24)$$

### 5.3 Relation between social and private benefit

A comparison of formulas 23 and 24 reveal the following relation between the social benefits and the commercial benefits from an interconnection investment with capacity  $K$ :

$$B_{private} = \delta K^2 + \phi K \quad (25)$$

$$B_{social} = \frac{1}{2} \delta K^2 + \phi K \quad (26)$$

where:

$$\delta = \frac{\alpha_s \alpha_d}{\alpha_s - \alpha_d} + \frac{\beta_s \beta_d}{\beta_s - \beta_d}$$

$$\phi = \frac{\alpha_s b - \alpha_d c}{\alpha_s - \alpha_d} - \frac{\beta_s d - \beta_d e}{\beta_s - \beta_d}$$

Consequently, the capacity maximizing social benefit is twice the capacity maximizing private benefit. Furthermore, also the actual benefits resulting from these capacities differ by a factor of 2 (see Figure 9). This relation may however change when one takes investment cost into account. The next section therefore focuses on the cost side of the cost-benefit analysis.

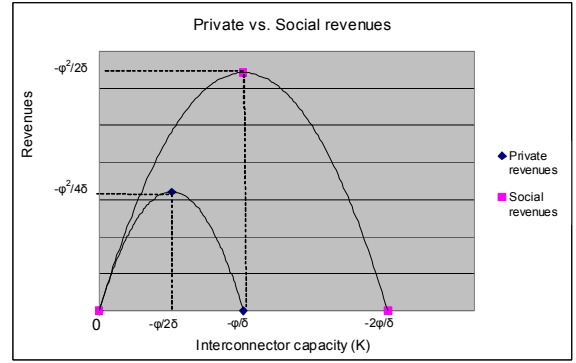
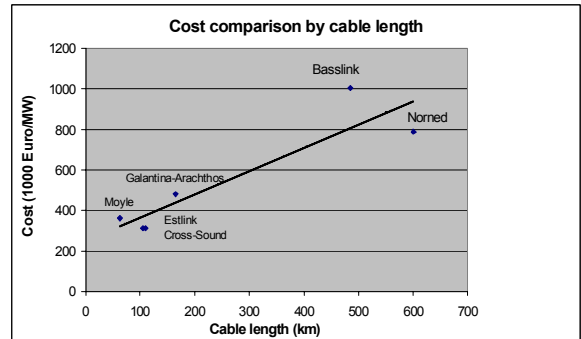


Figure 9: Optimum social and commercial benefits.

### 5.4 Costs of interconnection

Transmission investment is characterized by several special features. In the first place, transmission is a capital intensive business. Then, transmission investments are lumpy in the sense that they can only be installed economically in sufficient large unit sizes. Moreover, the transmission assets are usually designed for an expected lifetime ranging from 20 to 40 years, or even longer [10]. DC interconnection costs typically depend linearly on the cable length. Finally, transmission investments are ‘sunk’ investments; the resale value of the assets is low and transmission capacity cannot economically be relocated. Figure 10 visualizes the relation between total investment costs per MW and cable length of six different submarine DC cable projects [7].



Basslink: Tasmania - Australia  
Galatina/Arachthos: Italy - Greece  
Cross-Sound: Connecticut - Long Island  
Moyle: Scotland - Northern Ireland  
Estlink: Estonia - Finland  
NorNed: Netherlands - Norway

Figure 10: Relation between investment cost and cable length.

### 5.5 Cost elements

In this section, an estimate will be made of the cost of investing in interconnections in order to complete the cost-benefit analysis. The estimate is however limited to DC (direct current) cables as these are to be preferred for commercial links (due to the possibility to control the power flow through the cable).

#### Cable construction cost

Economies of scale in the construction of transmission lines are substantial [4]. Figure 11 shows the economies of scale based on real construction cost for above ground DC interconnections exclusive

right-of-way and converter cost [11]. The figure plots average cost (\$/MW/mile) in relation to the line's capacity. It suggests that beyond 750 MW long-run marginal costs are nearly constant. The extent of economies of scale depends on the fixed costs of the optimal technology relative to the size of the market [4].

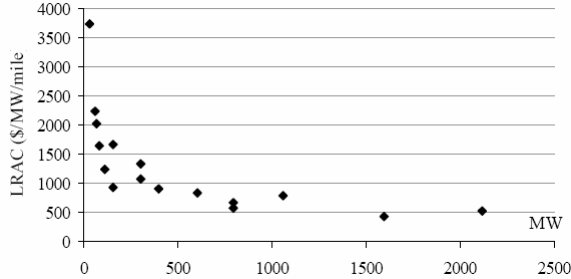


Figure 11: Economies of scale in transmission infrastructure (source: [4], cost in 1995 dollars).

### Converter cost

For DC interconnections AC/DC converter cost are substantial. Newbery et al [11] have shown that converter cost can be estimated by:

$$C_{converter} = \frac{K}{100} * 25MEuro \quad (27)$$

### Regulatory and environmental cost

Practical experience with DC interconnection has shown that delays and significant extra cost due to environmental rejections are rather rule than exception. For example, in the Basslink, as well as the Cross-Sound and Galatina-Arachthos projects the additional cost due to environmental opposition were significant [12]. Based on projects already completed, TCA [12] has concluded that the additional cost due to environmental and regulatory issues can be estimated as 25% of the total construction costs (cable and converters). In addition Brunekreeft [4] has observed that right-of-way charges may dominate the cable construction costs and may cause capacity expansion costs to have constant or even decreasing scale effects.

### O&M

Annual operation and maintenance cost of DC interconnections can be estimated as 3% of the total investment cost [12].

### Cost overrun

Roughly one fifth of large DC interconnection projects (submarine cables) are confronted with demonstrable budget overruns [9]. Only a small percentage overruns in large DC interconnection project correspond to large nominal amounts. For example, DTE took into account an overrun of 10% regarding the NorNed project [9].

### 5.6 DC interconnection investment cost

Based on the above cost estimates, the interconnection cost for DC cables between 150 and 1500 MW may (roughly) be calculated by the following formula:

$$C = \eta\omega\lambda(\phi K + v)KL + \omega K = (\eta\omega\lambda\phi L)K^2 + (\eta\omega\lambda(vL + \omega))K \quad (28)$$

where:

$\phi K + v$  = average investment cable construction (cost/MW/km)

$\omega$  = inverter cost/MW

L = cable length

$\eta$  = regulatory and environmental cost factor

$\sigma$  = O & M cost factor

$\lambda$  = risk factor cost overrun

The cable construction costs in this formula are assumed to be linear ( $\phi K + v$ ). Based on Figure 10 – corrected for inflation, longitudinal measurement and monetary unit – the value of  $\phi$  and  $v$  can be estimated by approximating the average interconnection construction cost (AIC) for links between 150 MW and 1500 MW as:

$$AIC(Euro / MW / km) = -0,447K + 1007 \quad (29)$$

In the following section, these estimates will be used for assessing the social and private investment optimum of a fictive link between two market areas.

## 6. CASE STUDY

### 6.1 Case description

Consider two nodes A and B as given in Figure 12. The question is now to assess the optimum capacity of the link in order to achieve maximum commercial profits and to achieve maximum social value.

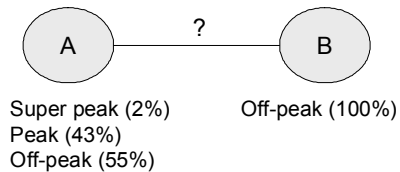


Figure 12: Case description

We assume a distance between the two nodes of 600 km. For node A we assume that 2% of the time a super peak price exists, 43% of the time there is a peak price situation and 55% of the time an off-peak situation which are typical value for e.g. the Netherlands. Node B is assumed to be always in an off-peak situation.

### 6.2 Relevant demand and supply curves

The relevant demand curves are based on three different hours (super peak, peak and off peak) on the Amsterdam Power Exchange (see Figures 13, 14 and 15). For these selected hours, the linear functions of

the relevant demand and supply curves are derived by means of linear regression around their intersection.

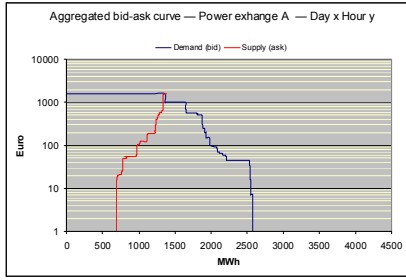


Figure 13: Supply and demand curves for a super peak hour (APX, 11-08-2003, hour 11)

$$\text{Demand curve} = 1,73q + 35,8 \cdot 10^2 \quad (R^2 = 0,91)$$

$$\text{Supply curve} = 8,10q - 97,7 \cdot 10^2 \quad (R^2 = 0,75)$$

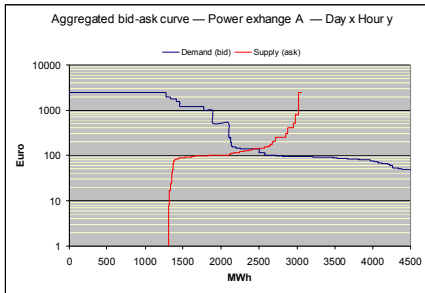


Figure 14: Supply and demand curves for a peak hour (APX, 03-03-2006 hour 11)

$$\text{Demand curve} = -0,0392q + 224 \quad (R^2 = 0,91)$$

$$\text{Supply curve} = 0,0965q - 86,6 \quad (R^2 = 0,71)$$

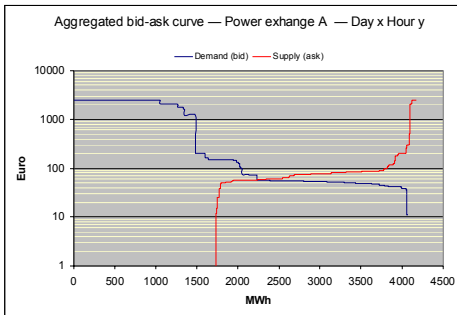


Figure 15: Supply and demand curves for an off peak hour (APX, 03-03-2006 hour 1)

$$\text{Demand curve} = -0,0203q + 118 \quad (R^2 = 0,74)$$

$$\text{Supply curve} = 0,0252q + 2,637 \quad (R^2 = 0,94)$$

Subsequently, from the demand and supply functions we derive the parameters  $\delta$  and  $\varphi$  (see Formula 25 and 26) for calculating the social and private benefit. Three situations can be identified here:

- **Situation 1 (2% the time)**  
Node A: super peak (SP), Node B: off peak (OP)
- **Situation 2 (43% the time)**  
Node A: peak (P), node B: off peak (OP)
- **Situation 3 (55% the time)**  
Node A: off peak (OP), node B: off peak (OP)

The results for each situation are given in Table 2.

Table 2: Parameters for benefit calculation.

Situation	$\delta$	$\varphi$
1. $A(SP) - B(OP)$	-1,44	$11,6 \cdot 10^2$
2. $A(P) - B(OP)$	-0,0391	67,7
3. $A(OP) - B(OP)$	-0,0225	0

From this, the average value of  $\delta$  and  $\varphi$  follow:

$$\delta = 0,02\delta_1 + 0,43\delta_2 + 0,55\delta_3 = -0,0580 \quad (30)$$

$$\varphi = 0,02\varphi_1 + 0,43\varphi_2 + 0,55\varphi_3 = 52.3 \quad (31)$$

### 6.3 Optimum interconnection capacity

Based on formulas 25 and 26 we can now calculate the interconnection capacities that maximise private respectively social benefit:

$$K_{private\_max\ benefit} = \frac{-(nAr_f\varphi)}{2nAr_f\delta} = 451MW \quad (32)$$

$$K_{private\_max\ benefit} = \frac{-(nAr_f\varphi)}{nAr_f\delta} = 902MW \quad (33)$$

where:

$n = 219 \cdot 10^3$  (the number of operational hours, assuming an economic lifetime of 25 years [9]).

$r_f = 0,314$  (risk factor concerning the benefits based on a risk factor percentage of 12% [9][12] and an economic life time of 25 years. This risk factor is high because the price development for a period of 25 years is very unpredictable [7]. We assume that the cables are financed out of private capital and the high project risk is taken into account by means of a high risk factor on project benefits).

$A=0,96$  (average interconnection availability [12]).

### 6.4 Interconnection capacity to maximize social value versus private profit

If we now include cost in our analysis, the capacities of the interconnection to maximize private profit respectively social value are derived for our typical case as follows:

$$K_{private\_optimal} = \frac{-(nAr_f\varphi - \eta\phi\lambda vL - \eta\phi\lambda\omega)}{2(nAr_f\delta - \eta\phi\lambda\phi L)} = 228MW \quad (34)$$

$$K_{social\_optimal} = \frac{-(nAr_f\varphi - \eta\phi\lambda vL - \eta\phi\lambda\omega)}{nAr_f\delta - 2\eta\phi\lambda\phi L} = 567MW \quad (35)$$

where:

$\lambda = 1,10$ : cost overrun, see section 5.5.

$\eta = 1,25$ : environmental/regulatory cost, see section 5.5.

$\phi = 1,696$ : O&M, see section 5.5 net present value based on economic lifetime of 25 years and interest rate of 3%.

$\omega = 250 \cdot 10^3$ : converter cost, see section 5.5.

$L = 600$ : cable length, assumption, see description case.

$v = 1007$ : cable construction cost, see section 5.6.

$\Phi = -0,447$ : cable construction cost, see section 5.6.

From the formulas 34 and 35 it can be concluded that the interconnection capacity to maximize social

value exceeds the capacity to maximize private profit by more than a factor of two.

## 7. MONOPOLISTIC INVESTMENT

Obviously, any additional interconnection capacity in parallel to the merchant interconnection would decrease the value of the merchant interconnection, so investors in merchant interconnections would try to prevent the construction of any additional, competing capacity. Kuijlaars and Zwart [8] have pointed out that merchant investment may lead to severe underinvestment relative to the welfare optimum, as the economies of scale involved in such projects may lead to foreclosure of the market by the first mover (by constructing capacity up to the no-entry point).

Another scenario is that a merchant party is able to allow itself to invest in less capacity than the profit maximizing optimum, for example with a view of maximizing return on investment instead of maximizing the profits on this particular investment. In this case the merchant investor must ensure that there is no satisfactory business case left for additional regulated or private investment. The latter scenario may result in a situation where the ultimate merchant investment level is even further from the social optimum.

## 8. CONCLUSIONS

Scarcity of interconnection capacity between neighbouring electricity systems has been identified as one of the reasons for hampering market integration. This observation combined with the trend of limited interconnection investment has induced the European legislator to offer a commercial alternative. Notwithstanding the policy intentions of the European Commission, private investments in interconnection capacity are not straightforward. A public cost-benefit analysis for interconnection significantly differs from a private cost-benefit analysis. Consequently, the optimal investment capacity from public perspective and private perspective significantly differs which is shown by means of a quantitative analysis. Moreover, the analysis illustrates that the interconnection capacity maximizing social value exceeds the capacity maximizing private profit by more than a factor of two.

It is true that in the short term a merchant interconnection increases the (physical) coupling of different electricity markets. However, as the merchant investment must be recouped from exploitation of the trade potential across the link, the parties involved have a considerable interest to keep separate markets. Especially when the merchant first mover succeeds in foreclosing the market both for regulated and merchant interconnections, a merchant interconnection could, thus, have the character of a Trojan horse [2], yielding more interconnection capacity in the short term, but proving an obstacle

to real market integration on the long term. European policymakers need to be aware of that in their quest for European electricity market integration and would do wise to start searching creative alternatives that allow for merchant participation in interconnection investment while at the same time securing the long-term social welfare objective.

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