Redistribution through cross-border electricity trade: How to achieve Pareto improvement?

AUTHORS

Polina Emelianova

Pia Hoffmann-Willers

Oliver Ruhnau

EWI Working Paper, No 25/11

Dezember 2025

Institute of Energy Economics at the University of Cologne (EWI)
www.ewi.uni-koeln.de

Institute of Energy Economics
at the University of Cologne (EWI)

Alte Wagenfabrik
Vogelsanger Str. 321a
50827 Köln
Germany

Tel.: +49 (0)221 277 29-100
Fax: +49 (0)221 277 29-400
www.ewi.uni-koeln.de

CORRESPONDING AUTHOR

Polina Emelianova
polina.emelianova@ewi.uni-koeln.de

ISSN: 1862-3808

Redistribution through cross-border electricity trade: How to achieve Pareto improvement?

Polina Emelianova[a,*], Pia Hoffmann-Willers[a], Oliver Ruhnau[a,b]

[a] *Institute of Energy Economics at the University of Cologne (EWI), Germany*
[b] *University of Cologne, Faculty of Management, Economics, and Social Sciences, Germany*

Abstract

The international integration of electricity markets offers numerous benefits but can lead to substantial redistribution between consumers and producers, which can be politically challenging to overcome. Several European interconnector projects have recently been canceled, despite being expected to enhance welfare. This article analyzes the distributional effects of interconnector expansion and identifies policy options that help achieve Pareto improvement. We first use an analytical model to analyze trade between two electricity markets and to derive general conditions under which the asymmetric sharing of interconnector costs and rents can avoid consumer losses in the exporting country. Second, we employ a numerical model of the European power sector to assess the real-world example of the canceled Hansa PowerBridge interconnector between Germany and Sweden. For the current electricity market configuration, we find that asymmetric sharing of interconnector costs and rents is likely insufficient to compensate losses of Swedish consumers, but the additional redistribution of increased surplus by Swedish state-owned producers could achieve Pareto improvement—even under external shocks. For an alternative market configuration with a German bidding zone split, the Hansa PowerBridge is expected to become Pareto-improving without requiring additional transfers. We conclude that the asymmetric sharing of interconnector costs and rents, the redistribution of surplus from state-owned or state-backed producers, and the reconfiguration of bidding zones are important policy levers to render welfare-enhancing interconnector projects Pareto-improving.

Keywords: Electricity trade, welfare effects, redistributive policy, Pareto improvement

JEL classification: C61, D47, Q41, Q48

*Corresponding author.

Email addresses: polina.emelianova@ewi.uni-koeln.de (P. Emelianova), pia.hoffmann-willers@ewi.uni-koeln.de (P. Hoffmann-Willers), oliver.ruhnau@ewi.uni-koeln.de (O. Ruhnau).

1. Introduction

The cross-border integration of electricity markets offers numerous benefits: system costs are reduced through dispatch cost optimization across countries; market power is mitigated through international competition; and supply becomes more secure through sharing supply resources within the interconnected area (Newbery et al., 2016). Expanding interconnection increases overall welfare whenever the benefits of the enhanced possibility to trade electricity exceed expansion costs. In Europe, for example, the welfare gains of interconnection were estimated to be approximately 34 billion EUR in 2021 (ACER, 2022b), and transmission system operators (TSOs) assume similar benefits in more recent years.[1] Market integration may become even more beneficial when energy systems are decarbonized, given the potential to reduce the integration costs of renewable energy sources (RES) (Fell et al., 2021; Gonzales et al., 2023).

However, the benefits of increased integration often come with substantial distributional implications. For instance, if a new interconnector is built between a market E with previously low electricity prices and a market I with previously high prices, electricity is exported from market E to market I, and prices rise in market E and fall in market I. As we will show below, with an optimally sized interconnector and symmetric sharing of interconnector costs and rents[2], welfare increases in both markets. However, producers in market E and consumers in market I win, but consumers in market E and producers in market I lose from the new interconnector. Interconnector expansion can thus lead to substantial redistribution within and between markets, creating win-lose situations.

These distributional consequences can lead to domestic political opposition against interconnector expansion, which can be challenging to overcome. One example of a recently canceled project is the Hansa PowerBridge, an additional interconnector between Sweden and Germany planned to be commissioned by around 2035 (Svenska Kraftnät, 2023). Despite the previously estimated increases in socio-economic welfare[3] for the year 2035 of 74 to 117 million EUR for Germany (50Hertz, Amprion, TenneT, TransnetBW, 2020; Voswinkel et al., 2022) and 30 to 150 million EUR for Sweden (Svenska Kraftnät, 2023), the project was canceled in June 2024 due to concerns about rising electricity prices in Sweden (50Hertz, 2024; Reuters, 2024). Similarly, the NorthConnect cable, intended to connect Norway and the UK, was put on hold in 2020 and officially canceled in March 2023 due to political concerns about rising electricity prices in Norway (Offshore Energy, 2023), despite the predicted welfare gains of about 100 to 400 million EUR per year

[1] According to personal communication with one of the German TSOs.
[2] Interconnector costs include mostly the investment, and interconnector rents arise from remaining price differences between the importing and exporting markets.
[3] For simplicity, we consistently use the term welfare throughout the paper to refer to socio-economic welfare.

(NorthConnect, 2015). Reasons why consumer opposition in exporting countries dominates public debates may include the higher visibility of consumer losses via electricity bills and the heavy electoral weight of consumers.[4]

This article examines two policy options that may help achieve Pareto improvement, which we define as a situation in which welfare and consumer surplus increase in at least one country and do not decline in the other.[5] The first policy option leverages the common European practice of TSOs of the connected countries jointly building and operating new interconnectors. Within this setting, we assess whether Pareto improvement can be achieved in terms of both welfare and consumer surplus through an asymmetric sharing of interconnector costs and rents between the TSOs, given that these are passed through to consumers via grid fees. While this policy option is explicitly mentioned in European cross-border cost allocation guidelines, it has rarely been used and not yet been systematically assessed (see Subsection 2.1). The second policy option builds on the fact that a sizable share of European electricity generation is state-owned, such as Vattenfall in Sweden, or state-backed, such as renewable generators under contracts for differences. Against this background, we analyze whether redistributing increased surplus from state-owned or state-backed producers to consumers in the exporting country can achieve Pareto improvement.

To analyze the above, we first develop an analytical model of two electricity markets to formally derive the impact of connecting them on consumer surplus, producer surplus, and welfare. We show that, for an optimally sized interconnector and symmetric sharing of interconnector costs and rents, welfare increases in both markets. This implies that the possibility of achieving Pareto improvement through redistributing increased surplus from state-owned or state-backed producers to consumers in the exporting market depends on the share of producers that is state-owned or state-backed. Furthermore, we derive the conditions under which an asymmetric sharing of interconnector costs and rents can achieve Pareto improvement, which depend on the sizes of the connected markets, the relative slopes of their supply curves, and the amount of the redistributable interconnector costs and rents.

Second, we further develop and apply a numerical model of the interconnected European electricity market to a real-world example: the canceled Hansa PowerBridge interconnector between Germany and Sweden. The numerical model enables us to estimate welfare gains and distributional effects of the interconnection expansion in 2035 and to assess whether Pareto improvement can be achieved for the two aforementioned

[4]For the example of Sweden, the spatial heterogeneity of consumer losses compounds opposition dynamics: interconnection-induced price increases are expected to be most pronounced in the southern bidding zone, triggering opposition from local consumers and energy-intensive industries (SKGS, 2024).

[5]We focus on consumer surplus and neglect producer surplus because of the observed focus of political debates on consumer losses.

policy options. Furthermore, we use our numerical model to assess the role of market configurations in achieving Pareto improvement. Specifically, we investigate the implications of an inner-Swedish grid expansion and a German bidding zone split for the necessity and effectiveness of redistributive policies. Finally, we test the robustness of our numerical results toward external shocks, namely, high fuel prices and low availability of RES.

Several previous studies provide evidence of welfare gains and redistribution through interconnector expansion. For example, by applying a numerical dispatch model, Valeri (2009) shows that interconnection between Ireland and Great Britain enhances welfare in both countries, but decreasing prices in Ireland and increasing prices in Great Britain affect various groups differently: Irish consumers and British producers gain, while Irish producers and British consumers may experience losses. Di Cosmo et al. (2020) find that interconnection between France and Ireland increases consumer surplus and decreases producer surplus in both markets, as mutual trade can reduce high prices in each market due to structural complementarities in electricity supply (France's nuclear generation and Ireland's wind generation). Urquijo and Paraschiv (2023) highlight the asymmetric effects of an interconnector expansion between France and Spain: Spanish consumers benefit from lower prices and Spanish emissions are reduced through the substitution of domestic fossil electricity generation with imports, while the impacts on the French market remain limited.

Comparatively few studies analyze the implications of and potential remedies for the distributional consequences of interconnector projects. Supponen (2011) highlights that balancing the maximization of societal benefits with a fair cost and benefit distribution is essential to further integrate EU electricity markets. He discusses the asymmetric sharing of interconnector costs and rents as a potential means to address distributional concerns, but without a quantitative assessment of such mechanisms. Asymmetric sharing of interconnector costs is also proposed by Huang et al. (2016) and justified by the beneficiary-pays-principle. The paper argues that allocating investment costs to benefiting stakeholders can facilitate investment decisions that enhance overall welfare. In addition to asymmetric cost and benefit allocation, Willems et al. (2025) recommends adjusting network tariffs to better reflect the distribution of benefits and investment risks, particularly by changing the structure of the injection charges.

We make three contributions to this existing literature. First, we quantitatively analyze the effectiveness of asymmetric sharing of interconnector costs and rents, which has previously been mostly qualitatively discussed. Second, we assess the redistribution of additional surplus from state-owned or state-backed producers to consumers, which has not yet been discussed in the literature. Third, we investigate the role of market configurations — namely, within-country grid expansion and bidding zone reconfiguration

— in achieving Pareto-improving interconnector expansion. Beyond the specific topic of interconnector expansion, we contribute to the broader literature on the distributional effects of electricity market design, including renewable electricity subsidies (Hirth and Ueckerdt, 2013; Unteutsch, 2014), flexible electricity demand (Emelianova and Namockel, 2025), bidding zone reconfiguration (Egerer et al., 2016; Czock, 2025), and the introduction of flow-based market coupling (Ovaere et al., 2023).

The remainder of this article is structured as follows. Section 2 provides further context for our analysis, Section 3 introduces our analytical model and the corresponding results, and Section 4 presents our numerical model and the related results. Section 5 discusses our results in the context of the existing literature, model limitations, and the particularities of our case study, and Section 6 concludes.

2. Context

This section provides further context for our analysis of electricity interconnector expansion, including relevant European regulations and the Hansa PowerBridge interconnector, which we use as a case study for our numerical simulations.

2.1. European regulation

Various European regulations aim to promote the development of cross-border electricity interconnection while managing the resulting distributional effects within and between the involved countries. The European Network of Transmission System Operators for Electricity (ENTSO-E) anticipates that promoting international electricity trade will yield significant economic and environmental benefits, including reduced electricity costs for consumers, increased profits for producers, and a reduction in CO_2 emissions.

The regulatory basis for identifying and evaluating cross-border electricity infrastructure projects is the Trans-European Networks for Energy regulation, originally adopted in 2013 and revised in 2022 (European Union, 2013, 2022). It defines strategic priority corridors and establishes the framework for identifying so-called Projects of Common Interest[6], which are eligible for dedicated regulatory support and access to EU funding instruments. For the assessment of individual projects, the EU Commission approved the fourth guideline for the cost-benefit analyses of grid development projects in 2024 (ENTSO-E, 2024). The cost-benefit analyses assess the extent to which projects are worthwhile from a societal perspective based on market simulation models and scenarios from the Ten-Year Network Development Plan (TYNDP) (ENTSO-E and ENTSOG, 2024).[7] The most common indicator in cost-benefit analyses is welfare, including consumer surplus, producer surplus, and net congestion rent. In addition, the cost-benefit analyses consider indicators such as CO_2 emissions, RES integration, and redispatch costs.

A crucial instrument for promoting interconnector development is the cross-border allocation of interconnector costs and rents. While the current Cross-Border Cost Allocation guidelines allow for splitting costs and revenues among participating TSOs (or countries) based on market studies of each country's benefits (Med-TSO, 2022), this option has rarely been used. The investment costs for interconnection projects are typically divided equally (50/50) between the participating TSOs (or countries) based on the notion that interconnection is a joint investment requiring equal partnership. Alternatively, it is common practice to

[6]Projects of Common Interest refer to electricity infrastructure projects that provide substantial benefits to at least two EU Member States. Similar provisions apply to Projects of Mutual Interest, which involve collaboration between Member States and third countries.

[7]The TYNDP provides transparency on the necessary expansion of the entire European transmission network, which plays a crucial role in selecting and evaluating Projects of Common Interest.

assign investment costs to the TSO on whose territory the corresponding assets are built, following the so-called territoriality principle (ACER, 2020). Similarly, the congestion rents of interconnectors are usually shared equally between the participating TSOs, although an exception clause in the European regulation allows for other sharing keys based on ownership shares, investment costs, exemption decisions, or regulatory decisions (ACER, 2023). While some older interconnectors have been realized as merchant projects (e.g., Baltic Cable), our analysis focuses on TSO-owned interconnectors, reflecting the fact that merchant projects are exceptional cases under more recent EU regulation (European Parliament and Council of the European Union, 2019).

Further financial support for Projects of Common Interest is provided by the Connecting Europe Facility, which funds studies (e.g., preparatory assessments and testing) and actual interconnector investment costs (e.g., procurement and construction). Projects that demonstrate a positive cost-benefit analysis across key dimensions, such as system integration, greenhouse gas reduction, or security of supply, may also qualify as a Cross-Border Renewable Energy (CB RES) project. Like Projects of Common Interest, Cross-Border Renewable Energy projects benefit from streamlined permitting and access to Connecting Europe Facility funding.

2.2. Hansa PowerBridge

The Hansa PowerBridge was planned to become the second interconnector between Sweden and Germany, developed jointly by the Swedish TSO Svenska Kraftnät and the German TSO 50Hertz. It was designed with a capacity of 700 MW and a length of approximately 300 km. The project costs were estimated at 600 million Euros and were supposed to be split equally between Svenska Kraftnät and 50Hertz (50Hertz, 2023). The Hansa PowerBridge was intended to complement the Baltic Cable, the existing submarine cable between the two countries, with a capacity of around 600 MW. The Baltic Cable is owned by the Norwegian state-owned company Statkraft and was commissioned in 1994, with an expected lifetime of 40 years (Svenska Kraftnät, 2023). As the Baltic Cable approaches the end of its operational lifetime, uncertainty over its renewal adds another layer of complexity to electricity trade between Sweden and Germany.

The Hansa PowerBridge project was expected to support RES integration by enhancing transmission capacity and facilitating a more efficient electricity exchange between Sweden and Germany. Despite these benefits, the project faced political and regulatory hurdles. Delays emerged due to regulatory complexities and growing stakeholder concerns. Initially planned for commissioning in 2025/2026, the latest anticipated commissioning date had shifted to around 2035 (Svenska Kraftnät, 2023).

In particular, the Swedish government raised concerns about the potential impact on Swedish electricity prices and the efficiency of the German electricity market (Reuters, 2024). Regarding the impact on Swedish electricity prices, it was argued that increased interconnection with Germany would raise prices in southern Sweden. This is related to the Swedish electricity market being organized in four regional bidding zones (SE1 to SE4). In 2024, average prices in southern Sweden (SE3: 35.77 EUR/MWh; SE4: 49.71 EUR/MWh) were already substantially higher than in northern Sweden (SE1: 25.05 EUR/MWh; SE2: 24.64 EUR/MWh). As Hansa PowerBridge would increase the connection between southern Sweden (SE4) and Germany, where average electricity prices in 2024 were even higher (77.8 EUR/MWh; all prices based on ENTSO-E (2025)), regional price disparities within Sweden may increase further. Fundamentally, the price differences are caused by transmission bottlenecks between the four Swedish bidding zones, which limit the effective distribution of electricity generated in northern Sweden to the south of the country, where the majority of consumption occurs (SE3: 83.8 TWh; SE4: 22.0 TWh; versus SE1: 10.8 TWh; SE2: 15.1 TWh).

The concern about the efficiency of the German electricity market refers to the uniform German bidding zone. The Swedish government argued that, in contrast to the multiple Swedish bidding zones, the uniform German bidding zone implies that local transmission constraints are not reflected in prices. This could distort price signals and potentially undermine the intended economic benefits of the interconnector (Reuters, 2024). As a result, the Swedish government formally rejected the Hansa PowerBridge project in June 2024 (50Hertz, 2024; Reuters, 2024). This decision reflects the general challenge of reconciling national interests with the promotion of cross-border electricity networks in Europe.

3. Analytical model

This section employs a stylized analytical model to examine the impact of an interconnector expansion between two electricity markets on market prices, consumer surpluses, producer surpluses, and interconnector rents. Our model shares elements with the models presented by Joskow and Tirole (2005), Fell and Kaffine (2018), and Michelet (2024). We use the model to investigate two contrasting scenarios: the 'connected' scenario, in which the two markets are connected with an interconnector of welfare-optimal capacity, and the 'separate' scenario, in which the markets are not connected. We start by introducing the 'separate' scenario. Then, we derive the optimal level of interconnector investment. On this basis, we analyze changes in consumer and producer surpluses and assess the conditions under which asymmetric sharing of interconnector costs and rents can achieve a Pareto improvement. We also examine overall welfare effects and derive a sharing key that ensures Pareto improvement at both the consumer and market levels. At the end of this section, we provide an exemplary calculation based on this analytical model and discuss the limitations that result from its simplicity.

Separate scenario

We represent two markets that differ by their levels of time-invariant and price-inelastic loads[8], denoted by L_I and L_E, and their marginal costs of thermal electricity generators, $MC_I(F_I)$ and $MC_E(F_E)$. In the 'separate' scenario, the total thermal generation in each market equals the price-inelastic load in that market, i.e., $F_I = L_I$ and $F_E = L_E$. The market price is set by the variable cost of the marginal power plant in each market, i.e., $p_I^s = MC_I(L_I)$ and $p_E^s = MC_E(L_E)$. We assume $p_I^s > p_E^s$, implying that market I will import, and market E will export in the 'connected' scenario. This scenario is depicted in Figure 1 (a) and (b).

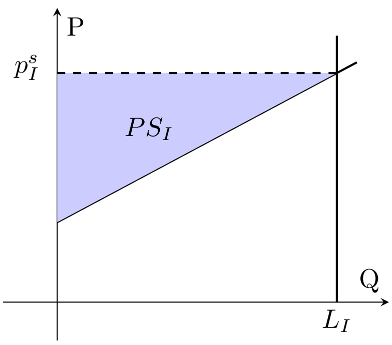
Optimal interconnector investment

In the 'connected' scenario, the volume K is transmitted from the exporting to the importing market. This reduces the price in the importing market to $p_I^c = MC_I(L_I - K)$ and increases the price in the exporting market to $p_E^c = MC_E(L_E + K)$, as depicted in Figure 1 (c) and (e).

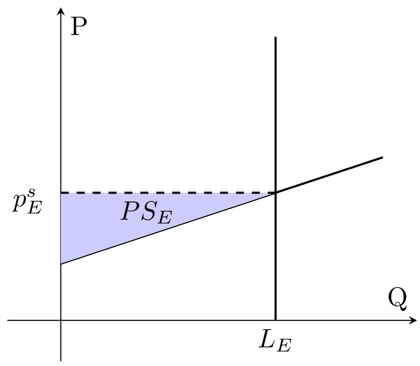
For the optimal interconnector capacity, which maximizes welfare across both markets, the remaining price difference between both markets times the annual utilization a must be equal to the annualized marginal interconnector cost, AMC_K, which we assume to be constant (Kirschen and Strbac, 2018, 238ff):

$$a \cdot (p_I^c - p_E^c) = AMC_K \tag{1}$$

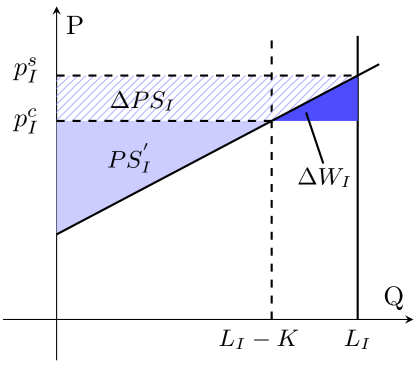
[8] The assumption of price-inelasticity seems an appropriate simplification, as recent empirical studies estimate very small elasticities (Hirth et al., 2024).



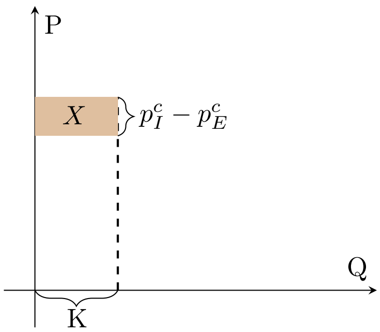
(a) Importing market: 'separate' scenario



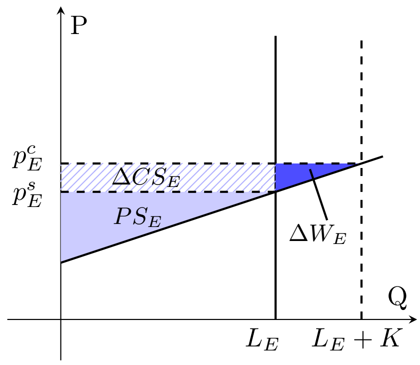
(b) Exporting market: 'separate' scenario



(c) Importing market: 'connected' scenario



(d) Interconnector rent



(e) Exporting market: 'connected' scenario

Figure 1: Welfare and distributive effects of electricity interconnection

Note: In the importing market, consumer surplus rises by the sum of the light-blue diagonal hatching and dark blue areas ($\Delta CS_I = -\Delta PS_I + \Delta W_I > 0$), while producer surplus declines by the light-blue diagonal hatching area ($\Delta PS_I < 0$), resulting in a producer surplus of $PS_I^{'}$. The net welfare gain of the importing market is ΔW_I. In the exporting market, consumer surplus decreases by the light-blue diagonal hatching area ($\Delta CS_E < 0$), while producer surplus increases by the sum of the light-blue diagonal hatching and dark blue areas ($\Delta PS_E = -\Delta CS_E + \Delta W_E > 0$), leading to a net welfare gain of ΔW_E. The interconnector rent depends on capacity K and the price difference $p_I^c - p_E^c$. The interconnector rent does not affect consumer and producer surpluses, as we assume that the interconnector rent equals the interconnector cost and that both cost and rent are symmetrically distributed between the importing and exporting markets.

Put differently, the interconnector should only be expanded to the point where the marginal value of the interconnector remains sufficient to cover the annualized marginal cost, AMC_K.[9] This implies that the price difference in the separate scenario needs to be larger than the annualized marginal interconnector cost, $p_I^s - p_E^s > AMC_K$, for the optimal interconnector capacity to be greater than zero. Furthermore, prices in

[9] As we derive below, the annualized investment cost for the example of the planned Hansa PowerBridge interconnector between Germany and Sweden amounts to 28 million EUR/a. Given the project's planned capacity of 700 MW, the annualized marginal cost can be estimated at 40,000 EUR/MW/a (assuming they are constant). If the interconnector was fully used for 8,000 h/a, the optimal remaining price difference would be 5 EUR/MWh. In our numerical model in Section 4, the interconnector rent is calculated to be 136 million EUR in 2035, significantly exceeding the annualized interconnector cost of 28 million EUR.

the importing market remain higher than in the exporting market, $p_I^c > p_E^c$, and the interconnector will be fully utilized and congested.

For an optimal interconnector of capacity K, the total interconnector rent IR and total interconnector cost IC are given as follows:

$$IR = a \cdot (p_I^c - p_E^c) \cdot K \tag{2a}$$

$$IC = AMC_K \cdot K \tag{2b}$$

Under the assumption of an optimal interconnector capacity and constant marginal interconnector cost, the annual interconnector rent equals the annual interconnector cost, and we jointly denote their value with X. This equality follows directly from Eqs. (1) and (2).

$$X \coloneqq IR = IC \tag{3}$$

As a result, the interconnector project (just) carries its own costs and would be economical to build either by TSOs or by a private company as a merchant interconnector. Figure 1 (d) illustrates the interconnector rent, determined by the capacity K and the price difference between both markets in the 'connected' scenario.

Change in consumer surplus

We now examine how connecting the two markets affects consumer surplus. The change in consumer surplus, ΔCS, arises from (i) changes in wholesale market prices between the 'connected' and 'separate' scenarios and (ii) the additional interconnector costs and rents in the 'connected' scenario, which we assume will be passed on to consumers via grid fees. This reflects the preference for TSO-owned interconnectors in the European regulation (European Parliament and Council of the European Union, 2019). The parameter $\varphi \in [0, 1]$ steers the allocation of interconnector costs and rents in a way that a larger φ is to the benefit of consumers in the exporting market. Hence, φ is the share of interconnector costs allocated to consumers in the importing market and the share of interconnector rents allocated to consumers in the exporting market. The remaining costs and rents are allocated to consumers in the other market.

$$\Delta CS_I = -a \cdot (p_I^c - p_I^s) \cdot L_I - \varphi \cdot IC + (1 - \varphi) \cdot IR = \underbrace{-a \cdot \Delta p_I \cdot L_I}_{>0} + (1 - 2\varphi) \cdot X \tag{4a}$$

$$\Delta CS_E = -a \cdot (p_E^c - p_E^s) \cdot L_E + \varphi \cdot IR - (1 - \varphi) \cdot IC = \underbrace{-a \cdot \Delta p_E \cdot L_E}_{<0} + (2\varphi - 1) \cdot X \tag{4b}$$

The symmetric distribution of interconnector costs and rents, which reflects the status quo in Europe, is represented by $\varphi = 0.5$. In that case, the consumer surplus increases in the importing market and decreases in the exporting market.

As an alternative, interconnector costs and rents could be allocated asymmetrically, with consumers in the exporting market receiving a larger share of the rent and consumers in the importing market bearing a larger share of the cost, i.e., $\varphi > 0.5$. We test under which conditions such an asymmetric allocation can achieve a Pareto improvement at the consumer level, meaning that no consumers in either market are worse off compared to the 'separate' scenario ($\Delta CS_I \geq 0$ and $\Delta CS_E \geq 0$). Using Eqs. (4a) and (4b), this yields:

$$a \cdot \Delta p_E \cdot L_E \leq (2\varphi - 1) \cdot X \leq -a \cdot \Delta p_I \cdot L_I \tag{5}$$

The equation defines the Pareto-improving range of φ that is sufficiently large to compensate consumer losses in the exporting market (light-blue diagonal hatching area in Figure 1 (e)) and does not exceed consumer gains in the importing market (light-blue diagonal hatching and dark blue areas in Figure 1 (c)).

Note that the case of $\varphi = 0.5$ also represents merchant interconnectors, where the corresponding costs and rents are accumulated in the private operating company. It becomes apparent that Eq. (5) cannot be fulfilled for $\varphi = 0.5$, as the left-hand side is greater than zero. Hence, TSO ownership is a precondition for achieving Pareto improvement at the consumer level through the asymmetric sharing of interconnector costs and rents.

Welfare effects

We now assess the impact of connecting the two markets on welfare. The welfare change in each market is determined by the sum of the changes in consumer and producer surplus (see Appendix B for the derivation). This yields the following expressions for welfare changes in the importing and exporting market:

$$\Delta W_I = \underbrace{a \cdot \left(\int_{L_I - K}^{L_I} MC_I(f)\, df - p_I^c \cdot K \right)}_{\geq 0} + (1 - 2\varphi) \cdot X \tag{6a}$$

$$\Delta W_E = \underbrace{a \cdot \left(p_E^c \cdot K - \int_{L_E}^{L_E + K} MC_E(f) df \right)}_{\geq 0} + (2\varphi - 1) \cdot X \tag{6b}$$

For the symmetric distribution of the interconnector rent and cost ($\varphi = 0.5$), both expressions are greater than zero, indicating a Pareto improvement at the market level. In the importing market, this is because the increase in consumer surplus is larger than the decrease in producer surplus (dark-blue area in Figure 1 (c)). Similarly, in the exporting market, the rise in producer surplus outweighs the loss in consumer surplus (dark-blue areas in Figure 1 (e)). The magnitude of each market's welfare gains increases with the slope of its supply curve.

Increasing welfare in the export market implies that Pareto improvements can, in principle, be achieved through transfers from producers to consumers. However, whether increased surpluses from state-owned or state-backed producers are sufficient to compensate consumer losses depends on the share of (inframarginal) producers that are state-owned or state-backed. We will get back to this question in our case study in Section 4.

For an asymmetric allocation of interconnector costs and rents to the benefit of consumers in the exporting market ($\varphi > 0.5$), welfare in the importing market decreases relative to the symmetric sharing ($\varphi = 0.5$). To maintain Pareto improvement in terms of welfare for the importing market ($\Delta W_I \geq 0$), the following condition can be derived from Eq. (6a):

$$(2\varphi - 1) \cdot X \leq a \cdot \left(\int_{L_I - K}^{L_I} MC_I(f)\, df - p_I^c \cdot K \right) \tag{7}$$

Eq. (7) implies that the asymmetrically distributed share of the interconnector costs and rents cannot be larger than the welfare gains in the importing market.

Pareto improvement at the consumer and market level

From the above, we can derive the following proposition on Pareto improvement at the consumer and market level.

Proposition 1. *For a welfare-optimal interconnector expansion, a Pareto improvement at the consumer and market level across an importing and an exporting market can be achieved through the asymmetric sharing of interconnector costs and rents if the corresponding sharing key,* $0 \leq \varphi \leq 1$, *can be chosen such that:*

$$a \cdot \Delta p_E \cdot L_E \leq (2\varphi - 1) \cdot X \leq a \cdot \left(\int_{L_I - K}^{L_I} MC_I(f)\, df - p_I^c \cdot K \right) \tag{8}$$

Proof. The lower bound follows from Eq. (5) and avoids consumer losses in the exporting market. The upper bound can be derived from Eq. (7) and ensures welfare gains in the importing market. The upper bound in Eq. (5) is irrelevant, as the welfare gains in the importing market are smaller than the consumer gains in that market. This is because part of the consumer gains is offset by a decline in producer surplus:

$$\underbrace{a \left(\cdot \int_{L_I - K}^{L_I} MC_I(f)\, df - p_I^c \cdot K \right)}_{\text{RHS of Eq. 7}} = \underbrace{-a \cdot \Delta p_I \cdot L_I}_{\text{RHS of Eq. 5}} + \underbrace{\Delta PS_I}_{<0} \tag{9}$$

Note that this also becomes apparent in Figure 1 (c), where the dark blue area is smaller than the sum of the dark blue area and the light-blue diagonal hatching area. Thus, the right-hand side of Eq. (7) forms the upper bound of Eq. (8). ■

Any sharing key satisfying Eq. (8) ensures the consumer-level Pareto improvement in the exporting market and the market-level Pareto improvement in the importing market. The lower bound of Eq. (8) corresponds to the light-blue diagonal hatching area in Figure 1 (e). This condition is relatively easy to fulfill if the interconnector-induced price change in the exporting market is small (e.g., if the supply curve is flat for a given K) or if the load in the exporting market is small. The upper bound of Eq. (8), corresponding to the dark blue area in Figure 1 (c), is relatively easy to fulfill if the supply curve in the importing market is steep (for a given K).

Proposition 1 implies that a Pareto improvement at the consumer and national level can only be achieved if the welfare gain in the importing country exceeds the consumer loss in the exporting country:

$$a \cdot \Delta p_E \cdot L_E \leq a \cdot \left(\int_{L_I - K}^{L_I} MC_I(f) \, df - p_I^c \cdot K \right)$$

Furthermore, it is required that the annual interconnector rent, X, exceeds the consumer loss in the exporting country. If either of these two conditions is not met, a Pareto improvement through asymmetric sharing cannot be achieved, even if market welfare increases.

Overall, the feasibility of achieving consumer-level Pareto improvement depends on the relative slopes of the supply curves in the two markets. Four cases can arise. Pareto improvement is most easily achieved when the importing market has a steep supply curve and the exporting market a flat one: the steep curve in the importing market induces a large price drop and thus substantial welfare gains, while the flat curve in the exporting market limits the price increase and consumer losses. In contrast, compensation becomes difficult when the importing market is flat and the exporting market steep, as the modest welfare gains in the importing market cannot offset the sizable consumer losses in the exporting one. When both markets are steep, compensation may remain feasible but would require large transfers from the importing to the exporting market, potentially exceeding the maximum transfers achievable through asymmetric sharing of interconnector costs and rents. Finally, when both markets are flat, the required compensation is small because price changes in either direction are limited.

Exemplary calculation

This subsection uses the analytical model to illustrate the potential distributional impacts of an interconnector project, using parameters that loosely reflect the example of the canceled interconnector Hansa PowerBridge between Germany and Sweden with a capacity of $K = 700$ MW (which we will also analyze in more detail with our numerical model in Section 4). Table 1 summarizes our assumptions for average load, the marginal cost slope, and average prices in both markets in the 'separate' scenario. From these assumptions, we derive the prices in the 'connected' scenario and the associated welfare effects with symmetric sharing of interconnector costs and rents. Note that we do not optimize the interconnector capacity; instead, we take it as an input. As a result, the rent of the interconnector exceeds its cost.

The results align well with our previous considerations: with symmetric sharing of interconnector costs and rents, consumer surplus decreases in the exporting Swedish market and increases in the importing German market, and welfare increases in both countries. Specifically, welfare rises by about 111 million EUR/a in the exporting country and by 100 million EUR/a in the importing country, indicating that both markets benefit to a similar extent from the interconnector with symmetric sharing of interconnector costs and rents. However, it becomes apparent that asymmetric sharing of interconnector costs and rents cannot achieve a Pareto improvement. Even if German consumers were to bear the full interconnector costs (28 million EUR/a) and Swedish consumers received the full interconnector rents (222 million EUR/a), this would be insufficient to compensate Swedish consumers for their losses (498 million EUR/a). The price increase in Sweden results in large consumer losses that exceed the available interconnector rents. Moreover, if Germany were to bear the full interconnector costs without receiving part of the interconnector rent, welfare in Germany would also turn negative (-25 million EUR/a). Hence, there is no value for φ that fulfills Eq. (8). The main factor preventing a Pareto-improving allocation in this illustrative calculation is the strong interconnector-induced price increase in the exporting market. As a result, the consumer loss

Table 1: Parameterization and welfare effects for a newly built interconnector ($K = 700$ MW)

Parameter	**Sweden**[a]	**Germany**	**Source**
Load [GW]	15	53	Fraunhofer ISE (2025)[b]
Price 'separate' scenario [EUR/MWh]	36	78	ENTSO-E (2025)[c]
Marginal cost slope $[\frac{\text{EUR/MWh}}{\text{GW}}]$	6.0	1.50	Own estimate[d]
Price 'connected' scenario [EUR/MWh]	41	77	Own calculation
Price change [EUR/MWh]	5	-1	Own calculation
Change in consumer surplus [million EUR/a]	-498	578	Own calculation
- Interconnector rent [million EUR/a]	111	111	Own calculation
- Interconnector cost [million EUR/a]	-14	-14	50Hertz (2023)[e]
Change in producer surplus [million EUR/a]	609	-478	Own calculation
Welfare change [million EUR/a]	111	100	Own calculation

[a] Swedish load reflects the sum of the subnational bidding zones, and prices reflect the load-weighted averages.
[b] This reflects the average load in 2024 for Sweden and Germany.
[c] This reflects the average annual Day-Ahead electricity prices in 2024.
[d] Marginal cost slopes estimated via a linear OLS regression of prices on domestic production (load plus net exports). We ignore potential endogeneity between load and prices, which is equivalent to assuming load to be price-inelastic. This simplification seems acceptable for the illustrative nature of this calculation, given the relatively small price elasticity of electricity demand (Hirth et al., 2024).
[e] Annualized investment costs of the Hansa PowerBridge, based on an estimated total investment of 600 million EUR. Further details on the annualization are provided in Subsection 4.1.

in the exporting country is relatively large compared to the interconnector rent, which could potentially be redistributed.

It is essential to note that this simplistic illustration overlooks key characteristics of the European power system. Our analytical model does not capture that thermal electricity generators are increasingly complemented with RES, and demand and supply conditions change on an hourly or even sub-hourly temporal resolution. As a result, the interconnector will likely not be fully used for trade throughout the year as assumed in our illustrative calculation. Furthermore, our analytical model focuses on two previously separate countries, neglecting that European countries (including Germany and Sweden) are already highly interconnected and that the discussion focuses on strengthening existing cross-border capacities. Nevertheless, our stylized model illustrates how interconnection generally affects market prices and rents and helps us investigate conditions under which an asymmetric sharing of interconnector costs and rents can achieve Pareto improvements. Our numerical model presented in the subsequent Section 4 will account for temporal variations and existing cross-border capacities (among other factors) to provide more detailed insights and tangible numbers. Additionally, we discuss potential redistribution instruments beyond the asymmetric sharing key to achieve Pareto improvement.

4. Numerical model

This section employs a detailed numerical model of the European electricity market to derive quantitative insights into the distributional effects of interconnector expansion and policy options to achieve Pareto improvement. We do so using the case study of the Hansa PowerBridge, an additional interconnection between Germany and Sweden (see Subsection 4.1). Subsection 4.1 introduces the model, scenarios, and evaluation parameters, while Subsection 4.2 presents the results.

4.1. Model and data

For our analysis, we extend and apply the existing European electricity market model SPIDER (Spatial Investment of Distributed Energy Resources), introduced in Schmidt and Zinke (2020) and further developed in Czock et al. (2023), Zinke (2023), and Czock (2025). We use SPIDER as a short-term partial equilibrium model of the interconnected European electricity market. For this study, the geographic scope of the model has been extended to include EU-27 (without Bulgaria, Romania, Cyprus, and Malta) as well as Great Britain, Switzerland, and Norway.[10] The model simulates the hourly dispatch of power plants and storage as well as trade between bidding zones, taking the assets' installed capacities as given. Assuming inelastic demand, perfect competition, and perfect foresight, the short-term equilibrium is represented by a central planner that minimizes total system cost, subject to meeting the electricity demand and complying with capacity constraints (see Section 5 for a discussion of these assumptions).

Trade between bidding zones is simulated using flow-based market coupling (FBMC) for the 13 European countries participating in the "Core Flow-Based Market Coupling" project (Zinke, 2023). With FBMC, transfer capacities between bidding zones are endogenously determined, given transmission constraints between and within bidding zones. Representing FBMC allows us to realistically simulate the impact of the additional interconnector on electricity trade, market prices, and welfare. In particular, we can also examine scenarios with alternative market configurations, such as the splitting of the German bidding zone. Granular network representation further allows us to simulate redispatch, i.e., power plant adjustments to resolve intra-zonal congestion after market clearing, as described in Czock (2025). Our simulation of FBMC encompasses network elements at both 220 kV and 380 kV voltage levels (as visualized in Figure 2). To simplify the modeling process and maintain a linear problem structure, we approximate non-linear AC power flow restrictions by DC power flow constraints following Zinke (2023).

[10] The following countries have newly been added: Great Britain, Ireland, Finland, Estonia, Latvia, Lithuania, Greece, and Portugal.

Figure 2: Regional scope and considered grid topology in 2035

Further European countries, as well as the four Swedish bidding zones (SE1, SE2, SE3, SE4, from north to south), are depicted as singular nodes. Grid congestion within these countries and the Swedish bidding zones is neglected, and the possibility to trade with other nodes is approximated via constant net transfer capacities (NTCs), following TYNDP values (ENTSO-E and ENTSOG, 2024). While FBMC has been recently introduced in the Nordics (Nordic Regional Coordination Centre, 2024), this is not captured in our model due to the lack of publicly available grid data, which also prevents the analysis of redispatch volumes and costs in that region.

Electricity prices are derived as shadow prices (dual variables) of each bidding zone's power balance constraint and represent the marginal costs of electricity generation in each bidding zone and time step. These shadow prices can be interpreted as wholesale electricity prices under the assumption of perfect competition and do not include additional components such as taxes, levies, and network charges paid by end consumers.

Scenarios

For our case study, we parametrize the model to represent scenarios for the European power system in 2035. We assess the impact of building the Hansa PowerBridge by comparing scenarios with and without this additional 700 MW interconnector between Germany and Sweden.[11] We conduct this assessment for three different market configurations, namely one baseline configuration, one with inner-Swedish grid expansion, and one with a German bidding zone split. This reflects the concerns raised by the Swedish government when rejecting the Hansa PowerBridge project (see Subsection). Furthermore, we complement our main scenario on supply costs and volumes with three sensitivities, namely one with a substantially higher natural gas price, one with exceptionally low renewable electricity availability in Germany, and one with exceptionally low hydropower availability in Sweden. These sensitivities reflect relevant weather-related uncertainty in German renewable generation and Swedish hydropower, and are motivated by the gas price shock observed during the 2022 energy crisis.

In our main scenario, country-specific capacities, demand, and fuel prices are based on the TYNDP 2024 report (ENTSO-E and ENTSOG, 2024), following the Global Ambition scenario and using the weather year 2009. The scenario assumptions include compliance with the currently set renewable energy targets in Europe (see Appendix C for an overview of other assumptions). We regionally distribute conventional and renewable power plants across nodes, following Zinke (2023). Additionally, we incorporated hydrogen-ready power plants into the model. While their overall capacity is fixed to the TYNDP values, their regional distribution within Germany is determined endogenously in a preliminary nodal model run.[12] We regionally distribute electricity demand based on population and, for commercial demand in Germany, based on gross value added (Zinke, 2023). Hourly time series for renewable generation are taken from meteorological data as described in Zinke (2023), and hourly demand profiles are based on the TYNDP 2024 report (ENTSO-E and ENTSOG, 2024).

We investigate two alternative market configurations, because inner-Swedish grid constraints and the uniform German bidding zone were two important arguments in the debate surrounding the Hansa PowerBridge (Reuters, 2024). For the first alternative configuration, inner-Swedish grid expansion ('SE grid'), we assume an increase in capacity by 2,000 MW between SE2 and SE1 and between SE2 and SE3, respectively, and by 500 MW between SE4 and SE3. These assumptions align with Svenska Kraftnät's updated long-term targets for increasing inner-Swedish transmission capacity (Svenska kraftnät, 2024b), which are not reflected in the TYNDP 2024 report. For the second alternative configuration, a split of the German bidding zone ('DE split'), we implement a split into two, based on Option 2 in the bidding zone review (ACER, 2022a).

[11]Following the TYNDP 2024, we assume that the Baltic Cable, the existing 600 MW interconnector between both countries, remains in operation in 2035, so that the Hansa PowerBridge complements the Baltic Cable (ENTSO-E and ENTSOG, 2024).

[12]In this nodal model run, not only inter-zonal but also intra-zonal transmission constraints are considered. This neglects potential capacity misallocation that Bertsch et al. (2017) identify as a key inefficiency of zonal markets. Investment in hydrogen-ready power plants is allowed at all nodes with currently installed conventional generators to leverage existing grid connections and minimize grid expansion needs (50Hertz, Amprion, TenneT, TransnetBW, 2023).

This split reflects the most significant grid constraints within Germany, resulting in one Northern German zone, which comprises the majority of Germany's renewable electricity generation, and a Southern German zone, which includes the majority of Germany's electricity load.

To explore the robustness of our findings in our main scenario, we analyze sensitivities to shocks regarding fuel prices and the availability of RES. The first sensitivity ('High gas price') assumes a natural gas price of 100 EUR/MWh, compared to the reference scenario price of 21.5 EUR/MWh. The second sensitivity ('DE Dunkelflaute') is based on the historical weather year 2007, which is characterized by prolonged periods of low wind and solar generation in Germany (EWI, 2024). The third sensitivity ('SE low hydro') uses the weather year 1996, which had the lowest hydropower availability in Sweden between 1995 and 2024 (Swedish Energy Agency, 2025).

Evaluation

We start with an overview of the effects of the new interconnector in the baseline market configuration using three indicators: welfare, emission savings, and RES integration. After having established this overview, we decompose welfare into consumer and producer surplus. The consumer surplus includes the consumers' wholesale rent, which we derive from wholesale market cost, i.e., the inelastic demand times the wholesale electricity prices.[13] Furthermore, the consumer surplus is reduced by the investment costs and increased by congestion rents, as these are typically passed on to end-users via grid fees. For Germany, we additionally incorporate changes in redispatch costs. The producer surplus is calculated by subtracting variable costs from wholesale market revenues. Here, we isolate the rents of state-owned and state-backed producers, as these may be easier to redistribute. The following paragraphs provide details on the underlying assumptions, including the allocation of congestion rents between countries, interconnector cost assumptions, and differentiation of producer surplus by producer type.

We make the following assumptions regarding the allocation of interconnector investment costs and congestion rents. For the new interconnector, we consider the annualized investment costs based on estimated investment costs of 600 million EUR (50Hertz, 2023), an estimated lifetime of 40 years Svenska Kraftnät (2023), and an estimated interest rate of 3.5% to calculate annualized costs. For these annualized investment costs as well as the annual congestion rents, we contrast the status quo in Europe, where investment costs and congestion rents are shared equally, with asymmetric cost and benefit sharing. For changes in congestion rents of other interconnectors, we assume equal sharing between the respective TSOs, except for merchant

[13] Because demand is inelastic, the consumer value from electricity consumption is constant, and the consumers' wholesale rent increases proportionately to the decrease in wholesale market cost.

interconnectors, such as the Baltic Cable. Changes in rents on merchant interconnectors are excluded from the analysis as they are fully retained by the owner and thus cannot be directly redistributed to end consumers.

We further estimate the fractions of producer surpluses that affect state-owned or state-backed producers. Here, we focus on the two most prominent examples of such state involvement: state-backed producers in Germany under the Renewable Energy Act (EEG) and the Swedish state-owned producer Vattenfall. In the case of the German Renewable Energy Act, RES generators receive a subsidy that depends on the nationwide market values of renewable electricity. Hence, if renewable market values decrease, the reduction in producer surplus is compensated for by an increase in subsidy payments. We approximate RES subsidies under the EEG in Germany following Czock (2025). The data basis for this analysis is the German core energy market data register (MaStR), which provides historical commissioning dates for RES installations. Following Czock (2025), it is assumed that RES installations receive subsidies for a period of 20 years. To estimate the share of state-owned producer surplus in Sweden by 2035, we assume that all currently announced capacity expansion projects by Vattenfall will be implemented as scheduled (Vattenfall, 2024, 2025a,b).[14] Based on these additions, we calculate the expected future share of generation and the corresponding surplus attributable to state-owned production.

4.2. Results

This section presents the impact of the interconnector expansion between Germany and Sweden on welfare and other key market indicators as estimated by our numerical model. First, we evaluate welfare, emissions savings, and RES integration in Sweden, Germany, and other EU countries. Second, we decompose welfare changes in Sweden and Germany into consumer and producer surplus. We begin by analyzing the interconnector's impact under the baseline market configuration, followed by an assessment of its impact under two alternative market configurations: inner-Swedish grid expansion and a German bidding zone split. Finally, we conduct sensitivity analyses on exogenous price and volume shocks for all market configurations.

Aggregate effects

Our modeling results provide (further) evidence on significant economic and environmental gains from an additional interconnector between Germany and Sweden, quantified in terms of welfare, emission savings, and RES integration. Welfare increases by approximately 160 million EUR in 2035. They occur mostly in Germany and Sweden, while additional, though smaller, welfare gains arise in other EU countries (Figure 3

[14]Vattenfall is fully owned by the Swedish state and represents the only major state-owned actor in the national power sector.

(a)). Power sector CO_2 emissions decrease by about 0.3 Mt in 2035 (see Figure 3 (b)), mainly in Germany and other EU countries. This emission reduction is calculated from the dispatch of fossil-fueled electricity generators using the respective emission factors. Within the EU ETS, overall emissions are capped; reductions in the power sector may therefore be offset by increased emissions in other sectors (waterbed effect). [15] The additional interconnector also increases RES integration in Germany (Figure 3 (c)), while Sweden and other EU countries see a slight decrease. In Germany, the modeled increase stems solely from the reduction of market-based curtailment, as existing RES support policies (e.g., feed-in tariffs) and operational measures such as redispatch are not accounted for. The modest absolute effect sizes are consistent with the limited size of a single additional interconnector relative to the overall European electricity system. Note that we only consider static effects, and dynamic effects may amplify the positive impact of the interconnector (Gonzales et al., 2023).

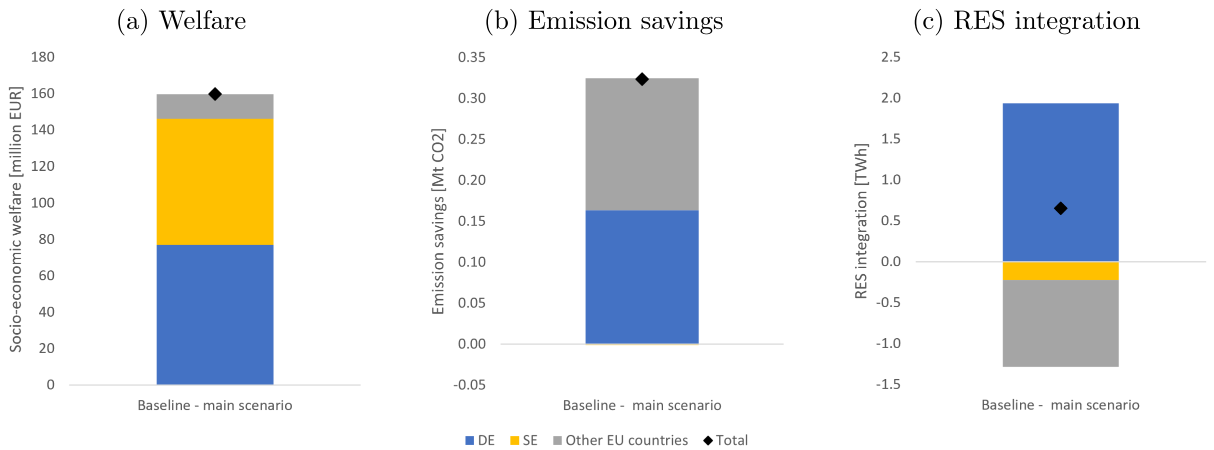


Figure 3: Impact on welfare, emission savings, and RES integration in Sweden, Germany, and other EU countries

Note: As outlined in Subsection 4.1, the model's spatial scope covers the EU-27 (excluding Bulgaria, Romania, Cyprus, and Malta) as well as Great Britain, Switzerland, and Norway, which are labeled as 'other EU countries' in the plots.

Welfare decomposition for the baseline market configuration

For the baseline market configuration, Figure 4 decomposes the simulated welfare effects in Sweden and Germany into the drivers of consumer and producer surplus. Through the interconnector expansion, the consumer wholesale rent decreases in Sweden (-182 million EUR) and increases in Germany (+433 million EUR, gray bars), as predicted by the analytical model (Section 3). In the numerical model, however, the interconnector's annual rents (+136 million EUR in total, dark yellow bars) exceed its annualized costs

[15] Note that emission reductions are also accounted for in the welfare calculation at the assumed ETS carbon prices shown in Table C.4.

(-28 million EUR in total, red bars). Assuming that these costs and rents are equally shared between the countries, which is currently the most common practice in Europe, and that they are redistributed to consumers via grid fees, this implies a net increase in consumer surplus in both countries. Furthermore, we observe changes in other congestion rents, which we assume are also allocated to consumers via grid fees. In Sweden, other congestion rents increase (+21 million EUR, yellow bar), mostly because prices in the Southern-Swedish bidding zones increase more substantially than prices further North (see Appendix E). In contrast, other congestion rents in Germany decrease (-32 million EUR), mostly because better integration with Sweden reduces price spreads on borders with other Nordic countries. Finally, we observe a slight decrease in German redispatch costs (-0.3 million EUR, orange bar). Given the structural grid congestion from Northern to Southern Germany, higher imports from Sweden tend to increase redispatch costs, while higher exports have the opposite effect. Hence, net savings in redispatch costs imply that the reduction in redispatch costs resulting from higher exports is larger than the increase in redispatch costs due to higher imports. In sum, the effect of the interconnector expansion on consumer surplus remains negative in Sweden, at -106 million EUR, and positive in Germany, at +455 million EUR (green bars).

The producer surplus increases in Sweden (+176 million EUR) and decreases in Germany (-378 million EUR, light and medium blue bars), which also matches the results of the analytical model. Meanwhile, the numerical model allows us to identify the changes in the producer surplus that imply changes in state payments. In Germany, approximately 40% of producer losses are compensated by the state via increased RES subsidies (light blue bar). In Sweden, approximately 40% of the producer surplus is captured by the state-owned utility Vattenfall (light blue bar). Overall, welfare increases by 69 million EUR in Sweden and 77 million EUR in Germany (dark blue bars), which aligns with the results of our analytical model. In sum, we can conclude that equal sharing of interconnector rents and costs leads to a Pareto improvement at the national level, but Swedish consumers incur losses.

Based on the above, we can evaluate policy options for achieving a Pareto-improving outcome. First, our results suggest that an asymmetric allocation of interconnector rents and costs between countries cannot achieve a Pareto improvement, as Germany's welfare gain does not fully offset consumer losses in Sweden. Second, the increase in producer surplus captured by the state-owned utility Vattenfall is also insufficient to cover the entire loss incurred by Swedish consumers. When the two policy options are combined, i.e., when Swedish state-owned producer surplus is used to compensate domestic consumers, and interconnector rents and costs are asymmetrically shared across countries, Pareto-improving outcomes become achievable. To characterize these, we calculate the value corridor for the allocation of interconnector costs and rents (φ) that yield Pareto improvements at both the consumer and national level. In the baseline market configuration and main scenario, this corridor ranges from approximately 70% to 100%. This implies that Swedish consumers would receive 70–100% of the rents while covering only 0–30% of the investment costs.

Alternative market configurations

Table 2 repeats the previous analysis under different market configurations.[16] The results show that strengthening internal interconnection capacity between Swedish bidding zones would reduce the interconnector-induced consumer losses in Sweden by approximately 17%, while further increasing consumer surplus in Germany (columns 2 and 5). However, the overall distributional pattern remains largely unchanged compared to the baseline: even under improved intra-Swedish grid conditions, the welfare gains in Germany remain insufficient to fully compensate Swedish consumer losses. Only by combining an asymmetric sharing key for interconnector rents and costs with the redistribution of surplus from state-owned producers in Sweden can a Pareto-improving outcome be achieved.

For a split of the German bidding zone, our results indicate an increase in consumer surplus in both Sweden (+10 million EUR) and Germany (+149 million EUR) with equal cost and rent sharing (Table 2, columns 3 and 6). Hence, a Pareto improvement is achieved without cross-country or internal redistribution. This outcome can be explained by the attenuating effect of the bidding zone split on the cross-border price spread between (northern) Germany and (southern) Sweden. As a result, the interconnector-induced increase in Swedish wholesale prices is roughly 25% smaller than under the baseline configuration, which reduces Swedish consumer wholesale losses. This mechanism aligns with the analytical model: smaller interconnector-induced price increases in the exporting country expand the Pareto-improving range for

(a) Sweden (b) Germany

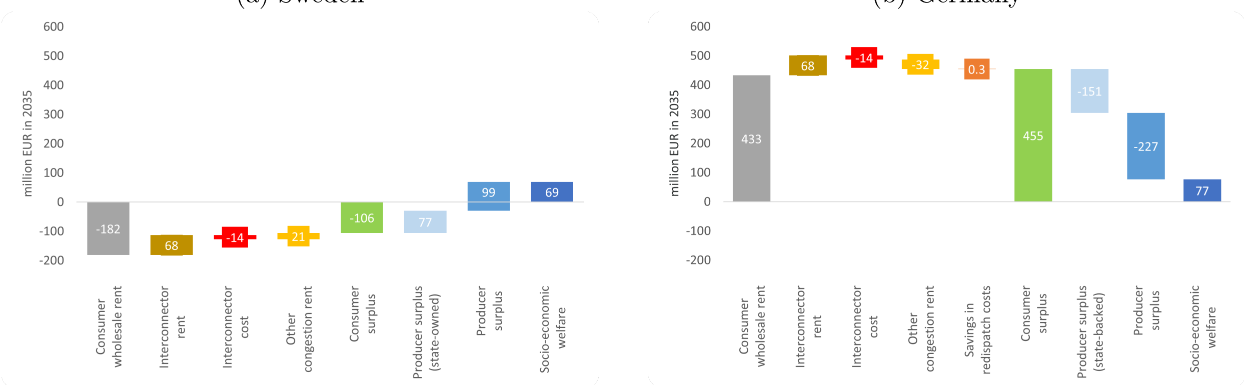


Figure 4: Breakdown of welfare under equal sharing of interconnector costs and rents in the baseline market configuration in Sweden and Germany.

[16]See Appendix D for a visualization of the results.

asymmetric sharing of interconnector costs and rents. In contrast to the analytical framework, interconnector rents exceed the annualized interconnector costs in our numerical case study, thereby supporting Pareto improvement. The change in consumer surplus in Germany remains positive under the German bidding zone split, albeit at a significantly lower level. Note that the increase in the German consumer surplus includes substantial redispatch savings of 11.1 million EUR in 2035. These savings are due to the interconnector expansion and add to those from the bidding zone split itself. Apparently, after the zonal split, increased imports and exports via the new interconnector align much better with the remaining grid congestion within the Northern German zone than they aligned with congestion in the uniform zone. The welfare remains positive for both countries (+49 million EUR in Sweden and +78 million EUR in Germany), confirming that this market configuration is Pareto-improving at the national level as well.

Table 2: Impact of market configurations on welfare and electricity prices for Sweden and Germany in the main scenario

	Sweden			Germany		
Market configurations	**Baseline**	**SE grid**	**DE split**	**Baseline**	**SE grid**	**DE split**
Welfare change [million EUR in 2035]						
Socio-economic welfare	69	72	49	77	79	78
- Consumer surplus	-106	-88	10	455	473	149
- *Consumer wholesale rent*	-182	-163	-41	68	448	128
- *Interconnector rent*	68	70	50	68	70	50
- *Interconnector cost*	-14	-14	-14	-14	-14	-14
- *Other congestion rent*	21	19	14	-32	-32	-26
- *Savings in redispatch costs*[a]	–	–	–	0.3	0.6	11.1
- Producer surplus (state-backed)	77	66	14	-151	-160	-11
- Producer surplus	99	94	24	-227	-234	-60
Price change [EUR/MWh]	0.97	0.90	0.25	-0.55	-0.57	-0.16

[a] Due to lack of publicly available grid data for the Nordics, redispatch volumes and costs are analysed only for Germany.

Robustness of results

To test the robustness of our results, we examine options to achieve Pareto efficiency under multiple shock scenarios. Specifically, we calculate the value corridors for the allocation of interconnector costs and rents (φ) that is Pareto-improving at the consumer and national level in Sweden and Germany. We distinguish between scenarios that include or exclude the redistribution of increased surplus of state-owned producers in Sweden to compensate domestic consumers (Figure 5).

In the baseline market configuration, cross-country redistribution alone can achieve Pareto improvement only if the hydro availability in Sweden is low ('SE low hydro'). The other shock scenarios resemble the main scenario in that the welfare gain in Germany is insufficient to fully offset consumer losses in Sweden. With the redistribution of the state-owned producer surplus, Pareto improvements can be achieved across

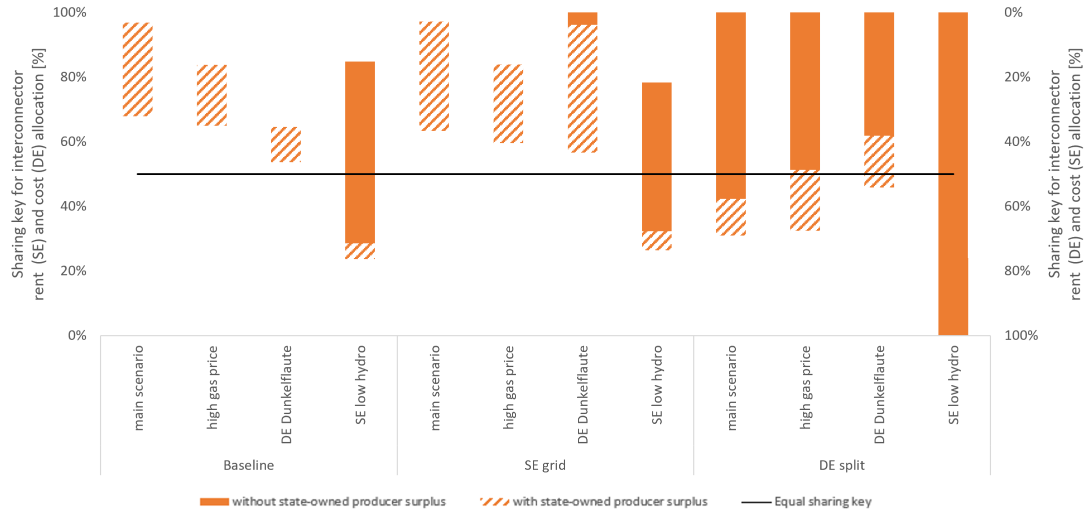


Figure 5: Corridors for the allocation of interconnector costs and rents (φ) ensuring Pareto improvements at the consumer and national levels in Sweden and Germany. The solid line represents the current European practice of equal sharing (50 %).

all shock scenarios. If one would like to fix a single value for the sharing key, roughly 70% across seems to be robust across the considered shocks. With inner-Swedish grid expansion, the Pareto-improving corridors for the allocation of interconnector costs and rents become somewhat wider, while following a similar pattern as in the baseline market configuration. Across the considered scenarios, a sharing key between 60% and 80% seems to be robustly Pareto-improving. Notably, for low renewable availability in Germany ('DE Dunkelflaute'), asymmetric sharing can achieve Pareto improvement at the consumer and national level without requiring additional redistribution (for sharing keys close to 100%). Under the German bidding zone split, the main scenario's finding that a Pareto improvement is achievable without redistribution is only partially robust to shocks. With high gas prices or low renewable availability in Germany, either asymmetric sharing of interconnector costs and rents or redistribution within Sweden is necessary for Pareto improvement.

For all three market configurations, the range of Pareto-improving sharing keys is widest under the sensitivity of reduced hydro availability in Sweden, and narrower under the high gas price and Dunkelflaute sensitivity. Taken together, we identify a robust sharing key φ of approximately 70% that ensures Pareto improvement across the considered sensitivities and market configurations, provided that state-owned producer surplus is redistributed.

5. Discussion

This section summarizes our main results and compares them with the literature. Furthermore, it discusses key modeling limitations and the applicability of our numerical results beyond the considered case study.

Our analytical model shows that building an interconnector with optimal capacity increases welfare in both connected markets, but it may have undesirable distributional implications: with a symmetric allocation of interconnector costs and rents, the consumer surplus in the exporting market decreases. On this basis, we derive that an asymmetric sharing of interconnector costs and rents can enable Pareto improvements at both the consumer and market levels, provided that the welfare gain in the importing market is relatively large compared to the consumer losses in the exporting market. Furthermore, we conclude that the share of state-owned and state-backed producers in the exporting market is decisive for whether their increased surpluses were sufficient to compensate consumer losses in that market.

Our numerical case study of the planned Hansa PowerBridge interconnector between Germany and Sweden suggests that this expansion project indeed increases welfare in both countries across all considered market configurations and scenarios. Our main scenario for 2035 indicates welfare gains of about 69–72 million EUR in Sweden and around 77–79 million EUR in Germany across all considered market configurations. Our numerical analysis also indicates the expected distributional effects and reveals their substantial size. For instance, in the baseline configuration and main scenario, consumers lose 106 million EUR in Sweden and gain 455 million EUR in Germany in 2035. It further reveals that asymmetric sharing of costs and rents alone is insufficient in the baseline market configuration and with inner-Swedish grid expansion, as it cannot fully offset the consumer losses in Sweden. However, we identify two options to enable Pareto improvements. The first combines the asymmetric sharing of interconnector costs and rents with the redistribution of the increased surplus of state-owned producers to consumers within Sweden. Second, splitting the German bidding zone can avoid reductions in Swedish consumer surplus without further redistribution. These results are robust to external price and volume shocks.

The current literature assessing the Hansa PowerBridge reports positive impacts on welfare for both Sweden and Germany, consistent with the findings of this study. For Sweden, we estimate welfare gains between 49 and 72 million EUR in 2035 across the three market configurations, which aligns with Svenska kraftnät (2024a) reporting values between 30 and 150 million EUR.[17] For Germany, our results for the main

[17] The cost-benefit analysis conducted by the Swedish TSO evaluates four distinct scenarios varying in terms of electricity consumption and generation. These scenarios are further divided based on two options: one where both the Baltic Cable is

scenario yield welfare gains of 67-78 million EUR, which is also similar to previous findings in the literature (74-117 million EUR (50Hertz, Amprion, TenneT, TransnetBW, 2020; Voswinkel et al., 2022)). Regarding redispatch costs, we estimate savings between 0.3 and 11.1 million EUR in 2035, while Voswinkel et al. (2022) report a cost increase of about 2 million EUR in 2035 and savings of about 1 million EUR in 2040. The remaining differences between our results and previous studies are primarily attributable to divergent modeling assumptions and scenario settings. Nevertheless, the positive sign and the order of magnitude of the welfare impacts tend to be robust.

Some limitations of the applied numerical model should be kept in mind when interpreting our results. First, our dispatch model focuses on static effects of further market integration. However, interconnector expansion may also lead to significant dynamic benefits, as underlined by Gonzales et al. (2023). Second, we only examine the year 2035. Many other cost-benefit analyses of interconnector projects also concentrate on short-term benefits and lack a long-term perspective (Willems et al., 2025). However, given the long lifetime of interconnectors, an analysis of how welfare impacts evolve over time may provide further relevant insights. Existing studies with a more long-term perspective, such as Svenska kraftnät (2024a) and Voswinkel et al. (2022), suggest that welfare gains could increase over time for both Sweden and Germany. Lastly, in addition to the analyzed benefits, cross-border infrastructure projects offer further advantages that are more difficult to quantify, including improved security of supply, greater grid resilience, reduced dependency on fossil fuels, and mitigated market power (Willems et al., 2025).

The analyzed case study highlights key preconditions for achieving Pareto improvements also with other interconnector projects.

First, a precondition for the asymmetric sharing of interconnector costs and benefits is that the interconnector is built and operated by a TSO. This precondition holds for the Hansa PowerBridge, which was planned as a joint project between the Swedish TSO and one of the German TSOs. Under EU regulations, the majority of cross-border interconnectors are TSO-owned, with merchant interconnectors representing exceptional cases requiring regulatory exemptions under strict conditions (European Parliament and Council of the European Union, 2019). However, some projects, including the Baltic Cable (the existing interconnector between Germany and Sweden), the BritNed (connecting the United Kingdom and the Netherlands), and the ElecLink (connecting the United Kingdom and France), are privately financed and operated (Gautier, 2020). In such cases, congestion rent cannot be (directly) distributed across consumers.

renewed and the Hansa PowerBridge is operational, and another where only the Hansa PowerBridge is in operation (Svenska kraftnät, 2024a).

Second, a precondition for a straightforward redistribution of producer surplus to consumers in the exporting country is the existence of state-owned or state-backed generation assets. Again, this precondition is applicable in Sweden, where the state-owned company Vattenfall owns a significant share of electricity generators. A similar situation is prevalent, for instance, in Norway, where many generators belong to the state-owned company Statkraft (Statkraft, 2025). Furthermore, many European countries use contracts-for-differences to support renewable electricity generation. With high shares of state-owned or state-backed producers, a redistribution of producer surplus may also contribute to achieving Pareto improvements in other countries.

A third precondition is the bidding zone configuration, which can be adjusted through structural changes in the market design. Our results indicate that a bidding zone split in Germany yields a Pareto improvement without requiring additional redistributive policies. In this case, the bidding zone split supports a Pareto improvement because it reduces the average electricity price in northern Germany and because the interconnector links southern Sweden to northern Germany. Hence, the bidding zone split reduces the interconnector-induced increase in Swedish electricity prices. The transferability of this result hinges on local geography and the spatial distribution of generation and load. The canceled NorthConnect project between the UK and Norway may be comparable to our case study: a more granular bidding zone configuration in the UK may reduce prices in northern UK and, with it, the interconnector-induced increase in Norwegian electricity prices, potentially supporting Pareto improvement. However, it is important to note that the within-country redistribution resulting from a bidding zone split should not be overlooked, as the intra-national effects can be substantial (Czock, 2025).

6. Conclusion

This study employs two complementary models to examine the impact of interconnector expansion on welfare and its distribution between consumers and producers, and to identify policy options to make interconnector expansion Pareto-improving.

First, we developed an analytical two-country market model to derive the optimal level of interconnector capacity and to investigate how consumer surplus, producer surplus, and the overall welfare change when the countries get connected. We compared symmetric sharing of interconnector costs and rents (the EU default) with asymmetric sharing. Our results show that a Pareto improvement is only possible if the distribution of interconnector costs and rents falls within a certain corridor. At the lower end, enough of the benefits must flow back to consumers in the exporting country to offset their price increases. At the upper end, the importing country must still retain part of its welfare gains from lower prices. Whether such a corridor exists depends on market conditions. For instance, large price differences between the two countries make it more likely that a redistribution solution can be found.

Second, we applied a numerical model to the case study of the Hansa PowerBridge - a canceled interconnector project between Germany and Sweden. Our results indicate that the project consistently increases national-level welfare in both countries, but Swedish consumers lose, while German consumers gain. This aligns with the analytical model and the existing literature, as electricity is, on average, exported from Sweden to Germany. To achieve Pareto-improving outcomes, we propose different policy options and assess their robustness to alternative market configurations and shocks.

Under the baseline market configuration, which reflects official scenarios in the TYNDP 2024, asymmetric sharing of interconnector costs and rents alone is insufficient to fully offset Swedish consumer losses. However, combining asymmetric sharing with the redistribution of the increased surplus of the Swedish state-owned producer Vattenfall enables Pareto improvements at both the consumer and national levels. The same findings hold with an expansion of the inner-Swedish power grid. Under a German bidding zone split, the Hansa PowerBridge becomes Pareto-improving without transfers. However, the German bidding zone split entails notable redistribution among German consumers and producers, which we do not analyze further (cf. Czock, 2025). These results are robust to external shocks regarding fuel prices and the availability of RES.

Our findings highlight the relevance of asymmetric sharing of interconnector costs and rents, the redistribution of surplus from state-owned or state-backed producers, and the reconfiguration of bidding zones as policy options to render welfare-enhancing interconnector projects Pareto-improving. These factors are currently overlooked in cost-benefit analyses, which often limit their scope to scenario sensitivities and symmetric sharing of costs and rents. Integrating these additional considerations into cost-benefit analyses may help identify solutions to address distributional concerns and, therefore, improve the approval prospects of economically sound projects that might otherwise be canceled due to adverse political economy.

Future research could examine the dynamic effects of interconnector projects, the impact of demand elasticity on the observed welfare effects, as well as additional benefits of market integration, such as market power mitigation.

Acknowledgements

The authors would like to thank Marc Oliver Bettzüge and Félix Michelet for thoughtful and constructive comments and discussions on this work. This work also benefited from discussions at the 13th International Ruhr Energy Conference 2024 (INREC), the European Climate and Energy Modelling Platform 2024 (ECEMP), the PhD Workshop on Energy Systems 2025 organized by UCLouvain and the Benelux Association for Energy Economics (BAEE), and the 13th Mannheim Conference on Energy and the Environment 2025 (MCEE). We further acknowledge the valuable exchanges during the Strommarkttreffen session on international electricity trading, hosted by Statkraft in Düsseldorf, as well as the valuable input by the Scientific Advisory Board of The Institute of Energy Economics at the University of Cologne.

Funding: This work was supported by the German Federal Ministry of Research, Technology and Space (BMFTR) within the Kopernikus-project 'New ENergy grid StructURes for the German Energiewende' (ENSURE) (grant number 03SFK1L0-3). In addition, this work received funding from the European Union's Horizon 2020 research and innovation programme through the MAGPIE project ('sMArt Green Ports as Integrated Efficient multimodal hubs'; Grant Agreement No. 101036594).

Appendices

A. ***Abbreviations***

Table A.1: Table of abbreviations

ACER	Agency for the Cooperation of Energy Regulators
EEG	Renewable Energy Act
ENTSO-E	European Network of Transmission System Operators for Electricity
FBMC	Flow-based Market Coupling
NTC	Net Transfer Capacity
RES	Renewable Energy Source
TSO	Transmission System Operator
TYNDP	Ten Year Network Development Plan

B. ***Analytical model: Change in producer surplus and welfare***

Change in producer surplus

Similar to consumer surplus, the change in producer surplus, ΔPS, captures the difference in outcomes between the 'connected' and 'separate' scenarios. The change in producer surplus for the importing and exporting markets can be expressed as follows:

$$\Delta PS_I = a \cdot \left(p_I^c \cdot (L_I - K) - p_I^s \cdot L_I + \int_{L_I - K}^{L_I} MC_I(f)\, df \right) < 0 \tag{B.1a}$$

$$\Delta PS_E = a \cdot \left(p_E^c \cdot (L_E + K) - p_E^s \cdot L_E - \int_{L_E}^{L_E + K} MC_E(f)\, df \right) > 0 \tag{B.1b}$$

In the importing market, producer surplus declines because the reduction in revenues (due to decreasing quantities and prices) exceeds the reduction in costs, depicted as light-blue diagonal hatching area (ΔPS_I) in Figure 1 (c). In contrast, in the exporting market, producer surplus rises due to access to the importing market via the interconnector. This access enables producers in the exporting market to sell greater quantities at higher prices, which generates larger additional revenues than costs. The resulting increase in producer surplus corresponds to the sum of the light-blue diagonal hatching and dark blue areas in Figure 1 (e).

Change in welfare

The welfare change in each market is determined by the sum of the changes in consumer and producer surplus as follows:

$$\Delta W = \Delta CS + \Delta PS \tag{B.2a}$$

$$\Delta W_I = -a \cdot (p_I^c - p_I^s) \cdot L_I + (1 - 2\varphi) \cdot X + a \cdot \left(p_I^c \cdot (L_I - K) - p_I^s \cdot L_I + \int_{L_I - K}^{L_I} MC_I(f)\, df \right) \tag{B.2b}$$

$$\Delta W_E = -a \cdot (p_E^c - p_E^s) \cdot L_E + (2\varphi - 1) \cdot X + a \cdot \left(p_E^c \cdot (L_E + K) - p_E^s \cdot L_E - \int_{L_E}^{L_E + K} MC_E(f)\, df \right) \tag{B.2c}$$

C. Modeling assumptions

Table C.2: Installed capacities in Germany and Swedish bidding zones (SE1–SE4) in 2035 by technology group

Technology group[a]	**Germany [GW]**	**Sweden [GW]**			
		SE1	**SE2**	**SE3**	**SE4**
Hydropower	4.75	5.44	7.65	2.29	0.24
Battery storage	34.25	0.00	0.00	0.00	0.00
Biomass	9.51	0.00	0.00	0.00	0.00
Combined-cycle gas turbines (CCGT)	14.78	0.00	0.00	0.00	0.00
H_2-ready CCGT	17.13	0.00	0.00	0.00	0.00
Coal / Lignite	0.00	0.00	0.00	0.00	0.00
Nuclear	0.00	0.00	0.00	8.35	0.00
Open-cycle gas turbines (OCGT)	1.64	0.10	0.00	0.00	0.00
Oil	0.75	0.00	0.00	0.00	0.00
Photovoltaic (PV)	299.47	0.00	3.00	16.53	6.90
Pumped storage	18.60	0.00	0.00	0.00	0.00
Wind Onshore	141.75	5.45	12.85	6.70	3.25
Wind Offshore	40.00	0.00	1.00	1.40	4.20
Others	13.39	0.20	0.74	2.55	0.70

[a] The category 'Others' includes technologies not explicitly listed (e.g. small-scale or residual generation). Data for Germany and Swedish bidding zones corresponds to TYNDP 2024 Global Ambition scenario values for year 2035 (ENTSO-E and ENTSOG, 2024). For Germany, 40 GW of Wind Offshore are assumed according to the Offshore Wind Energy Act (WindSeeG) (Federal Republic of Germany, 2024). Biomass capacity is assumed based on current values (UBA, 2025).

Table C.3: Electricity demand assumptions for Germany and Swedish bidding zones (SE1–SE4) in 2035

	Germany [TWh]	**Sweden [TWh]**			
		SE1	**SE2**	**SE3**	**SE4**
Annual demand[a]	766.61	50.90	50.09	106.73	44.34

[a] Demand corresponds to TYNDP 2024 Global Ambition scenario values for 2035 (ENTSO-E and ENTSOG, 2024).

Table C.4: Commodity and CO_2 price assumptions for 2035

Fuel type[a]	**Price [EUR/MWh]**
Uranium	6.05
Hard coal	6.16
Lignite	6.48
Biomethane	66.32
Oil	34.14
Natural gas	21.50
CO_2 price	130.20

[a] Commodity prices as well as assumed price of emission allowance follow TYNDP 2024 values for 2035 (ENTSO-E and ENTSOG, 2024).

D. Modeling results: Socio-economic welfare for different market configurations

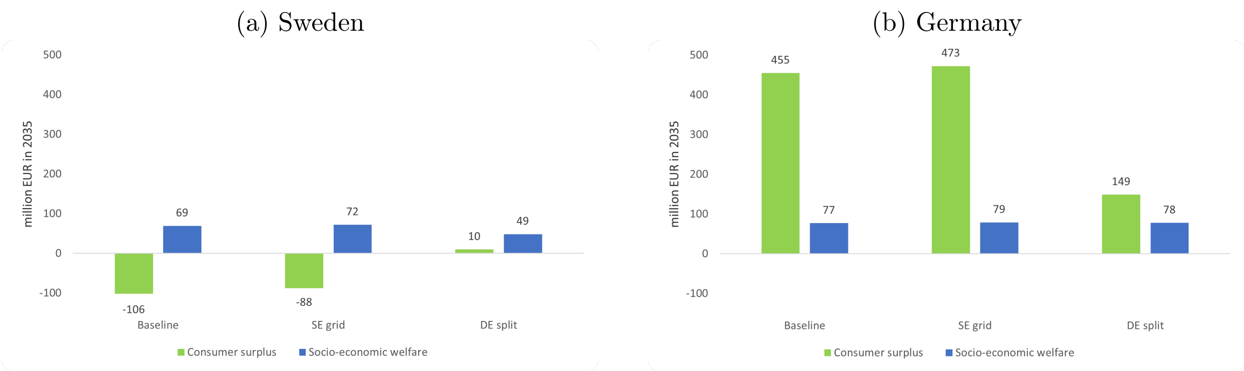


Figure D.1: Impact of alternative market configurations

Note: The figure shows the impact of alternative market configurations on consumer surplus and welfare for Sweden and Germany in the main scenario.

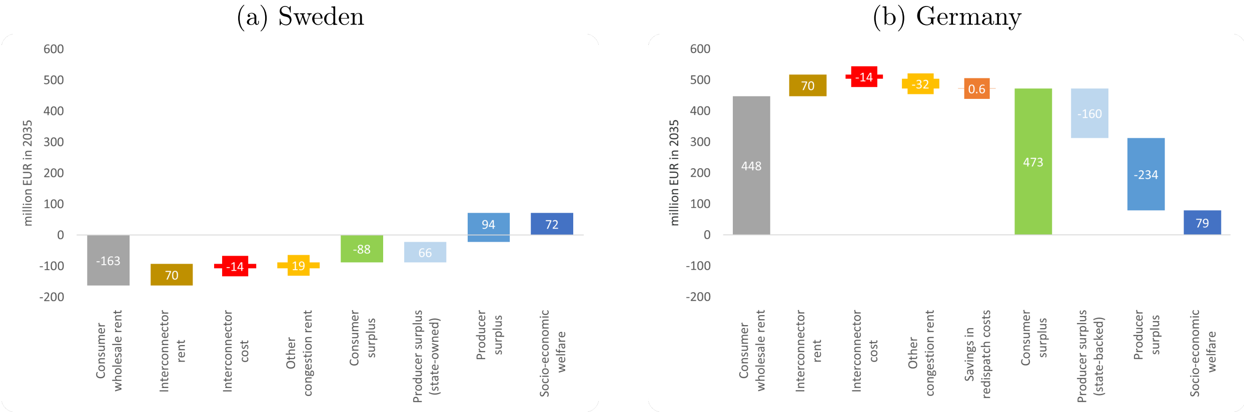


Figure D.2: Breakdown of socio-economic welfare - SE grid

Note: The figure shows the breakdown of socio-economic welfare under equal sharing of interconnector costs and rents under the inner-Swedish grid expansion ('SE grid'). Swedish consumers loose, while German consumers earn an immense surplus. In both countries the socio-economic welfare is positive.

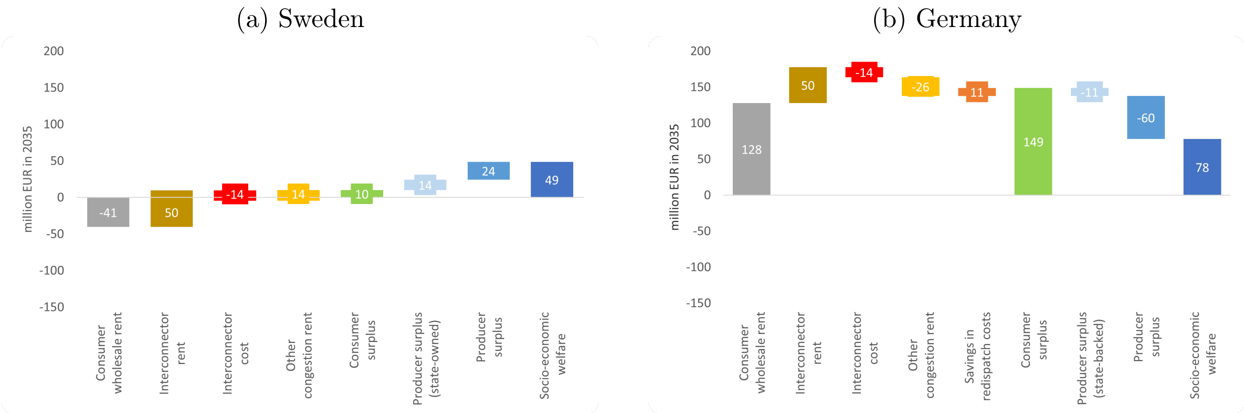


Figure D.3: Breakdown of socio-economic welfare - DE split

Note: The figure shows the breakdown of socio-economic welfare under equal sharing of interconnector costs and rents under the German bidding zone split ('DE split'). In both countries the consumer surplus and socio-economic welfare is positive.

*E. **Modeling results: Electricity prices in 2035***

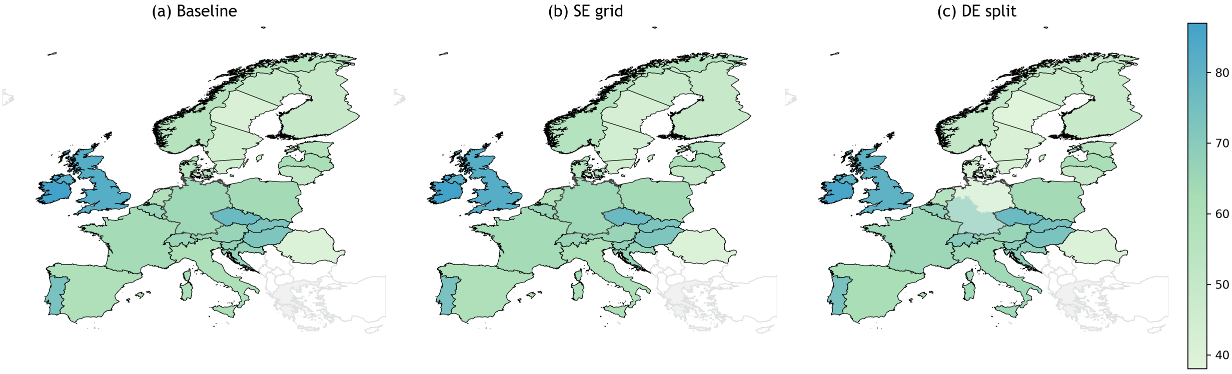


Figure E.4: Electricity prices across Europe in 2035

Note: The figure shows the average marginal electricity generation costs (EUR/MWh) across European countries or bidding zones for the analyzed market configurations without Hansa PowerBridge for the year 2035. The results refer to the main scenario with no external shocks.

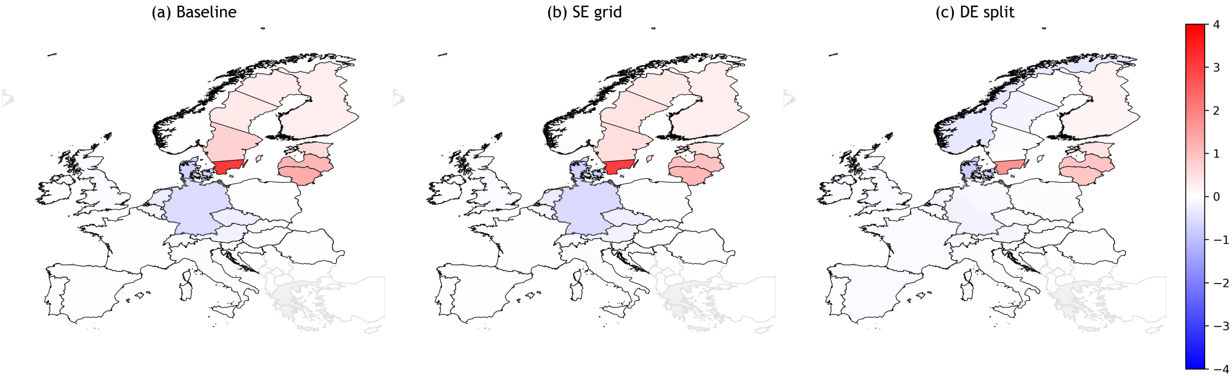


Figure E.5: Electricity price changes due to Hansa PowerBridge integration

Note: The figure shows the change in average marginal electricity generation costs (in EUR/MWh) by country or bidding zone, comparing a scenario with the Hansa PowerBridge to one without it. Red (blue) shading indicates an increase (decrease) in marginal generation costs due to the additional interconnector. The results refer to the main scenario with no external shocks.

References

50Hertz (2023). Hansa powerbridge. https://www.50hertz.com/en/Grid/Griddevelopement/Offshoreprojects/HansaPowerBridge/, accessed: 2024-05-29.

50Hertz (2024). Schwedische Regierung will Projekt Hansa Power Bridge nicht weiterverfolgen. https://www.50hertz.com/de/News/Details/14646/schwedische-regierung-will-projekt-hansa-power-bridge-nicht-weiterverfolgen, accessed: 2024-06-21.

50Hertz, Amprion, TenneT, TransnetBW (2020). Anhang zum Netzentwicklungsplan Strom 2030, Version 2019, Zweiter Entwurf, Aktualisierung Januar 2020 - Projektsteckbriefe Onshore. https://www.netzentwicklungsplan.de/sites/default/files/2022-11/NEP_Anhang_Aktualisierung_Januar_2020_komprimiert.pdf, accessed: 2024-06-02.

50Hertz, Amprion, TenneT, TransnetBW (2023). Netzentwicklungsplan Strom 2037 mit Ausblick 2045, Version 2023, Zweiter Entwurf. Tech. rep., Übertragungsnetzbetreiber, accessed: 2025-06-17.

ACER (2020). 4th monitoring report on cross-border cost allocation decisions. https://www.acer.europa.eu/sites/default/files/documents/Publications/2020-09_4th-ACER-CBCA-report.pdf, accessed: 2025-08-01.

ACER (2022a). Acer's decision on the alternative bidding zone configurations to be considered in the bidding zone review process. annex i list of alternative bidding zone configurations to be considered for the bidding zone review (text rectified by corrigendum of 14 october 2022). https://www.acer.europa.eu/sites/default/files/documents/Individual%20Decisions_annex/ACER%20Decision%2011-2022%20on%20alternative%20BZ%20configurations%20-%20Annex%20I.pdf, accessed: 2024-06-02.

ACER (2022b). Acer's final assessment of the eu wholesale electricity market design. https://www.acer.europa.eu/sites/default/files/documents/Publications/Final_Assessment_EU_Wholesale_Electricity_Market_Design.pdf, accessed: 2024-06-02.

ACER (2023). Acer's preliminary position on the tsos' proposal for amendments to: Congestion income distribution (cid) methodology. https://eepublicdownloads.entsoe.eu/clean-documents/nc-tasks/ACER_Decision_06-2023_on_CID_Annex_I.pdf, accessed: 2024-06-09.

Bertsch, J., Brown, T., Hagspiel, S. and Just, L. (2017). The relevance of grid expansion under zonal markets. *The Energy Journal* 38: 129–152.

Czock, B. H. (2025). Three Zones Fix All? Analyzing Static Welfare Impacts of Splitting the German Bidding Zone under Friction. Tech. rep., Energiewirtschaftliches Institut an der Universitaet zu Koeln (EWI).

Czock, B. H., Sitzmann, A. and Zinke, J. (2023). The place beyond the lines-Efficient storage allocation in a spatially unbalanced power system with a high share of renewables. Tech. rep., EWI Working Paper.

Di Cosmo, V., Collins, S. and Deane, P. (2020). Welfare analysis of increased interconnection between france and ireland. *Energy Systems* 11: 1047–1073.

Egerer, J., Weibezahn, J. and Hermann, H. (2016). Two price zones for the german electricity market—market implications and distributional effects. *Energy Economics* 59: 365–381.

Emelianova, P. and Namockel, N. (2025). Welfare redistribution through flexibility–who pays? *Energy Policy* 205: 114684.

ENTSO-E (2024). Guideline for cost benefit analysis of grid development projects. https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/news/2024/entso-e_4th_CBA_Guideline_240409.pdf, accessed: 2025-08-01.

ENTSO-E (2025). Transparency platform: Total load - day ahead / actual. https://transparency.entsoe.eu/load-domain/r2/totalLoadR2/show, accessed: 2025-10-15.

ENTSO-E and ENTSOG (2024). Tyndp 2024 draft scenarios report. https://2024.entsos-tyndp-scenarios.eu/download/, accessed: 2024-05-29.

European Parliament and Council of the European Union (2019). Regulation (eu) 2019/943 of the european parliament and of the council of 5 june 2019 on the internal market for electricity. Official Journal of the European Union, L158, 54-124.

European Union (2013). Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009. https://eur-lex.europa.eu/eli/reg/2013/347/oj/eng, accessed: 2025-08-07.

European Union (2022). Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure, amending Regulations (EC) No 715/2009, (EU) 2019/942 and (EU) 2019/943 and Directives 2009/73/EC and (EU) 2019/944, and repealing Regulation (EU) No 347/2013. https://eur-lex.europa.eu/eli/reg/2022/869/oj/eng, accessed: 2025-08-07.

EWI (2024). Wasserstoffspeicher in Deutschland und Europa – Modellbasierte Analyse bis 2050. Tech. rep., Energiewirtschaftliches Institut an der Universität zu Köln, accessed: 2025-04-25.

Federal Republic of Germany (2024). Offshore wind energy act (Windenergie-auf-See-Gesetz, windseeg). Federal Law Gazette I, Germany.

Fell, H. and Kaffine, D. T. (2018). The fall of coal: Joint impacts of fuel prices and renewables on generation and emissions. *American Economic Journal: Economic Policy* 10: 90–116.

Fell, H., Kaffine, D. T. and Novan, K. (2021). Emissions, transmission, and the environmental value of renewable energy. *American Economic Journal: Economic Policy* 13: 241–272.

Fraunhofer ISE (2025). Energy-charts. https://www.energy-charts.info/index.html?l=en&c=DE, accessed: 2025-10-14.

Gautier, A. (2020). Merchant interconnectors in europe: merits and value drivers .

Gonzales, L. E., Ito, K. and Reguant, M. (2023). The investment effects of market integration: Evidence from renewable energy expansion in chile. *Econometrica* 91: 1659–1693, doi:10.3982/ECTA20769.

Hirth, L., Khanna, T. M. and Ruhnau, O. (2024). How aggregate electricity demand responds to hourly wholesale price fluctuations. *Energy Economics* 135: 107652.

Hirth, L. and Ueckerdt, F. (2013). Redistribution effects of energy and climate policy: The electricity market. *Energy Policy* 62: 934–947.

Huang, D., De Vos, K., Van Hertem, D., Olmos, L., Rivier, M., Welle, A. Van der and Sijm, J. (2016). Mind the gap: Challenges and policy options for cross-border transmission network investments. In *2016 13th International Conference on the European Energy Market (EEM)*. IEEE, 1–6.

Joskow, P. and Tirole, J. (2005). Merchant transmission investment. *The Journal of industrial economics* 53: 233–264.

Kirschen, D. S. and Strbac, G. (2018). *Fundamentals of power system economics*. John Wiley & Sons.

Med-TSO (2022). Deliverable 4.2 procedure for cross border cost allocation application. https://med-tso.org/wp-content/uploads/2022/02/Deliverable_4.2_Procedure_for_Cross_Border_Cost_Allocation_Application.pdf, accessed: 2024-06-02.

Michelet, F. (2024). The impact of electricity market integration on the cost of co2 emissions abatement through renewable energy promotion .

Newbery, D., Strbac, G. and Viehoff, I. (2016). The benefits of integrating european electricity markets. *Energy Policy* 94: 253–263.

Nordic Regional Coordination Centre (2024). Successful go-live of the nordic flow-based market coupling project. Accessed: 2024-11-01.

NorthConnect (2015). Northconnect interconnector converter station and high voltage alternating current cable route - environmental statement volume 1 non-technical summary. https://northconnect.no/uploads/downloads/Britain/northconnect-es-volume-1-non-technical-summary1.pdf, accessed: 2024-06-11.

Offshore Energy (2023). Norway-uk interconnector hits a snag with license application refusal. https://www.offshore-energy.biz/norway-uk-interconnector-hits-a-snag-with-license-application-refusal/, accessed: 2024-06-02.

Ovaere, M., Kenis, M., Bergh, K. Van den, Bruninx, K. and Delarue, E. (2023). The effect of flow-based market coupling on cross-border exchange volumes and price convergence in central western european electricity markets. *Energy Economics* 118: 106519.

Reuters (2024). Swedish government says no to new power cable to germany. https://www.reuters.com/business/energy/swedish-government-says-no-new-power-cable-germany-2024-06-14/, accessed: 2025-01-30.

Schmidt, L. and Zinke, J. (2020). One price fits all? Wind power expansion under uniform and nodal pricing in Germany. Tech. rep., EWI Working Paper.

SKGS (2024). Opinion – skgs says no to hansa power bridge. Accessed: September 6, 2025.

Statkraft (2025). Organisation. https://www.statkraft.com/about-statkraft/organisation/, accessed: 2025-08-15.

Supponen, M. (2011). *Influence of national and company interests on European electricity transmission investments*. Aalto University.

Svenska Kraftnät (2023). Hansa powerbridge. Internal Document, unpublished.

Svenska kraftnät (2024a). Hansa powerbridge. https://www.svk.se/en/grid-development/grid-projects/hansa-powerbridge/, accessed: 2024-05-29.

Svenska kraftnät (2024b). Objectives for the increase of transmission capacity between sweden's electricity areas. https://www.svk.se/siteassets/om-oss/rapporter/2024/uppdrag-att-satta-mal-for-okning-av-overforingskapacitet_slutrapport.pdf, accessed: 2024-04-09.

Swedish Energy Agency (2025). Electricity production (net production) by type of power from 1970, twh. https://pxexternal.energimyndigheten.se/pxweb/en/Energimyndighetens_statistikdatabas/Energimyndighetens_statistikdatabas__Officiell_energistatistik__Arlig_energibalans__El_och_fjarrvarmeproduktion/EN0202_25.px/, accessed: 2025-04-16.

UBA (2025). Erneuerbare energien in zahlen. https://www.umweltbundesamt.de/en/topics/climate-energy/renewable-energies/renewable-energies-in-figures, accessed: 2025-03-18.

Unteutsch, M. (2014). Redistribution effects resulting from cross-border cooperation in support for renewable energy. Tech. rep., EWI Working Paper.

Urquijo, I. M. and Paraschiv, F. (2023). Cross-border effects between the spanish and french electricity markets: Asymmetric dynamics and benefits in the light of european market integration. *The Energy Journal* 44: 241–276.

Valeri, L. M. (2009). Welfare and competition effects of electricity interconnection between ireland and great britain. *Energy Policy* 37: 4679–4688.

Vattenfall (2024). Corporate factbook. https://group.vattenfall.com/siteassets/corporate/investors/investor_presentations/vattenfall-corporate-factbook-2024-09.pdf, accessed: 2025-02-18.

Vattenfall (2025a). News and stories. https://group.vattenfall.com/press-and-media/newsroom, accessed: 2025-02-18.

Vattenfall (2025b). Vattenfall's power plants. https://powerplants.vattenfall.com/#/types=Hydro/countries=Sweden/view=map/sort=name, accessed: 2025-02-18.

Voswinkel, S., Mikurda, J., Broll, R., Kramer, H., Breder, M., Brunsch, D., Meurer, F., Ostmeier, L., Radek, J., Stein, T. and Weber, C. (2022). Marktmodellierung und Interkonnektorbewertung für den Netzentwicklungsplan 2021-2035.

Willems, B., Brandstätt, C., Nieuwenhout, C., Le Coq, C. and Serrien, F. (2025). Cross-Border Cost Allocation for Electricity Transmission Networks. Cerre report, Centre on Regulation in Europe (CERRE).

Zinke, J. (2023). Two prices fix all? On the robustness of a German bidding zone split. Tech. rep., EWI Working Paper.