EFFECTS OF MORE AVAILABLE INTERCONNECTION CAPACITY ON THE ENERGY TRANSITION

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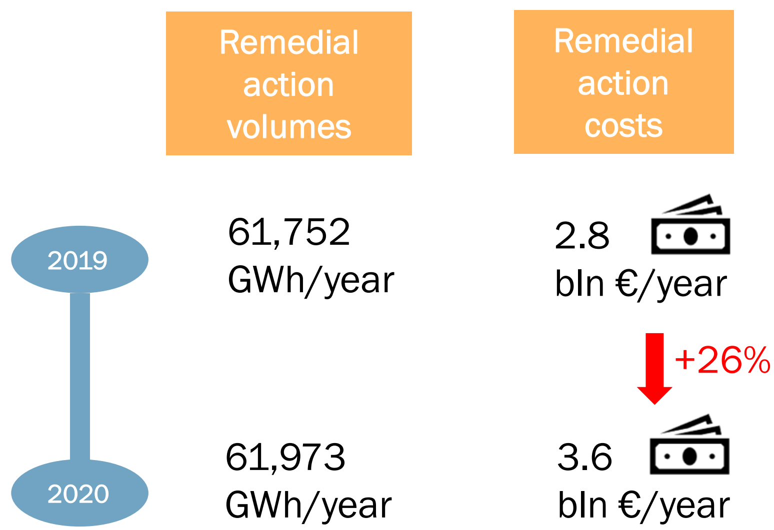
EXECUTIVE SUMMARY

EXECUTIVE SUMMARY
ISSUES WITH AVAILABLE INTERCONNECTION CAPACITY

- The lack of sufficient interconnection capacity impedes the realization of one European internal electricity market. Although available technical capacity between countries is increasing by grid expansion, the amount of grid capacity available for cross-border electricity trade increases much less and in some cases even has decreased (ACER, 2019; EU, 2019). This results from structural congestion within bidding zones prioritizing transactions within countries and concomitant loop flows over cross-border transactions.
- Costs of congestion-related remedial actions in EU-27 such as redispatching increased to € 3.6 billion in 2020. Amongst others, these high costs reflect that structural network congestions are partially within bidding zones and that a large part of congestions is dealt with by remedial actions (ACER, 2021).
- Electricity prices are becoming less reflective of the physical reality. After electricity trading has taken place, redispatching actions are required to avoid congestion, which means that resulting 'net' prices (electricity price plus congestion charge) are increasingly different from initial electricity prices. Less cost reflective initial prices provide adverse incentives for investment and operational decisions to producers and large consumers.



Source: ACER (2020a; 2021).

EXECUTIVE SUMMARY
BIDDING ZONE RECONFIGURATION IS IMPORTANT POLICY OPTION

- Given the importance of more interconnection capacity for achieving the EU-wide internal energy market, Regulation (EU) 2019/943 requires Member States to make available at least 70% of capacity on critical network elements for cross-zonal trade as of 31 December 2025.
- The remaining 30% may be used for reliability margins, loop flows and internal flows. If structural congestion is identified, Member States should adopt an action plan with a linear trajectory from the current situation to the 70% minimum target or reconfigure their bidding zone.
- However, many countries including the Netherlands are far from meeting the 70% minimum target at the moment.
- For achieving this target, there are basically three possibilities: (1) grid upgrading; (2) operational measures such as better capacity calculations and cross-border redispatch; (3) introduction of more bidding zones.
- First two solutions do not provide a timely solution i.e. by the end of 2025;
  - Grid upgrading takes a lot of time due to time-consuming spatial procedures and public opposition.
  - Operational measures such as better capacity calculation methods and application of cross-border redispatch are highly dependent on the implementation of European methodologies with long-term trajectories. Moreover, wider application of redispatch is hindered by lack of sufficient generation plants for redispatch.
- Consequently, this study explores the impacts of more bidding zones on the energy transition and social welfare of the EU-27 and Central Western European (CWE) countries* in 2030.

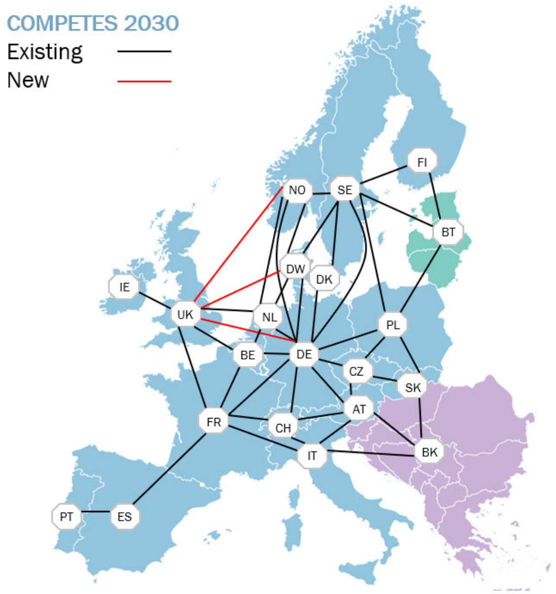
* Austria, Belgium, France, Germany (including Luxemburg) and the Netherlands

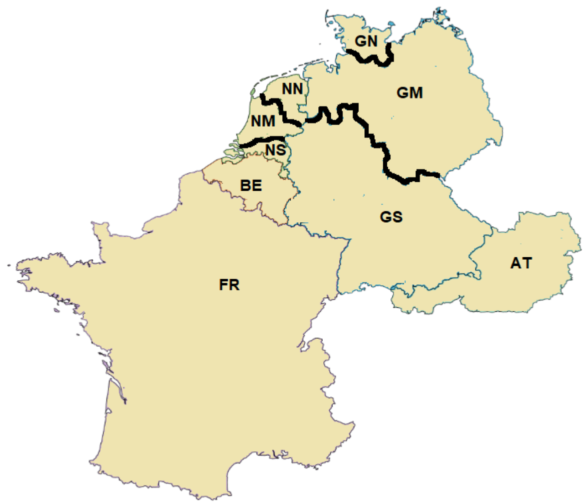
EXECUTIVE SUMMARY
RESEARCH QUESTIONS

- The project aimed to answer the following research questions:
  1. What are the effects of more available interconnection capacity, notably due to more bidding zones, on the energy transition and EU internal electricity market? What impact do main network reinforcements and the introduction of bidding zones in Germany have on the Netherlands?
  2. What is the impact of more available interconnection capacity on operational decisions of producers, consumers and TSO in the Netherlands in 2030? What are opportunities and threats for Dutch renewable electricity production and/or efficient Dutch gas-fired power stations?
  3. What is the impact of more available interconnection capacity on overall flex supply? What does it mean for the merit order of flex options i.e. flex from abroad through interconnections as well as demand response in the Netherlands in 2030, compared to a situation with less available interconnection capacity?

EXECUTIVE SUMMARY
MAIN ASSUMPTIONS: MARKET MODEL

- COMPETES ('Competitive Electric Transmission and Energy Simulator') is a power optimisation and economic dispatch model that seeks to minimise the total power system costs of the European power market (including UK, NO and CH) whilst accounting for the technical constraints of the generation units, transmission constraints between the countries as well as transmission capacity expansion and generation capacity expansion for conventional technologies.
- In line with current practise, a flow-based network representation is implemented for the CWE region (France, Germany, Belgium, the Netherlands, and Austria). For the remaining EU countries interconnections are modelled using the NTC approach.
- COMPETES assumes that every country constitutes one node. Exceptions are South East Europe or Balkan, and Baltic countries, that are both modelled as one zone. Another exception is Denmark, which consists of two zones that are part of different synchronous areas.
- Three bidding zones in both Germany and the Netherlands are tested, given the amounts of internal network congestion and expert-based TSO proposals for analysis in bidding zone review. TSOs in other CWE countries did not propose multiple bidding zones (ENTSO-E, 2019).





EXECUTIVE SUMMARY
DEFINITION OF BASE CASE AND PROJECT ALTERNATIVES

Base case

- Network capacities derived from JAO network capacities i.e. average 2019 capacities from joint allocation office (JAO), scaled with ENTSO-E network capacity figures for 2030.

Project alternative 1: More available interconnection capacity (IC)

- Network capacities from network reduction methodology, see Annex I, with interconnection degree 6 (ID6C)
- Assuming 1 bidding zone (BZ) per country

Project alternative 2: More bidding zones (BZs)

- Network capacities from network reduction methodology, with interconnection degree 6 (ID6Z)
- In line with expert-based TSO statements (ENTSO-E, 2019), DE and NL consist both of 3 zones per country, while AT, BE and FR consist of 1 zone per country.

For all cases a zonal topology is assumed

- In order to prevent effects of different network topologies (different circuits and hence reactances) for the comparison between base case and project alternatives and thus to allow for better comparability, the same circuits and reactances are assumed for all cases.

EXECUTIVE SUMMARY
EVALUATION CRITERIA

- The effects from the project alternatives with more bidding zones and more interconnection capacity are compared to the base case for:
  - Social welfare i.e. the sum of producer surplus, consumer surplus, and congestion rents, minus transition costs.
  - Electricity prices
  - Generation mix and CO_2 emissions
  - Electricity imports and exports
  - Deployment of demand response
- Higher social welfare and lower CO_2 emissions are considered as beneficial if there is a net benefit for the 5 CWE countries and/or the EU-27+CH+NO+UK (hereafter: EU-27+) as a whole
- Effects are also discussed separately for DE and NL, since these are the countries where more bidding zones are introduced. Although an overall positive effect is expected, some countries are likely to be affected negatively, consequently effects on individual countries are sometimes redistribution effects from broader perspectives (5 CWE countries and EU-27+).
- Changes in electricity prices, generation mix, net electricity exports, and deployment of demand response are partially behind changes of net social welfare but are also partially redistribution effects;
  - E.g. higher exports of *net exporting countries* imply higher electricity prices and thus higher producer surplus, which is partially compensated by lower consumer surplus. At the same time, consumers of *net importing countries* benefit from lower prices i.e. higher consumer surplus, which is partially compensated by lower producer surplus.
  - More flexibility supply from foreign countries through interconnections may replace flexibility supply from demand response.

EXECUTIVE SUMMARY
CALCULATION OF SOCIAL WELFARE EFFECTS

- **Effect of more available interconnection capacity (IC)** (in billion €): comparison of project alternative with more IC with base case, taking into account redispatch costs in the base case.

- **Effect of more bidding zones (BZs)** (in billion €): comparison of project alternative with more BZs with project alternative with more IC, taking into account redispatch costs in the base case.

- **Redispatch costs (RD)** (in billion €): although for electricity trading unlimited capacities within zones are assumed ('copper plate'), in practise network capacities within zones are limited, consequently curative redispatch of generation after closure of markets for electricity trading is required. If this effect is not taken into account, results of the base case are too optimistic, resulting in negative incremental effects of the project alternatives with more available interconnection capacity and bidding zones.
  - The effect is estimated by comparing the situation with limited internal network capacities against the situation with unlimited internal network capacities (i.e. network capacities inside DE and NL). Hence, both for base case and project alternative 1 two variants have been established;
  - One variant without taking into account RD i.e. with unlimited network capacities within countries
  - One variant with taking into account RD i.e. limited network capacities within countries
  - RD costs: difference between both variants (unlimited minus limited) for base case as well as project alternative 1 respectively

- **Total effect (in billion euro) = effect of more available interconnection capacity + effect of more bidding zones**

EXECUTIVE SUMMARY
SOCIAL WELFARE EFFECTS OF MORE INTERCONNECTION

- **Research question 1**: What are the effects of more available interconnection capacity, notably due to more bidding zones, on the energy transition and EU internal electricity market? What impact do main network reinforcements and the introduction of bidding zones in Germany have on the Netherlands?
- The COMPETES electricity market model has been adapted and run to test the effects of more available interconnection capacity and bidding zones on the energy transition and EU internal elec. market. An overall decrease of CO_2 emissions with 5.1 Mton in EU-27+ with flow-based network representation when accounting for redispatch costs, but in the Netherlands an increase of 2.6 Mton due to more electricity exports.
- Positive effects of more interconnection and more bidding zones compared to base case on social welfare (SWF) for EU-27+ for 2030:

Country *all figures in million €*	Total effect	More interconnection	More bidding zones
Austria	1	5	-4
Belgium	78	71	7
France	-155	-127	-28
Germany	81	46	35
Netherlands	614	422	191
Norway	-152	-107	-44
Total EU-27+CH+NO+UK	**477**	**318**	**159**

- Results indicate that bidding zones are indispensable to increase the utilization of network infrastructure and thus contribute to achieving the 70% minimum target of network capacity available for cross-zonal trade. Without bidding zones it is unlikely that significantly more available interconnection capacity will be realised by TSOs, hence both effects are intertwined.

EXECUTIVE SUMMARY
SOCIAL WELFARE EFFECTS OF MORE INTERCONNECTION (CON'D)

- Social welfare (SWF) increases by € 477 million per year in EU-27+ due to more available interconnection capacity and bidding zones compared to base case.
  - Mainly producer surplus increases (€ 928 million), while consumer surplus decreases (€ 409 million). This is likely to be the result of steeper supply curve in smaller and net exporting countries such as the Netherlands, while the supply curve is more gradual in larger and net importing countries such as Germany. Hence, substantial price increases occur in exporting countries but smaller price decreases in importing countries, increasing net producer surplus and decreasing net consumer surplus (cf. Supponen, 2012).
  - Congestion rents decrease (€ 43 million), although more bidding zones mean more borders where congestion rents can be earned. The latter effect is outweighed though by the correction for redispatch costs in the base case and therefore not visible. Since redispatch costs are underestimated due to assumptions of both EU wide and cost efficient redispatch, this is likely to be different in practice.
  - Transition costs and possible additional costs of remedial actions are not included in this estimate.
  - Redispatch costs amount to € 536 million per year for this geographical area and are thus essential for a fair assessment of the effects of bidding zones on both SWF and other assessment criteria. Hence, all figures mentioned here include redispatch costs in the base case.
- More available IC and more BZs have important redistribution effects, both between and within countries. E.g. SWF in the Netherlands increases by € 614 million per year, while SWF in France and Norway decreases by € 155 and € 152 million per year respectively.
- SWF effects are under/overestimated for the following reasons;
  - Model assumption of efficient and EU-wide cross-border redispatching, hence smaller effect of more bidding zones on SWF than in reality.
  - SWF effects increase with more renewables and the scenario includes 10 GW of additional offshore wind generation in the Netherlands, while no additional industrial demand has been investigated.

EXECUTIVE SUMMARY

SENSITIVITY NO HVDC NORTH-SOUTH CABLES IN GERMANY

Country *all figures in million €*	Producer surplus	Consumer surplus	Congestion rents	Transition costs	Net effect
Austria	20	-14	-4	PM	2
Belgium	-14	0	19	PM	5
France	73	-53	-22	PM	-2
Germany	72	-141	164	PM	95
Netherlands	-101	23	122	PM	44
Other EU-27+ countries	142	-141	-19	PM	-17
Total	**192**	**-325**	**260**		**127**

- In Germany, three major North-South HVDC cables are envisaged (Südlink, SüdOst-link and A-Nord projects, in total 8 GW) to diminish existing network congestion and thus to better connect offshore renewable energy in the North with load centres in the South.
- No HVDC N-S cables within Germany causes an *additional* net social welfare effect of ca € 130 million euro of more IC and BZs in EU-27+ (i.e. compared to the net social welfare effect in the situation with HVDC cables)
- The absence of these cables implies a more constrained electricity system and a major change of trading patterns. Consequently, more available interconnection capacity (IC) and bidding zones (BZs) have a larger SWF effect than in the original case.
- The adverse effects of the lack of HVDC cables on CO_2 emissions (notably in DE) and curtailment of wind generation are partially mitigated by more IC and BZs.

EXECUTIVE SUMMARY
SENSITIVITY BIDDING ZONES IN GERMANY ONLY

- This sensitivity sheds light on the question: Which part of the bidding zones effects is due to BZs in Germany and which part due to BZs in NL?
  - Rather than comparing a case with BZs in Germany only against the base case or project alternative 1, this has been simulated by excluding bidding zones in the Netherlands from project alternative 2.
- Excluding bidding zones in NL causes an insignificant overall net social welfare effect compared to the net SWF effect in the situation with BZs in both Germany and the Netherlands.
- This effect is in line with the earlier observation that in Germany differences in electricity prices between bidding zones within the country are quite significant in project alternative 2, while in the Netherlands they are really small. This indicates that network congestion and therefore the possible contribution of bidding zones to social welfare in Germany is significant, but in NL is limited.
- It is thus obvious that largest price effects of bidding zones are in Germany. Yet largest SWF effects of more BZs in DE are in NL. Possible explanations seem to relate to suboptimal market and network modelling;
  - Market modelling: more refined modelling of generation plants in the Netherlands i.e. with unit commitment (start-up costs, ramping rate, minimum uptime and downtime characteristics of plants), while generation is aggregated by technology for other countries like Germany i.e. without unit commitment. Therefore the merit order of generation units is less refined for other countries, hence changes in generation deployment cause less cost and price differences and therefore possibly less SWF changes in these countries. This may result in underestimation of social welfare effects of bidding zones as well as a more uneven distribution of SWF effects then in practice.
  - Network modelling: redispatch costs seem not adequately included in the base case of this specific sensitivity case. This is left for further research.

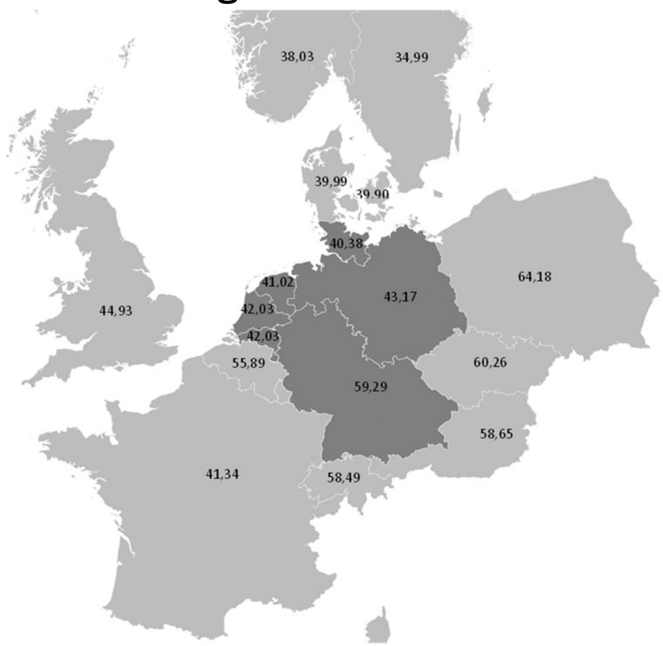
EXECUTIVE SUMMARY
EFFECTS ON PRODUCERS & CONSUMERS

- Research question 2: What is the impact of more available interconnection capacity on operational decisions by producers, consumers and TSO in the Netherlands in 2030? What are opportunities and threats for Dutch renewable electricity production and/or efficient Dutch gas-fired power stations?
  - Higher producer surplus (PS): although overall generation costs decrease, PS increases due to higher electricity prices and replacement of high marginal cost generation (mainly gas and coal) by low marginal cost generation (less curtailment of wind).
  - Lower consumer surplus (CS): mainly the opposite of PS since the advantage of higher electricity prices for producers is a disadvantage for consumers.

- More IC and BZs change electricity prices that producers receive and consumers pay;
  - Small decrease of weighted average prices in EU-27+ with more available interconnection capacity compared to base case due to more competition among producers.
  - Higher weighted average prices in EU-27+ with more BZs since congestion on internal borders is directly taken into account in electricity prices while without BZs this congestion is neglected in electricity pricing, resolved after electricity trading by redispatch and paid for by network tariffs. This decreases revenues from generation redispatch for producers and lowers network tariffs for consumers.

EXECUTIVE SUMMARY
EFFECTS ON PRODUCERS & CONSUMERS

More bidding zones in DE & NL



- More IC and BZs change electricity prices that producers receive and consumers pay (con'd):
  - Germany: average price difference of about € 19/MWh between Germany North and South. Price difference of about € 1/MWh between Netherlands North and Middle. No average price difference between NL Middle and South suggests no structural congestion between these areas and hence limited impact on generation dispatch. The latter might be the result of too optimistic generation capacity assumptions.
- More IC and BZs result in changes of the merit order of generation plants and hence in changes of generation mix, CO_2 emissions and net imports in the Netherlands and other CWE countries;
  - Higher deployment of gas-fired generation (CHPs and CCGTs), higher CO_2 emissions, more electricity exports, and less curtailment of offshore wind in NL
  - Effects for the NL seem a bit exaggerated though due to dissimilar modelling of generation in NL and other countries (see previous slides) and 10 GW of additional offshore wind generation in NL without additional industrial demand.

EXECUTIVE SUMMARY
EFFECTS ON NETWORK OPERATORS

- More available interconnection capacity results in less congestion and therefore lower congestion rents for TSOs, while more bidding zones mean more borders where congestion rents can be earned. The latter effect is outweighed though by the correction for redispatch costs in the base case and therefore not visible.

- Underestimation of redispatch costs in base case and project alternative with more interconnection due to assumptions of both EU wide and cost efficient redispatch, while in practise:
  1. Mainly national redispatch, cross-border redispatch is currently largely absent, but in development following EU regulations;
  2. Two-step approach (electricity trading followed by curative redispatch) causes major inefficiencies, amongst others due to different geographical delineation of both mechanisms (country-wide versus nodal). This offers market participants arbitrage opportunities and incentives for strategic bidding behaviour (Cf. Smeers, 2008; Hirth *et al.* 2019).

- Hence, in practise decrease of redispatch costs with more bidding zones is larger than shown in model results and there is a net positive result on the net revenues for TSOs from congestion rents and redispatching, which is usually passed through to consumers by lower grid tariffs.

EXECUTIVE SUMMARY
EFFECTS ON FLEX SUPPLY AND DEMAND RESPONSE

- Research question 3: What is the impact of more available interconnection capacity on overall flex supply? What does it mean for the merit order of flex options i.e. flex from abroad through interconnections as well as demand response in the Netherlands in 2030, compared to a situation with less available interconnection capacity?

- Overall supply of flexibility in the Netherlands of 5.3 TWh by interconnections, conventional generation, renewable generation (curtailment), and demand response is not affected.
- More available interconnection capacity increases the supply of flex from abroad through interconnections, and decreases the role of demand response in the Netherlands
  - Flex supply (both upwards and downwards) through interconnections and gas-fired generation increases, while VRE curtailment and demand response (P2H, HPs, EVs) provide less flexibility. The change of demand response is caused by less flex of EVs (50%) and P2H (50%).
  - Flex demand which is caused by VRE, non-flex demand, and DR, is not significantly affected.

Flexibility supply (TWh)			
	Base case	More interconnection and bidding zones	Change
Interconnections	1,4	2,1	0,7
Gas-fired generation	1,2	1,3	0,2
VRE curtailment	1,6	0,9	-0,7
Demand response	1,0	0,9	-0,1

EXECUTIVE SUMMARY
POLICY RELEVANCE

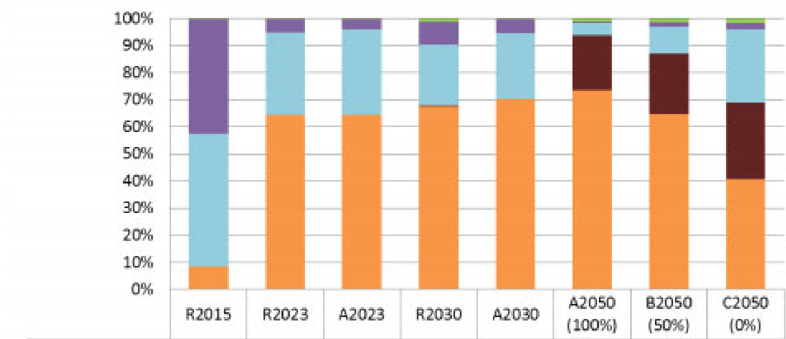
- ACER (2020b) outlines the methodology and assumptions that are to be used in the official and regular bidding zone (BZ) review process, and distinguishes four groups of criteria related to; (i) network security, (ii) market efficiency, (iii) stability and robustness of BZs, and (iv) energy transition.
- Although our analysis does not fulfill all ACER requirements concerning e.g. target year and modelling chain steps, it provides valuable insights in the main effects of alternative BZ configurations on market efficiency and energy transition;
  - Market efficiency and notably economic efficiency play a key role in the BZ review process. The assessment of economic efficiency is largely based on the change of SWF and is the first step for the assessment of alternative BZ configurations i.e. calculating monetized benefits.
  - Energy transition: the analysis provides insights in short-term effects on CO_2 emissions and RES integration (total amount of fed-in energy quantities from RES i.e. less curtailment) and their variability.
- It also shows that redistribution effects between and within countries are significant, which may lead to political resistance.
- For the assessment of alternative BZ configurations against the status quo also other (qualitative) evaluation criteria are relevant that were not in scope of the study, e.g. related to stability and robustness of BZs, and to market efficiency, a.o.
  - Market liquidity and transaction costs, to provide insight in hedging opportunities of market participants
  - Market concentration and market power in wholesale markets and redispatching mechanisms
- Further research into the effects of bidding zones may deliver a more complete and refined picture of the merits and demerits of alternative bidding zone configurations and its effects for EU-27+ in general and for the Netherlands in particular.

INTRODUCTION AND RESEARCH QUESTIONS

INTRODUCTION
FLEXIBILITY CROSS-BORDER TRADE KEY FOR ENERGY TRANSITION

- The Netherlands strives for a low-carbon energy system. This energy transition means, among others, (i) a larger share of electricity from variable renewable energy (VRE), in particular, solar and wind and (ii) a larger share of electricity in total energy consumption due to the electrification of other sectors (mobility, industry)
- These trends increase the need for flexibility in the energy system. There are several sources of flexibility like, conventional generators, curtailment of VREs, storage, demand response and foreign flexibility through cross-border trade.
- The FLEXNET project (Sijm et al. 2017) showed that access to foreign flexibility through cross-border electricity trade is the dominant flexibility option for a future electricity system with 80% renewable energy.

Total annual supply of flexibility options to meet total annual demand of flexibility, either upwards or downwards, in all scenario cases, 2015-2050.



	R2015	R2023	A2023	R2030	A2030	A2050 (100%)	B2050 (50%)	C2050 (0%)
Other RES-E	0.2%	0.1%	0.0%	1.1%	0.0%	1.1%	1.4%	1.7%
Coal	42.4%	5.0%	4.0%	8.6%	5.4%	0.6%	1.7%	2.4%
Gas	48.9%	30.4%	31.5%	22.2%	24.2%	4.6%	9.8%	26.8%
VRE curtailment	0.0%	0.0%	0.0%	0.3%	0.0%	20.2%	22.1%	28.2%
Net imports	8.5%	64.5%	64.5%	67.7%	70.4%	73.5%	64.6%	40.8%

Source: Sijm et al. (2017a; 2017b)
R = Reference scenario, Dutch National Energy Outlook 2015, accepted policy scenario
A = Alternative scenario, strong growth of additional electrification
A2050 = 100% of interconnection capacity (IC) expansion beyond 2050
B2050 & C2050 = A2050 scenario with 50% and 0% increase of IC respectively

INTRODUCTION
ISSUES WITH AVAILABLE INTERCONNECTION CAPACITY

- The lack of sufficient interconnection capacity impedes the realization of one European internal electricity market. Although available technical capacity between countries is increasing by grid expansion, the amount of grid capacity available for cross-border electricity trade increased much less and in some cases even decreased (ACER, 2019; EU, 2019). This results from structural congestion within bidding zones prioritizing transactions within countries and concomitant loop flows over cross-border transactions.
- Costs of congestion-related remedial actions in EU-27 such as redispatching increased to € 3.6 billion in 2020. Amongst others, these high costs reflect that structural network congestions are partially within bidding zones and that a large part of congestions is dealt with by remedial actions (ACER, 2021).
- Electricity prices are becoming less reflective of the physical reality. After electricity trading has taken place, redispatching actions are required to avoid congestion, which means that resulting 'net' prices (electricity price plus congestion charge) are increasingly different from initial electricity prices. Less cost reflective initial prices provide adverse incentives for investment and operational decisions to producers and large consumers.

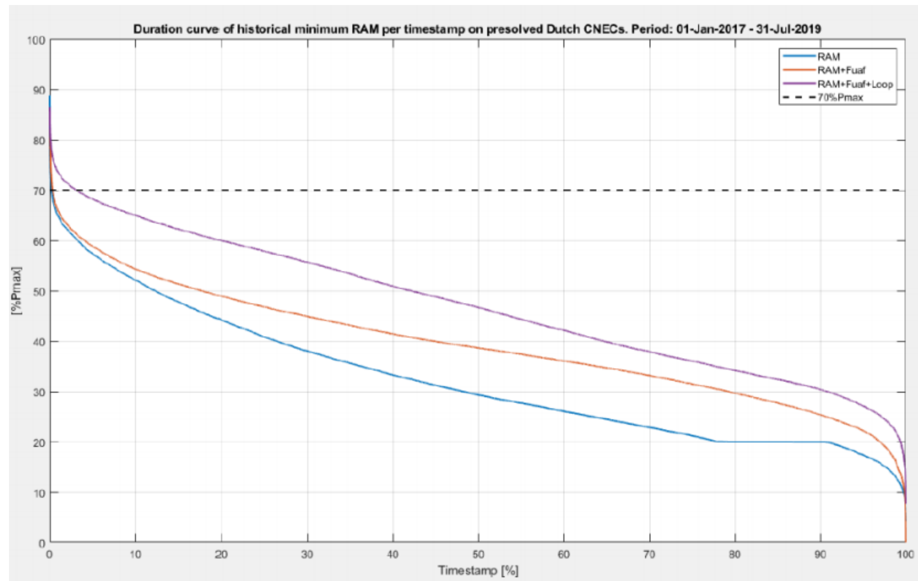
	Remedial action volumes	Remedial action costs
2019	61,752 GWh/year	2.8 bln €/year
		+26%
2020	61,973 GWh/year	3.6 bln €/year

Source: ACER (2020a; 2021).

INTRODUCTION

EU POLICY INTERVENTION TO INCREASE AVAILABLE GRID CAPACITY

- Given the importance of more interconnection capacity for achieving the EU-wide internal energy market, Regulation (EU) 2019/943 requires Member States to make available at least 70% of capacity on critical network elements for cross-zonal trade as of 31 December 2025.
- The remaining 30% may be used for reliability margins, loop flows and internal flows. If structural congestion is identified, Member States should adopt an action plan with a linear trajectory from the current situation to the 70% minimum target or reconfigure their bidding zone.
- However, many countries (including the Netherlands) are far from meeting the 70% minimum target at the moment. Based on a historical ('retrospective') analysis of the grid capacity offered for 2017-2019, TenneT showed that the 70% minimum target is achieved for only about 1% of timestamps (see orange line). ACER confirmed this result in their market monitoring report 2020 for 2018-2020.



Source: TenneT (2019)
RAM = remaining available margin
CNEC = critical network element with contingency
Fuaf = calculated value of unscheduled allocated flow of CNEC
Loop = calculated value of total loop flow of CNEC

INTRODUCTION

BIDDING ZONE RECONFIGURATION IS IMPORTANT POLICY OPTION

- For achieving the 70% minimum target, there are basically three possibilities: (1) grid upgrading; (2) operational measures such as better capacity calculations and cross-border redispatch; (3) introduction of more bidding zones.
- First two solutions do not provide a timely solution i.e. by the end of 2025;
  - Grid upgrading takes a lot of time due to time-consuming spatial procedures and public opposition.
  - Operational measures such as better capacity calculation methods and application of cross-border redispatch are highly dependent on the implementation of European methodologies with long-term trajectories. Moreover, wider application of redispatch is hindered by lack of sufficient generation plants for redispatch.
- Hence, it is useful to explore the impact of more bidding zones on the energy transition and social welfare of the EU-27 and Central Western European (CWE) countries* in 2030. Once structural congestion within large bidding zones is ignored, transactions *within* such bidding zones do not properly reflect physical reality of electricity systems and limit its availability for transactions *between* bidding zones. Smaller bidding zones provide price signals that decrease the use of interconnections for trading within zones significantly and provide congestion reflective price signals for investments to add.
- TenneT considers the division of the Netherlands into multiple bidding zones as a possibility to comply with the 70% minimum target and proposed to analyse a bidding zone configuration with three zones as part of the biennial bidding zone review process (ENTSO-E, 2019; TenneT, 2019).

* Austria, Belgium, France, Germany (including Luxemburg) and the Netherlands

INTRODUCTION
RESEARCH QUESTIONS

- The project aimed to answer the following research questions:
  1. What are the effects of more available interconnection capacity, notably due to more bidding zones, on the energy transition and EU internal electricity market? What impact do main network reinforcements and the introduction of bidding zones in Germany have on the Netherlands?
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MAIN ASSUMPTIONS AND CASE DEFINITIONS

MAIN ASSUMPTIONS
MARKET MODEL

- COMPETES ('Competitive Electric Transmission and Energy Simulator') is a power optimisation and economic dispatch model that seeks to minimise the total power system costs of the European power market (including UK, NO and CH) whilst accounting for the technical constraints of the generation units, transmission constraints between the countries as well as transmission capacity expansion and generation capacity expansion for conventional technologies.
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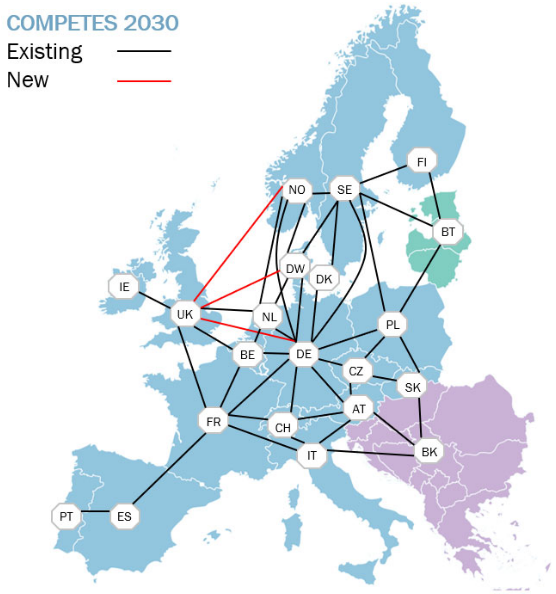
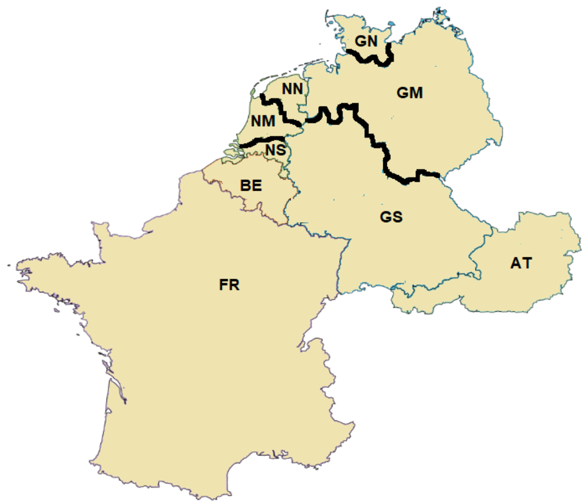
- Three bidding zones in both Germany and the Netherlands are tested, given the amounts of internal network congestion and expert-based TSO proposals for analysis in bidding zone review. TSOs in other CWE countries did not propose multiple bidding zones (ENTSO-E, 2019).





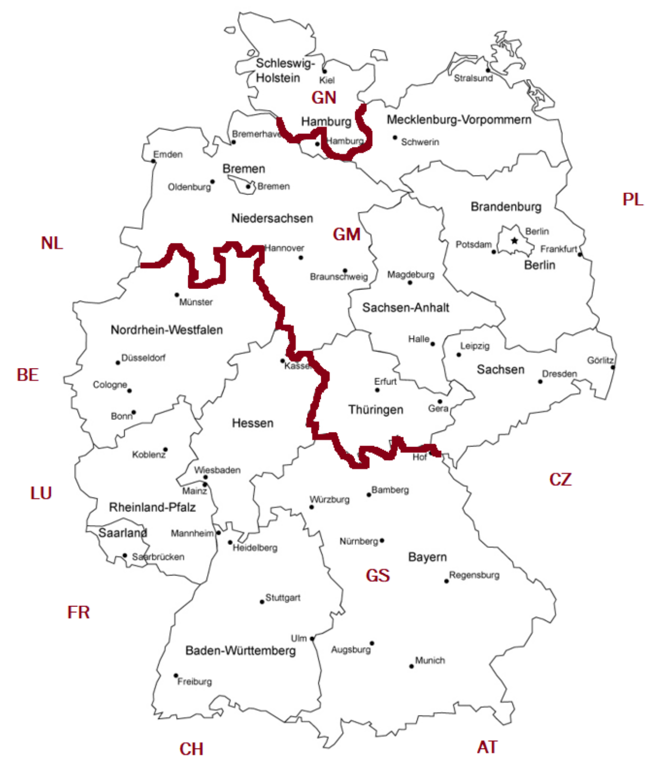
MAIN ASSUMPTIONS
LOAD AND GENERATION DATA

- Load data
  - ENTSO-E TYNDP 2020 national trends scenario for year 2030, only for NL KEV 2021 (PBL, 2020)
  - The hourly national profiles (Germany and Netherlands) are converted into hourly zonal profiles (NN, NM, NS, GN, GM, GS) using the distribution factors based on annual electricity consumption data of provinces/states.

- Generation data
  - Generation capacities are taken from ENTSO-E TYNDP 2020 national trends scenario for year 2030, only for NL KEV 2021. For details refer to the Annex II.
  - For assumptions about fuel prices, CO_2 price, assumed full load hours for wind and solar-PV, and network capacities, see Annex II.
  - The generation mixes of both countries are distributed among the different zones using the distribution keys based on geographical power plant data.
  - Distribution keys for Germany are based upon historical power plant data of the Bundesnetzagentur (version April 2020).
  - For the Netherlands they are based upon the COMPETES database updated with KEV 2021 info (conventional power plants), MIDDEN database and CBS statistics (CHPs), public info from EZK (OWF, including announcement of additional 10 GW), RVO (Monitor onshore wind 2020) and CBS (solar-PV).

MAIN ASSUMPTIONS
BIDDING ZONE DELINEATION IN GERMANY

- Given the required bidding zone review, the 4 German TSOs proposed to analyse three new congestion-based bidding zone configurations (ENTSO-E, 2019):
  - Configuration 1 splits Germany along the borders of the federal states Baden-Wurttemberg and Bavaria making up two new zones (North and South).
  - Configuration 2 splits Germany in two zones, roughly along the borders of the federal states of Bavaria, Hessen, and North Rhine-Westphalia, creating a North-East and a South-West bidding zones.
  - Configuration 3 uses bidding zone configuration 2 and introduces an additional zone that follows the border of the federal state Schleswig-Holstein.
- For this study configuration 3 was chosen as shown on the right. The three zones are hereafter referred to as Germany North (GN), Germany Middle (GM) and Germany South (GS).



MAIN ASSUMPTIONS
BIDDING ZONE DELINEATION IN THE NETHERLANDS

- Likewise, Dutch TSO TenneT proposed to analyse a congestion-based three-zone configuration for the Netherlands. The geographical delineation of the proposed zones Netherlands North (NN), Netherlands Middle (NM) and Netherlands South (NS) is shown on the right.
- TenneT (ENTSO-E, 2019) expects increasing congestion on North-South lines between NN and NM zones, since electricity generators in the Eemshaven area (conventional, wind onshore and offshore, and solar PV) will compete with cross-border flows originating from Denmark, Norway and Germany for the network capacity towards large industrial and residential areas in the Randstad area of the NM zone. Hence, the need to define the NN zone.
- Furthermore, current and foreseen congestion on lines between NS and NM zone i.e. the Geertruidenberg-Krimpen connection creates a need to define the NS zone. This could improve the control over north-south flows through the capacity calculation and the market coupling processes.

DEFINITION OF BASE CASE AND PROJECT ALTERNATIVES

Base case

- Network capacities derived from JAO network capacities i.e. average 2019 capacities, scaled with ENTSO-E network capacity figures for 2030.

Project alternative 1: More available interconnection capacity (IC)

- Network capacities from network reduction methodology, see Annex I, with interconnection degree 6 (ID6C)
- Assuming 1 bidding zone (BZ) per country

Project alternative 2: More bidding zones (BZs)

- Network capacities from network reduction methodology, with interconnection degree 6 (ID6Z)
- In line with expert-based TSO statements (ENTSO-E, 2019), DE and NL consist both of 3 zones per country, while AT, BE and FR consist of 1 zone per country.

For all cases a zonal topology is assumed

- In order to prevent effects of different network topologies (different circuits and hence reactances) for the comparison between base case and project alternatives and thus to allow for better comparability, the same circuits and reactances are assumed for all cases.

EVALUATION CRITERIA

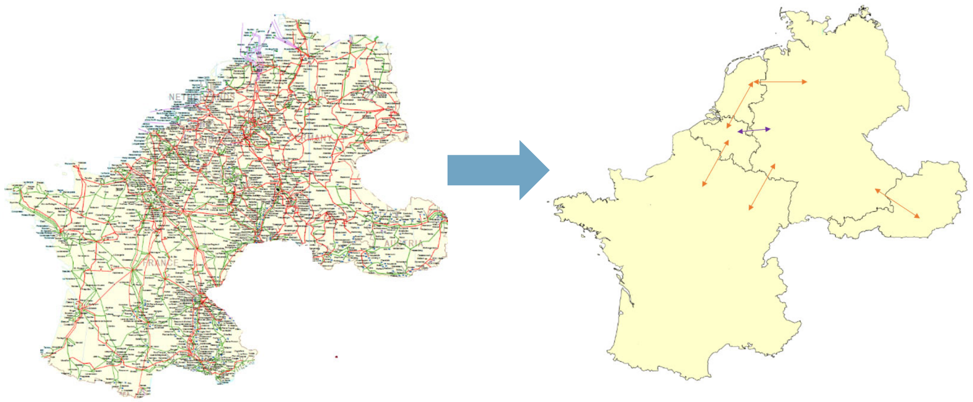
- The effects from the project alternatives with more bidding zones and more interconnection capacity are compared to the base case for:
  - Social welfare i.e. the sum of producer surplus, consumer surplus, and congestion rents, minus transition costs.
  - Electricity prices
  - Generation mix and CO_2 emissions
  - Electricity imports and exports
  - Deployment of demand response
- Higher social welfare and lower CO_2 emissions are considered as beneficial if there is a net benefit for the 5 CWE countries and/or the EU-27+CH+NO+UK (hereafter: EU-27+) as a whole
- Effects are also discussed separately for DE and NL, since these are the countries where more bidding zones are introduced. Although an overall positive effect is expected, some countries are likely to be affected negatively, consequently effects on individual countries are sometimes redistribution effects from broader perspectives (5 CWE countries and EU-27+).
- Changes in electricity prices, generation mix, net electricity exports, and deployment of demand response are partially behind changes of net social welfare but are also partially redistribution effects;
  - E.g. higher exports of *net exporting countries* imply higher electricity prices and thus higher producer surplus, which is partially compensated by lower consumer surplus. At the same time, consumers of *net importing countries* benefit from lower prices i.e. higher consumer surplus, which is partially compensated by lower producer surplus.
  - More flexibility supply from foreign countries through interconnections may replace flexibility supply from demand response.

UPDATE OF COMPETES MARKET MODEL

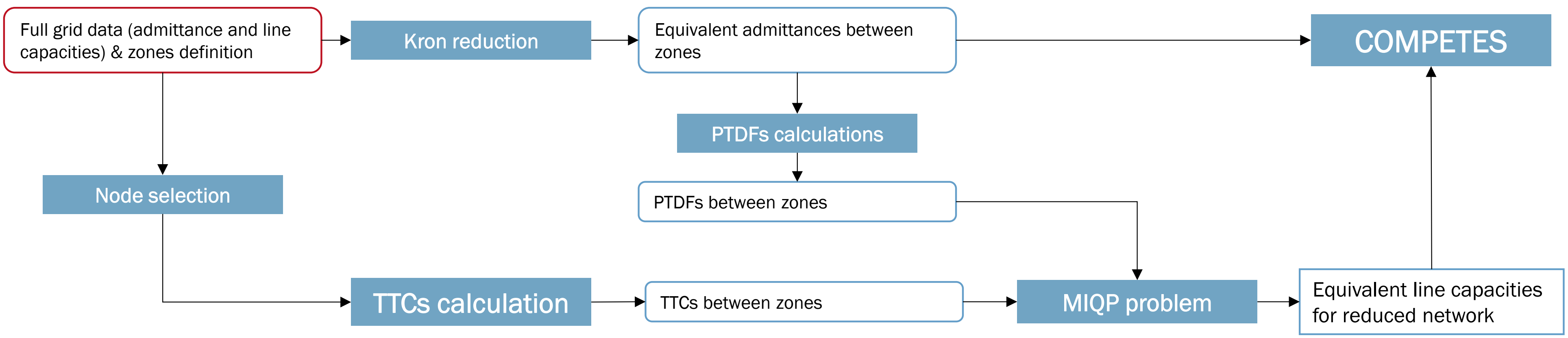
- The Kirchhoff laws of electricity rule how the power flows through the grid. Consequently, electricity is not transported over one path but flows are distributed over several network paths according to their physical characteristics (e.g. reactances).
- Until 2015 a transportation based network representation was assumed for cross-border electricity trading (i.e. market coupling), with the effect of commercial transactions between zones not explicitly translated into physical network flows but implicitly taken into account in the deployed average or net transfer capacity (ATC/NTC) values.
- By 2015, the calculation of cross-border capacities in the CWE countries switched to flow-based capacity calculation which explicitly accounts for Kirchhoff laws. The FB approach has also been laid down in European regulations as the standard grid capacity calculation method for areas with meshed grids such as Continental Europe and Scandinavia. The FB approach for the Netherlands is therefore the starting point when drawing up national action plans in line with the 70% minimum target.
- Projects are ongoing to expand flow-based capacity calculation to the whole CORE region (Continental Europe excluding Denmark, Italy, Portugal, Spain, Switzerland, Balkan, Baltics etc.) in 2022, and the Nordic region in 2023 respectively.
- COMPETES still assumed a transportation based network representation which meant that available network capacities for trading were not in line with practice. Hence, answering the research questions requires implementation of the FB approach in COMPETES in such a way that it allows for prospective analysis of the effects of more interconnection capacity within reasonable computation times.

NETWORK REDUCTION METHODOLOGY

- The study requires a more accurate representation of physical flows in the COMPETES electricity market model.
- Basically, two parameters of the physical grid are required:
  - Line admittances
  - Line capacities
- The first is essential since the power flow is dependent on the circuit admittances, whereas the second limits the maximum amount of power that can flow between two zones or areas.
- Using a complete network representation is unpractical due to the computational burden. Hence, a network reduction approach is applied to make an equivalent system with a lower computational burden and with comparable results to the original system.



OVERVIEW NETWORK REDUCTION METHODOLOGY



- For a detailed explanation, refer to Annex I

ANALYSIS OF MAIN EFFECTS

SOCIAL WELFARE EFFECTS
EFFECTS OF MORE INTERCONNECTION CAPACITY

Comparison of project alternative with more available IC against base case including RD costs

Country *all figures in million €*	Producer surplus	Consumer surplus	Congestion rents	Costs of remedial actions	Net effect
Austria	14	-12	3	PM	5
Belgium	-174	236	10	PM	71
France	-345	258	-39	PM	-127
Germany	-73	180	-61	PM	46
Netherlands	1014	-715	123	PM	422
Total	**436**	**-53**	**35**		**418**

- Overall higher producer surplus since Dutch generators benefit from higher electricity prices, while overall generation costs are lower due to replacement of gas, coal and nuclear generation by wind generation (less curtailment, mainly offshore wind).
- Slightly lower overall consumer surplus due to slightly higher electricity prices.
- Slightly higher congestion rents due to more trading, although partly compensated by smaller price differences since more IC tends to reduce network congestion. For NL more congestion rents due to higher exports.
- Operating closer to physical grid boundaries could increase need for operational actions during extreme circumstances (e.g. outage). This could increase system operation costs e.g. by more frequent activation of costly remedial actions. Since the need for such actions is not known, also associated costs have not been estimated.
- Net effect on EU 27+ € 320 million. The decrease of € 100 million compared to net results for the 5 FB countries mainly results from the decrease of consumer surplus in Norway by € 110 million, given increase of Norwegian average demand-weighted electricity prices by 0.84 €/MWh.

SOCIAL WELFARE EFFECTS
EFFECTS OF MORE BIDDING ZONES

Comparison of project alternative with more BZs against alternative with more IC including RD costs

Country *all figures in million €*	Producer surplus	Consumer surplus	Congestion rents	Transition costs*	Net effect
Austria	-25	19	2	PM	-4
Belgium	-49	74	-18	PM	7
France	-39	33	-23	PM	-28
Germany	-22	104	-47	PM	35
Netherlands	455	-303	38	PM	191
Total	**320**	**-73**	**-47**		**200**

* Net of possible additional costs for remedial actions in alternative with more IC

- Both cases dispose of same network topology, but more bidding zones allow TSOs to release more interconnection capacity (about 2.5 GW).
- Effects of more BZs are small, main effects on NL, net effect on Germany is quite small.
- Slightly lower congestion rents with more BZs, due to further increase of IC and therefore less congestion and smaller price differences. Given same network topology, both cases take into account congestion on additional internal zonal borders; in case with more BZs directly by implicit auction, in case with more IC indirectly through redispatching. Both cases account for equal amounts of congestion management costs given the model assumption of efficient cross-border redispatching at EU-scale. In practise the two-step approach of electricity pricing followed by curative redispatch is less efficient than one-step implicit auctions, implying the difference in congestion rents between both cases would be positive.
- Higher producer surplus due to higher electricity prices and replacement of gas and coal-fired generation with high marginal costs by wind generation (i.e. less curtailment) with low marginal costs
- Lower consumer surplus since consumers pay higher prices in NL
- No literature estimate of transition costs ('one-off costs') for BZ reconfiguration is yet available, hence pro memorie (PM) item.

SOCIAL WELFARE EFFECTS

EFFECTS OF MORE BIDDING ZONES FOR EU-27+

Comparison of project alternative with more BZs against alternative with more IC including RD costs

Country *all figures in million €*	Producer surplus	Consumer surplus	Congestion rents	Transition costs*	Net effect
5 selected countries	320	-73	-47	PM	200
Czech republic	-8	9	0	PM	1
Denmark East	4	-4	-1	PM	-1
Denmark West	12	-9	-4	PM	-1
Finland	10	-10	-1	PM	0
Ireland	0	0	0	PM	1
Italy	-28	35	5	PM	13
Poland	0	2	0	PM	2
Portugal	-4	2	0	PM	-2
Slovakia	-4	5	1	PM	1
Spain	-12	14	-1	PM	1
Sweden	48	-38	-1	PM	9
UK	60	-62	-6	PM	-8
Switzerland	-25	16	1	PM	-8
Norway	7	-49	-2	PM	-44
Balkan	-36	32	1	PM	-3
Baltic	0	0	-1	PM	-2
Total	**342**	**-130**	**-54**	**PM**	**159**

- Effects on social welfare in other countries are minor, except for Norway due to decrease of consumer surplus. This decrease originates from slightly higher electricity prices in case of more bidding zones (0.35 euro/MWh).
- Net effect of more BZs becomes ca 160 million euro when wider set of countries is taken into account (cf. 5 FB countries 200 million euro), and accounting for redispatch costs.

* Net of possible additional costs for remedial actions in alternative with more IC

SOCIAL WELFARE EFFECTS
TOTAL EFFECT

Country *all figures in million €*	Total effect	More interconnection	More bidding zones
Austria	1	5	-4
Belgium	78	71	7
France	-155	-127	-28
Germany	81	46	35
Netherlands	614	422	191
Norway	-152	-107	-44
Total EU-27+CH+NO+UK	**477**	**318**	**159**

- Total social welfare effect = effect of more available interconnection capacity (IC) + effect of more bidding zones (BZ)
- Transition costs and possible costs of more frequent activation of remedial actions are pro memorie cost items and hence not included in the estimation of the total effect
- Net effect of more IC is more significant than net effect of more BZ
- Next slides explain the price and volume effects behind the social welfare effects as well as the effects on generation mix – including curtailment of wind generation – and CO_2 emissions.

SOCIAL WELFARE EFFECTS
EFFECT OF INCLUDING REDISPATCH COSTS

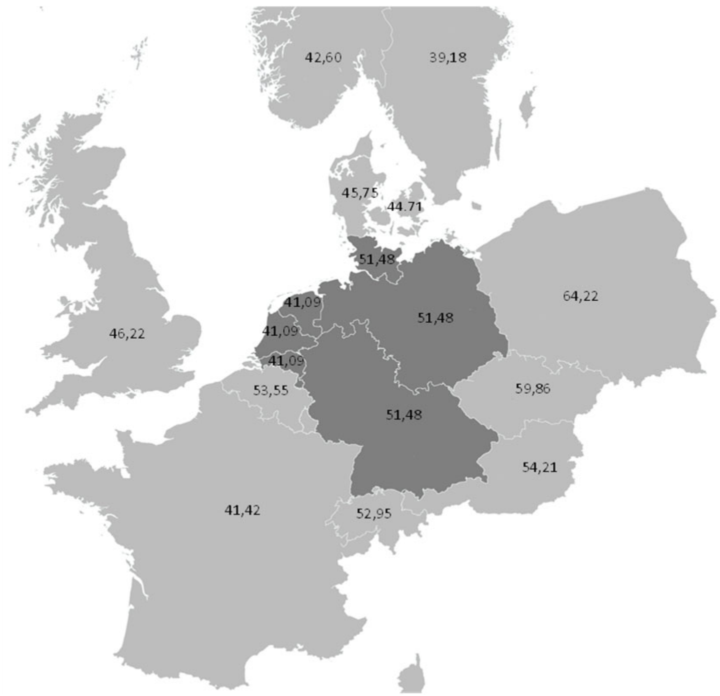
Country *all figures in million €*	Redispatching effect
Austria	6
Belgium	29
France	-157
Germany	1020
Germany North	354
Germany Middle	385
Germany South	280
Netherlands	27
Netherlands North	36
Netherlands Middle	20
Netherlands South	-29
Norway	*-648*
Other countries	*260*
Total	**536**

- Comparison of the base case with and without redispatch costs shows that taking these costs into account changes social welfare of more available interconnection capacity and bidding zones significantly.
- Including the redispatch costs in the base case turns negative overall social welfare effect of more IC and BZs into positive effect.
- This is the net effect, underlying changes in producer surplus, consumer surplus, and congestion rents are up to 2.6 billion euro each.
- Main redispatch costs are in Germany i.e. 1 billion euro, while some countries face a deterioration of social welfare due to redispatch, e.g. Norway and France.
- These negative redispatching costs are due to EU-wide optimization i.e. some zones lose for the benefit of the EU as a whole. In reality, redispatching is still performed and thus optimized at national scale.

EFFECTS ON ELECTRICITY PRICES
MORE INTERCONNECTION CAPACITY DECREASES AVERAGE PRICES

Base case

More interconnection capacity



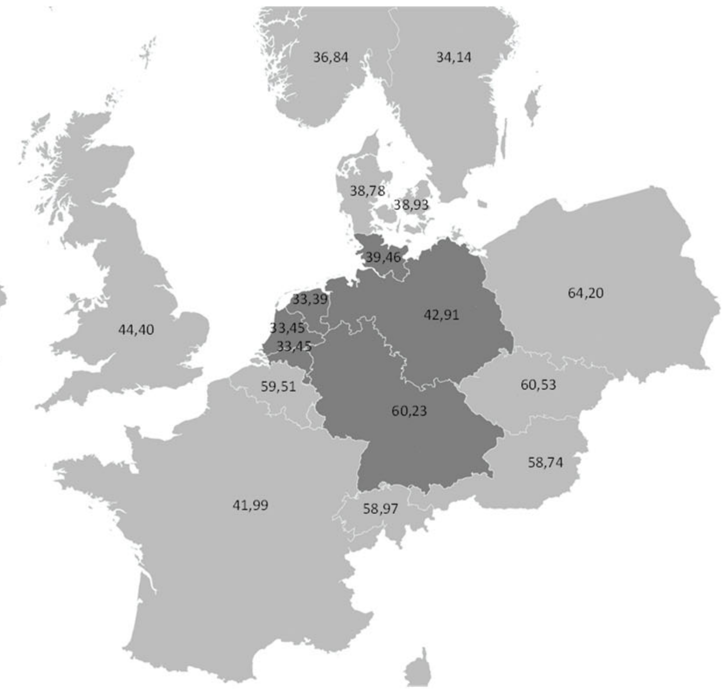
Effects of more available interconnection capacity compared to base case (both without redispatch costs):

- Allows for more trading benefits
- Hence, decrease of weighted average prices by 0.10 €/MWh for 5 FB countries and 0.04 €/MWh for EU-27+ countries
- In BE & DE price decreases of 2.17 and 1.12 €/MWh respectively due to less production and more imports
- in NL & AT price increases of 6.18 and 1.41 €/MWh respectively due to more production and exports

EFFECTS ON ELECTRICITY PRICES
ILLUSTRATION OF EFFECT OF REDISPATCH COSTS

Base case without redispatch

Base case with redispatch



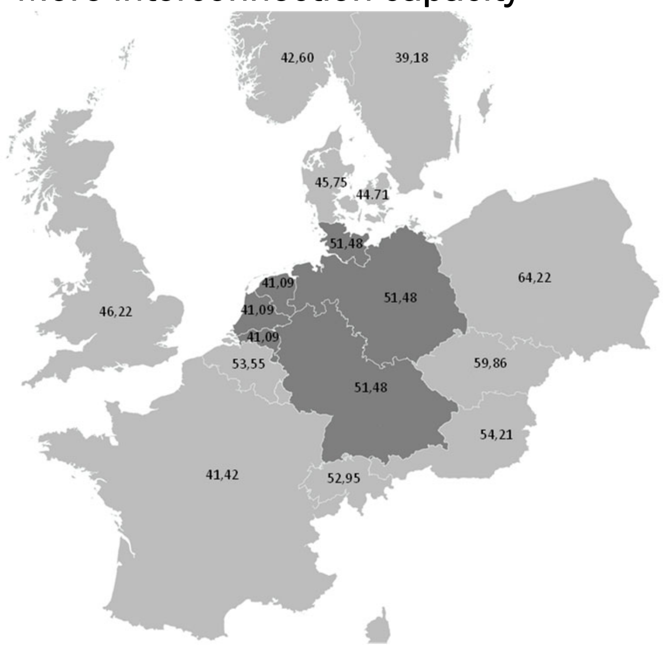
Effects of redispatch costs:

- Including congestion management costs to the initial electricity prices of the base case without redispatch increases implicit prices below the German North-South network constraints i.e. in Germany-South, CH, and AT, but also in BE.
- Including curative redispatch costs decreases prices above the N-S constraints i.e. in Germany Middle and North, NL, DK, NO, SE, and UK.
- Actual effects are likely to be larger since efficient and EU-wide cross-border redispatch is assumed while in practise redispatching has inefficiencies and is optimized nationally.

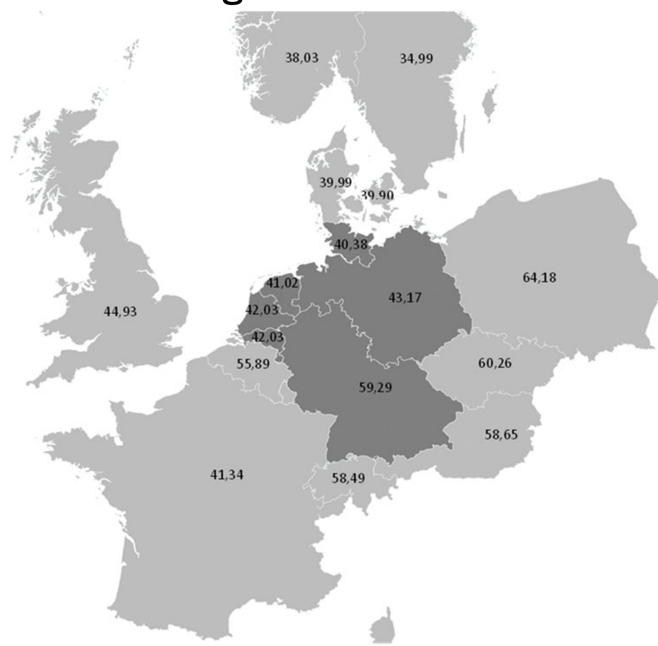
EFFECTS ON ELECTRICITY PRICES

MORE BIDDING ZONES INCREASE AVERAGE PRICES

More interconnection capacity



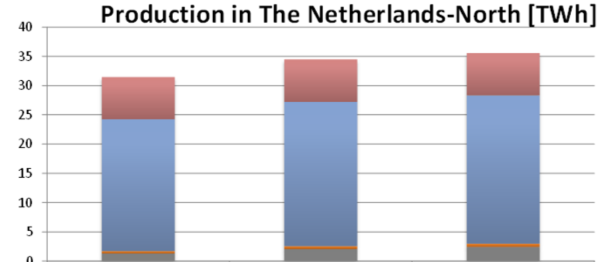
More bidding zones in DE & NL



- Effects of more bidding zones compared to case with more available interconnection capacity without redispatching costs:
  - 5 FB countries: increase of demand weighted average price by 1.5 €/MWh due to pricing of congestion on internal borders
  - DE: prices in GN and GM decrease by 10.8 and 8.0 respectively, in GS increase by 7.9 €/MWh
  - NL: increase of demand weighted average electricity prices by 1 €/MWh in NM and NS
  - Also prices in AT, BE, DK, CH, NO, SE, and UK significantly affected
  - Generally EU-27+: increase of demand weighted average price by 0.2 €/MWh

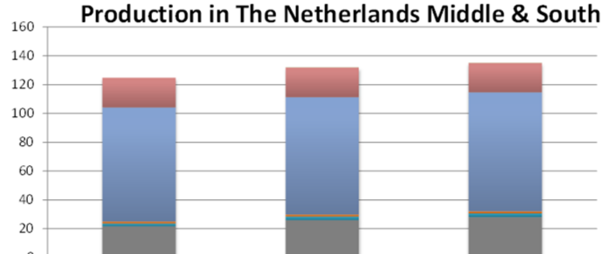
EFFECTS ON GENERATION MIX AND CO_2 EMISSIONS – THE NETHERLANDS

Production in The Netherlands-North [TWh]



	Base case with RD	Higher IC with RD	More BZs DE+NL
Hydro	0,0	0,0	0,0
Solar	7,2	7,2	7,2
Wind	22,5	24,7	25,4
Biomass and waste	0,4	0,5	0,6
Nuclear	0,0	0,0	0,0
Coal	0,0	0,0	0,0
Gas	1,3	2,1	2,4

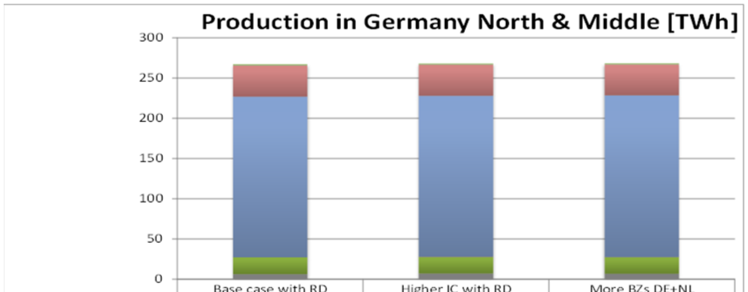
Production in The Netherlands Middle & South



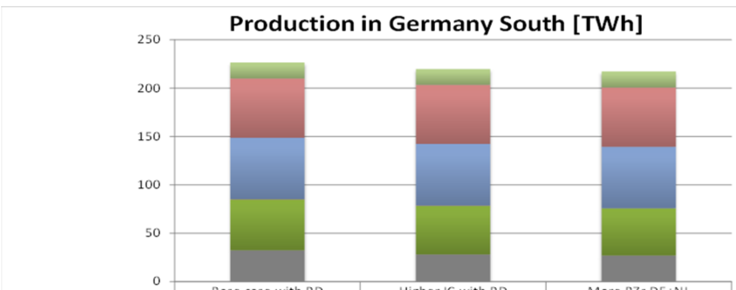
	Base case with RD	Higher IC with RD	More BZs DE+NL
Hydro	0,1	0,1	0,1
Solar	20,5	20,6	20,6
Wind	79,3	81,6	82,5
Biomass and waste	1,2	1,4	1,5
Nuclear	2,1	2,5	2,6
Coal	0,0	0,0	0,0
Gas	21,6	25,9	28,0

- Effect of more bidding zones compared to case with more IC including RD effect
  - Increase of electricity production from gas-fired generation and (mainly offshore) wind (less curtailment) with 2.5 and 1.6 TWh respectively
- Effect of more interconnection capacity compared to base case with RD:
  - Larger increase of electricity production mainly from gas-fired power plants (+5.1 TWh) and wind generation (+4.5 TWh)
- Net effect compared to base case with RD:
  - Increase of electricity production from gas-fired generation and wind generation with 7.6 TWh and 6.1 TWh respectively, and small increases of electricity from nuclear and biomass and waste
  - Increase of CO_2 emissions by 2.6 Mton due to increase of production from gas-fired power plants

EFFECTS ON GENERATION MIX AND CO_2 EMISSIONS – GERMANY



	Base case with RD	Higher IC with RD	More BZs DE+NL
Hydro	1,8	1,8	1,8
Solar	38,4	38,4	38,4
Wind	200,0	200,4	200,8
Biomass and waste	0,1	0,1	0,0
Nuclear	0,0	0,0	0,0
Coal	20,9	20,7	20,8
Gas	6,1	6,9	6,7

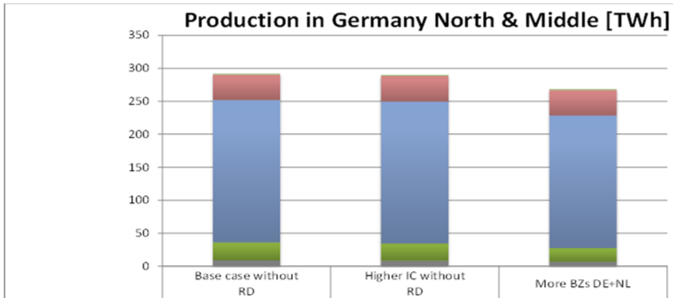


	Base case with RD	Higher IC with RD	More BZs DE+NL
Hydro	16,4	16,4	16,4
Solar	61,2	61,2	61,2
Wind	63,6	63,6	63,6
Biomass and waste	0,3	0,2	0,2
Nuclear	0,0	0,0	0,0
Coal	52,5	50,2	48,8
Gas	32,4	28,2	26,9

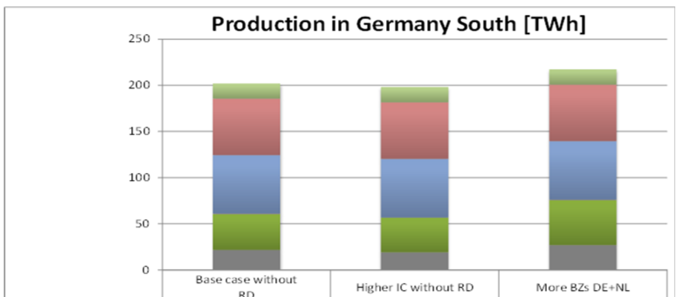
- Given limited internal capacities inside DE in base case much redispatch is needed since part of electricity trading is infeasible due to grid constraints.

- More BZs and more IC compared to base case with RD result in more efficient use of the German electricity grid and consequently in:
  - Increase of electricity production of wind by 0.8 TWh (less curtailment)
  - Decrease of electricity production from gas & coal-fired power plants by 8.7 TWh.
  - Hence, decrease of CO_2 emissions by 4.6 Mton
  - Replacement of electricity production by imports, notably from NL.

EFFECTS ON GENERATION MIX AND CO_2 EMISSIONS – GERMANY –WITHOUT REDISPATCH COSTS



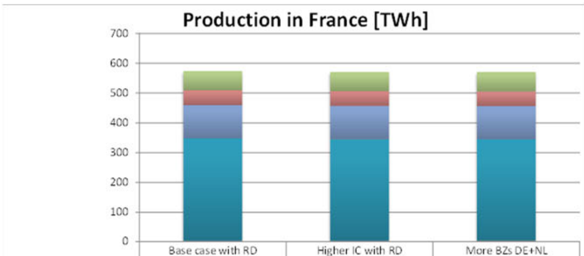
	Base case without RD	Higher IC without RD	More BZs DE+NL
Hydro	1,8	1,8	1,8
Solar	38,4	38,4	38,4
Wind	215,9	215,1	200,8
Biomass and waste	0,1	0,1	0,0
Nuclear	0,0	0,0	0,0
Coal	27,0	26,3	20,8
Gas	8,9	8,2	6,7



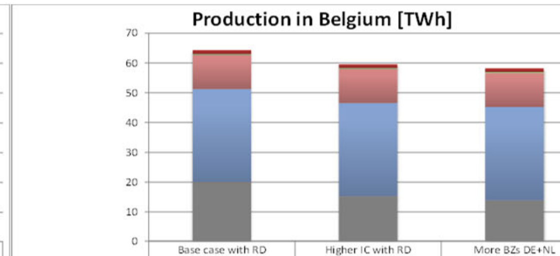
	Base case without RD	Higher IC without RD	More BZs DE+NL
Hydro	16,4	16,4	16,4
Solar	61,2	61,2	61,2
Wind	63,6	63,6	63,6
Biomass and waste	0,3	0,2	0,2
Nuclear	0,0	0,0	0,0
Coal	38,7	37,4	48,8
Gas	21,7	19,1	26,9

- Once the redispatch costs are not taken into account, more bidding zones compared to the case with more interconnection capacity imply:
  - Decrease of electricity production from wind (more curtailment) by 14.2 TWh in Germany North & Middle
  - Increase (decrease) of electricity production from coal and gas-fired power plants by 19.2 TWh (7.0 TWh) in Germany South (Germany North and Middle)
  - Increase of German CO_2 emissions by 6.4 Mton
- Hence, taking into account the redispatch costs is very important for a proper analysis of the effects of bidding zones

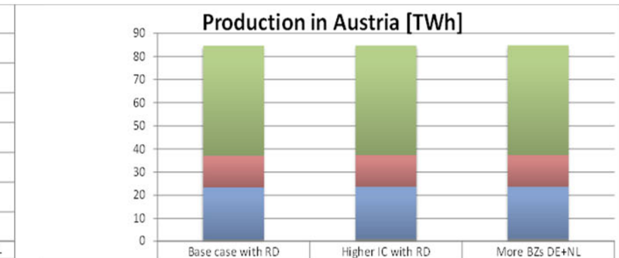
EFFECTS ON GENERATION MIX AND CO_2 EMISSIONS – FRANCE, BELGIUM, AND AUSTRIA



	Base case with RD	Higher IC with RD	More BZs DE+NL
Hydro	64,6	64,6	64,6
Solar	49,4	49,4	49,4
Wind	111,2	111,2	111,2
Biomass and waste	0,0	0,0	0,0
Nuclear	344,6	342,2	341,5
Coal	0,0	0,0	0,0
Gas	3,1	3,1	3,2



	Base case with RD	Higher IC with RD	More BZs DE+NL
Other renewables	1,4	1,3	1,3
Hydro	0,4	0,4	0,4
Solar	11,4	11,4	11,4
Wind	31,4	31,4	31,4
Biomass and waste	0,0	0,0	0,0
Nuclear	0,0	0,0	0,0
Coal	0,0	0,0	0,0
Gas	19,9	15,2	13,9



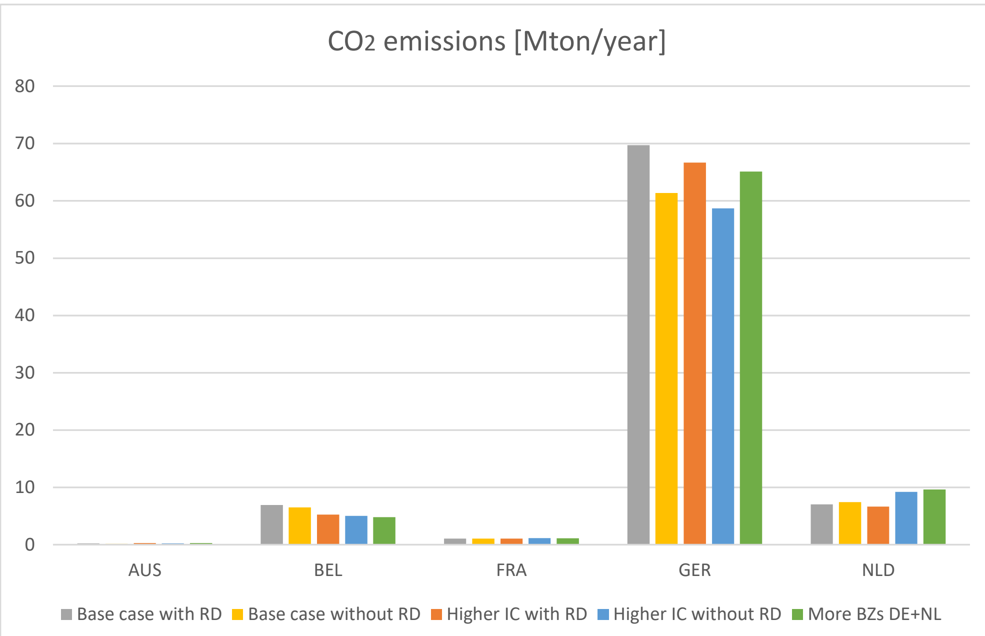
	Base case with RD	Higher IC with RD	More BZs DE+NL
Hydro	47,4	47,4	47,4
Solar	13,7	13,7	13,7
Wind	22,8	22,8	22,8
Biomass and waste	0,0	0,0	0,0
Nuclear	0,0	0,0	0,0
Coal	0,0	0,0	0,0
Gas	0,6	0,8	0,9

As a result of more available interconnection capacity and more bidding zones in DE&NL:

- In France, electricity from nuclear generation decreases by 3 TWh. No significant effect on CO_2 emissions.
- In Belgium, electricity from gas-fired power plants decreases by 6 TWh. Associated CO_2 emissions decrease by 2.1 Mton.
- In Austria, electricity from gas-fired power plants increases marginally by 0.2 TWh (rounded). Associated CO_2 emissions increase marginally as well.

EFFECTS ON OVERALL CHANGES IN CO_2 EMISSIONS

INCLUDING REDISPATCH IS VERY RELEVANT FOR OVERALL RESULT

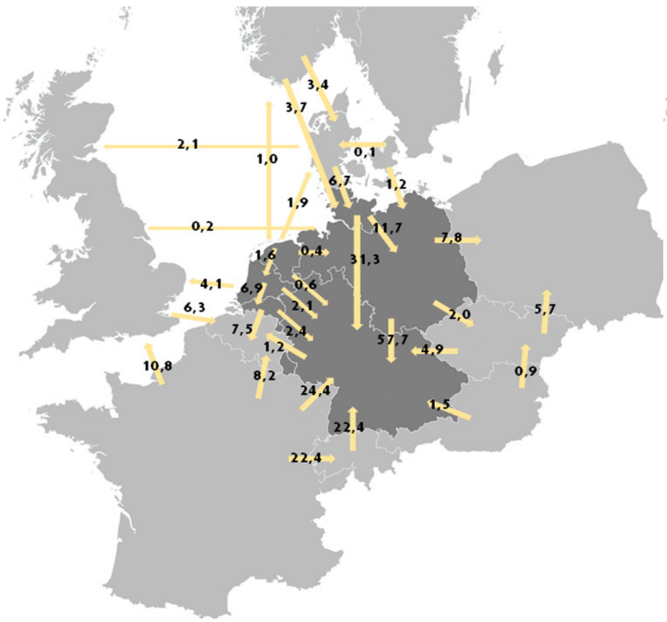


- Effect of more bidding zones compared to the case of higher IC without RD amounts to +6.7 Mton CO_2 emissions for FB countries, of which 5.7 Mton due to the need for redispatch i.e. net effect of +1.0 Mton.
- Effect of more available interconnection capacity compared to the base case without RD amounts to -2.2 Mton CO_2 emissions for FB countries, and even -5.0 Mton after accounting for redispatch costs.
- Total net effect without accounting for RD: +4.4 Mton CO_2 emissions for FB countries, but after accounting for redispatch actions -4.0 Mton.

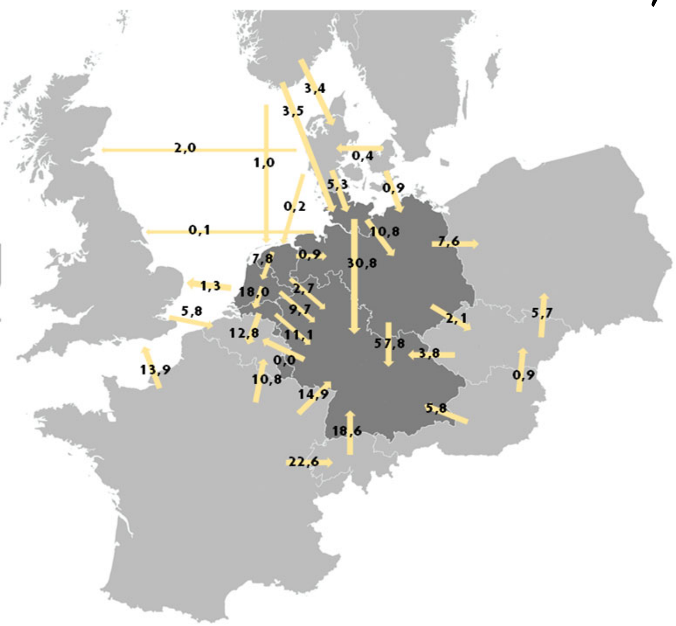
EFFECTS ON ELECTRICITY IMPORT AND EXPORT PATTERNS

MORE IMPORTS IN GERMANY, MORE EXPORTS IN NETHERLANDS

Base case



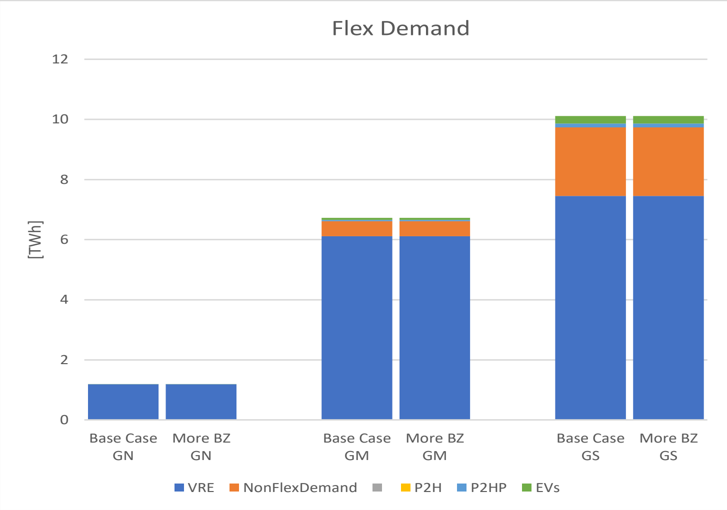
More bidding zones in DE & NL

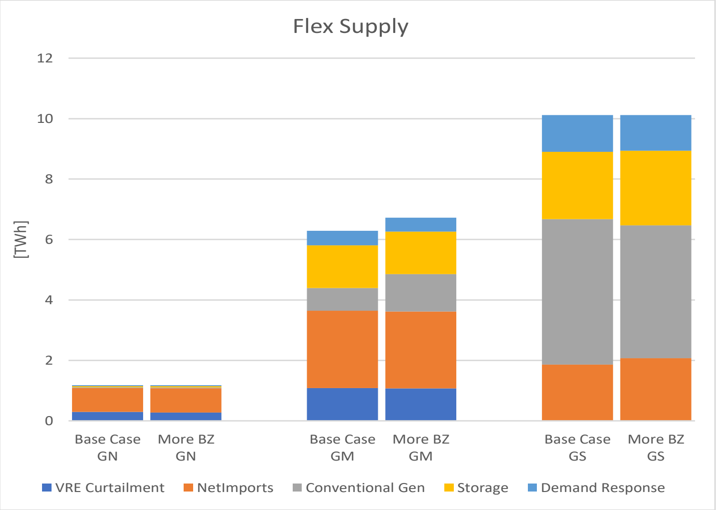


Base case has the same network topology as project alternative and includes imports/exports for redispatch actions, but consist of one bidding zone for Germany and the Netherlands respectively.

- Net effect of more bidding zones and more interconnection capacity including RD:
  - France remains largest net exporter, but its export is reduced by 3.0 TWh
  - Germany increases its imports by 8.2 TWh
  - Imports of the Netherlands are reduced by 17.4 TWh, main driver is an increase of exports to Germany by 19 TWh
  - Net import of Austria remains stable, imports of Belgium increase by 6.3 TWh
  - Net import of other EU 27+ countries increases by 0.2 TWh
- More bidding zones induce better generation dispatch in DE, more imports and hence better utilization (lower curtailment) of offshore wind in NL that is seeking demand.

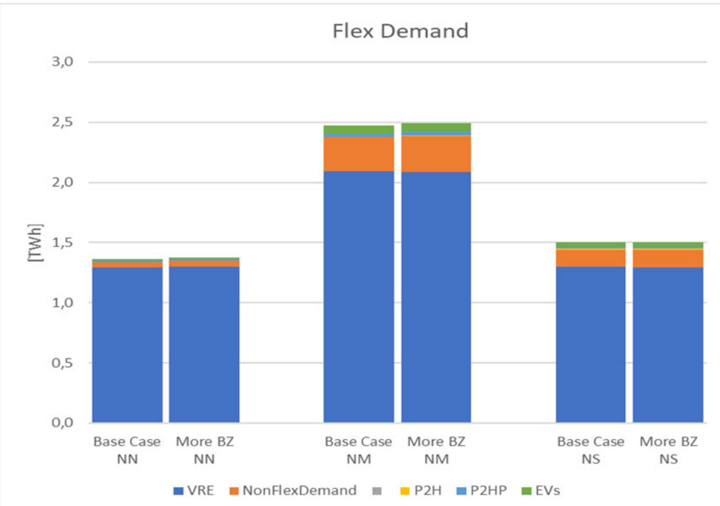
EFFECTS ON DEMAND RESPONSE
GERMANY

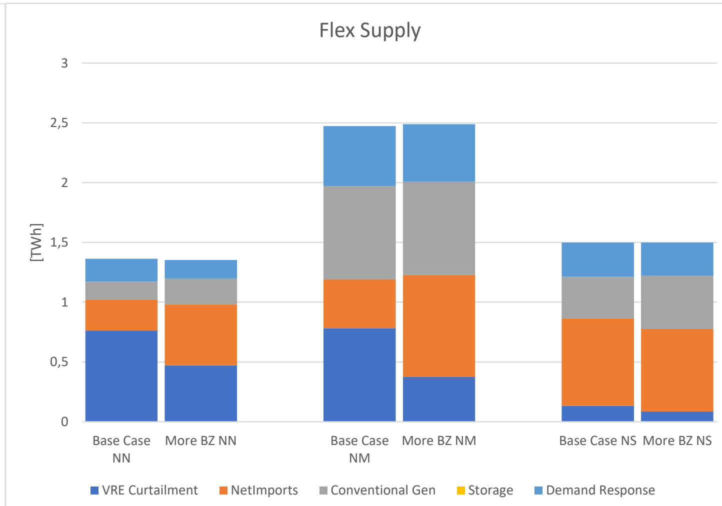




- More available interconnection capacity partly due to more bidding zones increases overall supply of flexibility from 17.6 to 18.0 TWh per year in Germany. This is probably the result of higher price differences within Germany, increasing the benefits of price arbitrage.
- The contributions of interconnections, storage and conventional generation increase a bit, but the role of demand response remains the same.
- For assumptions concerning demand response, refer to Annex II.

EFFECTS ON DEMAND RESPONSE
THE NETHERLANDS





- More available interconnection capacity partly due to more bidding zones does not significantly affect overall supply and demand of flexibility of about 5.2 TWh per year in the Netherlands.
- The contribution of different sources of flex in flex supply varies though, and shows a smaller role for demand response:
  - Flex supply (both upwards and downwards) through interconnections and gas-fired generation increases by about 0.7 and 0.2 TWh respectively
  - Contributions of VRE curtailment and demand response (P2H, HPs, EVs) decrease with 0.7 and 0.1 TWh respectively. The change of demand response is caused by less flex of EVs (50%) and P2H (50%).

CONCLUSIONS OF EFFECT ANALYSIS
OVERALL EFFECTS

- Social welfare (SWF) increases by € 477 million per year in EU-27+ due to more available interconnection capacity and bidding zones compared to base case.
  - Mainly producer surplus increases (€ 928 million), while consumer surplus decreases (€ 409 million). This is likely to be the result of steeper supply curve in smaller and net exporting countries such as the Netherlands, while the supply curve is more gradual in larger and net importing countries such as Germany. Hence, substantial price increases occur in exporting countries but smaller price decreases in importing countries, increasing net producer surplus and decreasing net consumer surplus (cf. Supponen, 2012).
  - Congestion rents decrease (€ 43 million), although more bidding zones mean more borders where congestion rents can be earned. The latter effect is outweighed though by the correction for redispatch costs in the base case and therefore not visible. Since redispatch costs are underestimated due to assumptions of both EU wide and cost efficient redispatch, this is likely to be different in practice.
  - Transition costs and possible additional costs of remedial actions are not included in this estimate.
  - Redispatch costs amount to € 536 million per year for this geographical area and are thus essential for a fair assessment of the effects of bidding zones on both SWF and other assessment criteria. Hence, all figures mentioned here include redispatch costs in the base case.
- SWF effects are under/overestimated for the following reasons;
  - Model assumption of perfect competition, hence less strong effect of more interconnection capacity on price-setting peaking generators than in reality where generators' market power during peak hours is reduced with more interconnection capacity
  - Model assumption of efficient and EU-wide cross-border redispatching, hence smaller effect of more bidding zones on SWF than in reality.
  - SWF effects increase with more renewables and the scenario includes 10 GW of additional offshore wind generation in the Netherlands, while no additional industrial demand has been investigated.
- CO_2 emissions decrease by 4.0 Mton and 5.1 Mton respectively for the 5 flow-based countries and EU-27+ as a whole.

CONCLUSIONS OF EFFECT ANALYSIS
REDISTRIBUTION EFFECTS

- Average electricity prices
  - Prices decrease due to more available interconnection capacity (IC) while they increase due to more bidding zones (BZs). The increase of electricity prices results from the pricing of congestion on internal borders due to more BZs. Once redispatch costs are taken into account in electricity prices of the base case, price increases are much smaller.
  - Effects on individual countries are more significant. In case of more IC, electricity prices increase by 6.2 €/MWh in the Netherlands due to more production and exports. More BZs in Germany result in price decreases in Germany North and Middle by 10.8 and 8.0 €/MWh respectively, while prices in Germany South increase by 7.9 €/MWh.
- Generation mix and CO_2 emissions
  - In the Netherlands, more IC and BZs increase electricity production from gas-fired generation and wind generation with 7.6 TWh and 6.1 TWh respectively, while electricity from nuclear, and biomass and waste increase less. Increase of CO_2 emissions by 2.6 Mton due to higher production from gas-fired power plants.
  - In Germany, decrease of electricity production from gas & coal-fired power plants by 8.7 TWh and additional imports, notably from NL. Hence, decrease of CO_2 emissions by 4.6 Mton.
- Electricity imports and exports
  - Large changes in import and export patterns due to more IC and BZs; Germany increases import by 8.2 TWh and Belgium by 6.3 TWh, while the Netherlands increases exports by 17.4 TWh.
  - More BZs induce better generation dispatch in Germany, more imports, and lower curtailment of offshore wind in the Netherlands.
- Deployment of demand response: no significant effects of more IC and BZs on the role of demand response in Germany and the Netherlands.

SENSITIVITY ANALYSES

SELECTION OF SENSITIVITY CASES

- Because effects of foreign measures such as a split of bidding zones in Germany matter for the extent to which the Netherlands must take measures to meet the 70% minimum target, a sensitivity analysis is carried out of the impacts of both important grid expansion projects in Germany and bidding zones in Germany only on the energy transition in the Netherlands.

- Hence, the following two sensitivity cases are researched:
  - No HVDC North-South cables in Germany
  - No bidding zones in the Netherlands

NO HVDC NORTH-SOUTH CABLES IN GERMANY
INTRODUCTION

- In Germany, three major North-South HVDC cables are envisaged (Südlink, SüdOst-link and A-Nord projects, in total 8 GW) to diminish existing network congestion and thus to better connect offshore renewable energy in the North with load centres in the South.
- Given that these cables are stretching large distances, require application of new HVDC technology on land (undergrounding), and given Germany's track record with large delays in grid expansion, it remains to be seen whether these are available by 2030. Hence, they are critical for our analysis of effects of more available interconnection capacity.
- Hence, we analyse the sensitivity of our analysis to an electricity network without these specific HVDC cables;
  - Base case with redispatching costs but without HVDC cables in Germany compared to the original base case with redispatching costs. This shows the effect of less grid expansion in Germany on the base case.
  - Project alternative with bidding zones but without HVDC cables in Germany compared to project alternative with bidding zones and HVDC cables in Germany. This shows the effects of a better network representation with more bidding zones and interconnection capacity in case of less German grid expansion.

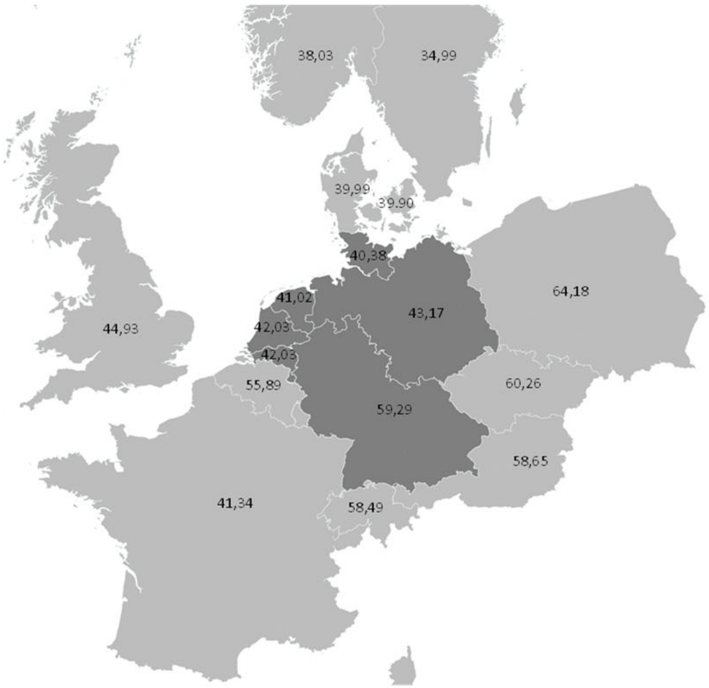
NO HVDC NORTH-SOUTH CABLES IN GERMANY
ADDITIONAL SOCIAL WELFARE EFFECTS OF IC AND BZ

Country *all figures in million €*	Producer surplus	Consumer surplus	Congestion rents	Transition costs	Net effect
Austria	20	-14	-4	PM	2
Belgium	-14	0	19	PM	5
France	73	-53	-22	PM	-2
Germany	72	-141	164	PM	95
Netherlands	-101	23	122	PM	44
Other EU-27+ countries	142	-141	-19	PM	-17
Total	**192**	**-325**	**260**		**127**

- No HVDC cables within Germany causes an *additional* net social welfare effect of € 140 million euro of more interconnection capacity and bidding zones (i.e. compared to the net social welfare effect in the situation with HVDC cables, in both cases assuming redispatch costs)
- Congestion rents in DE are most affected, followed by congestion rents of the Netherlands. Without German HVDC N-S cables the system is more constrained, increasing the use of other interconnections and thus driving up price differences.
- Consumer (producer) surplus decreases (increases) most in Germany and France, but also in Spain, Balkan, Switzerland, and Italy. Higher electricity prices decrease consumer surplus and increase producer surplus. Prices change due to changing trade patterns whereby production from DE, FR and NL is replaced by production from other EU countries (mainly Balkan, CZ, IT, UK, ES)
- Next slides discuss the price and volume effects behind the social welfare effects.

NO HVDC NORTH-SOUTH CABLES IN GERMANY
EFFECTS ON ELECTRICITY PRICES

Bidding zones

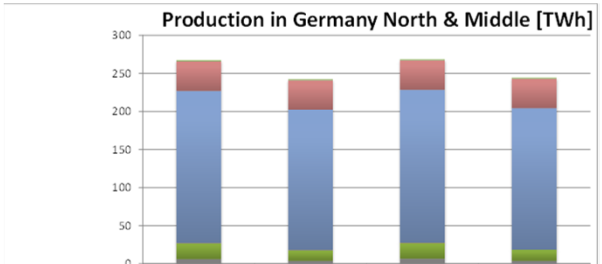


Bidding zones without DE HVDC N-S cables

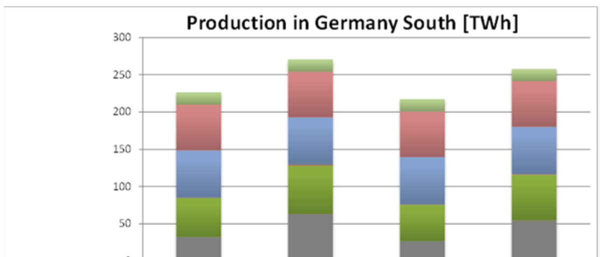
- Larger price disparities in Germany without HVDC North-South cables
- Northern Europe and NL exhibit lower prices due to less exports, higher prices in AT, CH, CZ due to more imports
- Average demand weighted electricity prices for the EU-27+ countries are about 1 euro/MWh lower without HVDC cables.
- In exporting areas with excess of cheap electricity (e.g. Germany North) prices decrease faster than prices increase in importing areas such as Germany South.

NO HVDC NORTH-SOUTH CABLES IN GERMANY

EFFECTS ON GENERATION MIX & CO_2 EMISSIONS IN GERMANY



	Base case with RD	Base case with RD no HVDC DE	More BZs DE+NL	More BZs DE+NL No HVDC DE
Hydro	1,8	1,8	1,8	1,8
Solar	38,4	38,4	38,4	38,4
Wind	200,0	184,2	200,8	185,9
Biomass and waste	0,1	0,0	0,0	0,0
Nuclear	0,0	0,0	0,0	0,0
Coal	20,9	14,1	20,8	14,5
Gas	6,1	3,8	6,7	3,8

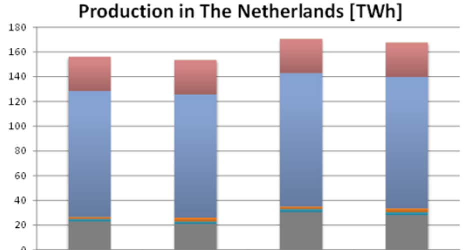


	Base case with RD	Base case with RD no HVDC DE	More BZs DE+NL	More BZs DE+NL No HVDC DE
Hydro	16,4	16,4	16,4	16,4
Solar	61,2	61,2	61,2	61,2
Wind	63,6	63,6	63,6	63,6
Biomass and waste	0,3	1,1	0,2	0,6
Nuclear	0,0	0,0	0,0	0,0
Coal	52,5	64,8	48,8	61,4
Gas	32,4	63,3	26,9	54,6

- In the base case without HVDC N-S cables deployment of much more gas and coal-fired generation in Germany South (+43 TWh), and decrease of both electricity from wind (16 TWh, due to more curtailment) and coal- and gas fired generation (9 TWh) in Germany North and Middle.
- German CO_2 emissions increase by about 14.4 Mton compared to the base case with HVDC cables.
- A better network representation with more IC and BZ mitigates the increase of electricity from gas and coal and the decrease of electricity of wind a bit. Electricity produced by gas and coal is reduced by 8.8 and 3.0 TWh respectively, and electricity from wind increases by 1.7 TWh.
- Hence, German CO_2 emissions decrease by 5.6 Mton in case of more IC and BZ.

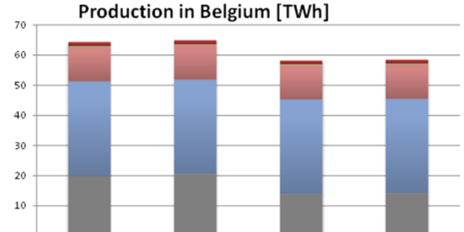
NO HVDC NORTH-SOUTH CABLES IN GERMANY
EFFECTS ON GENERATION MIX & CO_2 EMISSIONS OTHER

Production in The Netherlands [TWh]



	Base case with RD	Base case with RD no HVDC DE	More BZs DE+NL	More BZs DE+NL No HVDC DE
Hydro	0,1	0,1	0,1	0,1
Solar	27,8	27,8	27,8	27,8
Wind	101,8	99,6	107,9	106,1
Biomass and waste	1,6	3,2	2,1	3,3
Nuclear	2,1	2,0	2,6	2,5
Coal	0,0	0,0	0,0	0,0
Gas	22,9	20,9	30,4	28,0

Production in Belgium [TWh]

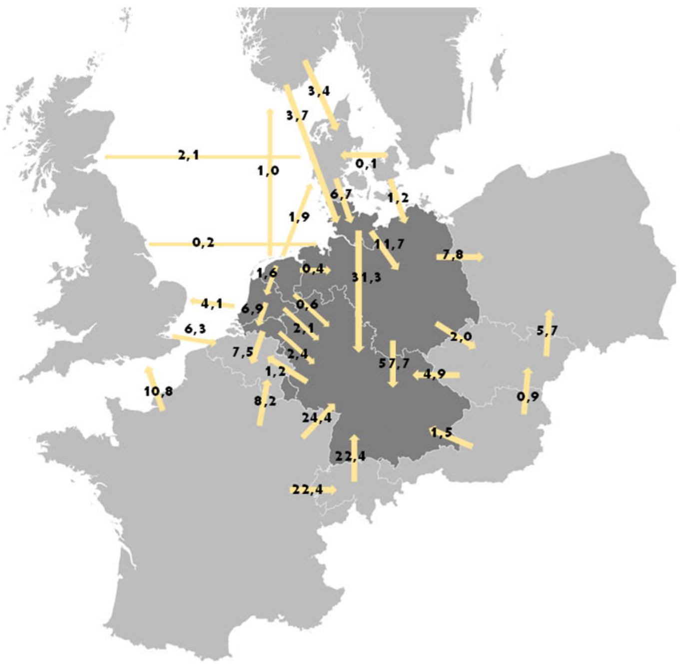


	Base case with RD	Base case with RD no HVDC DE	More BZs DE+NL	More BZs DE+NL No HVDC DE
Other renewables	1,4	1,4	1,3	1,3
Hydro	0,4	0,4	0,4	0,4
Solar	11,4	11,4	11,4	11,4
Wind	31,4	31,4	31,4	31,4
Biomass and waste	0,0	0,0	0,0	0,0
Nuclear	0,0	0,0	0,0	0,0
Coal	0,0	0,0	0,0	0,0
Gas	19,9	20,5	13,9	14,1

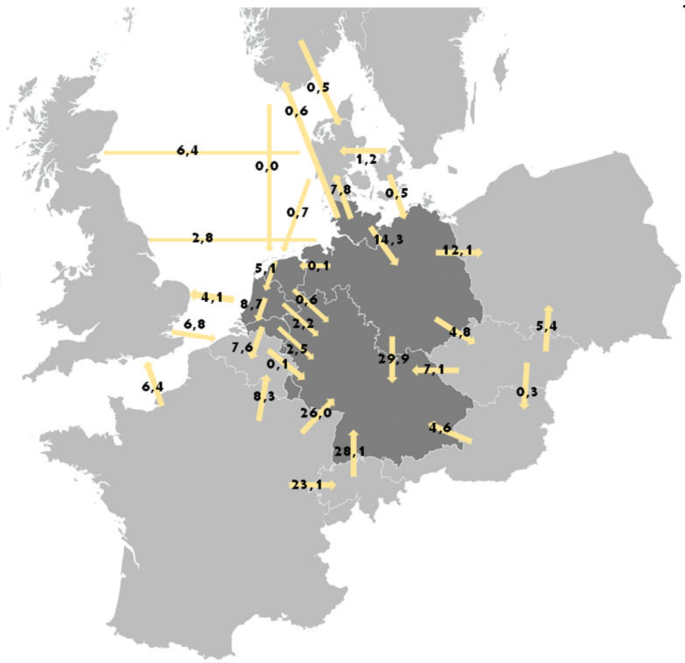
- In the base case with RD but without HVDC N-S cables, in EU-27+ excluding Germany, decrease of electricity from nuclear, RES other, gas, and wind by respectively 7, 6, 4.8 and 4.5 TWh with main effects in Sweden, UK, Poland and Netherlands.
- CO_2 emissions in EU-27+ countries excluding Germany increase by 1.1 Mton compared to the base case with RD and with HVDC cables.
- A better network representation with more IC and BZ mainly decreases curtailment of offshore wind in the Netherlands by 6.4 TWh. Furthermore, some redistribution effects e.g. +7 TWh electricity from gas-fired generation in NL, while in BE decrease by 6.4 TWh (More BZs without HVDC cables N-S in DE compared to base case with RD but without HVDC N-S cables in DE).
- Accompanying CO_2 emissions in EU-27+ countries excluding Germany increase only by 0.7 Mton.

NO HVDC NORTH-SOUTH CABLES IN GERMANY
EFFECTS ON IMPORTS AND EXPORTS – BASE CASE

Base case



Base case with no HVDC N-S cables



Effects of base case without no HVDC N-S cables compared to base case with HVDC cables):

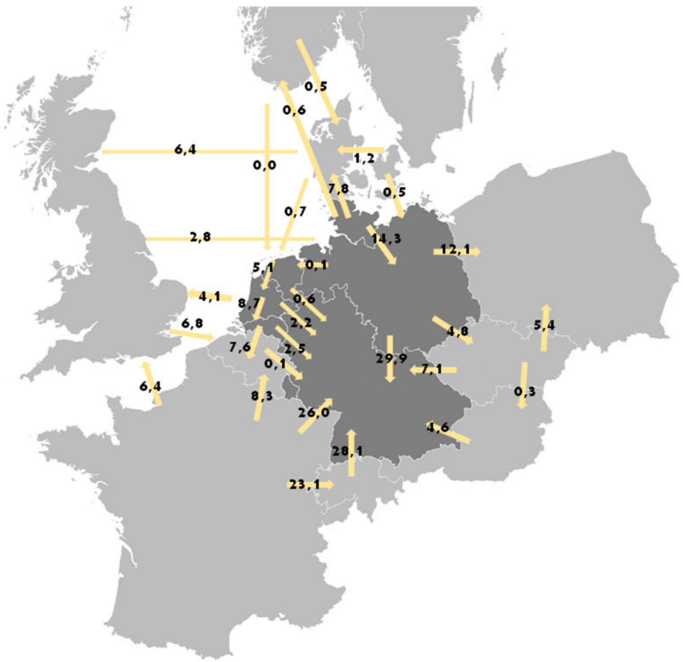
- No HVDC N-S cables decreases flows from North and Middle parts of Germany to South Germany with 59 TWh.
- Germany South imports 45 TWh less with no HVDC cables. Apparently, increasing production from gas and coal is cheaper than importing more from neighboring countries.
- Germany North no longer imports from Denmark West, but exports (net change of 14.5 TWh)
- CH, AT, CZ and FR export more to Germany South (in total: 12.5 TWh)
- EU-27+ overall generation costs increase by € 1.8 billion.

TNO innovation for life

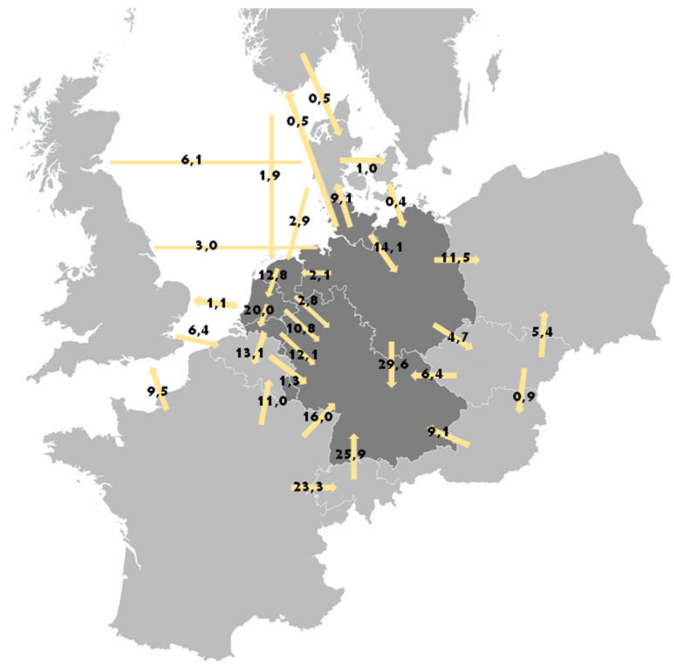
NO HVDC NORTH-SOUTH CABLES IN GERMANY

EFFECTS ON IMPORTS AND EXPORTS OF MORE IC AND BZ

Base case with no HVDC N-S cables



Project alternative with more IC and BZ



- Effects of more IC and BZ in case of no HVDC N-S cables compared to base case without HVDC cables):
  - More IC and BZs i.e. different pricing increases flows directly from NL and AT to DE (by 20.3 and 4.5 TWh respectively), and decreases flows from FR to DE with 10 TWh.
  - Overall generation costs decrease by € 0.8 billion, reducing increase of EU-27+ net overall generation costs due to no HVDC N-S cables to € 1.0 billion.

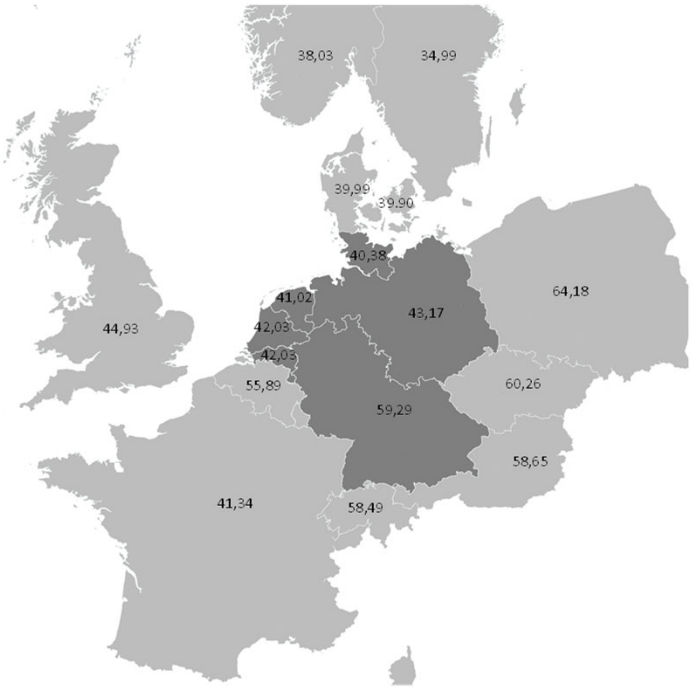
NO BIDDING ZONES IN THE NETHERLANDS
ADDITIONAL SOCIAL WELFARE EFFECTS

Country *all figures in million €*	Producer surplus	Consumer surplus	Congestion rents	Transition costs	Net effect
Austria	-1	1	0	PM	0
Belgium	-5	6	2	PM	3
France	8	-10	0	PM	-2
Germany	-9	11	7	PM	9
Germany North	2	0	-2	PM	*0*
Germany Middle	-6	5	1	PM	*1*
Germany South	-5	6	7	PM	*9*
Netherlands	5	3	-7	PM	1
Netherlands North	30	-17	-7	PM	*6*
Netherlands Middle	-14	13	-7	PM	*-7*
Netherlands South	-11	7	7	PM	*3*
Total	**-2**	**11**	**2**	**PM**	**11**

- This sensitivity sheds light on the question which part of the bidding zones effects is due to BZs in Germany and which part due to BZs in NL?
- No bidding zones in the Netherlands causes an insignificant overall *additional* net social welfare effect compared to the net SWF effect in the situation with BZs in NL. In both cases BZs in Germany are assumed.
- This effect is in line with the earlier observation that the case with bidding zones shows small price differences between the Northern part, and the Middle and Southern parts of the Netherlands, indicating that network congestion and therefore effect of no bidding zones in NL is limited.
- Producer and consumer surplus in the Northern part of the Netherlands are most effected. Higher (lower) electricity prices decrease (increase) consumer surplus and increase (decrease) producer surplus in North (Middle and South).

NO BIDDING ZONES IN THE NETHERLANDS
EFFECTS ON ELECTRICITY PRICES

Bidding zones

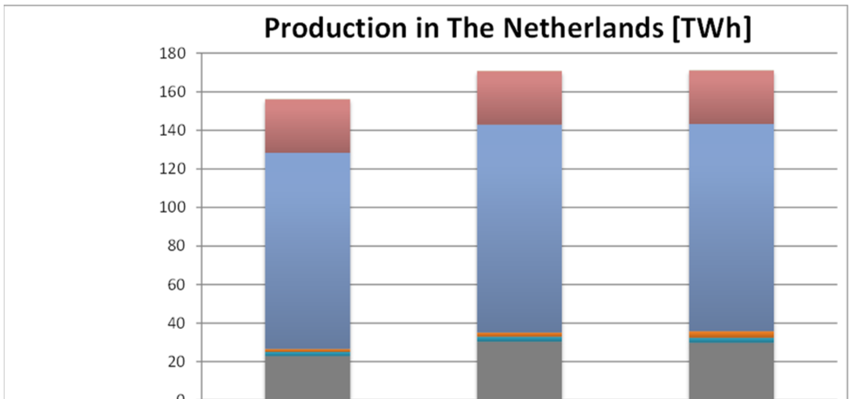


Bidding zones in DE only

- Marginal effect of no BZs in NL on electricity prices
- Electricity prices in Netherlands North increase, while prices in Middle and Southern part decrease a little bit
- Effects of this variant on imports/exports are not shown in next slide, since effects are nil

NO BIDDING ZONES IN THE NETHERLANDS

EFFECTS ON GENERATION MIX & CO_2 EMISSIONS



	Base case with RD	More BZs DE+NL	More BZs DE only
Hydro	0,1	0,1	0,1
Solar	27,8	27,8	27,8
Wind	101,8	107,9	107,6
Biomass and waste	1,6	2,1	3,4
Nuclear	2,1	2,6	2,5
Coal	0,0	0,0	0,0
Gas	22,9	30,4	29,8

- Generation mix changes marginally (+1.3 TWh waste incineration, -0.6 TWh from gas, -0.3 TWh from wind) and CO_2 emissions change marginally i.e. 1 Mton more in EU-27+ of which 0.9 Mton in the Netherlands.
- Overall, the approximation of the effect of no bidding zones in NL is suboptimal; it is assumed that once bidding zones are included in DE, network capacities in the Netherlands are infinite but it proved to be difficult to take the associated redispatch costs adequately into account. Consequently, this sensitivity case turned out to be less constrained than the project alternative with more BZs in both DE and NL, which is counterintuitive. The solution would be to run the network reduction process again for this sensitivity case, but this was not feasible due to time constraints.

CONCLUSIONS OF SENSITIVITY ANALYSES

- No HVDC North-South cables in Germany (-8 GW of network capacity)
  - The absence of these cables implies a more constrained electricity system and a major change of trading patterns. Consequently, more available interconnection capacity (IC) and bidding zones (BZs) have a larger SWF effect than in the original case.
  - The adverse effects of the lack of HVDC cables on CO_2 emissions and curtailment of wind generation are partially mitigated by more IC and BZs.

- No bidding zones in the Netherlands
  - Effect of introduction of bidding zones in Germany is much larger than effect of bidding zones in the Netherlands, which is also visible in small differences in electricity prices between zones in NL.
  - Excluding BZs in NL has a small effect, which is a bit surprising since largest SWF effects of more BZs are in the NL. Possible explanations seem to relate to suboptimal market and network modelling;
  - Market modelling: more refined modelling of generation plants in the Netherlands i.e. with unit commitment (start-up costs, ramping rate, minimum uptime and downtime characteristics of plants), while generation is aggregated by technology for other countries like Germany i.e. without unit commitment. Therefore the merit order of generation units is less refined for other countries, hence changes in generation deployment cause less cost and price differences and therefore less SWF changes in these countries. This may result in underestimation of social welfare effects of bidding zones as well as a more uneven distribution of SWF effects then in practice.
  - Network modelling: redispatch costs seem not adequately included in the base case of this specific sensitivity case. There was no time left to make a correction

CONCLUSIONS AND DISCUSSION

CONCLUSIONS AND DISCUSSION
SOCIAL WELFARE EFFECTS OF MORE INTERCONNECTION

- Research question 1: What are the effects of more available interconnection capacity, notably due to more bidding zones, on the energy transition and EU internal electricity market? What impact do main network reinforcements and the introduction of bidding zones in Germany have on the Netherlands?
- The COMPETES electricity market model has been adapted and run to test the effects of more available interconnection capacity and bidding zones on the energy transition and EU internal elec. market. An overall decrease of CO_2 emissions with 5.1 Mton in EU-27+ with flow-based network representation when accounting for redispatch costs, but in the Netherlands an increase of 2.6 Mton due to more electricity exports.
- Positive effects of more interconnection and more bidding zones compared to BAU base case on social welfare (SWF) for EU-27+ for 2030:

Country *all figures in million €*	Total effect	More interconnection	More bidding zones
Austria	1	5	-4
Belgium	78	71	7
France	-155	-127	-28
Germany	81	46	35
Netherlands	614	422	191
Norway	-152	-107	-44
Total EU-27+CH+NO+UK	**477**	**318**	**159**

- Results indicate that bidding zones are indispensable to increase the utilization of network infrastructure and thus contribute to achieving the 70% minimum target of network capacity available for cross-zonal trade. Without bidding zones it is unlikely that significantly more interconnection capacity will be realised by TSOs, hence both effects are intertwined.

CONCLUSIONS AND DISCUSSION

SOCIAL WELFARE EFFECTS OF MORE INTERCONNECTION (CON'D)

- Social welfare (SWF) increases by € 477 million per year in EU-27+ due to more available interconnection capacity and bidding zones compared to base case.
  - Mainly producer surplus increases (€ 928 million), while consumer surplus decreases (€ 409 million). This is likely to be the result of steeper supply curve in smaller and net exporting countries such as the Netherlands, while the supply curve is more gradual in larger and net importing countries such as Germany. Hence, substantial price increases occur in exporting countries but smaller price decreases in importing countries, increasing net producer surplus and decreasing net consumer surplus (cf. Supponen, 2012).
  - Congestion rents decrease (€ 43 million), although more bidding zones mean more borders where congestion rents can be earned. The latter effect is outweighed though by the correction for redispatch costs in the base case and therefore not visible. Since redispatch costs are underestimated due to assumptions of both EU wide and cost efficient redispatch, this is likely to be different in practice.
  - Transition costs and possible additional costs of remedial actions are not included in this estimate.
  - Redispatch costs amount to € 536 million per year for this geographical area and are thus essential for a fair assessment of the effects of bidding zones on both SWF and other assessment criteria. Hence, all figures mentioned here include redispatch costs in the base case.
- More available IC and more BZs have important redistribution effects, both between and within countries. E.g. SWF in the Netherlands increases by € 614 million per year, while SWF in France and Norway decreases by € 155 and € 152 million per year respectively.
- SWF effects are under/overestimated for the following reasons;
  - Model assumption of efficient and EU-wide cross-border redispatching, hence smaller effect of more bidding zones on SWF than in reality.
  - SWF effects increase with more renewables and the scenario includes 10 GW of additional offshore wind generation in the Netherlands, while no additional industrial demand has been investigated.

SENSITIVITY NO HVDC NORTH-SOUTH CABLES IN GERMANY

ADDITIONAL SOCIAL WELFARE EFFECTS OF MORE IC AND BZ

Country *all figures in million €*	Producer surplus	Consumer surplus	Congestion rents	Transition costs	Net effect
Austria	20	-14	-4	PM	2
Belgium	-14	0	19	PM	5
France	73	-53	-22	PM	-2
Germany	72	-141	164	PM	95
Netherlands	-101	23	122	PM	44
Other EU-27+ countries	142	-141	-19	PM	-17
Total	**192**	**-325**	**260**		**127**

- In Germany, three major North-South HVDC cables are envisaged (Südlink, SüdOst-link and A-Nord projects, in total 8 GW) to diminish existing network congestion and thus to better connect offshore renewable energy in the North with load centres in the South.
- No HVDC N-S cables within Germany causes an *additional* net social welfare effect of ca € 130 million euro of more IC and BZs in EU-27+ (i.e. compared to the net social welfare effect in the situation with HVDC cables)
- The absence of these cables implies a more constrained electricity system and a major change of trading patterns. Consequently, more available interconnection capacity (IC) and bidding zones (BZs) have a larger SWF effect than in the original case.
- The adverse effects of the lack of HVDC cables on CO_2 emissions (notably in DE) and curtailment of wind generation are partially mitigated by more IC and BZs.

SENSITIVITY BIDDING ZONES IN GERMANY ONLY
SOCIAL WELFARE EFFECTS

- This sensitivity sheds light on the question: Which part of the bidding zones effects is due to BZs in Germany and which part due to BZs in NL?
  - Rather than comparing a case with BZs in Germany only against the base case or project alternative 1, this has been simulated by excluding bidding zones in the Netherlands from project alternative 2.
- Excluding bidding zones in NL causes an insignificant overall net social welfare effect compared to the net SWF effect in the situation with BZs in both Germany and the Netherlands.
- This effect is in line with the earlier observation that in Germany differences in electricity prices between bidding zones within the country are quite significant in project alternative 2, while in the Netherlands they are really small. This indicates that network congestion and therefore the possible contribution of bidding zones to social welfare in Germany is significant, but in NL is limited.
- It is thus obvious that largest price effects of bidding zones are in Germany. Yet largest SWF effects of more BZs in DE are in NL. Possible explanations seem to relate to suboptimal market and network modelling;
  - Market modelling: more refined modelling of generation plants in the Netherlands i.e. with unit commitment (start-up costs, ramping rate, minimum uptime and downtime characteristics of plants), while generation is aggregated by technology for other countries like Germany i.e. without unit commitment. Therefore the merit order of generation units is less refined for other countries, hence changes in generation deployment cause less cost and price differences and therefore possibly less SWF changes in these countries. This may result in underestimation of social welfare effects of bidding zones as well as a more uneven distribution of SWF effects then in practice.
  - Network modelling: redispatch costs seem not adequately included in the base case of this specific sensitivity case. This is left for further research.

CONCLUSIONS AND DISCUSSION
EFFECTS ON PRODUCERS & CONSUMERS

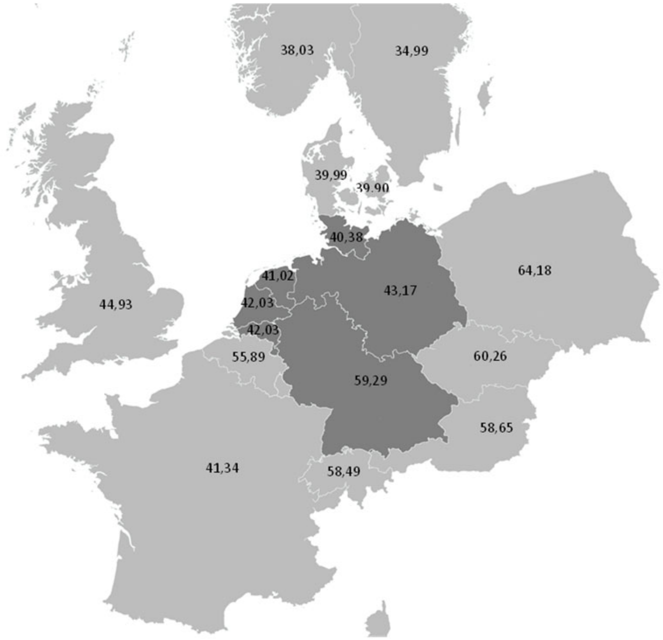
- Research question 2: What is the impact of more available interconnection capacity on operational decisions by producers, consumers and TSO in the Netherlands in 2030? What are opportunities and threats for Dutch renewable electricity production and/or efficient Dutch gas-fired power stations?
  - Higher producer surplus (PS): although overall generation costs decrease, PS increases due to higher electricity prices and replacement of high marginal cost generation (mainly gas and coal) by low marginal cost generation (less curtailment of wind).
  - Lower consumer surplus (CS): mainly the opposite of PS since the advantage of higher electricity prices for producers is a disadvantage for consumers.

- More IC and BZs change electricity prices that producers receive and consumers pay;
  - Small decrease of weighted average prices in EU-27+ with more available interconnection capacity compared to base case due to more competition among producers.
  - Higher weighted average prices in EU-27+ with more BZs since congestion on internal borders is directly taken into account in electricity prices while without BZs this congestion is neglected in electricity pricing, resolved afterwards by redispatch and paid for by network tariffs. This decreases revenues from generation redispatch for producers and lowers network tariffs for consumers.

CONCLUSIONS AND DISCUSSION

EFFECTS ON PRODUCERS & CONSUMERS

More bidding zones in DE & NL



- More IC and BZs change electricity prices that producers receive and consumers pay (con'd):
  - Germany: average price difference of about € 19/MWh between Germany North and South. Price difference of about € 1/MWh between Netherlands North and Middle. No average price difference between NL Middle and South suggests no structural congestion between these areas and hence limited impact on generation dispatch. The latter might be the result of too optimistic generation capacity assumptions.

- More IC and BZs result in changes of the merit order of generation plants and hence in changes of generation mix, CO_2 emissions and net imports in the Netherlands and other CWE countries;
  - Higher deployment of gas-fired generation (CHPs and CCGTs), higher CO2 emissions, more electricity exports, and less curtailment of offshore wind in NL
  - Effects for the NL seem a bit exaggerated though due to dissimilar modelling of generation in NL and other countries (see previous slides) and 10 GW of additional offshore wind generation in NL without additional industrial demand.

CONCLUSIONS AND DISCUSSION
EFFECTS ON NETWORK OPERATORS

- More available interconnection capacity results in less congestion and therefore lower congestion rents for TSOs, while more bidding zones mean more borders where congestion rents can be earned. The latter effect is outweighed though by the correction for redispatch costs in the base case and therefore not visible.

- Underestimation of redispatch costs in base case and project alternative with more interconnection due to assumptions of both EU wide and cost efficient redispatch, while in practise:
  1. Mainly national redispatch, cross-border redispatch is currently largely absent, but in development following EU regulations;
  2. Two-step approach (electricity trading followed by curative redispatch) causes major inefficiencies, amongst others due to different geographical delineation of both mechanisms (country-wide versus nodal). This offers market participants arbitrage opportunities and incentives for strategic bidding behaviour (Cf. Smeers, 2008; Hirth *et al.* 2019).

- Hence, in practise decrease of redispatch costs with more bidding zones is larger than shown in model results and there is a net positive result on the net revenues for TSOs from congestion rents and redispatching, which is usually passed through to consumers by lower grid tariffs.

CONCLUSIONS AND DISCUSSION
EFFECTS ON FLEX SUPPLY AND DEMAND RESPONSE

- Research question 3: What is the impact of more available interconnection capacity on overall flex supply? What does it mean for the merit order of flex options i.e. flex from abroad through interconnections as well as demand response in the Netherlands in 2030, compared to a situation with less available interconnection capacity?

- Overall supply of flexibility in the Netherlands of 5.3 TWh by interconnections, conventional generation, renewable generation (curtailment), and demand response is not affected.
- More available interconnection capacity increases the supply of flex from abroad through interconnections, and decreases the role of demand response in the Netherlands
  - Flex supply (both upwards and downwards) through interconnections and gas-fired generation increases, while VRE curtailment and demand response (P2H, HPs, EVs) provide less flexibility. The change of demand response is caused by less flex of EVs (50%) and P2H (50%).
  - Flex demand which is caused by VRE, non-flex demand, and DR, is not significantly affected.

Flexibility supply (TWh)			
	Base case	More interconnection and bidding zones	Change
Interconnections	1,4	2,1	0,7
Gas-fired generation	1,2	1,3	0,2
VRE curtailment	1,6	0,9	-0,7
Demand response	1,0	0,9	-0,1

POLICY RELEVANCE

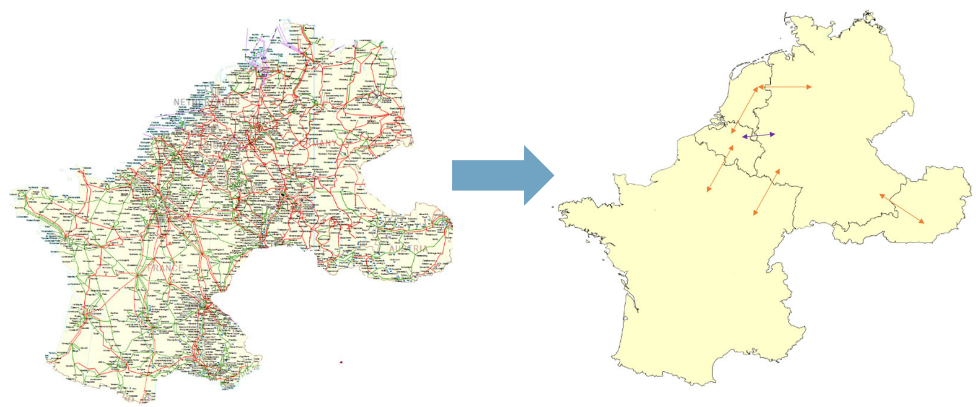
- ACER (2020b) outlines the methodology and assumptions that are to be used in the official and regular bidding zone (BZ) review process, and distinguishes four groups of criteria related to; (i) network security, (ii) market efficiency, (iii) stability and robustness of BZs, and (iv) energy transition.
- Although our analysis does not fulfill all ACER requirements concerning e.g. target year and modelling chain steps, it provides valuable insights in the main effects of alternative BZ configurations on market efficiency and energy transition;
  - Market efficiency and notably economic efficiency play a key role in the BZ review process. The assessment of economic efficiency is largely based on the change of SWF and is the first step for the assessment of alternative BZ configurations i.e. calculating monetized benefits.
  - Energy transition: the analysis provides insights in short-term effects on CO_2 emissions and RES integration (total amount of fed-in energy quantities from RES i.e. less curtailment) and their variability.
- It also shows that redistribution effects between and within countries are significant, which may lead to political resistance.
- For the assessment of alternative BZ configurations against the status quo also other (qualitative) evaluation criteria are relevant that were not in scope of the study, e.g. related to stability and robustness of BZs, and to market efficiency, a.o.
  - Market liquidity and transaction costs, to provide insight in hedging opportunities of market participants
  - Market concentration and market power in wholesale markets and redispatching mechanisms
- Further research into the effects of bidding zones may deliver a more complete and refined picture of the merits and demerits of alternative bidding zone configurations and its effects for EU-27+ in general and for the Netherlands in particular.

ANNEX I - NETWORK REDUCTION METHODOLOGY

NETWORK REDUCTION

HOW TO OBTAIN AN ACCURATE REDUCED GRID FOR THE FB APPROACH IMPLEMENTATION?

- The aim of modelling flow-based market coupling comes down to more accurately representing physical flows in the COMPETES electricity market model.
- Basically, two parameters of the physical grid are required:
  - Line admittances
  - Line capacities
- The first is essential since the power flow is dependent on the circuit admittances, whereas the second limits the maximum amount of power that can flow between two zones or areas.
- Using a complete network representation is unpractical due to the computational burden. Hence, a network reduction approach is applied to make an equivalent system with a lower computational burden and with comparable results to the original system.



NETWORK REDUCTION

STEPS

- First step: Network partition

  Can be based on:

  - Geographical areas (countries, provinces) i.e. expert-based approach (ENTSO-E, 2019)
  - Locational marginal prices (LMPs) from model-based approach (ACER decision BZR)

- Second step: Node selection

  Can be based on:

  - Interconnection degree
  - Electrical distance

- Third step: Equivalencing techniques

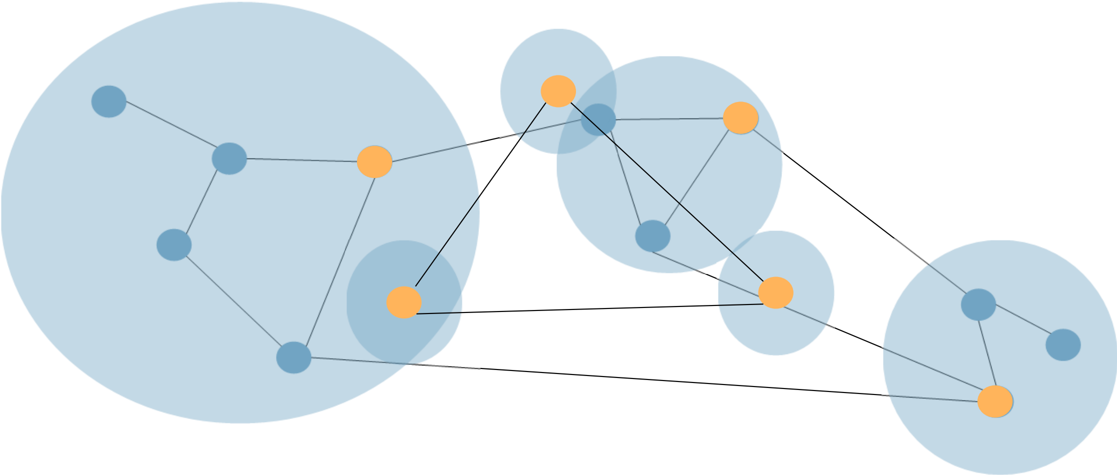
  - Admittances

    Kron method
    Ward method

  - Line capacities

    Optimization
    Historical maximum power flow between zones

The application of the selected options in the methodology is illustrated in the following slides.



- Given lack of information about LMPs, network partition is based upon ENTSO-E info
- Given lack of methodological soundness for node selection based upon electrical distance, nodes are selected based upon their interconnection degree
- The equivalencing technique selection is explained in the next slide.

NETWORK REDUCTION
EQUIVALENCING TECHNIQUES SELECTION

- Admittances
  - The Kron reduction and its derivation (Ward technique) are based on the Gaussian elimination of non-border buses. The Kron reduction is chosen in this approach due to more extensive literature and examples against which we validated its implementation. These two methods are similar but can be used to solve different equivalencing problems.

- Line capacities
  - Historical maximum power flows could serve as a simple heuristic value for a transfer link capacity between zones. Nevertheless, this approach is limited when exploring new zone configurations and in forward-looking analysis due to lack of information. Hence, calculating new line capacities that can transfer specific power between new zones is necessary.

NETWORK REDUCTION
NODE SELECTION

- This network reduction approach takes into account nodes that could restrict the total transfer capacities between countries or zones.
- Interconnection degree (ID): the number of connections a node has to other nodes in the network.
- Studying the impact of every node is infeasible. There could be nodes limiting the maximum total transfer capacity (TTC) that are not relevant for this study (e.g. a small node at a rural area in Germany) since in practice these are not critical for cross-border trade. If nodes with lower ID are considered, more network restrictions or critical branches are taken into account resulting in a lower TTC.
- Once an interconnection degree is chosen, nodes with that interconnection degree or higher are studied. The table on the right shows the number of nodes to study when selecting different interconnection degrees.

Interconnection degree	# of nodes to study
1	1048
2	794
3	445
4	241
5	149
6	94
7	62

NETWORK REDUCTION
EQUIVALENCING TECHNIQUE - EQUIVALENT ADMITTANCES

- Kron reduction is a standard tool for eliminating nodes while preserving the electrical characteristics of a network. The Kron reduction method is based on the Gaussian elimination of nodes. Using these, the new network features should represent the original one accurately, and the inter-area flows in it should be the same as those of the original network (Dorfler & Bullo, 2013).
- The admittance of the new inter-zone lines generated by this procedure can be deduced with the Kron reduction formula:

$$Y_{i,j}new = Y_{i,j} - \frac{Y_{i,k}Y_{k,j}}{Y_{k,k}}$$

Where:
$Y_{i,j}$ = admittance between bus i and bus j
$Y_{i,j}$new = equivalent admittance between bus I and bus j
k = bus number to be eliminated

NETWORK REDUCTION
EQUIVALENCING TECHNIQUE - EQUIVALENT LINE CAPACITIES

- Objective: to create a reduced network that replicates the total transfer capacities (TTCs) of the full network between reference nodes.
- TTC is the maximum network capacity available for electricity transport between pairs of zones with the assumption that electricity exchanges in the rest of the grid (i.e. other zonal net positions) are zero i.e. TTCs are non-simultaneous values.
- Step 1: Obtain TTCs using the full network between selected reference nodes and power transfer distribution factors (PTDFs) of the reduced network.
- Step 2: Obtain line capacities of the reduced network that matches the TTCs of the full network as accurately as possible. This is done using an optimization problem.
- The next slides explain these steps in more detail.

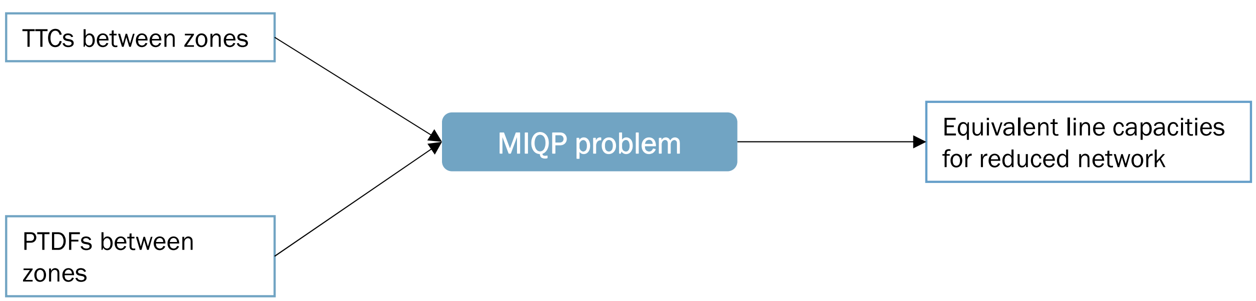
NETWORK REDUCTION
CALCULATING TTCs BETWEEN NODES

- TTCs are obtained by injecting power in one node and subtracting it in the other until one element of the network is saturated, taking into account the electrical properties of the network (Kirchhoff laws).
- To calculate the TTC, power transfer distribution factors (PTDFs) are introduced to linearly approximate the impact of commercial exchanges (net positions) on the physical flows through critical lines.
- Contingencies are not considered in the calculation of the yearly TTC. Nevertheless, a flow reliability margin is introduced to account for uncertainties inherent to the capacity calculation processes.
- An unloaded system is assumed to ensure no operating point dependency. This also means that the system is direction independent. In practice, power injections and withdrawals may lead to different TTCs depending on the direction of the power flows.
- The power transfer for a transaction obeys a line limit that is upper-bounded, where F_{l_i} is the nondirectional line limit of l and $\varphi_{l_i}^{(w_p)}$ is the PTDF of the transaction w_p:

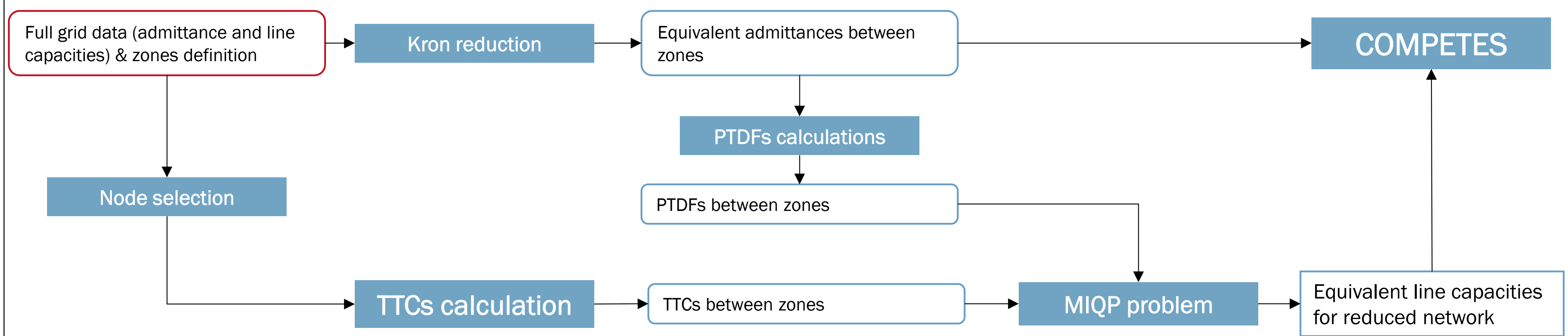
$$P^{(w_p)} = \frac{F_{l_i}}{\varphi_{l_i}^{(w_p)}}$$

NETWORK REDUCTION
LINE CAPACITIES OPTIMIZATION

- The objective is that the equivalent line capacities of the reduced network present TTCs that are as similar as possible to the TTCs of the full network. We achieve this with the following steps:
  1. Obtain TTCs of the full network (Through PTDFs, see previous slides)
  2. Obtain reduced network (See Kron reduction, previous slides)
  3. Solve an optimization problem to obtain the equivalent line capacities for this reduced network: The problem obtains all the line capacities in a way that minimize the total squared mismatch between the TTCs of the selected nodes of the full network and the TTCs of the reduced network. The formulation is written as a Mixed-Integer Quadratic Programming (MIQP) problem

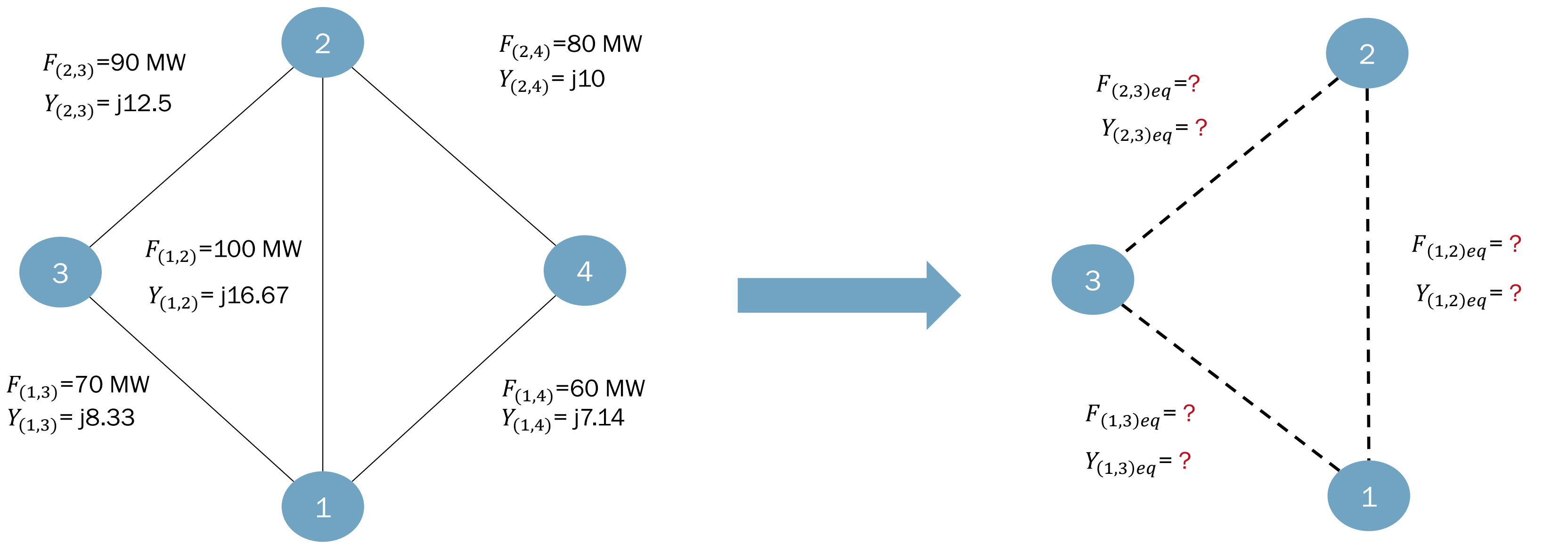


NETWORK REDUCTION
FLOWCHART - FULL METHODOLOGY



NETWORK REDUCTION EXAMPLE
HOW TO ELIMINATE ONE NODE FROM A NETWORK?

- In this example we show the developed network reduction methodology by a fictitious example, not reflecting a real life situation; we reduce the 4-node network to 3-nodes by aggregating node 4 to node 1.
- When aggregating node 4, the properties of the network change. Parameters such as equivalent line limits F_{leq} and admittances Y_{leq} have to be calculated for the new network. These equivalent parameters should represent the full network as accurately as possible.

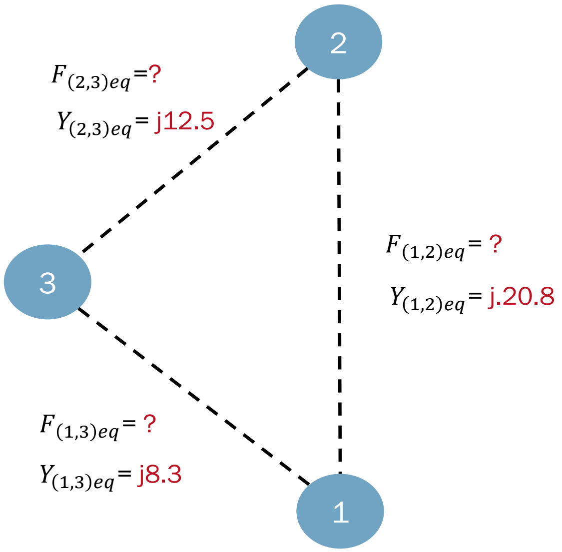


NETWORK REDUCTION EXAMPLE
EQUIVALENT ADMITTANCES

- Step 1: Obtaining equivalent admittances $\boldsymbol{Y_l}$
  - As previously explained, we apply the Kron network reduction method to obtain the equivalent admittances once a node is eliminated
  - When using the Kron method, the new network features should represent the original one accurately, and the inter-area flows in it should be the same as those of the original network (Dorfler & Bullo, 2013).
  - The figure below shows the equivalent line admittances of the 3-node network that accurately represent the 4-node network shown in the previous slide.
  - The line limits of the equivalent lines are still to be calculated

$$Y_{i,j}new = Y_{i,j} - \frac{Y_{i,k}Y_{k,j}}{Y_{k,k}}$$

Where:
$Y_{i,j}$ = admittance between bus i and bus j
$Y_{i,j}\mathrm{new}$ = equivalent admittance between bus I and bus j
k = bus number to be eliminated

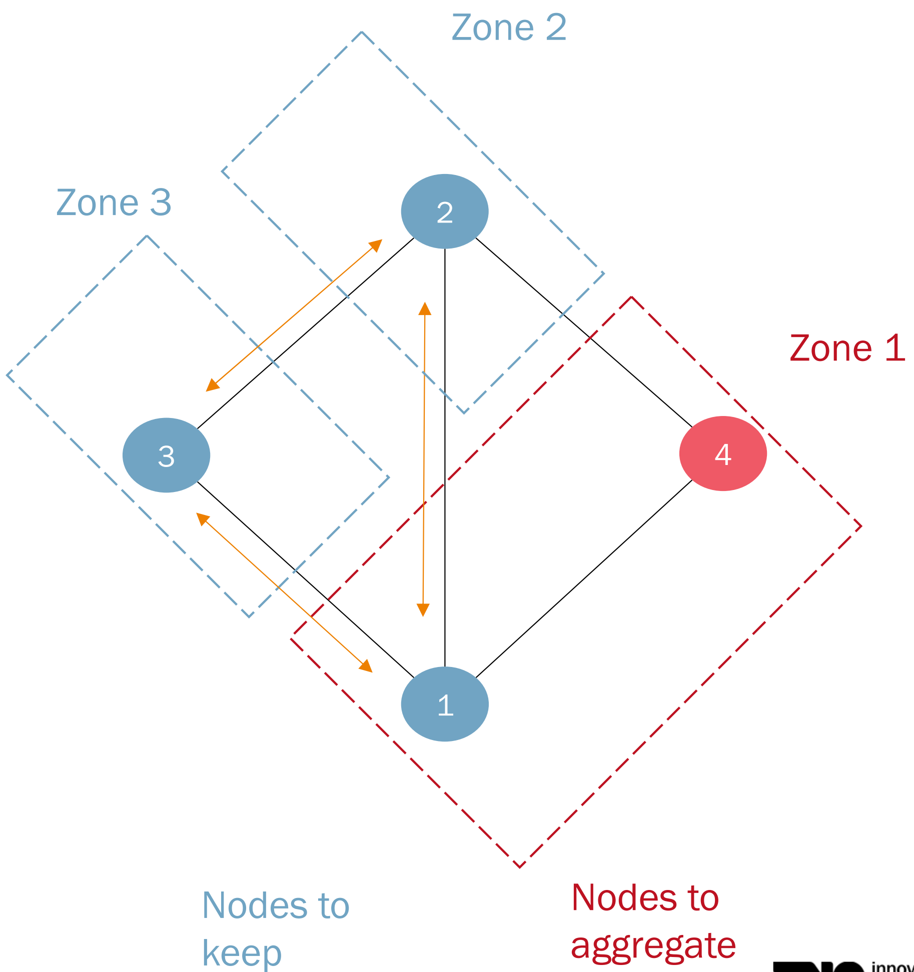


NETWORK REDUCTION EXAMPLE
LINE CAPACITIES

- The calculation of equivalent line capacities is done in two steps:
  1. Calculating the total transfer capacities (TTCs) between the nodes of different zones that remains after the node aggregation.
  2. Using an optimization problem to obtain the line capacities
- Using the full network we calculate the TTCs between the defined zones, i.e.:
  - 1 ↔ 2
  - 1 ↔ 3
  - 2 ↔ 3

The following slides illustrates the TTC calculation between nodes 1 and 2.

Note: a zone can consist of a number of nodes e.g. zone 1 is made up by node 1 and node 4.



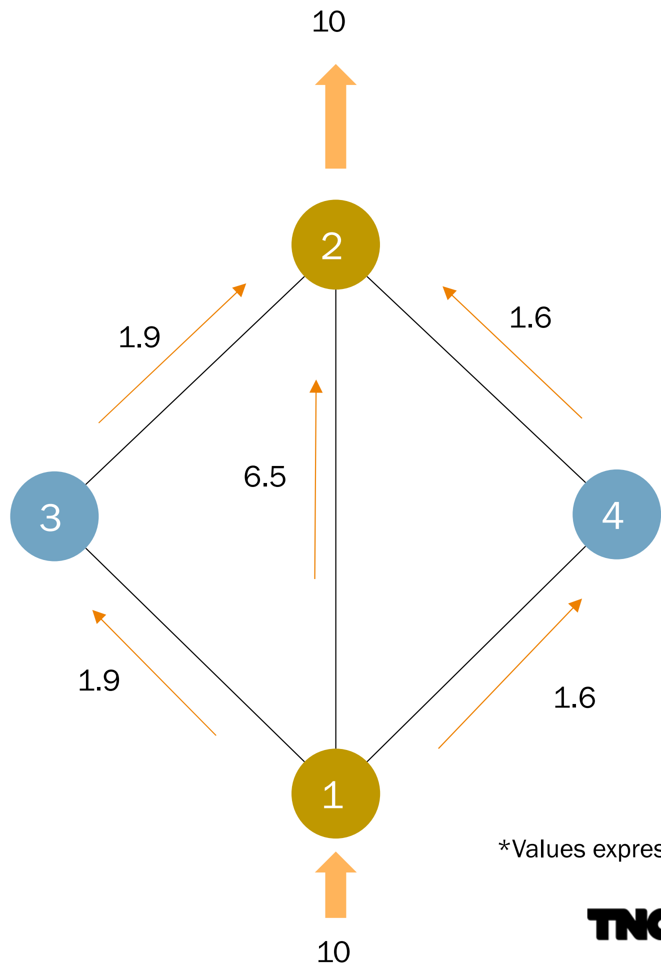
NETWORK REDUCTION EXAMPLE

NODES 1 → 2

- First, PTDFs or $\varphi_{(l)}^{(w)}$ are calculated for transaction w=1,2.
- By obtaining the $\varphi_{(l)}^{(w)}$ we can calculate the amount of power that will flow through each line if injected in node 1 and withdrawn in node 2. For example, if there is a 10 MW transaction between nodes 1 and 2, the power will flow as seen in the figure.
- $P_{(1,2)}$ is the maximum amount of power that can be injected in node 1 and withdrawn in node 2 than can flow through a line l without saturating it.

Line (l)	Line Limit [MW] F_{l_i}	PTDF $\varphi_l^{(w)}$	Max power $P_l = F_{l_i}/\varphi_l^{(w)}$
(1,2)	100	0.65	155
(1,3)	70	0.19	362
(1,4)	60	0.16	372
(2,3)	90	0.19	465
(2,4)	80	0.16	496

- Note: If there is a transaction in the opposite direction i.e. 2→1, the flows will be of the same magnitude with the opposite direction.

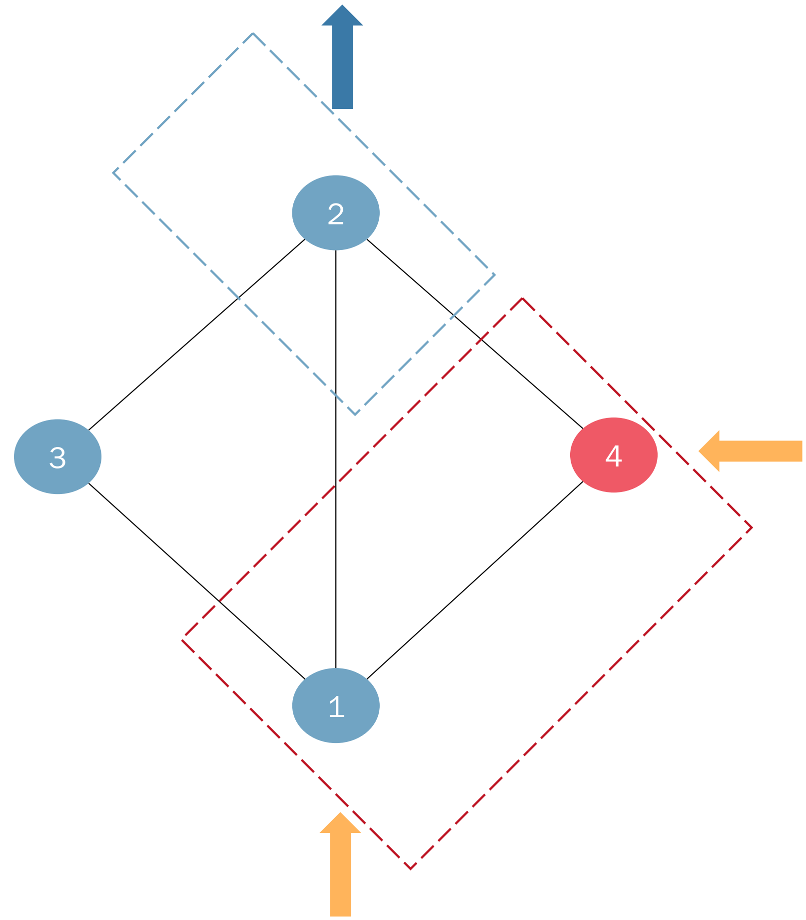


*Values expressed in MW

NETWORK REDUCTION EXAMPLE

TTC BETWEEN ZONE 1 AND 2

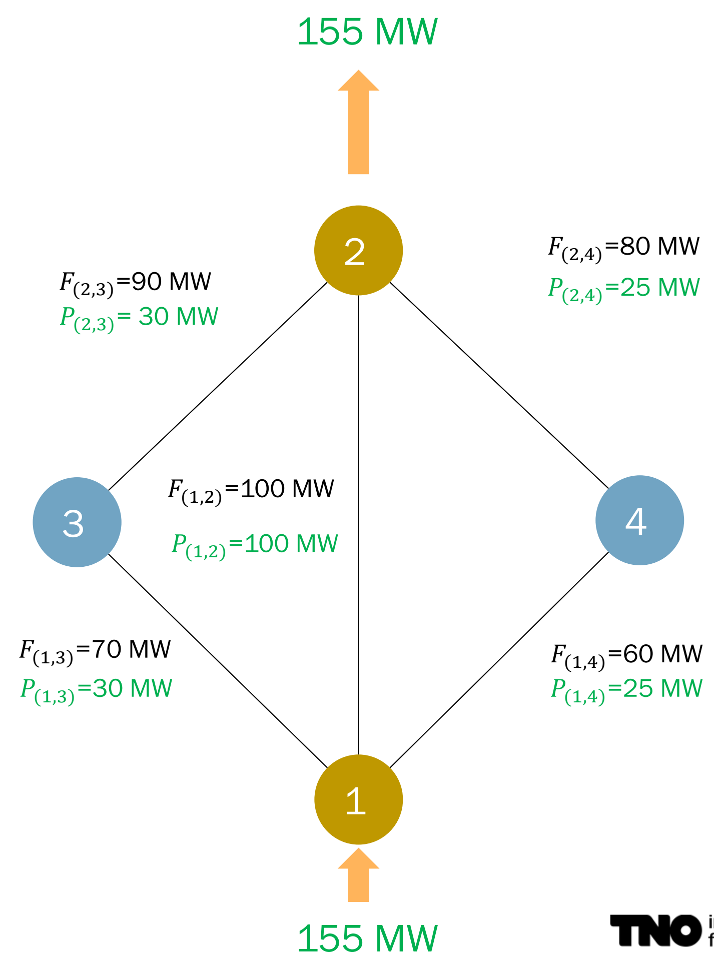
- To obtain the TTC of the equivalent circuit between zone 1 and 2, we first calculate the minimum TTC that the circuit can transport between the combination of nodes between zones i.e.
  - 1 ↔ 2
  - 4 ↔ 2
- Once these two are obtained, we average the two minimum TTCs.
- We average the two minimum TTCs since once the network is loaded there is no possibility to know where the injections or withdrawals of power come from within a zone.



NETWORK REDUCTION EXAMPLE
TTC 1 → 2 MIN

- In case the minimum value of the maximum power P_l of the table is taken, there is a power transfer of 155 MW between node 1 and 2 which is distributed over different network paths.
- By using the minimum P value, we make sure that the lines limits in the network are not exceeded. Nevertheless, some of the lines are underused (facilitating simultaneous injections/ withdrawals in other nodes).

Line (l)	Line Limit [MW] F_{l_i}	$\varphi_l^{(w)}$	$P_l = F_{l_i}/\varphi_l^{(w)}$
(1,2)	100	0.65	155
(1,3)	70	0.19	362
(1,4)	60	0.16	372
(2,3)	90	0.19	465
(2,4)	80	0.16	496

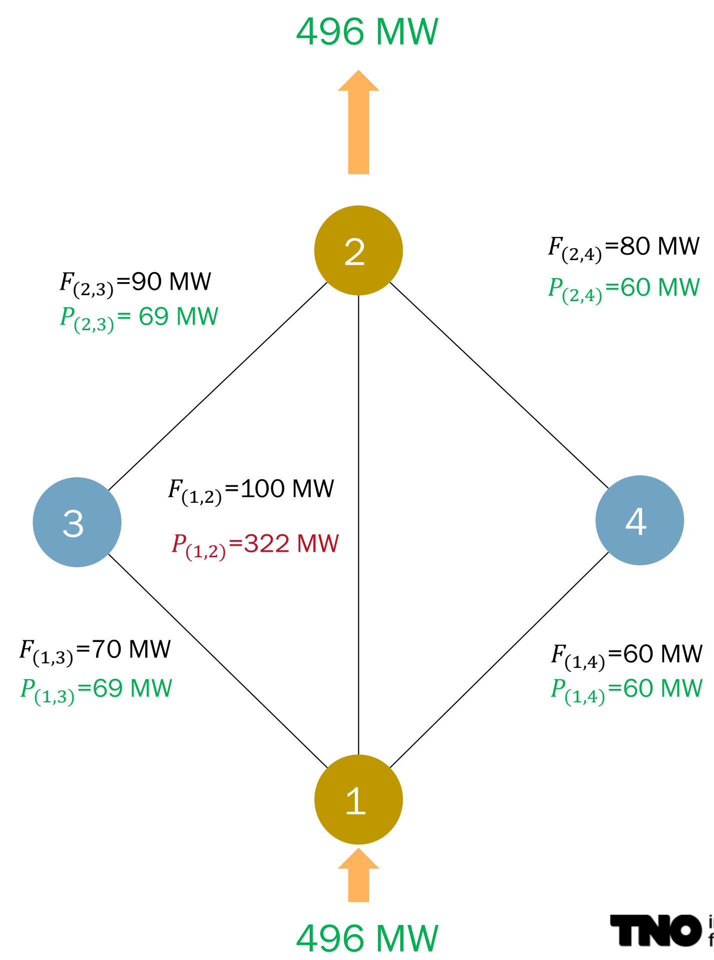


NETWORK REDUCTION EXAMPLE

TTC 1 → 2 MAX

- In case the maximum value of the maximum power P_l of the table is taken, there is a power transfer of 496 MW between node 1 and 2 which is distributed over different network paths.
- By using this value, the line limit (1,2) is violated.

Line (l)	Line Limit [MW] F_{l_i}	$\varphi_l^{(w)}$	$P_l = F_{l_i}/\varphi_l^{(w)}$
(1,2)	100	0.65	155
(1,3)	70	0.19	362
(1,4)	60	0.16	372
(2,3)	90	0.19	465
(2,4)	80	0.16	496

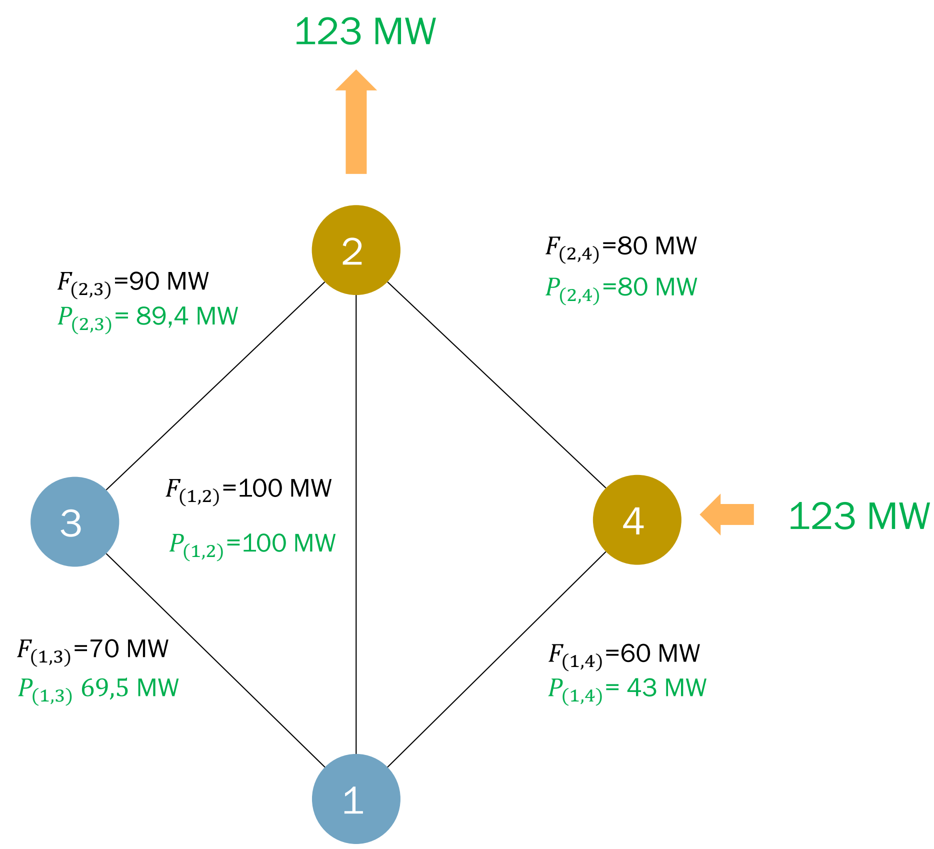


NETWORK REDUCTION EXAMPLE

TTC 4 → 2 MIN

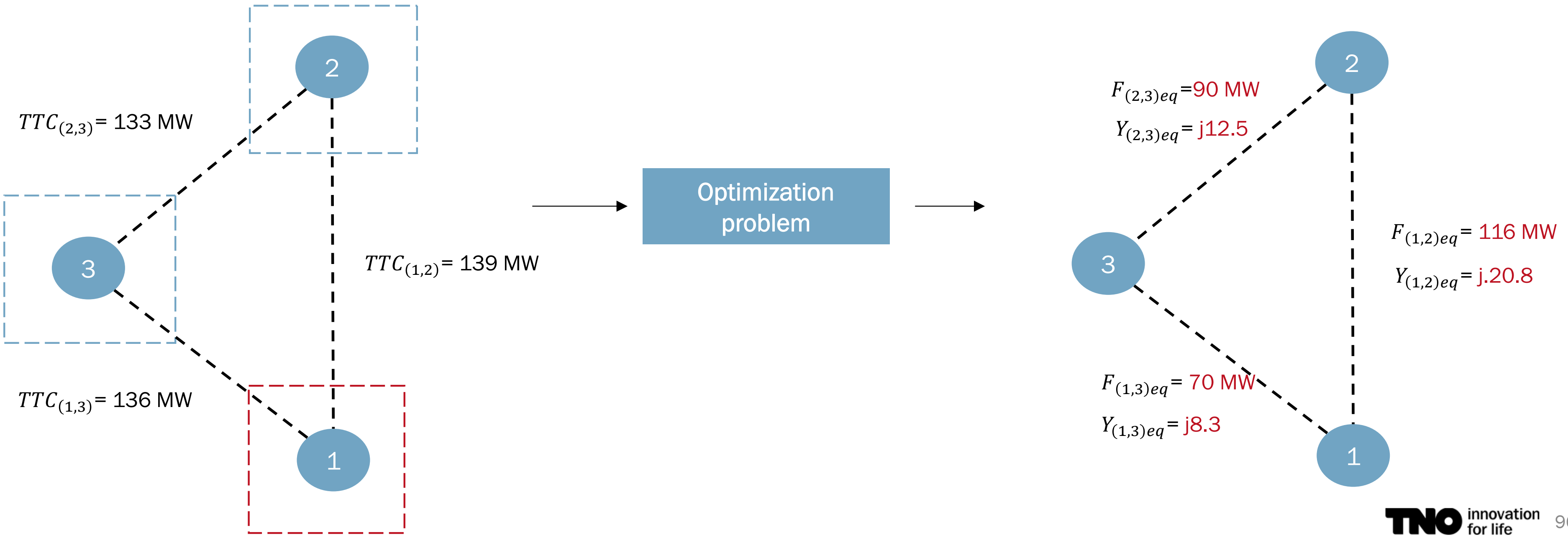
- Similar to the TTC from 1 → 2, we do the same calculation for nodes 4 → 2. Note that since the transaction source is different the $\varphi_l^{(w)}$ changes with respect to transaction 1 → 2. The new $\varphi_l^{(w)}$ are shown in the table.
- If the minimum P_l value is chosen then there is a 123 MW power transfer between node 4 and node 2.

Line (l)	Line Limit [MW] F_{l_i}	$\varphi_l^{(w)}$	$P_l = F_{l_i} / \varphi_l^{(w)}$
(1-2)	100	0.27	372
(1-3)	70	0.08	868
(2-3)	90	0.08	1117
(1-4)	60	0.35	172
(2-4)	80	0.65	123



NETWORK REDUCTION EXAMPLE
EQUIVALENT LINE CAPACITIES

- Following the previous steps, we calculate the TTCs for the other two pairs of nodes: 1 ↔ 3 and 2 ↔ 3.
- After obtaining the TTCs between the nodes of the new network we proceed to calculate the line capacities.
- The obtained TTCs together with a set of PTDFs of the equivalent network, serve as inputs for an optimization problem. The problem calculates the line capacities the new circuit must have in order to achieve (as accurately as possible) the input TTCs.



NETWORK REDUCTION CONCLUSIONS
NETWORK REPRESENTATION IN COMPETES IMPROVED

- The developed network reduction methodology delivers a good approximation of the full physical network with an acceptable computational burden. It has been successfully deployed in electricity market model COMPETES.
- The optimization problem has an inherit error or mismatch between the full network total transfer capacities and the equivalent network ones. The error is minimized as much as possible by using advanced optimization algorithms developed in this project. Our approach yields a lower error than in earlier work with a different method, e.g. in Mohapatra *et al.* (2014), since our approach guarantees global optimality.
- As every method also this network reduction methodology has some limitations;
  - Contingencies are not considered in the calculation of the yearly TTC, apart from a 10% flow reliability margin to account for uncertainties inherent to the capacity calculation process, hence the increase of interconnection capacity could not be fully feasible.
  - An unloaded system is assumed to ensure no operating point dependency. This also means that the system is direction independent. In practice, power injections and withdrawals may lead to different TTCs depending on the direction of the power flows.
  - Selection of the right interconnection degree proved to be challenging, since the reference node selection is not optimal.
  - It does not allow to measure the contributions of more interconnection capacity and bidding zones to the 70% minimum target.

ANNEX II – DETAILED ASSUMPTIONS

ELECTRICITY DEMAND

TWH, 2030

Table: COMPETES: Electricity demand parameters for the Netherlands and Germany

Parameter	Unit	NN	NM	NS	GN	GM	GS
Conventional power demand	TWh	23.0	63.8	34.1	14.2	164.9	362.0
Total power demand	*TWh*	*27.4*	*76.0*	*40.6*	*14.5*	*168.5*	*370.0*
# Power to Mobility (EVs, flexible demand)	TWh	0.5	1.3	0.7	0.2	2.0	4.5
# Power to Heat (household heat pumps, flexible demand)	TWh	0.4	1.1	0.6	0.2	1.6	3.5
# Power to Heat (industry, potential hybrid flexible demand)	TWh	3.5	9.9	5.2	0.0	0.0	0.0
Total additional power demand ('electrification')	*TWh*	*4*	*12*	*6*	*0*	*4*	*8*

Sources: PBL (2019), PBL (2020), ENTSO-E (2018)

*Power to hydrogen demand is not included in this study.

FUEL AND CO_2 PRICES
EURO/GJ, 2015

Fuelname	Fuel price	Unit
Biomass	2.66	€ 2015/GJ
Coal	2.66	€ 2015/GJ
Coke oven gas	6.93	€ 2015/GJ
Lignite	1.29	€ 2015/GJ
Natural gas	6.93	€ 2015/GJ
Nuclear	0.78	€ 2015/GJ
Oil	12.86	€ 2015/GJ

- CO_2 price: 57.59 euro 2015/ ton (2030 price from KEV 2021: 62 euro 2020/ton)

GENERATION CAPACITIES

MW, 2030

in MW	BIOMASS Standalone	BIOMASS Cofiring	COAL PC	GAS CCGT	GAS CHP	GAS GT	HYDRO CONV	HYDRO PS	LIGNITE PC	NUCLEAR -	OIL -	RESE others	SOLAR CSP	SOLAR PV	WASTE Standalone	WIND ONSHORE	WIND OFFSHORE
AT	0	599	0	3778	0	591	8576	5697	0	0	168	0	0	12005	0	8999	0
BE	0	541	0	8930	0	1079	148	1395	0	0	158	206	0	10454	0	4279	4271
FR	0	2549	0	13087	0	636	21800	3500	0	58213	0	0	0	38600	0	36000	4920
GN	0	334	197	319	0	62	0	100	0	0	59	0	0	3626	0	10650	3922
GM	0	1605	2857	10492	0	2036	538	3011	4523	0	202	0	0	32168	0	46698	13131
GS	0	4682	6798	20736	0	4009	4842	6926	4708	0	580	0	0	56983	0	25397	0
NN	49	0	0	3357	660	144	0	0	0	0	0	0	0	6770	73	1495	5356
NM	67	0	0	3370	5249	124	19	0	0	0	0	0	0	11718	188	3084	9888
NS	33	0	0	2846	1874	0	23	0	0	484	0	0	0	7552	32	1071	5562
CZ	0	0	372	2575	0	0	1095	1158	5021	4041	14	1064	0	4900	0	960	0
DK	0	532	0	58	0	520	0	0	0	0	0	265	0	700	0	1000	1700
DW	0	647	0	615	0	0	0	0	0	0	0	406	0	1600	0	4000	3100
FI	0	1201	0	960	0	319	3200	0	0	4384	0	3043	0	850	0	6460	42
IE	0	0	0	4291	0	300	238	292	424	0	324	149	0	400	0	5120	3500
IT	0	0	0	44659	0	5399	15201	11899	0	0	0	4933	880	50000	0	17521	900
PL	0	2614	12712	11819	0	0	721	1502	7433	0	0	1414	0	8167	0	7239	3600
PT	0	0	0	3615	0	0	4763	4387	0	0	0	1105	300	8844	0	8901	260
SK	0	221	437	743	0	91	1533	926	100	2767	0	257	0	679	0	102	0
ES	0	0	0	28244	0	0	14610	9520	0	3054	0	2226	7300	36134	0	48580	0
SE	0	0	0	267	0	111	16630	0	0	5851	0	4185	0	4010	0	16950	1190
CH	0	0	0	890	0	0	12265	3989	0	1190	0	1197	0	5500	0	255	0
NO	0	0	0	265	0	0	0	36062	0	0	0	76	0	800	0	7248	0
UK	0	3984	0	43704	0	2297	1969	4004	18	9281	565	4891	0	17123	0	17504	25100
BK	0	165	1045	10867	0	2444	24455	5929	19100	8901	818	2502	270	20274	0	17326	0
BT	0	0	0	1675	0	0	1737	1125	0	0	1156	339	50	1220	0	1958	1028

FULL LOAD HOURS OF WIND AND SUN

2030

Country	Wind Offshore	Wind Onshore	Sun PV
AT	0	2533	1144
BE	4735	2608	1089
CZ	0	2358	1110
DK	4755	3101	960
DW	4755	3101	960
FI	4584	2461	560
FR	4220	2514	1281
GN	4412	2506	1074
GM	4412	2506	1074
GS	0	2506	1074
IE	5321	3812	942
IT	2938	2386	1443
NN	4735	2750	1067
NM	4735	2750	1067
NS	4735	2750	1067
PL	4563	2419	1076
PT	3423	2399	1625
SK	0	2301	1161
ES	3271	2398	1608
SE	4442	2907	867
UK	4907	3187	914
CH	0	1518	1213
NO	5347	2511	790
BK	3402	2294	1358
BT	4624	2421	958

- Hourly profiles for wind offshore and onshore and sun PV from (Pfenninger & Iain, 2016)
- Weather year 2015
- Capacity factors (Ruiz Castello et al, 2019)
- The hourly VRE profiles were constructed by using the timeseries retrieved from (Pfenninger & Iain, 2016), which were optimized to achieve the capacity factors from (Ruiz Castello et al, 2019).

NETWORK CAPACITIES
MW, 2030, CWE REGION ONLY

Zone A	Zone B	Technology	Base case	More IC	More BZ
AT	GS	AC	1057	1741	1741
BE	FR	AC	436	1435	1484
BE	NS	AC	1178	1487	1661
BE	GS	HVDC	1000	1000	1000
FR	BE	AC	1073	1435	1484
FR	GS	AC	3192	2211	2025
GM	GN	AC	4104	4104	4104
GM	GS	AC	3691	3691	3691
GM	NN	AC	237	593	832
GM	GS	HVDC	4000	4000	4000
GN	GM	AC	4104	4104	4104
GN	GS	HVDC	4000	4000	4000
GS	AT	AC	3673	1741	1741
GS	FR	AC	3876	2211	2025
GS	GM	AC	3691	3691	3691
GS	NL	AC	409	1019	1432
GS	NN	AC	111	277	389
GS	NS	AC	457	1140	1602
GS	BE	HVDC	1000	1000	1000
GS	GM	HVDC	4000	4000	4000
GS	GN	HVDC	4000	4000	4000
NL	GS	AC	301	1019	1432
NL	NN	AC	2735	2735	2735
NL	NS	AC	4694	4694	4694
NN	GM	AC	175	593	832
NN	GS	AC	82	277	389
NN	NL	AC	2735	2735	2735
NS	BE	AC	964	1487	1661
NS	GS	AC	337	1140	1602
NS	NL	AC	4694	4694	4694

- Base case shows direction dependent network capacity values, while network reduction algoritm provides direction independent network values by definition
- HVDC lines and cables are more controllable than AC lines and hence constant
- AC line capacity often increases from base case to more IC to more BZ, with GS-FR as main exception

NETWORK CAPACITIES

MW, 2030, EU 27+ CAPACITIES EXCLUDING CWE REGION

Zone A	Zone B	Technology	2030
AT	BK	AC	1750
AT	CH	AC	1700
AT	CZ	AC	900
AT	IT	AC	1229
BE	GS	HVDC	1000
BE	UK	HVDC	1000
BK	AT	AC	1750
BK	IT	AC	640
BK	SK	AC	1800
BK	IT	HVDC	2700
BT	FI	HVDC	1016
BT	PL	HVDC	700
BT	SE	HVDC	700
CH	AT	AC	1700
CH	FR	AC	1300
CH	GS	AC	4600
CH	IT	AC	3742
CH	IT	HVDC	1000
CZ	AT	AC	900
CZ	GM	AC	1475
CZ	GS	AC	1125
CZ	PL	AC	1000
CZ	SK	AC	2100
DK	GM	AC	400
DK	SE	AC	1700
DK	DW	HVDC	600
DK	GM	HVDC	585
DW	GN	AC	3500
DW	DK	HVDC	590
DW	NN	HVDC	700
DW	NO	HVDC	1371

Zone A	Zone B	Technology	2030
DW	SE	HVDC	715
DW	UK	HVDC	1400
ES	FR	AC	5000
ES	PT	AC	4200
FI	SE	AC	2000
FI	BT	HVDC	1016
FI	SE	HVDC	1200
FR	CH	AC	3116
FR	ES	AC	5000
FR	IT	AC	4100
FR	IE	HVDC	700
FR	UK	HVDC	5400
GM	CZ	AC	1130
GM	DK	AC	400
GM	PL	AC	2000
GM	DK	HVDC	600
GM	UK	HVDC	1400
GN	DW	AC	3500
GN	NO	HVDC	1400
GN	SE	HVDC	1315
GS	CH	AC	3300
GS	CZ	AC	870
GS	BE	HVDC	1000
IE	UK	AC	1250
IE	FR	HVDC	700
IE	UK	HVDC	500
IT	AT	AC	1067
IT	BK	AC	670
IT	CH	AC	1715
IT	FR	AC	2001
IT	BK	HVDC	2700
IT	CH	HVDC	1000

Zone A	Zone B	Technology	2030
NL	UK	HVDC	1000
NN	DW	HVDC	700
NN	NO	HVDC	687
NO	SE	AC	3117
NO	GN	HVDC	1400
NO	DW	HVDC	1632
NO	NN	HVDC	685
NO	UK	HVDC	2800
PL	CZ	AC	800
PL	GM	AC	3000
PL	SK	AC	990
PL	BT	HVDC	700
PL	SE	HVDC	600
PT	ES	AC	3500
SE	DK	AC	1300
SE	FI	AC	2000
SE	NO	AC	3273
SE	BT	HVDC	700
SE	GN	HVDC	1315
SE	DW	HVDC	715
SE	FI	HVDC	1200
SK	BK	AC	2600
SK	CZ	AC	1600
SK	PL	AC	990
UK	IE	AC	1200
UK	BE	HVDC	1000
UK	GM	HVDC	1400
UK	DW	HVDC	1400
UK	FR	HVDC	5400
UK	IE	HVDC	500
UK	NL	HVDC	1000
UK	NO	HVDC	2800

- In cases without BZs same capacities, but GN, GM and GS are DE, and NN = NL.

NETWORK DEVELOPMENT PLANS
ASSUMPTIONS

- Netherlands AC reinforcement projects [1]

Reinforcement	Border	Zone Border	Result	Year	Included COMPETES
Increase capacity BSL-RLL380 with four circuits 3 kA; Fmax increases from 2x1975 MVA to 4x1975 MVA;			Reactance change	2022	yes
Increase capacity ZVL-RLL380 to 4 kA; Fmax increases from 2x1200 MVA to 2x2400 MVA	Zanvliet - Rilland	BE-NL	Cross border capacity increase BE-NL	2023	yes
Increase capacity from 3 to 4 kA; Fmax increases from 2x1975 MVA to 2x2635 MVA	Lelystad-Ens	NN-NM	Cross border capacity increase NLN-NLM	2020	yes
Conditional increase capacity from 1,8 to 3 kA.; Fmax increases from 2x1200 MVA to 2x1950 MVA	Meeden-Diele	NN-GM	Cross border capacity increase NLN-GEM	2021	yes
increase capacity from 3 to 4 kA; Fmax increases from 2x1975 MVA to 2x2635 MVA	Diemen-Lelystaad		Internal capacity increase NLM	2022	yes
New connection VVL-EOS380 (2x4 kA);	Eemshaven Oudeschip - Vierverlaten		Internal capacity increase NLN	2023	yes
increase capacity from 3 to 4 kA; Fmax increases from 2x1975 MVA to 2x2635 MVA	Geertruidenberg- Krimpen a/d Ijssel	NM-NS	Cross border capacity increase NLM-NLS	2023	yes
increase capacity from 3 to 4 kA; Fmax increases from 2x1975 MVA to 2x2635 MVA	Ens-Zwolle		Internal capacity increase NLN	2024	yes
increase capacity from 3 to 4 kA; Fmax increases from 2x1975 MVA to 2x2635 MVA	Eindhoven-Maasbracht		Internal capacity increase NLS	2025	yes

- Germany AC reinforcement projects [2]

Reinforcement	Border	Zone Border	Result	Year	Included COMPETES
New line	2: Ganderkesee – Wehrendorf	GM-GS	Cross border capacity increase GEM-GES	2023	Yes
New line	5: Dörpen West – Niederrhein	GM-GS	Cross border capacity increase GEM-GES	2023	Yes
New line	6: Wahle – Mecklar	GM-GS	Cross border capacity increase GEM-GES	2024	Yes
Increase from 220kV	11: Neuenhagen – Wustermark			2021	Yes
New line	16: Wehrendorf – Gyestersloh	GM-GS	Cross border capacity increase GEM-GES	2026	Yes
Increase from 220kV	18: Lyesstringen – Westerkappeln			2022	Yes
New line	19: Kruckel – Dauersberg		Internal capacity increase GEM-GEM	2025	No
New line	14: Niederrhein – Osterath		Internal capacity increase GES-GES	2024	No
New line	15: Osterath – Weißenthurm		Internal capacity increase GES-GES	2024	No
380 kV AC OHL between Isar and St. Peter with a total capacity of 4,100 MVA	St. Peter (AT) and Isar (DE)	GS-AT	Cross border Increased capacity GES-AUS	2025	Yes

- [1] https://www.government.nl/binaries/government/documents/publications/2019/12/20/action-plan-increasing-the-availability-of-cross-zonal-transmission-capacity-for-electricity-trade/Action+plan+Increasing+the+availability+of+cross-zonal+transmission+capacity+for+electricity+trade.pdf
- [2] https://www.netzausbau.de/leitungsvorhaben/de.html#AnkerEnLAG

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THANK YOU FOR YOUR ATTENTION

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