Technische Universität Berlin
Fachgebiet **W**irtschafts- und **I**nfrastruktur**p**olitik

Studies of the European energy system - National motivations in an electricity transmission expansion game

CenSES årskonferanse

10. December 2013

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Based on Egerer and Nylund (2013).

Agenda

1. Introduction: Perspectives on Transmission Planning
2. Methodology: National Decisions on Cross-Border Capacity
3. Application: Non-Cooperative Transmission Planning
4. Conclusion

Introduction: Perspectives on Transmission Planning

1) Additional cross-border transmission investments are required for

a. the internal European market for electricity

b. the low-carbon transformation of the energy system

2) Transmission planning has become more transparent with

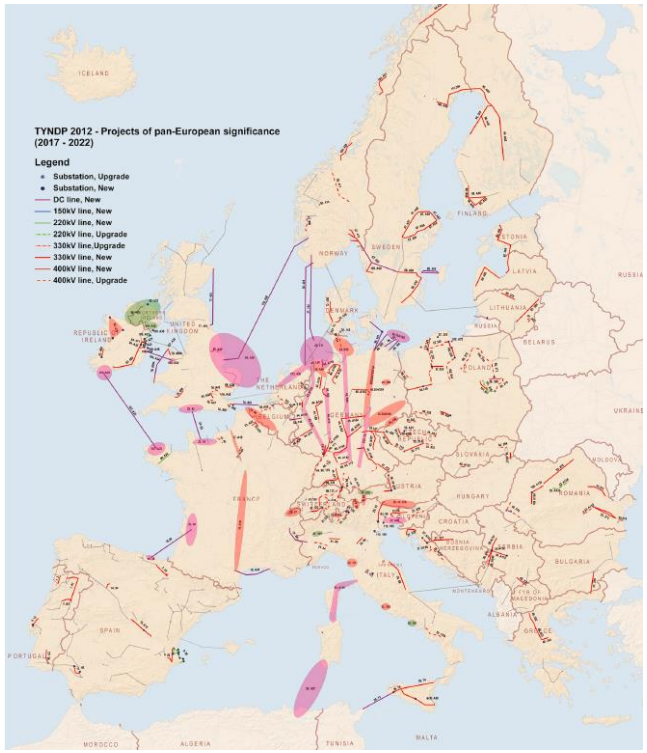
a. the National Network Development Plans

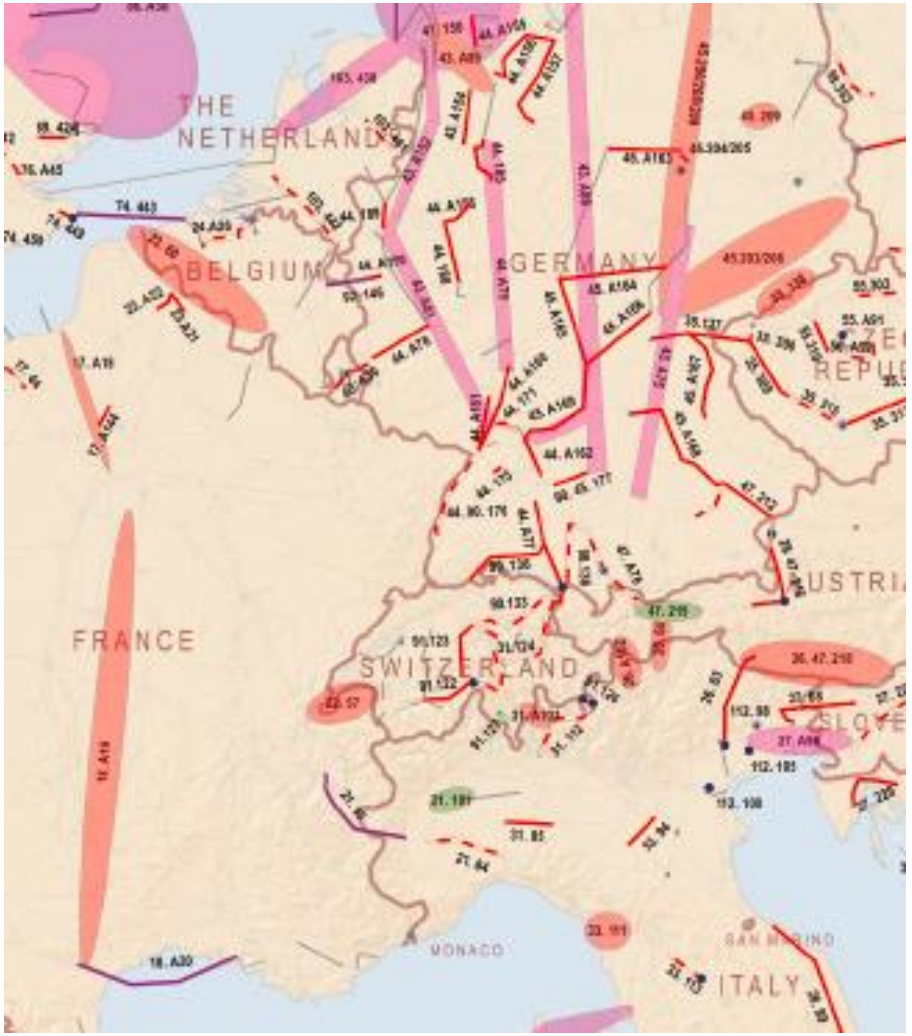
b. the European TYNDP

Introduction: Perspectives on Transmission Planning

10-Year Network Development Plan:

Projects for 2017 - 22





Sources: ENTSO-E (2012).

Introduction

National development plans:

Switzerland, Austria and Italy:

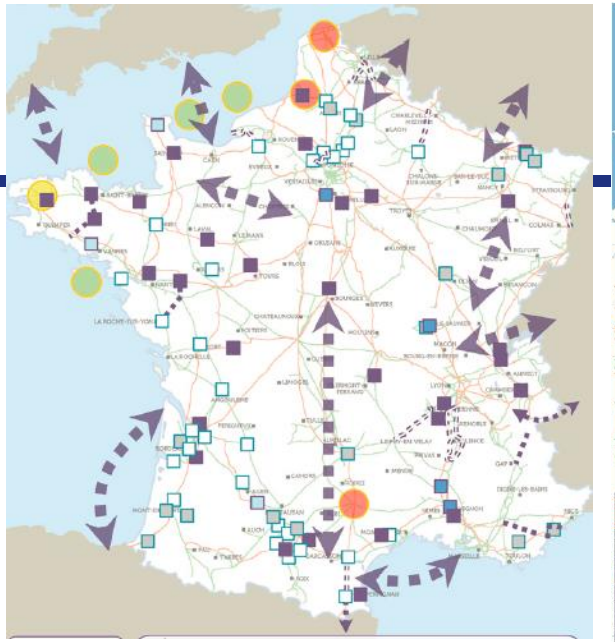
- Focus on intra-national expansions
- No connection Italy to AT/CH

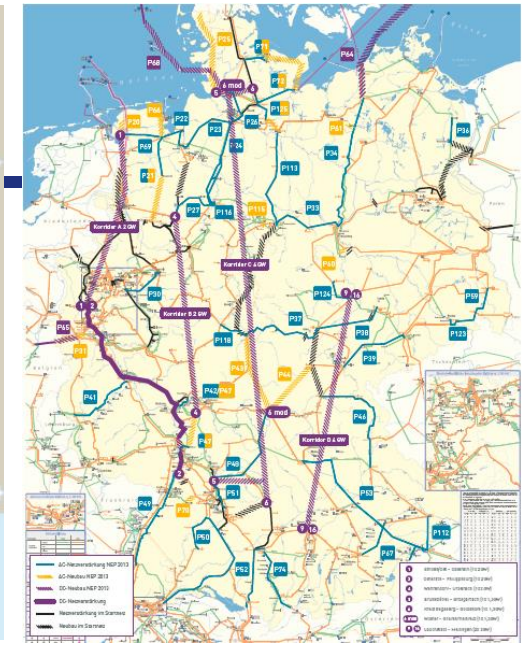
Germany:

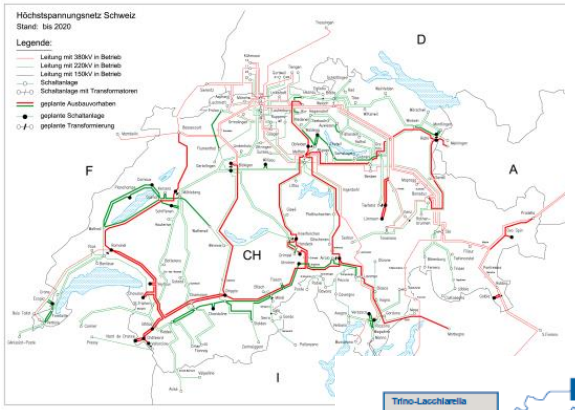
- Mainly north-south expansion (national and cross-border)

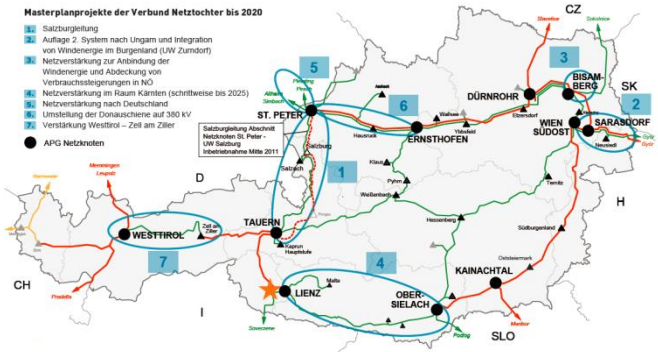
France:

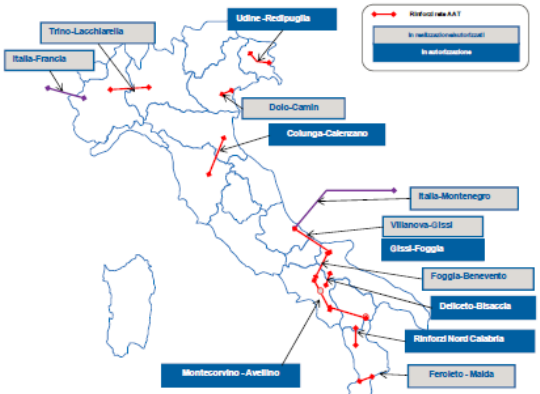
- Strong integration to neighbors











Sources: 50Hertz et al. (2013), APG (2013), RTE (2013), Swissgrid (2013), and Terna (2013).

Introduction: Perspectives on Transmission Planning

1) Additional cross-border transmission investments are required for

a. the internal European market for electricity

b. the low-carbon transformation of the energy system

2) Transmission planning has become more transparent with

a. the National Network Development Plans

b. the European TYNDPs

3) Individual countries could be in favor / against stronger integration for economic considerations on national level

a. Investment costs

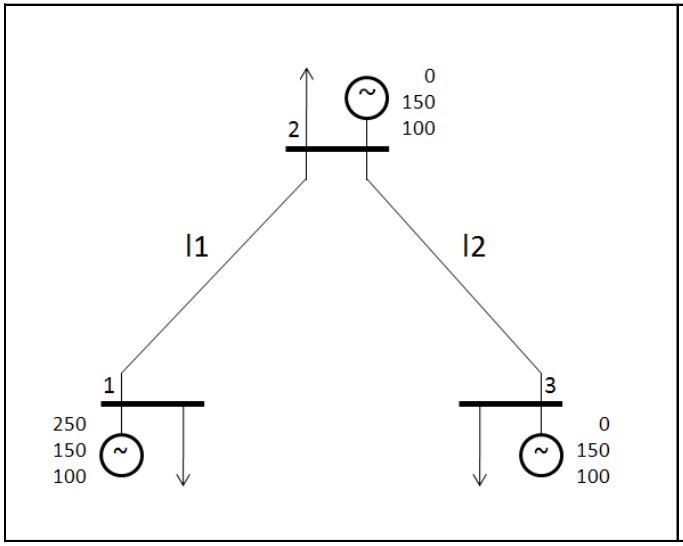
b. Price and welfare implications

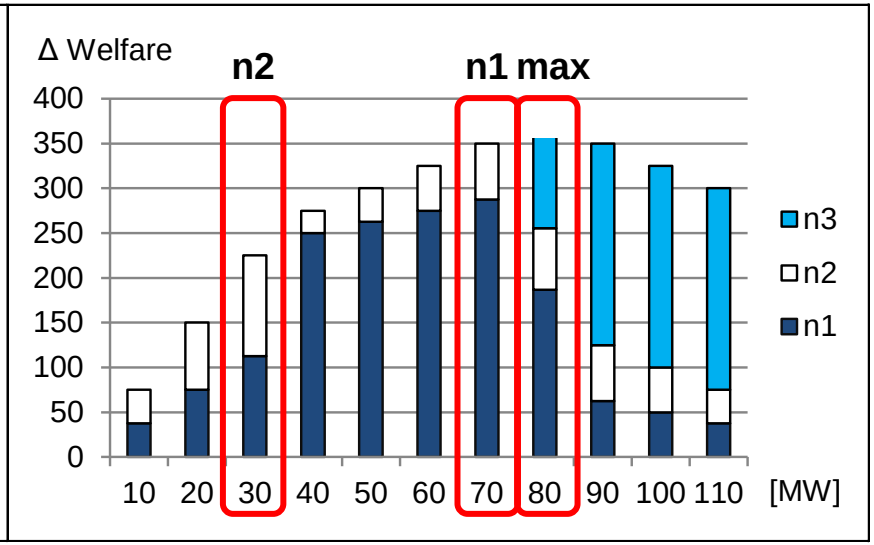
c. Distributional effects for stakeholders

Implication of Market Integration on Allocation

Three node transit example:

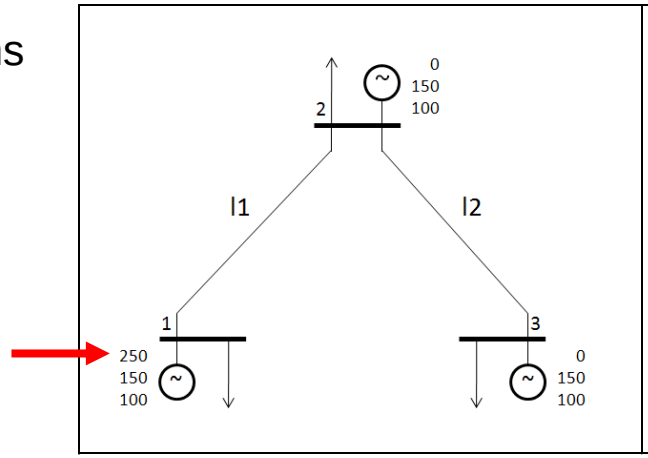
- Three nodes (n1, n2, and n3) with nodal demand 200 MW
- Demand function with reference price of 25 €/MWh and point elasticity of -0.25
- Cheap generation 20 €/MWh, middle one 25 €/MWh and lower one 30 €/MWh
- Line 2 (l2) unconstraint and initial capacity of line 1 (l1) is 10 MW
- Expansion cost 2.5 €/MW

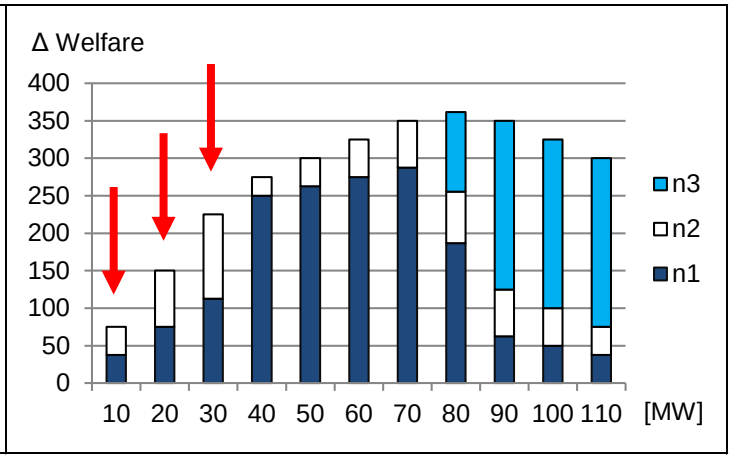




Implication of Market Integration on Allocation

Price remains equal:
- CR gain



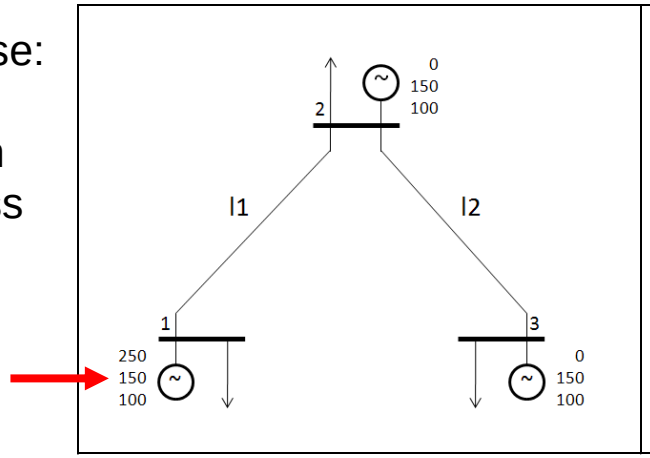


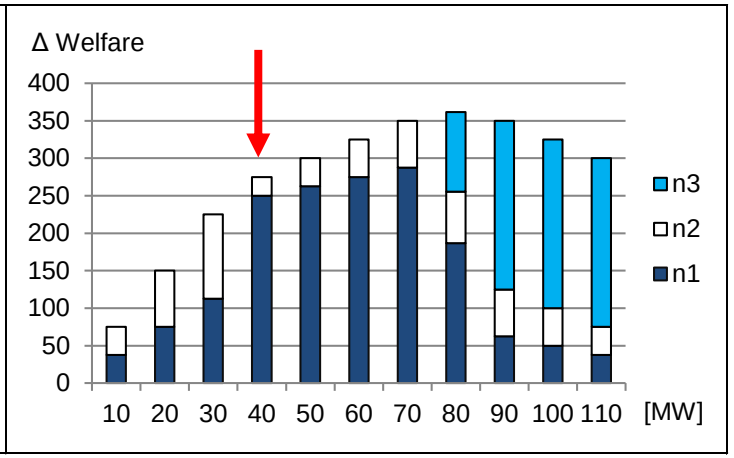
[MW]	n1	n2	n3	CS1	CS2	CS3	PS1	PS2	PS3	CR1	CR2	CR3
10 + 10	20	30	30	0	0	0	0	0	0	**50**	**50**	0
10 + 20	20	30	30	0	0	0	0	0	0	**100**	**100**	0
10 + 30	20	30	30	0	0	0	0	0	0	**150**	**150**	0

Cong. rent gains (+100€ per 10MW)

Implication of Market Integration on Allocation

Price increase:
- CR loss
- Export gain
- Welfare loss





[MW]	n1	n2	n3	CS1	CS2	CS3	PS1	PS2	PS3	CR1	CR2	CR3
10 + 30	20	30	30	0	0	0	0	0	0	+150	+150	0
10 + 40	**25**	30	30	**-1.025**	0	0	**+1.250**	0	0	**+75**	**+75**	0
10 + 50	25	30	30	-1.025	0	0	+1.250	0	0	+100	+100	0
10 + 60	25	30	30	-1.025	0	0	+1.250	0	0	+125	+125	0

Price increase (+5€/MWh)

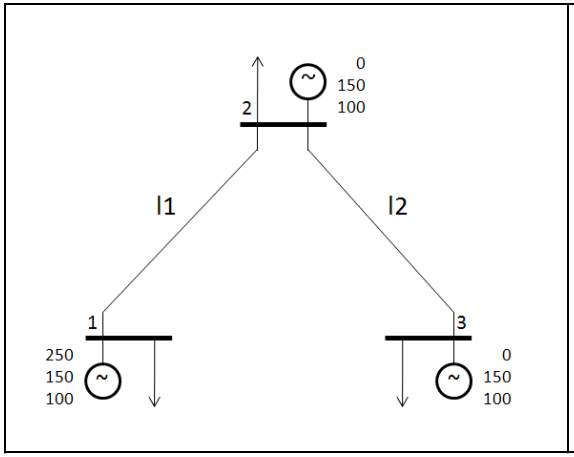
Welfare losses (-25€)

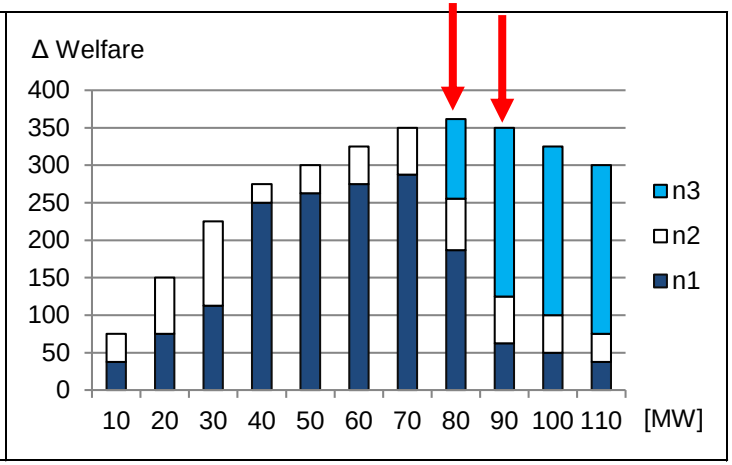
Trade gains (+250€)

Cong. rent losses (-75€)

Implication of Market Integration on Allocation

Price decrease:
- Integration
- Welfare gain





[MW]	n1	n2	n3	CS1	CS2	CS3	PS1	PS2	PS3	CR1	CR2	CR3
10 + 70	25	30	30	-1.025	0	0	+1.250	0	0	+150	+150	0
10 + 80	25	27.5	27.5	-1.025	+481	+481	+1.250	-375	-375	+62	+62	0
10 + 90	25	25	25	-1.025	+975	+975	+1.250	-750	-750	-50	-50	0

Price decrease (-2.5€/MWh)

Welfare gains (+106€/119€)

Cong. rent losses (-88€/112€)

Agenda

1. National versus European Perspective on Transmission Investment
2. **Methodology: National Decisions on Market Integration**
3. Application: Non-Cooperative Transmission Planning
4. Conclusion

Methodology: National Decisions on Market Integration

Assumptions on the local objective function

- Players are rational and seek to maximise their own welfare.
- Welfare is defined as the sum of consumer surplus, producer surplus and congestion rents minus costs for transmission investments. The congestion rent is shared equally between the two adjacent players.

Assumptions on the market design

- Short-term marginal pricing with implicit auctioning of exchange capacity defines the market outcome.
- Static setting for generation capacities, their variable costs, and the demand functions.
- Transfer flows are modelled with the two approaches a) transport flows and b) load flows (DC load flow approximation).

Procedure

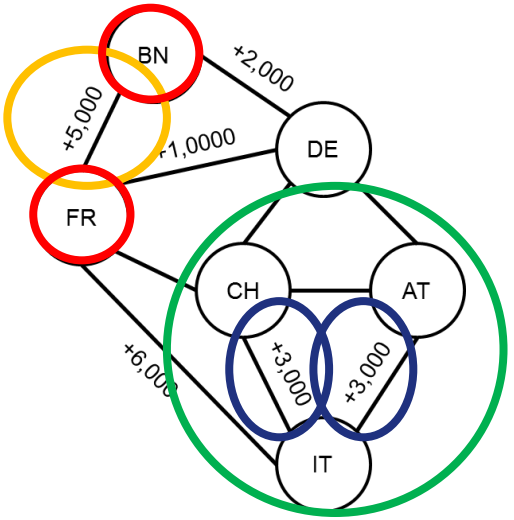
1) Determine welfare optimal solutions
2) Model market results for all possible investment combinations (steps of 1,000 MW)
3) Test the payoff matrix for stable solutions

Methodology: National Decisions on Market Integration

Assumptions on the game

- Static game with simultaneous moves, described in strategic form with: Players=TSOs; Strategies=Transmission expansion choices; Payoffs=National welfare.
- Complete information, meaning that the complete payoff matrix is known to all players.
- Each player has exclusive decision power over grid expansions on its own territory.
- The number of expansion options is finite.
- The stable outcomes of the game are defined by Nash equilibriums in pure strategies.
- The strategic considerations include blocking of expansion by single players and preferring different stable outcomes:

1) If any player has the power to increase its own welfare, given a particular outcome, by reducing or increasing investment on one of its own lines the outcome is not considered to be stable.
2) Also the incentive to diverge to a different expansion path can result in a non-stable outcome if all players involved in changed planning are better off compared to the initial outcome.



Methodology: National Decisions on Market Integration

Bilateral versus Regional sharing of costs in electricity transmission expansion

Option A

Welfare optimal planning of perfect mechanism with compensation payment

Sharing of benefits

EU planner – BUT: Sharing of benefits difficult to realize

Non-cooperative national investments

Cost allocation schemes:

Option B.1

Nation where line is located

In case of cross-border:

Bilateral 50:50 sharing

Option B.2

Costs are split according to benefits

Proportional sharing of costs

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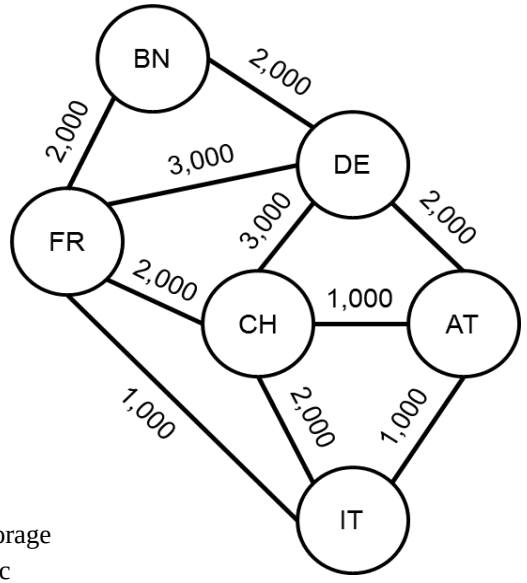
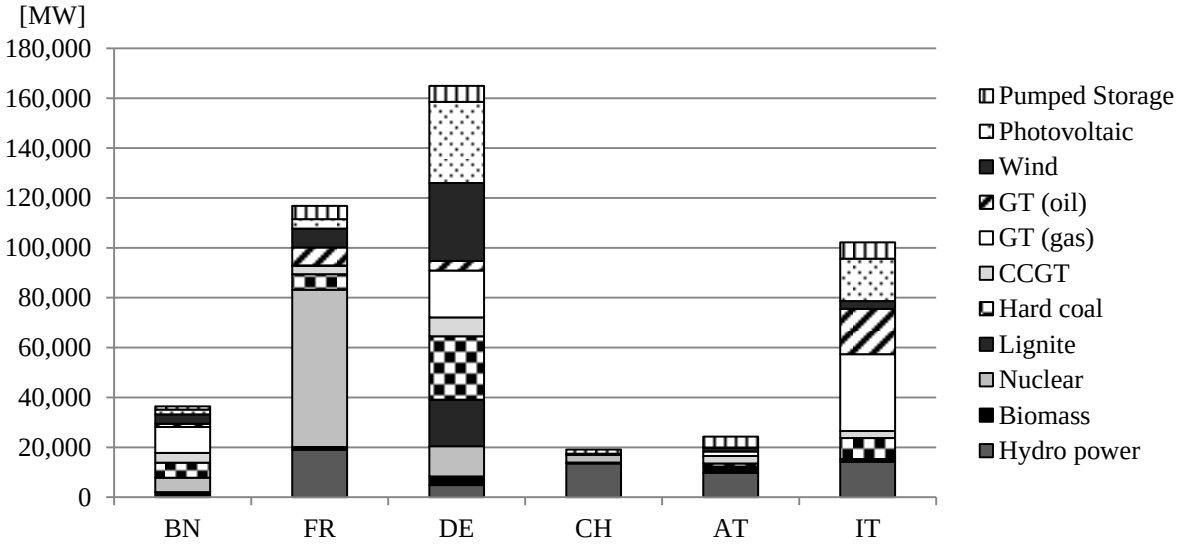
Application: Non-Cooperative Transmission Planning

Simple system representation:

- **6 nodes / 10 cross-border lines**
- **11 technologies**
- **2012 quantities and price:**
  - 4 x 168 hours, elasticity demand -0.25
  - Time series for renewable generation and demand
- **Transmission expansion in steps of 1,000 MW**

Initial Network:

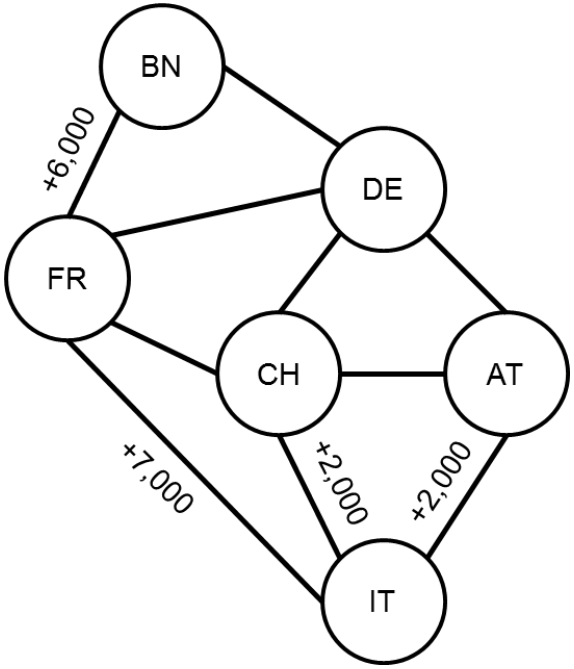




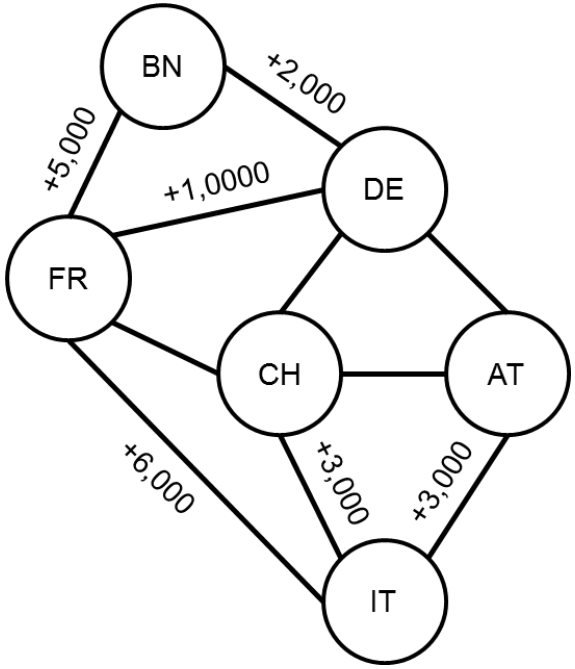
Application: Non-Cooperative Transmission Planning

Welfare optimal expansion

Transport model



DC load flow model



Results from the transport model reflect the current European zonal market design.

Application: Non-Cooperative Transmission Planning

Transport flows

with bilateral cost sharing:

- 28 stable solutions
- avg. 79% of optimal welfare gains
- avg. 70% of optimal capacity expansion

[M€]	AT	BN	CH	DE	FR	IT
Minimum	137	-112	122	-801	475	84
Maximum	440	772	710	-293	1,451	1,139
Average	323	363	362	-559	925	703
Optimum	239	410	390	-754	1,380	985

with regional cost sharing:

- 8 stable solutions
- avg. 94% of optimal welfare gains
- avg. 117% of optimal capacity expansion

[M€]	AT	BN	CH	DE	FR	IT
Minimum	118	462	310	-837	1,164	876
Maximum	282	551	373	-690	1,378	1,051
Average	233	505	346	-786	1,286	959
Optimum	227	468	332	-754	1,356	1,021

Application: Non-Cooperative Transmission Planning

DC load flow:

	Bilateral	Regional
Stable solutions	6	2
Spread welfare gains	62% - 95%	96% - 98%
Average welfare gains	82%	97%
Average of optimal capacity extension	62%	100%

Application: Non-Cooperative Transmission Planning

DC load flow: Bilateral cost sharing

Coalition	Expansions, MW	Payoffs, M€						
		AT	BN	CH	DE	FR	IT	%
{AT, CH, FR, IT}, {BN}, {DE}	3,000: CH-IT 4,000: AT-IT, FR-IT	436	26	93	-261	384	1,397	62
{AT, BN, DE, FR, IT}, {CH}	1,000: AT-IT, DE-FR 3,000: FR-IT 4,000: BN-FR	291	685	-460	87	1,129	448	65
{AT, BN, CH, FR, IT}, {DE}	3,000: AT-IT, BN-FR, CH-IT 5,000: FR-IT	348	535	-21	-246	1,151	1,443	96
{AT, BN, CH, DE, FR, IT}	1,000: DE-FR, CH-IT 2,000: AT-IT 3,000: BN-FR 4,000: FR-IT	441	558	-182	-40	1,097	817	81
	1,000: BN-DE 2,000: AT-IT, CH-IT 3,000: BN-FR 4,000: FR-IT	306	666	159	-181	1,052	1,054	92
	1,000: BN-DE 3,000: BN-FR, CH-IT 4,000: AT-IT 5,000: FR-IT	414	605	115	-259	1,025	1,276	95

Application: Non-Cooperative Transmission Planning

DC load flow: Regional cost sharing

Coalition	Expansions, MW	Payoffs, M€						
		AT	BN	CH	DE	FR	IT	%
{AT, BN, CH, DE, FR, IT}	1,000: DE-FR 3,000: BN-DE, CH-IT 4,000: AT-IT, BN-FR 5,000: FR-IT	431	721	145	-384	1,120	1,158	96
	1,000: DE-FR, CH-IT 3,000: AT-IT, BN-DE, CH-IT 4,000: BN-FR 6,000: FR-IT	413	687	57	-371	1,190	1,283	98

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1. National versus European Perspective on Transmission Investment
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Conclusion

Effect of national market zones

- National electricity market price is available
- The price can become an important (political) decision variable for/against network investments
- Distributional effects internal bottlenecks → national borders
- Large price zones: Effects of additional exchange capacity is spread over the entire continent

Results from the non-cooperative transmission planning

- Several stable strategies
- Sharing costs:
    - i) More investments
    - ii) Stable strategies: Less and more homogenous
- Flow-based capacity integration reduces stable strategies

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Thank you for your attention

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