Enerday Conference

19. April 2013

European Electricity Grid Infrastructure Expansion in a 2050 Context

Jonas Egerer, Clemens Gerbaulet, and Casimir Lorenz

TU Berlin / DIW Berlin

Agenda

Introduction

Starting out from European scenarios on national level for generation capacity we address the two questions:

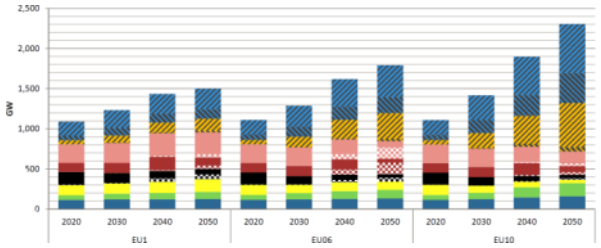
a) What is the cost minimal extension of the transmission infrastructure?

b) Are the scenarios different in their regional / national character?

Presentation on One Page

Infrastructure for “National”, “Regional” and “European” Scenarios of the Electricity System?

1) Allocate national capacities on nodal level

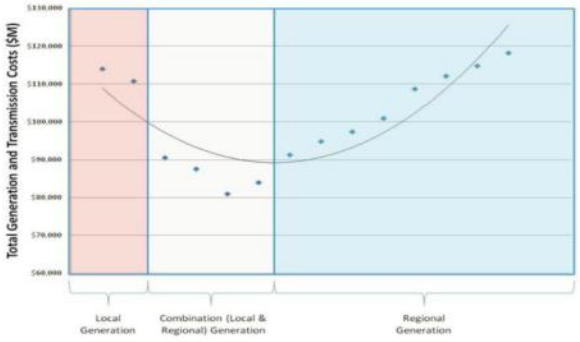


1)

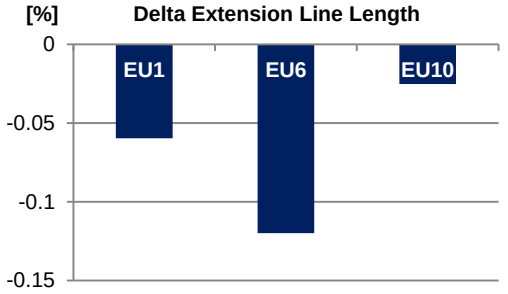
2) Model line sharp network investment

2)

3) Correlation between regional character and total cost of generation and transmission



4) Sensitivities on line expansion costs to analyze regional character of scenarios



Agenda

1. Introduction
2. Generation Scenarios for Europe
3. ELMOD Model Application: Transmission Investments
4. Regional versus European Scenarios
5. Transmission Costs and Investment
6. Conclusion

Long-Term EMF Scenarios for Europe 2050

Technology dimension						
		Default w CCS	**Default w/o CCS**	**Pessimistic**	**Optimistic**	**Green**
CCS		on	off	off	on	off
Nuclear energy		ref	ref	low	ref	low
Energy efficiency		ref	ref	ref	high	high
Renewable energies		ref	ref	ref	ref	opt
Policy dimension for the EU	**Policy dimension for the Rest of the World (ROW)**					
No policy baseline (no policy, also without the 2020 target)	no policy	EU11				
Reference: including the 2020 targets and 40% GHG reduction by 2050	"moderate policy" scenario ModPol; no emission trading across macroregions (but trade within macroregions e.g. within EU)	EU1	EU2	EU3	EU4	EU5
Mitigation1: 80% GHG reduction by 2050 (with Cap&Trade within the EU)	"moderate policy" scenario ModPol; no emission trading across macroregions (but trade within macroregions e.g. within EU)	EU6	EU7	EU8	EU9	EU10
Mitigation2: 80% GHG reduction by 2050 (with Cap&Trade within the EU)	IMAGE2.9 scenario; full emission trading for ROW, but no emission trading between ROW and EU. Regional relative contributions to mitigation based on the Mitigation 1 scenario	EU12			EU14	
Mitigation3: global 480ppme target with full Cap&Trade	IMAGE2.9 scenario; emission trading is allowed between all regions	EU13			EU15	

Scenario package for the models that go for the technology dimension (11

Scenario package for the models that go for the policy dimension (7 altogether)

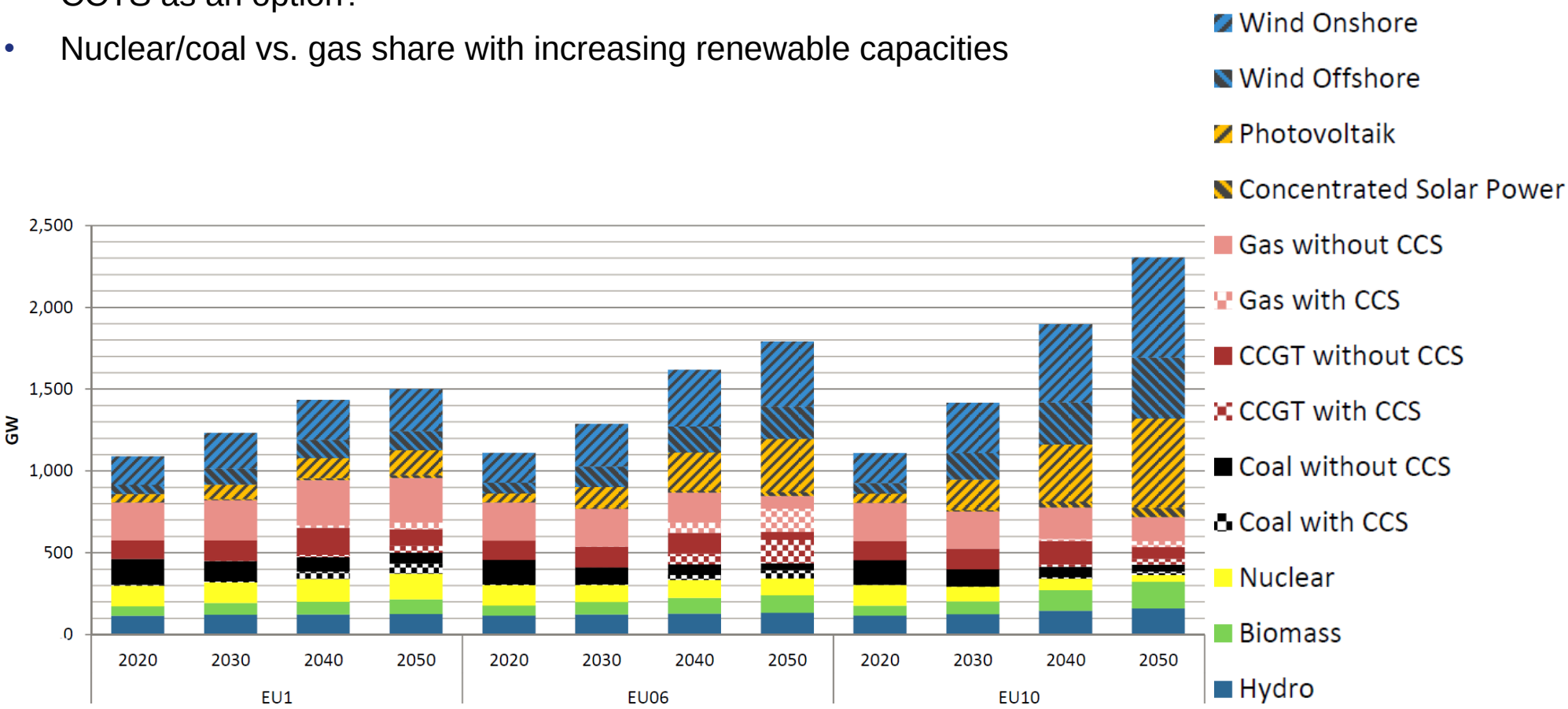
included in both scenario packages

Additional optional scenarios for models that go for the policy dimension

Technology Specific Generation Capacity for Europe

Primes results in a European context; main aspects:

- Renewable generation capacities
- CCTS as an option?
- Nuclear/coal vs. gas share with increasing renewable capacities



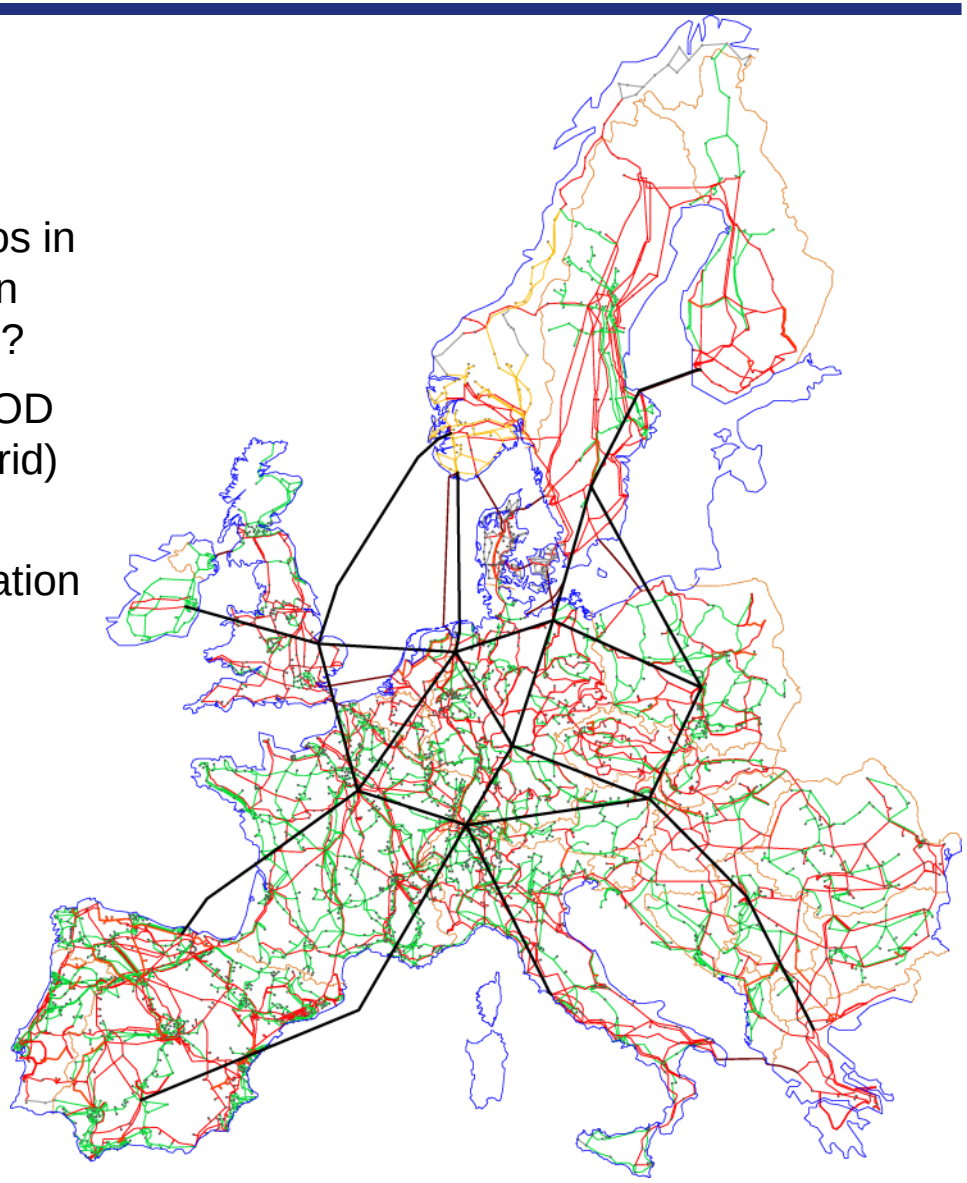
Agenda

1. Introduction
2. Generation Scenarios for Europe
3. **ELMOD Model Application: Transmission Investments**
4. Regional versus European Scenarios
5. Transmission Costs and Investment
6. Conclusion

ELMOD Application:
Expansion Pathways for the European Transmission Network

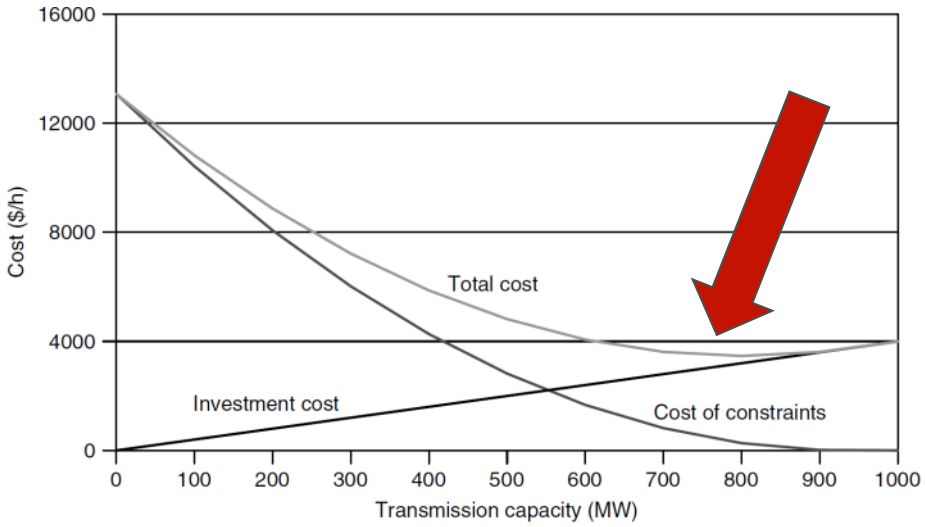
Pan-European Transmission Investment for the EMF28 Scenarios

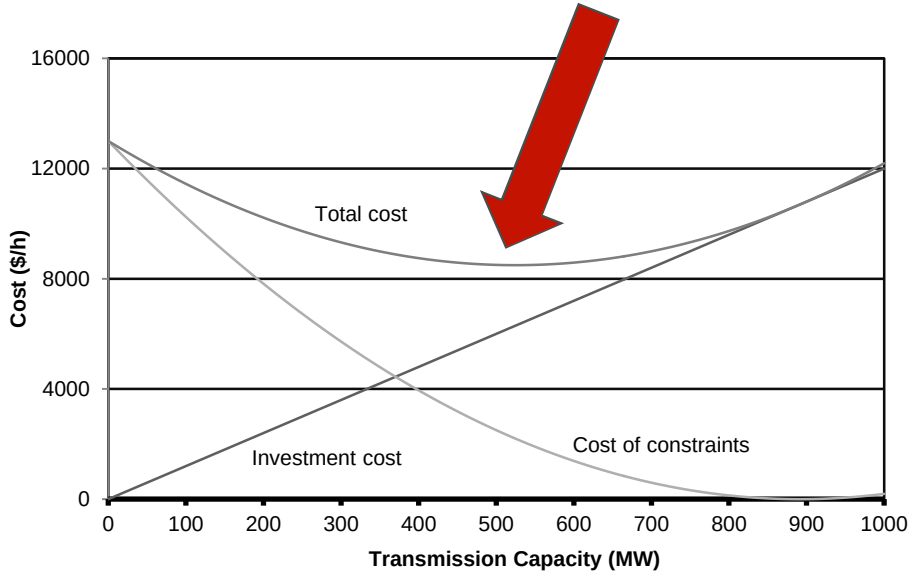
- Question: How do the different EMF 28 scenarios in their choice of technology and national allocation effect the demand on infrastructure investments?
- Bottom up DC Load Flow model based on ELMOD (3,523 nodes and 5,145 lines plus DC overlay grid)
- Endogenous determination of grid investments needs up to 2050 in 10-year steps. The optimization minimizes the cost of the expansion as well as system operation.
- Model runs for the EMF28-Scenarios
  - **EU1** (40% GHG reduction until 2050),
  - **EU6** (80% GHG reduction until 2050)
  - **EU10** (green, 80% GHG reduction until 2050)
- Additional case for each scenario: doubling of costs for cross border lines



„Optimal“ Transmission Investments

- **„Optimal“ infrastructure includes temporary congestions**
- **Transmission is a low cost option (compared to generation investment) for common assumptions on line investment costs (cable costs, etc.)**
- **Higher costs for transmission investment (transaction costs, etc.) reduce the „optimal“ amount of infrastructure**





Source: Kirschen, Strbac (2004) p 241

Iterative Solving of Mixed Integer Linear Problem (MILP)

$$\min cost = \sum_{n,g,t}(g_{n,g,t} * MC_{n,g}) + \sum_{d}(expdc_d * Cdc_d) + \sum_{l}(up_l * Cup_l + exp_l * Cexp_l) \quad (1)$$

s.t.

$$0 = \sum_{g} g_{n,g,t} + res_{n,t} + dcinput_{n,t} + acinput_{n,t} - Demand_{n,t} \quad \forall n,t \quad (2)$$

$$g_{n,g,t} \leq Gmax_{n,g} \ \forall n,g,t \quad (3)$$

$$res_{n,t} \leq Resmax_{n,t} \ \forall n,t \quad (4)$$

$$dcinput_{n,t} = \sum_{d} dcflow_{d,t} * DCInc_{d,n} \quad (5)$$

$$acinput_{n,t} = \sum_{nn}(B_{n,nn} * \delta_{nn,t}) \quad (6)$$

$$\sum_{n} H_{l,n} * \delta_{n,t} \leq PF0_l + PFexp_l * exp_l + PFup_l * up_l \quad \forall l,t \quad (7)$$

$$\sum_{n} H_{l,n} * \delta_{n,t} \geq -PFL0 - PFexp_l * exp_l - PFup_l * up_l \quad \forall l,t \quad (8)$$

$$dcflow_{d,t} \leq PFdc0_d + expdc_d * PFdcexp_d \ \forall d,t \quad (9)$$

$$dcflow_{d,t} \geq -PFdc0_d - expdc_d * PFdcexp_d \ \forall d,t \quad (10)$$

Non-linear relation between physical line characteristics and DC load flow parameters: Calculations are repeated with updated line characteristics after expansion until they converge.

AC Investments by 2050

EU1 – “40% GHG reduction”	EU6 – “80% GHG reduction”	EU10 – 80% + “green”

- **Investments in transmission lines increase with lower emission targets**
- **EU6 and EU10 are similar in the volume (km and €) of investments**

DC Investments by 2050

DC Grid infrastructure investments mostly offshore connectors (preliminary results)

EU1 – “40% GHG reduction”	EU6 – “80% GHG reduction”	EU10 – 80% + “green”

Aggregated Figures for Investments until 2050

Total investment costs for transmission capacity in Europe:

- **Large investments in 2020 for all scenarios**
- **In EU6 and EU10 investments increase in 2040/50 after stagnation in 2030**

in mn €	2020	2030	2040	2050	Total
EU1	17,025	2,002	4,318	7,250	30,595
EU6	18,864	4,318	18,670	15,067	56,919
EU10	15,971	5,955	10,447	24,460	56,834

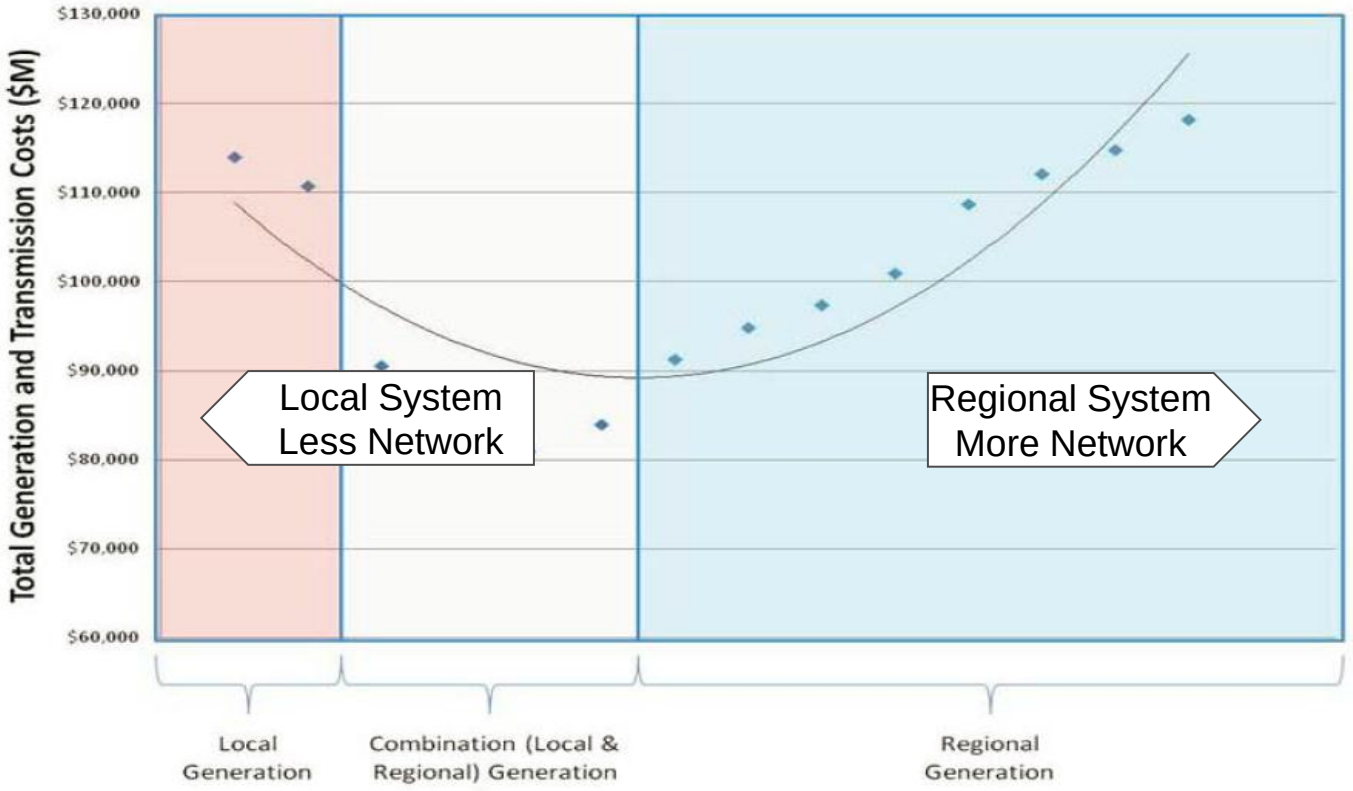
Agenda

1. Introduction
2. Generation Scenarios for Europe
3. ELMOD Model Application: Transmission Investments
4. Regional versus European Scenarios
5. Transmission Costs and Investment
6. Conclusion

Impact of Integrated System Planning

Assumption: National (local) generation scenarios are less price sensitive in transmission investments to investment costs than European (regional) scenarios

- **Analyze impact of higher cross-border investment costs for EU1/6/10 scenarios**



Source: Midwest ISO (2010).

Agenda

1. Introduction
2. Generation Scenarios for Europe
3. ELMOD Model Application: Transmission Investments
4. Regional versus European Scenarios
5. **Transmission Costs and Investment**
6. Conclusion

Aggregated Figures for Investments until 2050

Assumption of higher transaction costs for cross-border lines in a Regional case has different impact on scenarios:

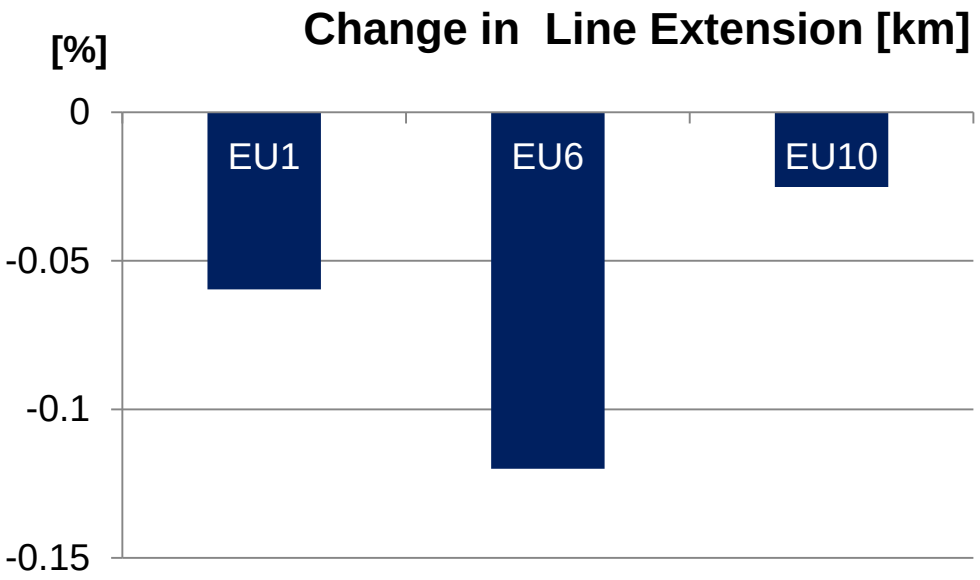
Scenario	Case	DC	AC National	AC Cross-Border	Total
EU1	European	4.174	19.194	4.611	**27.978**
	Regional	3.243	18.860	4.207	**26.310**
EU6	European	5.346	39.905	7.173	**52.424**
	Regional	3.194	36.132	6.808	**46.135**
EU10	European	7.057	39.799	4.138	**50.993**
	Regional	4.654	40.967	4.088	**49.709**

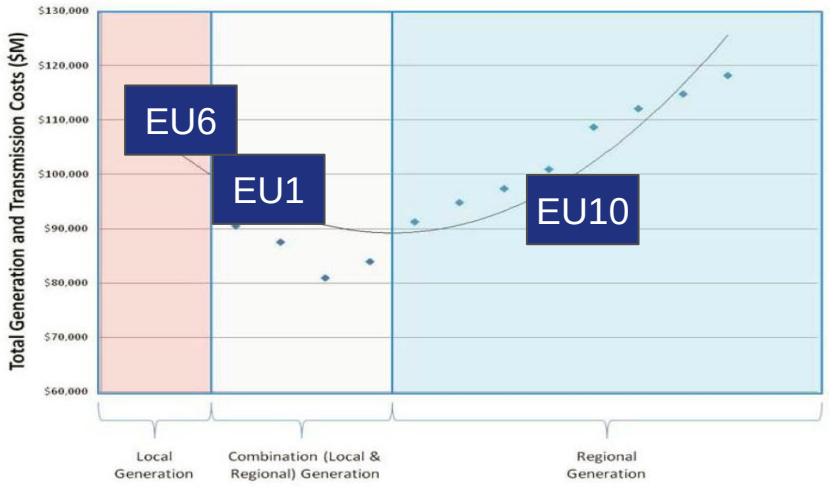
- Decrease in network investments in all scenarios (mainly DC lines)
- Overall investments are least affected in the EU10 scenarios

Aggregated Figures for Investments until 2050

Assumption of higher transaction costs for cross-border lines in a Regional case has different impact on scenarios:

- Decrease in network investments in all scenarios (mainly DC lines)
- Overall investments are least affected in the EU10 scenarios





Agenda

1. Introduction
2. Generation Scenarios for Europe
3. ELMOD Model Application: Transmission Investments
4. Regional versus European Scenarios
5. Transmission Costs and Investment
6. Conclusion

Conclusion

Starting out from national scenarios for generation capacity we address the two questions:

a) What is the cost minimal extension of the transmission infrastructure?

- Investments include DC offshore connectors in the North and Baltic Sea but no onshore overlay network
- Network investments increase with higher GHG reduction target but are similar for EU6 (80% & CCS/Nuclear) and EU10 (80% & RES)
- Impact of regional correlation of wind/pv availability not considered!

b) Are the scenarios different in their regional / national character?

- Higher investment costs of cross-border lines to evaluate national / regional character of scenarios
- Some indication for regional character:
  → EU6 more National
  → EU10 more European

Thank You for Your Attention!

Jonas Egerer, Clemens Gerbaulet, and Casimir Lorenz
DIW Berlin / Fachgebiet Wirtschafts- und Infrastrukturpolitik (WIP)

Technische Universität Berlin
Fakultät für Wirtschaft und Management
Fachgebiet Wirtschafts- und Infrastrukturpolitik (WIP)

Sekretariat H 33
Straße des 17. Juni 135
D-10623 Berlin

Tel.: 030 / 314 - 25 048
Fax: 030 / 314 - 26 934

http://wip.tu-berlin.de
je@wip.tu-berlin.de