Influence of renewable energy sources on transmission networks in Central Europe

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ECOCEP conference, 2016

Outline

1. Motivation
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Introduction

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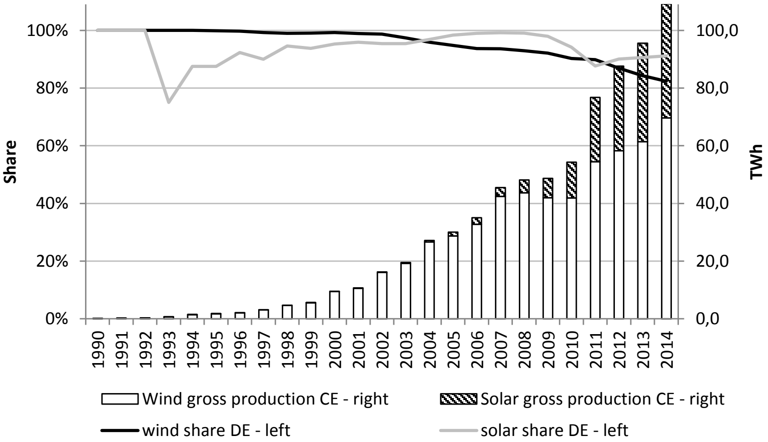
  - German is in delay with extension of transmission lines
- German-Austrian bidding zone
- **Lack of literature focused on CE**

Situation in CE
VRES production



*This includes CZ, SK, AT, DE, PL

Situation in CE

RES and nuclear production centers, German-Austrian bidding zone

Outline

Model of the European Electricity Market - ELMOD

- large-scale spatial model of the European electricity market (Leuthold et al. 2012)
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- bottom-up model combining electrical engineering and economics:
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- simulations on an **hourly basis**, taking into account variable demand, intermittent RES, start-up costs, pump storage, and other details.

ELMOD specification - objective function

$$\max_{g,q} \quad \sum_{T}\sum_{N}\left((A_{nt}q_{nt} + \frac{1}{2}D_{nt}q_{nt}^2) - \sum_{C} g_{nct}M_{nc}\right) \tag{1}$$

A_{nt} non-negative intercept
q_{nt} demand at node n in time t
D_{nt} negative slope coefficient which

g_{nct} generation of unit c at n in t
M_{nc} time-invariant marginal cost of generation for each power plant unit c at node n

A_{nt} and D_{nt} are used to estimate the linear inverse demand function:

$$\pi_{nt}(q_{nt}) = A_{nt} + D_{nt}q_{nt}. \tag{2}$$

ELMOD specification - constrains

Nodal balance and installation capacity

Nodal balance constraint:

$$\sum_{c} g_{nct} + G_{nt}^{wind} + G_{nt}^{solar} + PSP_{nt}^{out} - PSP_{nt}^{in} + \sum_{nn} \theta_{nn,t} B_{n,nn} - q_{nt} = 0 \quad \forall n, t. \tag{3}$$

Electricity production of power plant is bounded by the installed capacity:

$$g_{nct} \leq G_{ct}^{max} \quad \forall n, c, t. \tag{4}$$

G_{nt}^{wind} Wind input at n in t
G_{nt}^{solar} Solar input at n in t
PSP_{nt}^{out} Pump storage plant release at n in t
PSP_{nt}^{in} Pump storage loading at n in t

$\theta_{nn,t}$ flow angle at n in t
$B_{n,nn}$ network susceptance matrix
G_{ct}^{max} maximal generation of generation unit c in t

ELMOD specification - constrains

Electricity flows and transmission lines

Electricity flows:

$$p_{lt} = \sum_{n} H_{ln}\theta_{nt} \quad \forall l, t. \tag{5}$$

Capacity limits of individual transmission lines:

$$|p_{lt}| \leq P_{lt}^{max} \quad \forall l, t. \tag{6}$$

p_{lt} power flow over line l in time t
H_{ln} network transfer matrix
P_{lt}^{max} maximal available capacity limit of line l in time t

Data

- Original dataset by Egerer et al. (2014) (data year 2012) is updated and adjusted as follows:
  - VRES production and load, fuel and electricity prices updated to 2015
  - DE **CZ, SK, AT, PL** - in detail, other countries with interconnections to the CE region as a single node
- 593 nodes, 10 country-specific nodes and 981 lines.
- four representative weeks:
  - **Week 4** - **lowest** cumulative production from wind and sun
  - **Week 14** - **highest** cumulative production from wind and sun
  - Week 27 - high production from sun and low from wind
  - Week 49 - high production from wind and low from sun

Week profiles in CE region

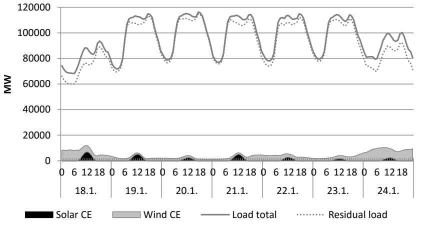
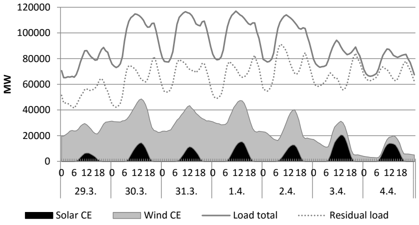


Figure : Week 4 profile



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Reference scenario - *base*

Current situation in the power sector based on the data as specified in section

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Policy scenario - *full*

German energy policy goals for the year 2025

- electricity consumption reduced by 12.5% compare to 2008 (on 541 TWh)
- RES production increase to reach 45.91% electricity consumption
- nuclear power plants are phased-out in 2022

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Scenario - *res*

- Isolated impact of renewables on transmission networks
- Same as *full* but still in operation even after 2022.

Outline

Results

- The higher VRES feed-in, the higher the exchange balance and total transport of electricity between TSO areas
- VRES induce growth of volatility of transmission
- Increase in number of critical event (grid stability emergency)
- In Week 14 total transmission average rises 2.54 times, maximal relative increase about 3.41 times (CZ-Tennet profile) and maximal increase by 670.3 GWh (50Hz -Tennet profile).
- Interconnectors between Germany and Austria are under the biggest volatility pressure; highest values achieve 50% increase.

Results
Transmission in CE

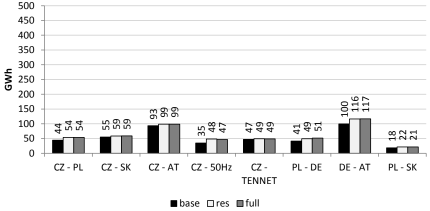

Figure : Week 4 transmission in CE

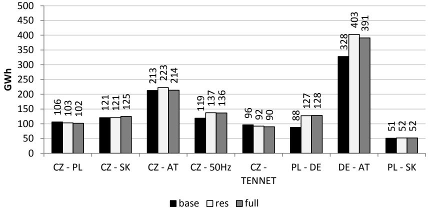

Figure : Week 14 transmission in CE

Results

Extrem load overview (75% of thermal limit of the line)

		# extrems											
Interconnector	Substations	w4 base	w4 res	w4 full	w14 base	w14 res	w14 full	w27 base	w27 res	w27 full	w49 base	w49 res	w49 full
PL ⟹ CZ	Bujakow-Liskovec	-	-	-	-	1	-	-	-	-	-	-	-
CZ ⟹ PL	Liskovec-Kopanina	-	-	-	-	-	-	-	-	-	-	-	-
PL ⟹ CZ	Wielopole-Nosovice	-	-	-	-	-	-	-	-	-	-	-	-
CZ ⟹ PL	Albrechtice-Dobrzen	-	-	-	-	-	-	-	-	-	-	-	-
SK ⟹ CZ	Varin-Nosovice	-	-	-	-	-	-	-	-	-	-	-	-
CZ ⟹ AT	Slavetice-Durnrohr	-	-	-	-	-	-	-	-	-	-	-	-
CZ ⟹ SK	Sokolnice-Stupava	-	-	-	-	-	-	-	-	-	-	-	-
CZ ⟹ SK	Sokolnice-Krizovany	-	-	-	-	-	-	-	-	-	-	-	-
CZ ⟹ AT	Sokolnice-Bisamberg	-	-	-	-	-	-	-	-	-	-	-	-
SK ⟹ CZ	Povazska Bystrica-Liskovec	-	-	-	-	-	-	-	-	-	-	-	-
SK ⟹ CZ	Senica-sokolnice	-	-	-	-	-	-	-	-	-	-	-	-
CZ ⟹ Tennet	Hradec II-Etzenricht	-	-	-	-	-	-	-	-	-	-	-	-
CZ ⟹ 50Hertz	Hradec I-Rohrsdorf	-	-	-	-	-	-	-	-	-	-	-	-
CZ ⟹ Tennet	Prestice-Etzenricht	-	-	-	-	-	-	-	-	-	-	-	-
PL ⟹ SK	Lemesany-Krosno Iskrzynia	-	-	-	-	-	-	-	-	-	-	-	-
DE ⟹ AT	Aux-Oberbayern-Burs	-	-	-	-	3	8	5	4	3	-	-	-
9	DE⇔AT	...	...	...	...	...	...	...	...	...	...	...	...
DE ⟹ AT	Simbach-Sankt Peter	-	-	-	1	3	3	10	28	44	-	-	-
DE ⟹ AT	Pleinting-Sankt Peter	-	-	-	-	6	3	6	14	17	-	-	-
DE ⟹ AT	Pleinting-Sankt Peter	-	-	-	-	6	3	6	16	18	-	-	-
PL ⟹ DE	Mikulowa-Neuerbau	-	-	-	-	1	-	-	-	-	-	-	-
PL ⟹ DE	Krajnik-Vierraden	1	-	-	13	46	40	-	3	5	17	38	49

Summary

- High VRES $\implies$ growth of cross- border transmission both on intra-national lines as well as on the cross-zonal ones; significant rise in volatility of flows
- Nuclear phase-out does not significantly contribute to the amount of transmission as well as to the average load on lines; but **volatility grows**.
- **High solar** and **low wind** feed-in $\implies$ high volatility and cross-border flows on the Czech-Austrian and German-Austrian borders.
- **Low solar** and **high wind** feed-in $\implies$ the highest observed flows within Germany as well as on transnational lines, except the ones on German-Austrian borders $\implies$ loop flows through other CE countries.
- Additionally, while the situation remains manageable in CE, the North-Western Europe should be concerned about this issue much more.

Model simplification and further potential for improvement

- **Model simplification**
  - assumption of one TSO $\Longrightarrow$ TSO in oligopolistic structures
  - no transmission expansion
- **Other potential for improvement**
  - update of parameters of all relevant countries
  - add demand node in Balkan

Thank you for your attention and comments

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Acknowledgement: The research leading to these results was supported by the European Union's Horizon 2020 Research and Innovation Staff Exchange programme under the Marie Sklodowska-Curie grant agreement No 681228. The authors further acknowledge financial support from the Czech Science Foundation (grants number 16-00027S and 15-00036S).