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Electricity Market Design

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How (and When) can RES compete?

by

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Our Paper …

- … computes market equilibria on the electricity market applying partial equilibrium models. The approach couples
  - a European power market investment and dispatch model with
  - a European renewable energy market model
- … derives empirical estimates on the future electricity market computing investments in conventional power plants and RES-technologies as well as prices (for both CO_2-emission certificates and wholesale electricity).
- Furthermore, by comparing two scenarios, the paper calculates the differences in RES additions under two different policy systems.

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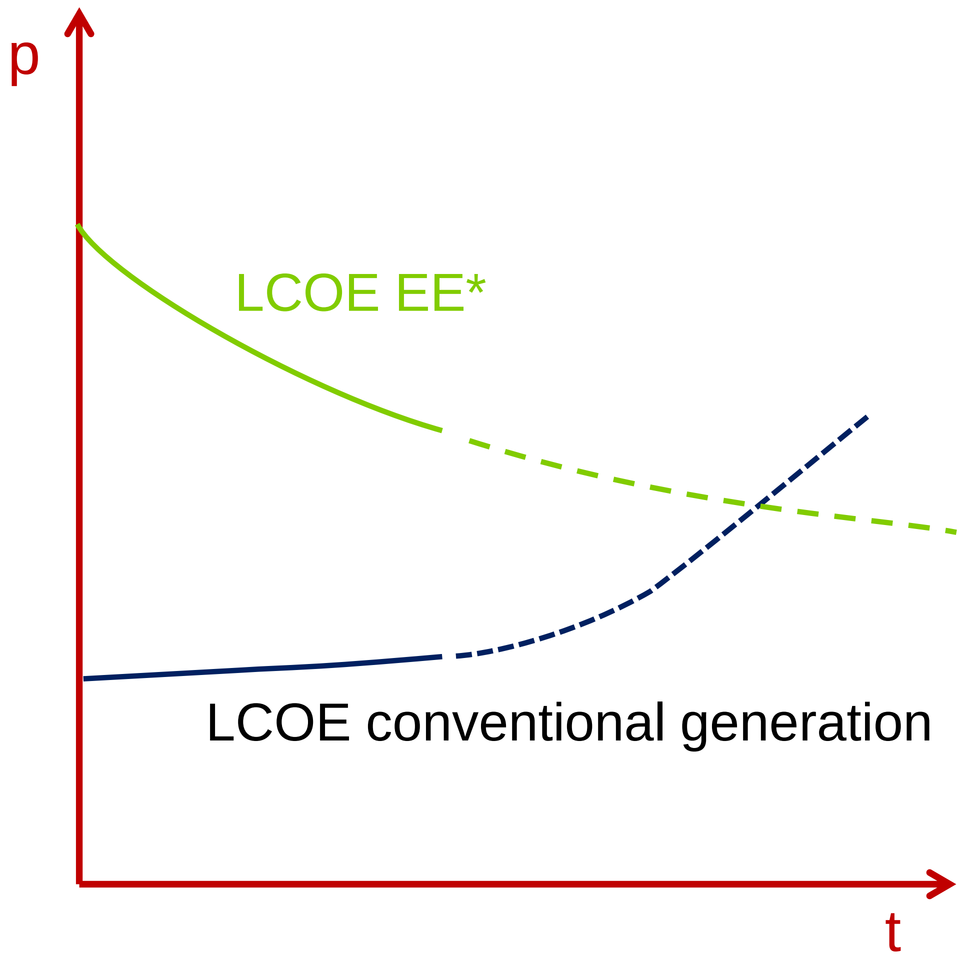
Two Scenarios

- One scenario ('scenario integration') assumes that climate protection in the EU ETS is the single source to drive the change in the energy system. No additional RES-specific subsidy is included. This scenario answers the central question how much RES will be built when and where in an environment without RES-specific subsidies.
- A second scenario ('scenario BAU', 'business as usual') assumes RES receive additional subsidies. In effect, RES production is assumed to be exogenously given (differentiated by technology and country). Based on a literature survey, we assume that the share of RES will be 60% in Europe and 66% in Germany in 2050.

Research Question: When can RES compete?



- In the future, the competitiveness of RES will improve:
  - their learning effects are likely to exceed those for conventional technologies (cost degression)
  - increasing costs for climate protection for conventional electricity generation.
- The problem exhibits additional complexity. Our paper considers:
  - Limited potentials for RES in different regions, i.e. RES capacities at ‚good sites' are restricted.
  - endogenous learning by RES
  - market values (and ‚self cannibalization') for RES
  - Other aspects: capacity credits, international power exchange, …

*LCOE: Levelized Costs of Electricity (total cost of electricity generation)

The Electricity Market Model

- Long-term investment and dispatch model
- Computes market equilibria on the electricity market
- Fundamental optimization model (LP)
- Objective: minimization of total system costs
- Resolution: Simultaneous optimization
  - of seven representative years (2020, 2025, 2030, 2035, 2040, 2045, 2050)
  - with 4,380 load levels per year;
  - EU 27 (plus Norway and Switzerland), but peripheral countries are combined to reduce size of problem,
  - with up to 27 technologies per region.
- Shadow prices used as price estimators for both CO_2-emission prices and wholesale electricity prices

The RES Model

- Long term investment model for RES
- Fundamental optimization model (LP)
- Objective: minimization of total system costs
- Resolution: chosen to match the electricity market model
  - seven representative years (2020, 2025, 2030, 2035, 2040, 2045, 2050)
  - with 4,380 load levels per year;
  - EU 27 (plus Norway and Switzerland), but peripheral countries are combined to reduce size of problem.
- The model can be run with different constraints. In this paper, we use two different approaches:
  1. RES are built based on revenues from electricity sales alone ('scenario integration')
  2. Shares of RES are exogenously fixed for RES technologies and countries, based on political goals ('scenario BAU')
- For an in-depth discussion of the RES model, refer to :
  Wissen, Ralf (2012) Die Ökonomik unterschiedlicher Ausbaudynamiken Erneuerbarer Energien im europäischen Kontext – eine modellbasierte Analyse. PhD thesis, Universität zu Köln

European Electricity Market Model
Objective Function

$$\min Z = \sum_y f_y^d(y) \cdot$$

$$(num\_years(y) \cdot$$

variable costs $$\{ \left(\sum_{p,t,r} num\_hours \cdot f_p^d(p) \cdot z_{\text{var}}(y,p,t,r) \cdot G_{plant}(y,p,t,r)\right.$$

fixed costs $$\{ + \sum_{t,r} z_{fixed}(y,t,r) \cdot C_{inst}(y,t,r))$$

investment costs $$\{ + \sum_{t,r} s_{invest}^{cost}(y,t) \cdot z_{invest}(y,t,r) \cdot C_{add}(y,t,r))$$

Constraints (1)

(1) $C_{inst}(y,t,r) = C_{inst}(y-1,t,r) + C_{add}(y,t,r) - C_{sub}(y,t,r)$

In addition to (1), there is an original capacity endowment in t=0 and the possibility for exogenous additions and reductions

(2) $C_{avail}(y,t,r) \leq f_{avail}(y,t,r) C_{inst}(y,t,r)$

(3) $G_{plant}(y,p,t,r) \leq C_{avail}(y,t,r)$

(4) $$W(y,p,r) = W(y,p-1,r) + num\_hours \cdot \left(U(y,p,r) s_{pump}^{eff}(y) - G_{stor}(y,p,r) \frac{1}{s_{turb}^{eff}(y)} + w_{nat}(y,p,r) \right)$$

European Electricity Market Model

Constraints (1)

(5)
$$
\begin{aligned}
& d(y,p,r) \\
& + U(y,p,r) + \sum_{r'} E(y,p,r,r') + e_{net\_ex}(y,p,r) + G_{RES\_sur}(y,p,r) \\
& = \\
& \sum_t G_{plant}(y,p,t,r) \\
& + G_{stor}(y,p,r) + \sum_{r'} E(y,p,r',r)
\end{aligned}
$$

(6)
$$\sum_{p,t,r} num\_hours \cdot G_{plant}(y,p,t,r) \cdot f_{CO2}(y,t) \leq end_{CO2}(y)$$

These are simplified versions of the key constraints. A complete version of a similar model (including objective function and all constraints) can be found in: Lenzen, V., Lienert, M. and Müsgens, F. (2012): ‘Political Shocks and Efficient Investment in Electricity Markets‘, *IEEE Conference Proceeding EEM 2012*, DOI 10.1109/EEM.2012.6491508.

Coupling the two Models

- In the first scenario, an iterative approach is necessary because RES capacities (calculated in the RES model) influence the electricity price (calculated in the electricity market model EMM) – and vice versa.
  - The EMM uses starting values for RES feed-in profiles in the 27 different countries of the EU for all periods of observation and optimizes the conventional electricity system.
  - Resulting wholesale electricity prices (and market values) for RES are transferred to the RES model.
  - Taking these electricity prices and market values as given, the RES model computes how much RES capacity would be built and what the respective RES feed-in profile would look like.
  - The resulting RES feed-in profile is transferred to the electricity market model.
  - The process is repeated until convergence.
- In the second scenario, iterations between the models are not necessary. We assume that RES are built independently of the electricity price as subsidies cover any differences between RES costs and revenues.
  - the RES model computes hourly RES feed-in for the exogenously given RES capacity additions
  - these are transferred to the EMM

Key Assumptions

- Climate protection: Emission reduction of 80% in the power sector until 2050 (compared to 1990 levels)
- Electricity demand based on a forecast by Eurelectric (extended with a reduced growth rate post 2030, table shown in the appendix)
- RES starting value for 2020 identical in both scenarios (based on National Renewable Energy Action Plans)
- Fuel prices based on World Energy Outlook 2011 (graph in appendix)
- Learning rates (cost reduction per doubling of installed capacities) for RES:
  - wind onshore: 4%
  - wind offshore: 4%
  - PV: 15%
- CCS-option included (sensitivities confirm improved profitability for RES without this option)

Results

CO_2-Prices

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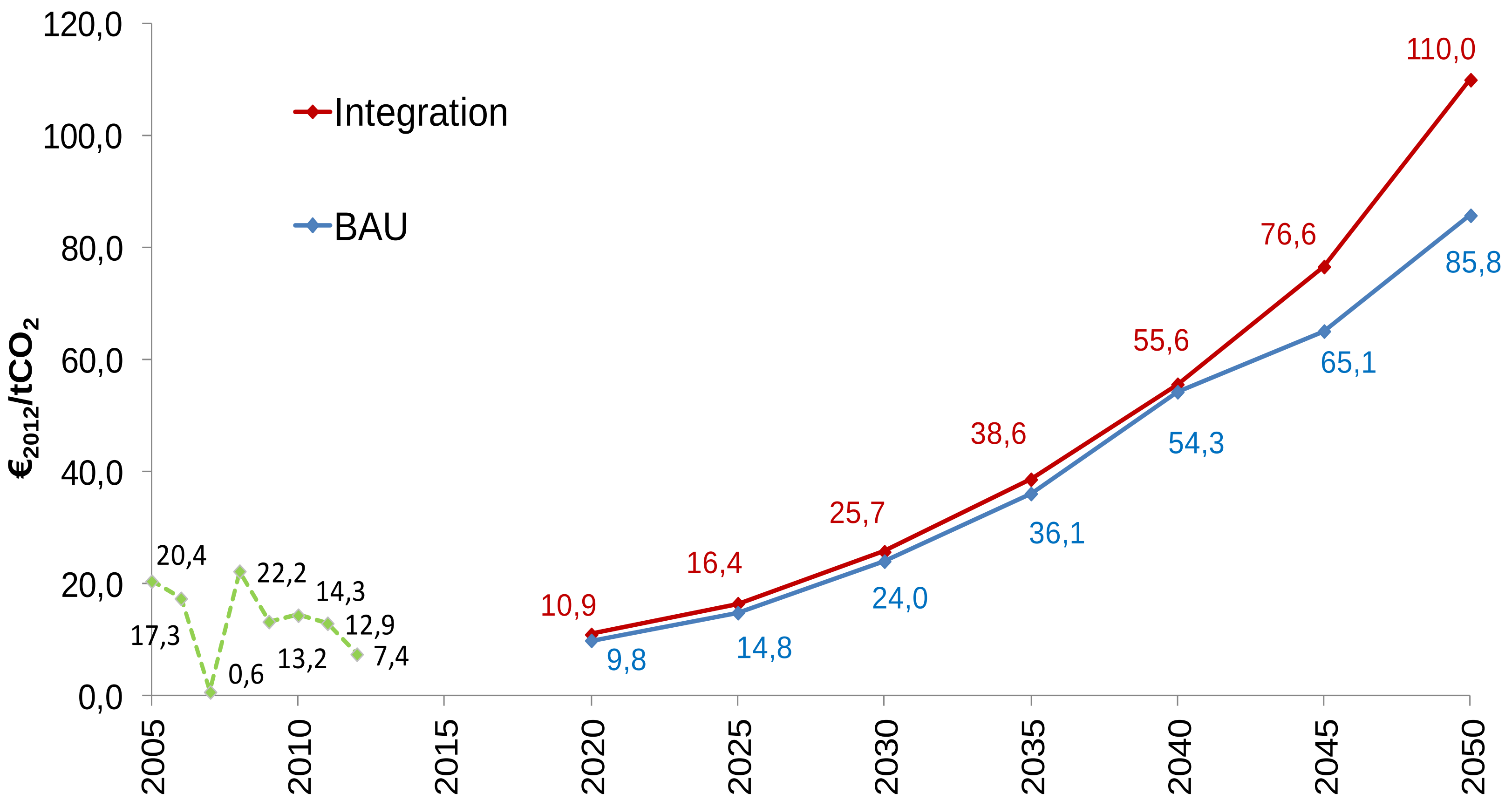
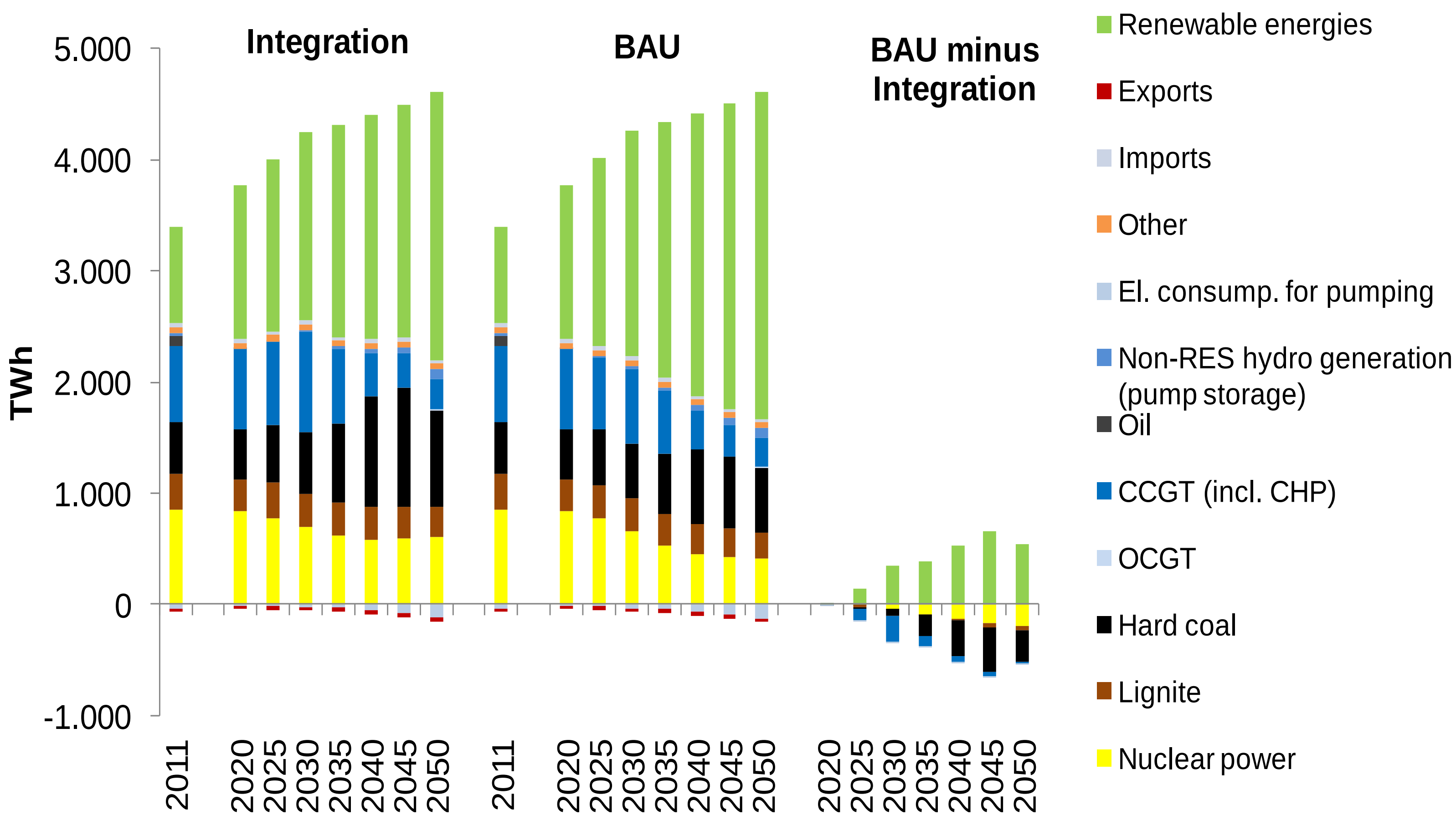


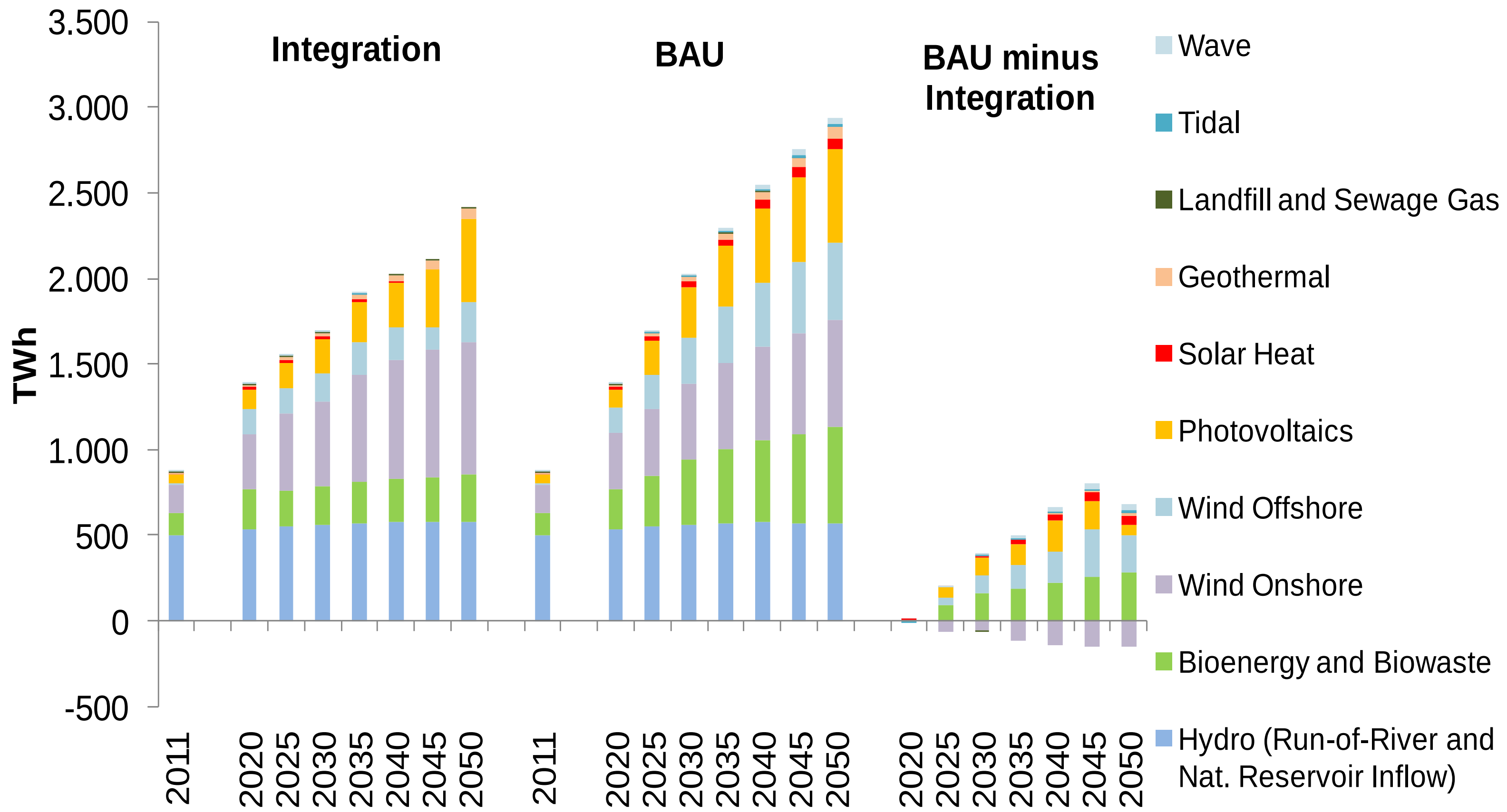
Results

Electricity Generation in Europe



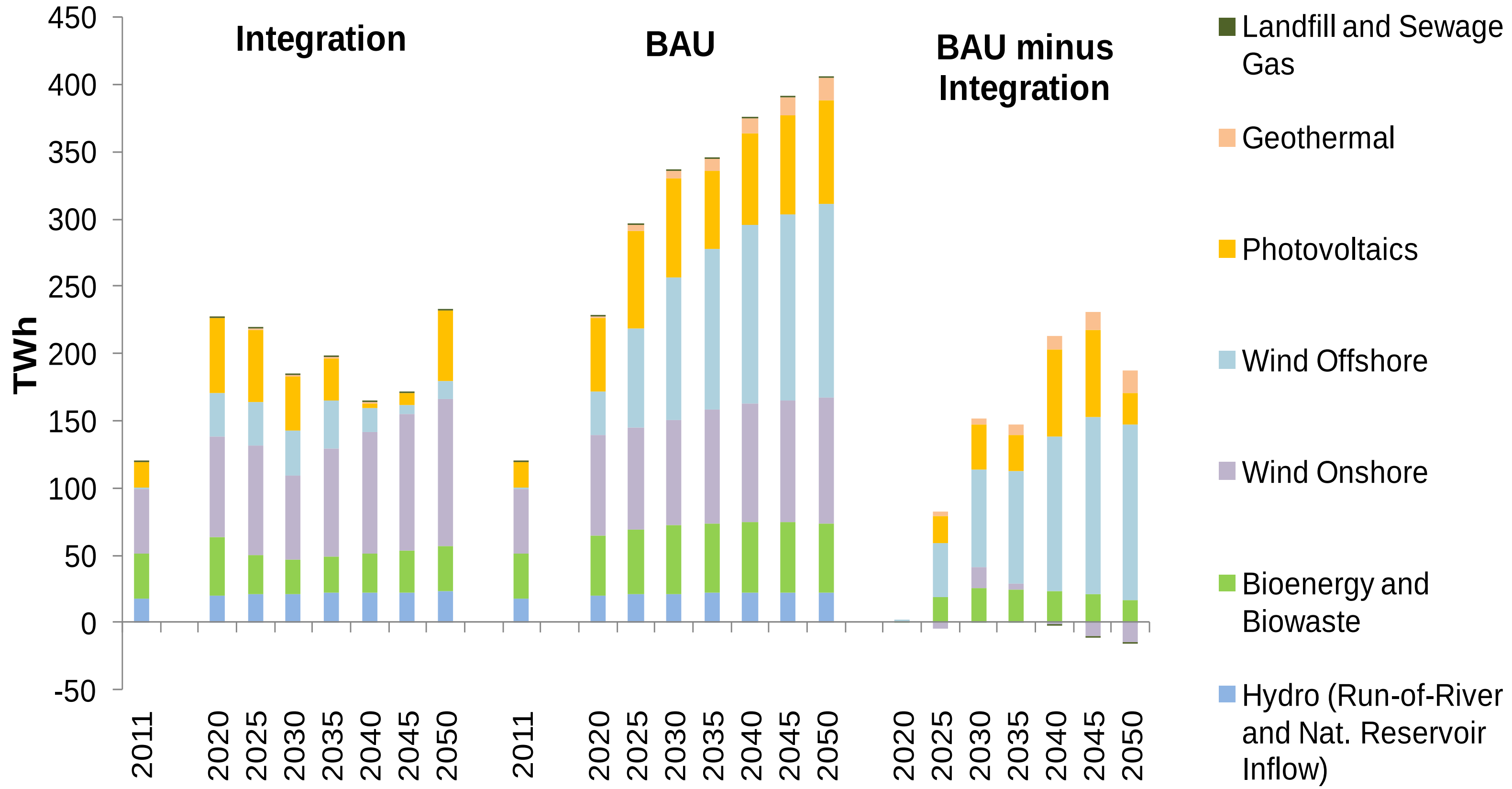
Results

Electricity Generation from RES in Europe



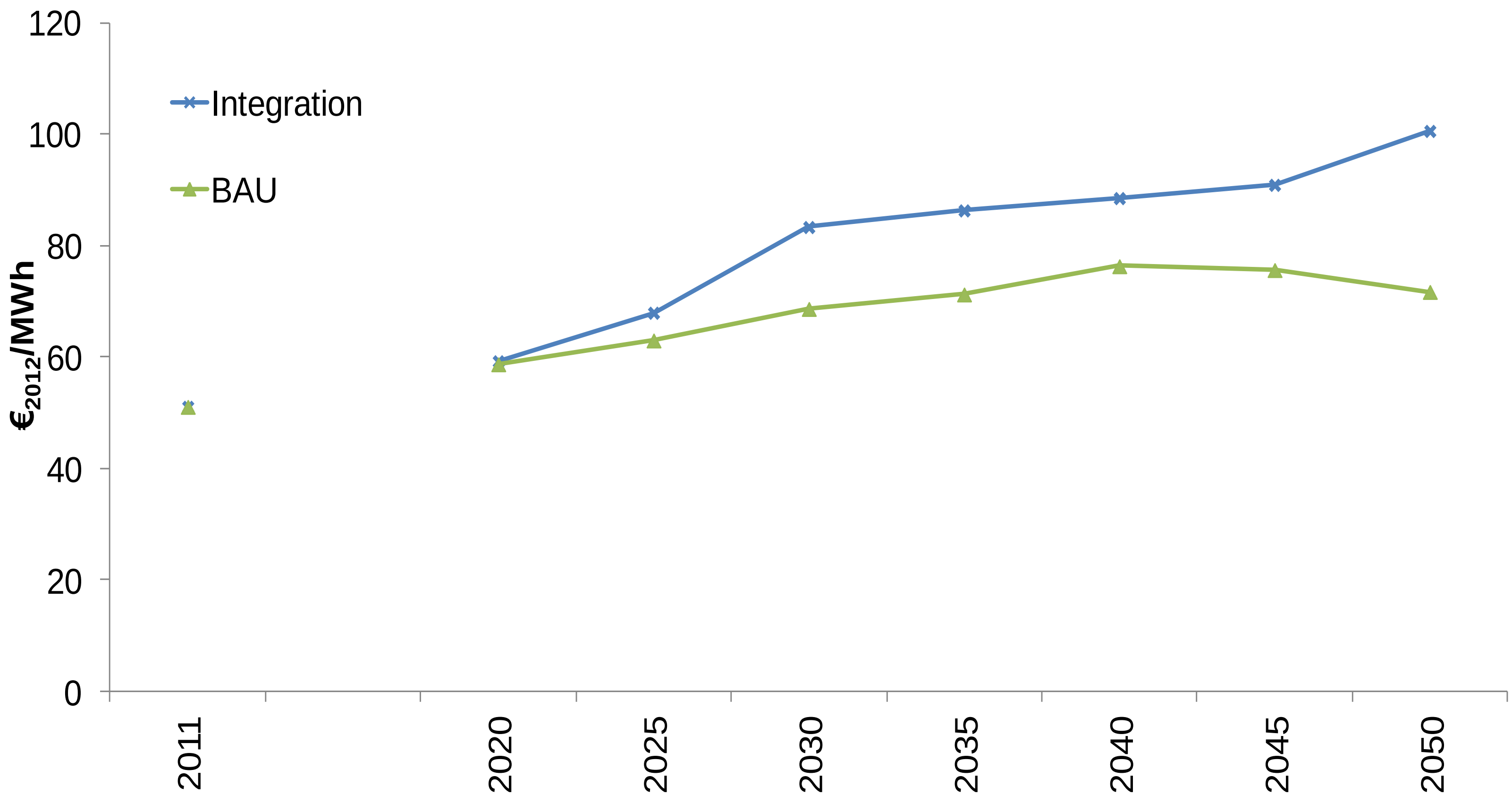
Results

Electricity Generation from RES in Germany



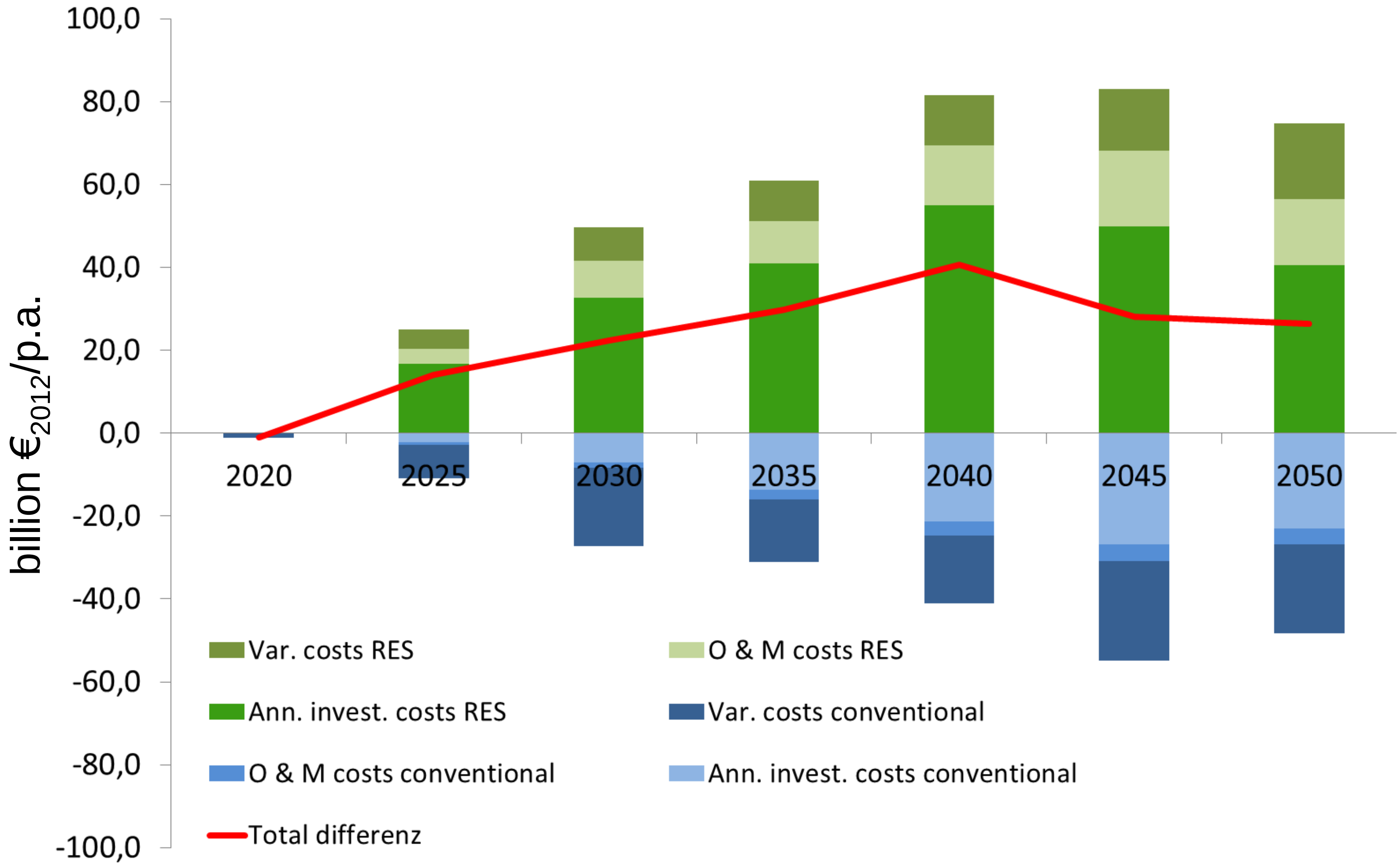
Results

Development of Wholesale Electricity Prices in Germany



Results

Comparison of Costs between the two Scenarios ('BAU' minus 'integration')



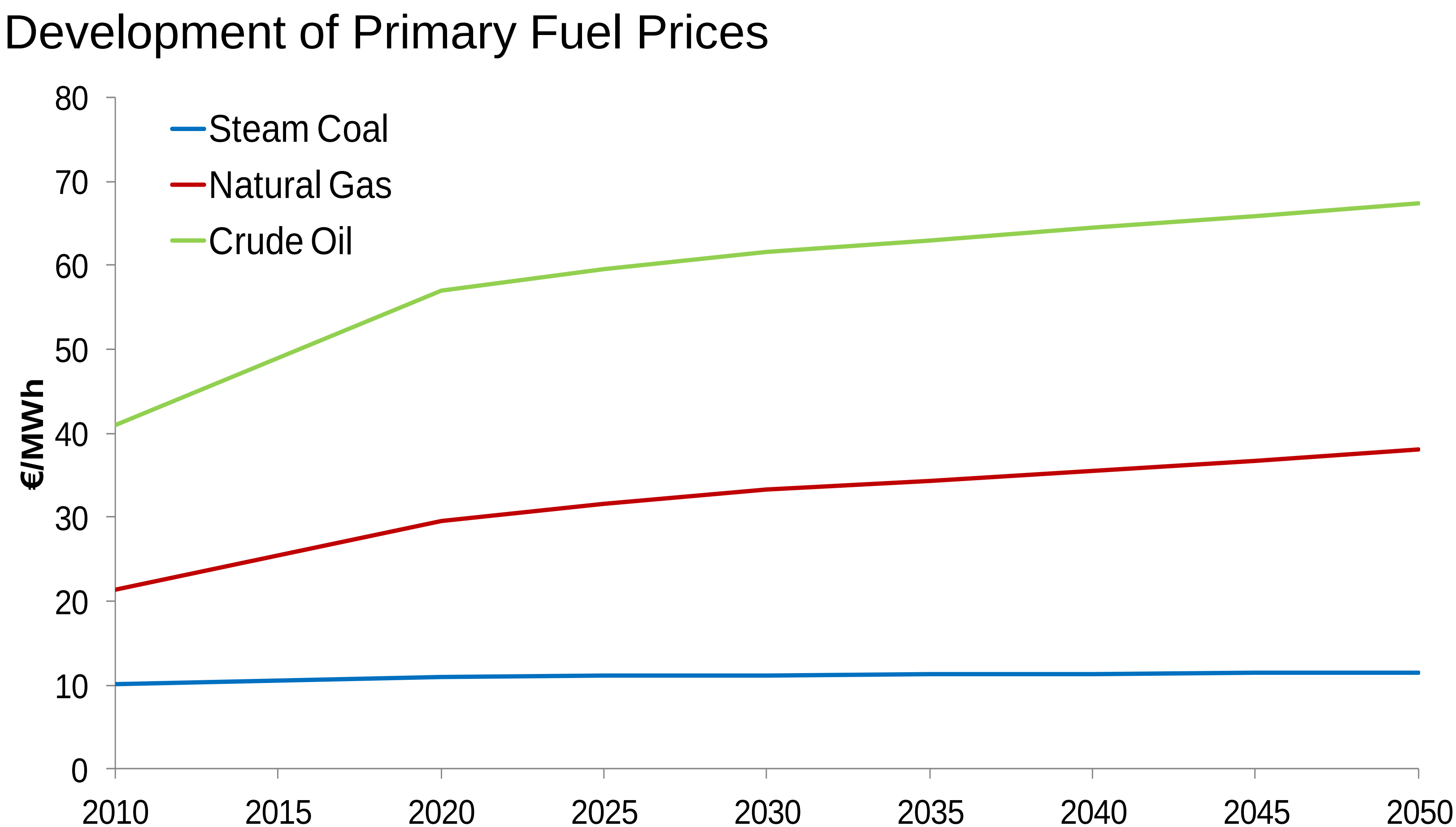
Conclusion

- Even in the scenario ‚integration‘, the share of RES in the *European* electricity market increases constantly (up to 49% in 2050). This change is driven by increasingly binding targets for climate protection and happens without any particular RES subsidies.
- However, the situation is different in *Germany*. Partly due to the large share of RES already built and partly due to relatively unfavorable RES-conditions, RES shares in Germany decrease for a time before recovering in the long run.
- Additional RES subsidies increase costs – but might be justified by advantages of RES in addition to climate protection → Further research.

Thank you very much!

Questions?

Assumptions
Development of Primary Fuel Prices



Assumptions

Electricity Demand (in TWh per year) for all Countries

		2011	2020	2025	2030	2035	2040	2045	2050
AT	TWh	66,0	75,5	81,0	86,5	88,0	89,5	91,1	92,6
BE	TWh	88,7	113,9	109,9	105,8	102,0	98,3	94,7	91,3
BG	TWh	40,0	52,7	60,1	67,4	69,5	71,7	74,0	76,3
CH	TWh	63,1	69,0	72,5	76,3	77,2	78,2	79,2	80,2
CY	TWh	5,5	7,2	9,4	11,5	12,2	13,0	13,8	14,6
CZ	TWh	64,5	77,5	80,3	83,0	83,7	84,4	85,2	85,9
DE	TWh	**558,4**	**558,4**	**558,4**	**558,4**	**558,4**	**558,4**	**558,4**	**558,4**
DK	TWh	35,7	38,2	41,0	43,8	44,6	45,3	46,1	46,9
EE	TWh	9,0	10,1	10,8	11,6	11,8	12,0	12,2	12,4
ES	TWh	286,0	340,0	375,5	411,0	420,9	431,1	441,5	452,2
FI	TWh	84,5	99,0	104,0	109,0	110,3	111,7	113,0	114,4
FR	TWh	493,3	523,1	538,7	554,3	558,3	562,4	566,5	570,6
GB	TWh	361,5	397,4	413,0	428,5	432,6	436,7	440,8	445,0
GR	TWh	60,8	69,3	74,6	80,3	81,8	83,4	84,9	86,5
HU	TWh	40,4	47,0	50,6	54,2	55,2	56,2	57,2	58,2
IE	TWh	27,4	30,1	31,3	32,5	32,8	33,1	33,5	33,8
IT	TWh	338,7	424,0	482,1	548,1	566,1	584,8	604,0	623,9
LT	TWh	10,9	13,4	16,2	19,0	19,9	20,7	21,7	22,6
LU	TWh	6,4	7,2	7,4	7,5	7,5	7,6	7,6	7,7
LV	TWh	7,3	8,9	9,9	10,8	11,1	11,3	11,6	11,9
MT	TWh	2,2	2,4	2,4	2,5	2,5	2,6	2,6	2,6
NL	TWh	117,4	132,4	143,1	153,7	156,6	159,6	162,6	165,7
NO	TWh	125,6	138,0	142,0	146,0	147,0	148,1	149,1	150,2
PL	TWh	143,0	171,7	197,0	222,2	229,5	237,1	245,0	253,1
PT	TWh	54,3	62,2	69,9	77,6	79,8	82,1	84,4	86,8
RO	TWh	56,8	64,2	72,6	81,0	83,4	85,8	88,4	91,0
SE	TWh	139,1	144,6	145,6	146,5	146,7	146,9	147,2	147,4
SI	TWh	12,8	14,9	16,3	17,7	18,1	18,5	18,9	19,4
SK	TWh	27,2	35,2	37,4	39,5	40,1	40,7	41,3	41,9
Europe	TWh	**3.326,3**	**3.727,5**	**3.952,4**	**4.186,1**	**4.247,7**	**4.311,1**	**4.376,3**	**4.443,4**