SEERMAP

South-East Europe Electricity Roadmap

European Electricity Market Model

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REKK FOUNDATION

Goals of SEERMAP project

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Modelling

- Analyse the impact of the transition to a low carbon and energy secure pathway the electricity sector until 2050 in line with EU 2050 Roadmap (*Long Term Electricity Roadmap for the SEE region*) that highlights the potential synergies beyond the limited confines of national assessments
- Application of state of the art energy sector models of the participating consortia partners (electricity and gas sector market models of REKK, Green-X of Technical University of Vienna and the regional electricity network model of EKC)

Dialogue and capacity building

- Effectively distribute the findings of this roadmap to the high level decision-makers in the energy administration of the countries
- Build up capacities – in the form of training courses - amongst policy makers, TSO members, energy regulators and local think tanks in the field of renewable energy deployment and transmission network planning issues
- Build up a network of regional think tanks capable of contributing to the debate on the long term decarbonisation pathways in the SEE region
- Trigger discussions on electricity scenarios at a national level

Modell interlinkages

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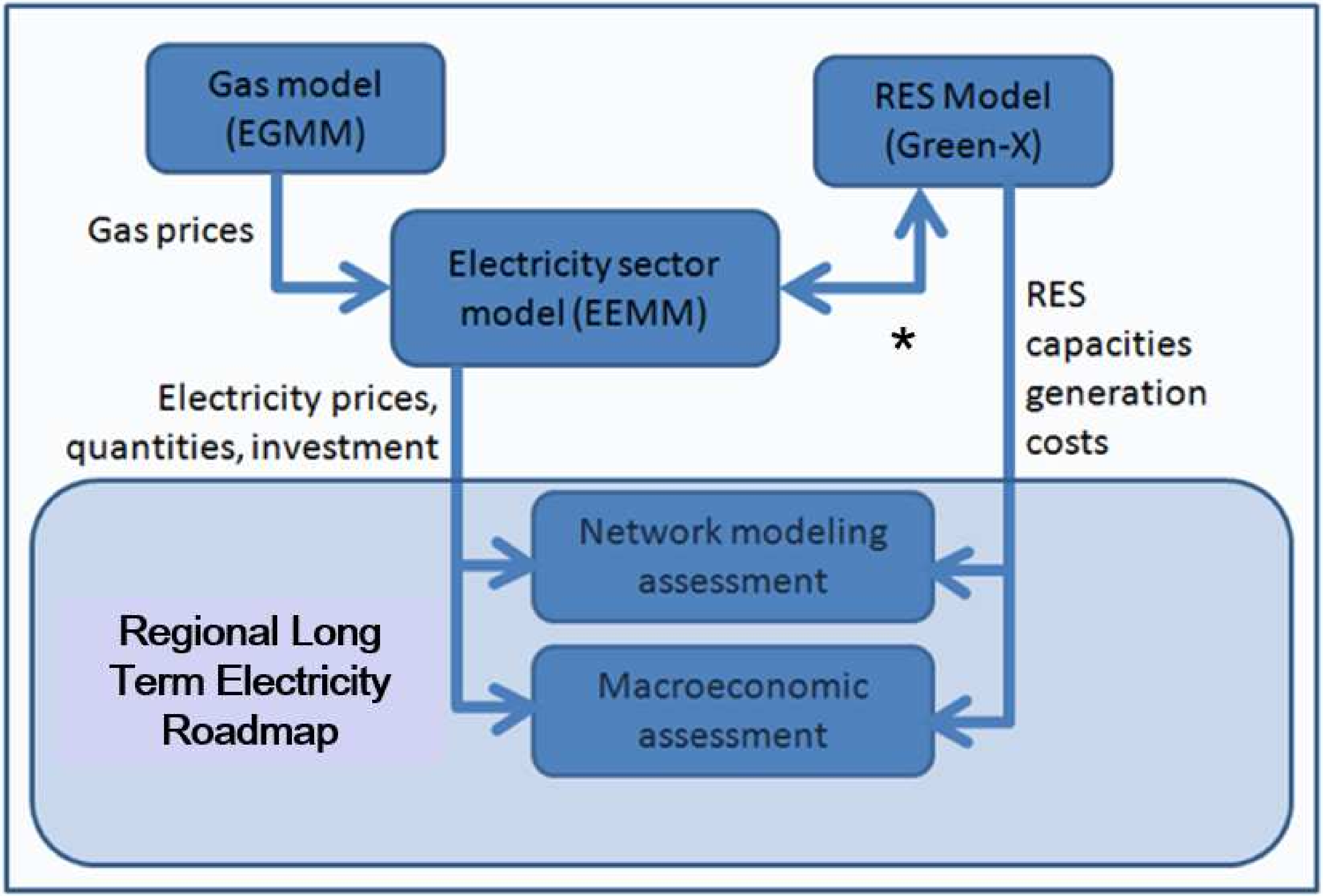

* Electricity wholesale price, RES value, curtailment

Model functionality

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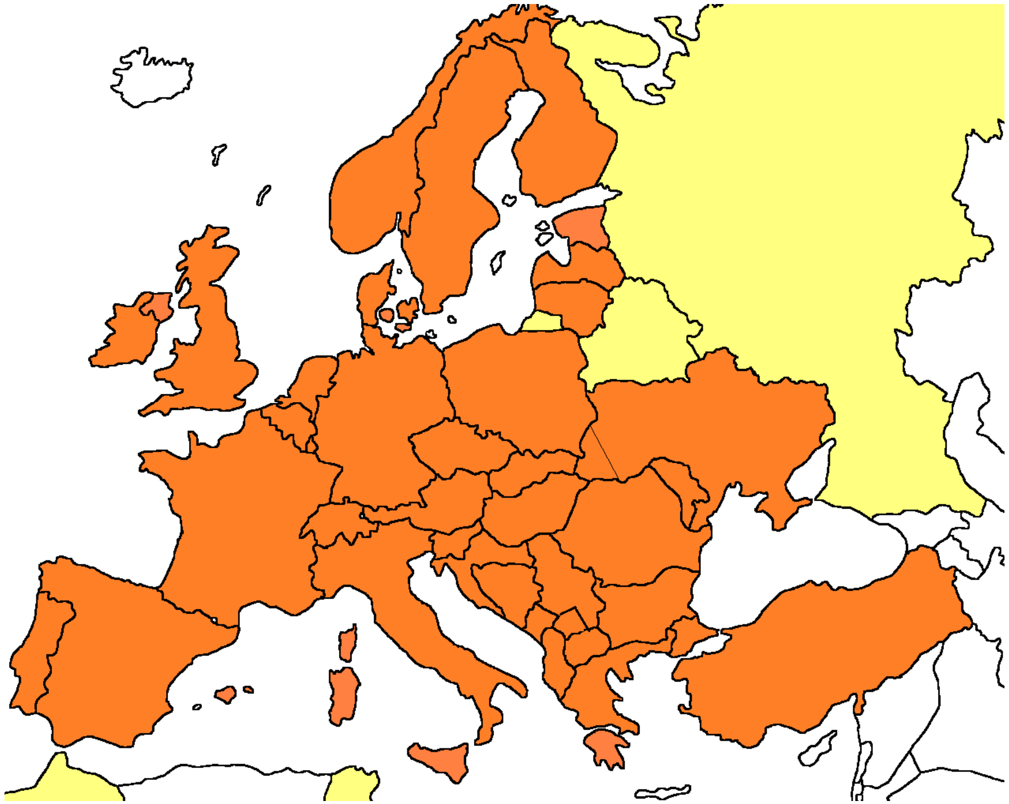

Comments:

- ►40 countries are handled in the model
- ►Morocco, Tunisia, Russia and Belarus are considered as exogenous markets
- ►In these markets the net export position are equal with the fact in 2014 (assumed a baseload flow)
- ►The model is calculating the marginal cost of around 3400 power plant blocks and sets up the merit order country by country
- ►Taking into consideration the merit order and exports/import, the model calculates equilibrium prices
- ►Power flow is ensured by 104 interconnectors between countries

Basic economics in the model

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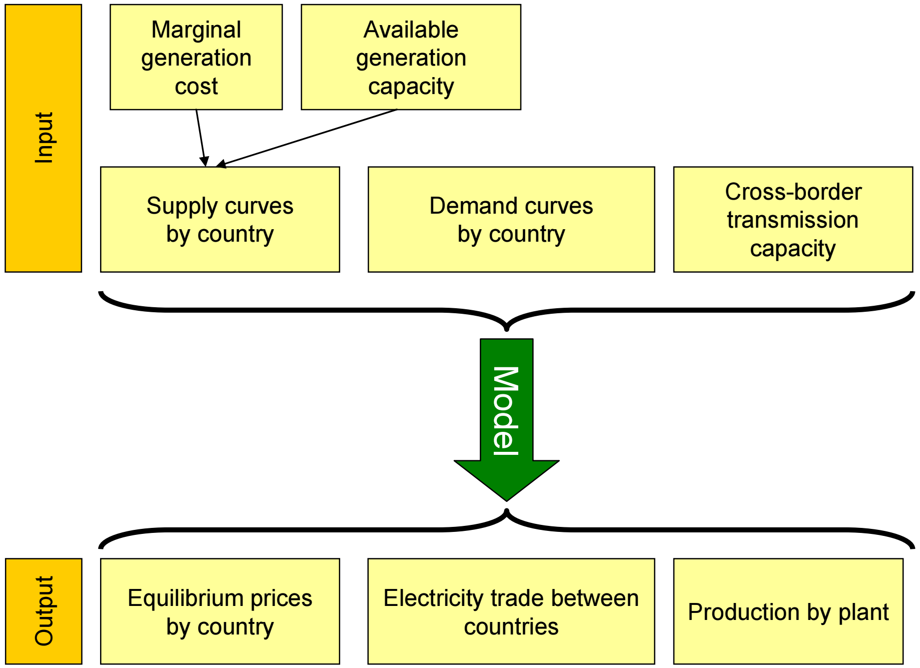
- Competitive behavior by power generators
  - „if someone is willing to pay more for my energy than what it costs me to produce it, then I will produce”
- Prices equalize supply and demand
- Efficient cross-border capacity auctions
  - „we export electricity to wherever it is more expensive and import from wherever it is cheaper”
- Capacity limits
  - in production and cross-border trade
- Large country prices around the region are exogenous to the model, the rest are determined by the model

Economic description and main assumptions

Main inputs and outputs of the model



- The model calculates regional power supply – demand balance at certain capacity and import/export constraints
- Demand evolution, power plant capacities, availability and cross border power flow defines market price
- Fuel prices are estimated based on available information

Main model assumptions

- The applied model is a partial equilibrium microeconomic model in which a homogeneous product is traded in several neighboring markets.
- Production and trade are perfectly competitive, there is no capacity withholding by market players.
- Production takes place in capacity-constrained plants with marginal costs and no fixed cost.
- Electricity flows are modeled as bilateral commercial arrangements between markets with a special spatial structure.
- Power flows on an interconnector are limited by NTC values in each direction.
- Fuel prices reflect power plant gate prices, transportation/ transmission costs are taken into consideration.
- Only ETS countries buy CO_2 allowances

Defining demand periods

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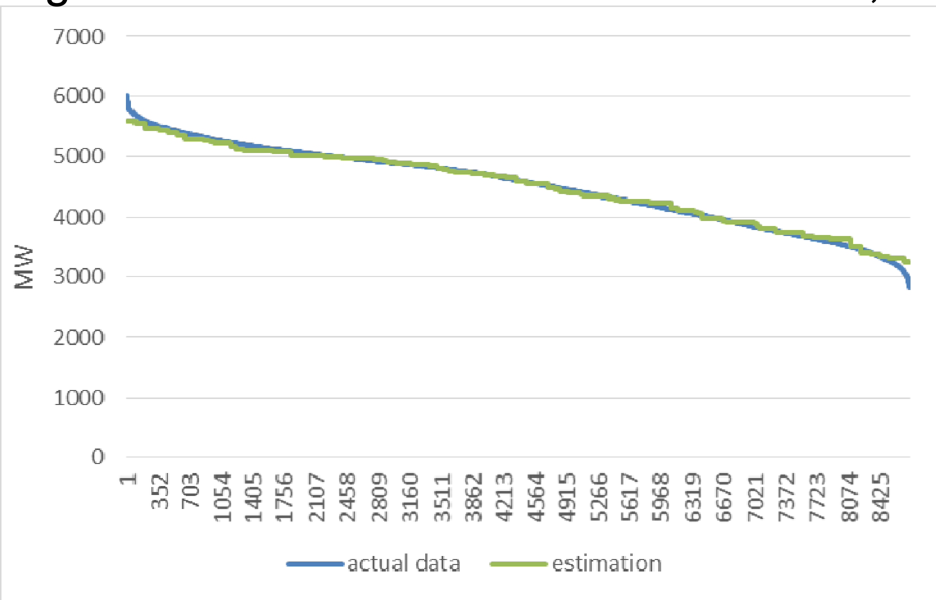
- We model one hour in one run
- In a year 90 reference hours are modeled
- Reference hours are based on historical data (2015)
- From all the 24 (6*4) groups smaller subgroups are created in a “difference minimizing” way
- Consumption of the reference hour: The average hourly consumption in the given sub-groups
- The average difference is around 2% of the average consumption

Hungarian actual and estimated load curve, 2015



1	1
2	3
3	3
4	4
5	5
6	6
7	4
8	2
9	2
10	2
11	3
12	1

Load scenario value, season

Load scenario value, daily

1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	4
9	4
10	3
11	3
12	2
13	2
14	2
15	3
16	3
17	3
18	4
19	4
20	4
21	1
22	1
23	1
24	1

Demand forecast

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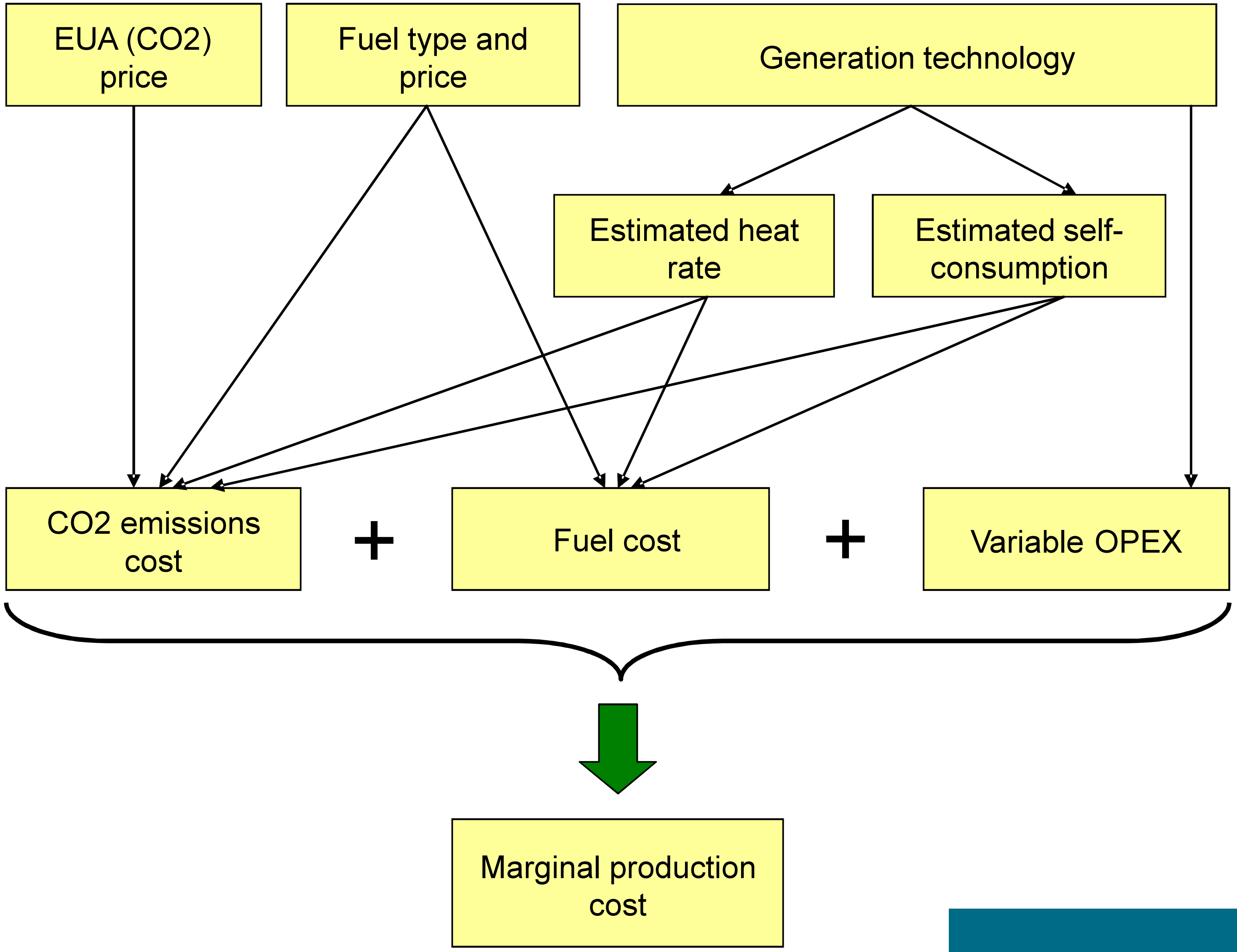
- Historical data (2015) based on ENTSO-E (or in some countries modified by Local Partners)
- The latest PRIMES country specific yearly growth rates are applied by 2050, if Local Partners did not give a different forecast

	Yearly gross consumption, GWh									Yearly growth rate, 2016-2050
	2015	2016	2020	2025	2030	2035	2040	2045	2050	
AL	8 017	8 267	9 346	9 945	10 548	11 180	11 787	12 444	12 908	1.3%
BA	11 733	12 009	13 986	15 393	16 923	18 149	19 689	20 666	21 576	1.7%
BG	33 244	33 549	34 795	35 727	36 469	36 921	37 919	38 993	40 856	0.6%
GR	50 730	51 104	52 624	51 220	49 641	51 869	53 159	53 851	55 142	0.2%
HR	16 984	17 150	17 829	17 686	17 851	18 461	19 200	20 315	21 681	0.7%
KO*	n.a.	5 802	5 955	6 330	6 934	7 510	7 776	8 187	8 549	1.1%
ME	3 426	3 440	3 815	4 093	4 440	4 612	4 863	5 106	5 320	1.3%
MK	8 170	8 004	7 658	8 164	8 544	9 017	9 649	10 193	10 474	0.8%
RO	53 640	54 432	57 720	58 713	58 511	59 577	61 899	64 771	69 016	0.7%
RS	33 524	34 119	36 607	38 791	40 899	43 022	45 188	47 112	48 828	1.1%

Green	From Local Partners
Yellow	PRIMES growth rate
Blue	ENTSO-E

Components of marginal cost



Power plants database

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- Technology:
  - Non-RES: Thermal, OCGT, CCGT, nuclear
  - Renewable: Hydro (run-of-river, storage, pumped storage), wind, solar, tide and wave, geothermal
- Fuel type:
  - Non-RES: coal, lignite, LFO, HFO, natural gas, nuclear
  - Renewable: Hydro (run-of-river, storage, pumped storage), wind, solar, tide and wave, geothermal
- Existing power plant database
  - Data sources
    - National regulators
    - System operators
    - Individual power company and plant websites
    - EWEA, EPIA
    - PLATTS database
  - All cross-checked with Eurostat and ENTSO-E aggregated value, all differences remained below 10%

Installed capacity in SEE, MW, 2015

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	Coal	Lignite	Natural gas	Nuclear	HFO/LFO	Hydro with storage	Run-of-river	Pumped storage	Solar	Wind	Biomass	Total
AL	0	0	0	0	0	0	1 801	0	2	0	5	**1 808**
BA	0	1 970	0	0	0	1 252	403	440	1	0	0	**4 066**
BG	635	4 759	422	2 000	0	841	951	1 399	1 064	700	58	**12 829**
GR	0	4 736	4 763	0	730	2 527	223	699	2 605	2 298	52	**18 633**
HR	0	330	689	398	761	1 488	421	293	69	422	72	**4 943**
KO*	0	1 478	0	0	0	0	49	0	0	1	0	**1 528**
ME	0	219	0	0	0	649	19	0	3	0	0	**890**
MK	0	822	294	0	210	546	127	0	20	37	7	**2 062**
RO	2 125	3 040	3 058	1 413	0	3 416	2 927	357	1 317	3 026	121	**20 800**
RS	0	4 351	0	0	0	917	1 539	614	3	11	11	**7 446**

Investment module of the EEMM

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- **Fossil-based capacities:**
  - 6 different technologies:
    - Coal w/wo CCS
    - CCGT w/wo CCS (natural gas)
    - OCGT w/wo CCS (natural gas)
  - Yearly profit calculation for all type of technologies:
    - Fix OM cost (€/kW) – based on EIA
    - Annualized investment cost (€/kW) – based on EIA
    - Total profit: Yearly total revenue – yearly total variable cost (CO2, fuel cost, variable part of OM)
  - If profit >(fix OM cost + annualized investment cost) than the most profitable technology will be built in a given country, in a given year
- **Nuclear:**
  - Exogenous based on IEA
- **RES-E:**
  - Installed capacity based on GREEN-X modell

Efficiency parameters

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- Taken from literature, dependent on the commission year and the type of the PP

Year of commissioning	Fuel efficiency and self-consumption for various power plant types		
	Gas/Oil ST	Coal ST/Biomass	CCGT
1960	37.0%	35.0%	50.0%
1965	38.0%	36.0%	50.0%
1970	39.0%	37.0%	50.0%
1975	40.0%	38.0%	50.0%
1980	41.0%	39.0%	50.0%
1985	42.0%	40.0%	50.0%
1990	43.0%	41.0%	50.0%
1995	44.0%	42.0%	52.5%
2000	45.0%	43.0%	55.0%
2005	46.0%	44.0%	56.5%
2010	47.0%	45.0%	57.0%
2015	48.0%	46.0%	58.0%
2020	49.0%	47.0%	59.0%
2025	50.0%	48.0%	60.0%
2030	51.0%	49.0%	61.0%
2035	52.0%	50.0%	62.0%
2040	53.0%	51.0%	63.0%
2045	54.0%	52.0%	64.0%
2050	55.0%	53.0%	65.0%
Self-consumption	**5.0%**	**13.0%**	**5.0%**

- Availability: Fossil: 95%; Geothermal: 85 %; Biomass: 80%; Tide and wave: 85%

Availability of nuclear and RES-E

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- Nuclear: Differ by country and season scenarios -> based on monthly historical data (ENTSO-E)
- Wind: Yearly utilization rate differ by country (source: IEA and calculated). Utilization depends on reference hour
- Solar: Yearly utilization rate differ by country (source: JRC and calculated). Utilization also depends on season and day scenarios
- Hydro:
  - Run-of-river: Differ by season and country (based on historical data), baseload production within a day
  - Storage: Differ by season and country (based on historical data), but the daily production is not baseload. High availability in peak hours, lower availability in off-peak hours
  - Pumped storage: Historical utilization rates (Eurostat); produce in peak hours and consume in off-peak hours. Losses are also taken into account and differ by countries (based on actual data).

Special PPs - CHP

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- CHP generators
  - Must-run power plants (production does not depend on wholesale electricity price)
  - Plant-by-plant determine whether is a CHP or not -> cross checked with aggregated database (Eurostat)
  - Availability based on historical data

CHP							
		Season					
		1	2	3	4	5	6
Day	1	30%	6%	30%	3%	3%	0%
	2	36%	6%	36%	3%	3%	0%
	3	42%	6%	42%	3%	3%	0%
	4	48%	6%	48%	3%	3%	0%

Fuel price forecasts

- Oil price
  - Based on EIA Annual Energy Outlook (2016) and PRIMES (2016)
- Gas price
  - Based on REKK EGMM (European Gas Market Model)
  - Differ by country
- Coal
  - Hard coal price equal ARA price and same in all countries
  - Coal price forecasts are based on EIA: Annual Energy Outlook 2016
  - Lignite price = hard coal * 0.55 (there is no liquid lignite market in Europe)
- Nuclear
  - Taken from literature, but irrelevant (never marginal)
- HFO, LFO
  - Indexed to crude oil price
  - Not especially important (hardly ever marginal)

Assumed fuel prices

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Year	2016	2020	2025	2030	2035	2040	2045	2050
Crude oil; $2014/bbl	37.5	79.1	91.1	110.0	115.0	120.0	125.0	130.0
Exchange rate; $/€	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
CO2 price, €/t	4.2	15.0	21.5	31.5	35.0	52.0	80.0	87.0
ARA coal price, €/GJ	1.5	2.0	1.9	1.9	2.0	2.0	2.0	2.0

Variable OPEX

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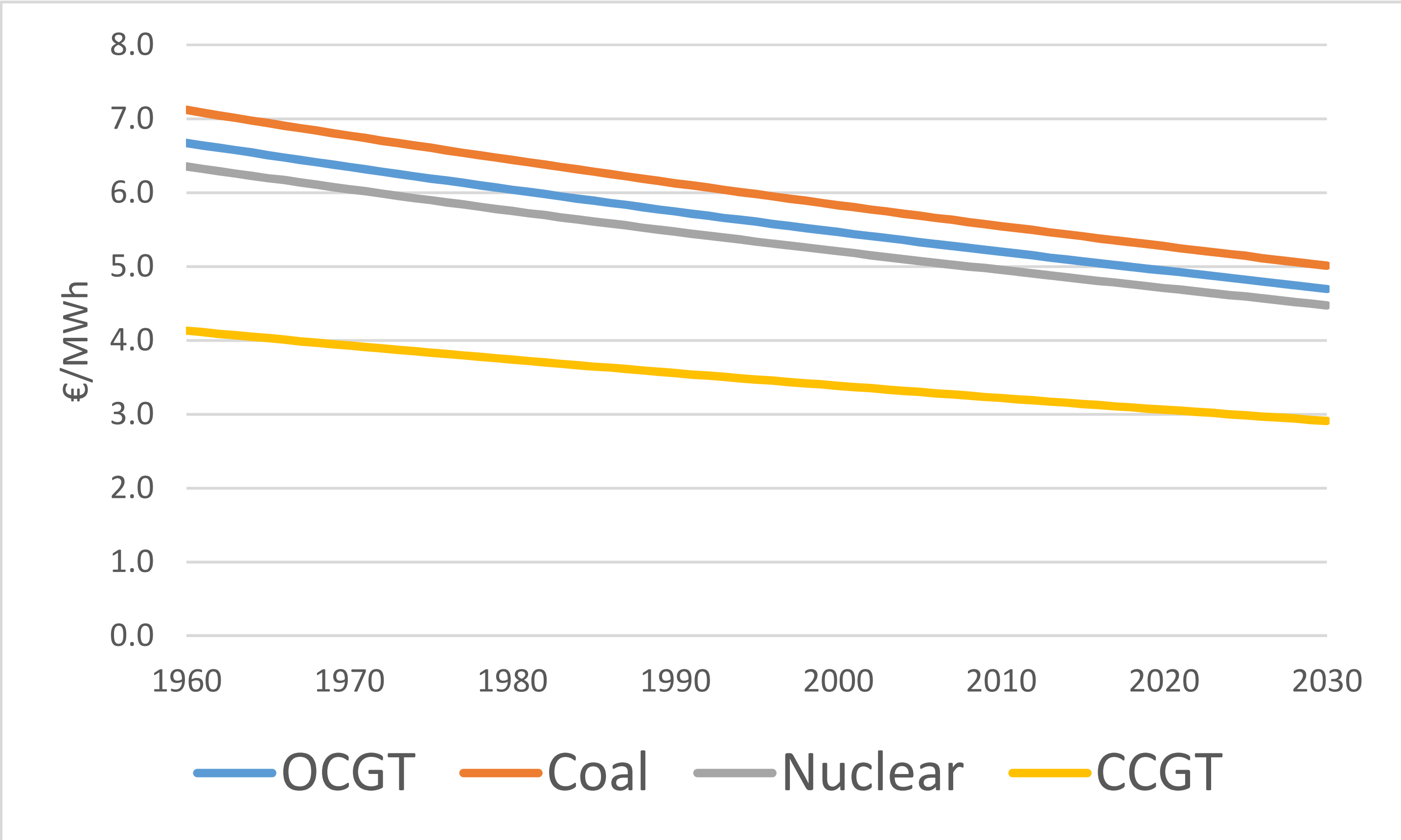
- Taken from literature
- Only variable OPEX are taken into account



Determing short-term marginal cost

Short term marginal cost

=

Fuel cost

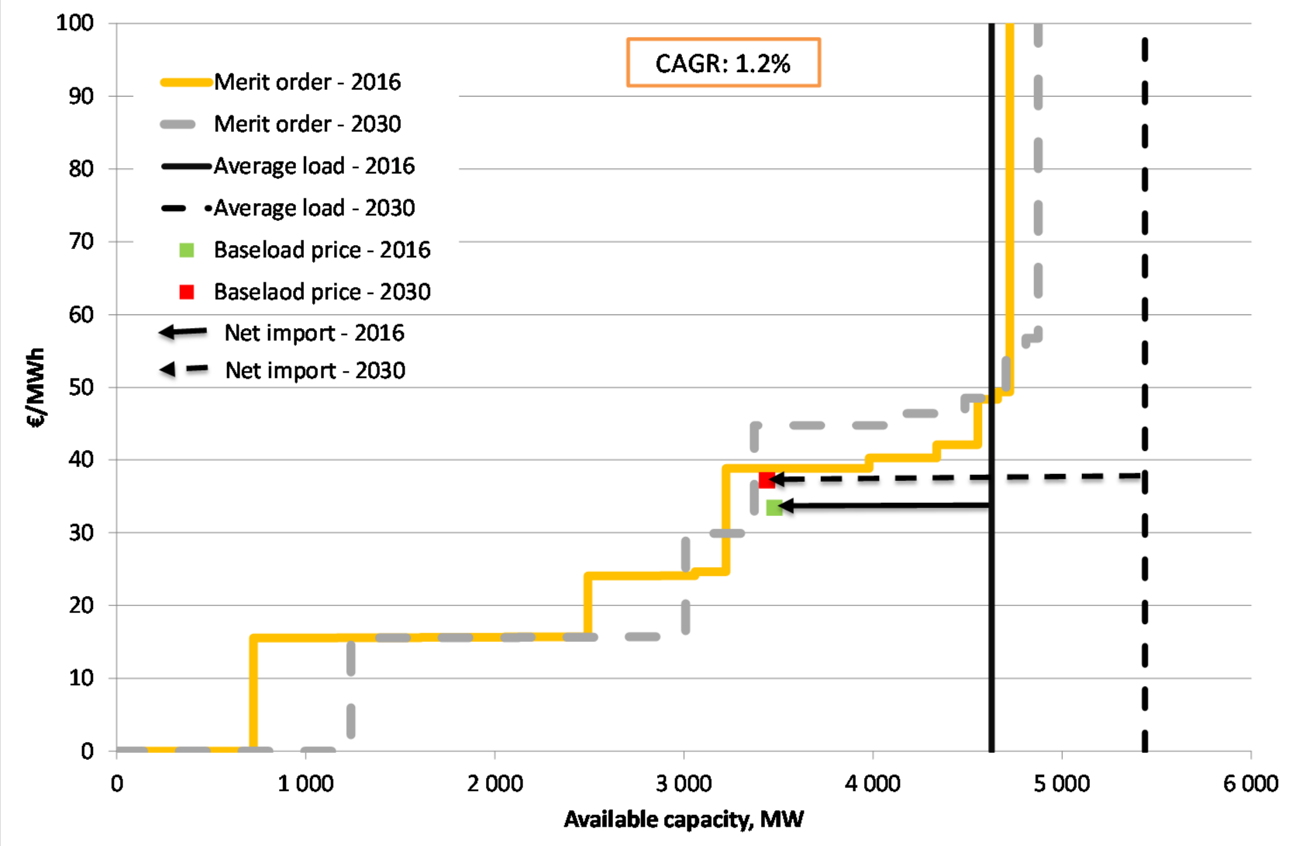
+

CO_2 cost

+

Variable part of the OPEX

Merit order curve – HU example



MC, €/MWh		Lignite	Coal	Natural gas
2016	Non-efficient tech.	24.8	31.8	56.9
	Efficient tech.	19.8	25.4	38.1
2030	Non-efficient tech.	39.2	45.4	65.4
	Efficient tech.	31.4	36.3	44.0

- High consumption growth
- Small increase in RES-E generation
- No new nuclear capacity is assumed
- A new lignite capacity is assumed (440 MW), existing coal/lignite fired PPs will be decommissied by 2030
- Due to higher CO2 price, MC of lignite/coal production increases significantly
- MC of natural gas PPs increases due to CO2 price and natural gas price increase
- Net import position is growing significantly, increasing consumption will be satisfied by import

Cross-border capacity

- One country -> one node (except DK and UA)
- NTC based trading
- NTC differ by borders, seasons and direction
- NTC value based on the historical value published by ENTSO-E
- Future CBC expansions:
  - based on ENTSO-E TYNDP 2014 and 2016

Present CBC capacity in the region

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Origin and destination country		NTC values for different season, MW	
From	To	O ->D	D->O
BA	HR	684	637
BA	ME	459	467
BA	RS	507	476
BG	GR	500	341
BG	MK	202	100
BG	RO	178	175
BG	RS	324	237
HR	HU	982	1 182
HR	RS	489	465
HR	SI	1 234	1 389
HU	RO	353	431
HU	RS	720	813
IT	GR	500	500
MK	GR	261	350
MK	RS	275	590
KO*	AL	218	223
RS	ME	627	653
RS	RO	364	554
RO	UA_W	54	54
ME	AL	400	400
AL	GR	248	248
GR	TR	184	134
RO	MD	310	310
KO*	RS	no congestion	no congestion

Future CBC development in the region

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New cross-border capacities						
From	To	Year of commissioning	Investment status	O -> D	D -> O	TYNDP 2016 code
ME	IT	2019	1	1200	1200	28
BA	HR	2022	3	650	950	136
BG	RO	2020	2	1000	1200	138
GR	BG	2021	2	0	650	142
RS	RO	2023	2	500	950	144
ME	RS	2025	2	400	600	146
KO*	RS	2016	1	700	700	147a
AL	MK	2020	2	250	250	147b
RS	ME	2025	2	500	500	227a
RS	BA	2025	2	600	500	227b
BA	HR	2030	3	350	250	241
HR	RS	2030	3	750	300	243
HU	RO	2035	3	200	800	259
RS	RO	2035	3	500	550	268
RS	BG	2034	3	50	200	272
RS	RO	2035	3	0	100	273
RS	BG	2034	3	400	1500	277
GR	BG	2030	3	250	450	279
IT	GR	2033	4	1500	1500	E-Highway
IT	GR	2037	4	1500	1500	E-Highway
IT	GR	2043	4	1000	1000	E-Highway
IT	GR	2046	4	1000	1000	E-Highway
UA_E	RO	2038	4	700	700	E-Highway

The importance of cross-border capacities – an effect of one-year delay of the commissioning of the IT-ME undersea cable

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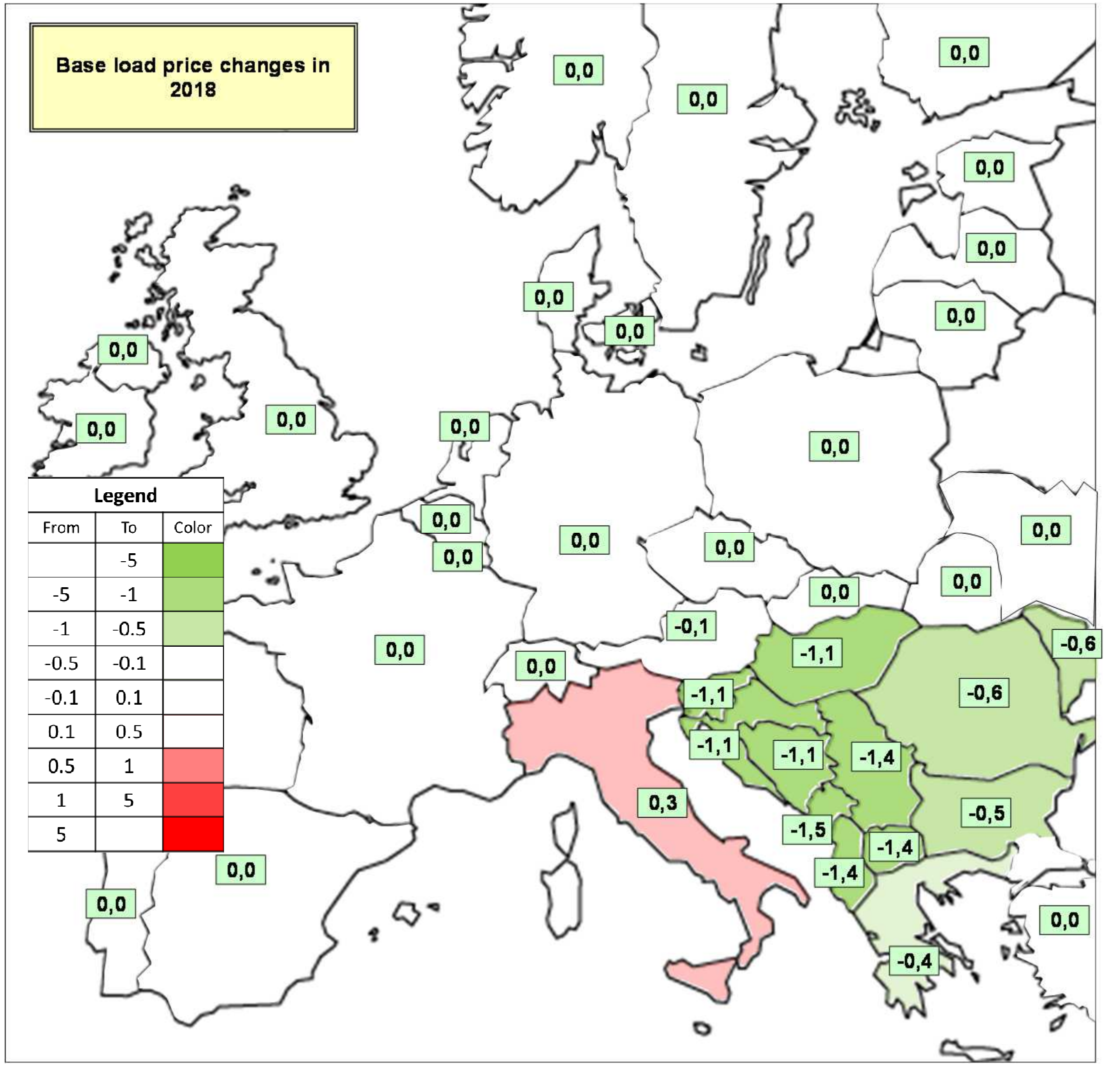

Legend

From	To	Color
	-5	
-5	-1	
-1	-0.5	
-0.5	-0.1	
-0.1	0.1	
0.1	0.5	
0.5	1	
1	5	
5		

- In REF IT-ME (1000 MW) will be commissioned in 2018
- IT is a more expensive country than the Balkan region -> the new line decreases the IT prices, and increases the price in the Balkan region
- This cable has a significant effect on HU baseload prices as well

Model output

- Equilibrium price in a demand period
- Baseload and peakload prices
- Electricity trade between countries, net import position
  - Price of cross border capacities
- Production by plants
- Gas consumption
- CO_2 emission

Modelled vs. exchange prices, €/MWh, 2014

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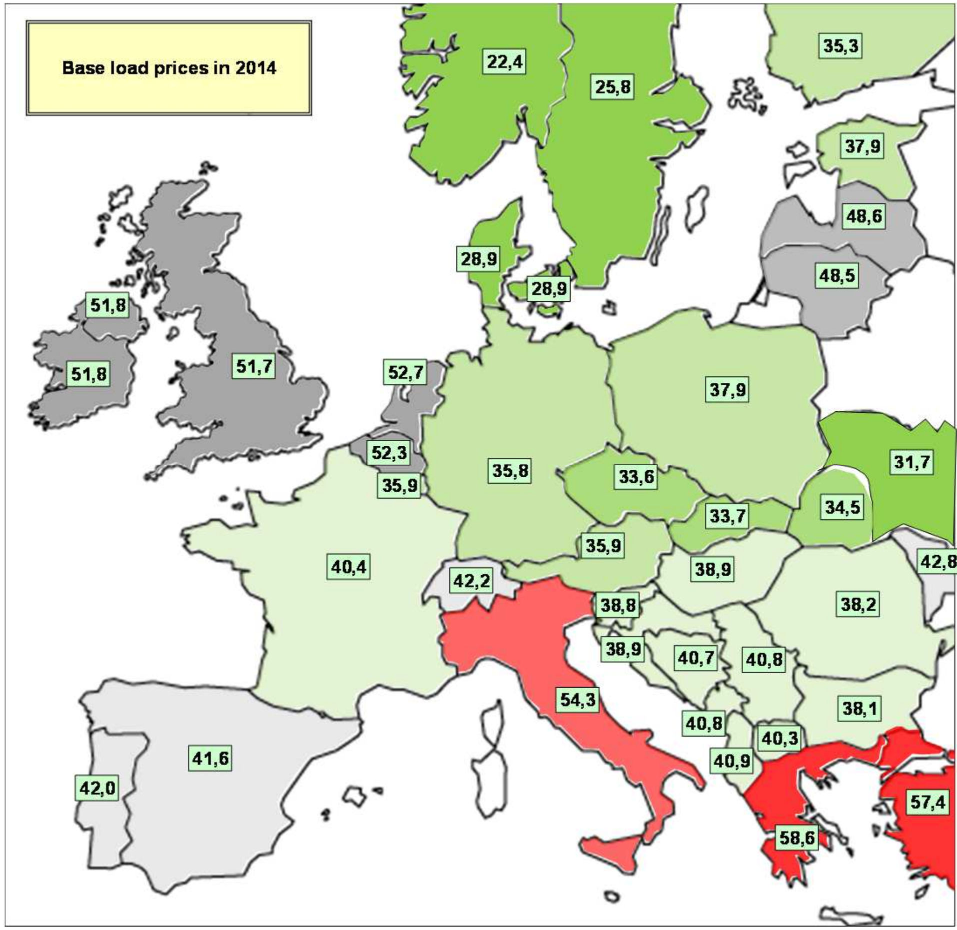
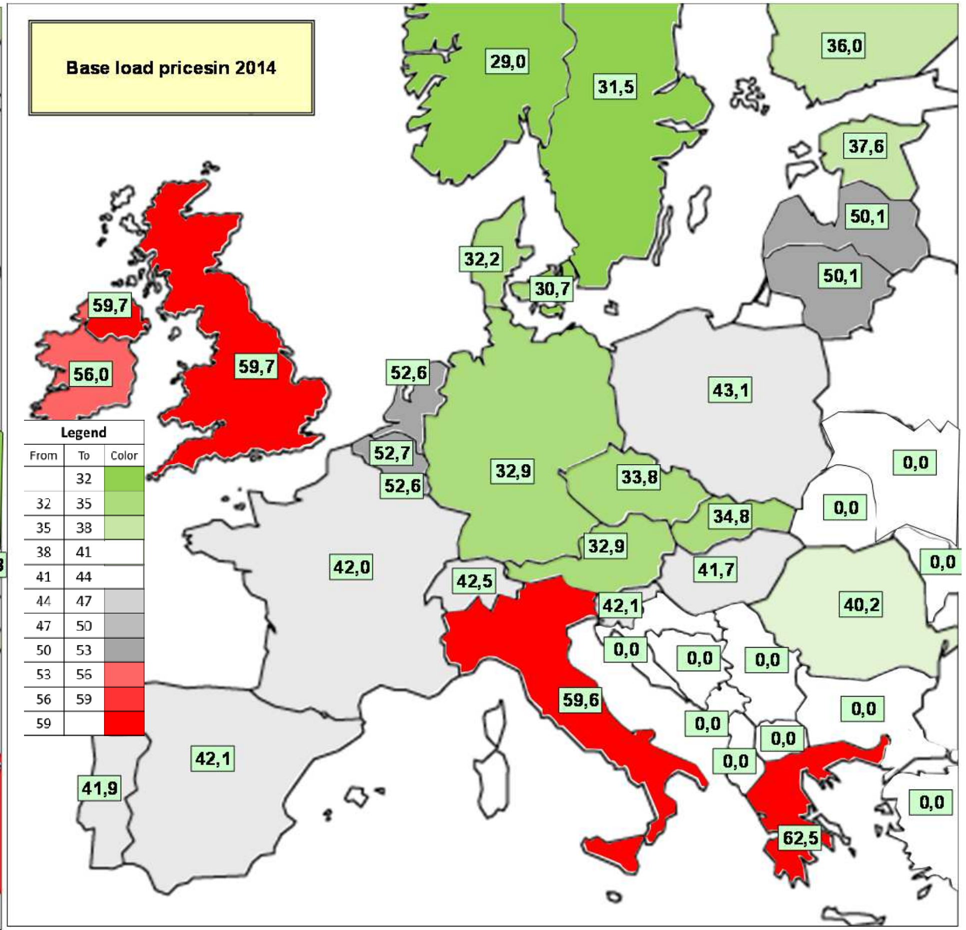
Modelled



Fact



Legend		
From	To	Color
	32	
32	35	
35	38	
38	41	
41	44	
44	47	
47	50	
50	53	
53	56	
56	59	
59		

Modelled vs. exchange prices, €/MWh, 2015

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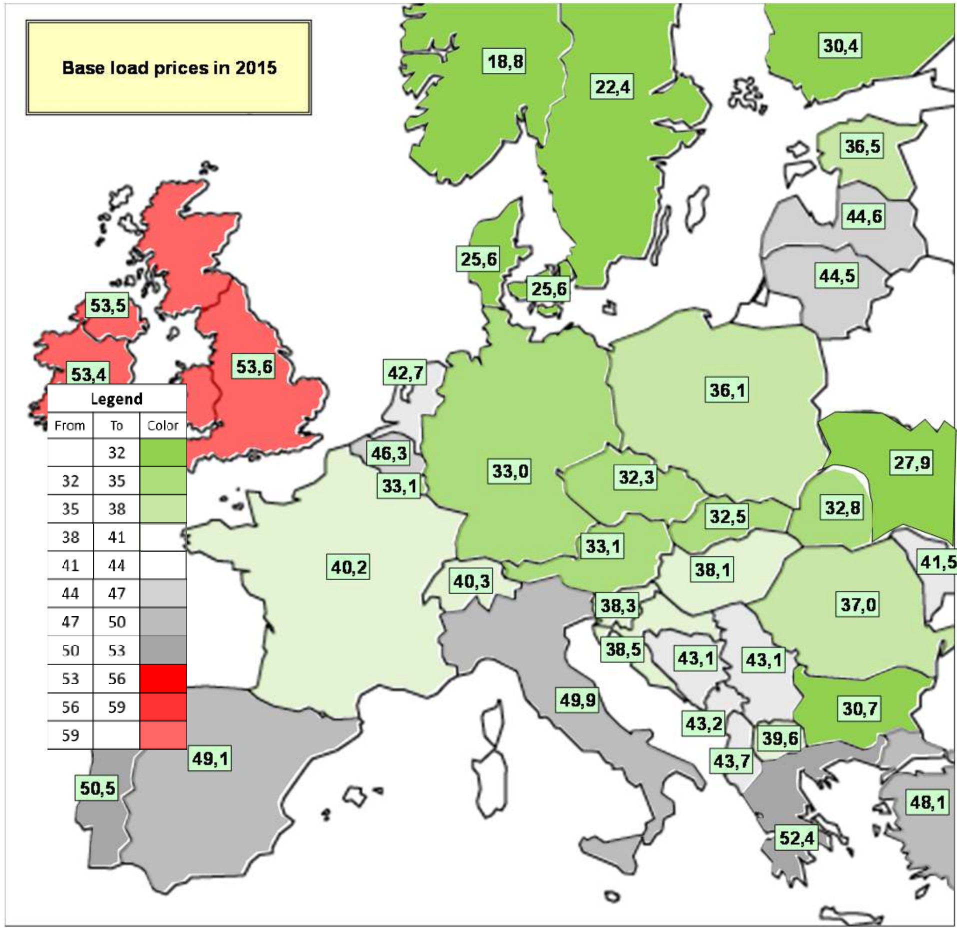
Modelled



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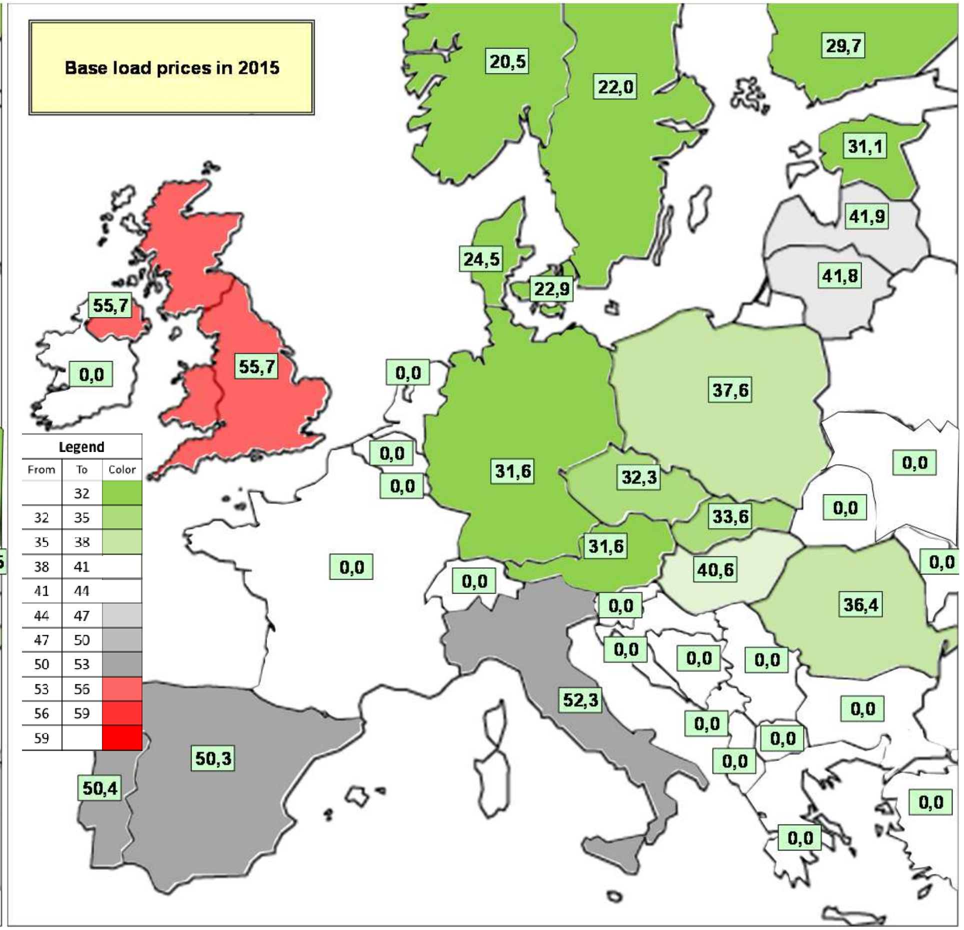

Relative differences of modelled vs. exchange prices in the region, 2012-2015, %

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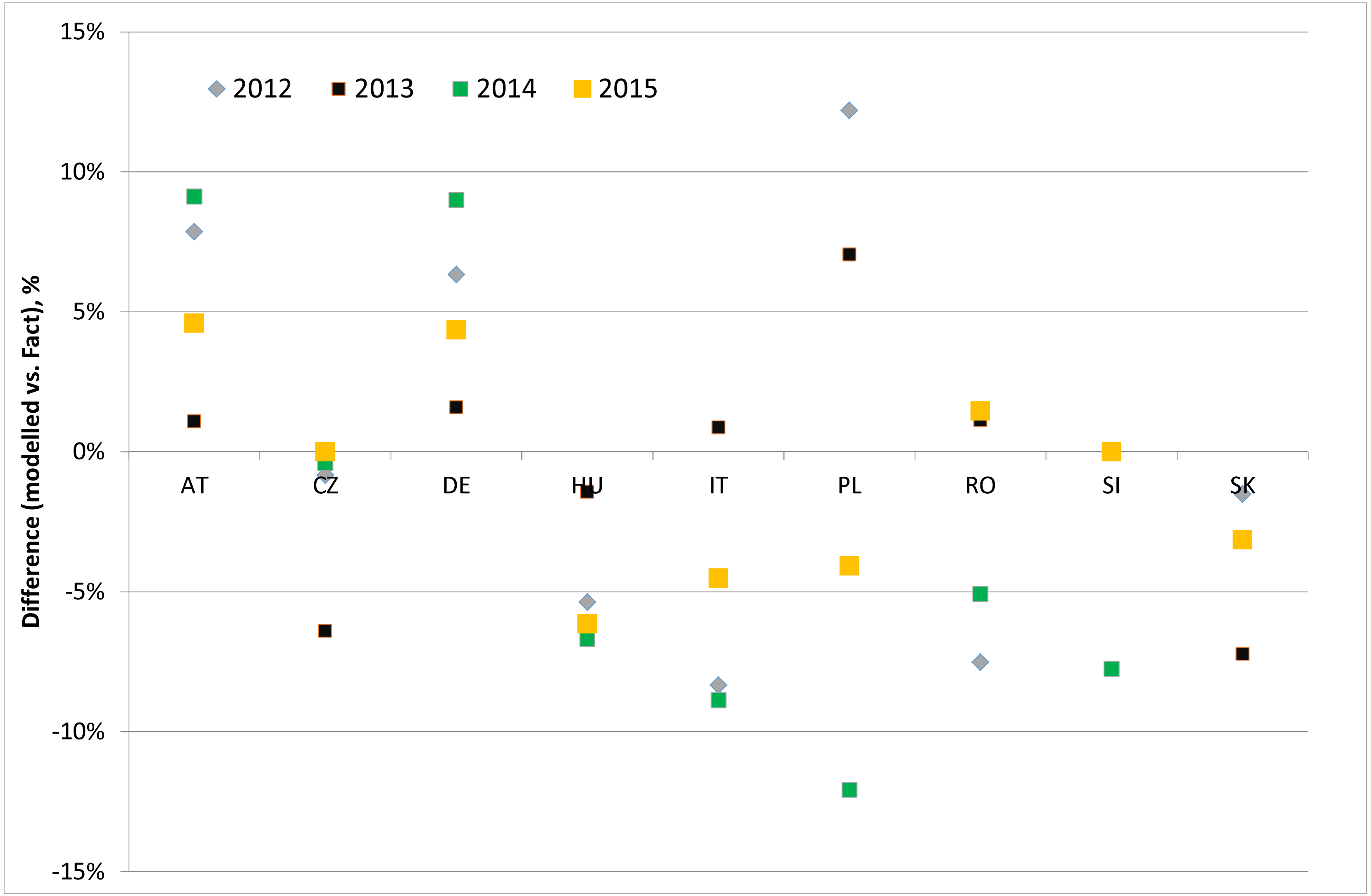

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