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Generation Portfolio and Investment Timing until 2030:
Technological Choice and Flexibility

Danny Auerswald, Florian Leuthold EE²

Chair of Energy Economics and Public Sector Management

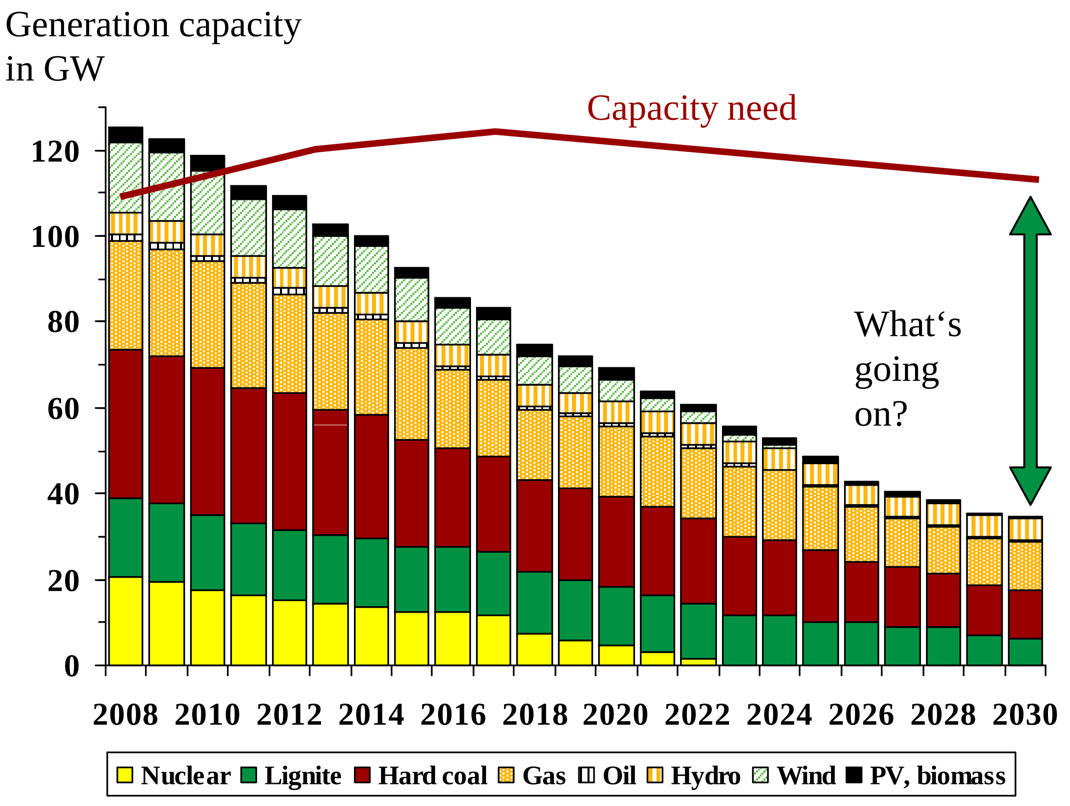
Agenda

1. Motivation
2. Flexible investment opportunities
3. Model for the optimal generation portfolio
4. Conclusions
5. References

Due to high uncertainty and political pressure, needed investments in power plants are delayed

► Motivation for the work

Expected generation investment potential in Germany



Source: RWE (2008a), DLR (2008)

Only few existing projects

- High uncertainty of future power plant projects
  - Durability of nuclear phase-out unclear
  - Increases in prices for fuels and power plant components
- Uncertainty about European Trading Scheme
  - Decisions for NAP III (post 2012) will heavily influence future CO_2 price
  - Political pressure is getting higher in the course of Global Warming

What will be the optimal generation portfolio until 2030 ?

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Our approach is to combine technological and timing flexibility into a classical NPV approach

▶ Traditional investment assessment methods

Net Present Value

- Approach for evaluating a project, company, etc. using the concept of the time value of money
- Present value of future incomes is calculated by discounting all estimated cash flows
- Risk-adjusted interest rate can be determined by Capital Asset Pricing Model (CAPM)

Decision Tree Analysis

- Assumption: Today's decisions have impact on future action opportunities
- All sequent decision situations are presented as tree structure consisting of:
  - Decision nodes (investors decide between different alternatives)
  - Chance nodes (illustrate possible developments resulting from uncertain market conditions)
  - End nodes (represent the final value for a certain path through the tree)

+ Flexibility

+ Irreversibility

→ Dynamic linear optimization model

Monte Carlo simulation

- Generation of a project's risk profile by modeling the probability distribution of the decision criterion
- Random numbers are linked with input parameters to calculate a distribution of the target value

Made investment decisions are static in a dynamic future

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The model objective is to find the profit-maximizing generation portfolio for Germany until 2030

▶ Model idea

Generation portfolio changes

- German generation portfolio is anticipated to change
- Utilities have to face uncertainties
  - Expected increases in fuel prices
  - Consequences of political decisions in terms of global warning

Capacity planning problem

- Utilities have to decide about investments
- Alternative renewable sources
  - Low-risk characteristics
  - No/low fuel costs
  - Marginal emissions
  - Capital intensive
  - Mostly only available in small unit sizes
- Alternative fossil fuels
  - Long payback periods and thus higher investment risks

Appropriate valuation approach

- Decision-makers own flexibility
  - Which plant type?
  - What point in time?
- Decisions are irreversible alternatives

Complete model

- Multitude of model requirements
  - General approaches for option pricing overstrained
  - Own model development necessary
- The basic idea based on Kumbaroglu et al. (2008) but simplified
  - Impact of the ETS

The determination of the optimal generation portfolio depends on several plant-specific input parameters

► Model formulation (1/2)

Objective function

- The accumulated capacity additions $X^{total}_{i,t}$ for each technology *i* (indicating the chosen plant type) in time *t* are assessed at each time step to maximize the Net Present Value

$$NPV = \max \sum_{t=t_0}^{T} \frac{1}{(1+r)^{t-t_0}} \left[\begin{array}{ll} \sum_i \left(p_t^{opeak} \cdot L_{i,t}^{total} \cdot \theta_i \cdot ld_i\right) & + \sum_i \left(p_t^{peak} \cdot L_{i,t}^{total} \cdot \theta_i \cdot (1-ld_i)\right) \\ -\sum_i \left(vfc_{i,t} \cdot L_{i,t}^{total} \cdot \theta_i\right) & - \sum_i \left(vc_{i,t} \cdot L_{i,t}^{total} \cdot \theta_i\right) \\ -\sum_i \left(fc_i \cdot X_{i,t}^{total}\right) & - \sum_i \left(ann_i \cdot X_{i,t}^{total}\right) \\ -\sum_i \left(em_{i,t} \cdot L_{i,t}^{total} \cdot \theta_i\right) & \end{array} \right]$$

- Notations:

- p_t	Electricity price	- $em_{i,t}$	Emission cost factor
- L^{total}_{it}	Accumulated load of new capacity	- fc_i	Annual fixed costs
- θ_i	Full load hours of plant type I	- ann_i	Annuity of investment costs
- $vfc_{i,t}$	Variable fuel costs	- r	Interest rate (WACC)
- $vc_{i,t}$	Variable auxiliary costs for O&M	- ld_i	percentage of covered off-peak load

The model constraints facilitate decision-making close to reality

▶ Model formulation (2/2)

Phase-in constraint

$$X^{total}_{i,t} = \sum_{k=t-lead(i)-phase(i)}^{t-lead(i)} X_{i,k}$$

$$X_{i,k} \geq 0$$

- Regards different lead times $lead_i$ and running times $phase_i$
- $X_{i,k}$ indicates amount of added capacity in the year in which the investment decision is taken

Load constraints

$$L^{total}_{i,t} \leq af_i \cdot X^{total}_{i,t}$$

$$\varpi_{i,t} \leq af_i \cdot \Omega_{i,v}$$

- Available output load $L^{total}_{i,t}$ is determined by availability factor af_i (percentage of time in which the plant is ready to use)
- The relation between already existing capacities $\Omega_{i,t}$ and usable load $\omega_{i,t}$ underlies the same assumption

Demand constraint

$$\sum_i \left[\left(L^{total}_{i,t} + \omega_{i,t} \right) \cdot \theta_i \right] \leq d_t \cdot (1+m)$$

- Electricity generation from previously installed power plants does not exceed the demand d_t
- m represents the reserve margin to imply potential outages

Price constraint

$$d_t(p_t) = \alpha \cdot p_t^{\xi}$$

- Demand for electricity is assumed to be price-sensitive
- Scale parameter α adjusts demand to designated basis
- ξ denotes price elasticity of electricity demand

To keep the modeling feasible, some limitations have to be made and allow for further research

► Model limitations

Consideration of market mechanisms

- Influence of increasing electricity prices on demand is only regarded by an elasticity factor
- If demand is not completely satisfied by installed capacity, electricity price would change
- Implementation of a supply curve and equilibrium quantities required (Takashima 2007)

Temporal demand distributions

- The place in the merit order determines the usage and the contribution margin of a specific power plant, defined by the marginal power plant
- In the model, full load hours are set exogenously, and not depending on the plant’s cost structure

Impacts of Renewables Energy Sources Act (EEG)

- Revenues for renewables depend on simulated electricity prices and not on fixed feed-in tariffs
- Future cost benefits only regarded by decreasing annual fixed costs

Outlook to further research

Required data is based on an extensive analysis of recognized studies and actual annual reports

► Further data background

Existing power plant fleet	• Development of already installed generation capacities is assumed to follow projections by DLR (2008) • Projected investment potential amounts to 70 GW until 2030
Weighted Average Cost of Capital	• Discount rate for NPV determination is calculated by applying the CAPM; required data is provided by annual reports 2007 from EnBW, E.ON, and RWE • Company-specific WACC is weighted with utilities' market share to end up with a general WACC for German electricity generators
Future CO_2 prices	• Future price development is derived by analyzing selected studies (DLR 2008, EWI and EEFA 2008) • CO_2 price is determined as average of multiple scenarios and price paths
Price Elasticity	• Price elasticity for electricity is lower than in other markets; Green (2007) applies a range for price elasticity from -0.05 to -0.3 • Relatively low value of -0.1 is assumed since economic growth is not regarded in particular

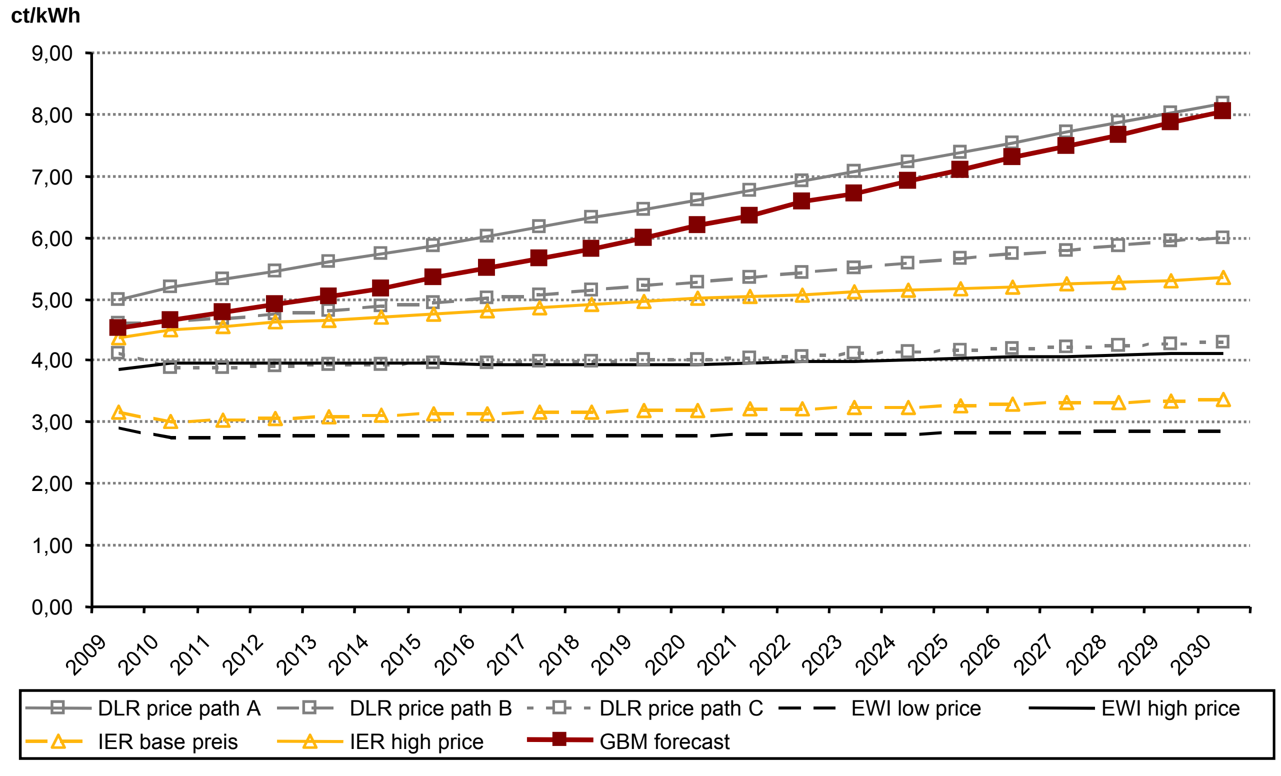
Sanity checks with external studies are carried out for each simulated price process to prove simulation results

► Sanity check for simulation results

Study cross-check

- Each simulated price development is compared to assumptions of several studies
- Simulations are quite in line with external trajectories:
  - Simulated fuel prices correspond both in trend and in absolute level

Example for natural gas



Source: Own calculations, DLR (2008), IER (2008), EWI/Prognos (2005), EWI and EEFA (2008)

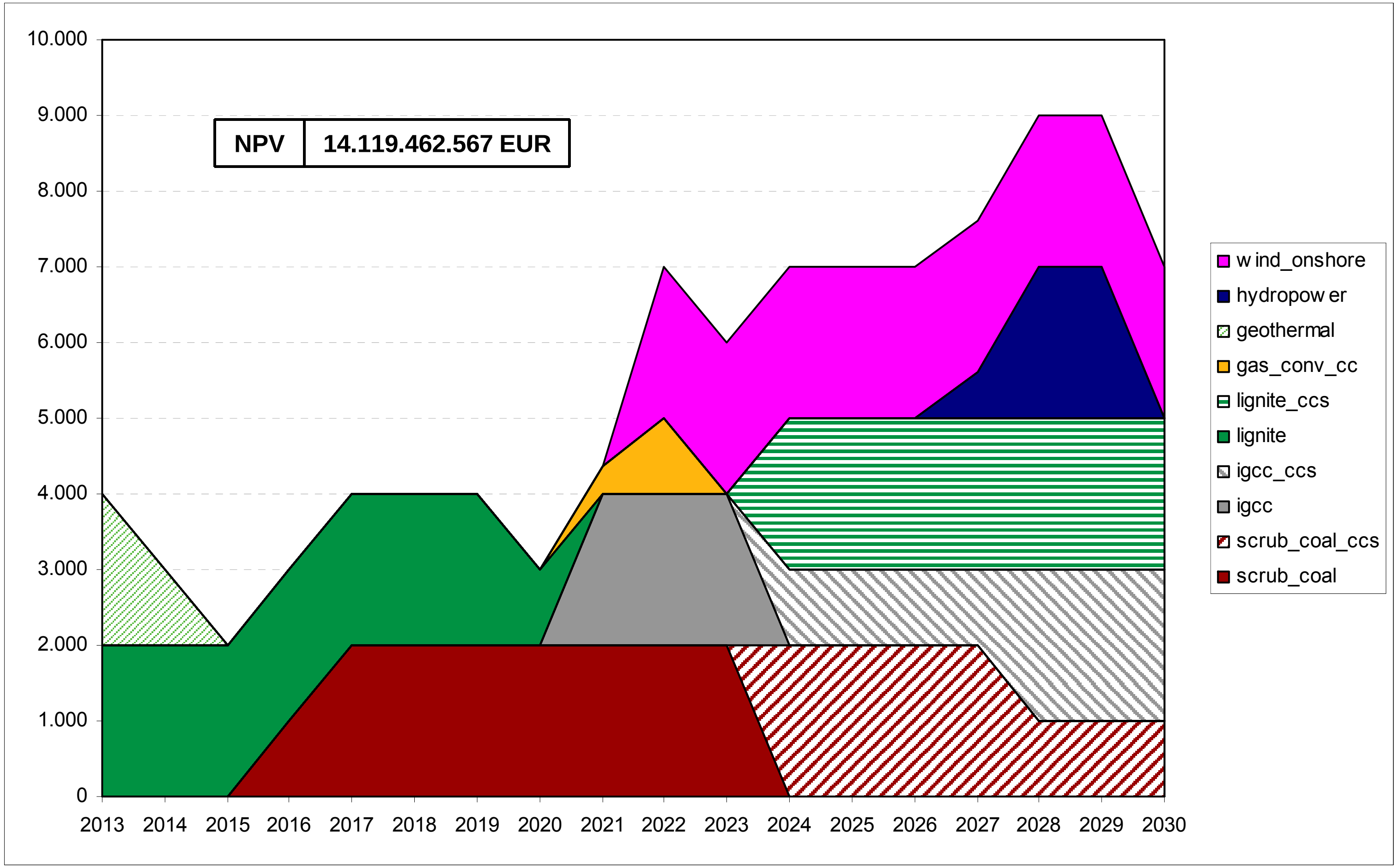
Selected scenarios are applied to illustrate a wide scope of consequences of possible future changes in the political framework

► Scenario development

Scenario	Assumptions
"Business as usual"	• Restrictions for geothermal (3 GW), photovoltaic (1.5 GW), hydro (5.2 GW) coal-based technologies (15 GW each); • Annual investments limited at 2 GW
"Nuclear"	• Expansion of nuclear power allowed • Scenario investigates the consequences of abolishing the nuclear phase-out
"Climate"	• EU-wide target of 20% of renewable sources on total final energy consumption • Kaltschmitt (2008) derives a 27% share in electricity generation for Germany
"CO_2 high"	• Scenario investigates a tighten CO_2 certificate allocation • The highest expected price path among the analyzed studies is chosen
"CO_2 low"	• Scenario investigates an eased CO_2 certificate allocation • The lowest expected price path among the analyzed studies is chosen

Investments feature a significantly positive NPV until 2030; Wind power and geothermal are the only expanded renewable sources

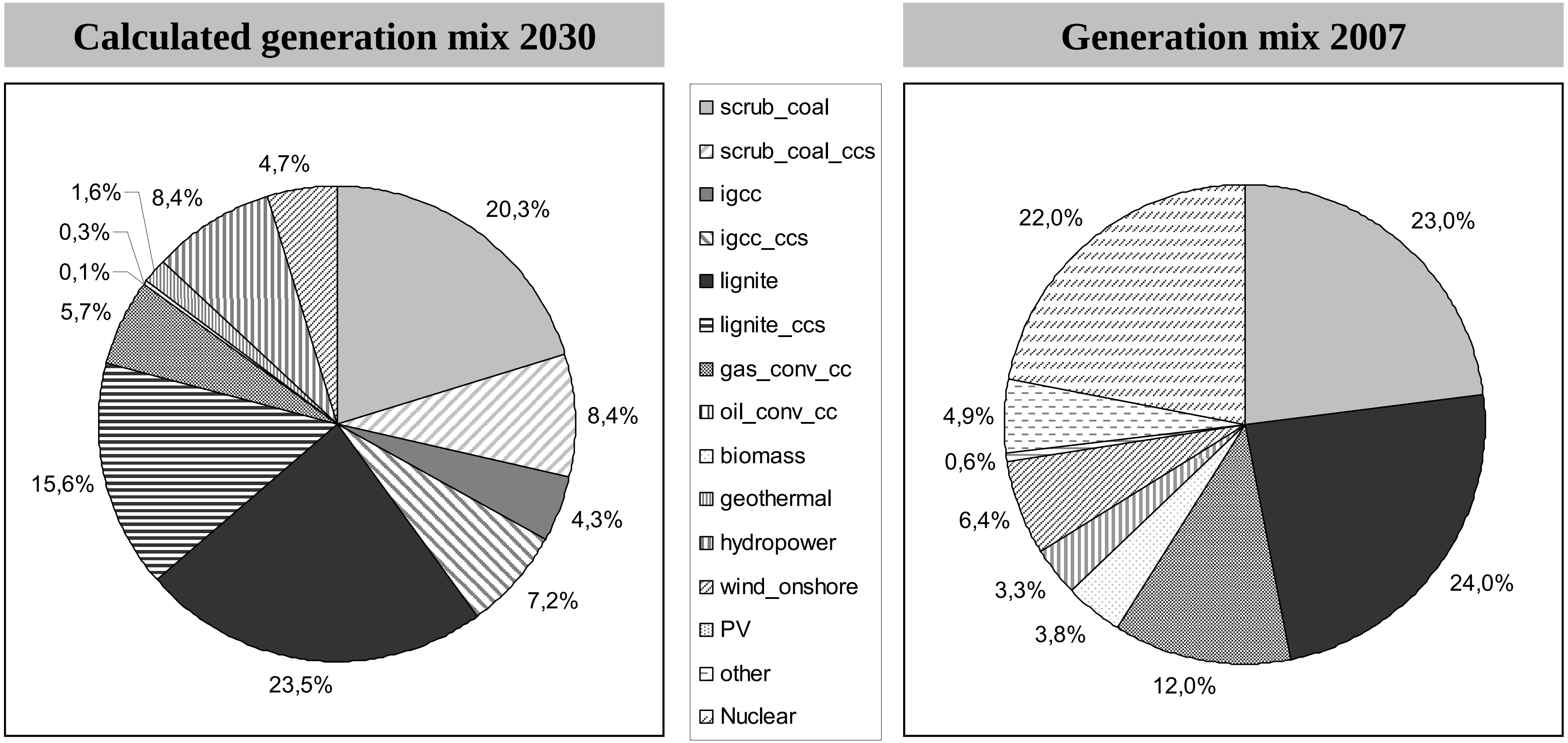
► Results – Capacity additions “BAU”



Source: Own calculations

Renewable share ends up with 17% which is slightly above the present share, mainly due to wind power and geothermal generation

► Results – Generation portfolio “BAU”

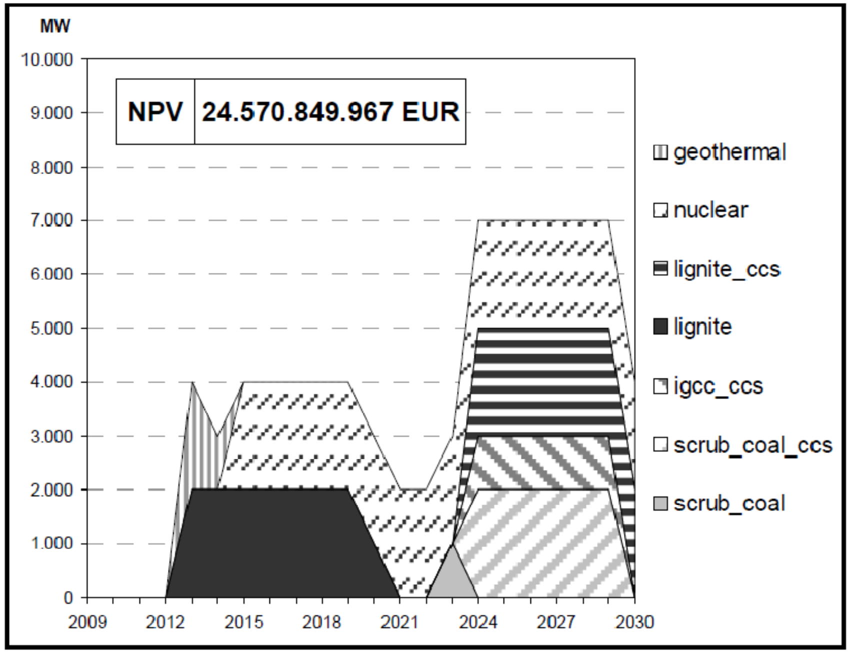


Source: Own calculations, Renewables Energies Agency (2008)

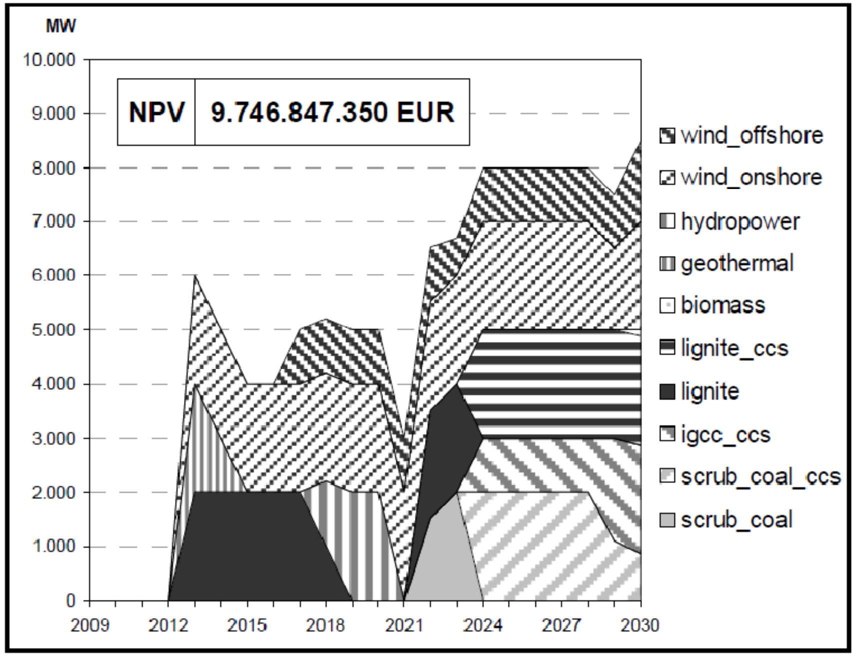
Nuclear power diminishes expansion of renewables; Wind power is technology of choice to reach climate targets

► Results – Capacity additions “Nuclear” and “Climate”

Scenario “Nuclear”



Scenario “Climate”

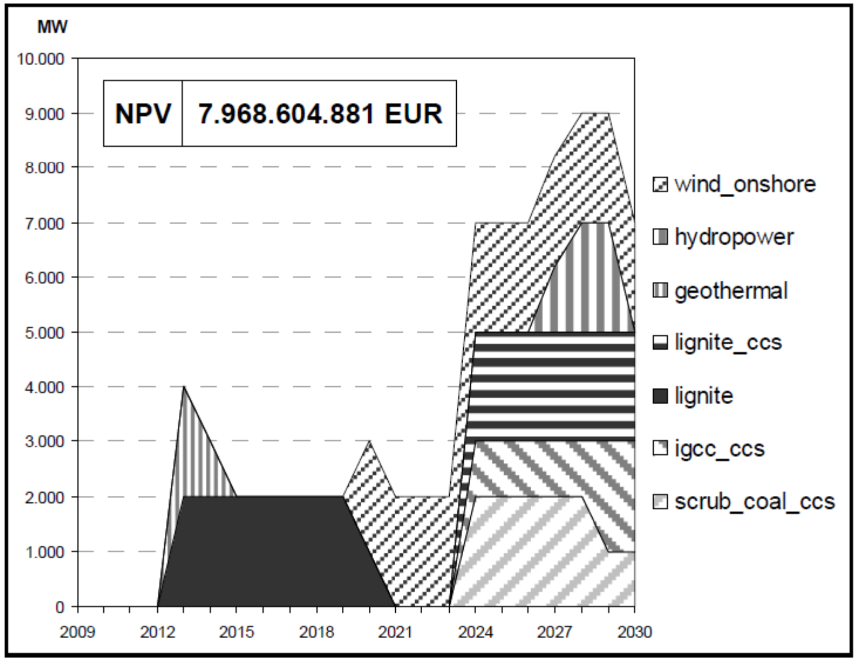


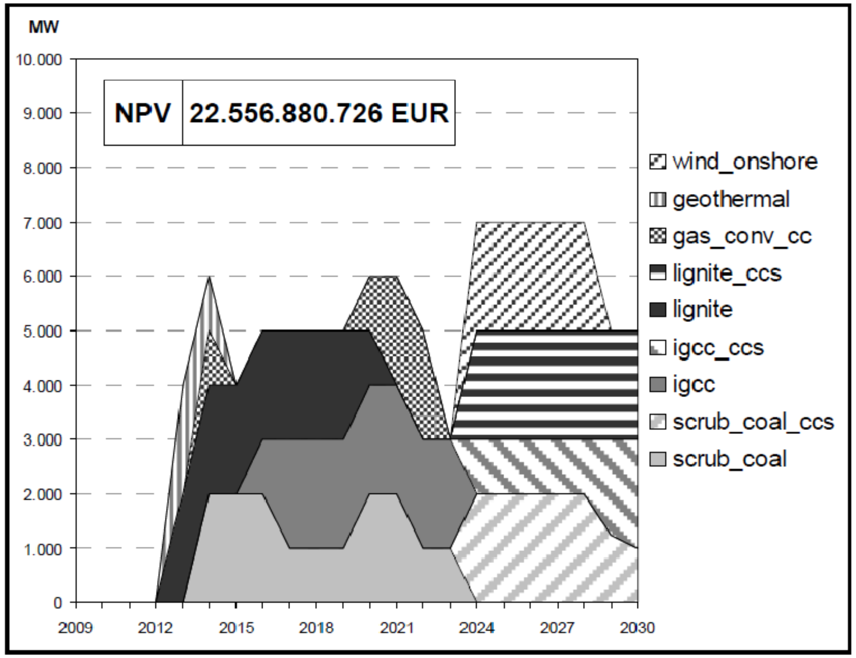
Source: Own calculations

Future CO_2 prices have a tremendous impact on the types of capacity additions and their economic efficiency

► Results – Capacity additions “CO_2 high” and “CO_2 low”

Scenario “CO_2 high”	Scenario “CO_2 low”



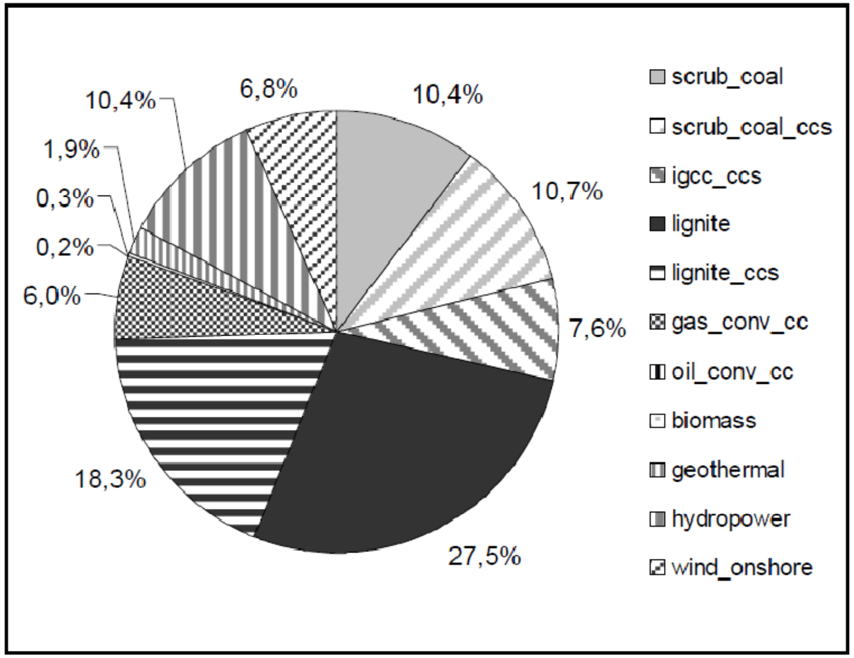


Source: Own calculations

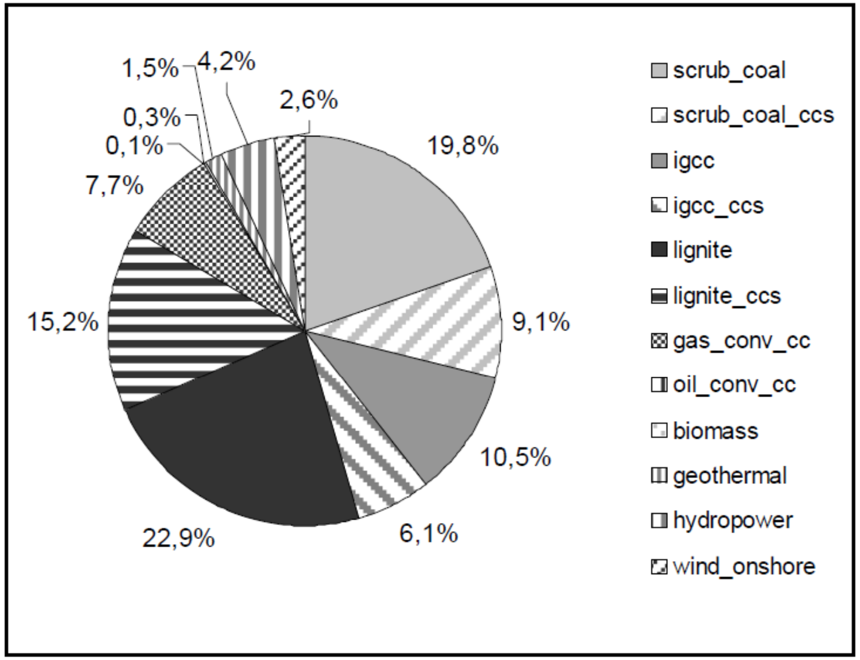
High CO_2 prices cause a strong expansion of renewable sources and an increased use of CCS technology

► Results – Generation portfolio “CO_2 high” and “CO_2 low”

Scenario “CO_2 high”



Scenario “CO_2 low”

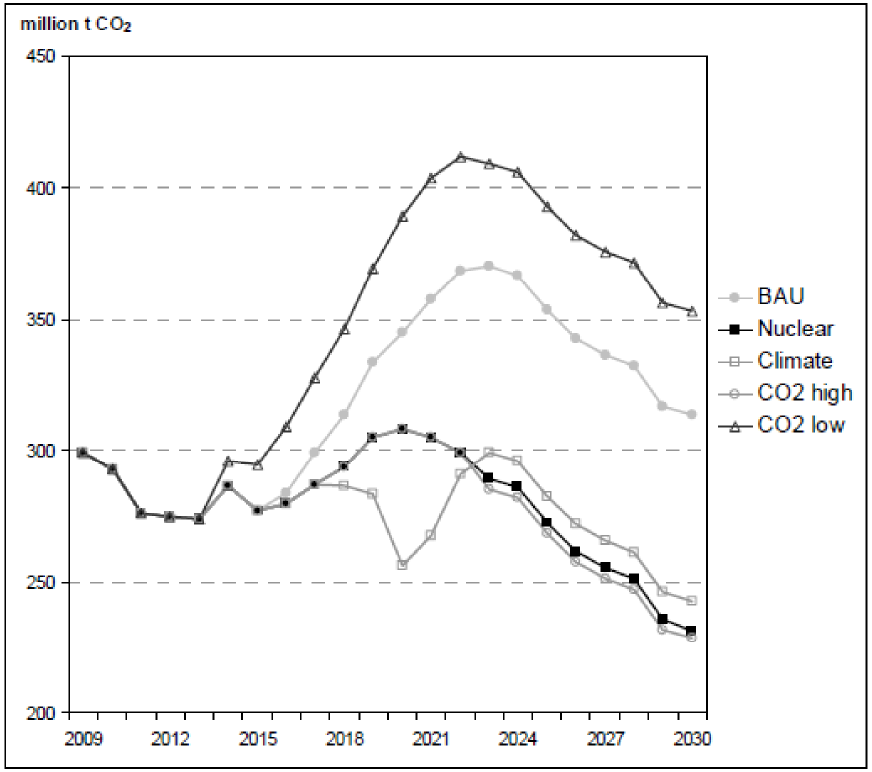


Source: Own calculations

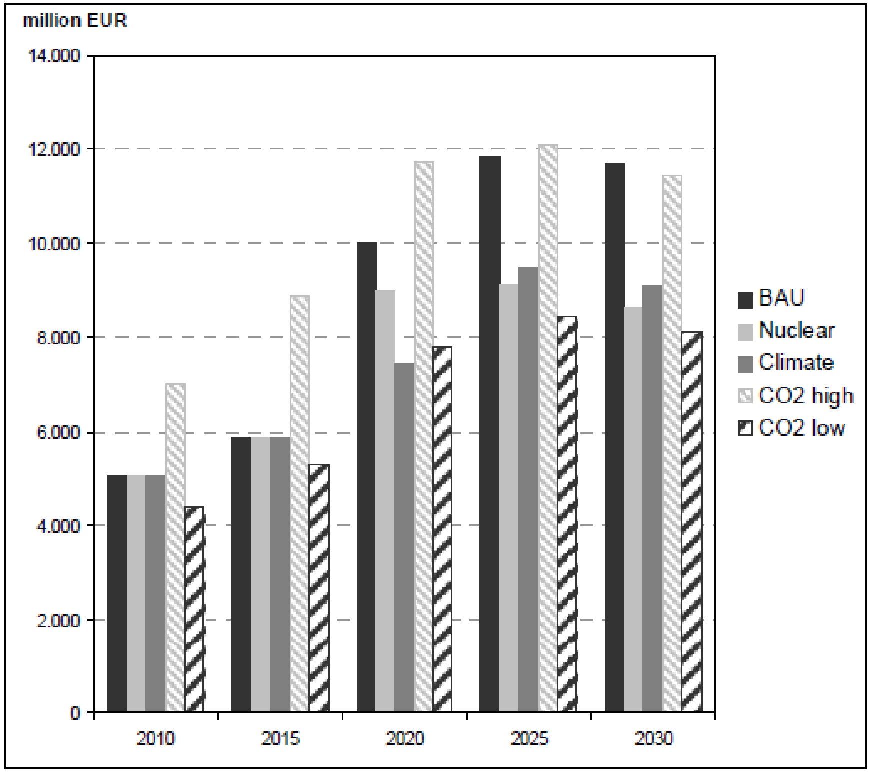
High CO_2 prices lead to lower total emissions than compulsory targets for renewables sources from the EU

► Results – CO_2 emissions

Total amount of CO_2 emissions



Total costs of CO_2 emissions



Source: Own calculations

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Economic efficiency of generation investments cause significant capacity additions until 2030, also in “clean” technologies

► Conclusions

- Investments in the German power plant fleet feature a NPV of **14.1 billion EUR until 2030** (BAU scenario)
- No investments are carried out up to the year 2013 due to lead times
- Total capacity additions amount to **98 GW until 2030** CCS technology is applied **as soon as available**
- Gap from nuclear phase-out is closed by an **expansion of fossil** generation types
- **Renewable share ends up with 17%** of the generation portfolio which is slightly above the present share, mainly due to wind power and geothermal generation
- Results demonstrate that obligations like quotas for renewables indeed heighten their diffusion but **do not automatically lead to reductions** of CO_2 emissions
- Only **increasing prices for emission allowances** stimulate generation portfolios that meet policy targets and simultaneously reduce emissions

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References (Selected)

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Thank you very much for your attention!

Any questions or comments?

florian.leuthold@tu-dresden.de **EE^2**

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Backup

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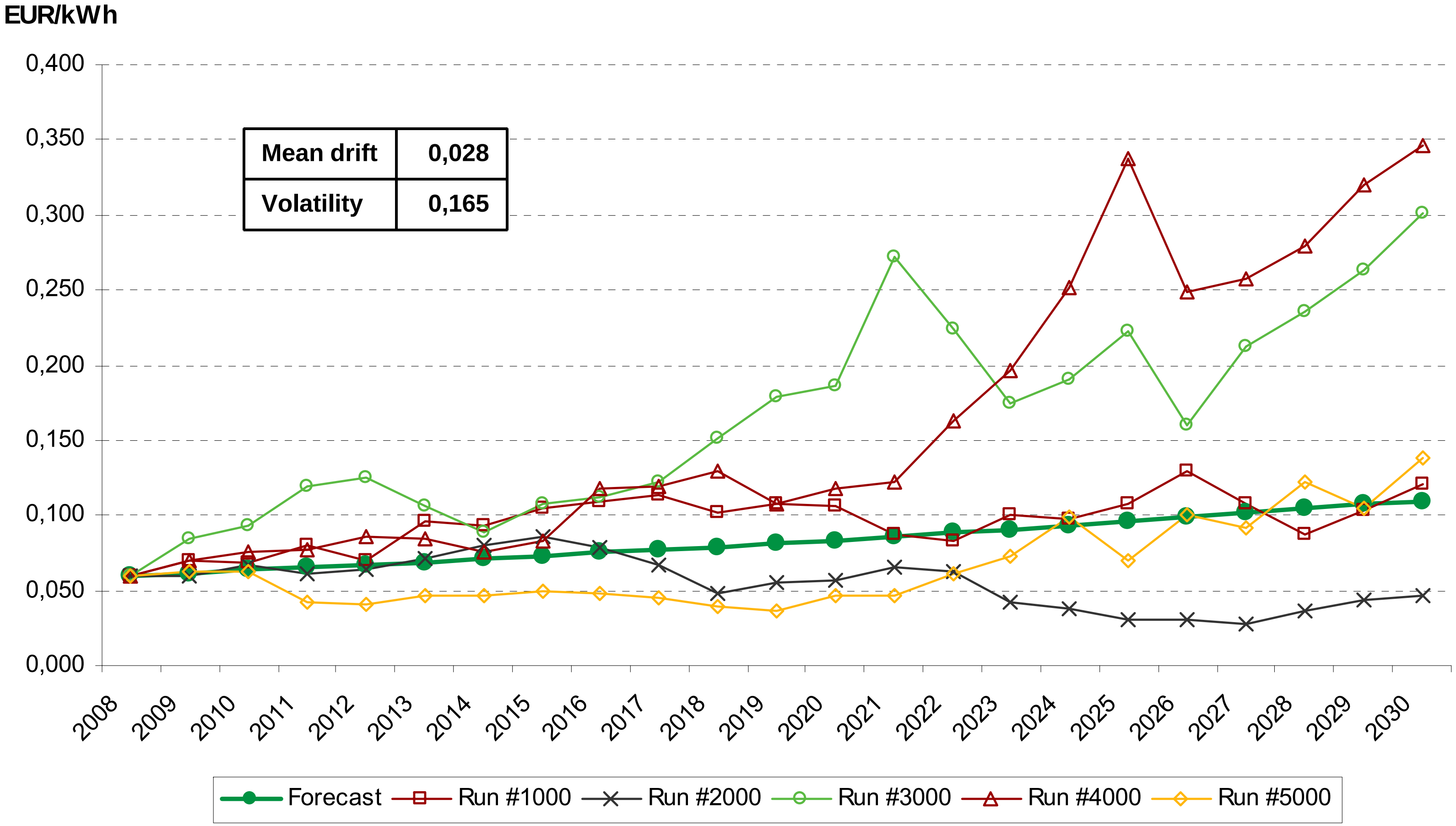
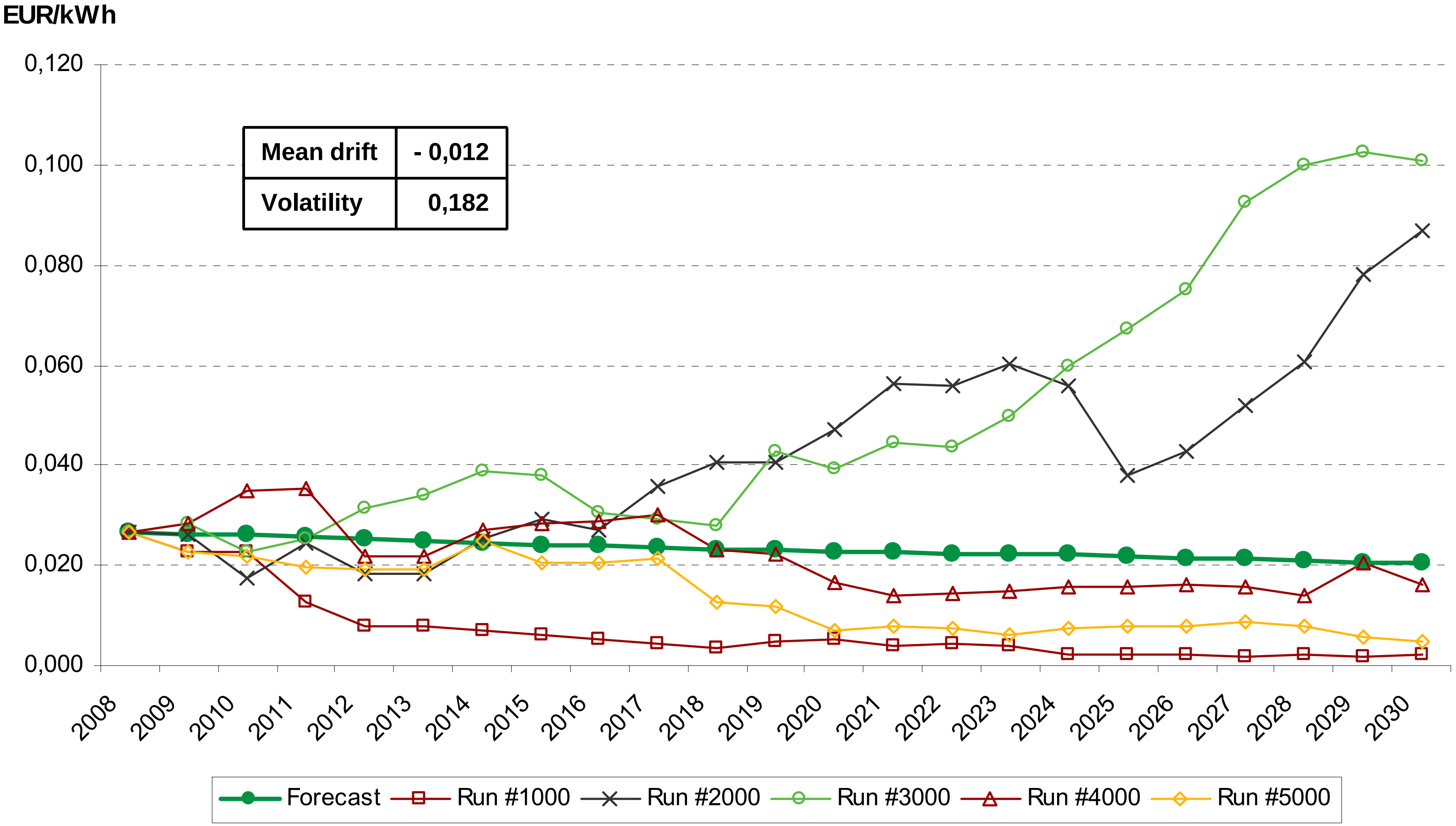
▶ GBM simulation – Electricity price



Source: Own calculations

Backup

▶ GBM simulation – Hard coal

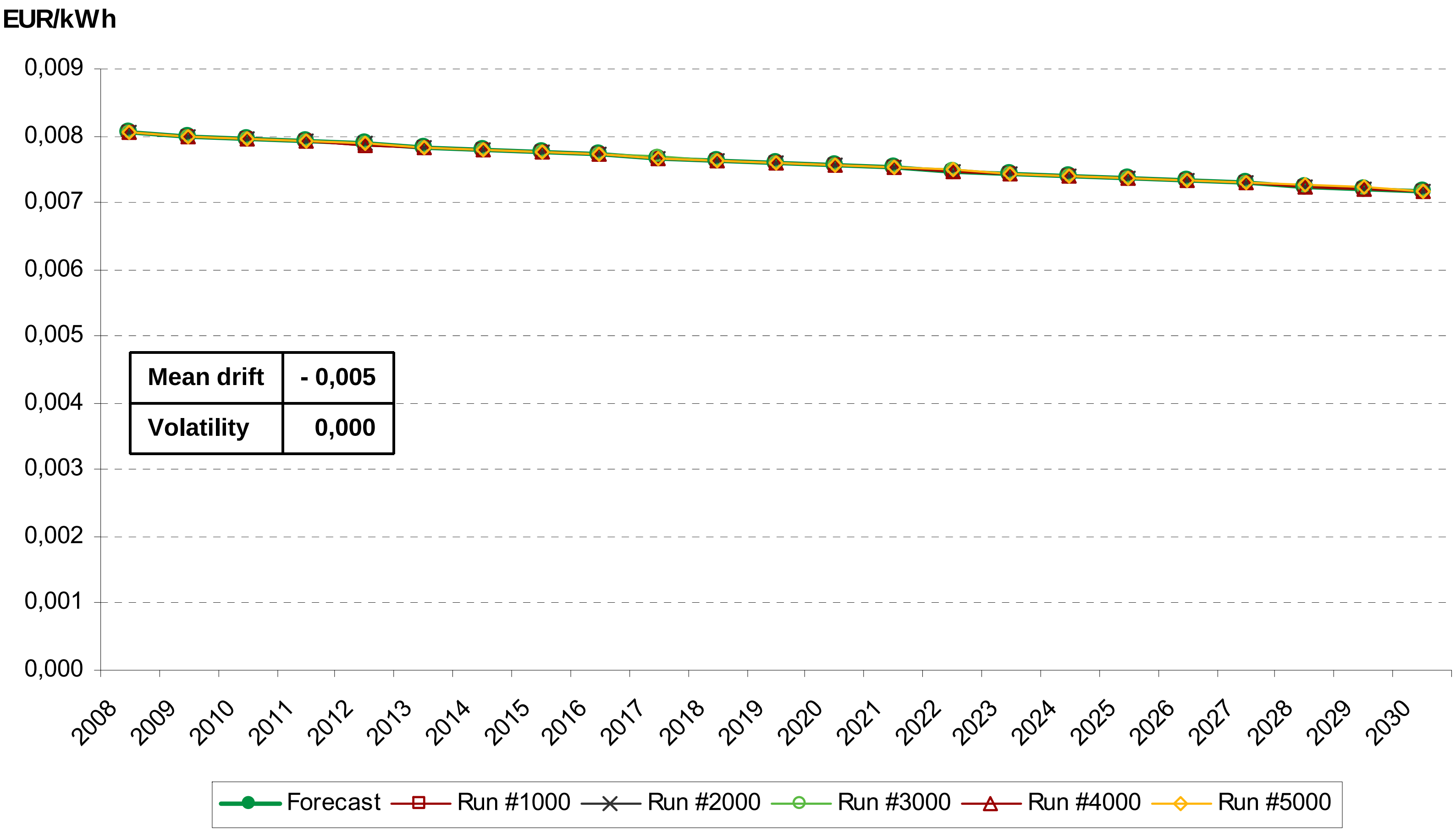


Mean drift	- 0,012
Volatility	0,182

Source: Own calculations

Backup

▶ GBM simulation – Lignite

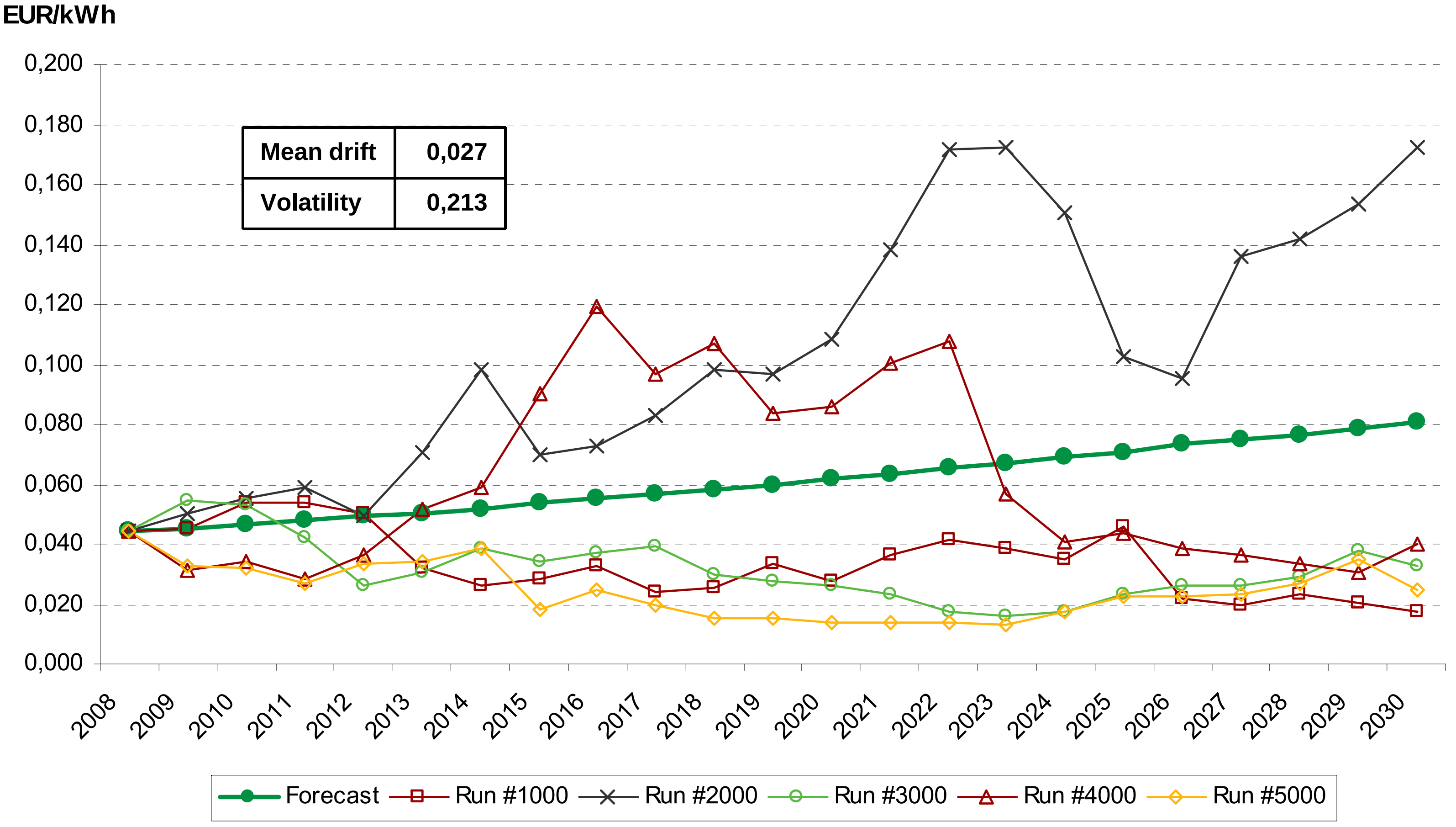


Mean drift	**- 0,005**
Volatility	**0,000**

Source: Own calculations

Backup

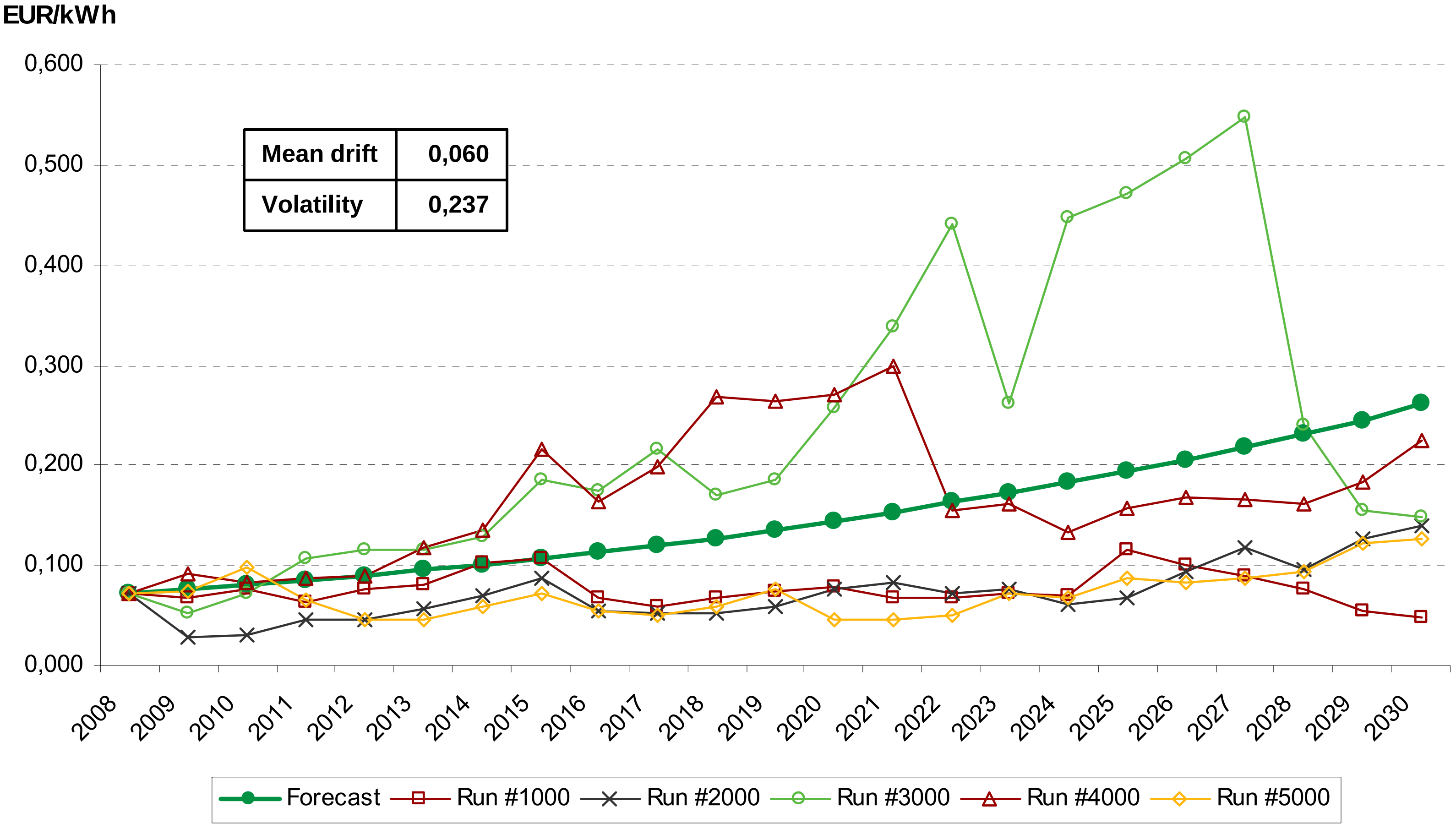
▶ GBM simulation – Natural gas



Source: Own calculations

Backup

▶ GBM simulation – Oil

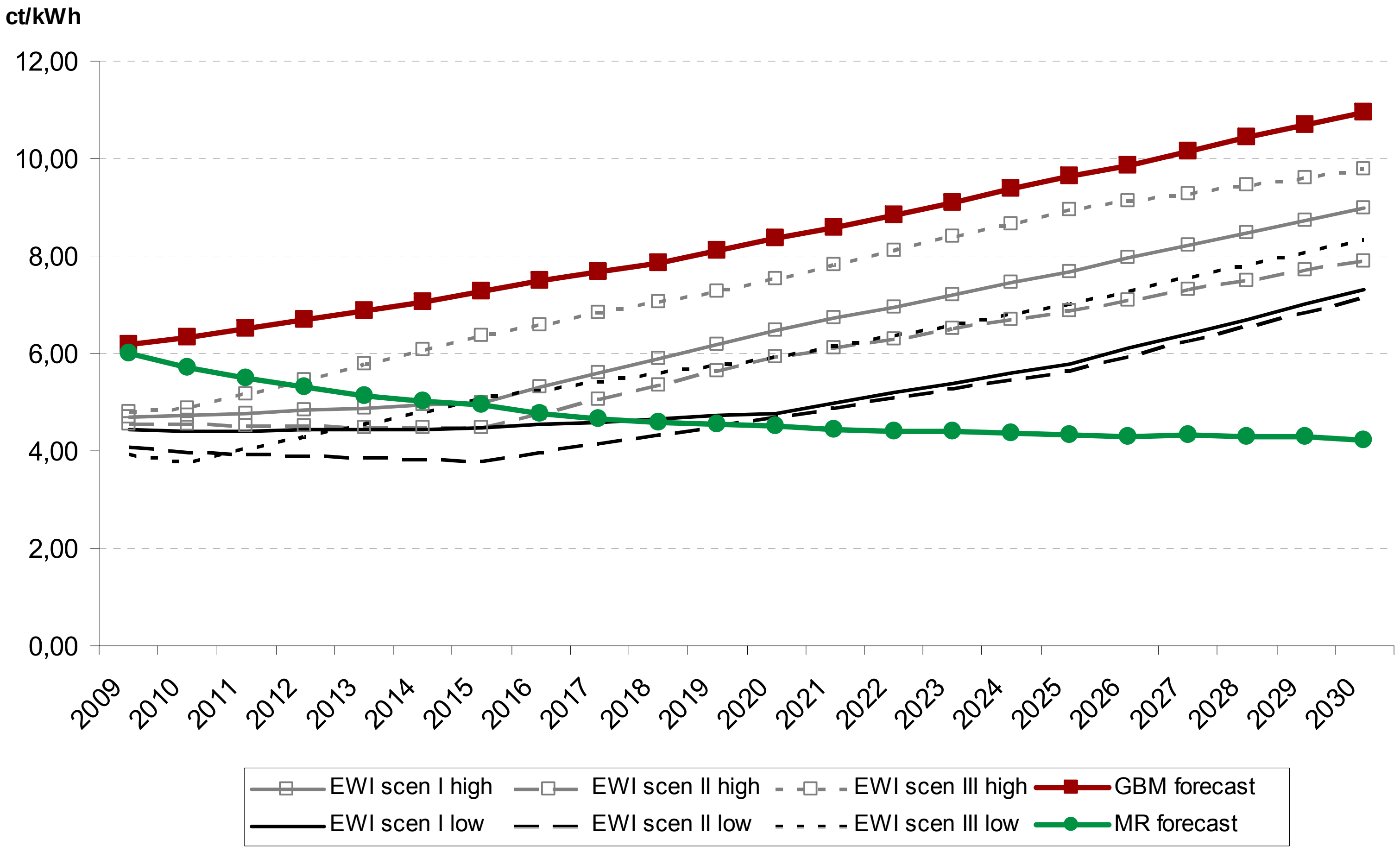


Mean drift	**0,060**
Volatility	**0,237**

Source: Own calculations

Backup

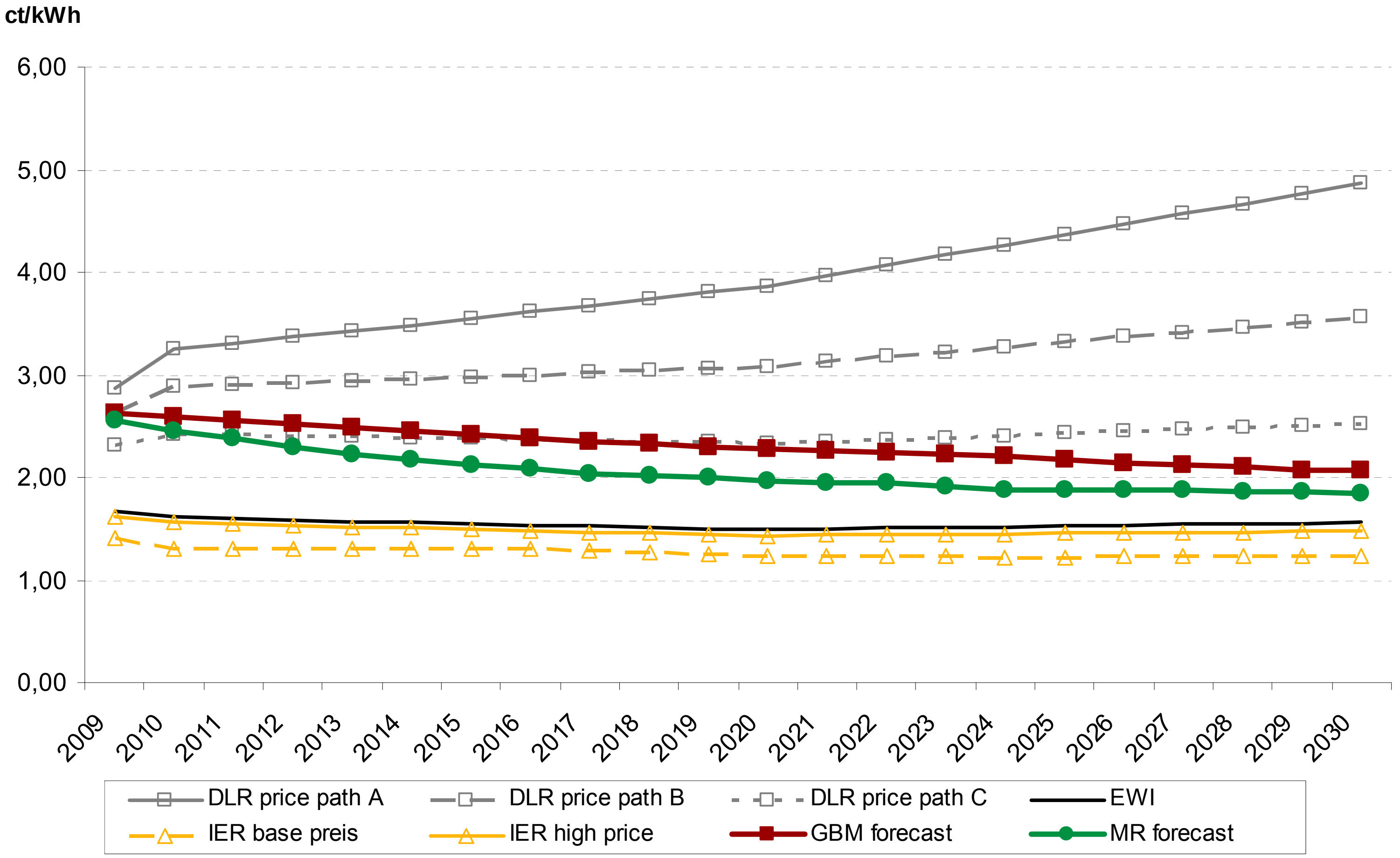
► Sanity check – Electricity



Source: Own calculations, DLR (2008), IER (2008), EWI/Prognos (2005, 2008)

Backup

▶ Sanity check – Hard coal



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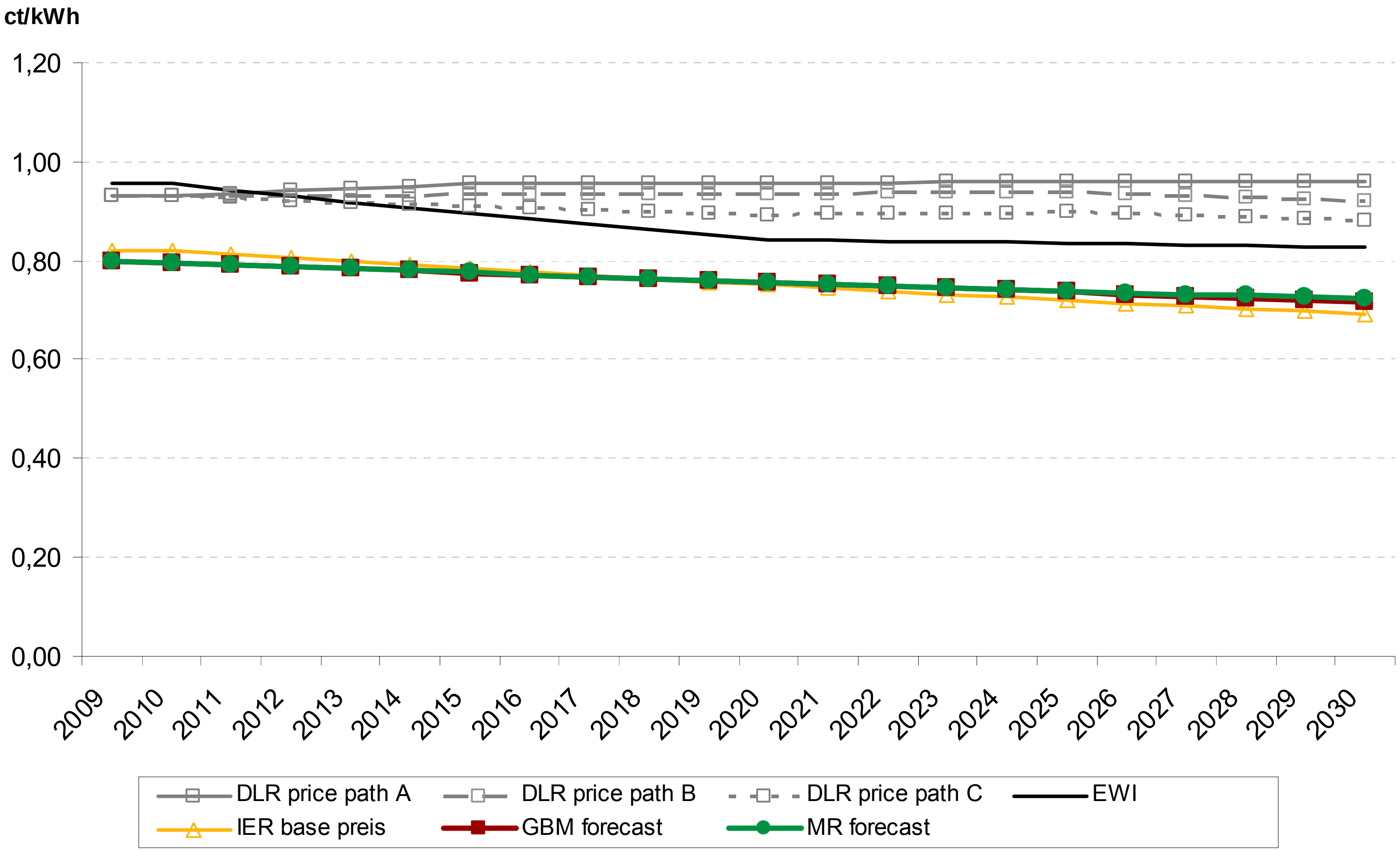

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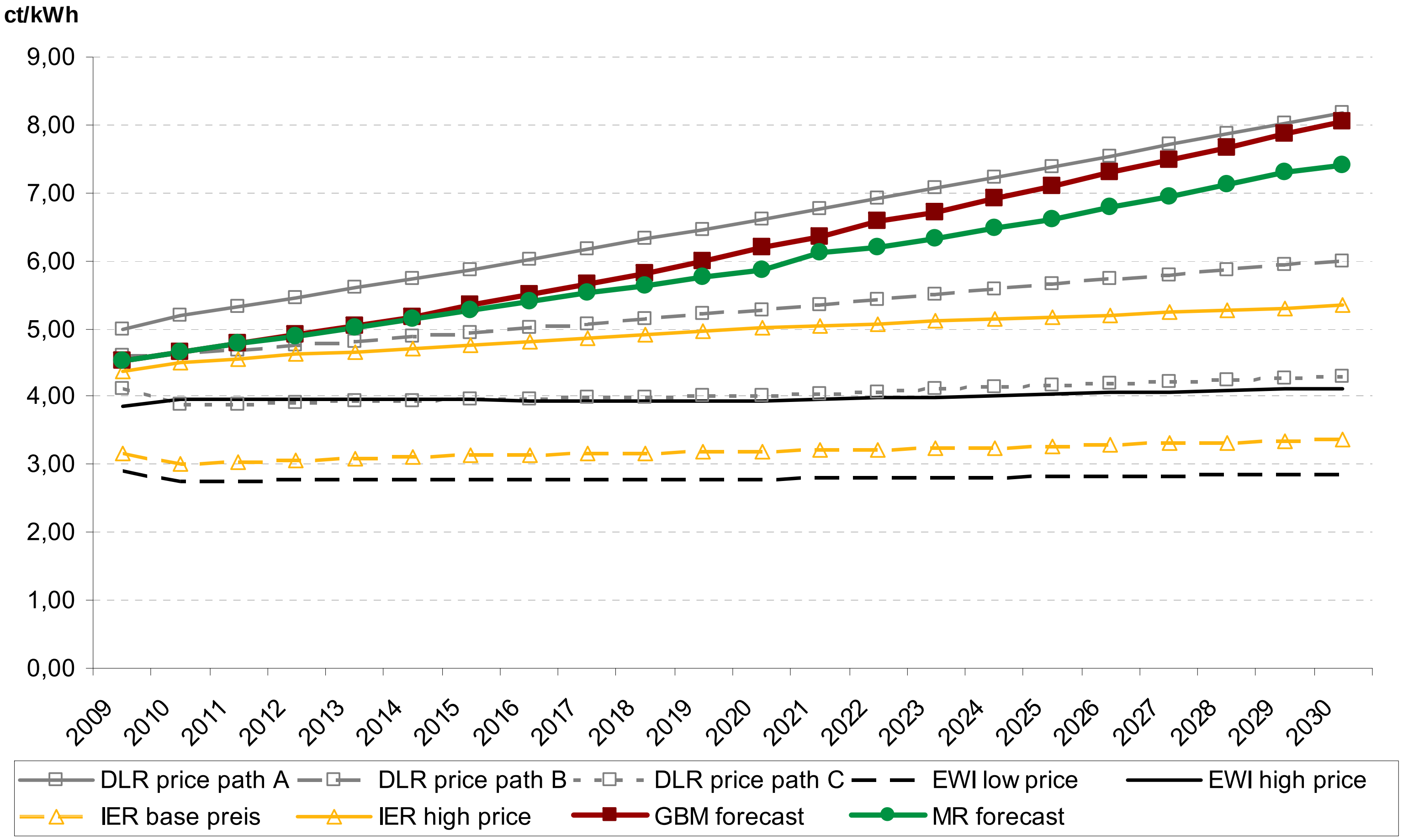
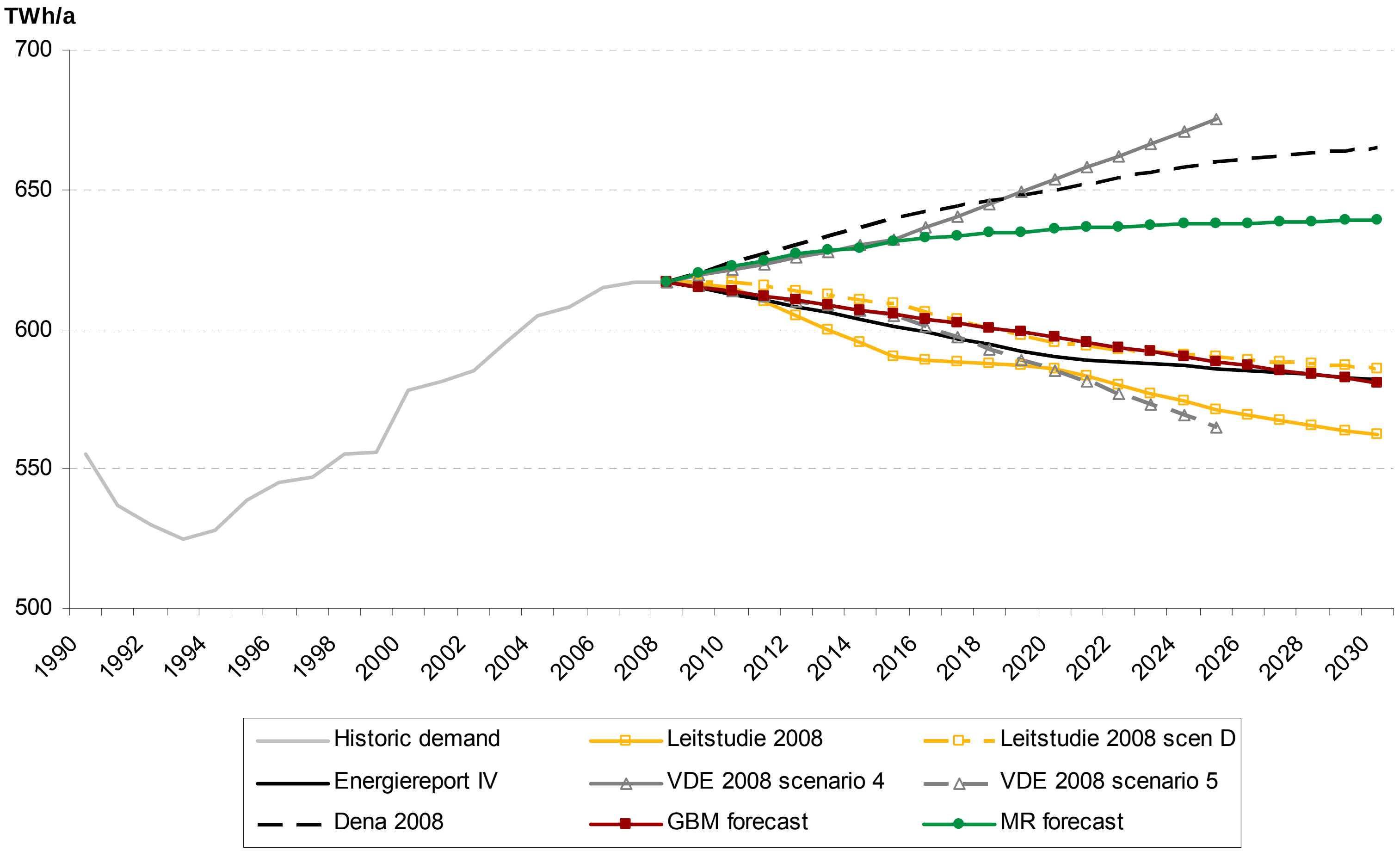
► Sanity check – Natural gas



Source: Own calculations, DLR (2008), IER (2008), EWI/Prognos (2005, 2008)

Backup

► Sanity check – Demand



Source: Own calculations, VDE (2008), DLR (2008), Dena (2008), EWI/Prognos (2005), EWI and EEFA (2008)