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Macroeconomic Cycles as a Source of Uncertainty in Long-Term Energy Scenarios

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Motivation and treatment of uncertainty in scenarios

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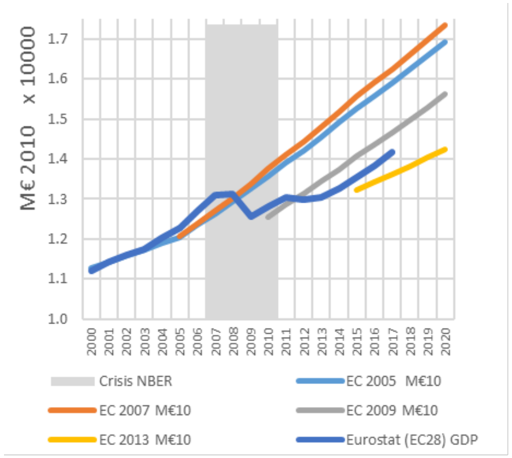


Figure 1 – Development of assumptions about the EU(28) GDP in the baseline scenarios

For the reason of simplification, the modeling frameworks applied to energy system studies tend to assume:

- **Continuous (or even linear) trends** for key factors as economic growth, energy prices, technological improvements (e.g. efficiency, learning rates)
- **Perfect forecasts** of prices that produce systematic forecasting errors [Price and Keppo, 2017]
- **Certain time intervals / periods**

A choice of the historic time span that may fall onto periods of structural changes (as a crisis or technological change):

> “If the effectiveness of the energy policy were to be analyzed in the second half of 1990 based on the technological data post-1973, the results would be overly optimistic”
>
> [Kuper and Van Soest, 2003]

Motivation and treatment of uncertainty in scenarios

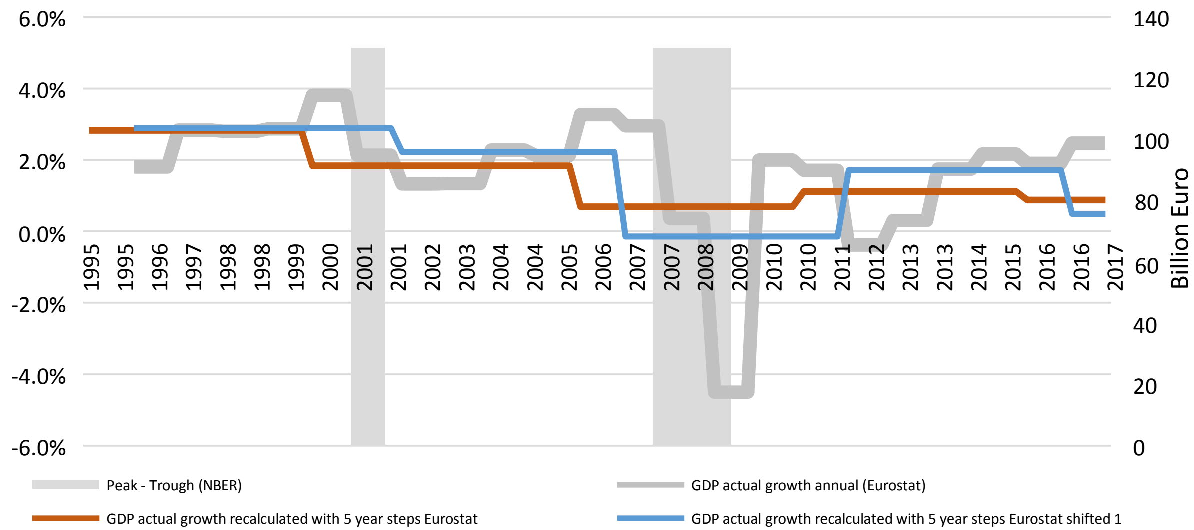


Figure 2 – Development of the EU(28) GDP

*EU 28 Source: Eurostat database (2018)

Approaches to defining uncertainty and how it is addressed in the energy modeling exercises:

- ***Context uncertainty:*** (or uncertainty that is addressed by scenario techniques) [Guivarch C. et al., 2014]
  - Story and simulation (SAS) approach [Alcamo, 2008] implemented for IPCC SRES Scenarios 2000
  - Cross-impact balance (CIB) analysis [Weimer-Jehle, 2006, Schweizer and Kriegler, 2012]
  - Socio-technical scenarios and transition pathways [Verbong and Geels, 2007]
  - Shared socio-economic transition pathways [O’Neill et al. and Van Vuuren et al., 2014]
  - Multi-objective scenarios (multi-criteria analysis) [Buchholz et al., 2009]

Motivation and treatment of uncertainty in scenarios

- ***Parametric uncertainty:*** *"input socio-economic, technical and environmental data, all of which comes with its own inherent uncertainties of varying severity, now and into the future"* [Price and Keppo, 2017]
    - *Sensitivity analyses: e.g. Monte-Carlo methods*
- ***Structural uncertainty:*** *"model's necessarily simplified representation of the extreme complex real energy-environment-economy system"* [op. cit.]
    - Implementation of myopic decision-making [Keppo and Strubegger, 2010]
    - Finding near cost-optimal solutions [Trutnevyte, 2016]
    - Stochastic modeling of uncertainty [Weijde and Hobbs, 2012]

> "…input data is rarely harmonized, structural uncertainty is mixed with parametric, or neglected" [Price and Keppo, 2017]

Motivating questions:

- How does consideration of **different time intervals** and average price/cost growth forecasts impacts the modeling results?
- How does unobserved **fluctuations inside the time intervals** impact investment decisions?
- Why 2005-2014? This period gives us a good overview of **business cycles**:
    - economic growth (January 2005 until May 2008),
    - recession (May 2008 until April 2009),
    - timid growth / recovery (April 2009 until July 2010).

Model description and experiment setting

Linear electricity market optimisation dispatch and investment model

- Time period 2005-2014
- Modelled:
  - yearly, with historic exogenous data on capacity, GDP, fuel prices, electricity demand
  - yearly, period 2005-2014
  - yearly, period 2005-2009 and 2009-2014

Averages or average growth taken for GDP, fuel prices, electricity demand

Supply Characteristics

Capacity
- composition of the generation fleet; hourly conventional power plants, solar, wind and hydro availability

- fuel and variable costs, CO_2 costs

Costs

Optimization

Minimize costs:

$$Z = \sum_{h,i,d} Pr(h,i,d) \cdot Cst(i,d) + \sum_{h,d,k} Im(h,d,k) \cdot T \quad (1)$$

Subject to:

$$\sum_{i} [Pr(h,i,d)] - \sum_{k} Im(h,d,k) + \sum_{j} Im(h,j,d) = Dm(h,d) \quad (2);$$

$$Pr(h,i,d) \le Cp(h,i,d) \quad (3)$$

$$Im(h,i,d) \le NTC(j,k) \quad (4)$$

Demand Characteristics

Hourly load data

National electricity market in a country *j*

Import

Export

EU electricity market

Model description and experiment setting

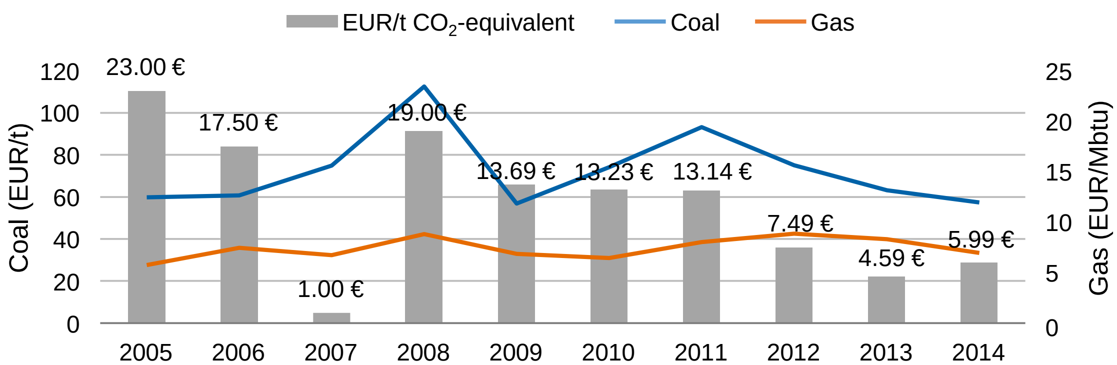


Figure 3 – Changes in fuel prices

Sources: (EUA price 2005-2008) Trends and projections in the EU ETS, EEA (2017); (EUA price 2009-2014) EEX; (coal and gas) BP Statistical Review of World Energy (2017)

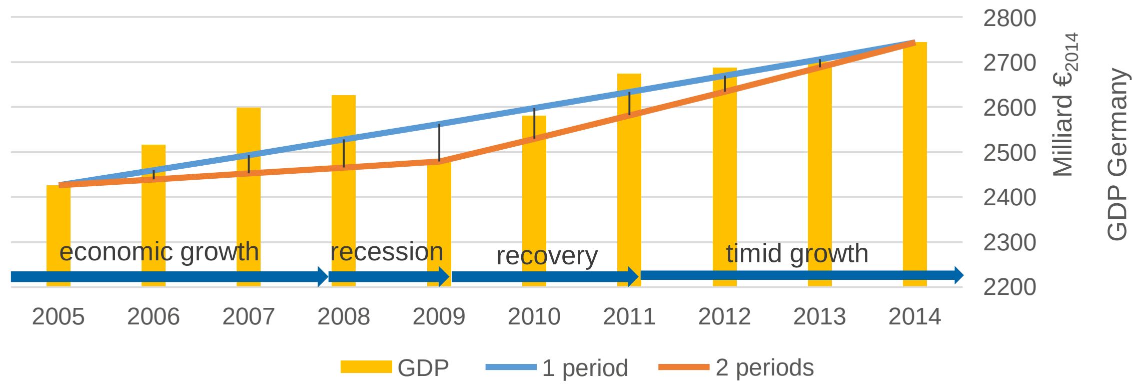
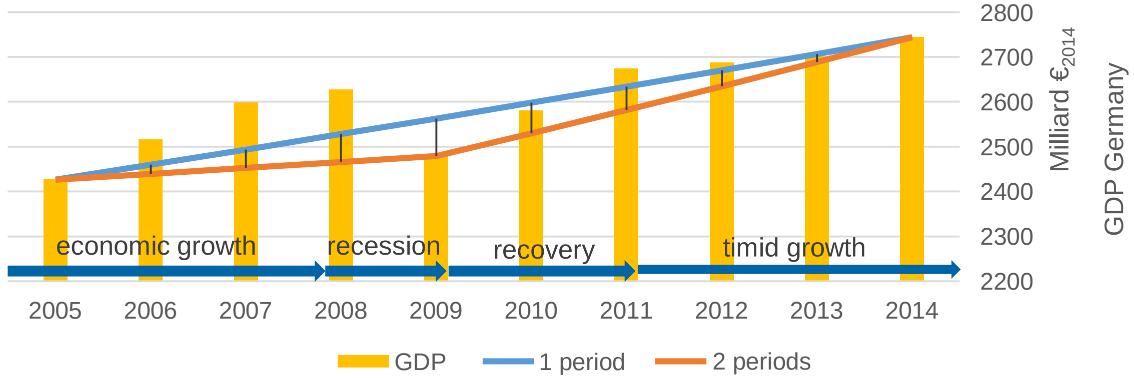


Figure 4 – Changes in German GDP

Sources: (World Development Indicators database (2017)

Main results: producer surplus



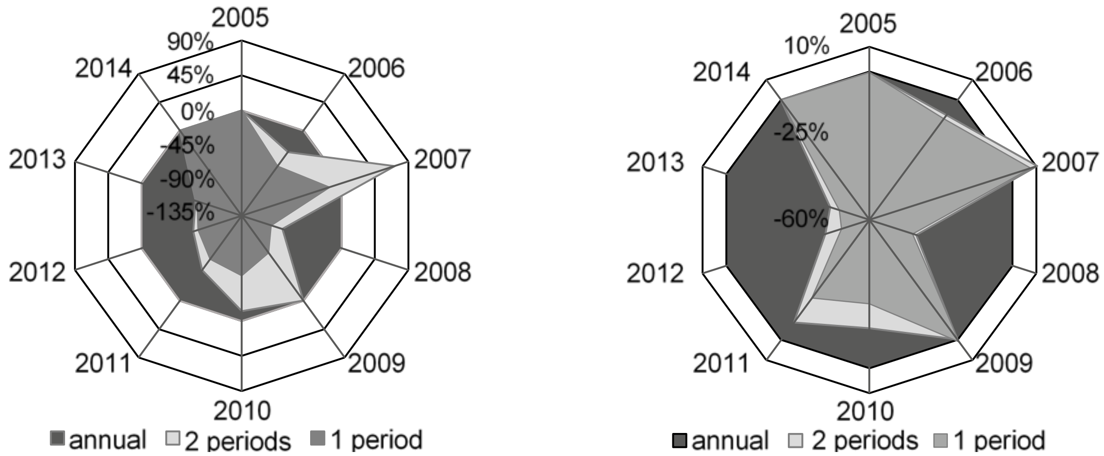
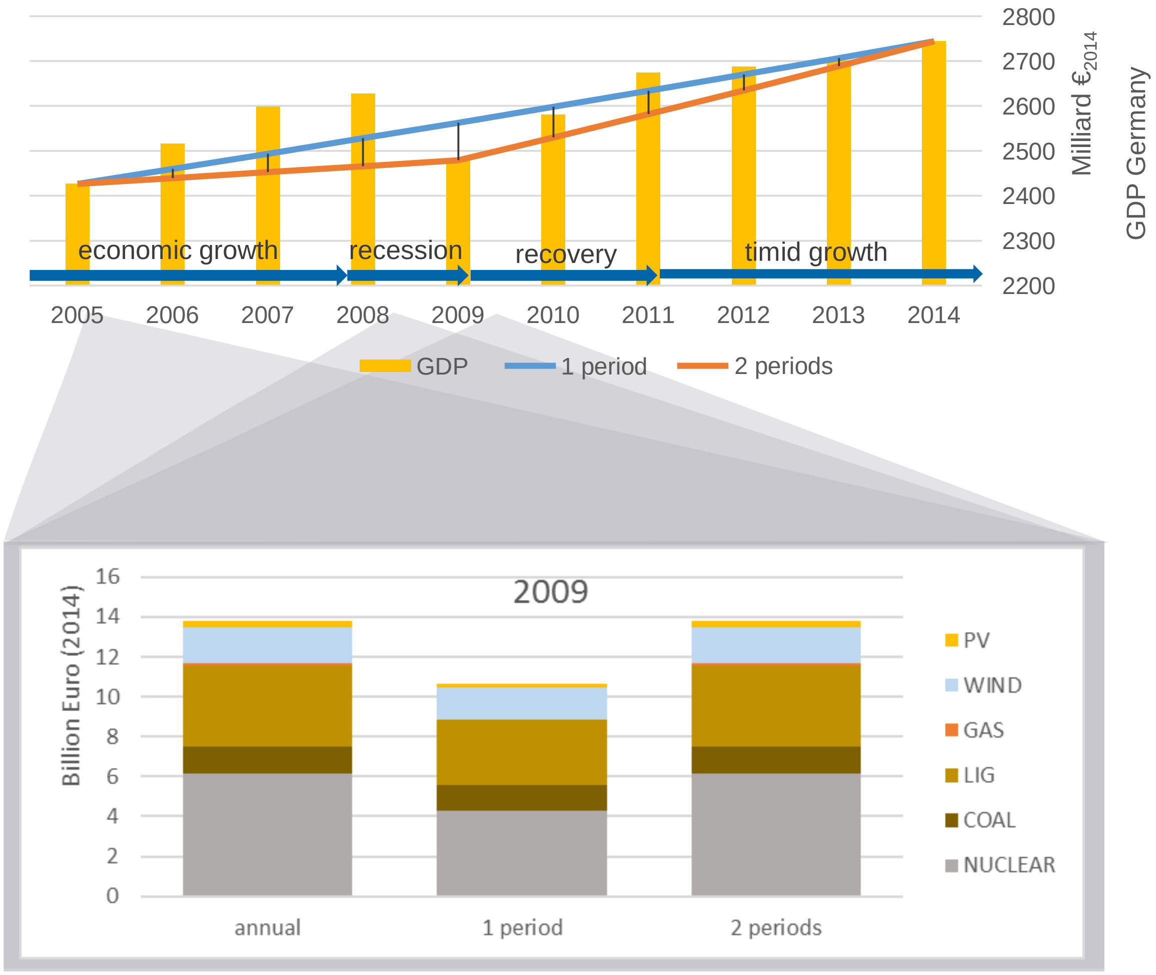
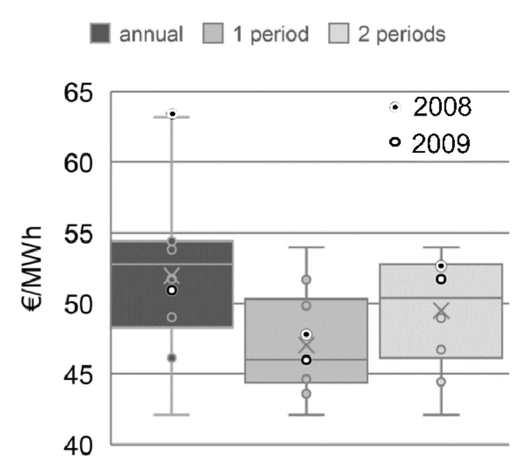


Figure 5 – Changes in Producer surplus (model results)

Main results: producer surplus



Main results: producer surplus and (wholesale) electricity prices



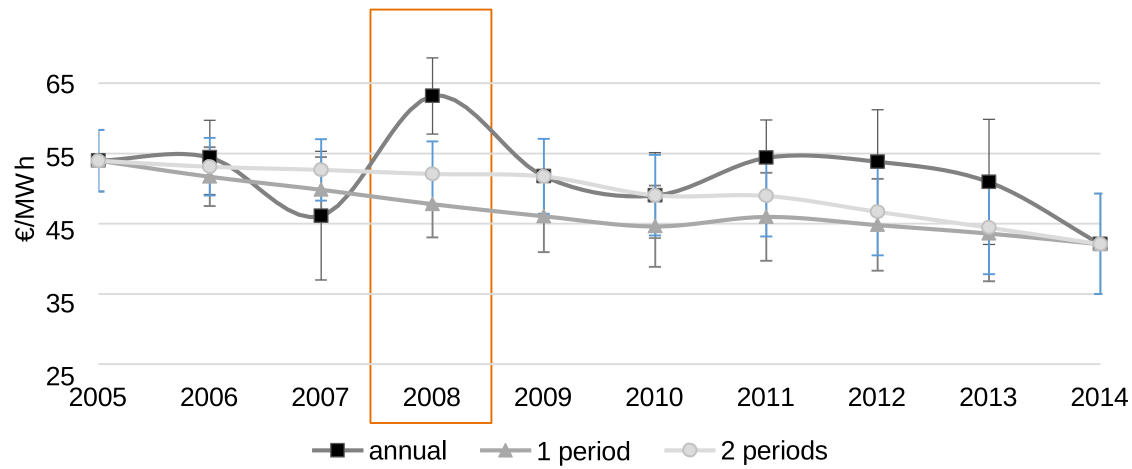
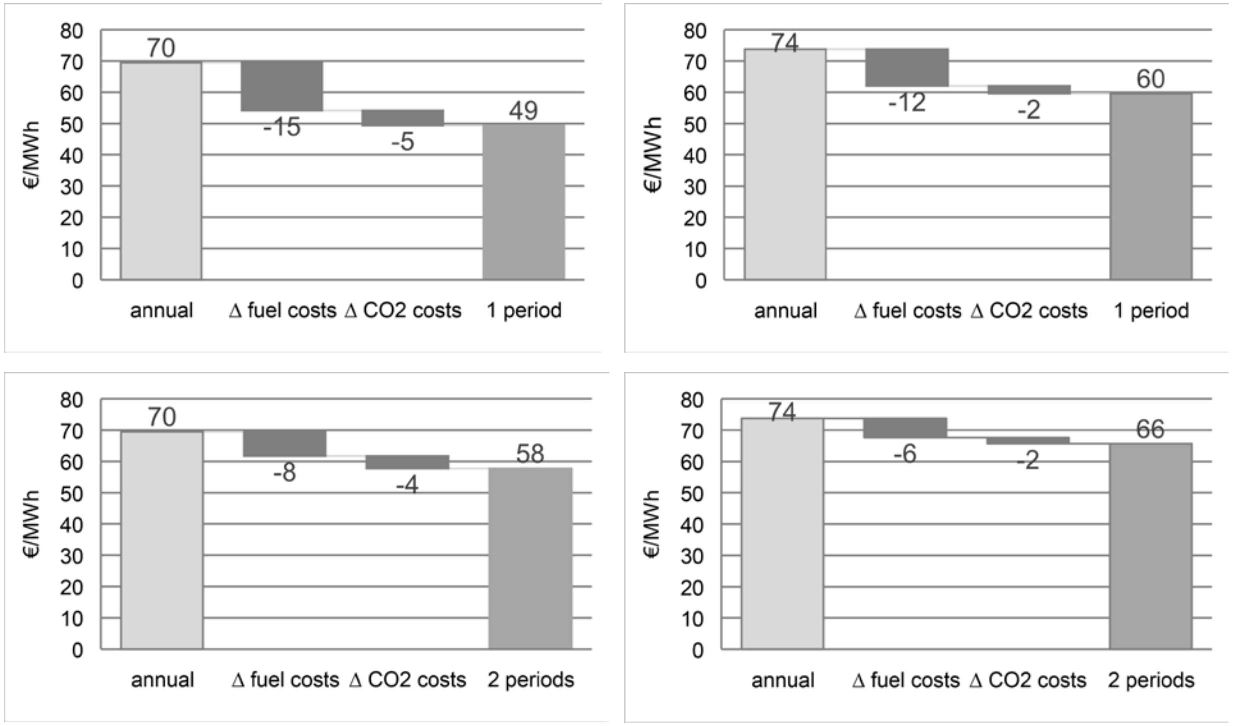


Figure 6 – Range of electricity prices over the period 2005-2014 (model results)

Main results: producer surplus and (wholesale) electricity prices



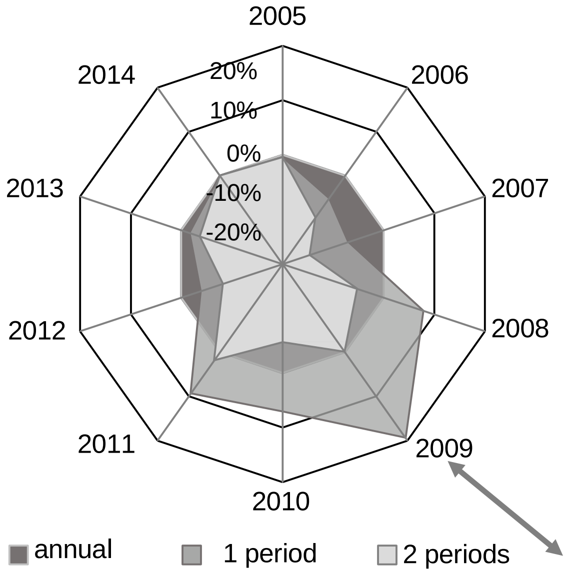
(a) Average variable costs (€/MWh) for typical mid-load power plant (here: hard coal).

(b) Average variable costs (€/MWh) for typical peak-load power plants (here: CCGT).

Figure 7 – Decomposition of changes in the input variable generation costs in the three scenarios (given for the year 2008) (model results)

Main results: CO_2 emissions

Underestimated emissions and their root causes



- More coal in the mix
- No change in coal prices relative to changes in gas prices over 2005-2009

Figure 8 – Development of CO_2 emissions from electricity generation over the period 2005-2014 (model results)

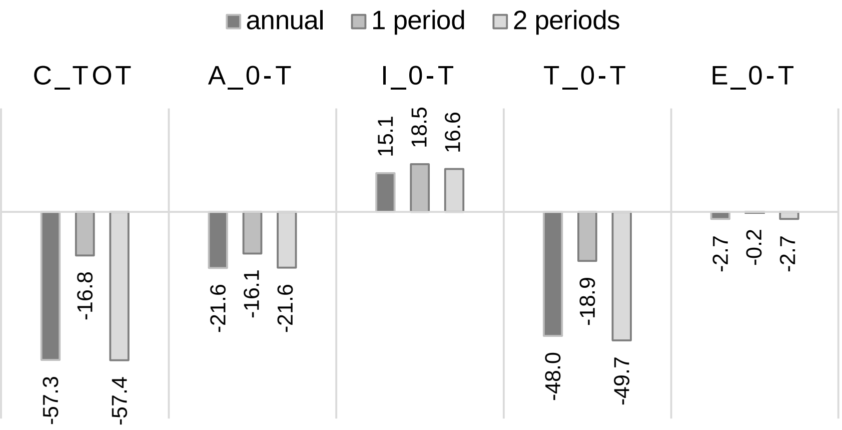


Figure 9 – Decomposition of changes in CO_2 emissions from fuel combustion in the electricity sector comparing 2014 (0) to 2009 (t). (model results)

$$\Delta C_{0-t} = C_0 - C_t = \Delta A_{0-t} + \Delta I_{0-t} + \Delta T_{0-t} + \Delta e_{0-t}$$

Karmellos et al. (2016)

A_t - activity effect

I_t - electricity intensity effect

T_t - electricity trade effect

$e_{i,t}$ - energy efficiency effect

Main results: Investment

Changes in the investment patterns

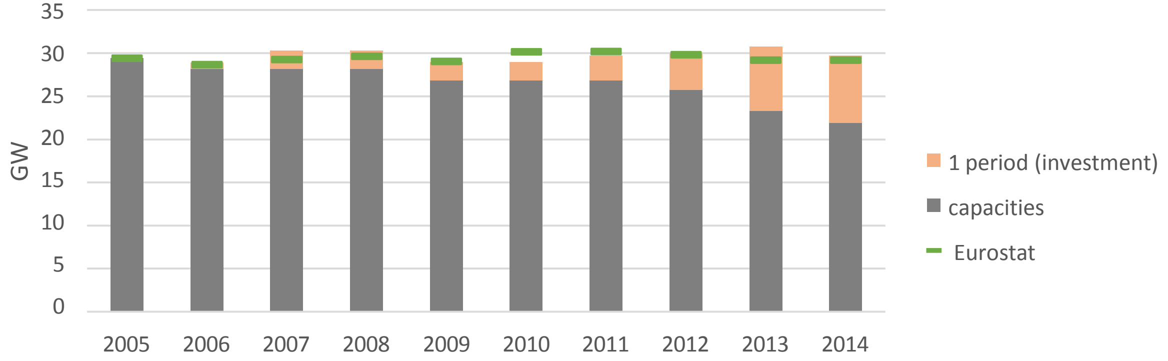
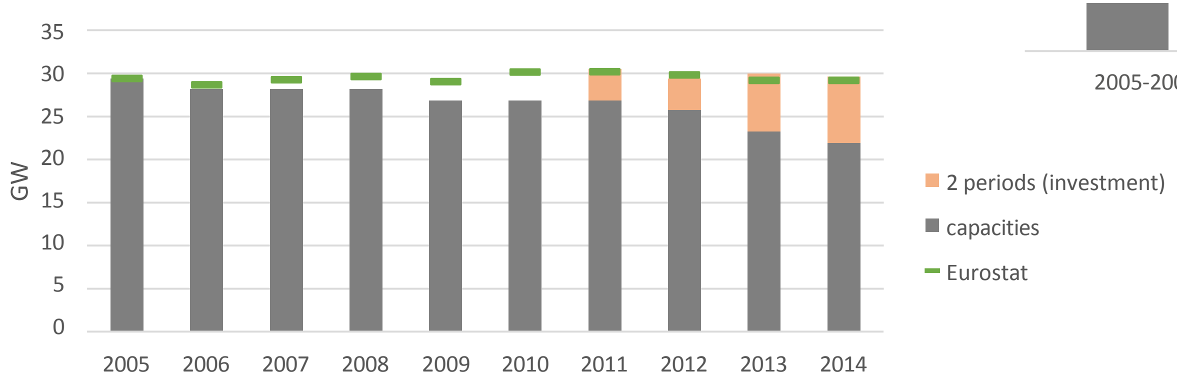


Figure 10-11 – Investment in coal-fired capacities in the period 2005-2014 (model results)



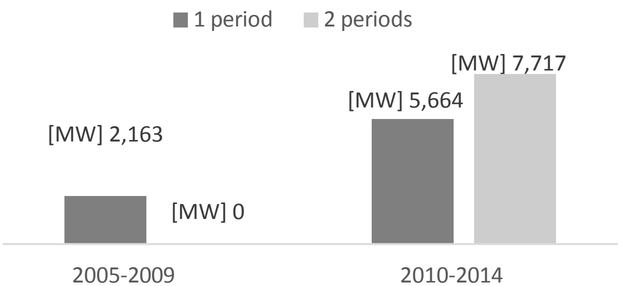


Figure 12 – Investment in coal-fired capacities in two periods (model results)

Main results: Investment

Changes in the investment patterns

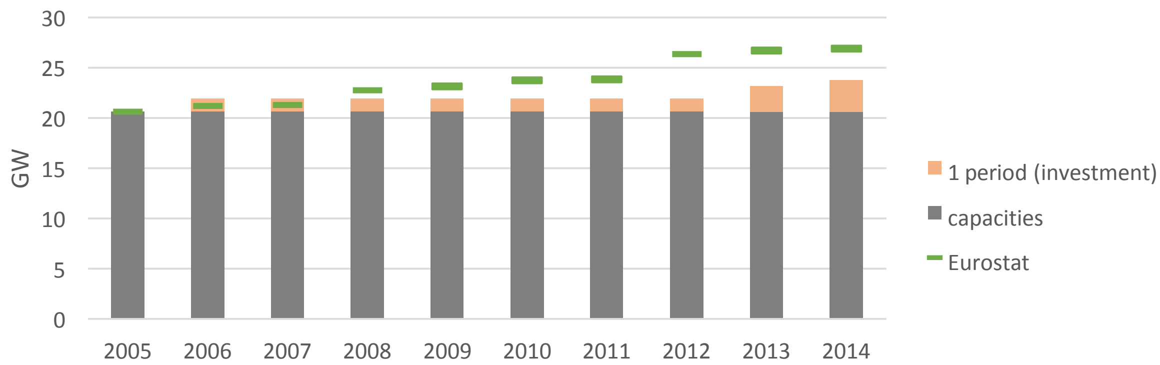
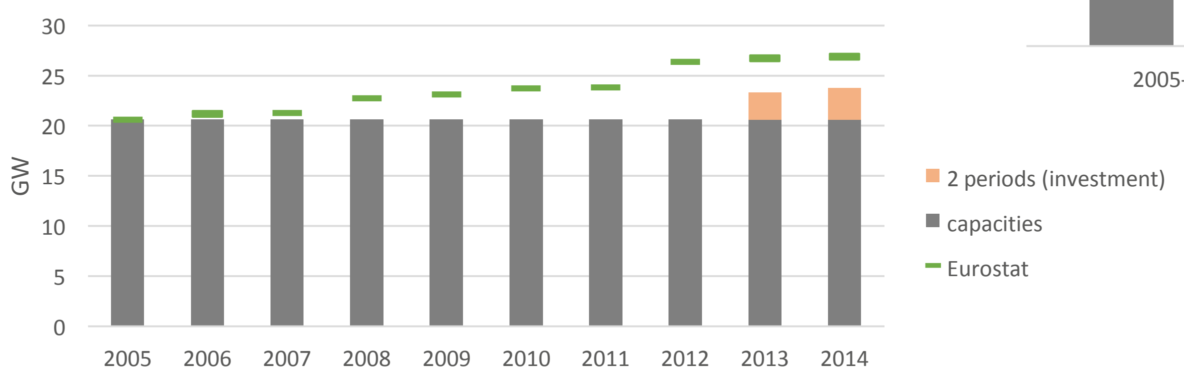


Figure 13-14 – Investment in gas-fired capacities over the period 2005-2014 (model results)



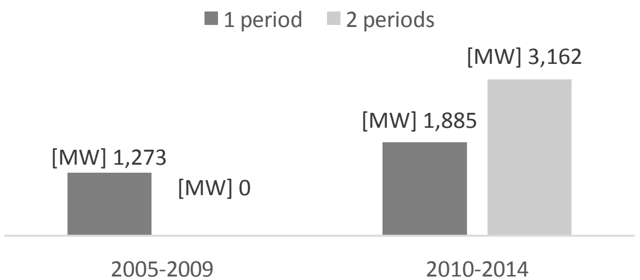


Figure 15 – Investment in gas-fired capacities in two periods (model results)

Conclusions and takeaway

1. CO_2 emissions respond to cyclical fluctuations in GDP, thus environmental policies should be adjusted to business cycles.

2. The assumption on fixed policy targets over the long time horizon may hinder the success of transition pathways, reinforcing or hampering links between different system-levels: the socio-economic landscape and regimes and niches [Geels et al., 2016]

3. Dynamic developments create uncertainty for the profitability of electricity producers and level of consumer prices

Conclusions and takeaway

4. Disregard of discontinuities in economic development (recessions and booms), can significantly affect the accuracy of long-term projections.

5. The choice of the number and the length of time intervals (e.g. 5 or 10 years) plays a decisive role as well since it determines how sensitive the projection will be to uncertain events inside the intervals.

6. The choice of time resolution significantly affects the accuracy of the results, considering the expansion of generation capacity, and not least electricity prices.

Thank you for your attention

Looking forward to your questions

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