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Bridging the gap using energy services: Demonstrating a framework for soft-linking top-down and bottom-up models

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Plan of Talk

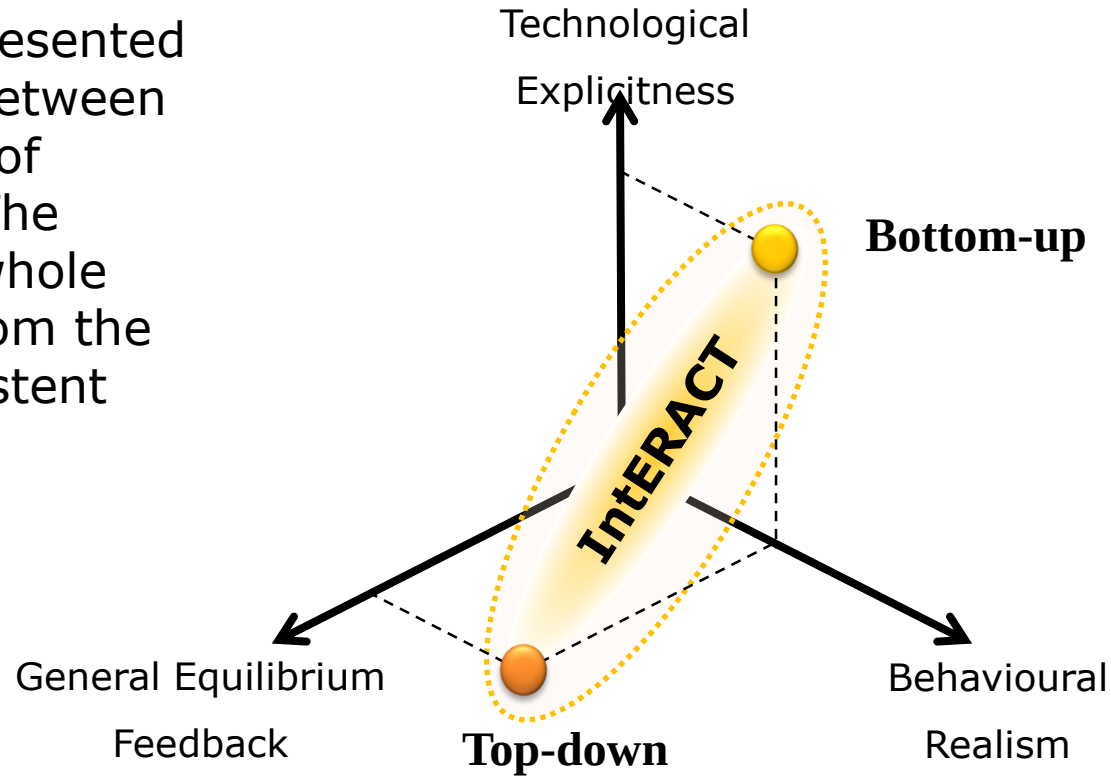
- Background
- Defining the gaps
- Developing a fully consistent soft-linking strategy
- Full scale implementation of soft-linking strategy
- Forced introduction of coal CCS in cement industry
- Conclusion

The IntERACT model and soft-linking methodology

The soft-linking method and the IntERACT model presented here was developed to understand the interaction between the energy system and the macro economy in light of Danish long term climate and energy policy goals. The method combines a detailed representation of the whole energy system while capturing demand feedback from the households, firms and international trade in a consistent manner.

Key features:

- Technology explicit
- Behavioural feedback
- Macroeconomic consistency
- Fully automated iterative soft-link method



Bridging what gap exactly?

Policymakers: *"We want to ban technology "X" by year 2035, what is the exact impact?"*

Engineers:
"Design the optimal system!"

GAP

Academic research:
"We provide insights…"

Economists:
"Uniform CO2-price across sectors and countries!"

Hybrid modelling approaches

1. **Hard link:** Focus on one model type while representing the other in terms of ”reduced form” specification (e.g. TIAM-Macro model).

2. **One directional soft-linking**: Use output from either a top-down or bottom-up model as input into the other type of model without considering possible feedback to the initial model (e.g. Hartwig et al., 2017)

3. **Iterative soft-linking:** Method for soft-linking bottom-up and top-down model in an iterative loop until some convergence criterion is meet. This method as mostly been used to soft-link existing models, see e.g. Fortes et al. (2014) and Krook-Riekkola et al. (2017).

4. **Integrated approach**: This method is based on the equivalence between the Karush–Kuhn–Tucker (KKT) conditions of a bottom-up linear programming (LP) problem and optimality conditions of a CGE model using mixed complementarity. That is an equivalence between the shadow prices of the LP constraints and market prices of the CGE model. Dimensionality and complexity impose limitations in terms of large scale implementation of the integrated approach (Böhringer and Rutherford, 2008).

Decomposing the integrated approach into an equally consistent iterative soft-linking strategy designed for large scale application in 3 steps

Integrated approach

Iterative soft link strategy

- Adds flexibility and transparency as the top-down and bottom-up models can now be used and developed independently.
- Adds additional insight, as it is possible to track how a policy propagate between the economy and energy system.

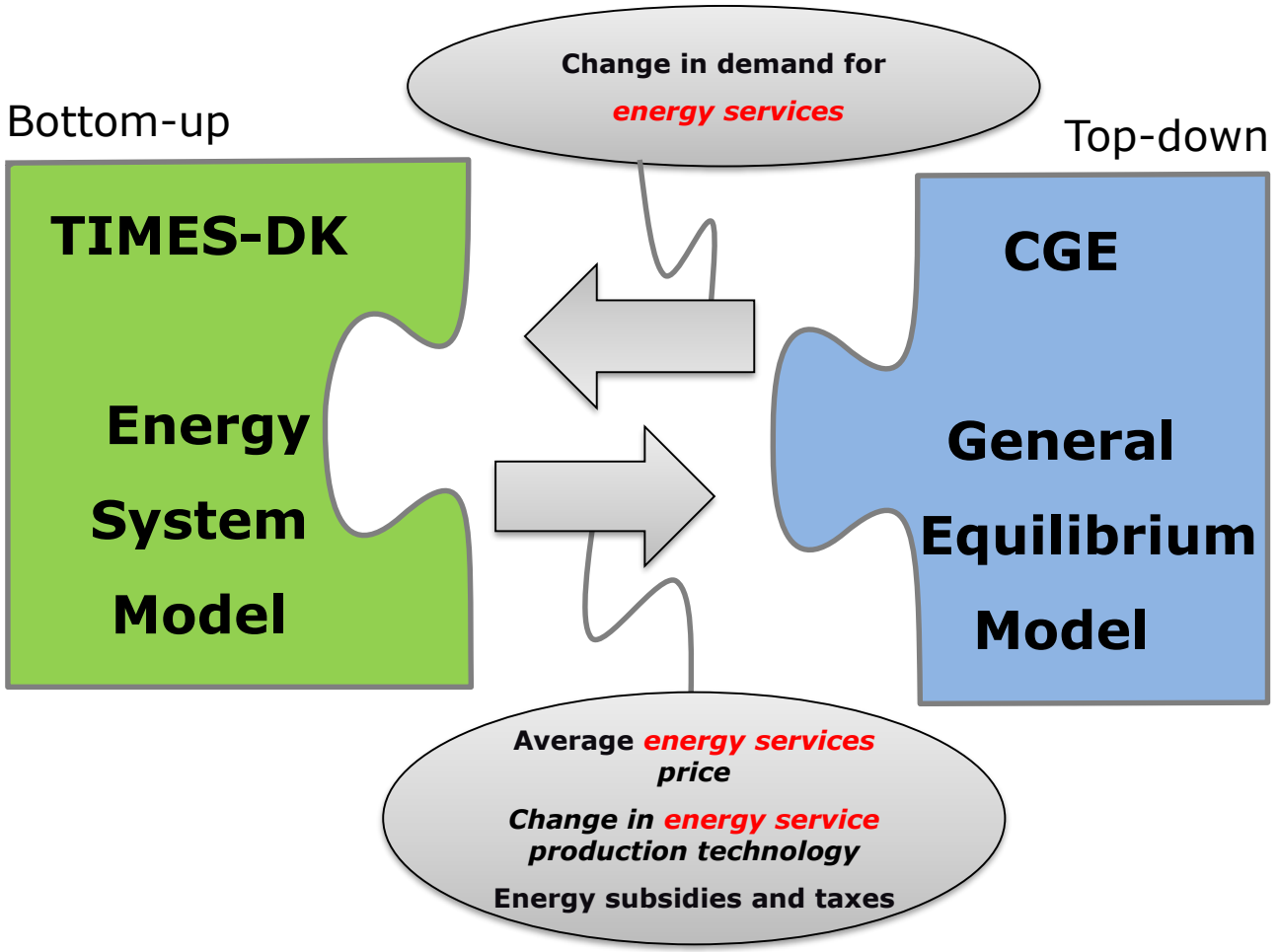
Iterative soft link strategy **using average cost pricing**

- Bridges the gab between the heterogeneity of energy services in the bottom-up model and the aggregated nature of energy services in the top-down modelling. Aggregated in the sense that CGE models traditionally neglect geographical, temporal and technological details.

Iterative soft link strategy using average cost pricing and **partial information**

- Overcomes the conceptual differences related to capital between the top-down and bottom-up model. This is done without explicit exchanging information on capital demand associated with energy service from the bottom-up model to the top-down model.

IntERACT:
Bridging the gab between Engineers and Economists



TIMES-DK

- Optimizes Danish energy system towards 2050
- 12 Economic sectors
- Power and district heat sector
- Residential sector
- Transport sector
- Electricity exchange with neighbouring countries
- 32 time slices

CGE model

- 20 economic sectors
- One household
- Government
- Foreign trade

Soft-link

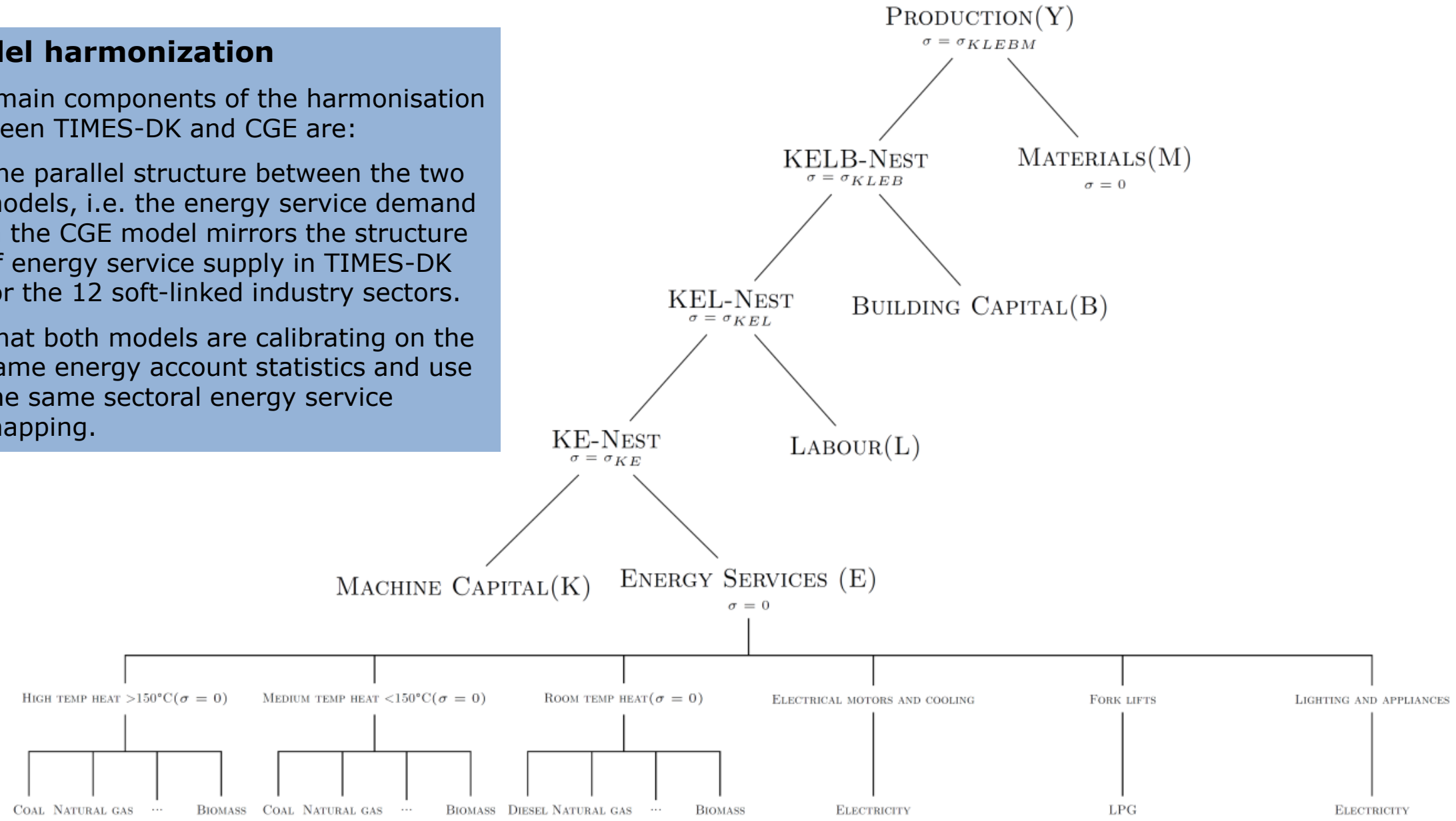
- 12 Economic sectors
- Power and district heating sector
- Residential sector

Modelling energy services in the top-down model

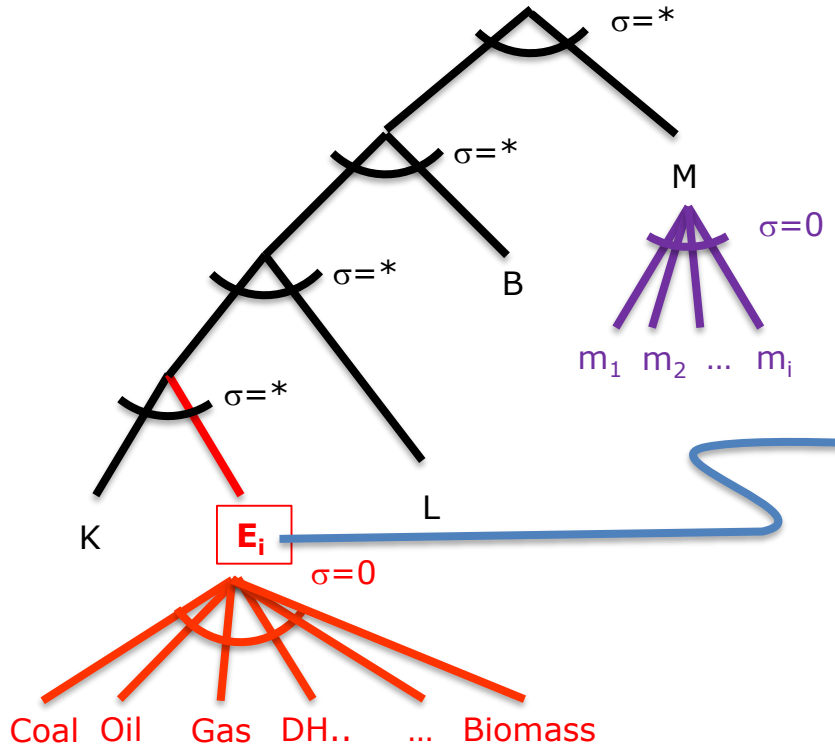
Model harmonization

The main components of the harmonisation between TIMES-DK and CGE are:

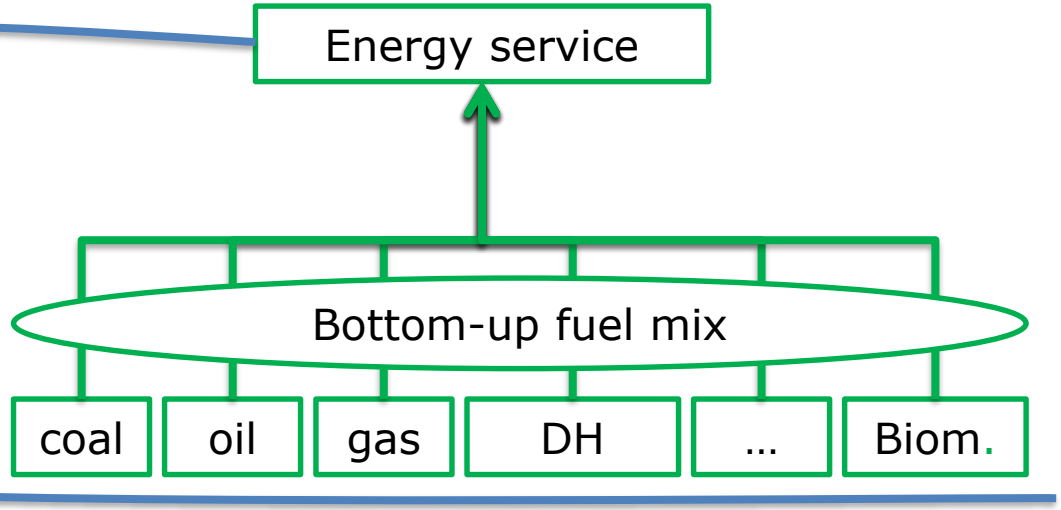
- The parallel structure between the two models, i.e. the energy service demand in the CGE model mirrors the structure of energy service supply in TIMES-DK for the 12 soft-linked industry sectors.
- That both models are calibrating on the same energy account statistics and use the same sectoral energy service mapping.



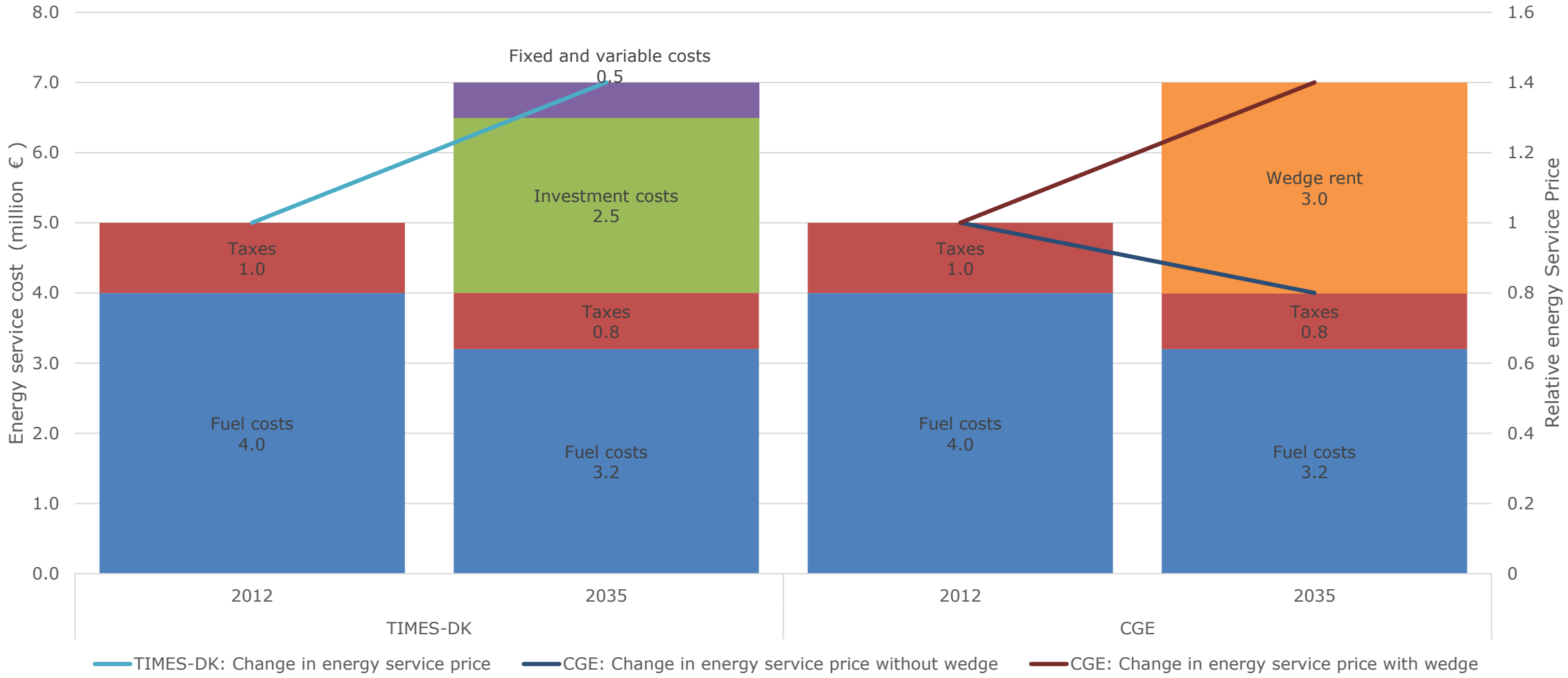
Soft-linking economic sectors



TIMES-DK determines the price of energy service and fuel mix needed, which is implemented in the CGE as Leontief-shares



Capturing capital demand from TIMES-DK model for a given sectoral energy service in the CGE model (illustrative)

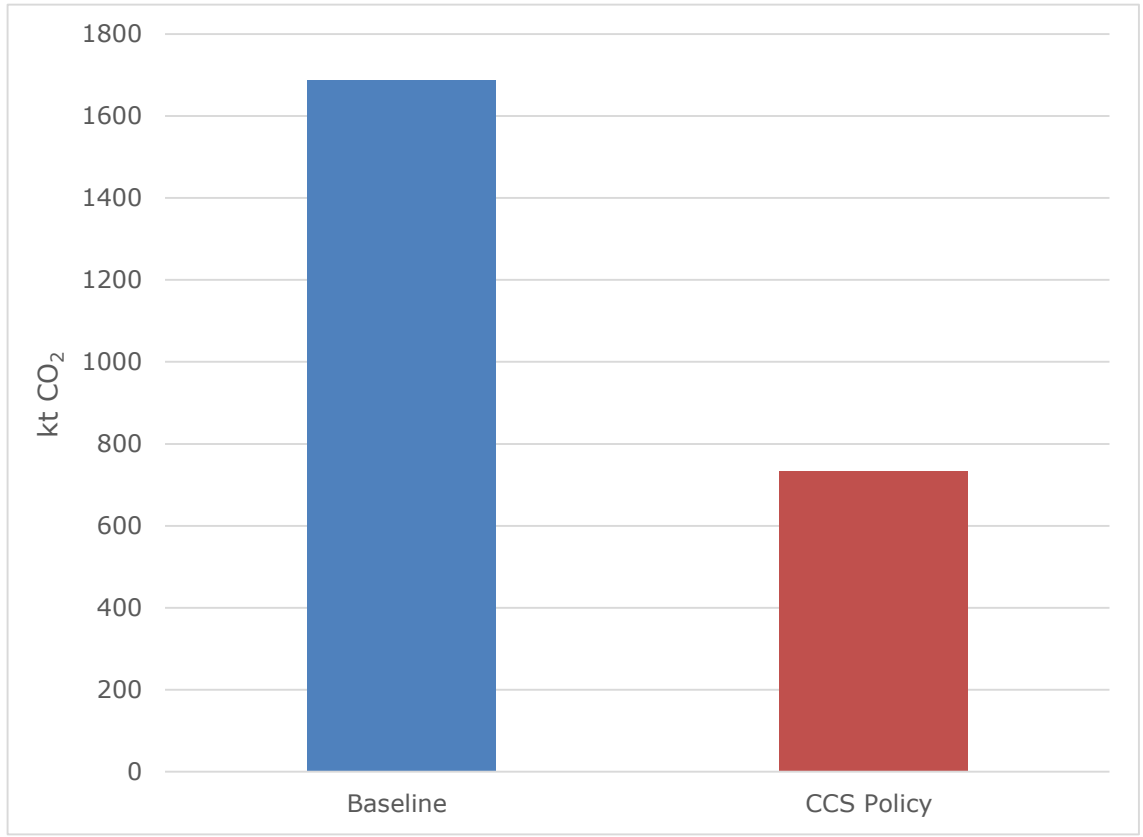


Sector specific adaptation of CCS coal technology

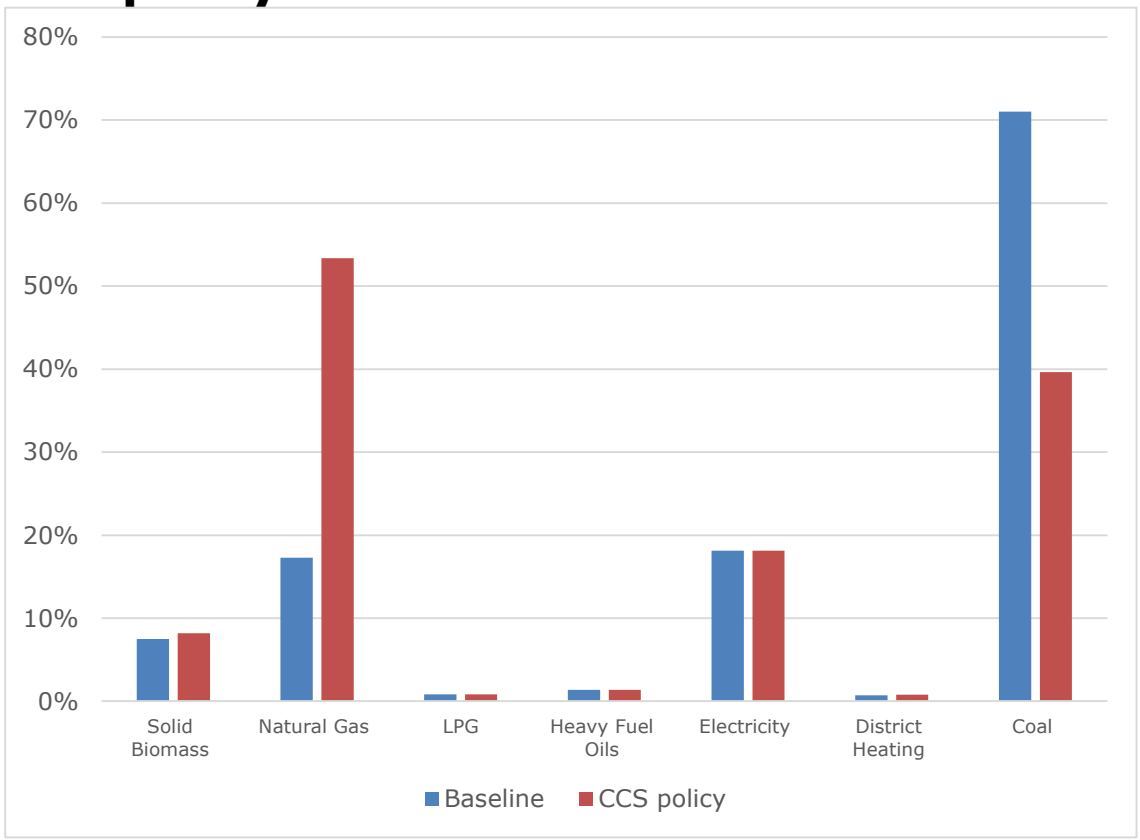
Policymakers: *"We want to ban this technology by year 2035, what is the exact impact?"*

- To demonstrate the potential of our soft-linking strategy we consider a unilateral implementation of coal CCS-technology in the Danish concrete sector.
- This CCS policy is by no means cost effective in terms of CO_2 abatement as it violates basic textbook recommendations, most notably that the marginal abatement cost should be equal across firms and countries.
- However, given the proposed role of CCS technology in limiting global temperature increase to below 2° C, it is crucial to have modelling tools that can evaluate both the energy system and economy-wide effect of introducing CCS technology.

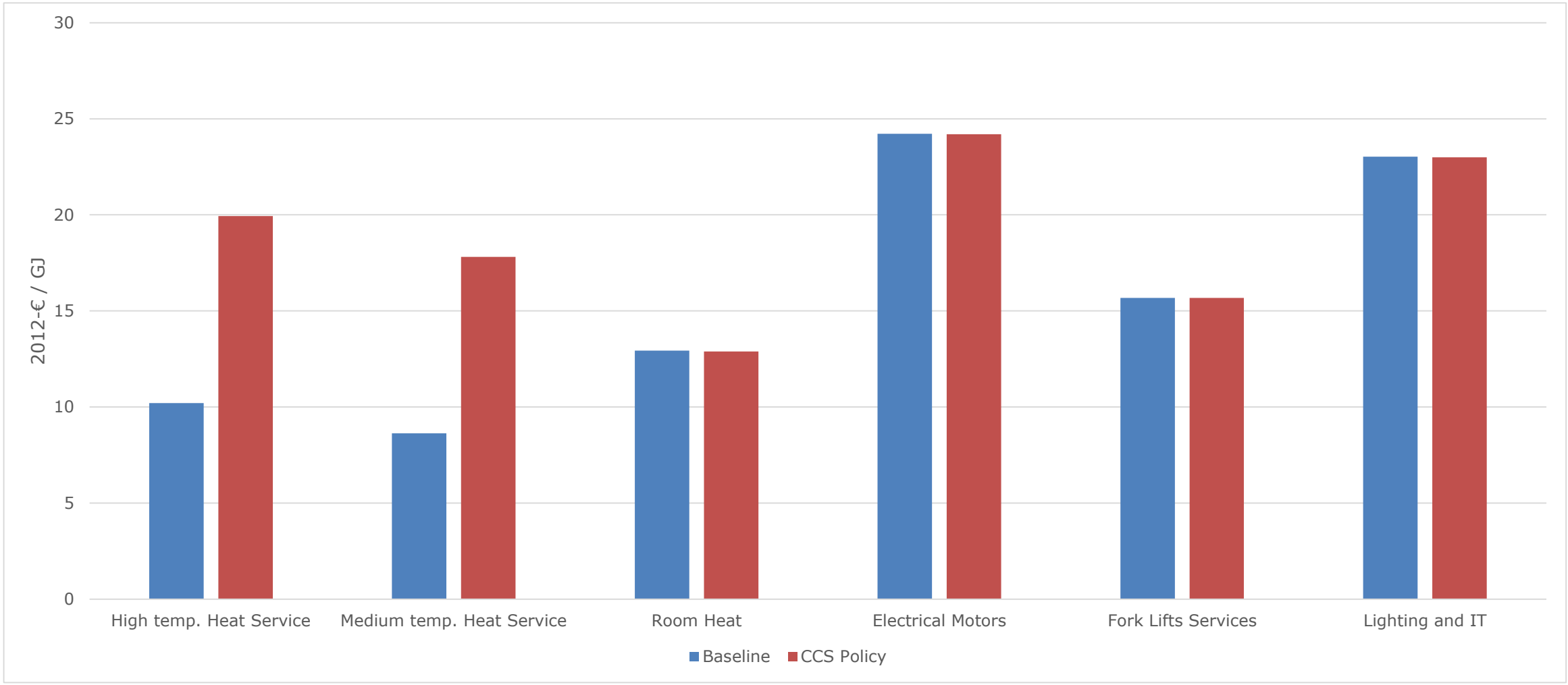
CO_2 emissions in 2035 from the concrete sector in baseline and policy scenario



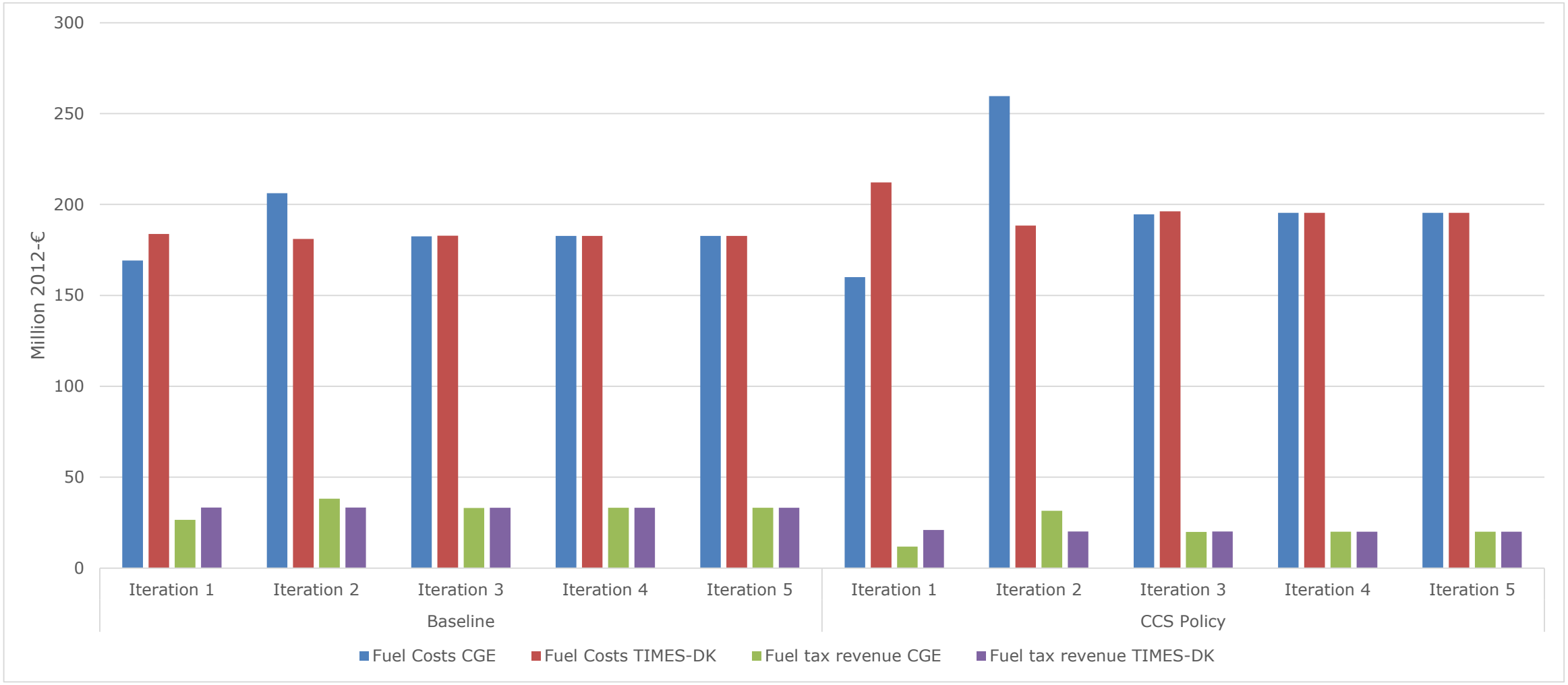
Share of fuel input in the concrete sector by energy content in 2035 in baseline and policy scenario



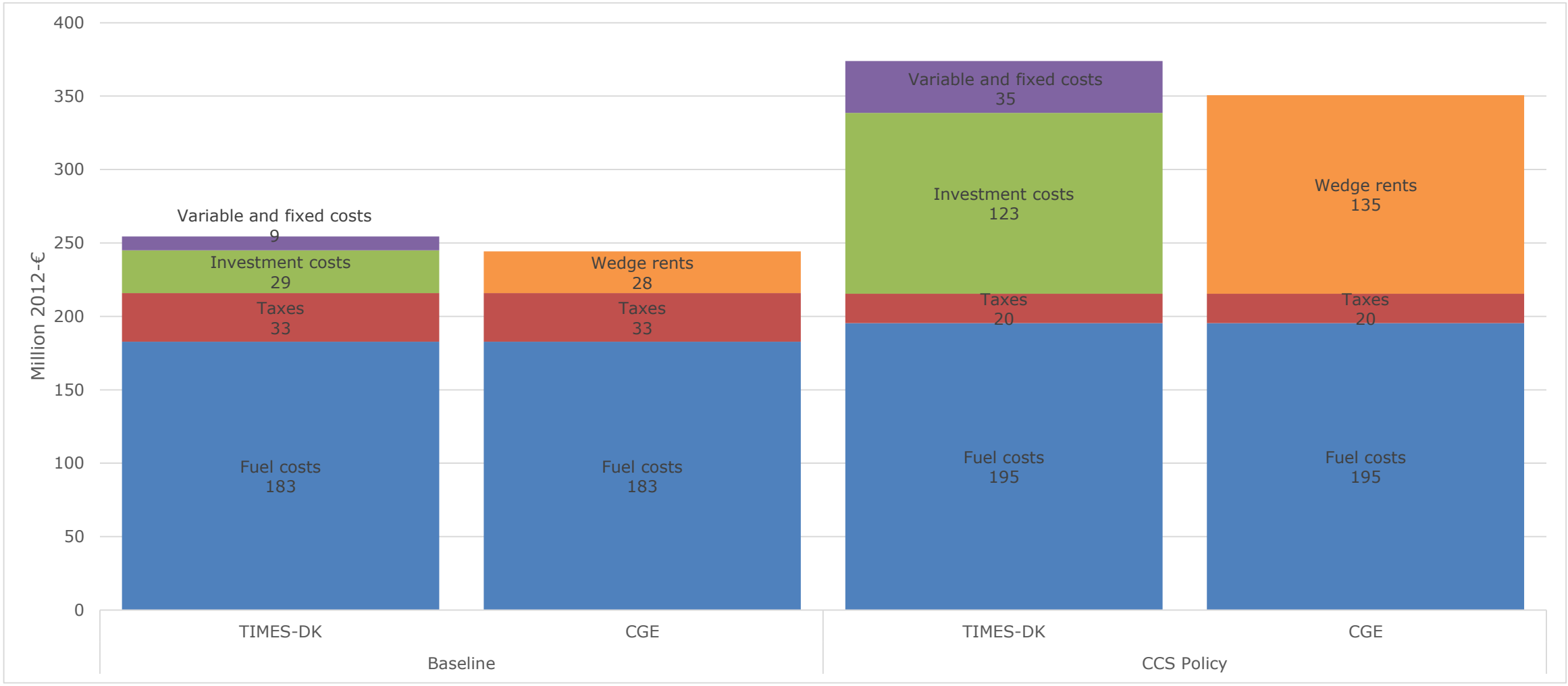
Average energy service prices in concrete sector in 2035 Baseline and CCS Policy



Convergence of total fuel costs and tax revenue between TIMES-DK and CGE for concrete sector in 2035



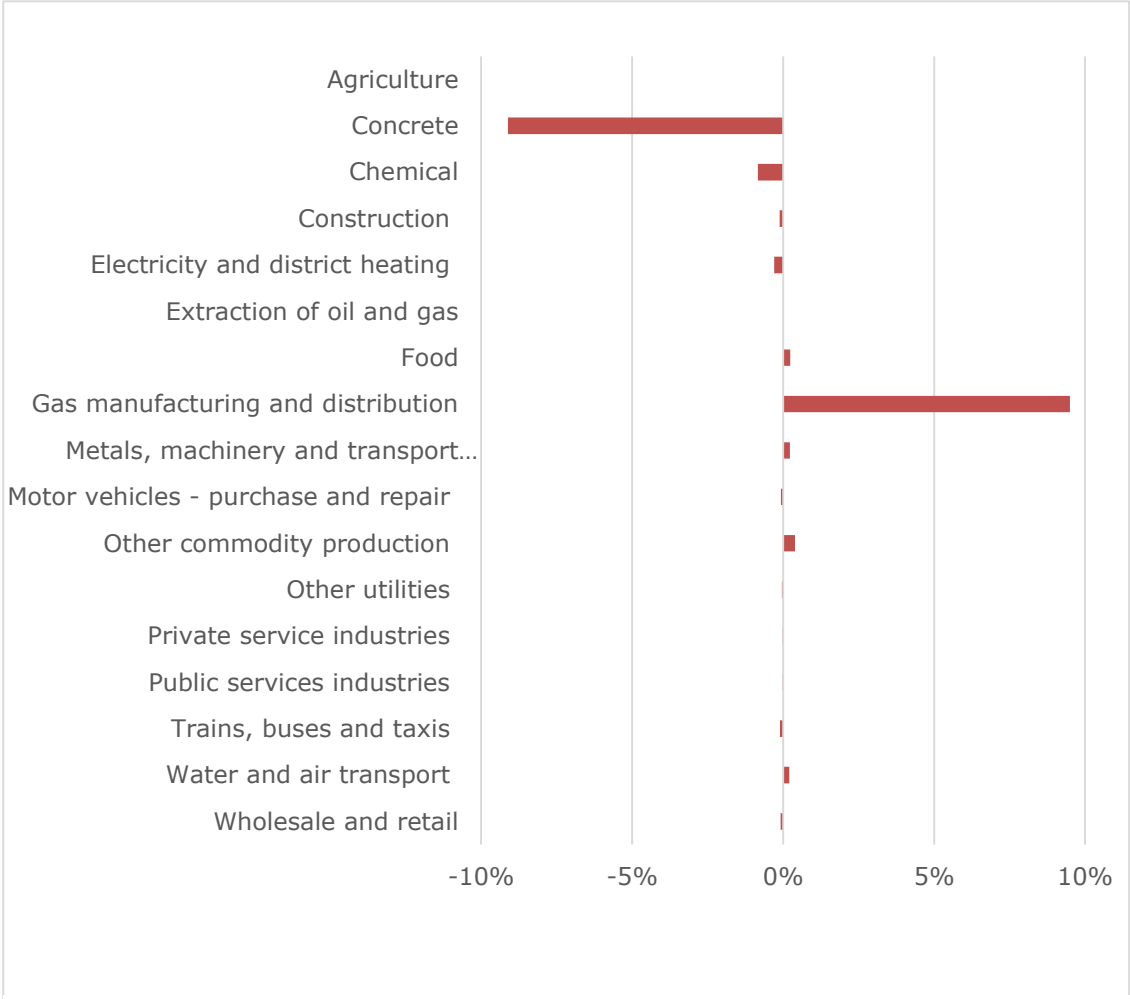
Decomposition of energy service cost in the concrete sector in 2035 for baseline and CCS policy scenario



Carbon leakage, capital crowding out and sectoral impact

- The coal CCS policy reduces domestic production from the cement sector by €357 million in 2035, whereas net import increases by €316 million. This suggest a **carbon leakage of around 88 percent.** It may be higher or lower depending on the CO2 emission associated with foreign concrete production.

- The policy scenario leads to a reduction in gross domestic product (GDP) of 0.05 percent compared to the baseline in 2035. A rough estimate suggest that **half the reduction in GDP is due to the capital crowding out effect** from additional capital demand associated coal CCS technology in the cement sector.



Relative change in sectoral activity relative to baseline across the 20 sectors in the CGE model

Conclusions

Method conclusion

1. The paper solves the issues of complexity and dimensionality associated with an integrated approach by developing an iterative soft-linking strategy that relies on the exchange of partial information and average cost pricing.

2. The soft-linking strategy overcomes the conceptual difference related to capital demand between the top-down and bottom-up models. This allows us to capture the macroeconomic cost of changes in investment flows associated with energy service production in the bottom-up model.

3. The paper show how modelling energy service demand in the top-down model allows us to create a fully consistent parallel structure between a top-down and a bottom-up model.

Policy conclusion

Imposing capital intensive climate mitigation technologies on economic sectors will be associated with significant macroeconomic feedbacks in terms of sectoral activity and leakage effects. We, ”as modellers”, have to develop tools to provide insight to policy makers on this issue.

Future work

The importance of capital demand for the policy conclusion, future research will explore the linking methodology related to the price of capital and capital accumulation. A key part of this will be to improve the dynamic properties of the CGE model, i.e. by introducing endogenous investment and capital accumulation decisions.

Thank you for your attention!

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