Comparing linking versus integration in hybrid modeling – Combining TIMES with CGE models

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TIMES-CGE Workshop

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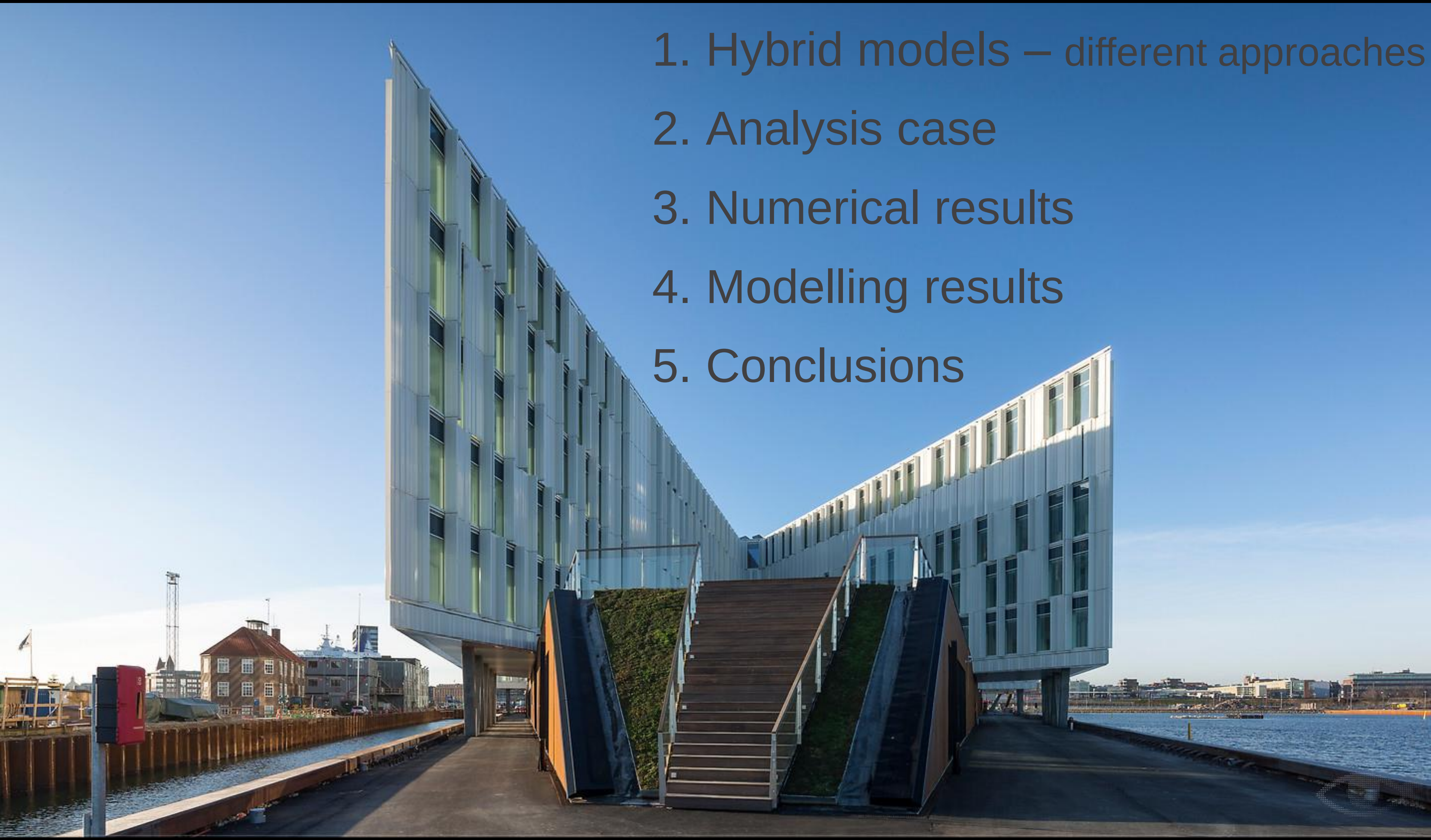
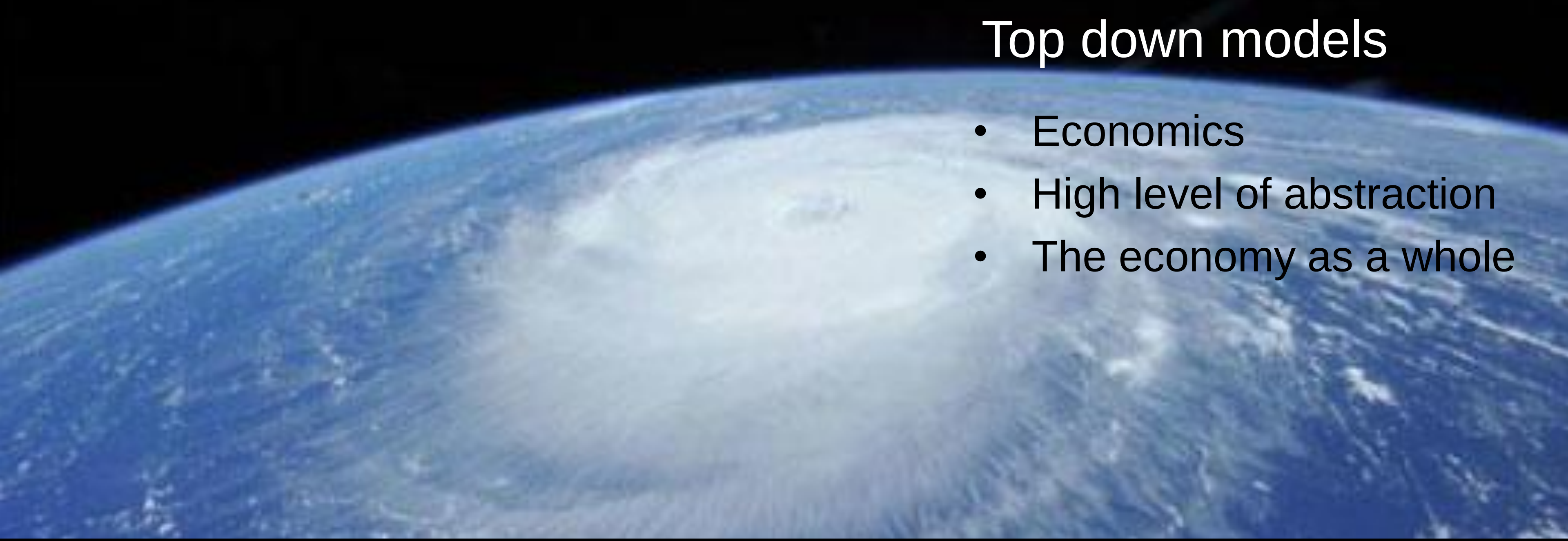
Outline



1. Hybrid models – different approaches
2. Analysis case
3. Numerical results
4. Modelling results
5. Conclusions



Top down models

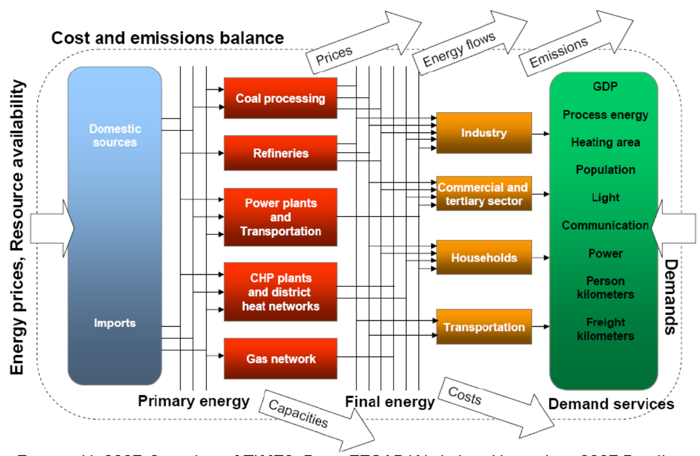
- Economics
- High level of abstraction
- The economy as a whole

Bottom up

- Engineering
- Technology rich
- Physical laws of nature

TIMES

CGE



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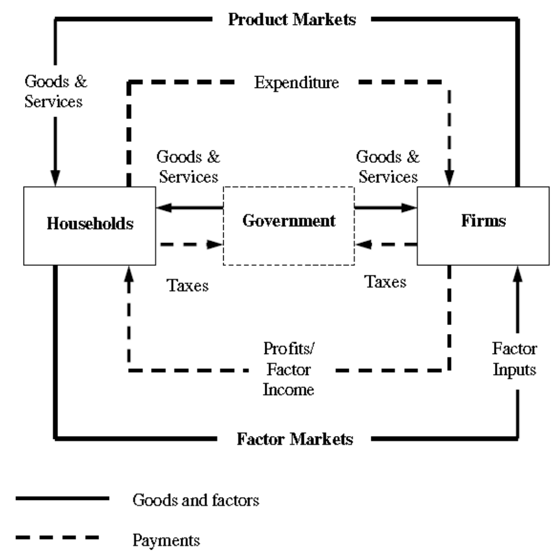
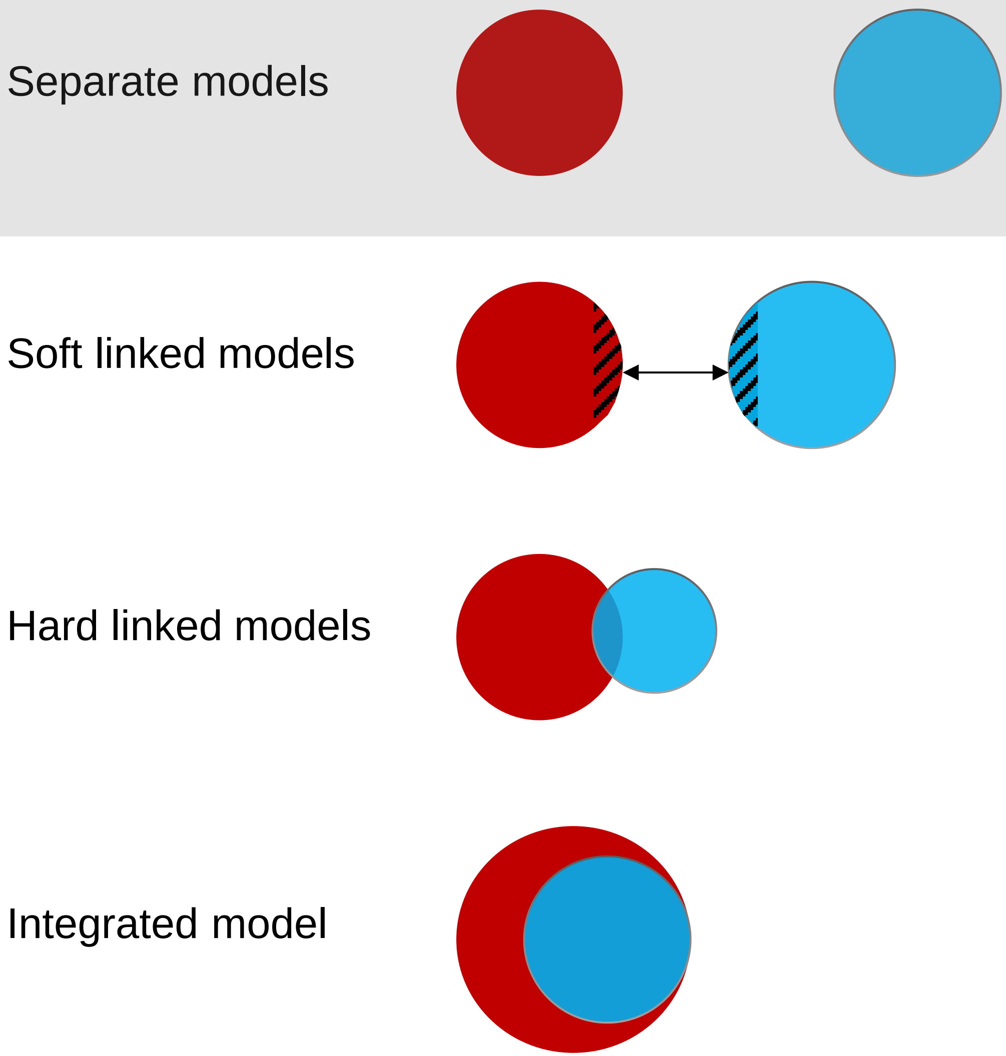


Limitation: Solutions from TIMES could indicate future energy prices that are inconsistent with the exogenously assumed future demand – and versus relative prices in other sectors.

Limitation: The future energy mix in the CGE could be inconsistent with the technical knowledge embedded in TIMES.

Hybrid models

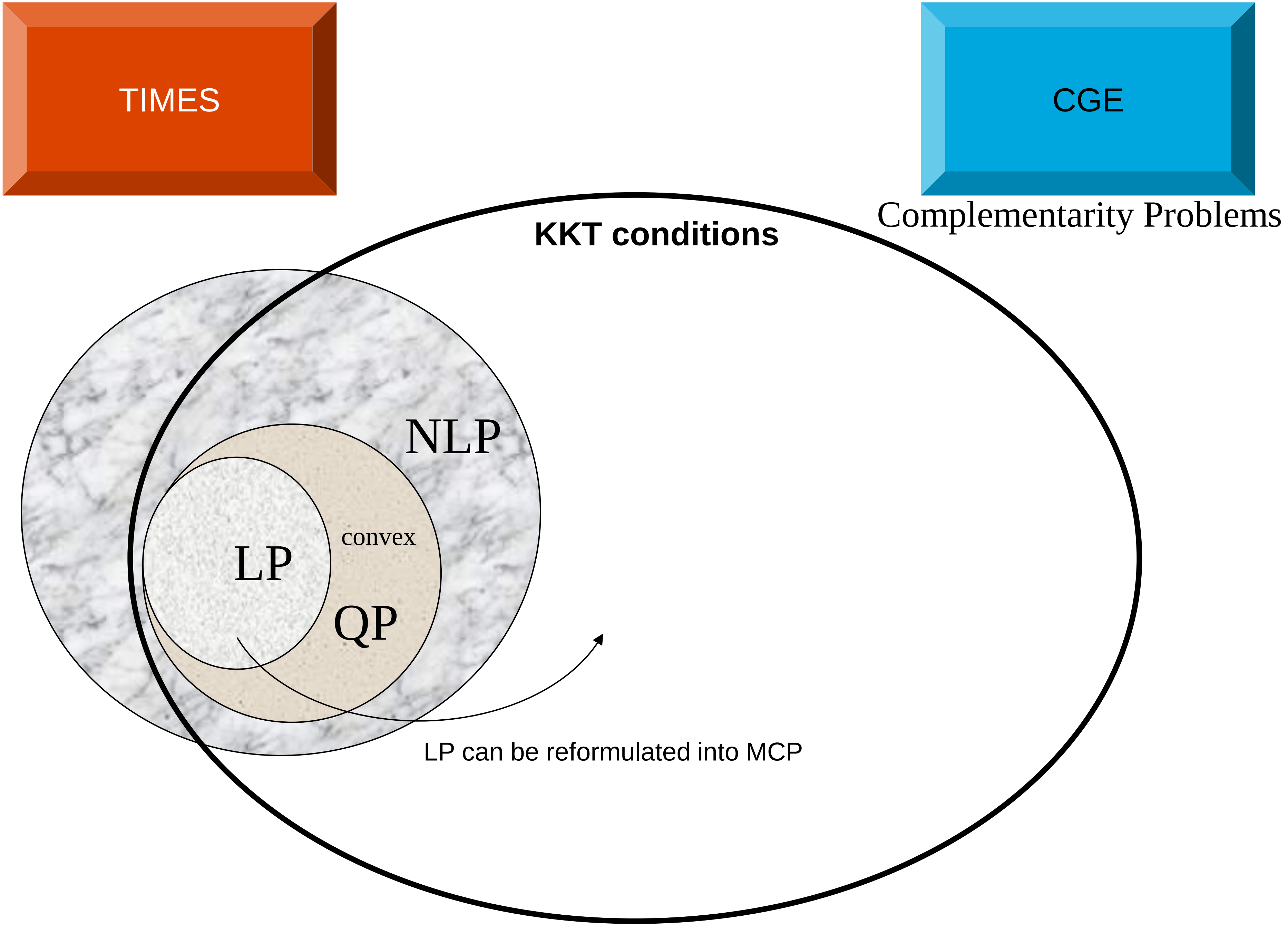


Research questions

How should a bottom-up engineering optimization model and a top-down economic complementarity model be linked?

Can they be integrated?

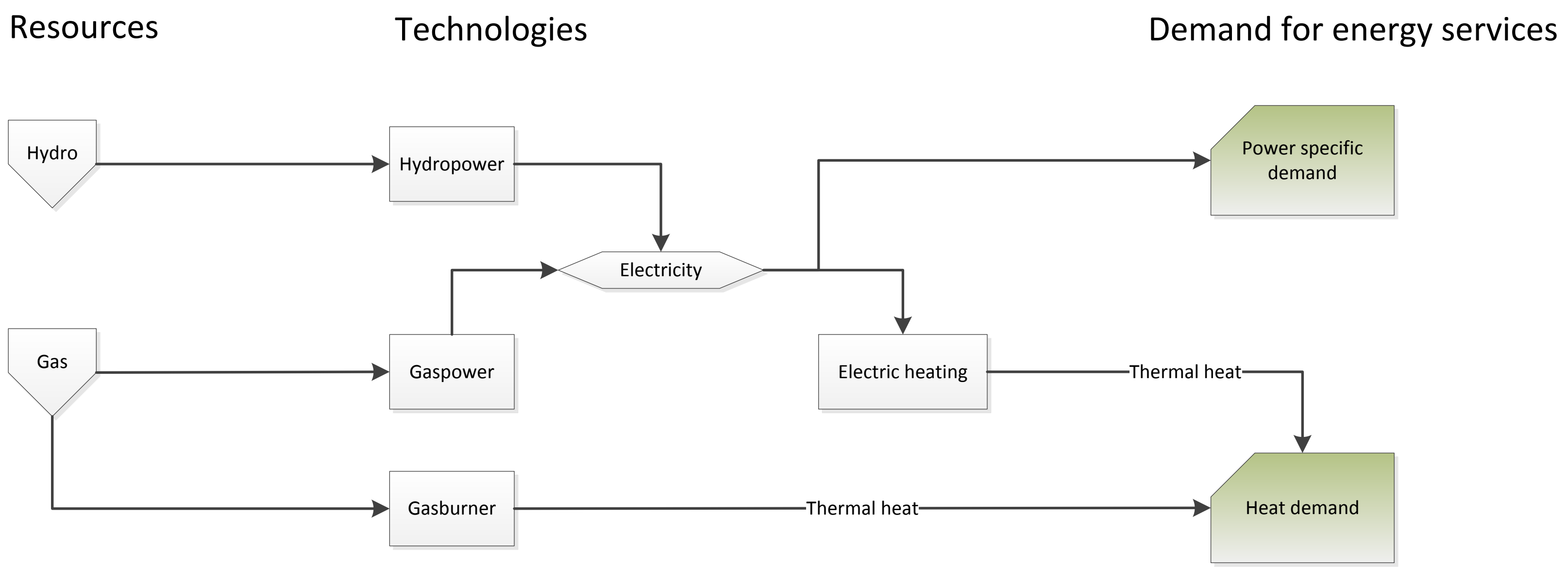
Will linked models and an integrated model produce the same solutions?



Source: Prof. Steven Gabriel

Analysis case

TIMES test model
Reference Energy System (RES)



<u>Solution</u>: *capacity investments, production*

Computable General Equilibrium test model

- Four producers and one (representative) consumer

Agents	Markets
Firm 1 Firm 2 Firm 3 Firm 4 Household	Natural Gas Commodity Electricity Commodity Manufacturing Commodity Nonmanufacturing Commodity Capital Labor

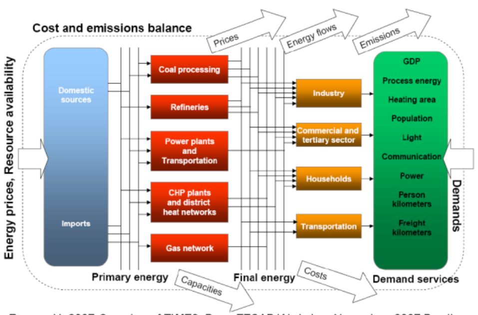
- Data – Social Accounting Matrix:

	GAS	ELE	MAN	NON	L	K	HOU	total
GAS		4	2	3			1	10
ELE	1	1	7	8			5	22
MAN	1	3	6	26			2	38
NON	5	10	10	30			92	147
L	1	1	5	53				60
K	2	3	8	27				40
HOU					60	40		100
total	10	22	38	147	60	40	100	

<u>Solution</u>:
relative prices,
resource allocation

TIMES

CGE



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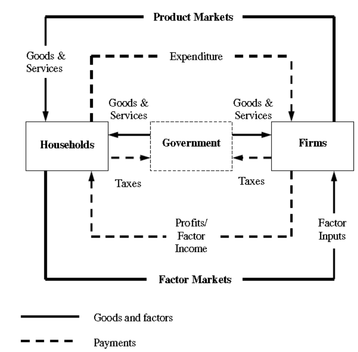


2010 Base year

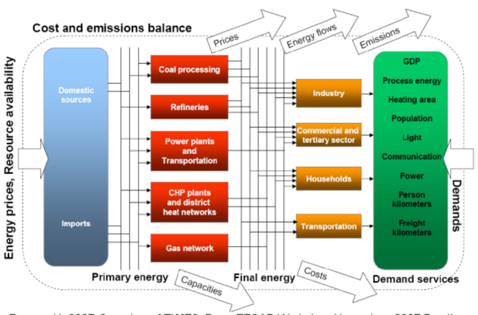
2010 Base year

TIMES

CGE

Demand

2020 Future equilibrium



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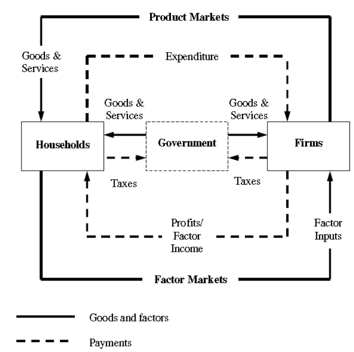


2010 Base year

2010 Base year

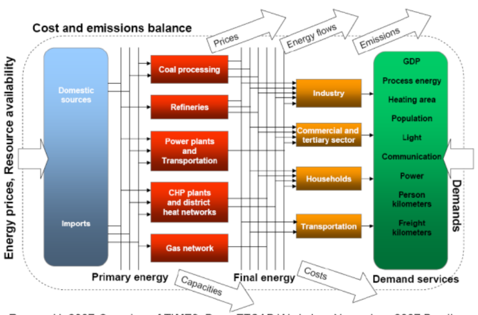
TIMES

CGE

Demand

2020 Future energy system

2020 Future equilibrium



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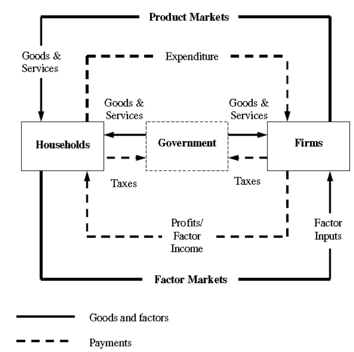


2010 Base year

2010 Base year

TIMES

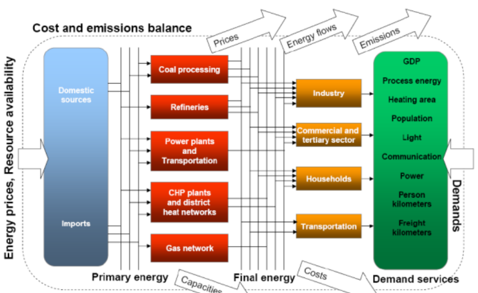
CGE

Demand

2020 Future energy system

2020 Future equilibrium

Energy mix
Capital



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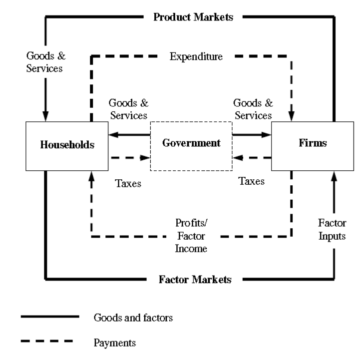
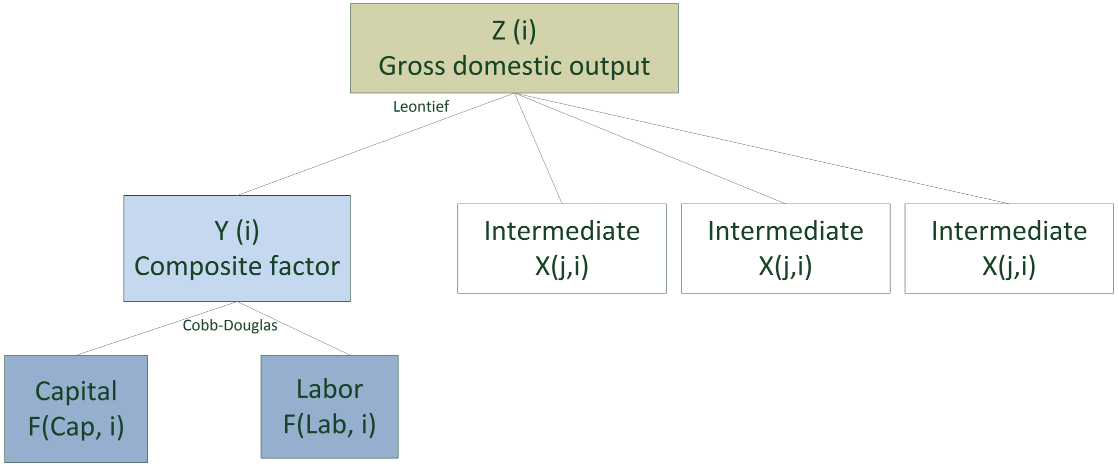


2010 Base year

2010 Base year

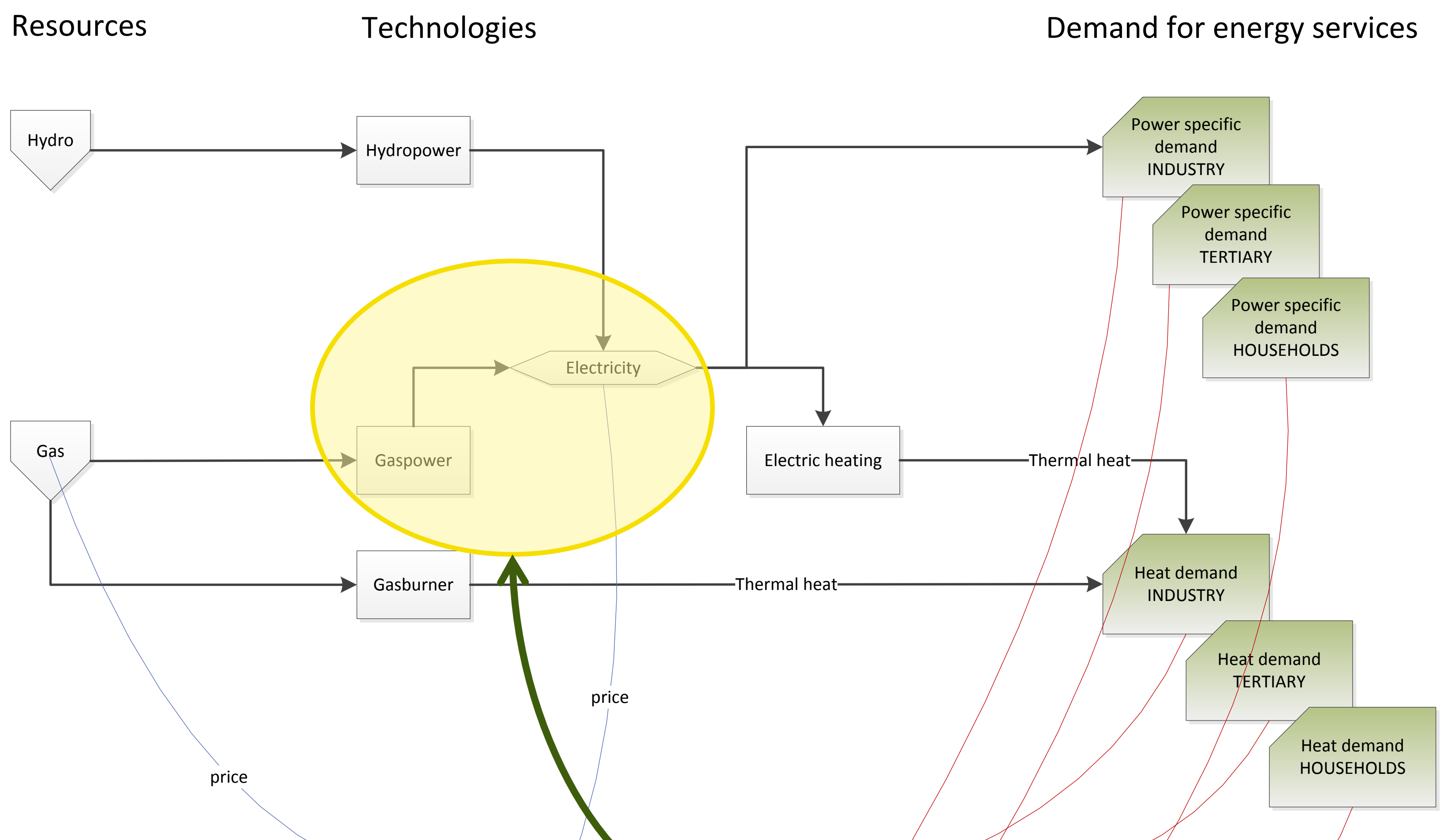
Adjusting the nesting structure

- The production technology is described by nested CES production functions.
- In this version we have used a standard nesting structure:



- We want to adjust this structure based on the energy mix from the bottom-up model.

Linking the models

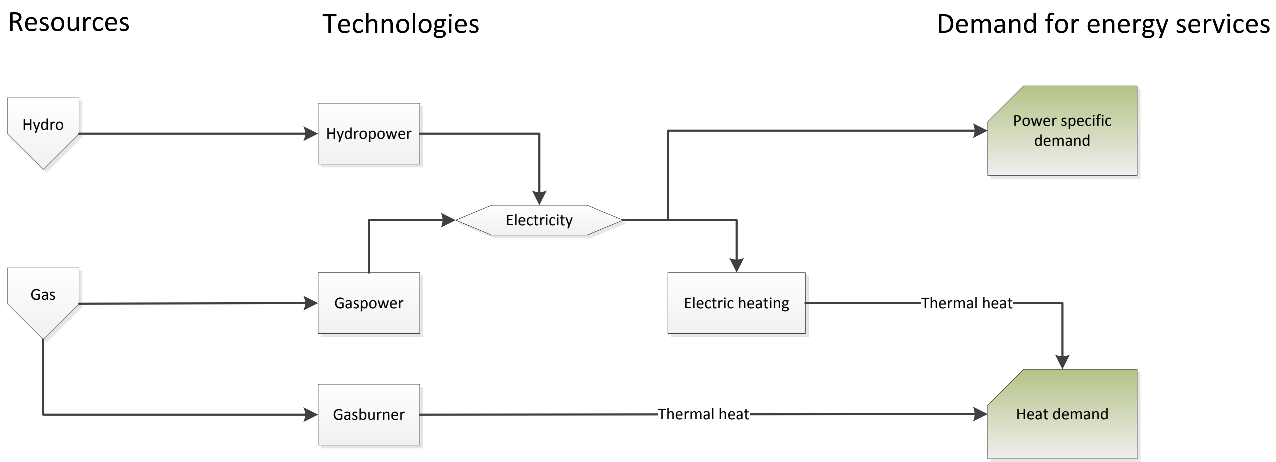


	GAS	ELE	MAN	NON	HOU
GAS		4	2	3	1
ELE	1	1	7	8	5
MAN	1	3	6	26	2
NON	5	10	10	30	92

Numerical results

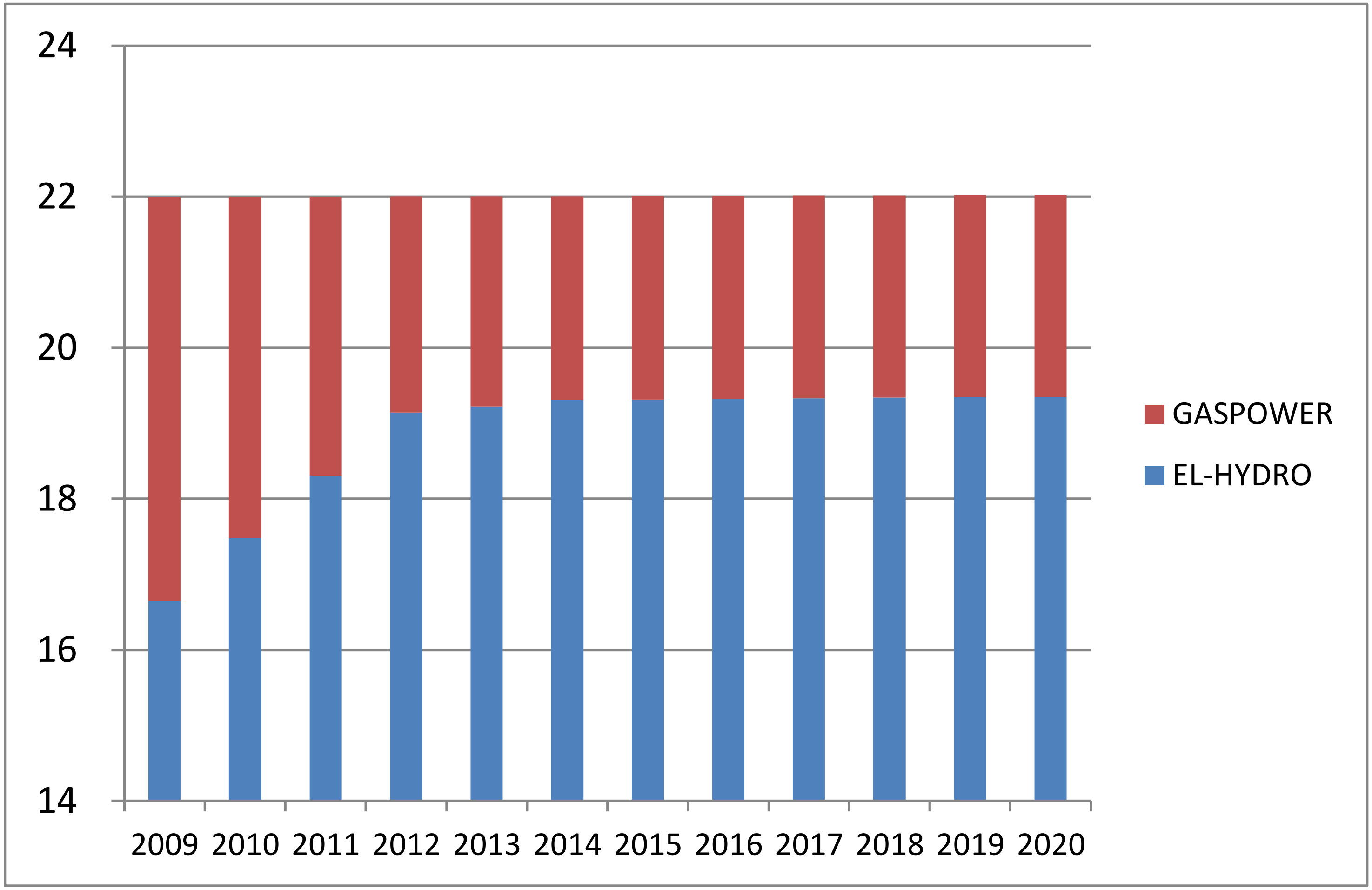
Bottom up situation

- We assume that the energy system has unused potential for hydro electricity, and the bottom up model invests in hydro production facilities.



- The physical share of gas in the electricity production decreases.
- We estimate the value share of gas in the electricity production from TIMES

Electricity production from TIMES (basecase)



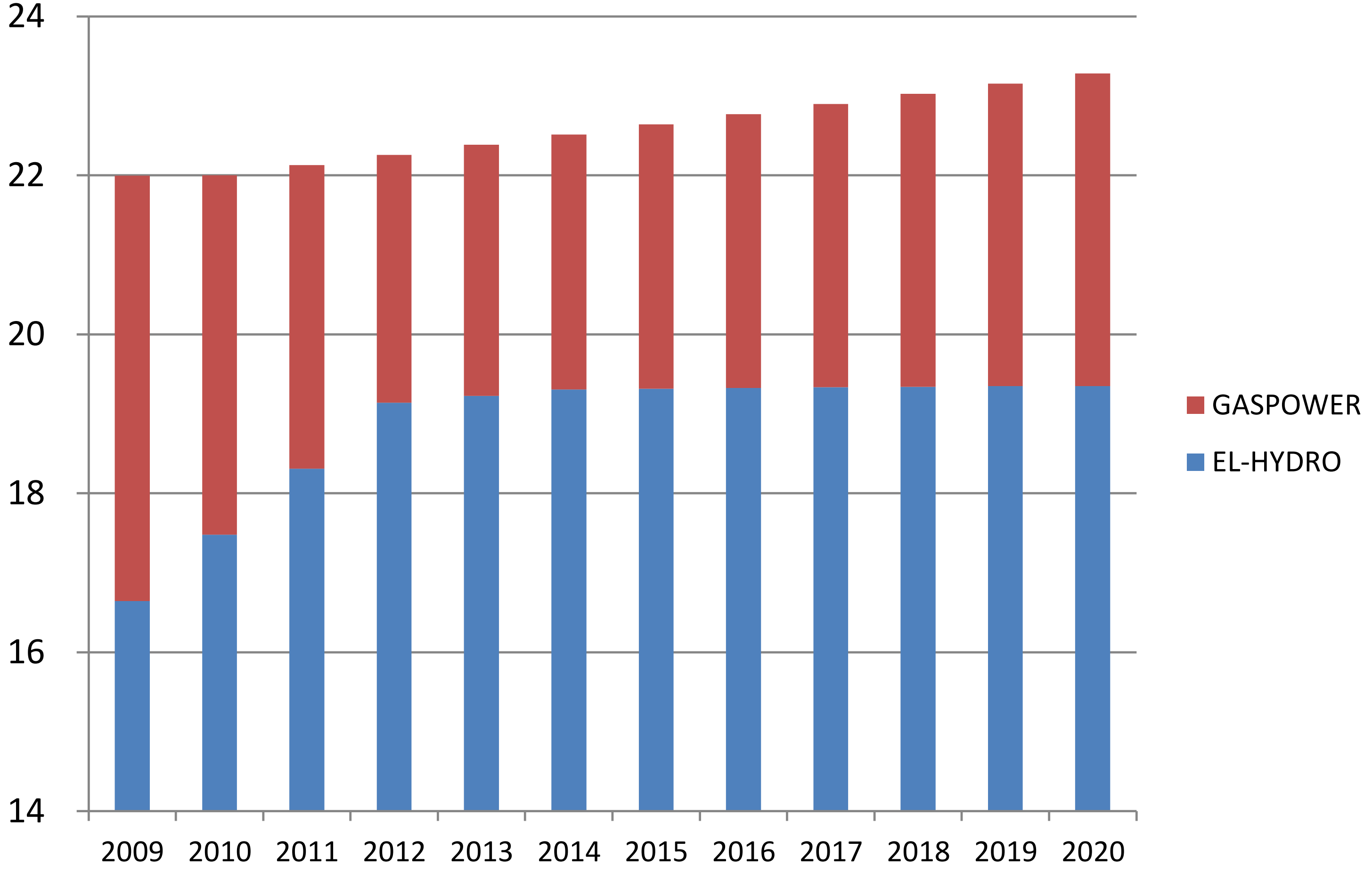
Top down situation

- We assume that labor availability increase by 11% (based on national projections)
- The CGE-model spends the increased labour factor, and calculates a future equilibrium
- Relative changes (in values):

	GAS	ELE	MAN	NON	HOU	total	*price increase*
GAS		11,1 %	11,6 %	11,8 %	10,0 %	11,3 %	5 %
ELE	11,3 %	11,1 %	11,6 %	11,9 %	9,0 %	11,1 %	5 %
MAN	11,5 %	11,2 %	11,8 %	12,0 %	9,5 %	11,8 %	5 %
NON	10,1 %	9,9 %	10,4 %	10,7 %	10,8 %	10,7 %	4 %
L	13,2 %	12,2 %	12,2 %	10,8 %		*11,0 %*	*0 %*
K	13,2 %	14,4 %	13,3 %	8,7 %		10,3 %	10 %

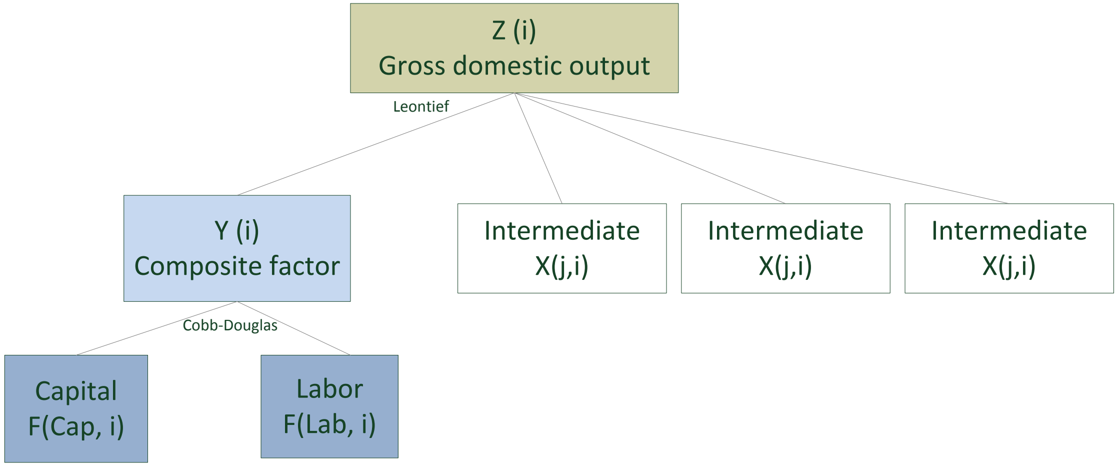
- The increase of aggregated energy demand (in volume) is **5.9%**, which is presented to the energy system.

Bottom up response - electricity production



Top-down response

- The nonlinear production function of the electricity good is adjusted in the top-down model. In this version we have used a standard nesting structure:



- A reduced share of gas input is necessary to produce the same amount of electricity.
- This change is a result of capital investments.
  - Could also have been caused by other technology improvements
- The bottom-up effect should increase the household utility further (in addition to the effect of the increased labour factor).

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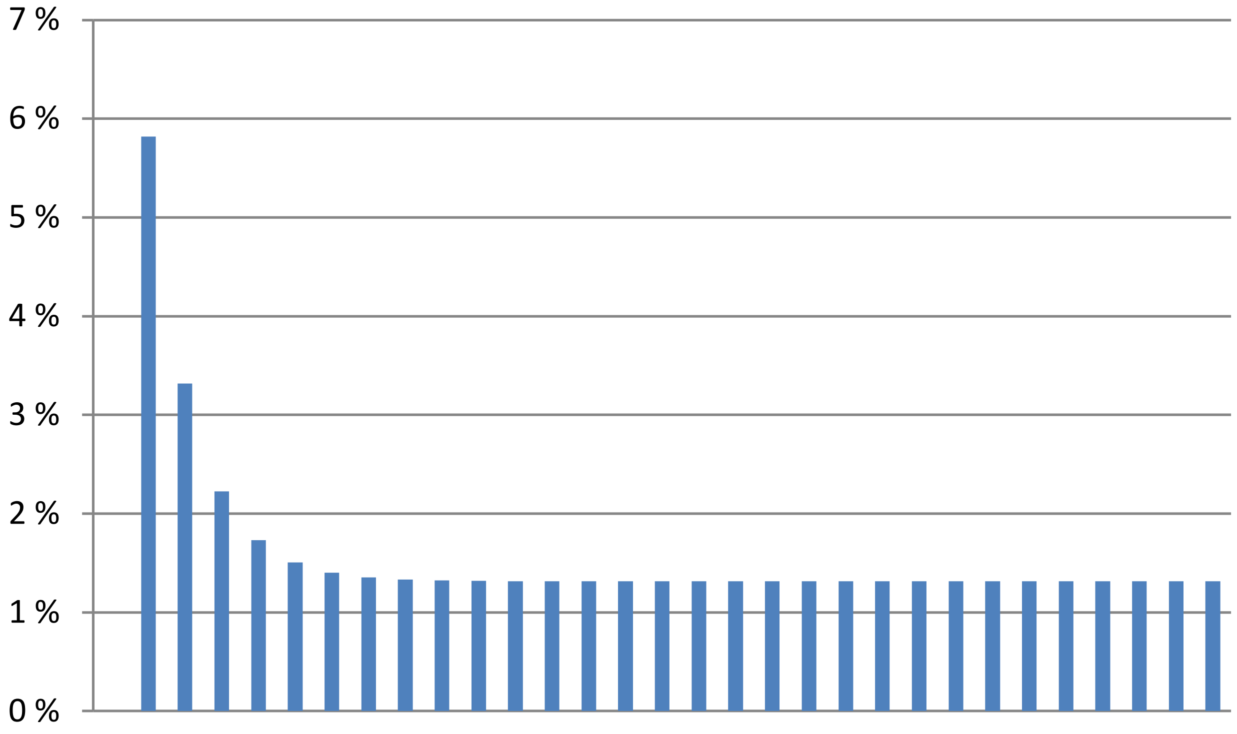
Aggregated energy demand

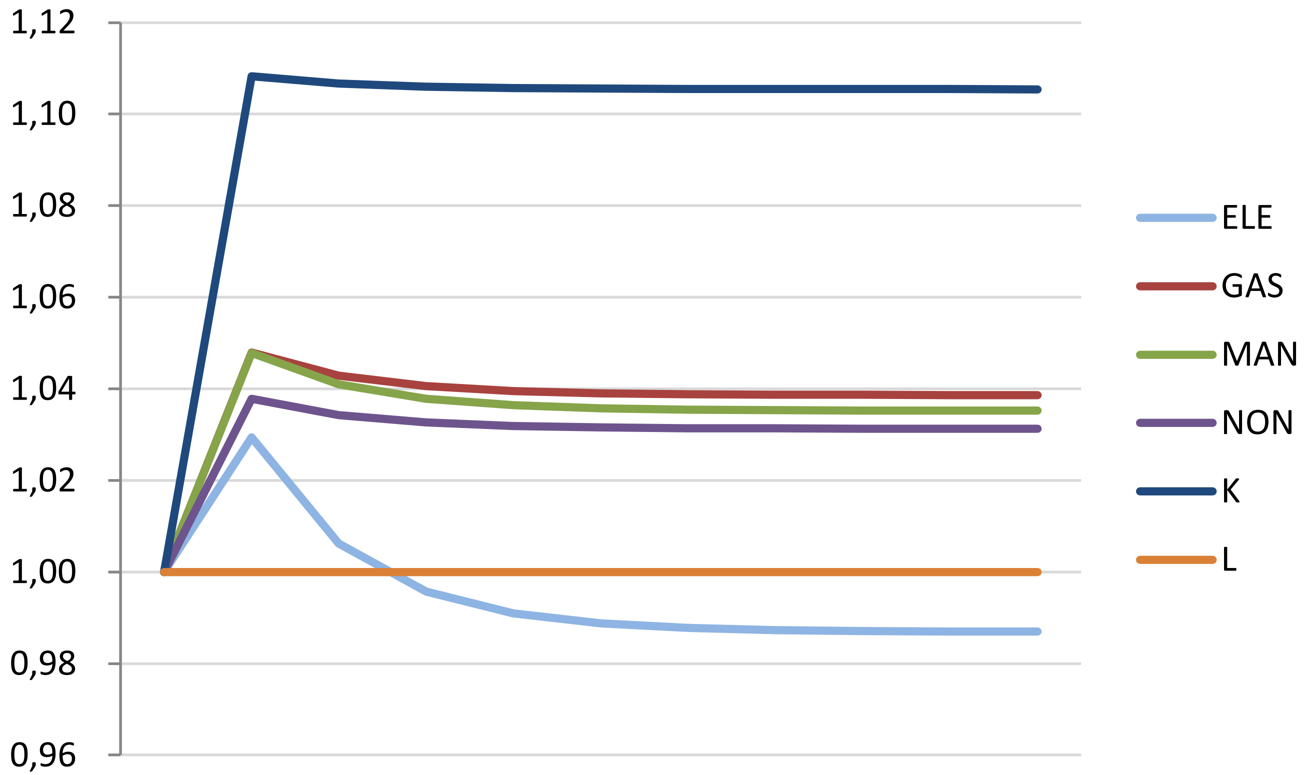
Due to the change in production tehcnology, the top-down model reallocates resources, and (somewhat surprisingly) calculates a *reduced* energy demand after the inital increase:



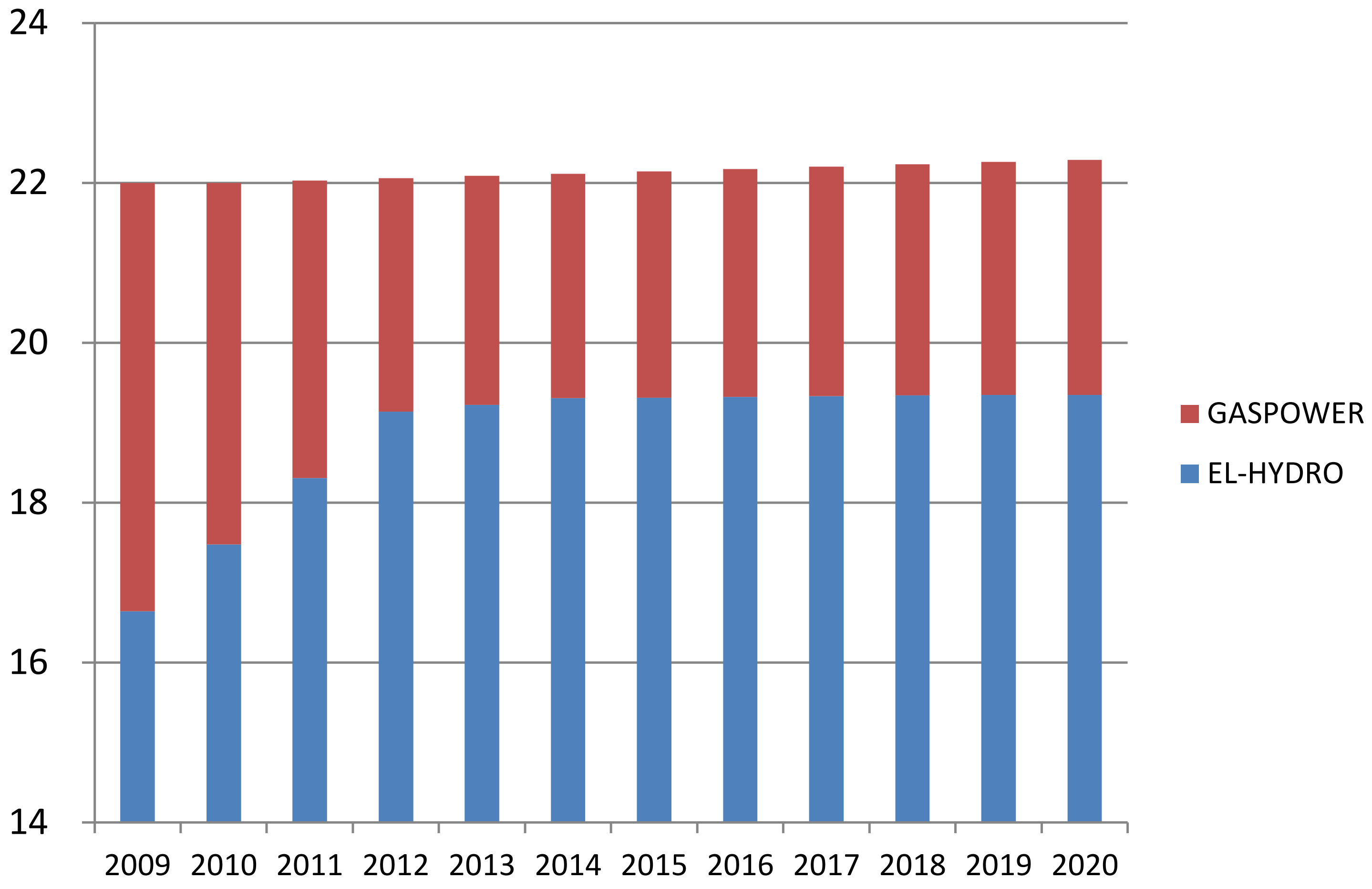
Capital is the scarce factor

We have more labour available, and power generation is cheaper (thanks to capital investments).

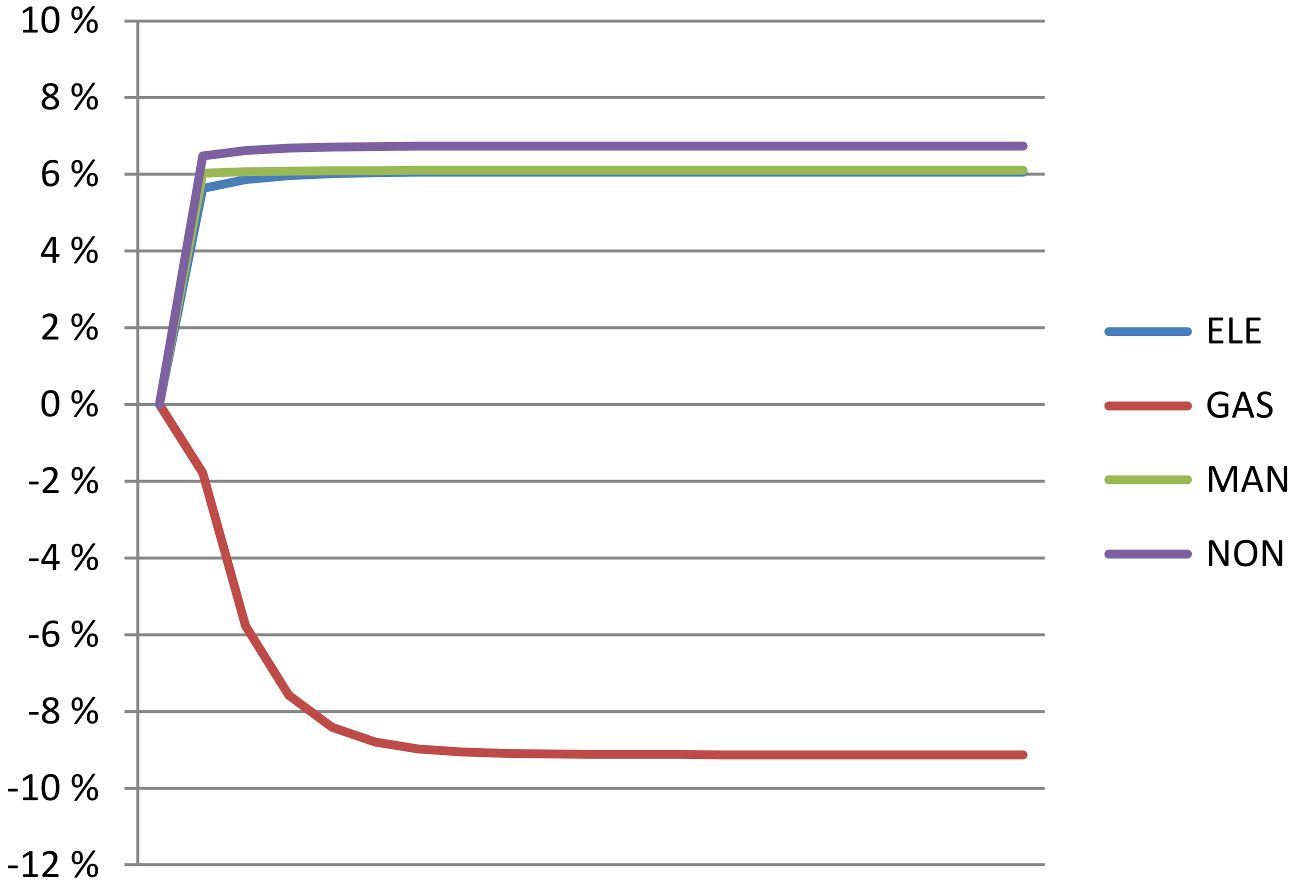
Relative prices:



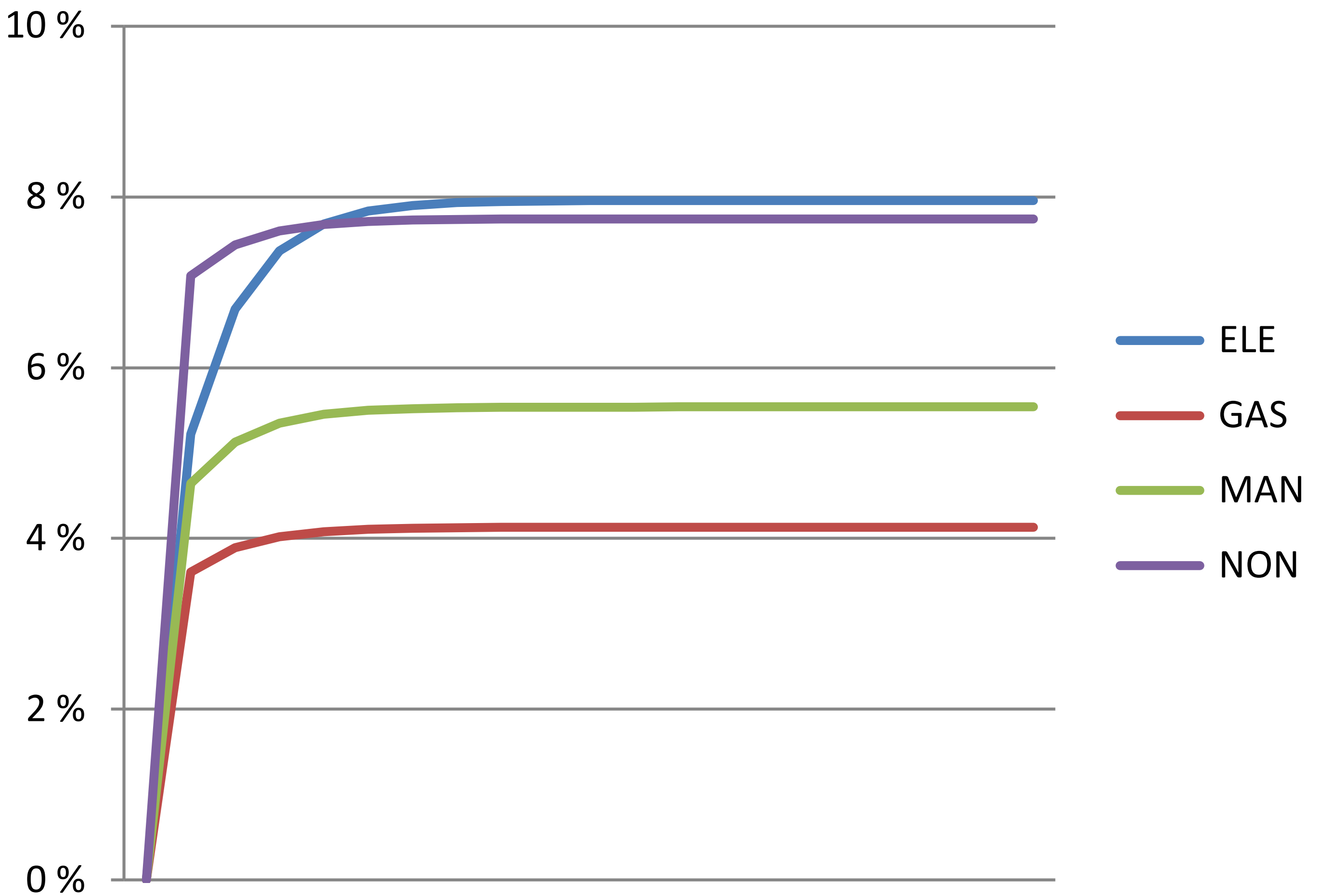
Electricity production (converged)



Sector activity

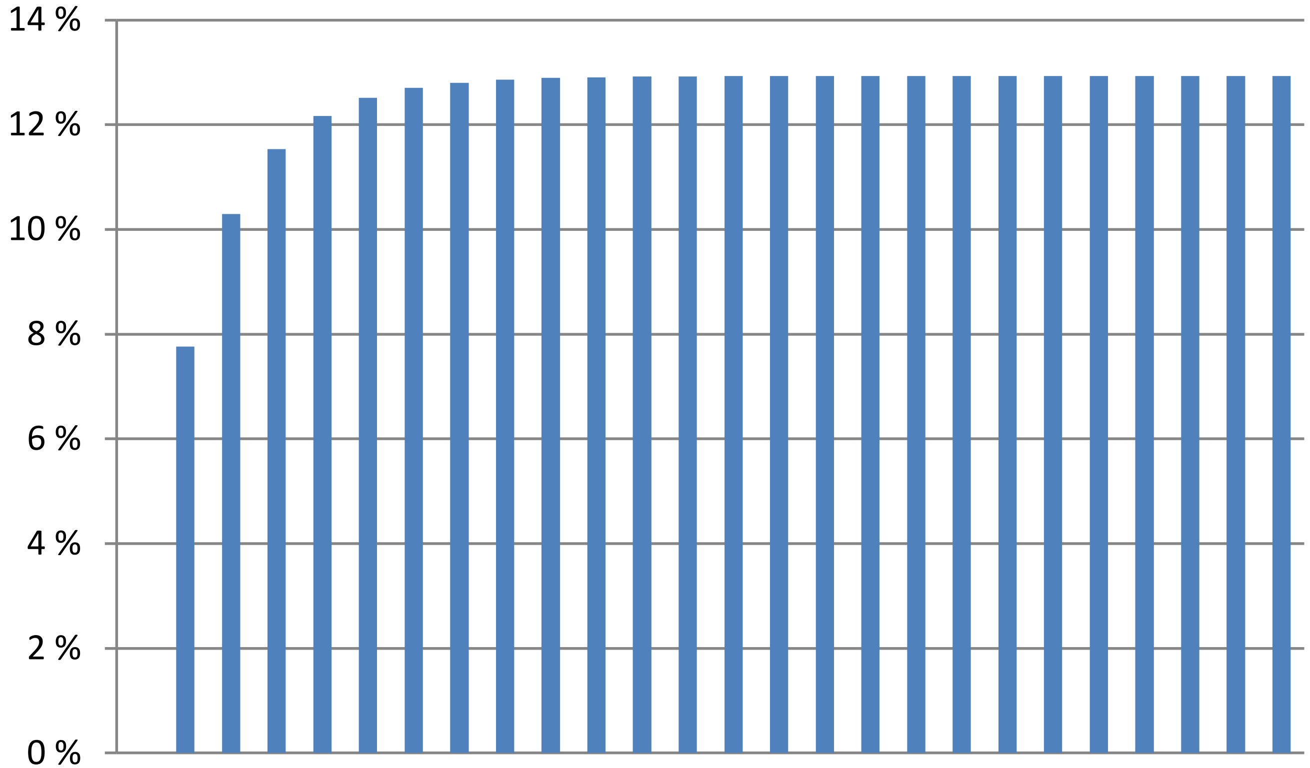


Household consumption



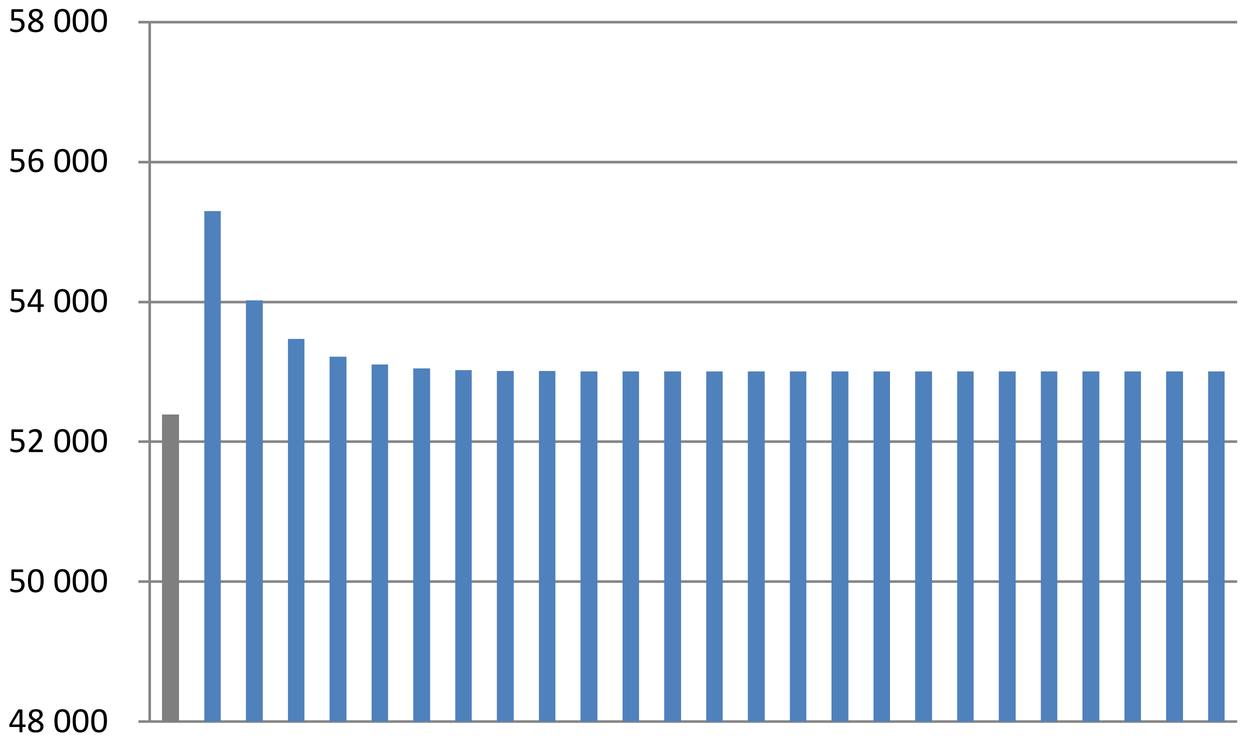
Household utility increase

The household utility increases monotonically.
We have used a Stone-Geary utility function.



Energy system costs

Energy system costs mimics the energy demand changes.



Modelling results

Model implementations

	CGE		TIMES
Linked	MCP	*Demand* →	LP
Linked	MCP	*Demand* →	MCP
Integrated	MCP	*Demand* →	MCP
Integrated	*MPSGE*	*Demand* → / ← *Energy mix*	MCP

MPSGE

Mathematical Programming System for General Equilibrium

- Instead of using standard GAMS language, an MCP can be formulated using MPSGE as programming interface.
- The nonlinear equations are automatically generated from a tabular description.
- The MCP version of TIMES is included as auxiliary constraints.
- Integration: Defining model structure using variables from the other model.

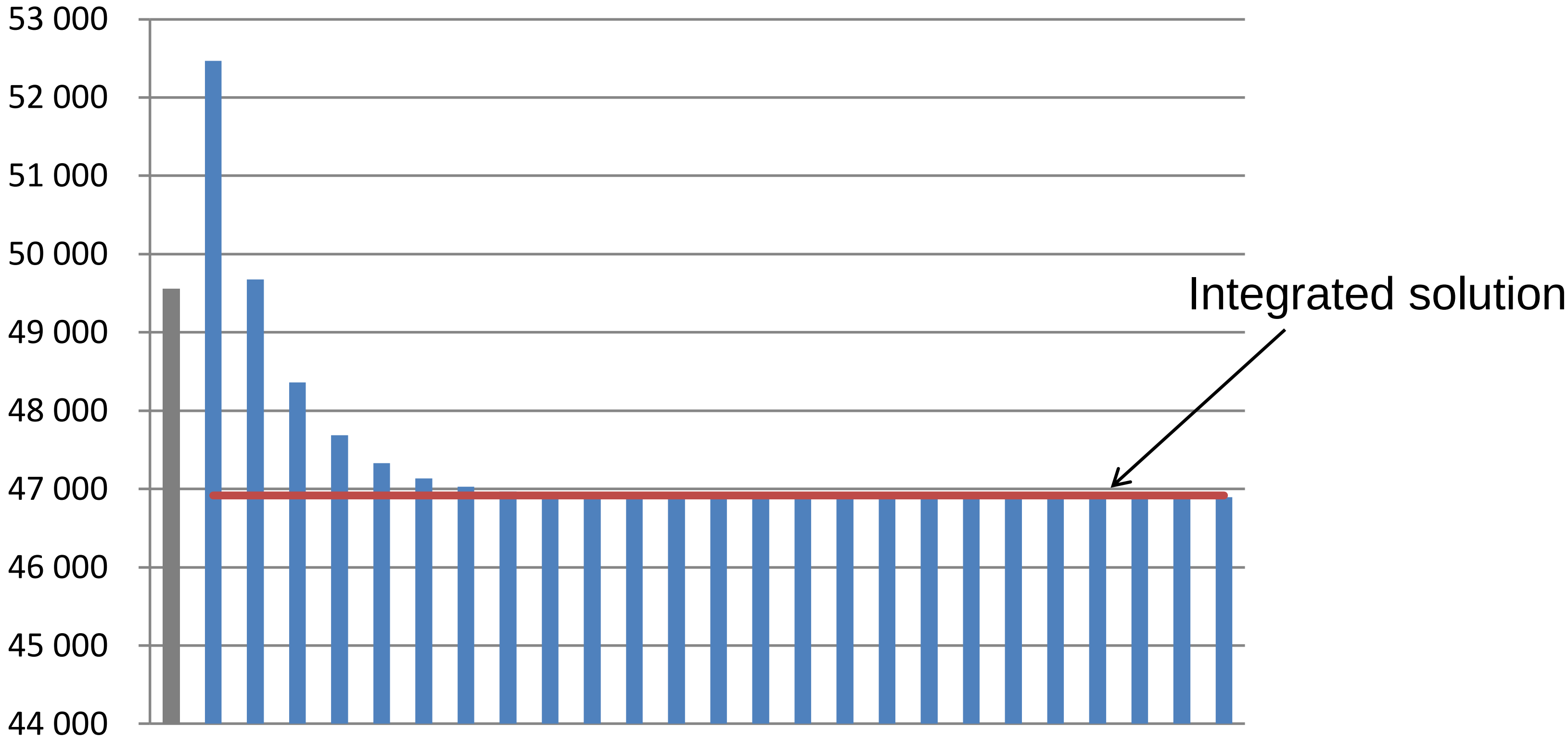
```
$ONTEXT

$MODEL: M4sec

$SECTORS:
       Y(sec)   ! Activity level for sectors

$COMMODITIES:
        P_(I)   ! Price index for commodities
        PF(F)   ! Price index for primary factors

$CONSUMERS:
        HOU     ! Income level for consumer HOU - Household

$AUXILIARY:
  VAR_ACT(R,T,T,P,S )       !        Overall activity of a process
  VAR_NCAP(R,T,P)           !        New capacity of a process
  VAR_COMPRD(R,T,Com,S )    !        Total production or consumption of a commodity

  U_CAPACT(R,T,T,P,S)       !   Dual - capacities for production processes
  U_COMBAL(R,T,Com,S)       !   Dual - commodity balances
  V_COMPRD(R,T,Com,S)       !   Dual - commodity production
  U_NCAP_UP(R,T,P)          !   Dual for upper bounds

$PROD:Y(I)$(not ele(i)) s:0  va:elasH(I)
        O:P_(I)  Q:Y0tot(I)
        I:P_(J)  Q:Y0(J,I)
        I:PF(F) Q:FD0(F,I)  va:

$DEMAND:HOU s:1
        D:P_(I)   Q:(C0(I)-muH(I))
        E:PF(F)  Q:(E(F)*ENDOW(F))
        E:P_(I)   Q:-muH(I)
```

Model implementations

	CGE		TIMES
Linked	MCP	*Demand* → / ← *Energy mix*	LP
Linked	MPSGE	*Demand* → / ← *Energy mix*, *Capital*	MCP
Integrated	MPSGE	*Demand* → / ← *Energy mix*, *Capital*	MCP

Energy system costs

This was what I hoped for:



The linked models and the integrated model producing the same solution

Conclusions

Conclusions

How should a bottom-up engineering optimization model and a top-down economic complementarity model be linked?

→ The economic model can provide projected demand, the engineering model can provide energy mix and capital investment

Can they be integrated?

→ Yes – at least the simple test models can be integrated

Do linked models and an integrated model produce the same solutions?

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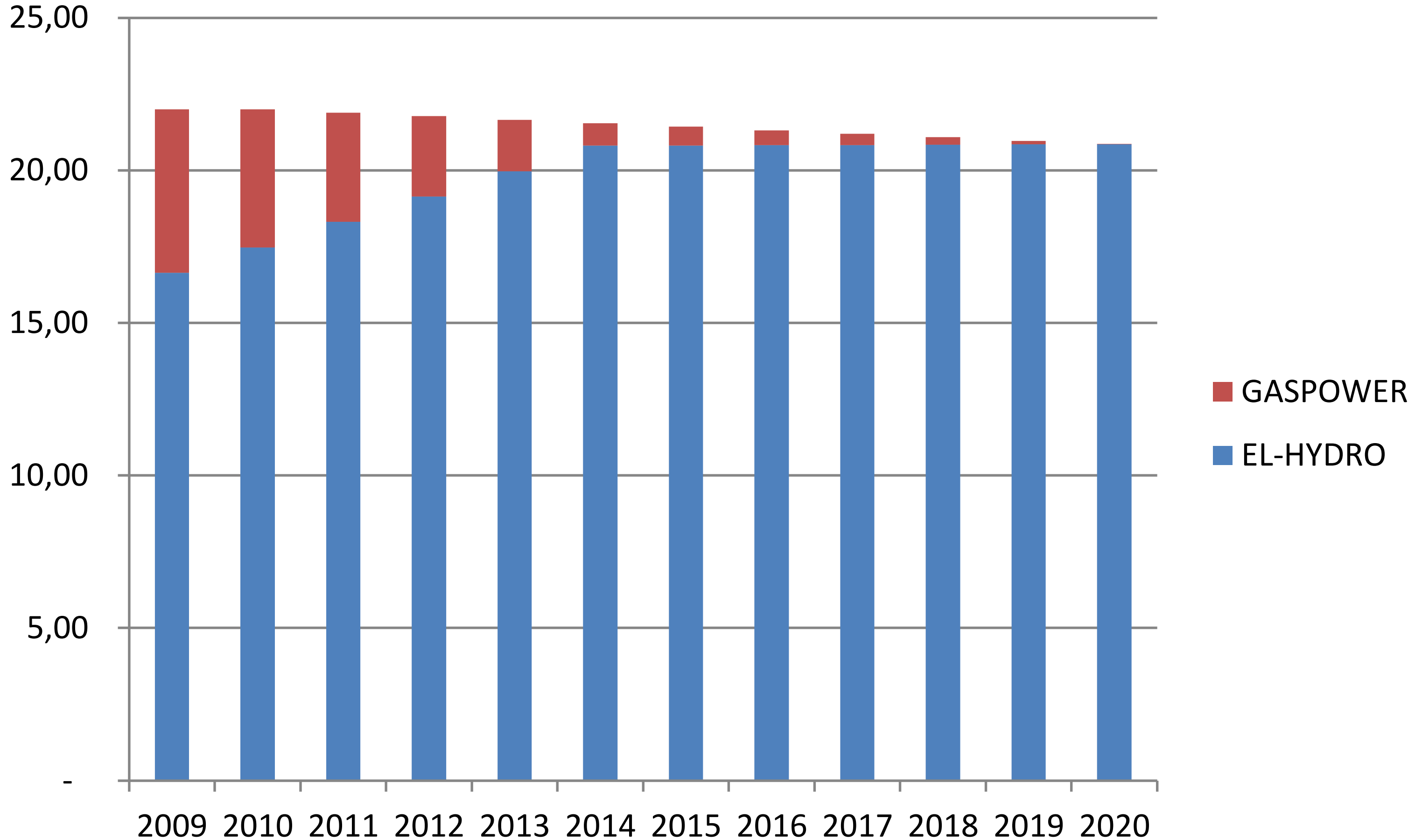
"Corner solution"



Conclusions

How should a bottom-up engineering optimization model and a top-down economic complementarity model be linked?

→ The economic model can provide projected demand, the engineering model can provide energy mix and capital investment

Can they be integrated?

→ Yes – at least the simple test models can be integrated

Do linked models and an integrated model produce the same solutions?

→ Not necessarily

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Conclusions

We have successfully implemented linked and integrated models in different modelling configurations.

The hybrid modelling leads to different solutions than running the models separately.

The linked and the integrated models currently do not converge to the same solution.

➔ Results may depend on modelling approach.

Thank you for your attention

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