DTU

DTU

Professor Marie Münster,
Technical University of Denmark, DTU Management
Keynote SDEWES 12/10 2021

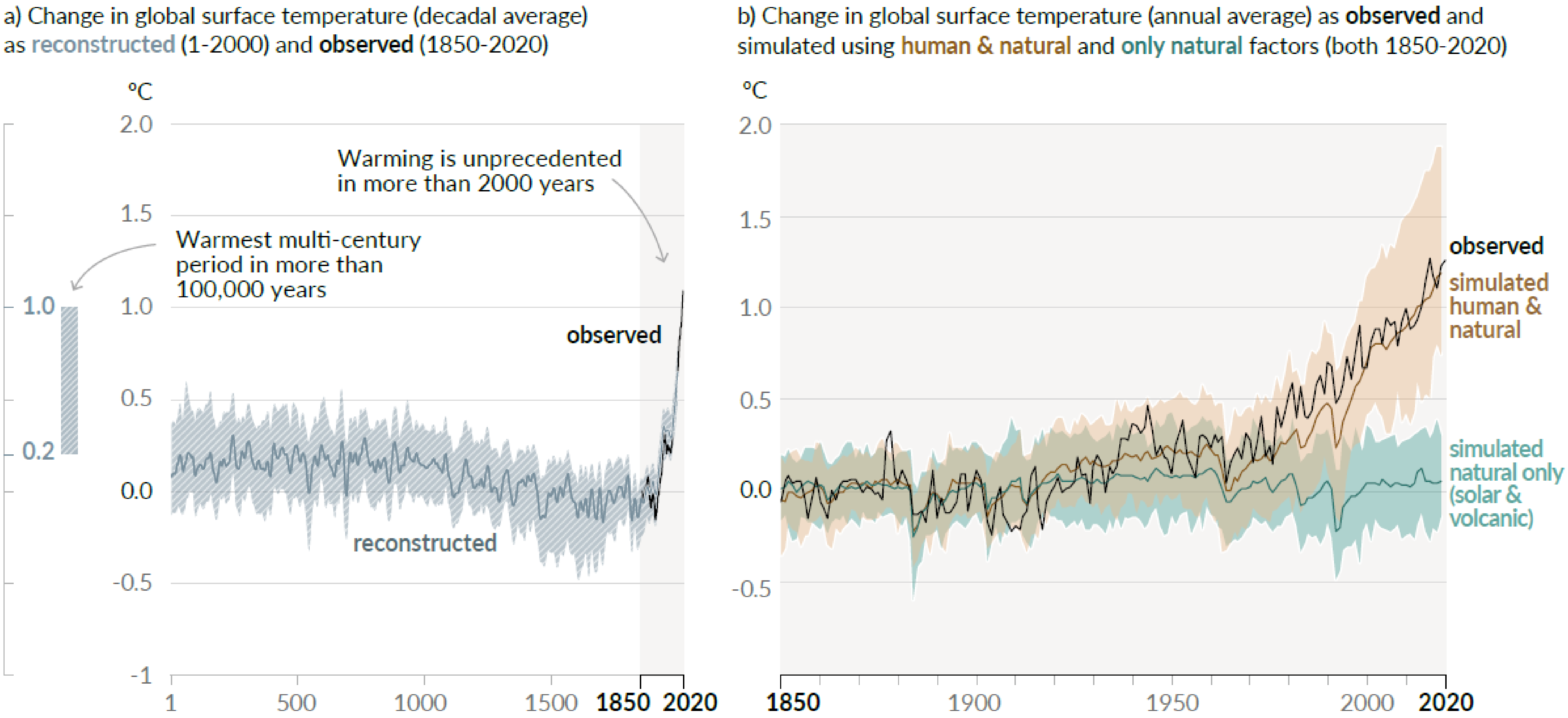
The Impact of Sector Coupling on Future Energy Systems

Global Challenges

https://www.stockholmresilience.org/research/planetary-boundaries.html

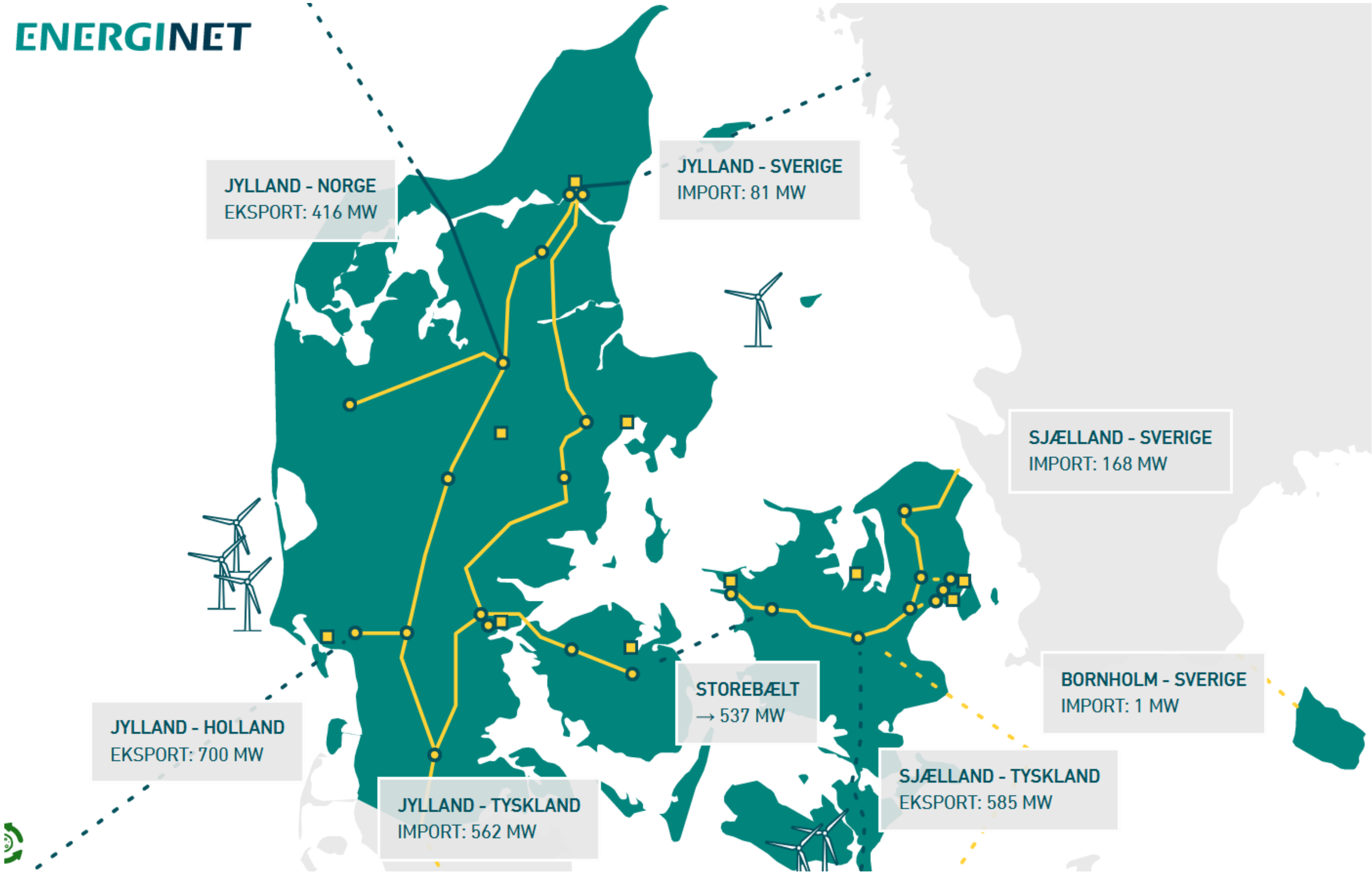
Global warming

Changes in global surface temperature relative to 1850-1900



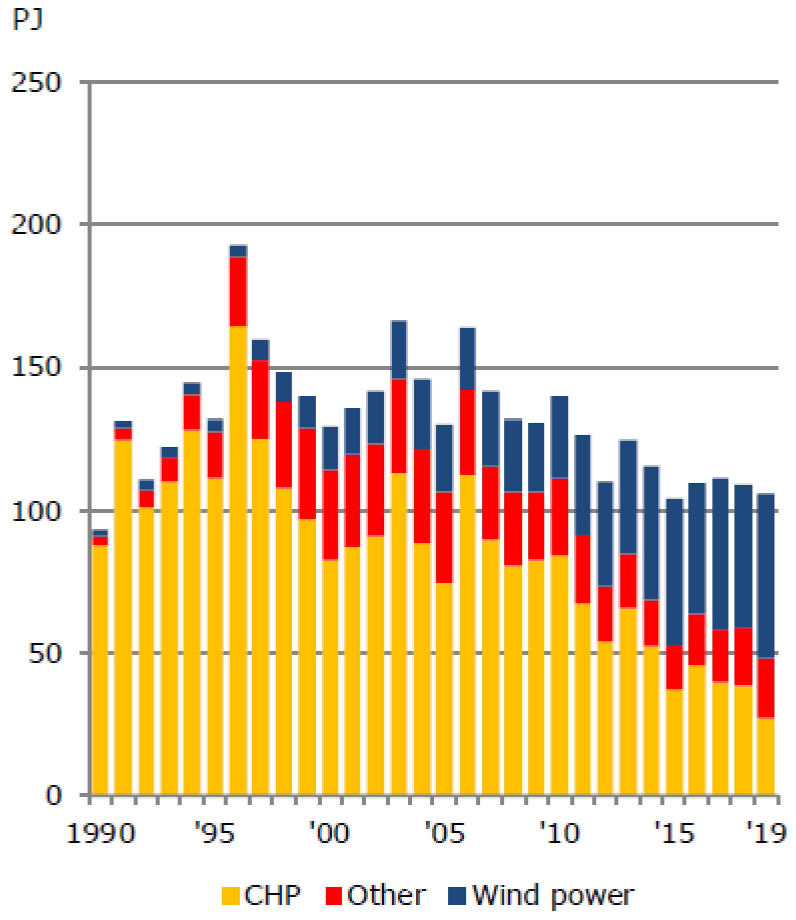
Summary for Policymakers IPCC AR6 WGI 2021

Denmark as a case

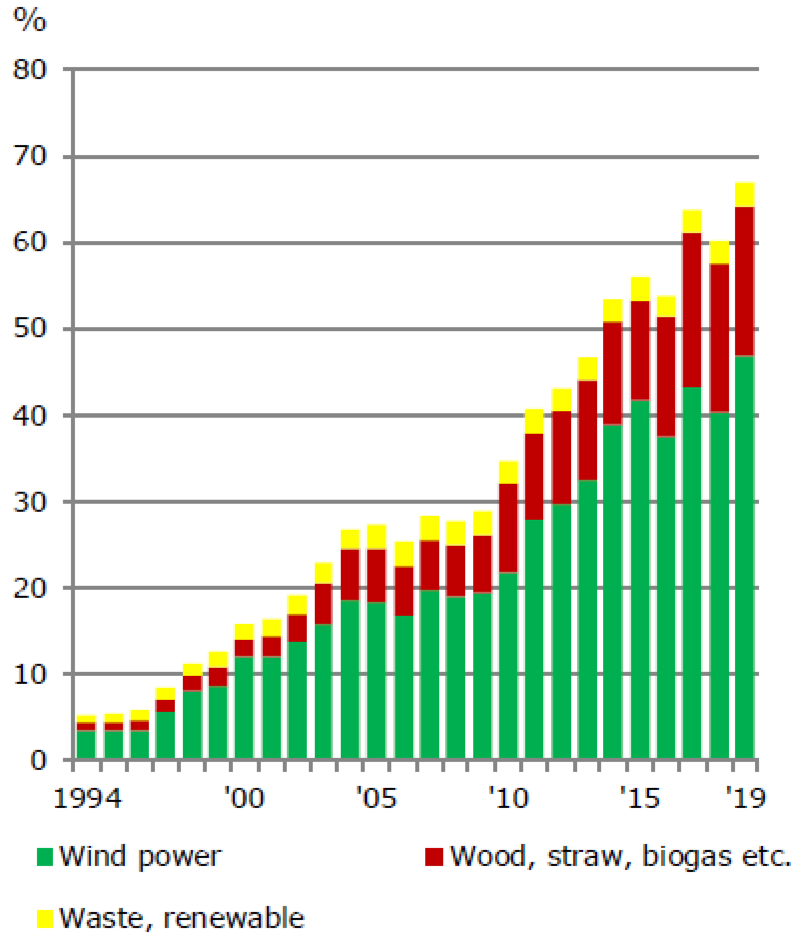


Danish electricity production

Electricity production by type

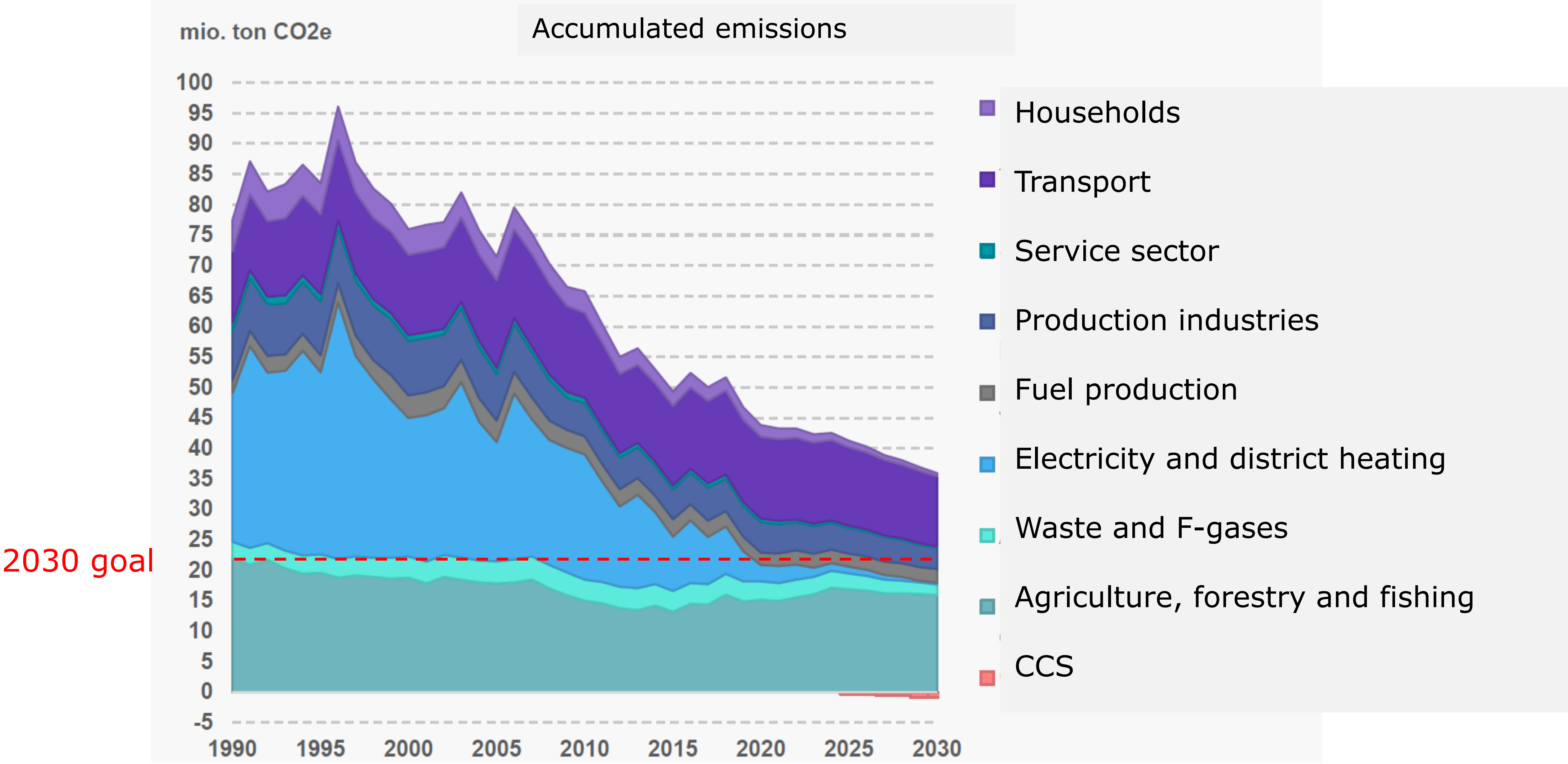


Electricity generated by renewables: Share of domestic electricity supply



Energy in Denmark, DEA, 2019

GHG challenges in DK



From Klimastatus og -fremskrivning, DEA, 2021

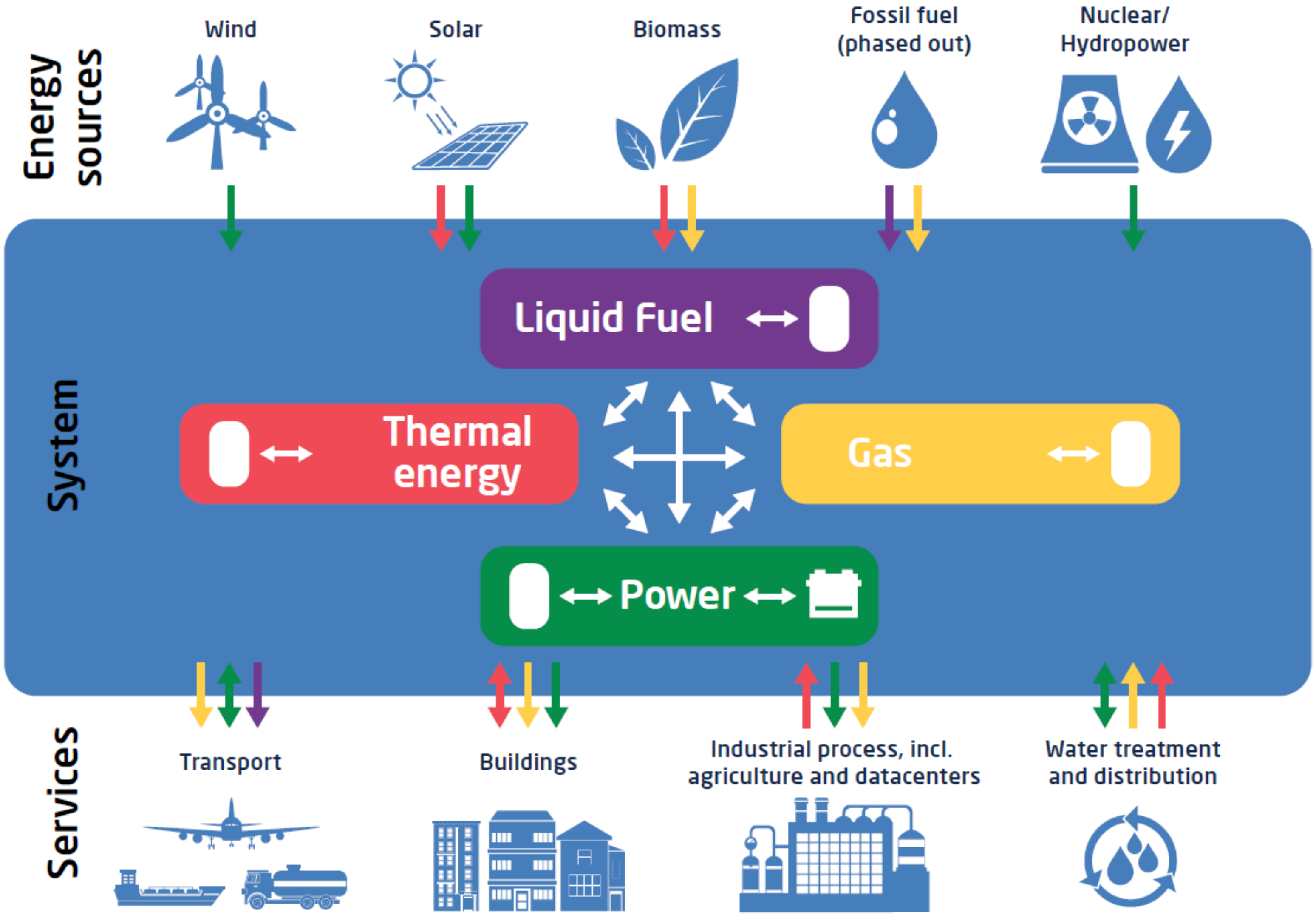
Smart energy systems and sector coupling

Power to other sectors

- Direct and indirect electrification

Others to power sector

- Flexibility and storage



UK Summary of DTU Sector Development report about Smart Energy Systems. July 2020

Defining Sector Coupling

Two types of sector coupling:

- **“End-use sector coupling** involves the electrification of energy demand while reinforcing the interaction between electricity supply and end-use.”

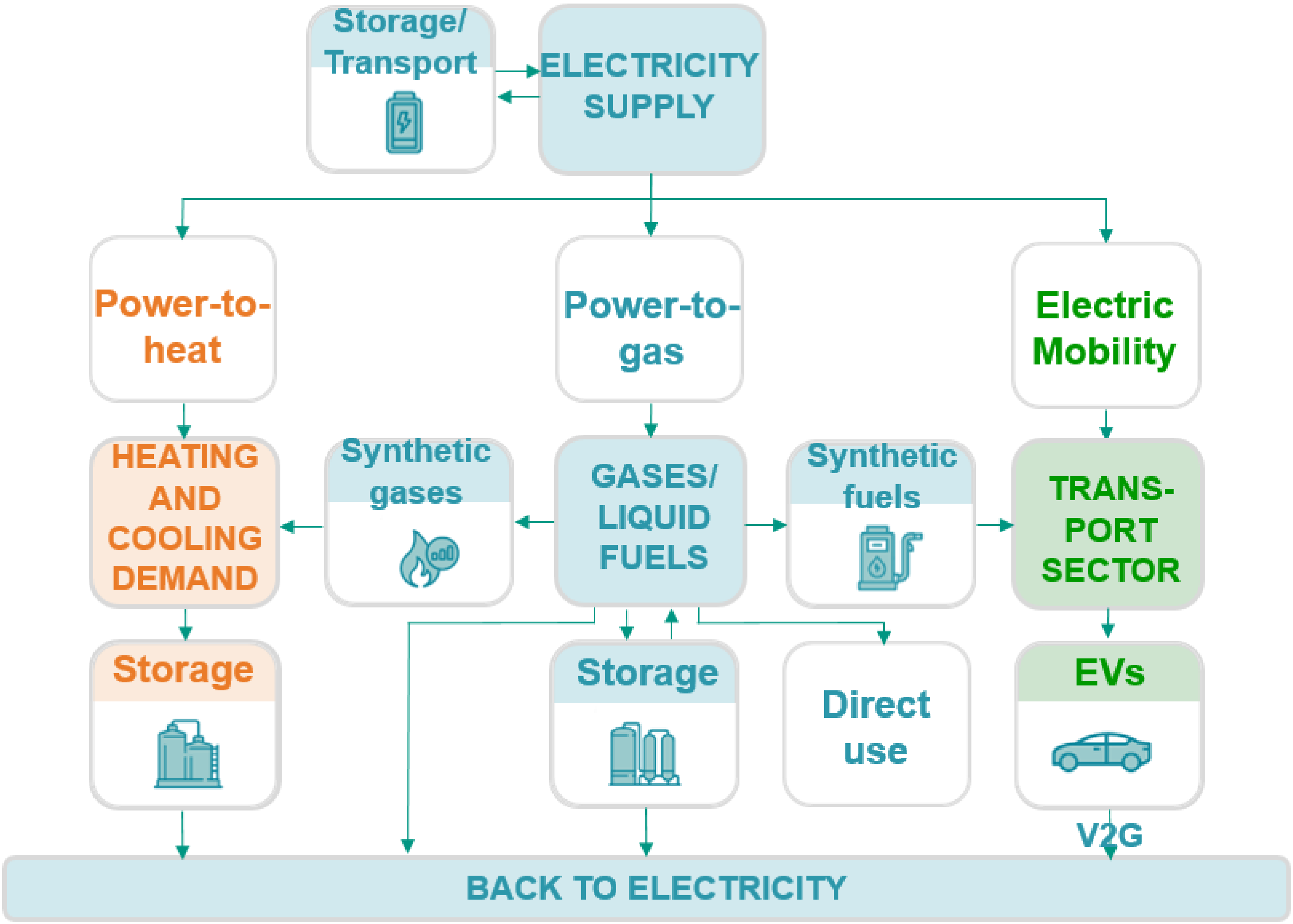
- **“Cross-vector coupling** involves the integrated use of different energy infrastructures and vectors, in particular electricity, heat and gas, either on the supply side, e.g. through conversion of (surplus) electricity to hydrogen, or at the demand side, e.g. by using residual heat from power generation or industrial processes for district heating.”

(DG for Internal Policies, European Parliament, Nov. 2018)

Alternative terms (UK, EERA-European Energy Research Alliance):

„Energy Vector Coupling“ or „Energy Systems Integration“

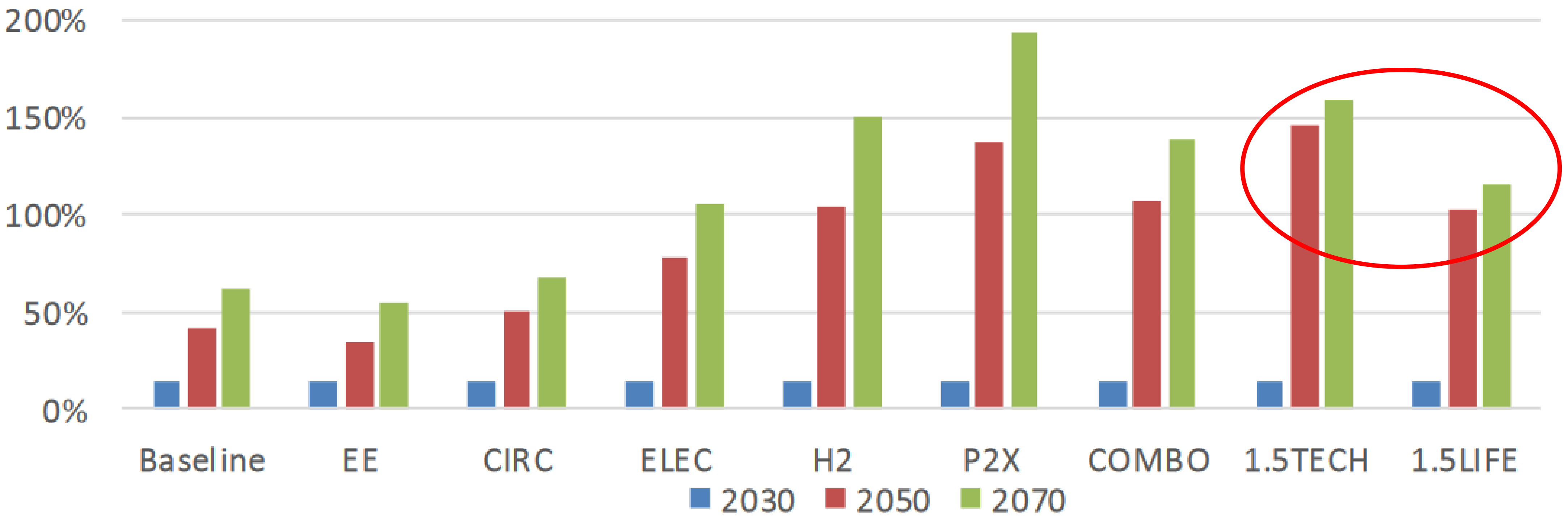
Different ways of Sector Coupling



Source: IEA, 2019

Potential electricity demand increases

Figure 22: Increase in gross electricity generation compared to 2015



Source: Eurostat (2015), PRIMES.

(A Clean Planet for all -A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" EU Commission, Nov 2018)

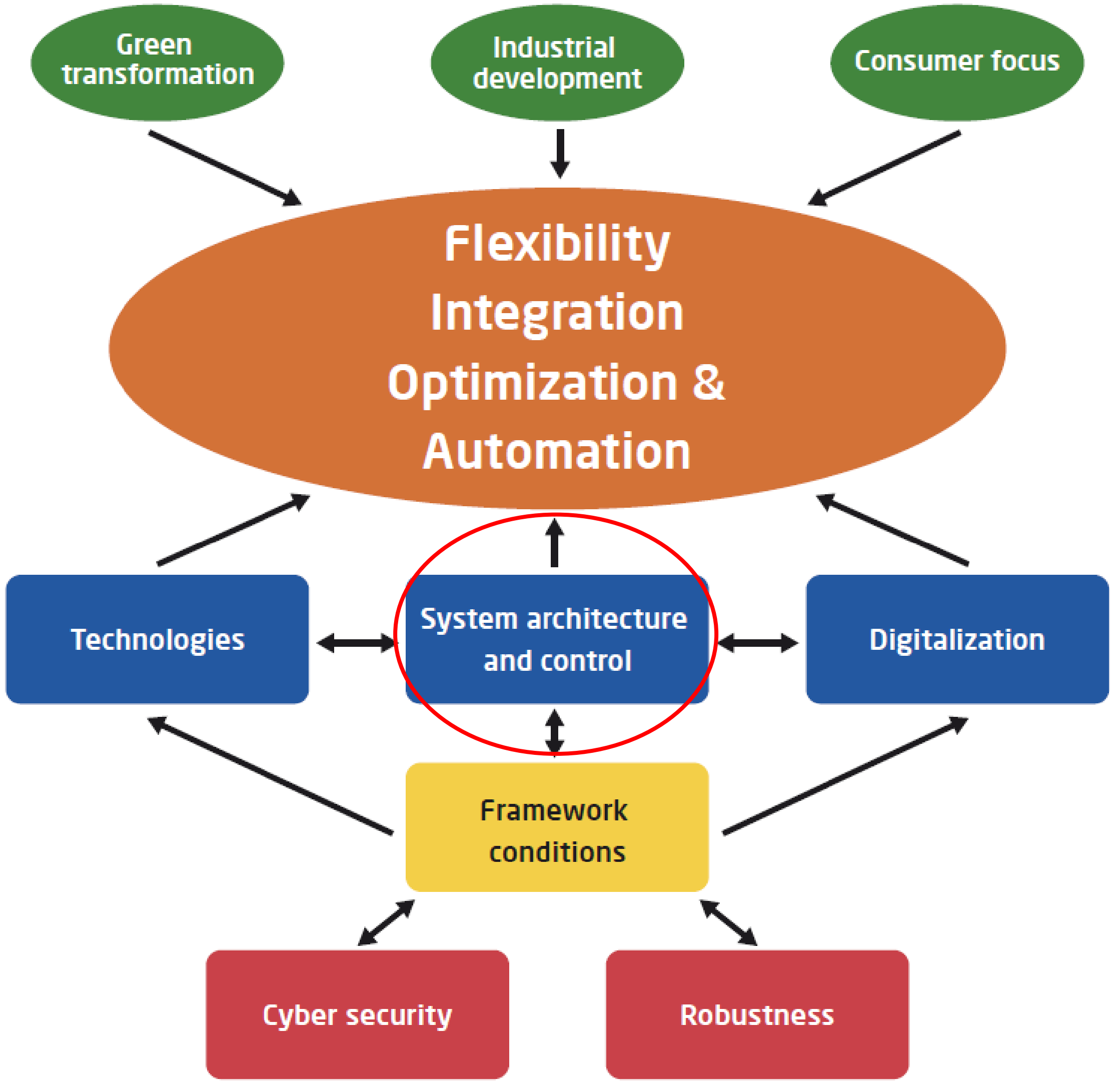
Research needs

Objectives we want to fulfill …

… by smart energy means like …

…facilitated by …

… based on a development of …



UK Summary of DTU Sector Development report about Smart Energy Systems. July 2020

Modelling sector coupled systems

Plant level system optimisation

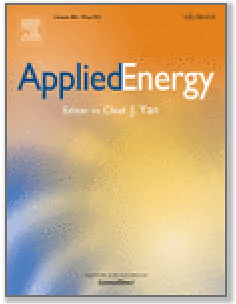
- All other is equal
- Operating hours and e.g. average electricity and heat prices
- More details - e.g. on internal heat optimisation
- LCOE (no system costs or competition) - and local emissions

Large-scale energy system optimisation

- Integrating variable renewable energy production (wind and solar)
- Assessing competition between technologies and synergies (generation, storage, transmission, flexible demand)
- Location of renewable energy sources and energy infrastructure
- International energy markets (power, gas, fuels)
- Impact on energy prices and operating hours (all other is not equal)
- System costs, electricity and DH prices - and system emissions

NorENS

Applied Energy
Volume 289, 1 May 2021, 116685



The role of sector coupling in the green transition: A least-cost energy system development in Northern-central Europe towards 2050

Juan Gea-Bermúdez [a], Ida Græsted Jensen [a], Marie Münster [a], Matti Koivisto [b], Jon Gustav Kirkerud [c], Yi-kuang Chen [c], Hans Ravn [d]

Balmorel

Input

Heat and electricity demand
Fuel prices and emissions
Efficiencies and costs
Hourly distribution of demands
and production from RE sources
Capacities of existing plants and transmission
Time aggregation

Output

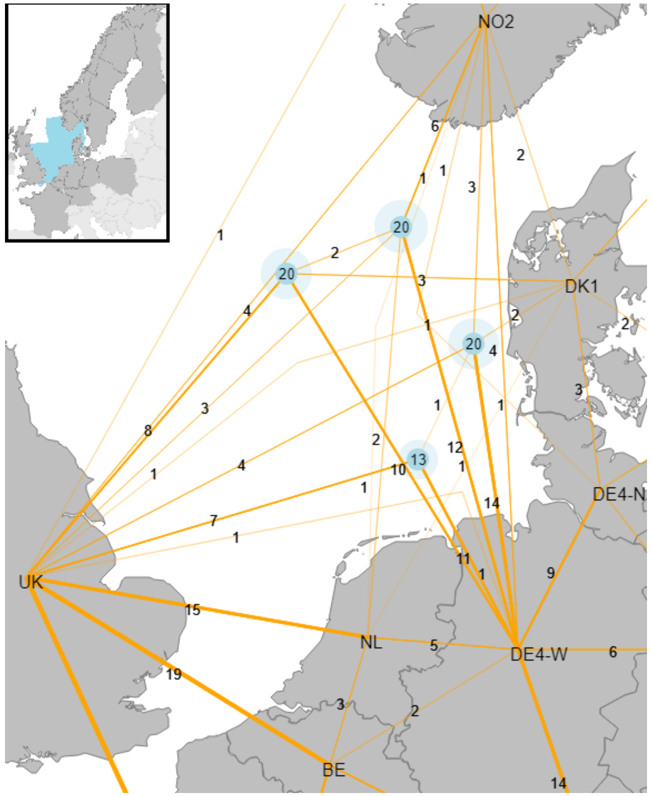
Energy conversion
Fuel/ electricity consumption
Electricity import/export
Emissions
Investments in plants
and transmission lines (el/DH)
Prices on traded energy
Total costs

Modes

LP or MIP
(e.g. economy of scale)
Myopic investments or
Rolling horizon

Assumptions

Economic rationality
Perfect markets
Perfect foresight within a year



J. Gea-Bermúdez et al., The role of sector coupling in the green transition

https://www.techrxiv.org/articles/preprint/The_role_of_sector_coupling_in_the_green_transition_A_least-cost_energy_system_development_in_North_Europe_towards_2050/12933071/1

Balmorel objective function

The mathematical formulation of the objective function is represented as a minimizing problem for the simulated year:

$$min.\mathcal{V}_{obj} = \sum_{\mathcal{C},\mathcal{R},\mathcal{A},\mathcal{G},\mathcal{T}} \left(C^{fuel}_{\mathcal{A},\mathcal{G},\mathcal{T}} + C^{O\&M}_{\mathcal{A},\mathcal{G},\mathcal{T}} + C^{inv}_{\mathcal{A},\mathcal{R},\mathcal{G},\mathcal{T}} + C^{trans}_{\mathcal{R},\mathcal{T}} + T^{fuel}_{\mathcal{C},\mathcal{R},\mathcal{A},\mathcal{G},\mathcal{T}} + T^{ems}_{\mathcal{C},\mathcal{G},\mathcal{T}} + T^{other}_{\mathcal{A},\mathcal{G},\mathcal{T}} \right)$$

$C^{fuel}_{\mathcal{A},\mathcal{G},\mathcal{T}}$ represents the fuel costs for Generation technology $\mathcal{G}$ in Area $\mathcal{A}$ at Time $\mathcal{T}$

$C^{O\&M}_{\mathcal{A},\mathcal{G},\mathcal{T}}$ represents the fixed and variable operation costs related to the Generation technology $\mathcal{G}$ in Area $\mathcal{A}$ at Time $\mathcal{T}$

$C^{inv}_{\mathcal{A},\mathcal{R},\mathcal{G},\mathcal{T}}$ represents the investment costs in the new Generation technology $\mathcal{G}$ in Area $\mathcal{A}$, and transmission capacity between Regions $\mathcal{R}$, at Time $\mathcal{T}$

$C^{trans}_{\mathcal{R},\mathcal{T}}$ represents the transmission costs related to the electricity exchange between Regions $\mathcal{R}$ at Time $\mathcal{T}$

$T^{fuel}_{\mathcal{C},\mathcal{R},\mathcal{A},\mathcal{G},\mathcal{T}}$ represents the fuel taxes for Generation technology in Country $\mathcal{C}$ or in Regions $\mathcal{R}$ or Area $\mathcal{A}$ at Time $\mathcal{T}$

$T^{ems}_{\mathcal{C},\mathcal{G},\mathcal{T}}$ represents the emission taxes e.g. CO2 costs, for Country $\mathcal{C}$, emitted by Generation technology $\mathcal{G}$ at Time $\mathcal{T}$

$T^{other}_{\mathcal{A},\mathcal{G},\mathcal{T}}$ represents other taxes which can be related to district heating and heat only Generation technologies $\mathcal{G}$ in Area $\mathcal{A}$ at Time $\mathcal{T}$

Balmorel constraints

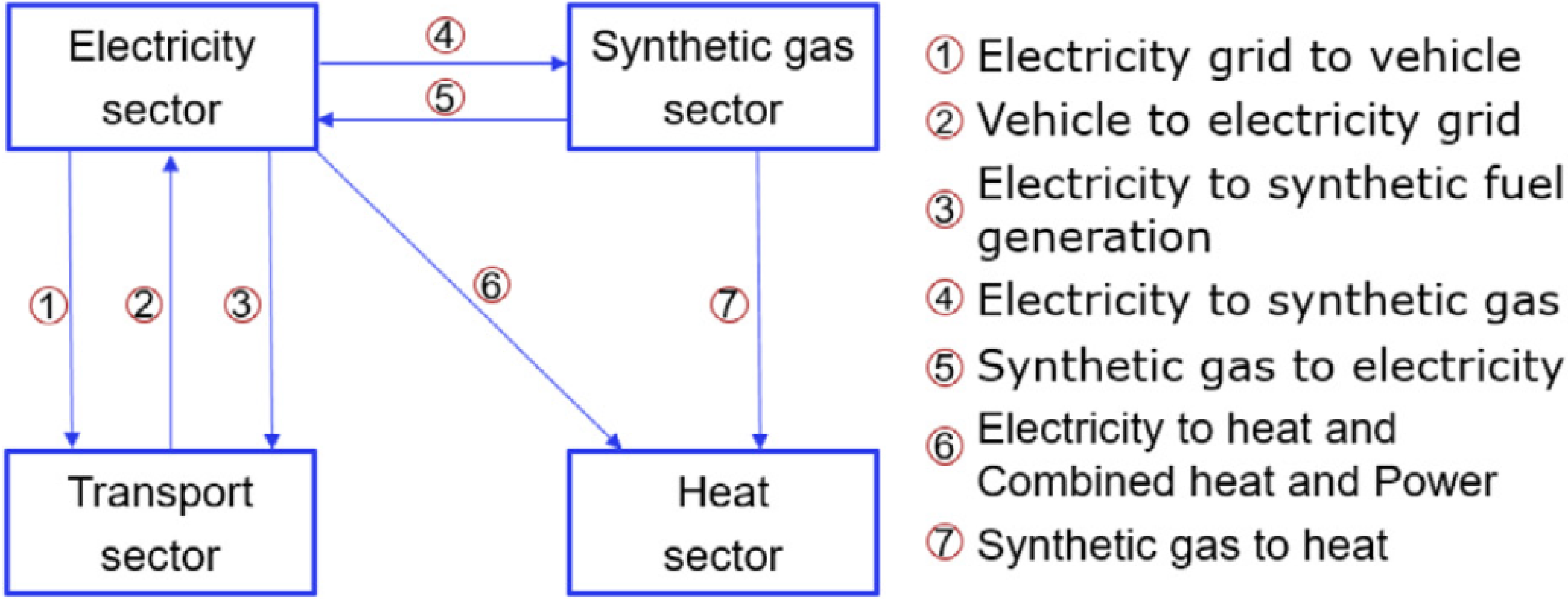
The objective function minimizes:

- **Costs**: investment costs, operation and maintenance costs, fuel costs, taxes etc.

Constraints

- Balance equations
- Capacity constraints
- Energy constraints
- Operational constraints
- Emission caps/ renewable energy targets

Sector coupling - System analysis example

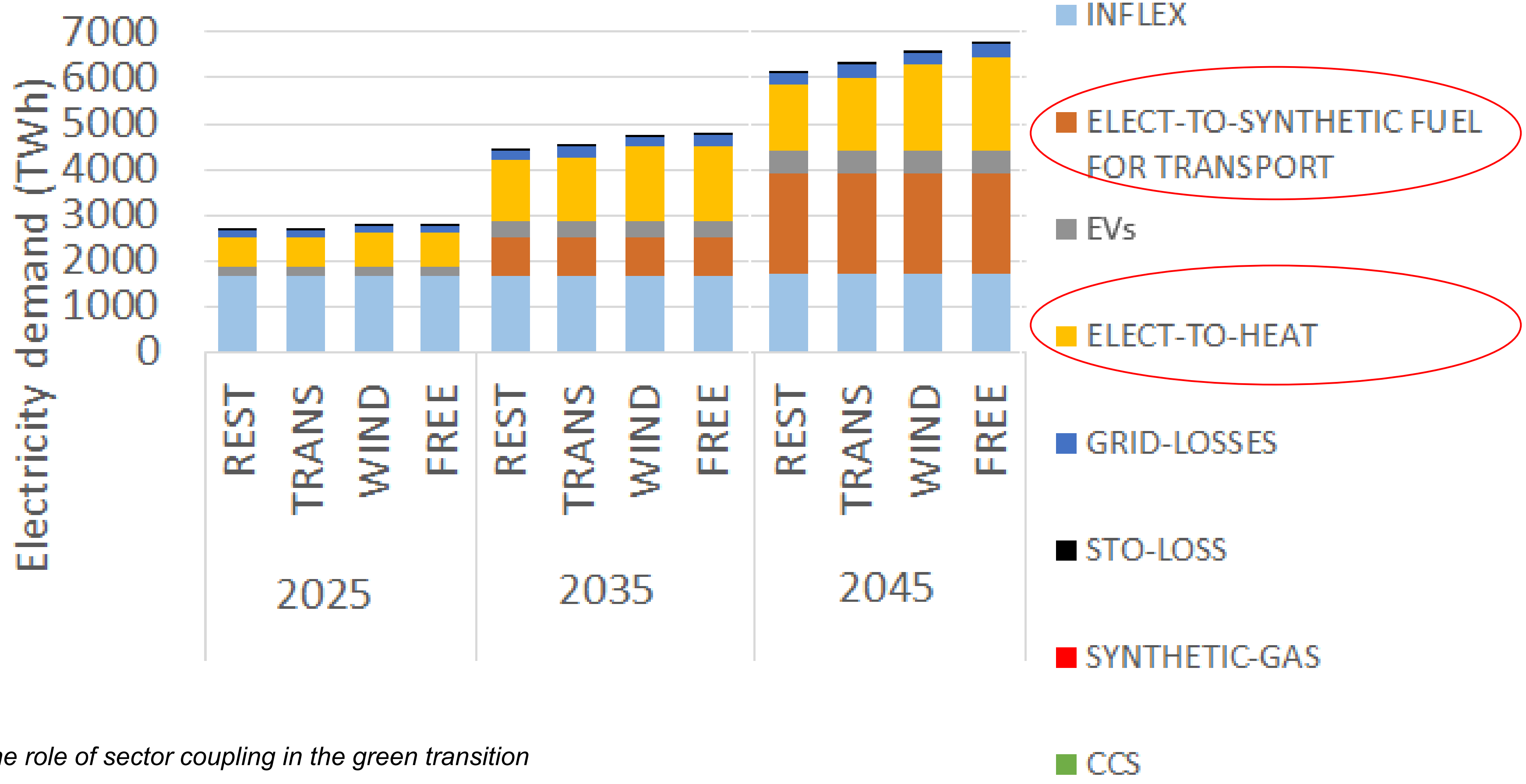


(a) Sectors included in the model and their possible synergies.

Scenario	Transmission investments	High onshore wind potential	P2H investments	Decarboni-sation of the transport sector	Synthetic gas investments
REST (Restricted)	-	-	+	+	+
TRANS (Transmission)	+	-	+	+	+
WIND *(High onshore potential)*	-	+	+	+	+
FREE	+	+	+	+	+

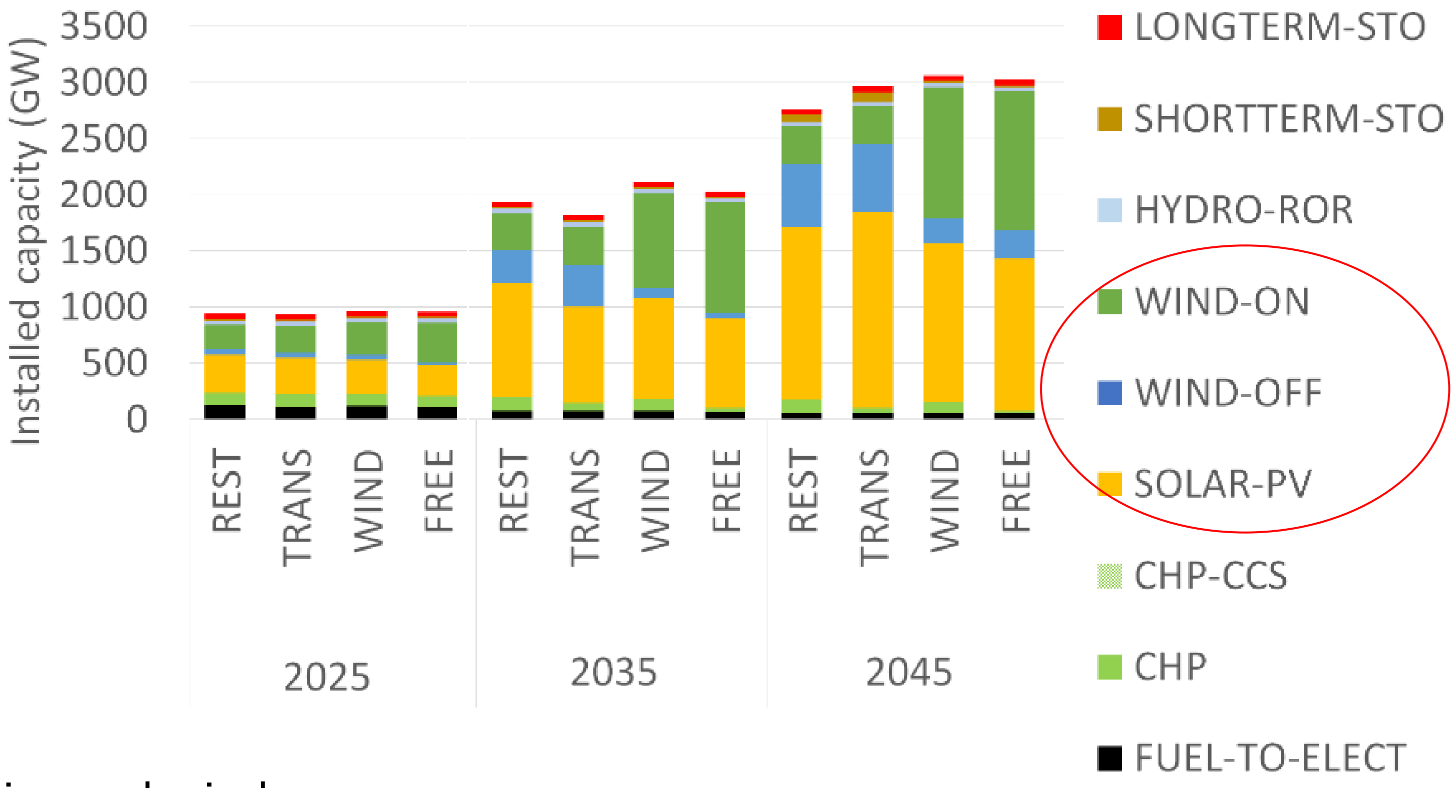
Electricity demand in North Europe

- Sector coupling leads to higher electricity demand
- Higher electricity demand leads to higher need for VRE installations



J. Gea-Bermúdez et al., The role of sector coupling in the green transition
https://www.techrxiv.org/articles/preprint/The_role_of_sector_coupling_in_the_green_transition_A_least-cost_energy_system_development_in_North_Europe_towards_2050/12933071/1

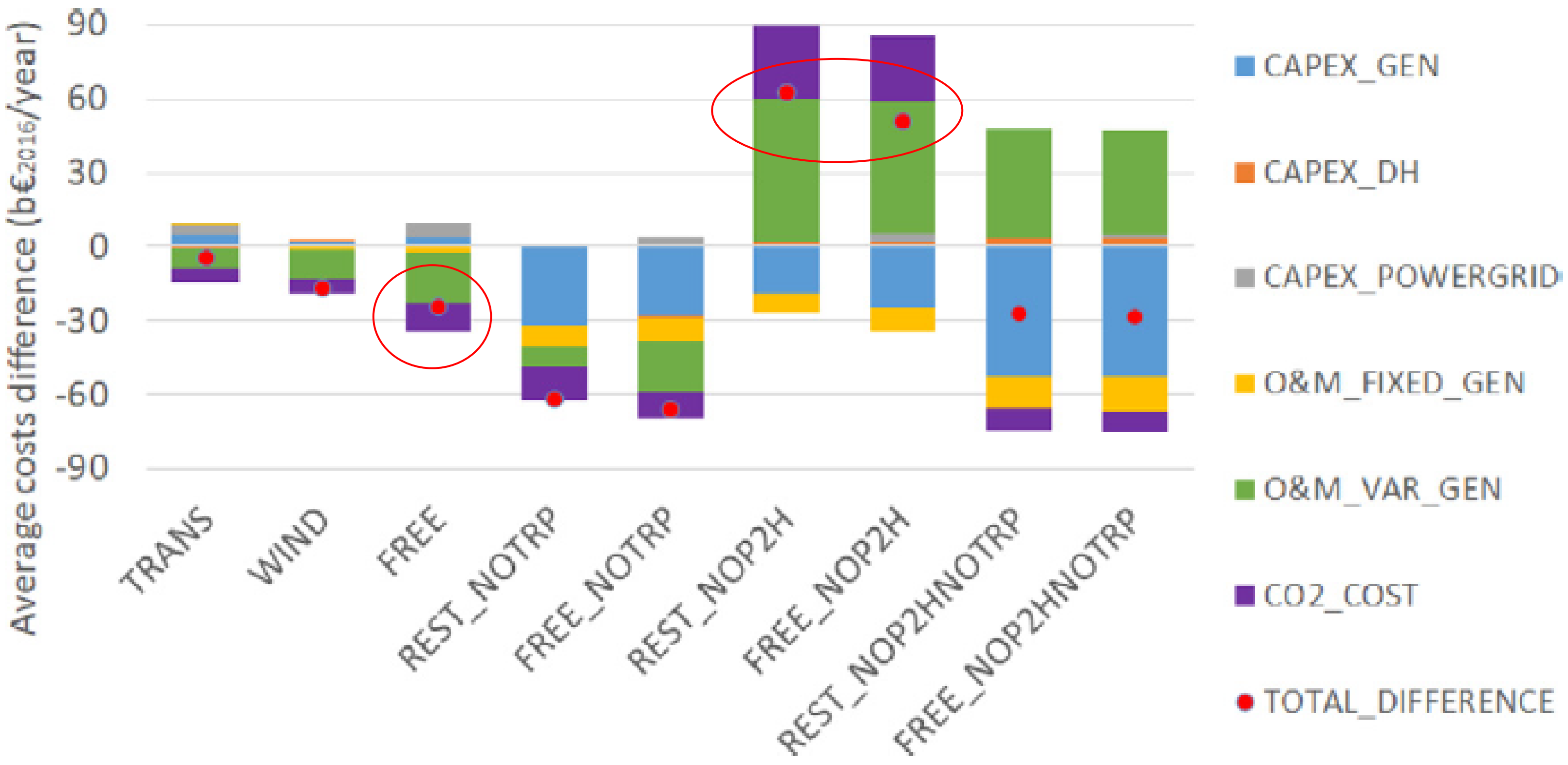
Electricity generation capacity in North Europe



- Mainly photo voltaics and wind power
- Onshore wind restrictions increase offshore wind investments

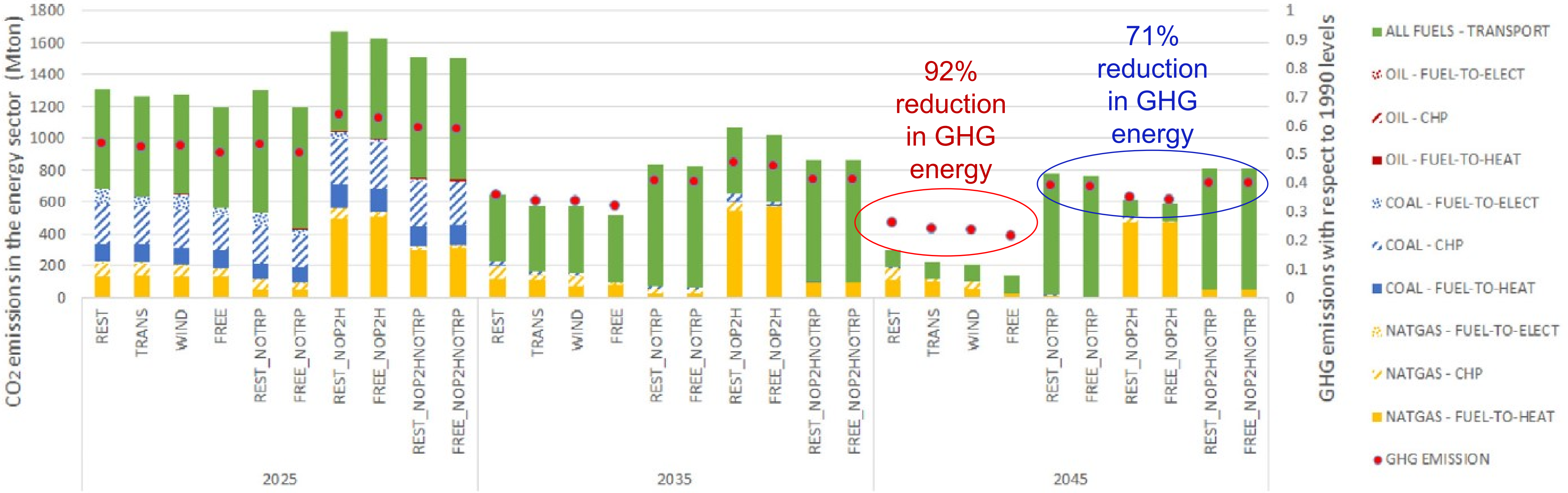
J. Gea-Bermúdez et al., The role of sector coupling in the green transition
https://www.techrxiv.org/articles/preprint/The_role_of_sector_coupling_in_the_green_transition_A_least-cost_energy_system_development_in_North_Europe_towards_2050/12933071/1

Difference in system costs (North Europe)



The possibility to invest in P2H units leads to annual savings of around 30%

GHG emissions w/wo sector coupling (in North Europe)



Sector coupling leads to leads to around 20 percent points lower GHG emissions in the energy sector

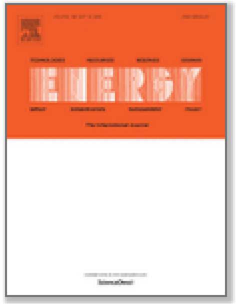
Conclusions

- Sector coupling facilitates increased electricity demand, VRE integration, heat storage capacity, and electricity and district heating transmission expansion towards 2050
- Sector coupling can facilitate lower costs and GHG emissions - assuming perfect markets and digitalization
- Main new electricity demands are PtH and PtX (from 2035), which can both feed into district heating
- Onshore wind potential highly influences offshore wind development. Sector coupling has the potential to significantly increase offshore wind investments, and hence, the value of offshore grids

www.futuregas.dk

Energy

Volume 199, 15 May 2020, 117408



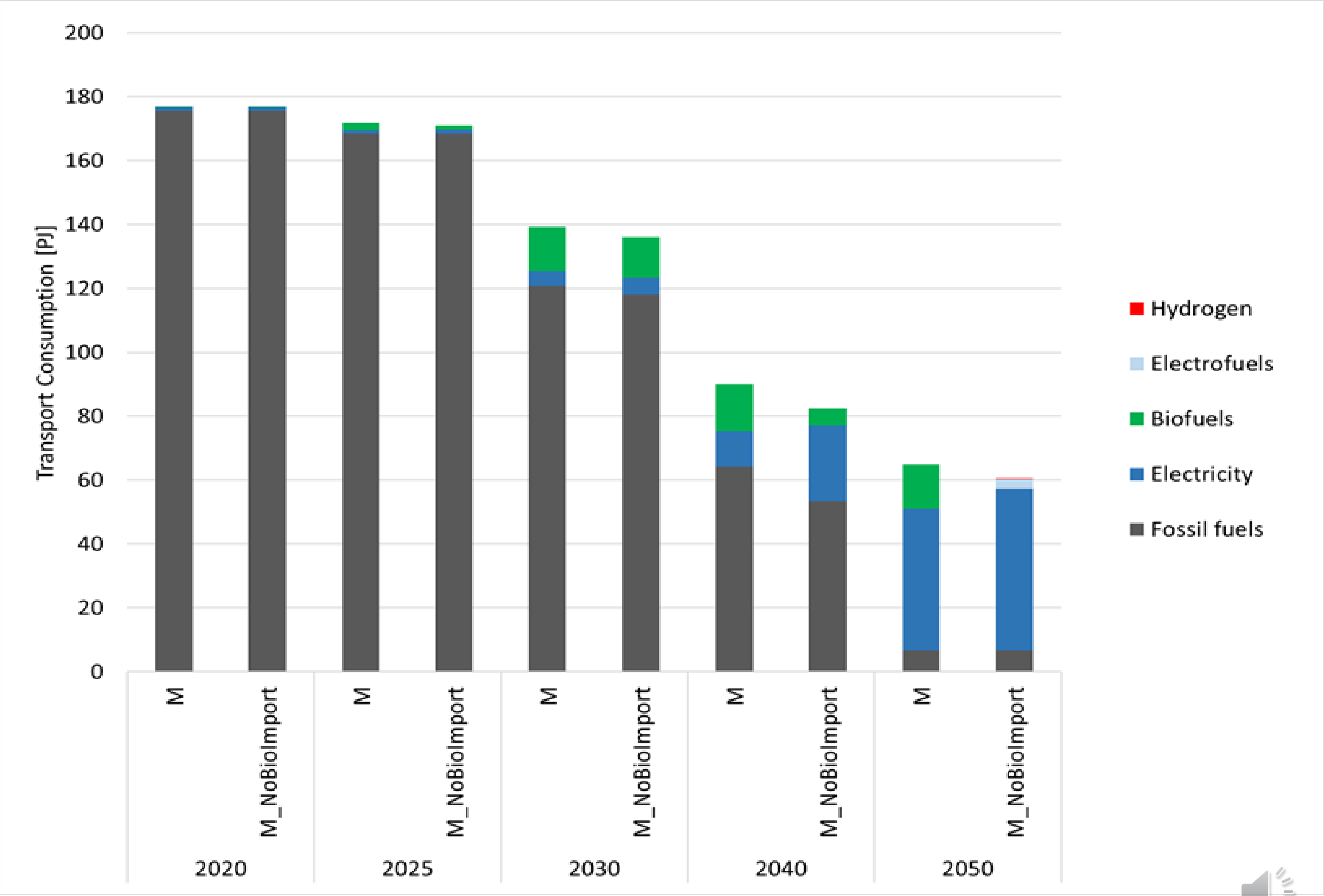
Analysis on Electrofuels in Future Energy Systems: A 2050 Case Study

Mason Scott Lester, Rasmus Bramstoft, Marie Münster

FutureGas Transport Consumption (TIMES)

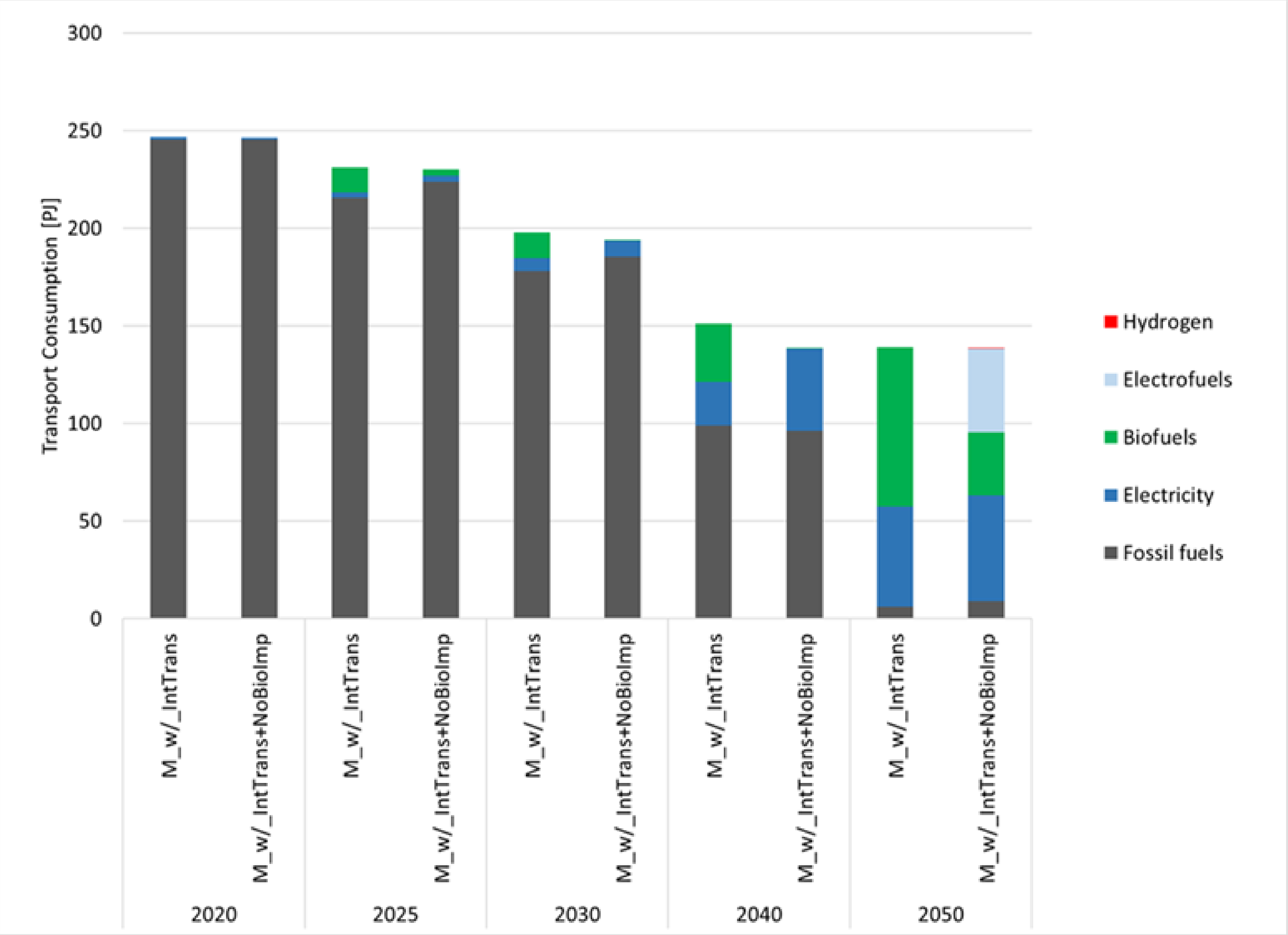
w/wo biomass import

www.futuregas.dk

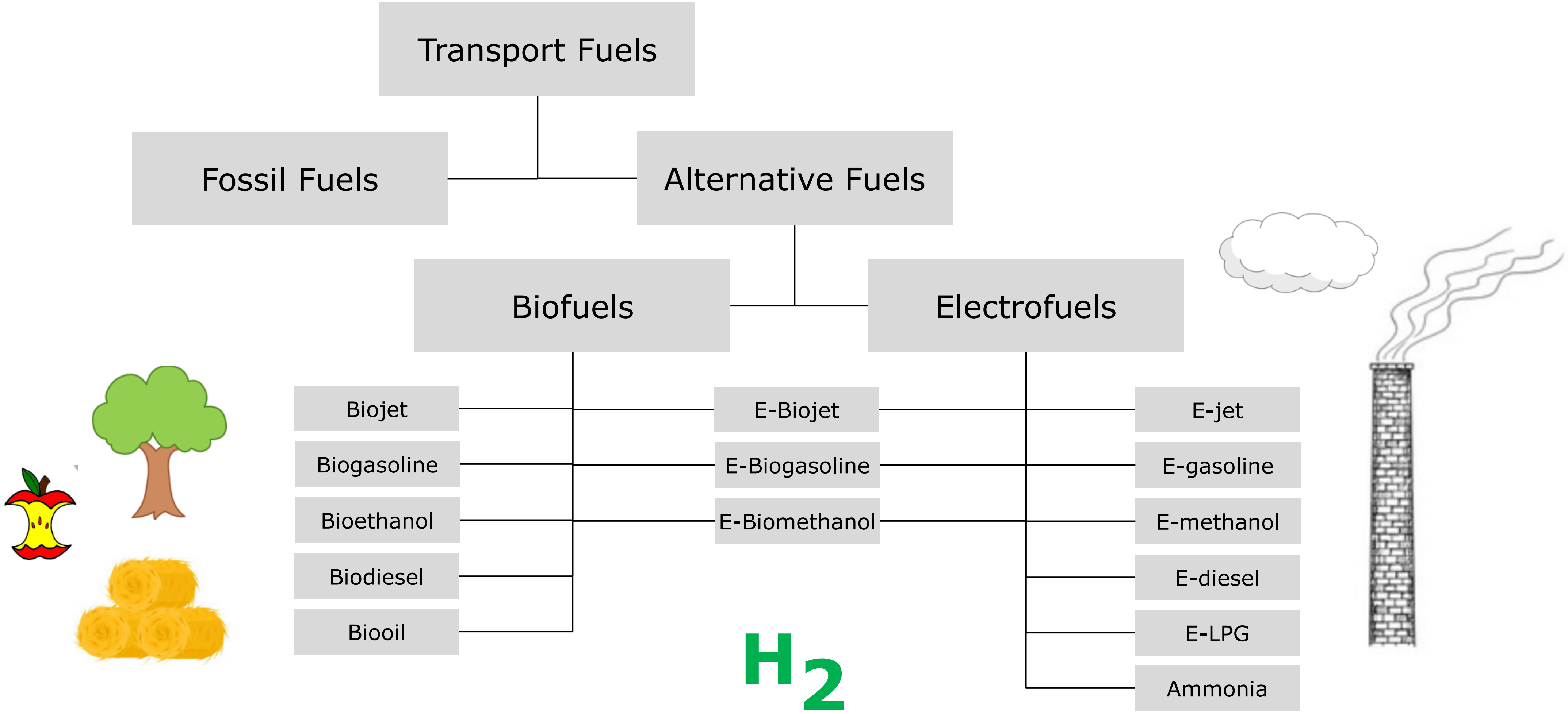


FutureGas Transport Consumption (TIMES)

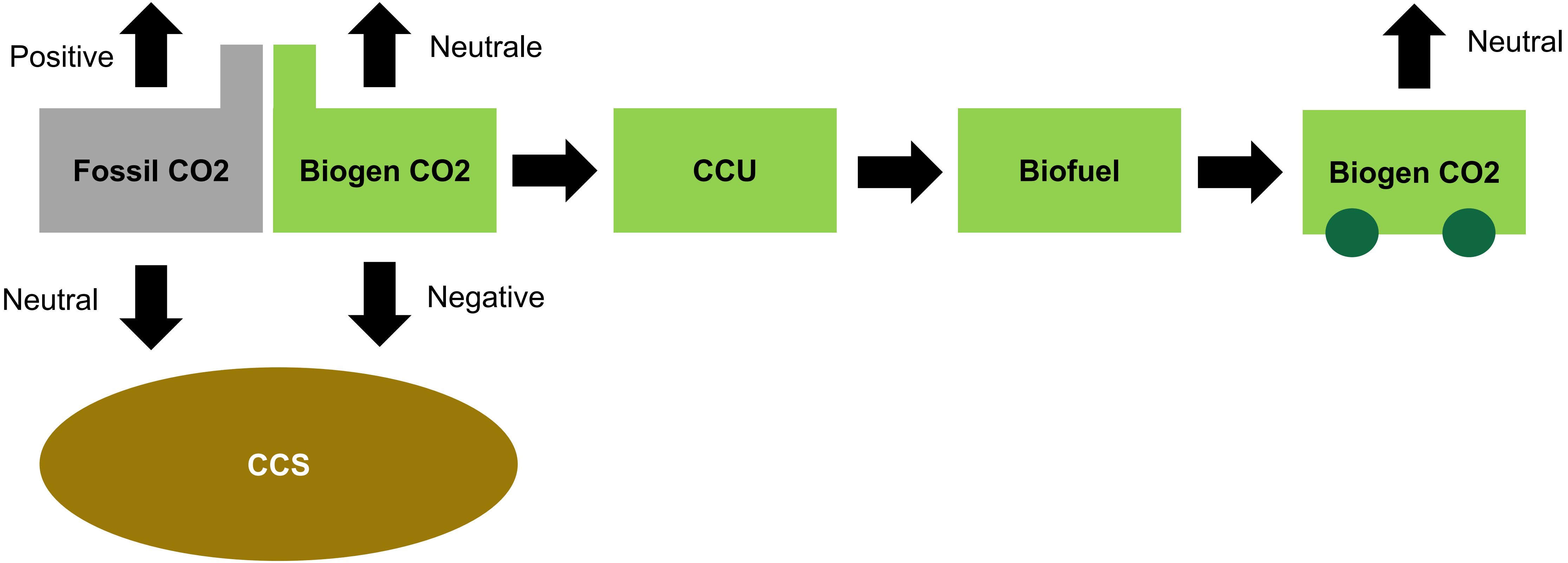
w international transport
w/wo biomass import
www.futuregas.dk

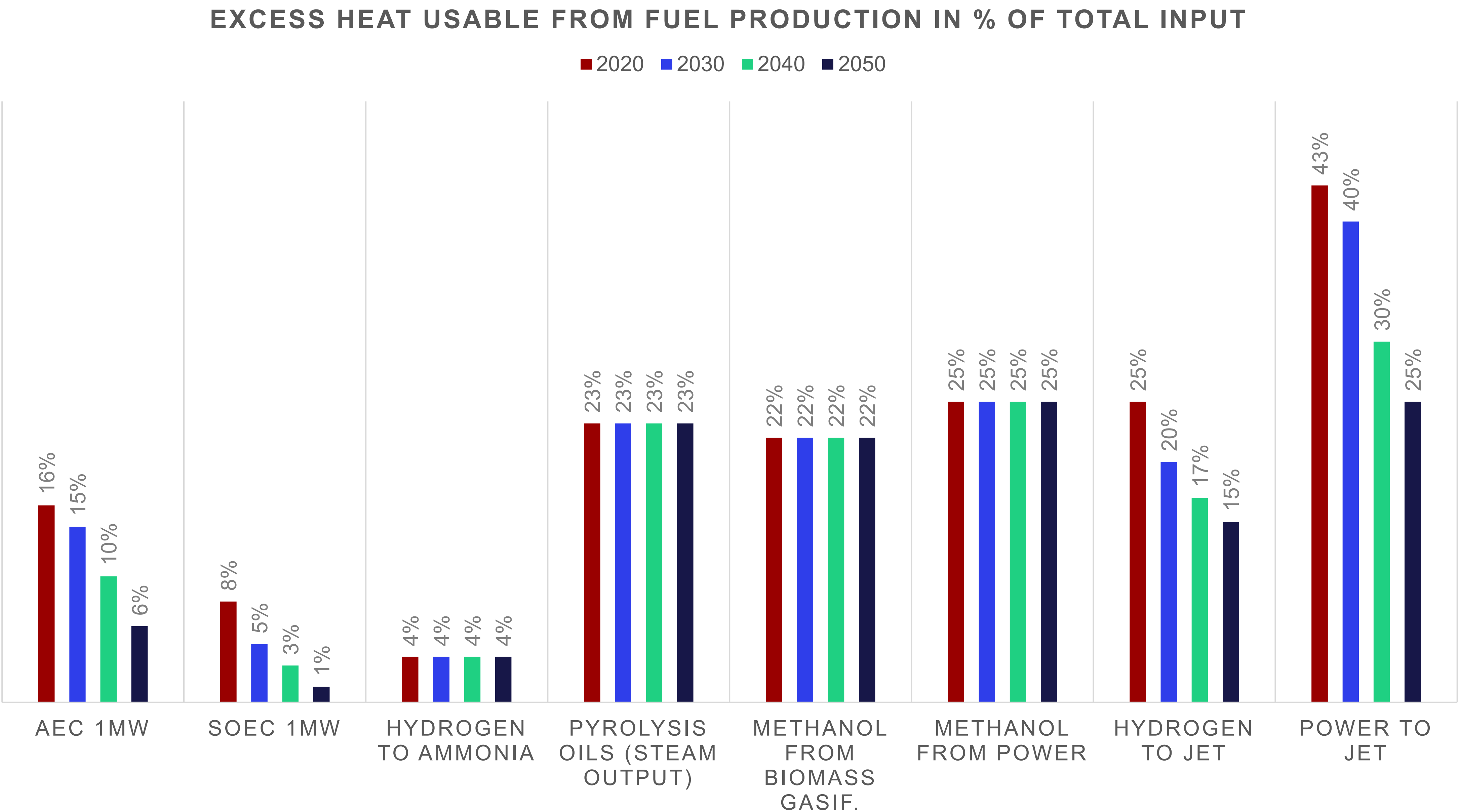


Fuel production



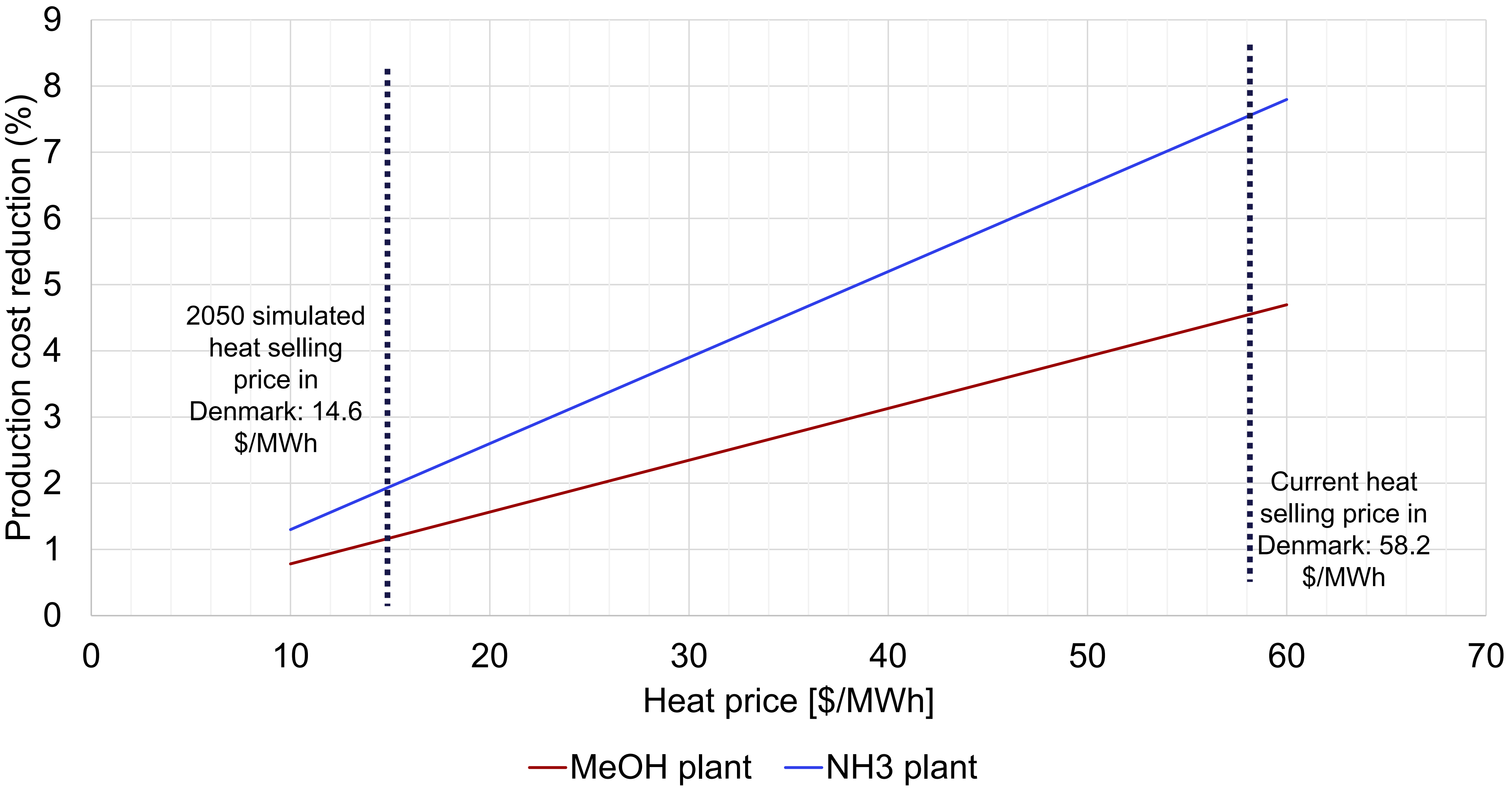
CCS vs CCU?


Positive
Neutrale
Neutral
Fossil CO2
Biogen CO2
CCU
Biofuel
Biogen CO2
Neutral
Negative
CCS



Technology Data for Renewable Fuels, Danish Energy Agency & Energinet, April 2021

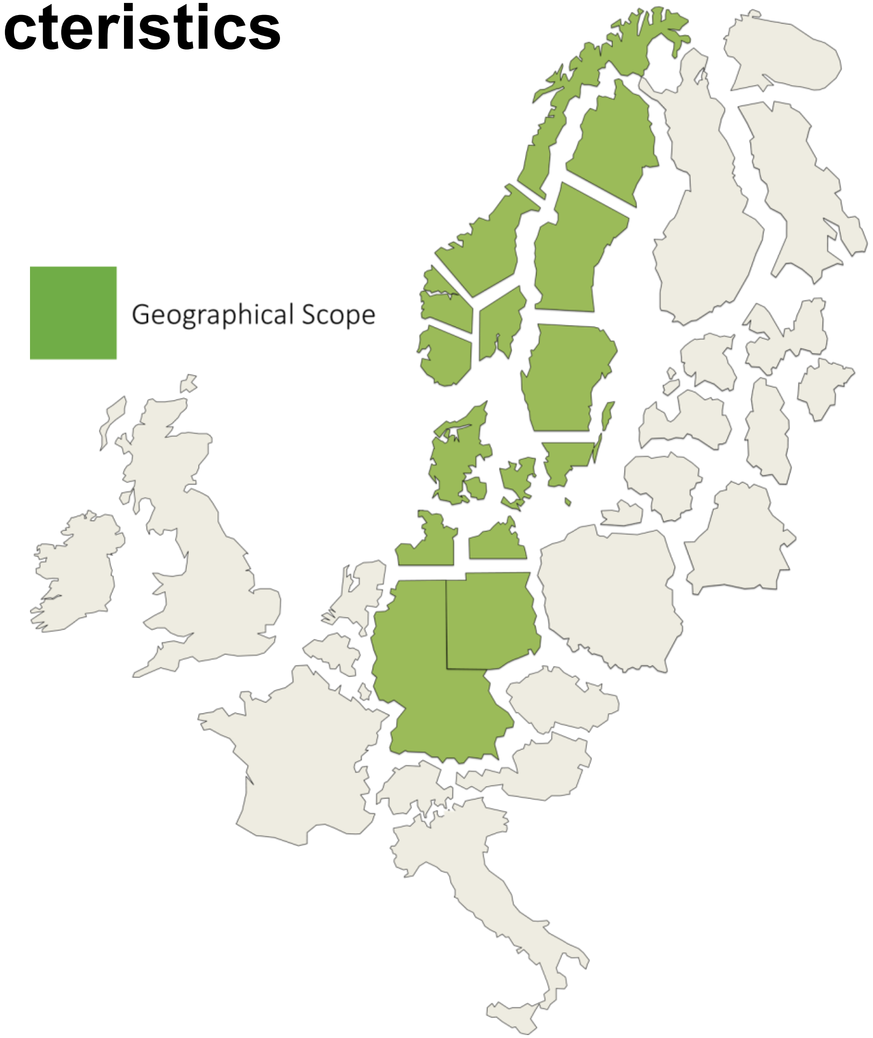
Decrease of fuel production cost thanks to excess heat sale



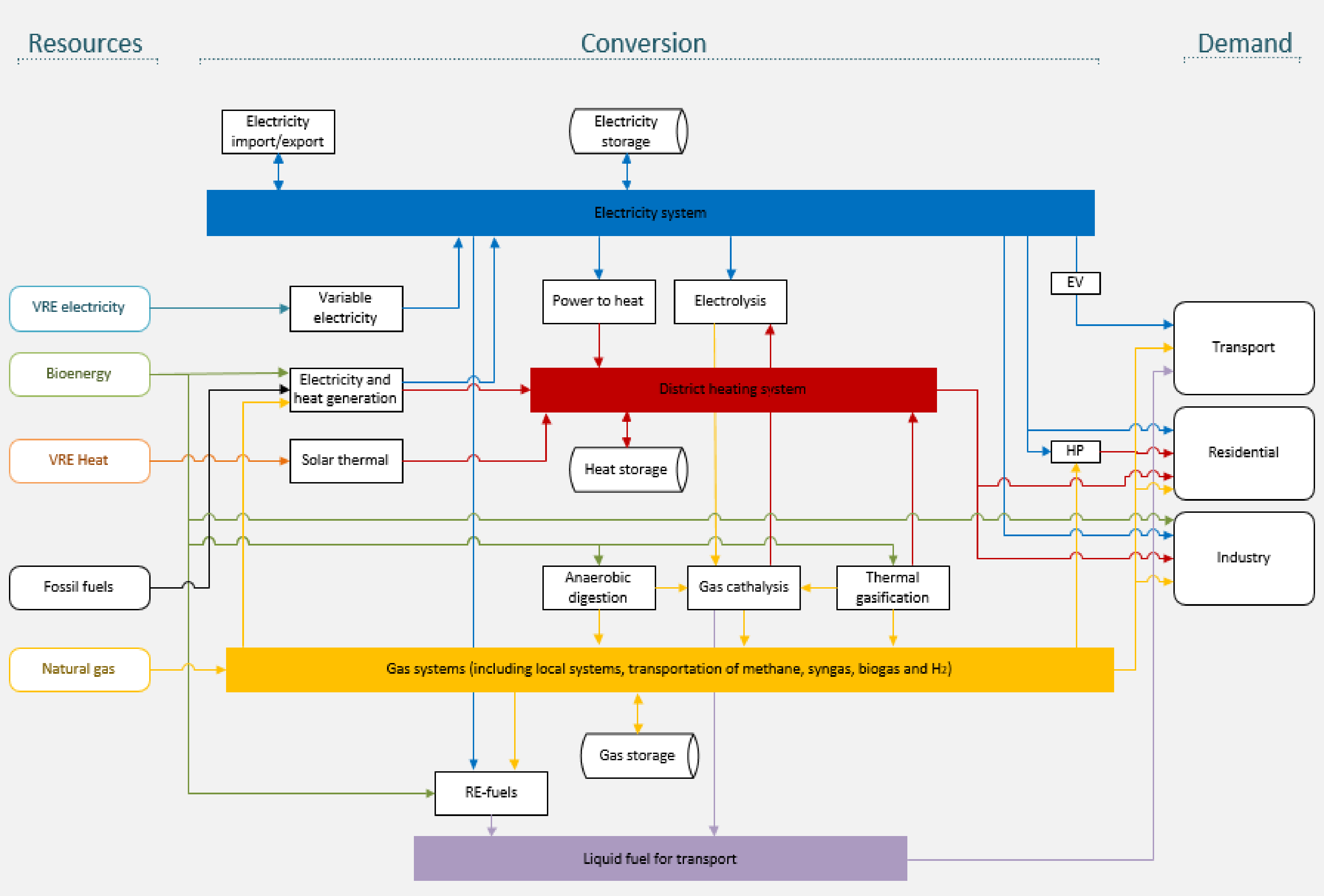
Electrofuels analysis

Balmorel-OptiFlow Model Characteristics

- Investment and operation optimization
- High geographical resolution
- High temporal resolution
- Decommissioning of technologies
- Endogenous electricity prices
- Least-cost socio economic optimization



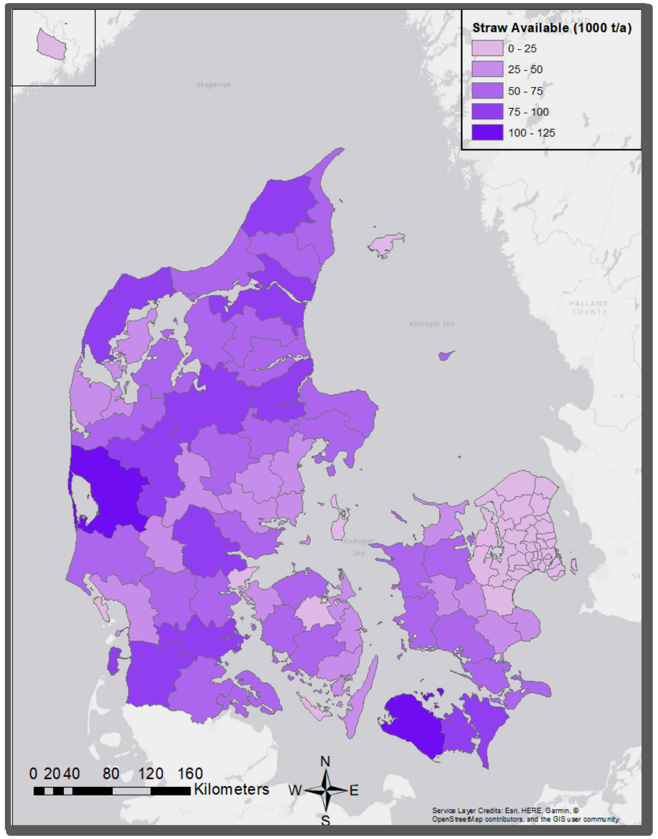
Analysis on Electrofuels in Future Energy Systems: A 2050 Case Study Lester, M. S., Bramstoft, R. & Münster, M., 2020, In : Energy. 199, 117408.



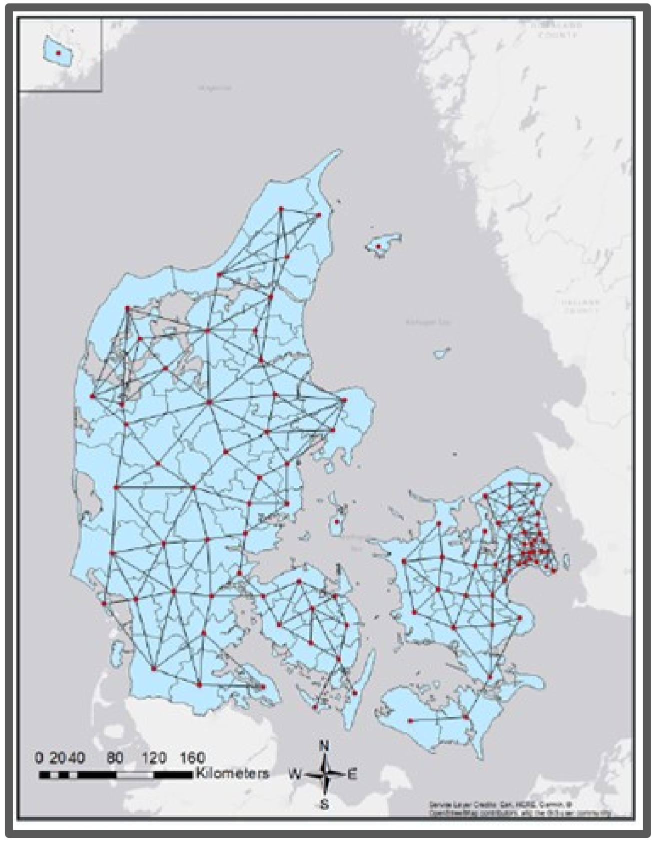
Resources
Conversion
Demand
Electricity import/export
Electricity storage
Electricity system
VRE electricity
Variable electricity
Power to heat
Electrolysis
EV
Transport
Bioenergy
Electricity and heat generation
District heating system
VRE Heat
Solar thermal
Heat storage
HP
Residential
Industry
Fossil fuels
Anaerobic digestion
Gas cathalysis
Thermal gasification
Natural gas
Gas systems (including local systems, transportation of methane, syngas, biogas and H2)
Gas storage
RE-fuels
Liquid fuel for transport

Detailed spatial resolution

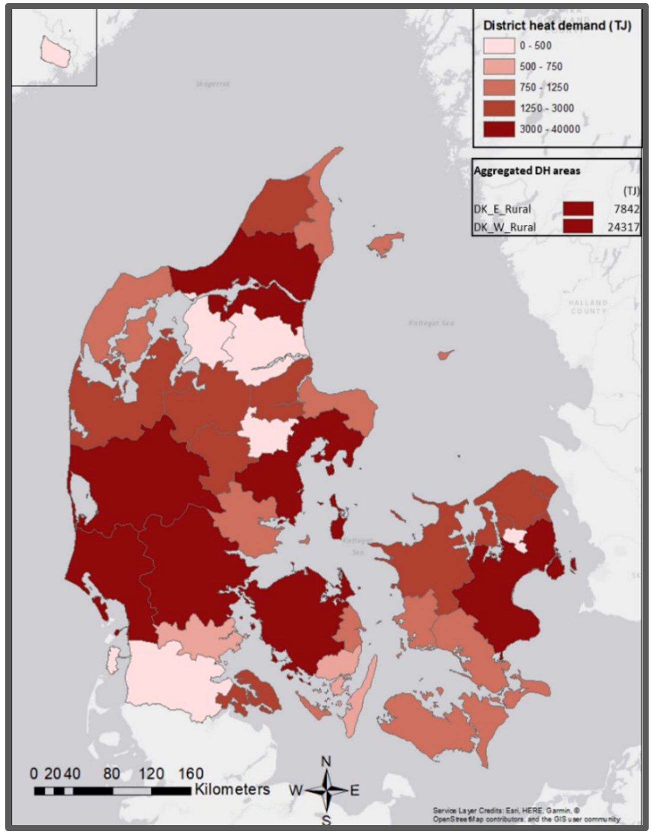
Resources



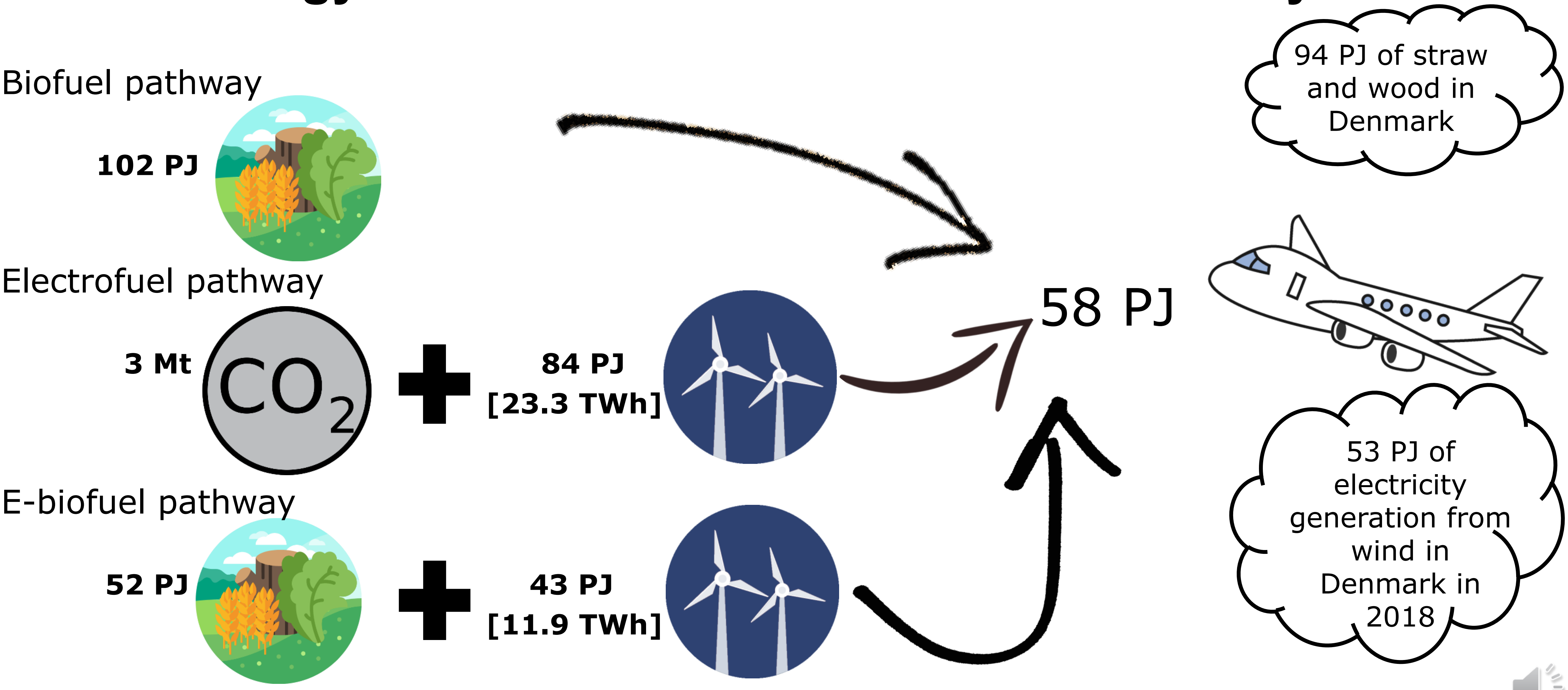
Transportation of resources



District heating areas



Energy Demands for Alternative Fuel Pathways

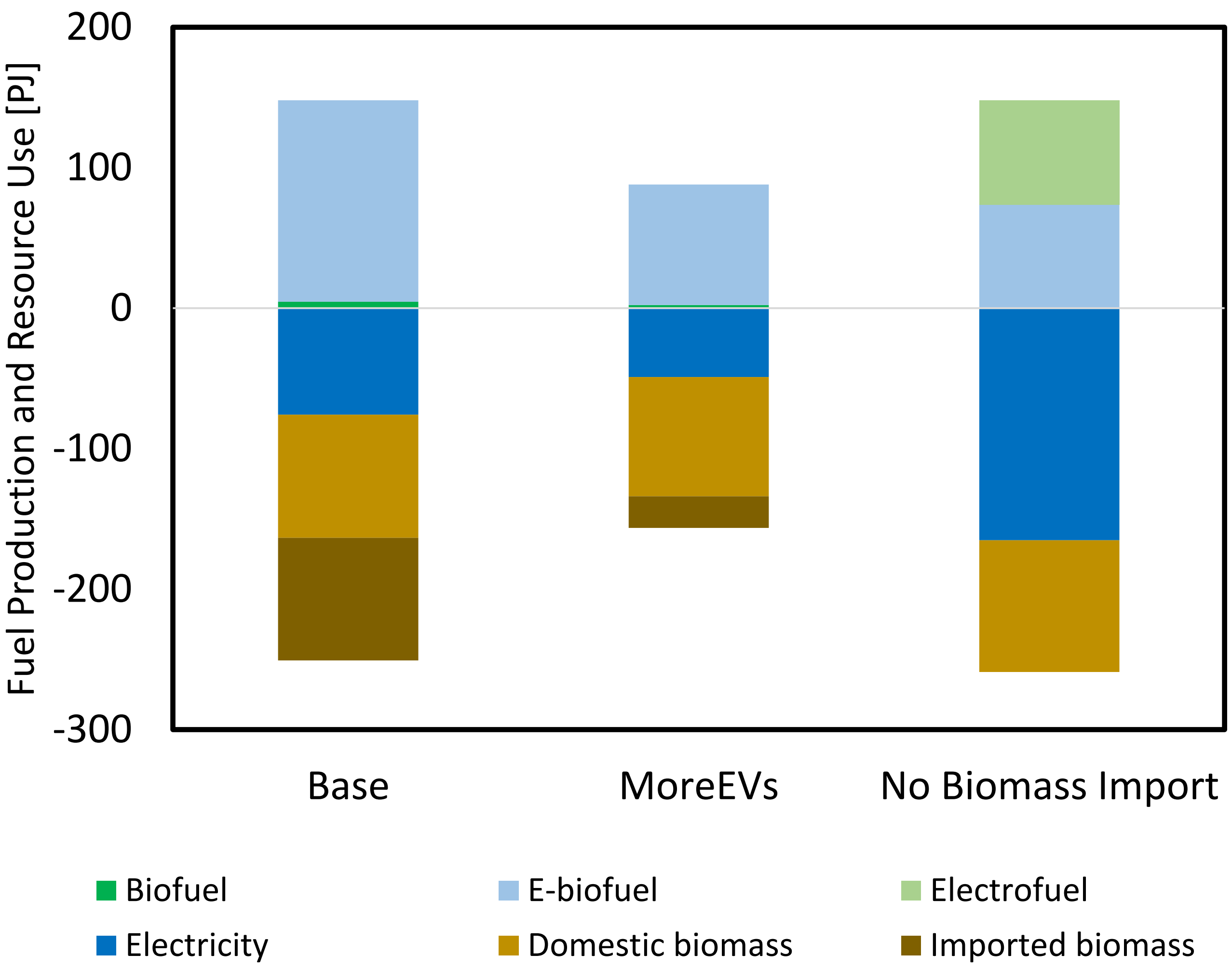


Fuel Production

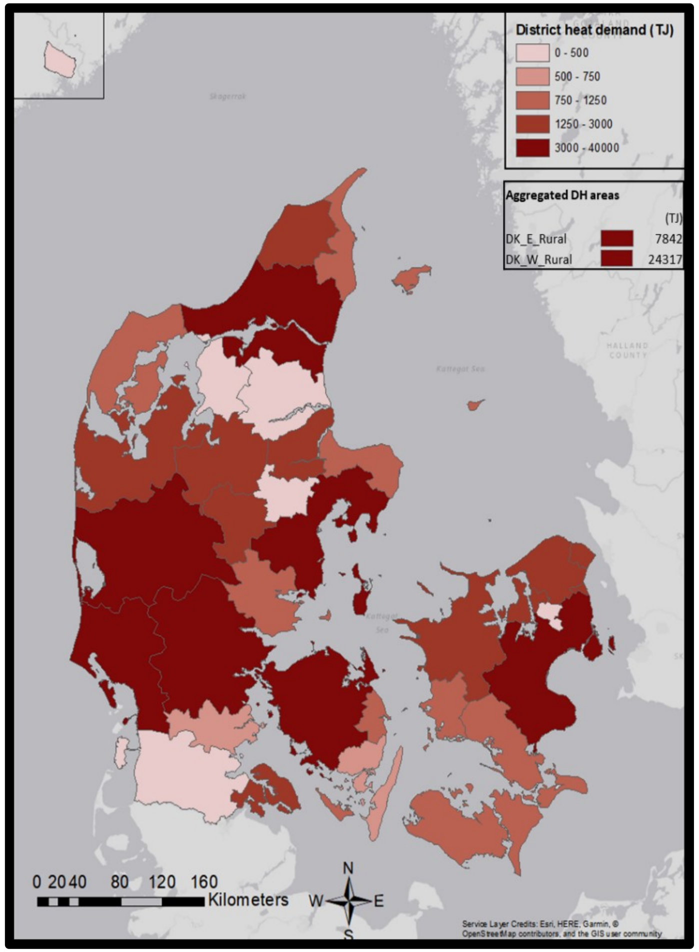
~14-46 TWh electricity for hydrogen production

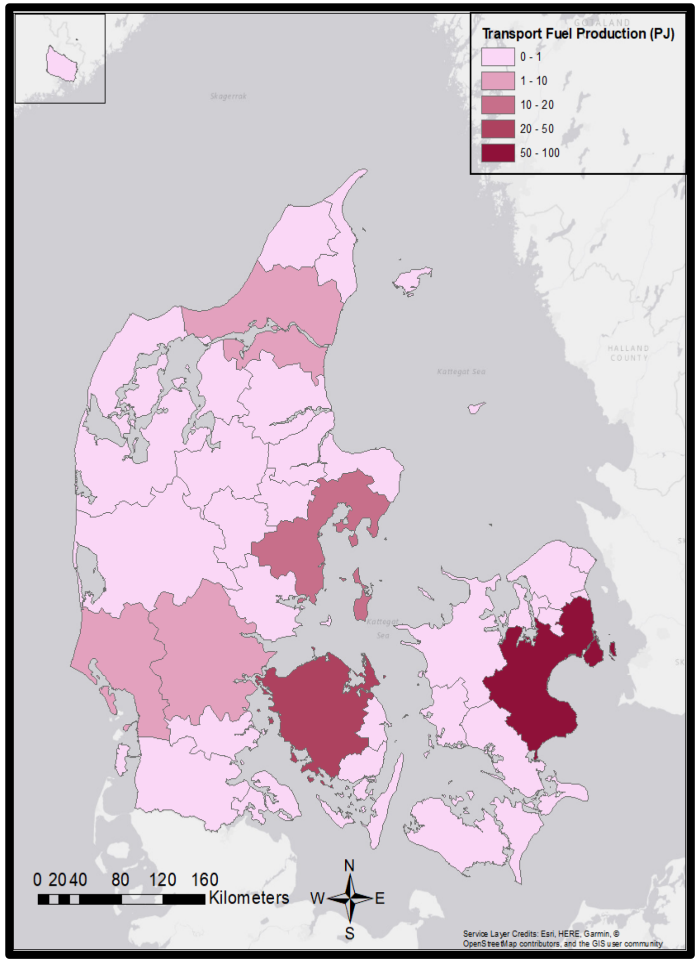
Full utilization of domestic straw and wood

Production of e-biofuels



~12 TWh of excess heat for district heating
~20% of district heating demand in 2050

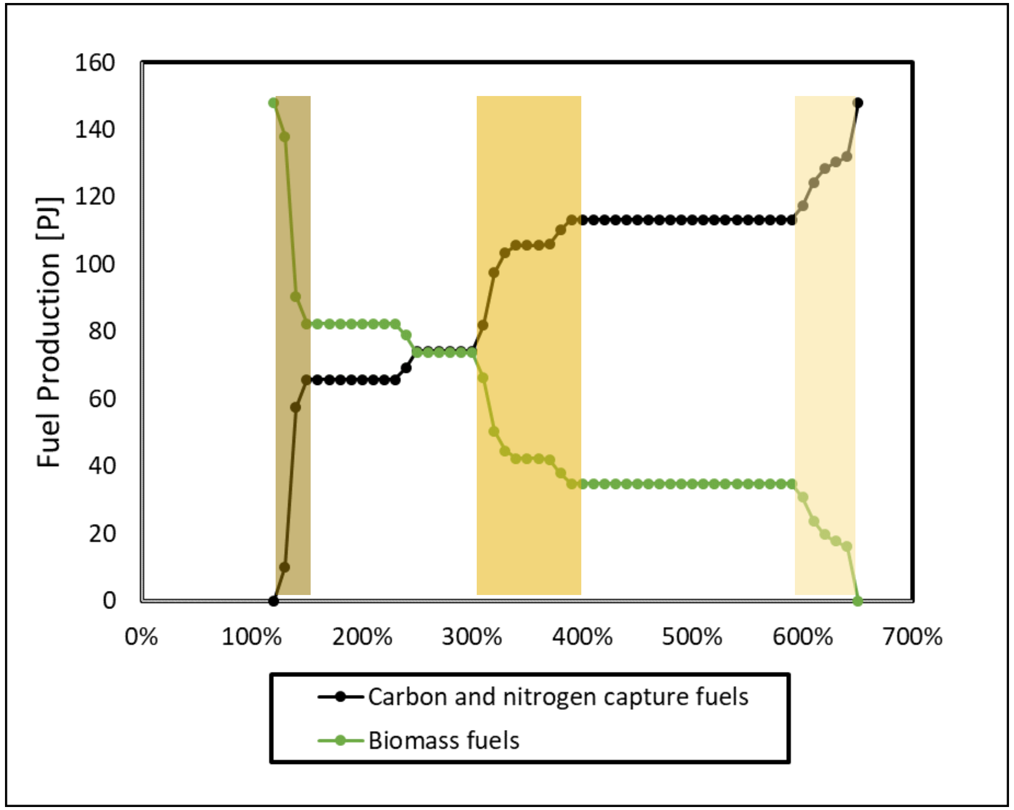




Analysis on Electrofuels in Future Energy Systems: A 2050 Case Study Lester, M. S., Bramstoft, R. & Münster, M., 2020, In : Energy. 199, 117408.

PtX production is highly sensitive to biomass costs

	Price [€/GJ]
Straw	6.8
Wood chips	7.9
Wood pellets (imported)	9.8



Take Aways

Biomass availability/costs

Excess heat from PtX

Inclusion of international transport

Carbon capture (and biochar)

E-biofuels

Conclusions

- **Geography matters**! Both on the ressource and energy infrastructure side
- Results indicate that **domestic biomass potentials in 2050 will not be sufficient** in creating a fossil fuel independent energy system in Denmark when taking road, sea and air travel into account.
- Because of this, the **use of electrofuels is crucial** and aids in the balancing of the electricity grid and provides heat to the district heating network.
- Fuels that **utilize both hydrogen and biomass** prove to be the most economically feasible and exploit the limited domestic biomass most optimally.

DTU

Sector coupling in EU

Focus on electrification

Technological overview

1. Power to heating and cooling (PtH)
2. Power to mobility (EV)
3. Power to gas/ fuels (PtX)
   - Status
   - Potential
   - Barriers

SUPER P2G
www.superp2g.eu

https://energypolicycast.podbean.com/e/sector-vector-and-smart-sector-coupling/

https://www.etip-snet.eu/sector-coupling-concepts-state-art-perspectives/

Recent related articles

The role of sector coupling in the green transition: A least-cost energy system development in Northern-central Europe towards 2050
J Gea-Bermúdez, IG Jensen, M Münster, M Koivisto, JG Kirkerud, Y Chen, H Ravn, Applied Energy 289, 116685

Modelling of renewable gas and renewable liquid fuels in future integrated energy systems
R Bramstoft, A Pizarro-Alonso, IG Jensen, H Ravn, M Münster, Applied Energy 268, 114869

Analysis on electrofuels in future energy Systems: A 2050 case study
MS Lester, R Bramstoft, M Münster, Energy, 117408

Potential role of renewable gas in the transition of electricity and district heating systems
IG Jensen, F Wiese, R Bramstoft, M Münster, Energy Strategy Reviews 27, 100446

Pathways to climate-neutral shipping: A Danish case study
T ben Brahim, F Wiese, M Münster, Energy 188, 116009

Uncertainties towards a fossil-free system with high integration of wind energy in long-term planning
A Pizarro-Alonso, H Ravn, M Münster, Applied Energy 253, 113528

Impact and effectiveness of transport policy measures for a renewable-based energy system
G Venturini, K Karlsson, M Münster, Energy Policy 133, 110900

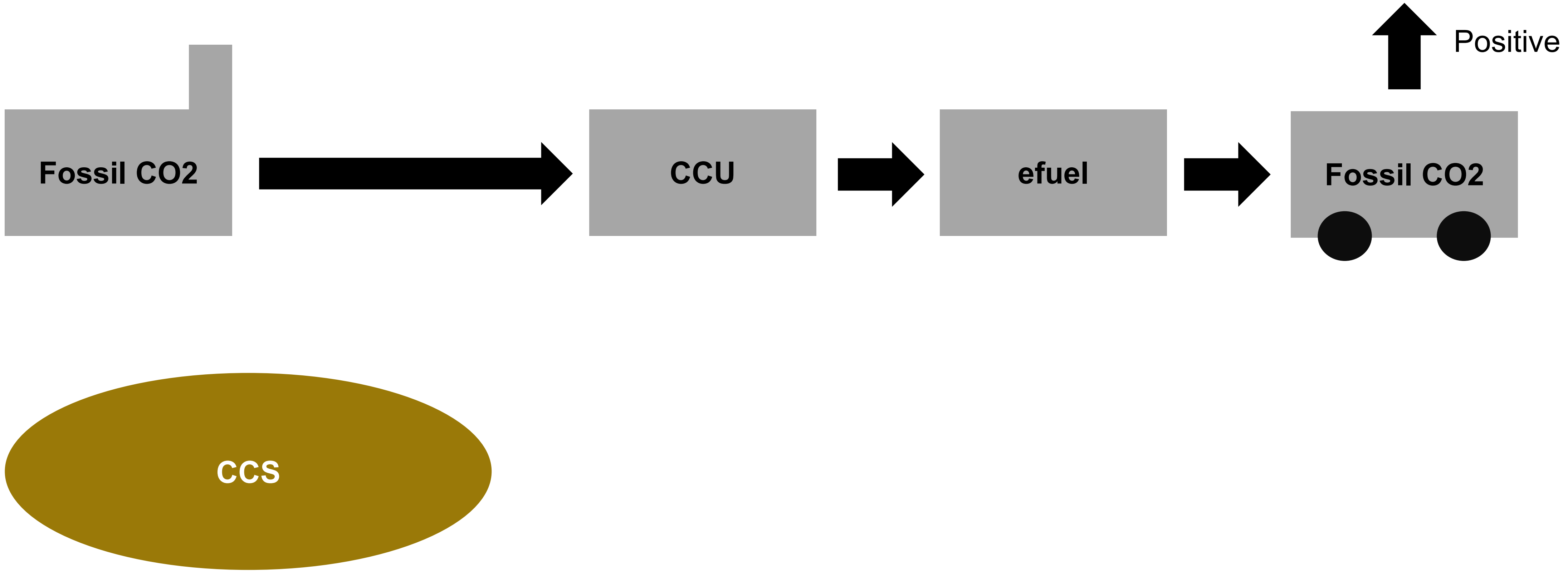
How to maximise the value of residual biomass resources: The case of straw in Denmark
G Venturini, A Pizarro-Alonso, M Münster, Applied Energy 250, 369-388

Balmorel open source energy system model
Wiese, F., Bramstoft, R., Koduvere, H., Pizarro Alonso, A. R., Balyk, O., Kirkerud, J. G., Tveten, Å. G., Bolkesjø, T. F., Münster, M. & Ravn, H. V., 2018, Energy Strategy Reviews. 20

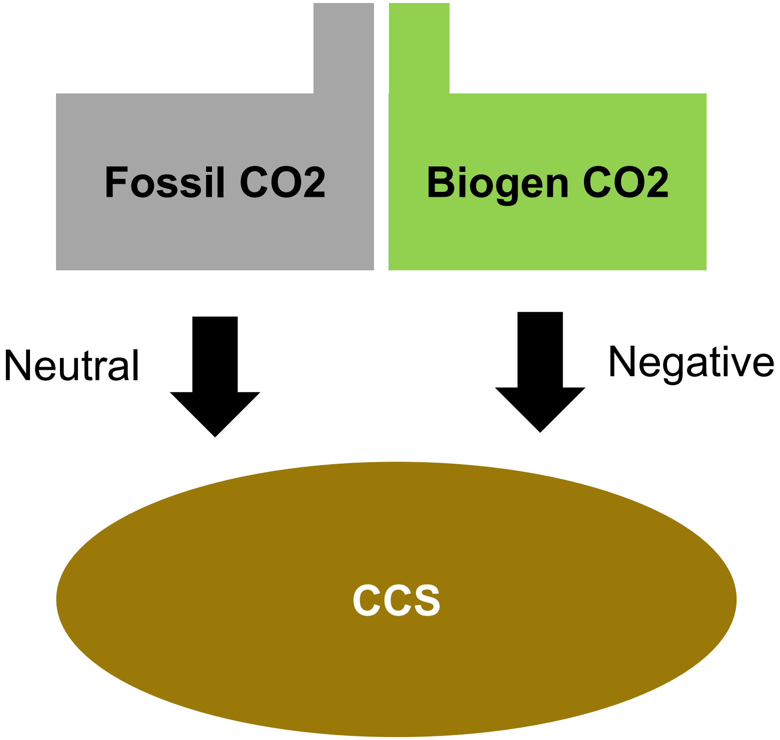
Thank you!
Hvala vam!

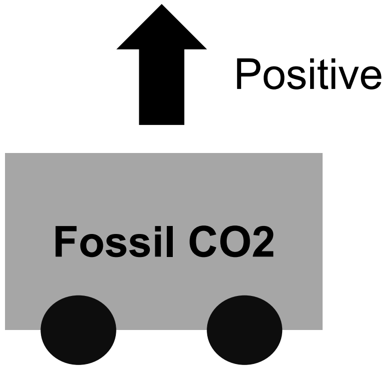
Marie Münster, maem@dtu.dk
Twitter: @MarieMynster
LinkedIn: https://www.linkedin.com/in/marie-münster-b161293
Website: https://orbit.dtu.dk/en/persons/marie-münster

CCS vs CCU?

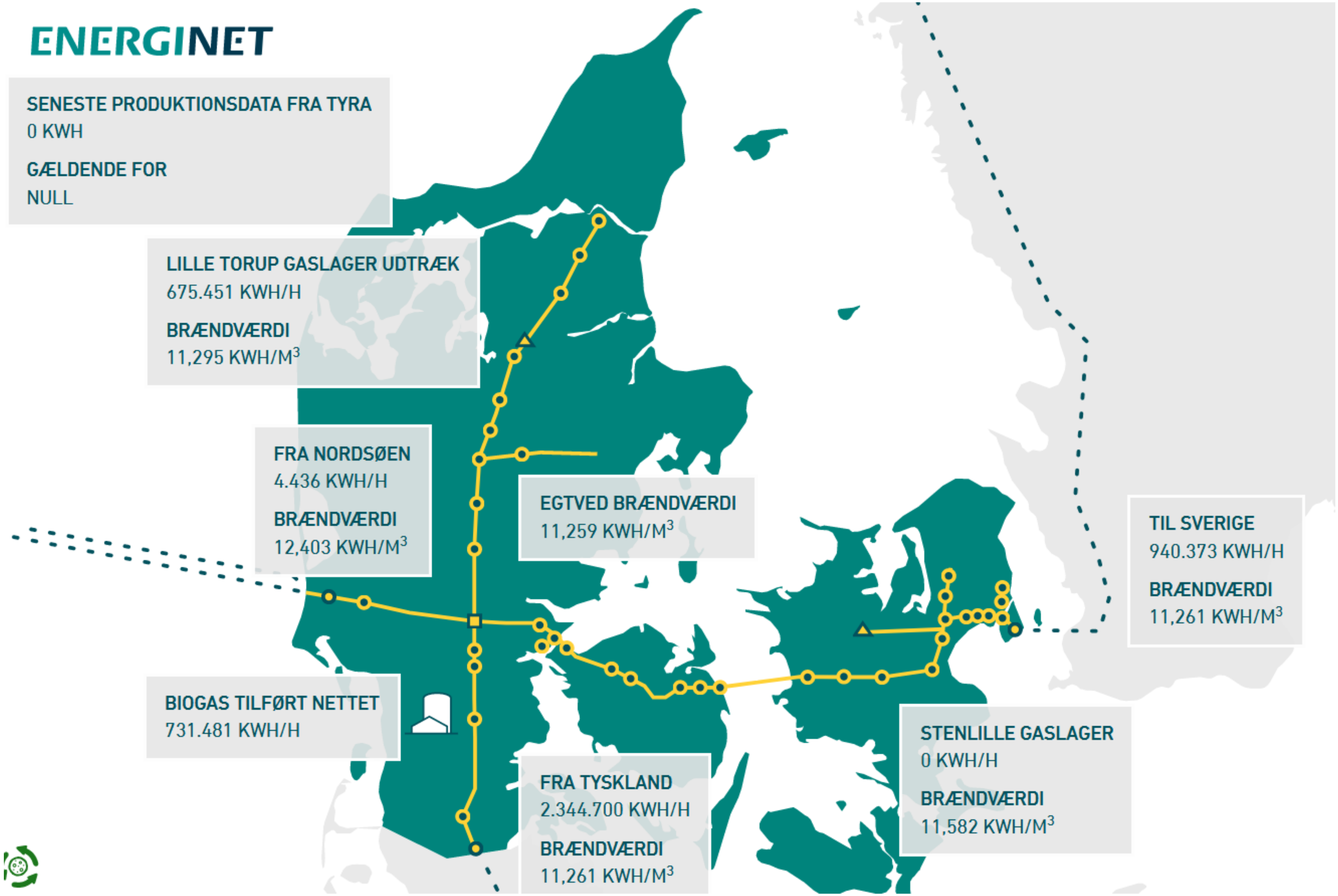


CCS vs CCU?


Fossil CO2
Biogen CO2
Neutral
Negative
CCS


Positive
Fossil CO2

Extra slides


ENERGINET
SENESTE PRODUKTIONSDATA FRA TYRA
0 KWH
GÆLDENDE FOR
NULL
LILLE TORUP GASLAGER UDTRÆK
675.451 KWH/H
BRÆNDVÆRDI
11,295 KWH/M3
FRA NORDSØEN
4.436 KWH/H
BRÆNDVÆRDI
12,403 KWH/M3
EGTVED BRÆNDVÆRDI
11,259 KWH/M3
TIL SVERIGE
940.373 KWH/H
BRÆNDVÆRDI
11,261 KWH/M3
BIOGAS TILFØRT NETTET
731.481 KWH/H
FRA TYSKLAND
2.344.700 KWH/H
BRÆNDVÆRDI
11,261 KWH/M3
STENLILLE GASLAGER
0 KWH/H
BRÆNDVÆRDI
11,582 KWH/M3

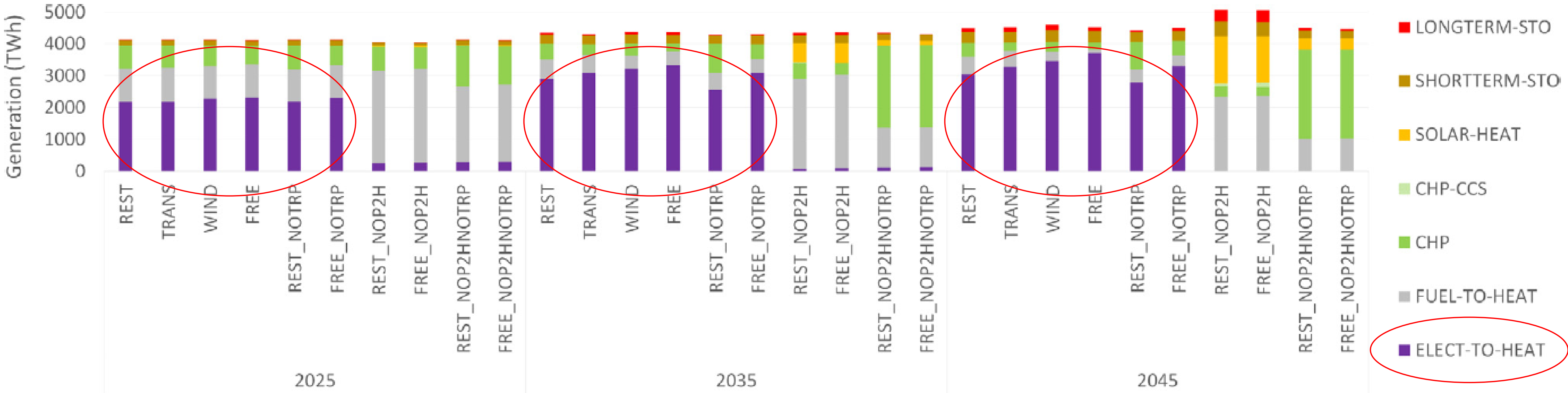
Sector coupling definition

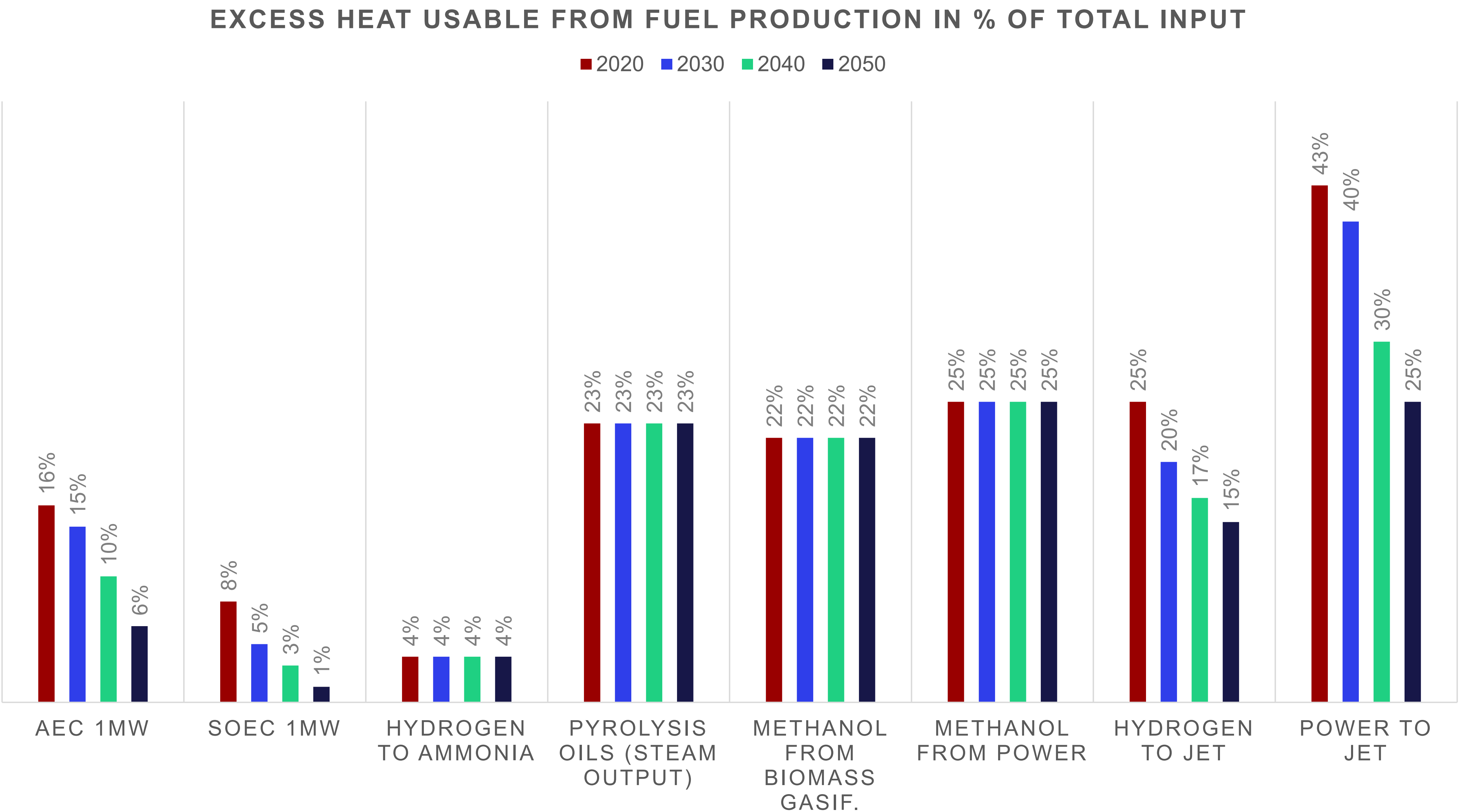
Combining the positive features of end-uses (flexible loads) and of storage devices,

sector coupling consists of converting electricity into another form of energy, which can then be either:

- stored for successive re-conversion to electricity, shift in time and in some cases also in space (when being transported as molecules);
- consumed, with a beneficial substitution of other energy sources, temporarily (operational optimisation) or permanently (electrification);
- transported as heat or molecules, when convenient, instead of through transmission or distribution power lines of electrons.

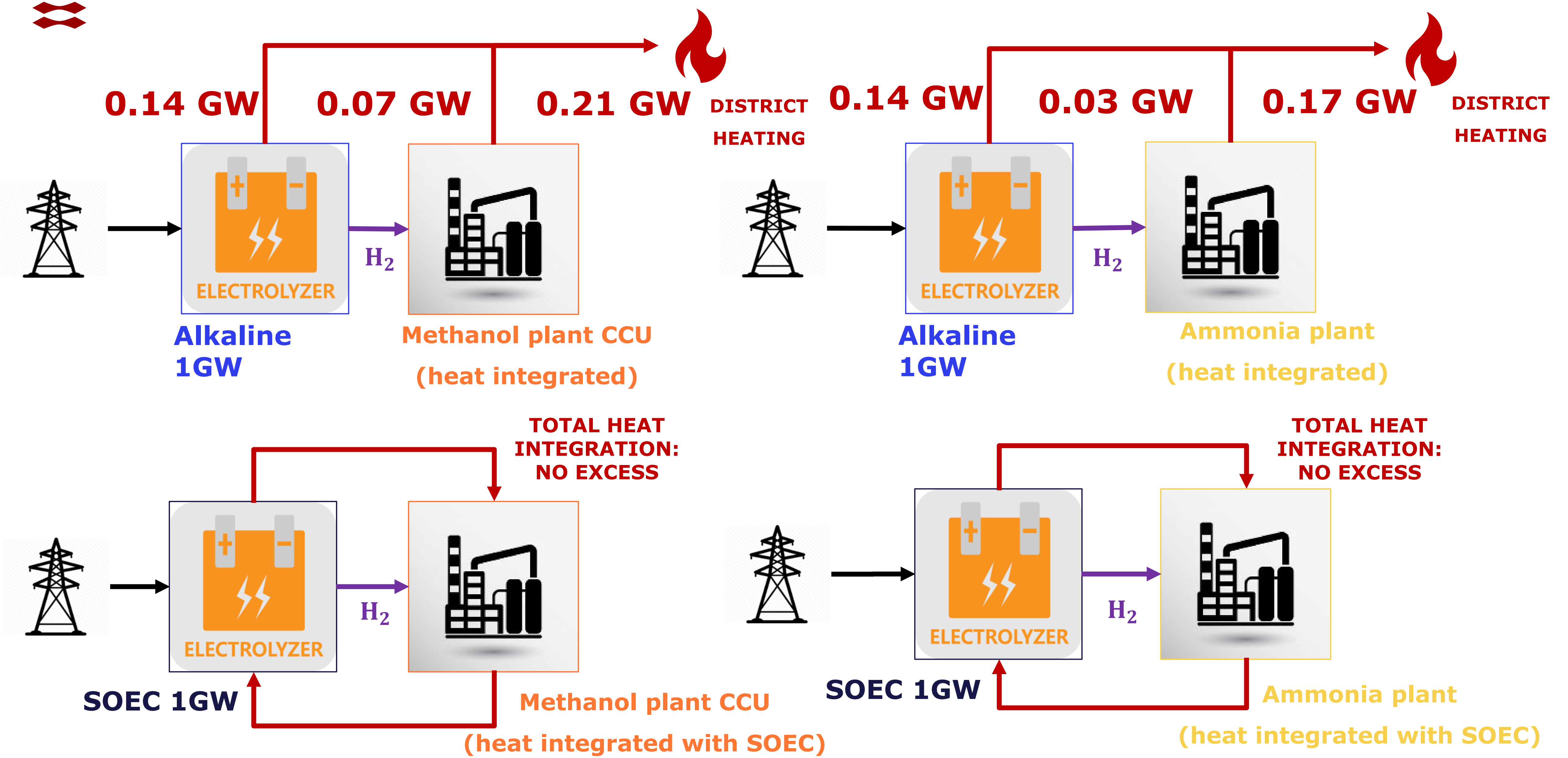
Heat generation per technology type





Technology Data for Renewable Fuels, Danish Energy Agency & Energinet, April 2021

PtX to DH


0.14 GW
0.07 GW
0.21 GW
DISTRICT HEATING
H_2
ELECTROLYZER
Alkaline 1GW
Methanol plant CCU
(heat integrated)
0.14 GW
0.03 GW
0.17 GW
DISTRICT HEATING
H_2
ELECTROLYZER
Alkaline 1GW
Ammonia plant
(heat integrated)
TOTAL HEAT INTEGRATION: NO EXCESS
H_2
ELECTROLYZER
SOEC 1GW
Methanol plant CCU
(heat integrated with SOEC)
TOTAL HEAT INTEGRATION: NO EXCESS
H_2
ELECTROLYZER
SOEC 1GW
Ammonia plant
(heat integrated with SOEC)

Extras