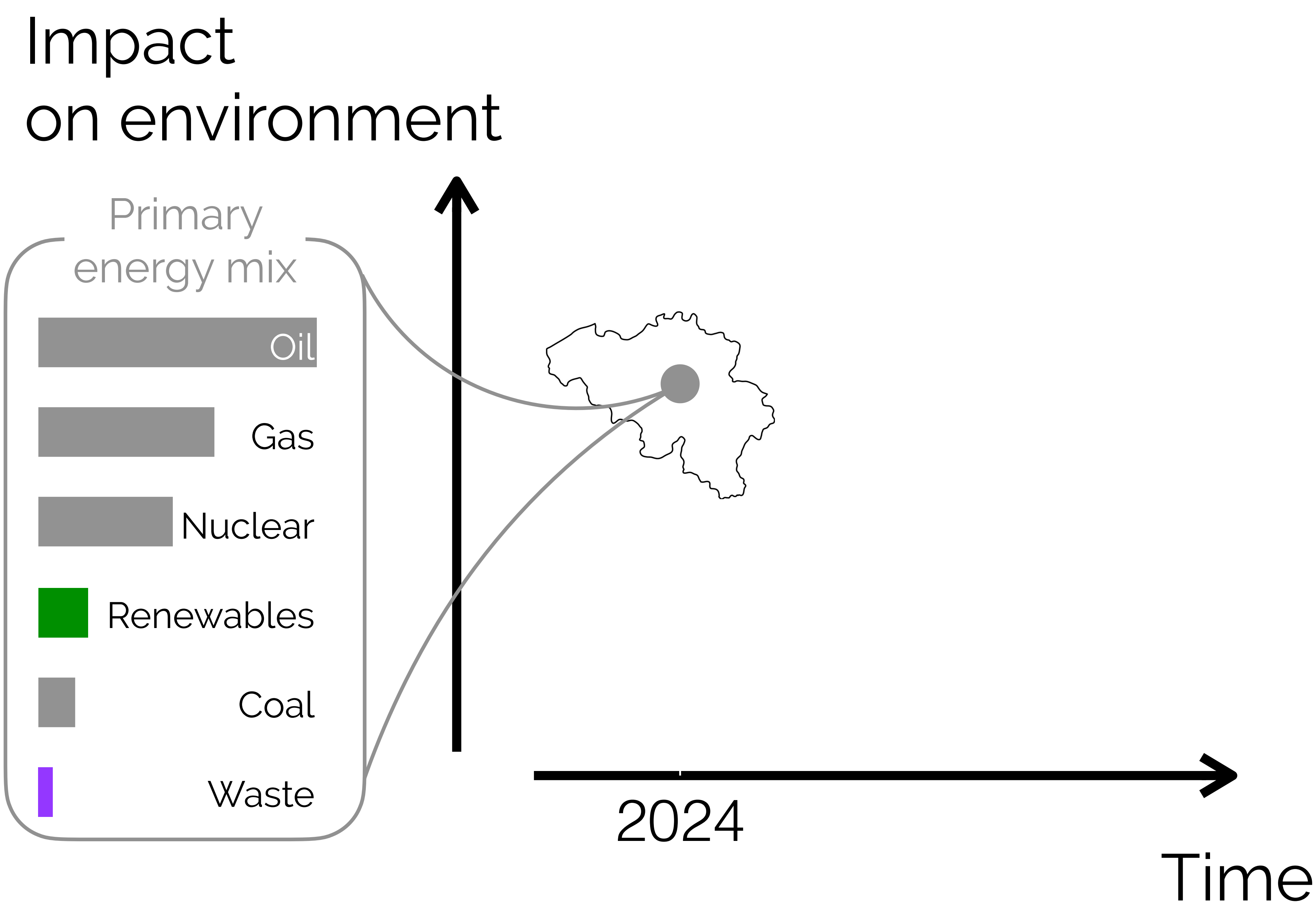
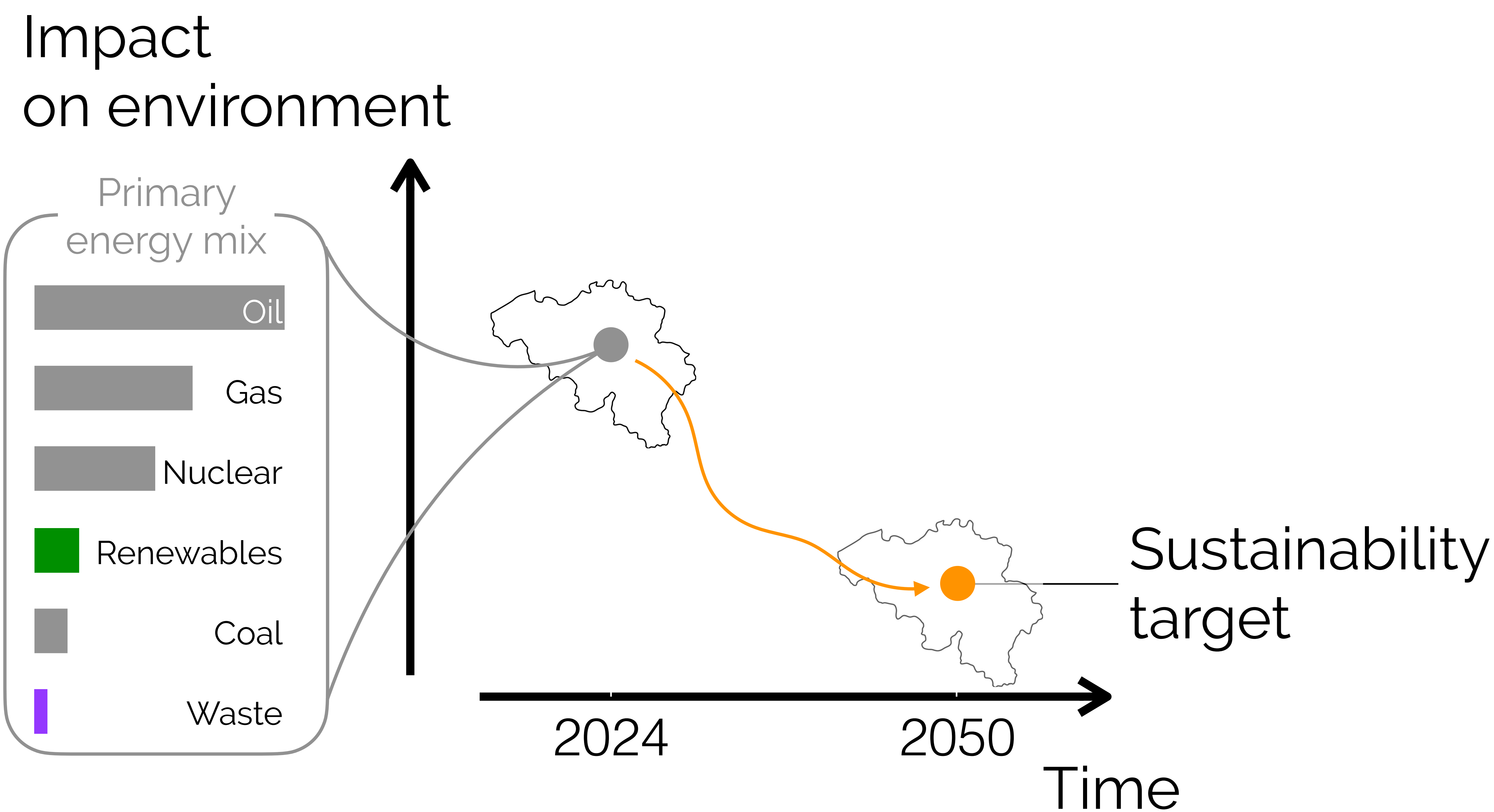
Progress of the BEST project

Joint Workshop of the BEST and PROCURA projects
March 19, 2024
Brussels

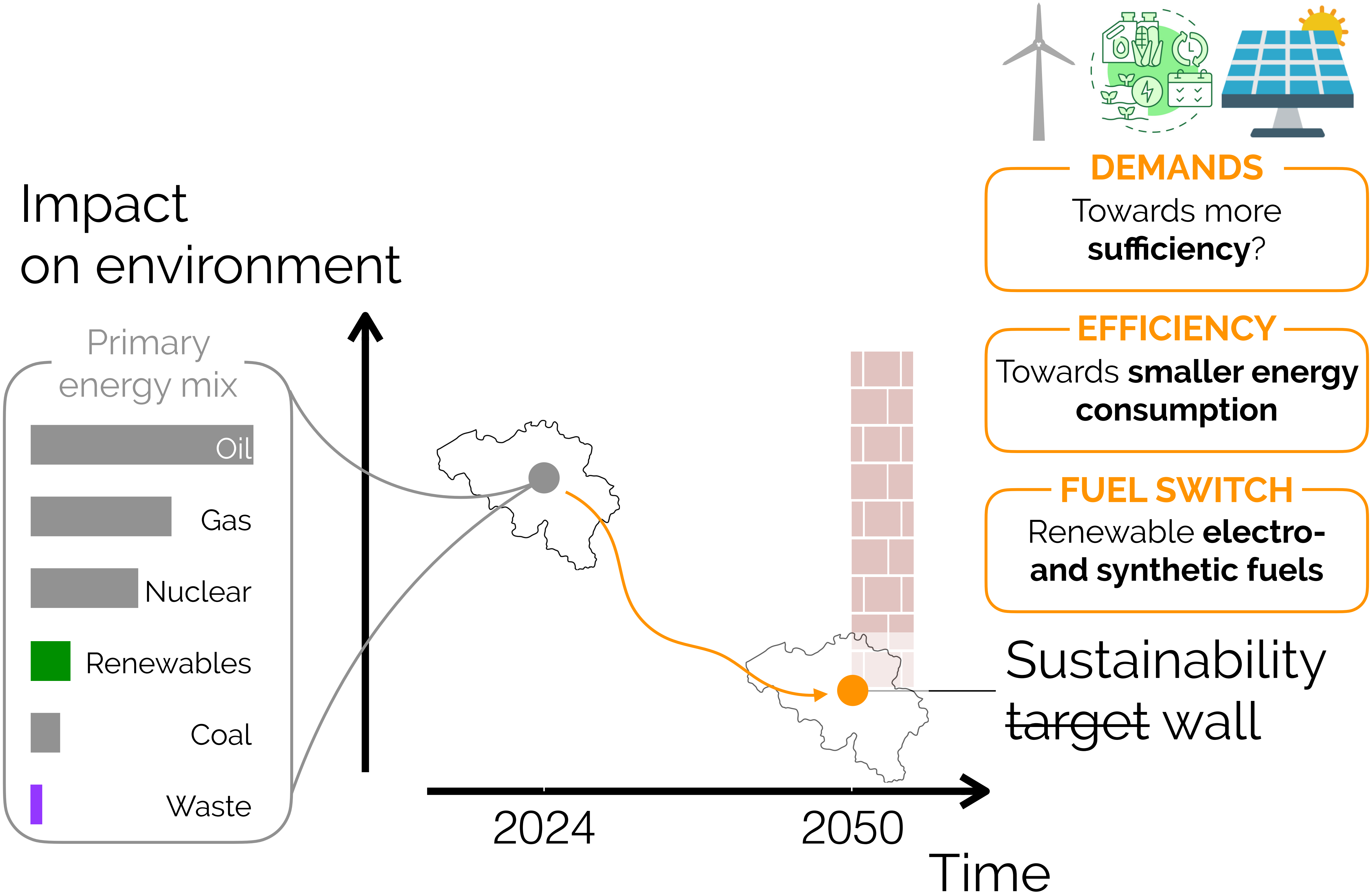
From where we are…



… to where we want to go

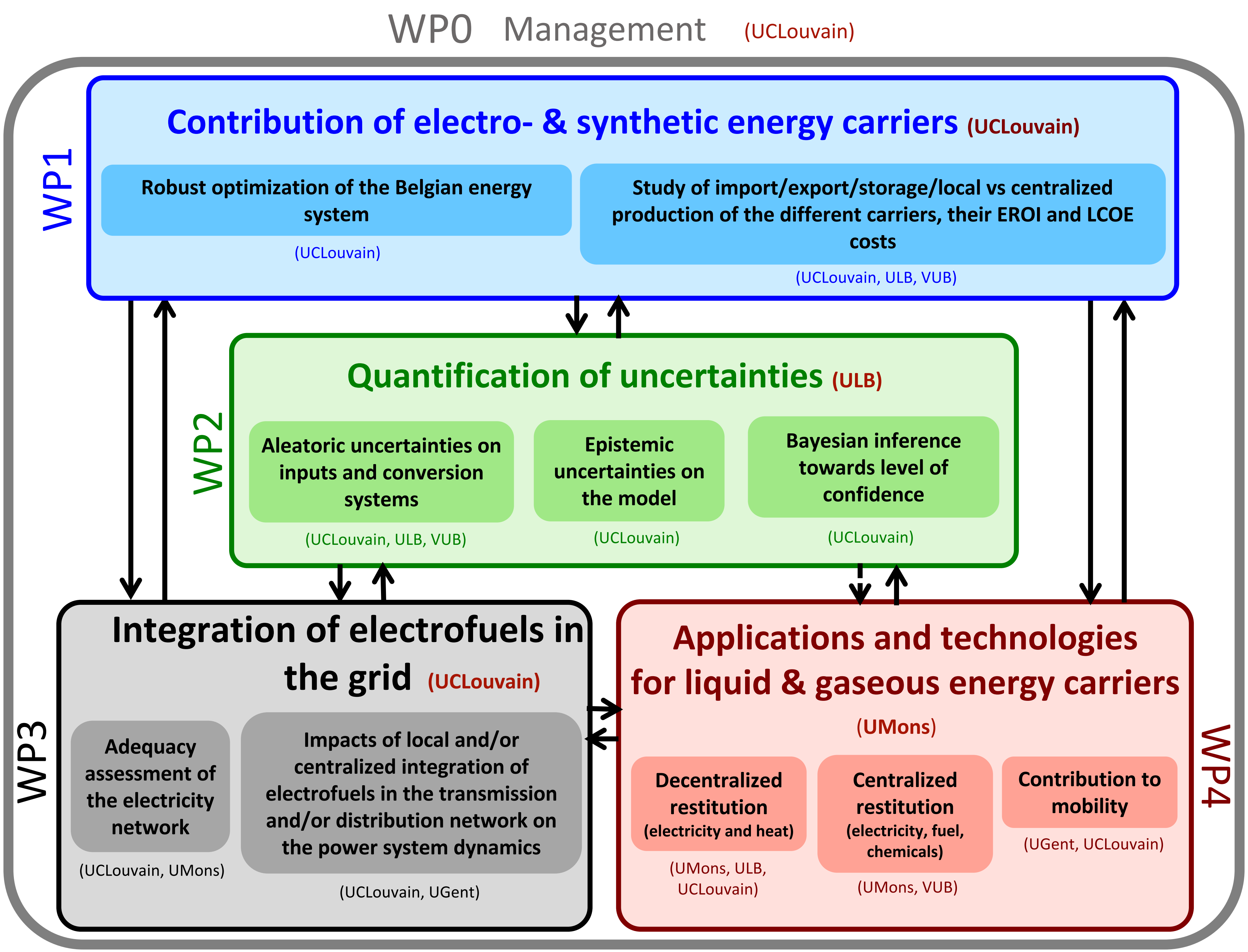


… to where we want to go



Work out, for Belgium, the most economical electro- and synthetic energy carrier routes needed to face the climate change issues and ensure the stability of the grid and the security of supply in 2040 and beyond.

Interconnected WPs to circumvent the mission statement



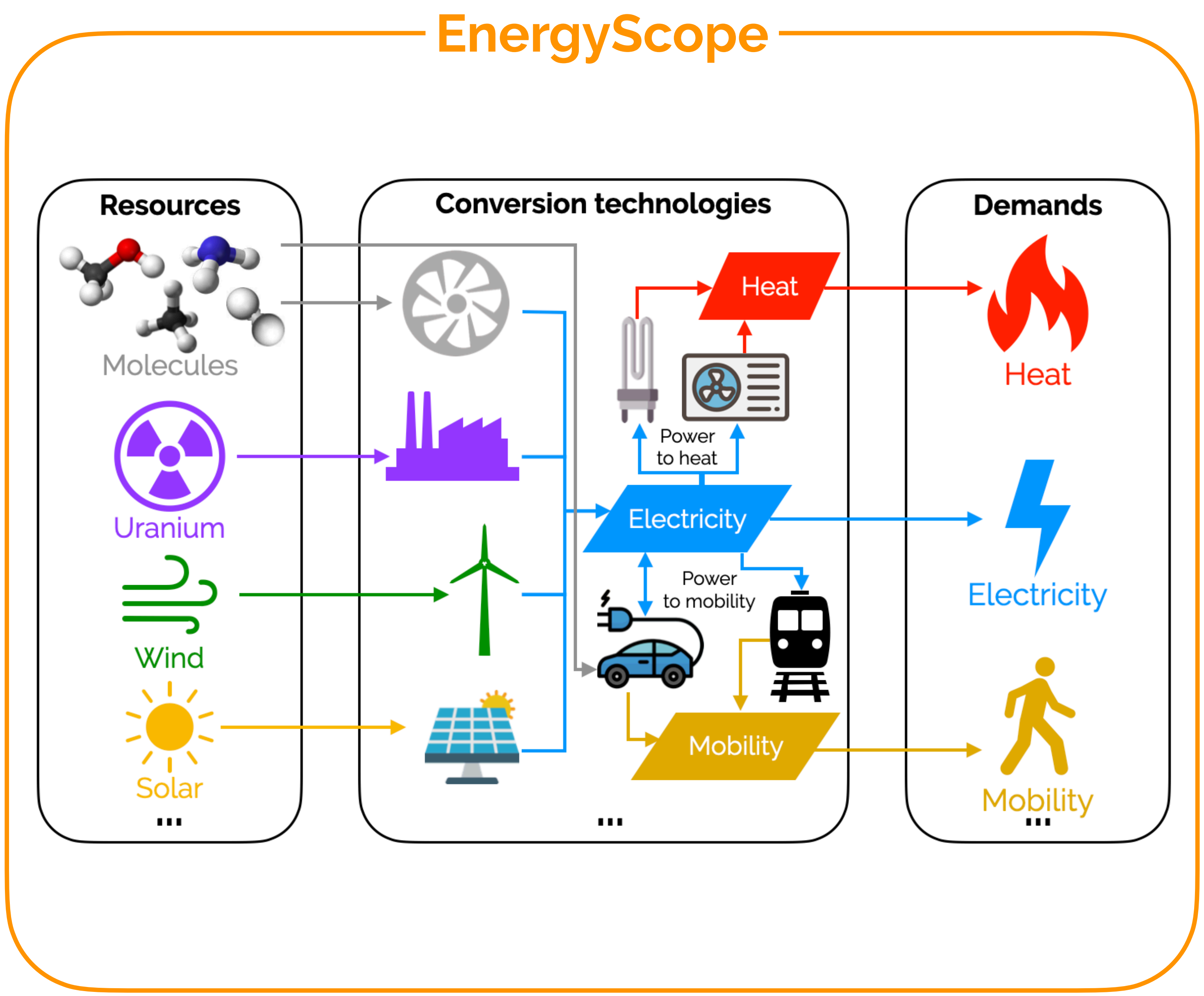
WP1 WP2

Work out, for Belgium, the most economical electro- and synthetic energy carrier routes needed to face the climate change issues and ensure the stability of the grid and the security of supply in 2040 and beyond.

Whole-energy system model

ENERGYScope

ENERGYScope: a whole-energy system model to minimize the total cost, under CO2 constraint



Snapshot modeling approach
optimisation of a target future year

Multi-**sector**
and multi-**carrier**

Optimization of **investment & operation** strategies

Hourly resolution
required by high integration of renewables and storage

Tractable formulation
suitable for uncertainty quantification

Open
Open-source, open-access and documented

WP1

WP2

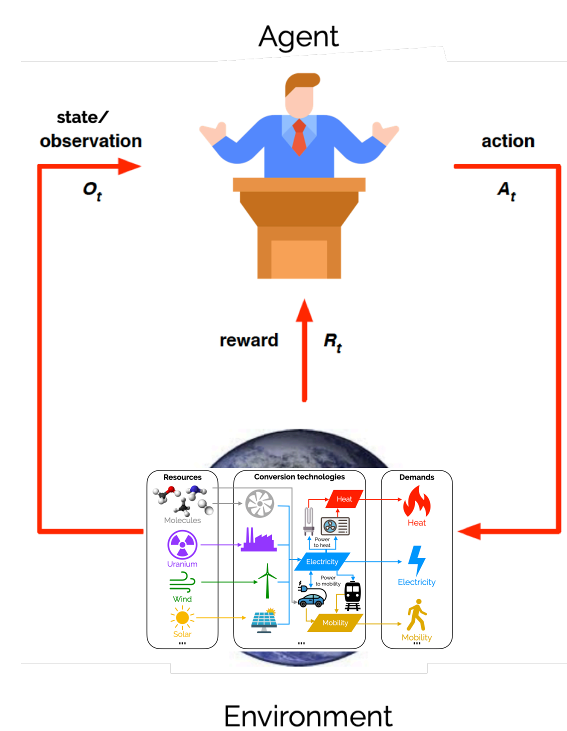
Whole-energy system model

ENERGYScope

Biomass characterization

Boundary conditions for Belgium

Pathway exploration under uncertainties



WP1 WP2

Whole-energy system model

ENERGYScope

Biomass characterization

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Pathway exploration under uncertainties

We need to properly characterize the resources, their costs and their potentials

Biomass… a versatile and diverse resource

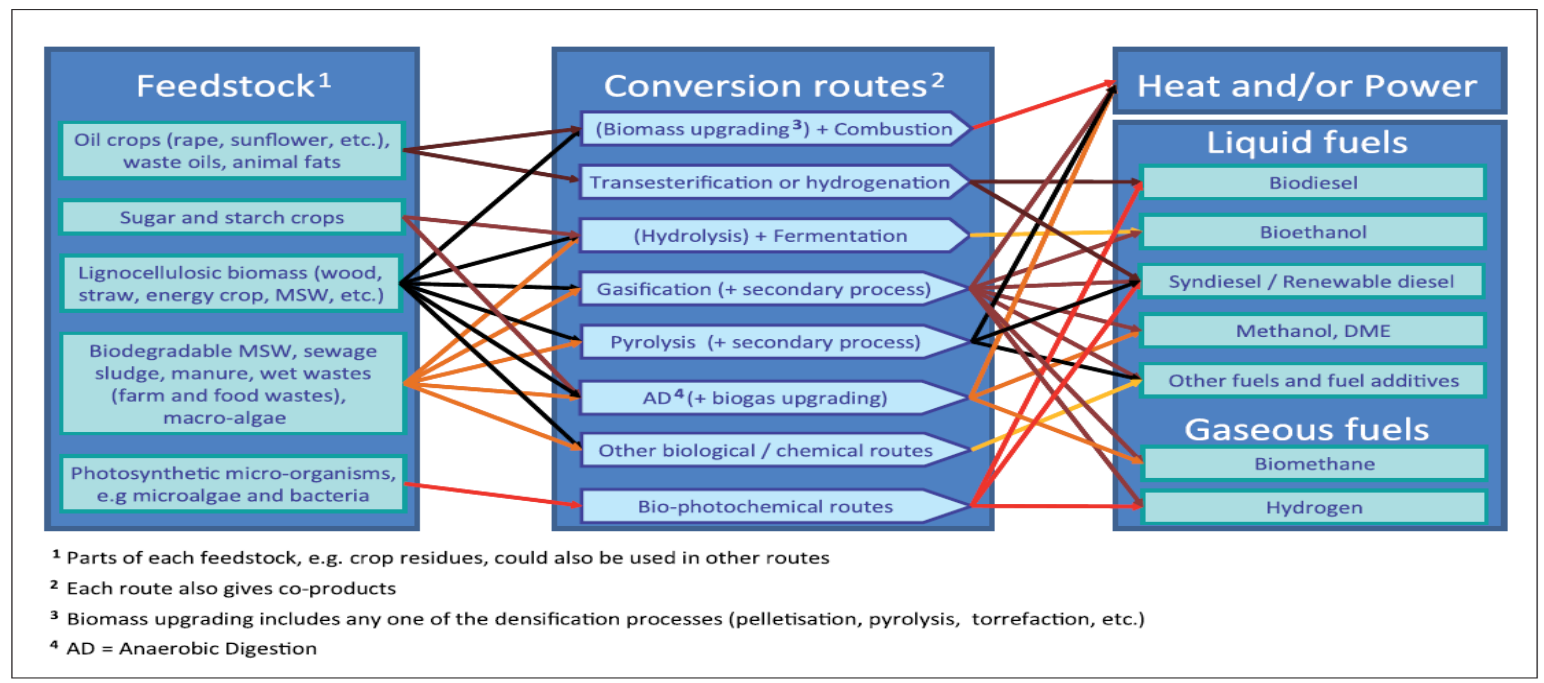
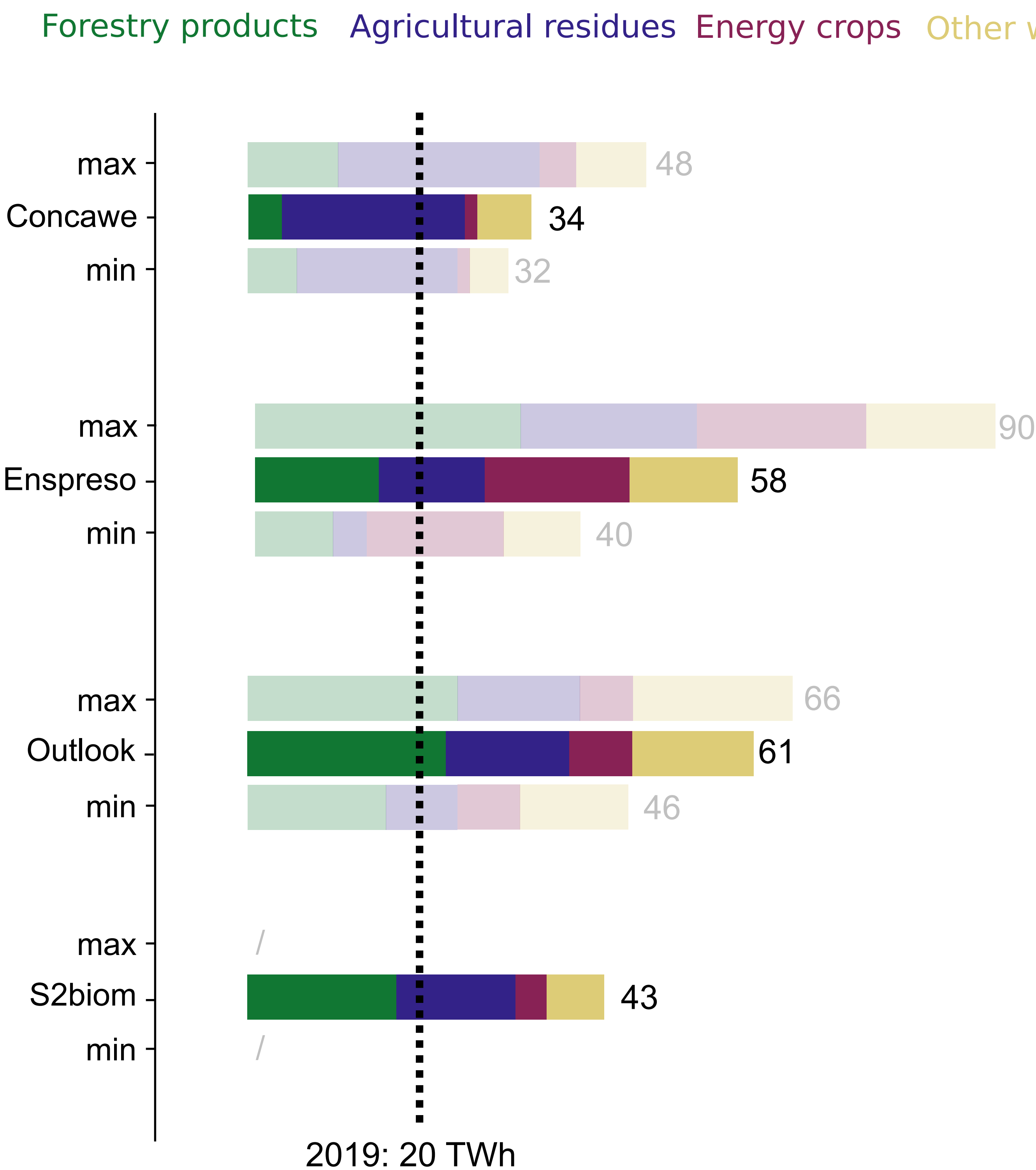


Figure 3: Schematic view of the wide variety of bioenergy routes. Source: E4tech, 2009.

Biomass potential in Belgium for 2030… what to believe?

Review of databases

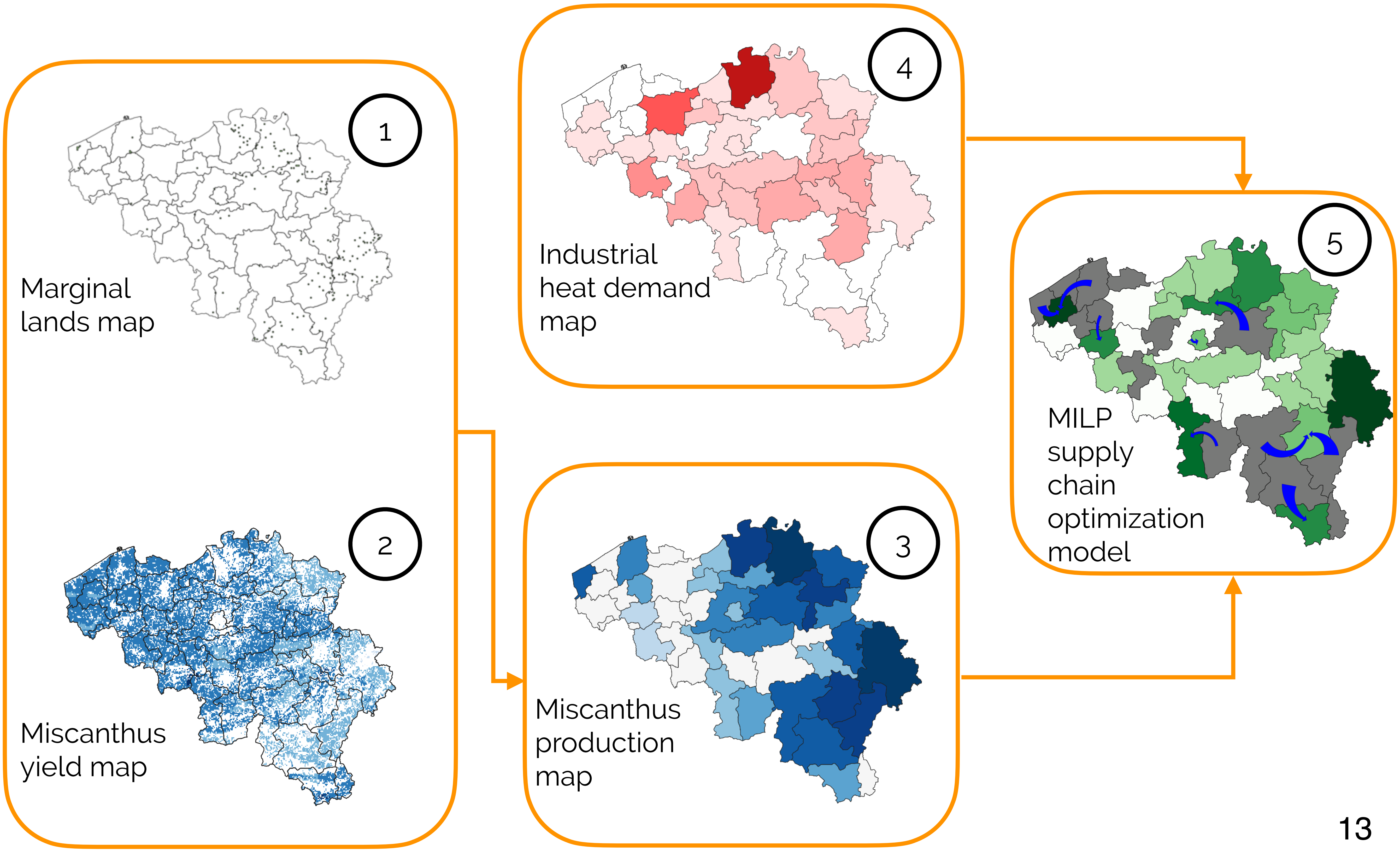


The variability relies on key assumptions and considerations such as

- Diet and land availability
- Agricultural landscape and structure (for biogas)
- Mechanisation and yield boosting with inputs and irrigation
- Competing use and extraction rates with related effects on biodiversity and sustainability

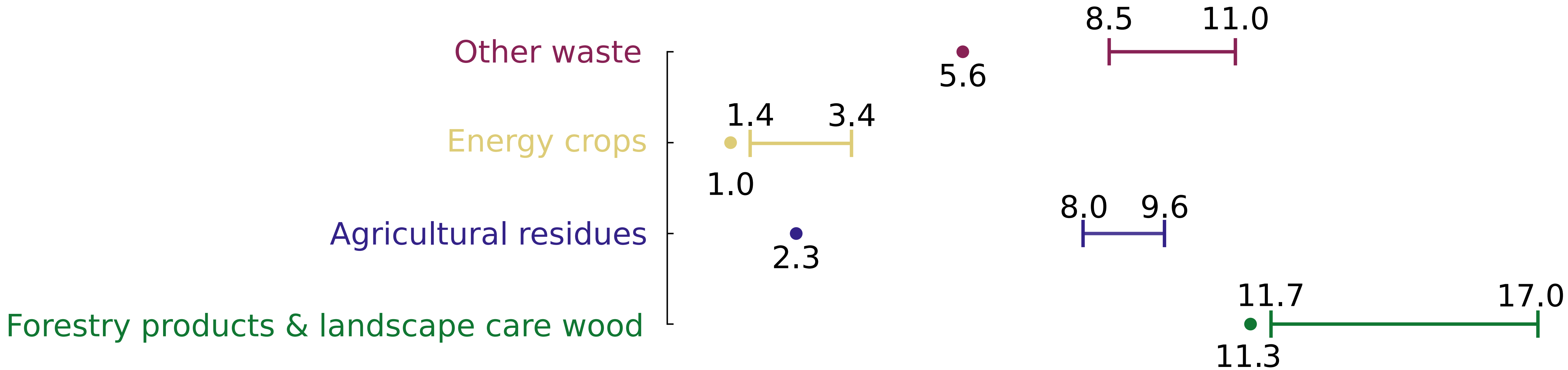
The choice of potential implies a specific system and is not neutral or objective.
It is political.

Energy crops on marginal lands - an option to increase biomass potential in Belgium?



Pragmatic biomass potential in Belgium evaluated from 30 to 41 TWh in 2030

Outcome of a critical discussion for Belgium



Now that it is properly characterized, it can be used in the whole-energy system model

WP1 WP2

Whole-energy system model

ENERGYScope

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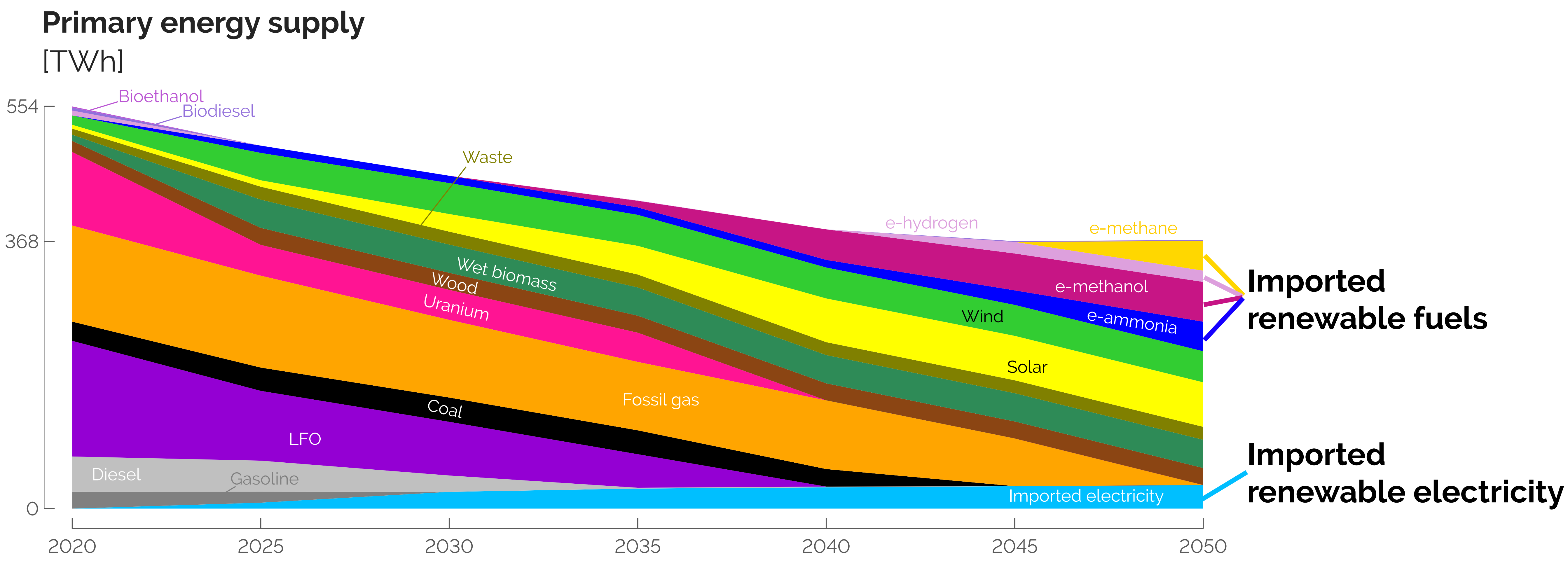
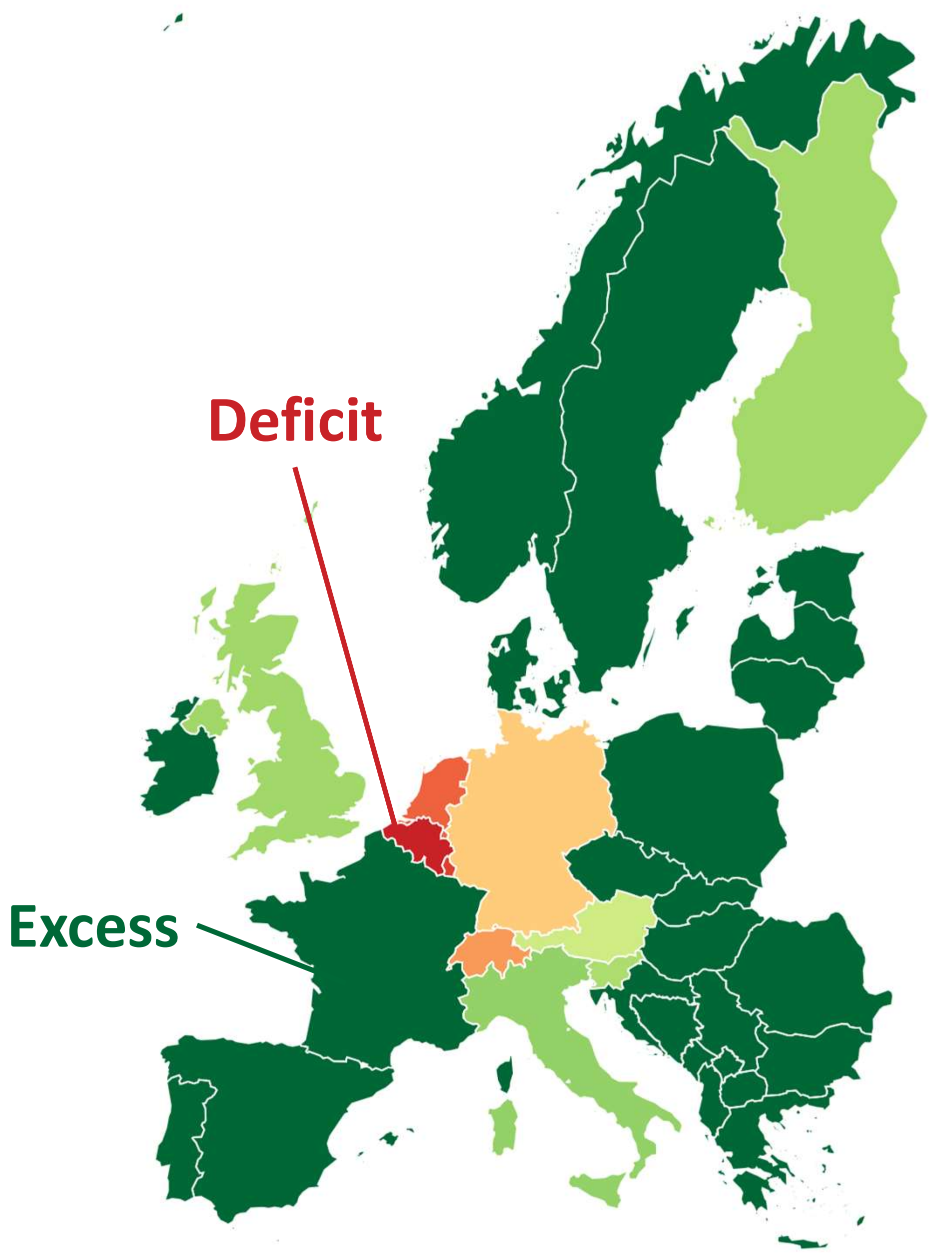
Belgium will need to import renewable fuels and electricity



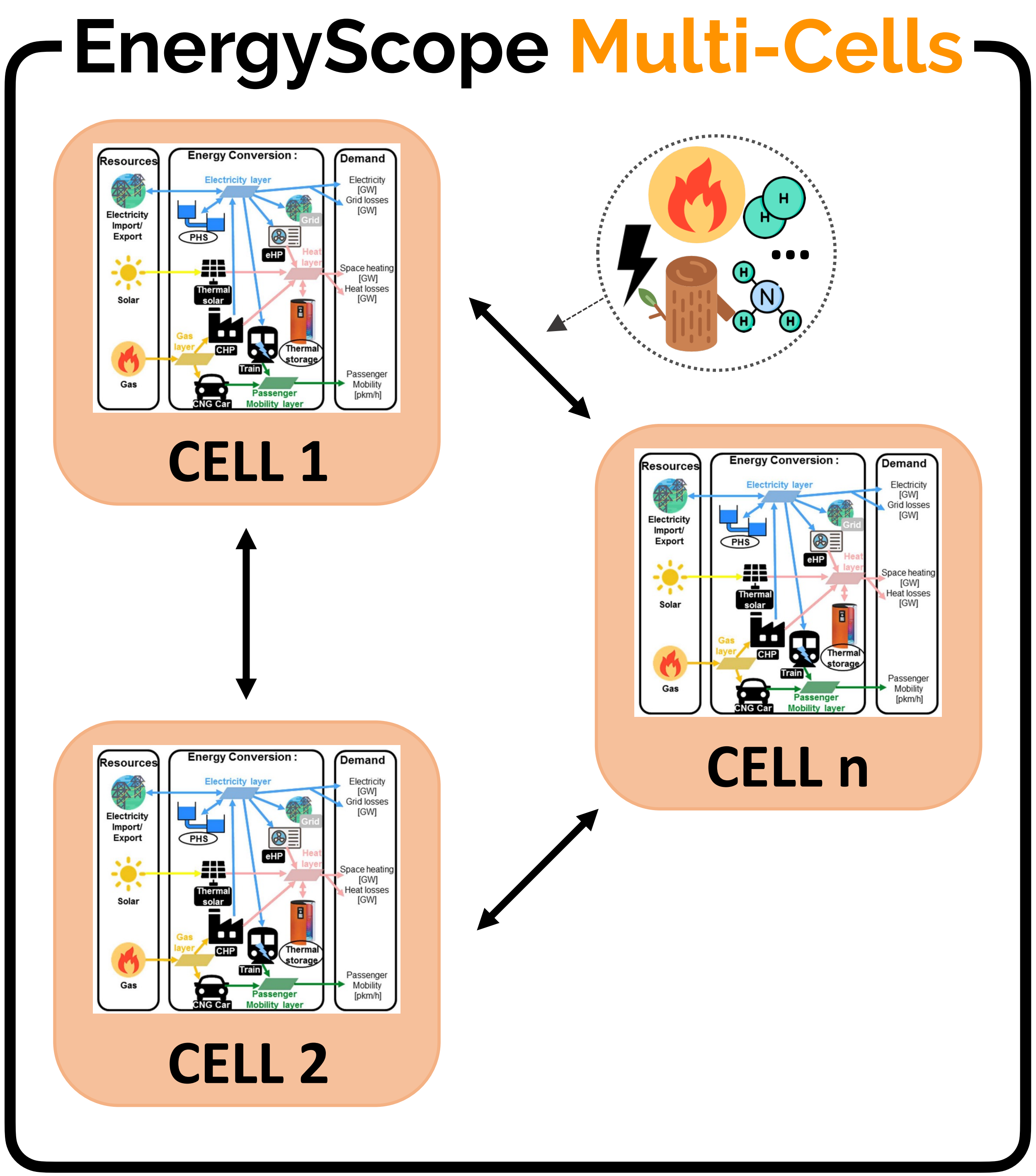
Some European countries could produce renewable energy in excess

Mapping of renewable potentials and demands for EU countries



- What is the contribution of energy exchanges with neighboring countries to Belgium's security of supply in a fossil free energy system?
- What is the role of renewable fuels in a fossil free European energy system?

EnergyScope Multi-Cells is suited to model the competing interests for renewable fuels



Characteristics

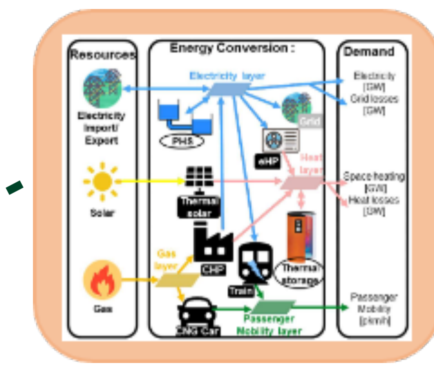
- ✓Whole-energy system model
  - ✓All energy uses (10)
  - ✓All energy vectors (32)
- ✓Hourly resolution over a year
- ✓Optimisation of design & operation
- ✓Open-source and documented
- ✓Multi-regional

Case study: a fossil and nuclear free Europe in 2050

34 European countries

+ all countries can import renewable fuels from the exterior at a certain cost

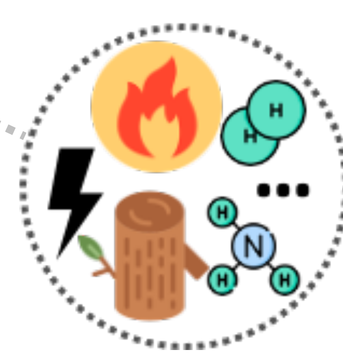
For each country



Renewable potentials
End-use demands:

1. Specific electricity
2. Space heating and hot water
3. Space cooling
4. Passenger mobility (Mpkm)
5. Freight (Mtkm)
6. Aviation (Mpkm)
7. Shipping (Mtkm)
8. High-temperature heat
9. Process cooling
10. Non-energy demand (NED)

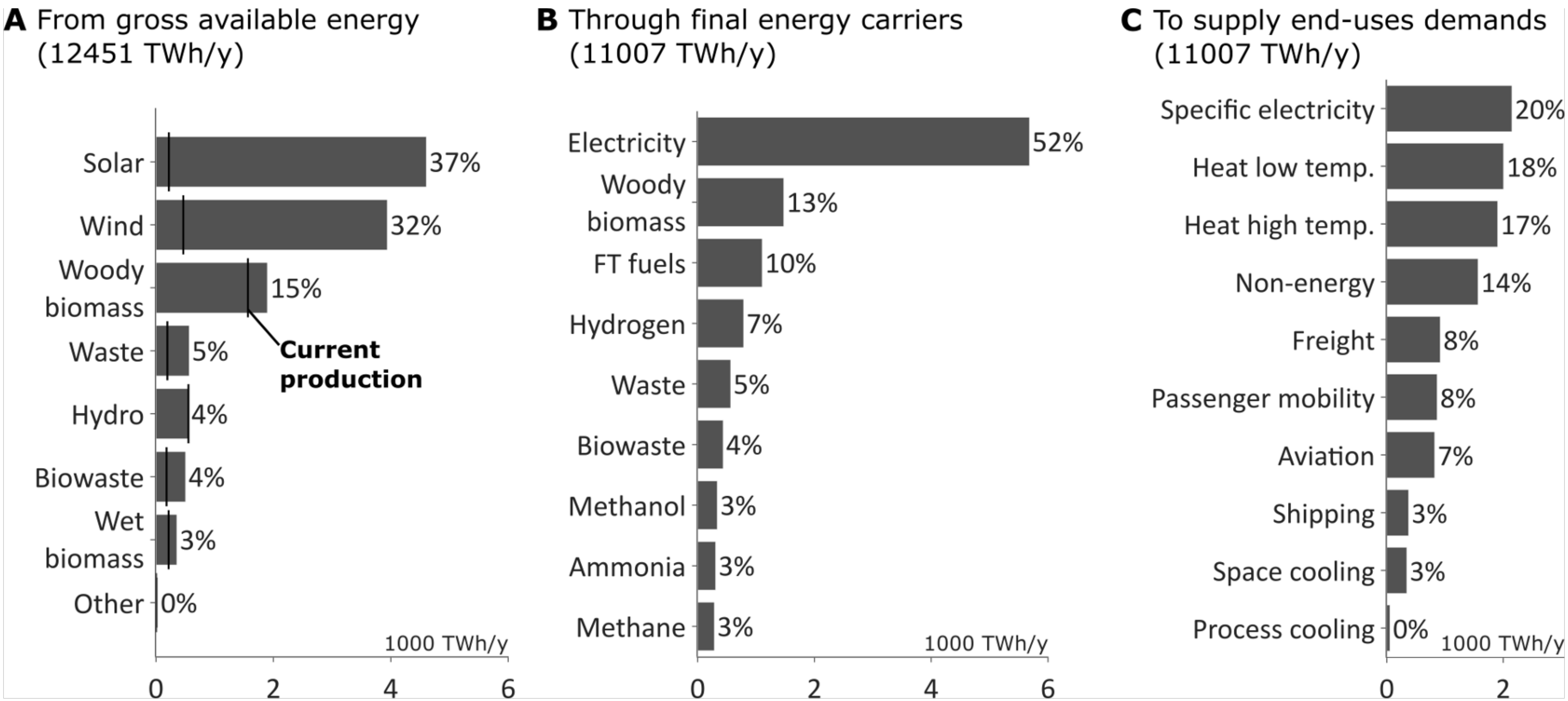
Interconnected



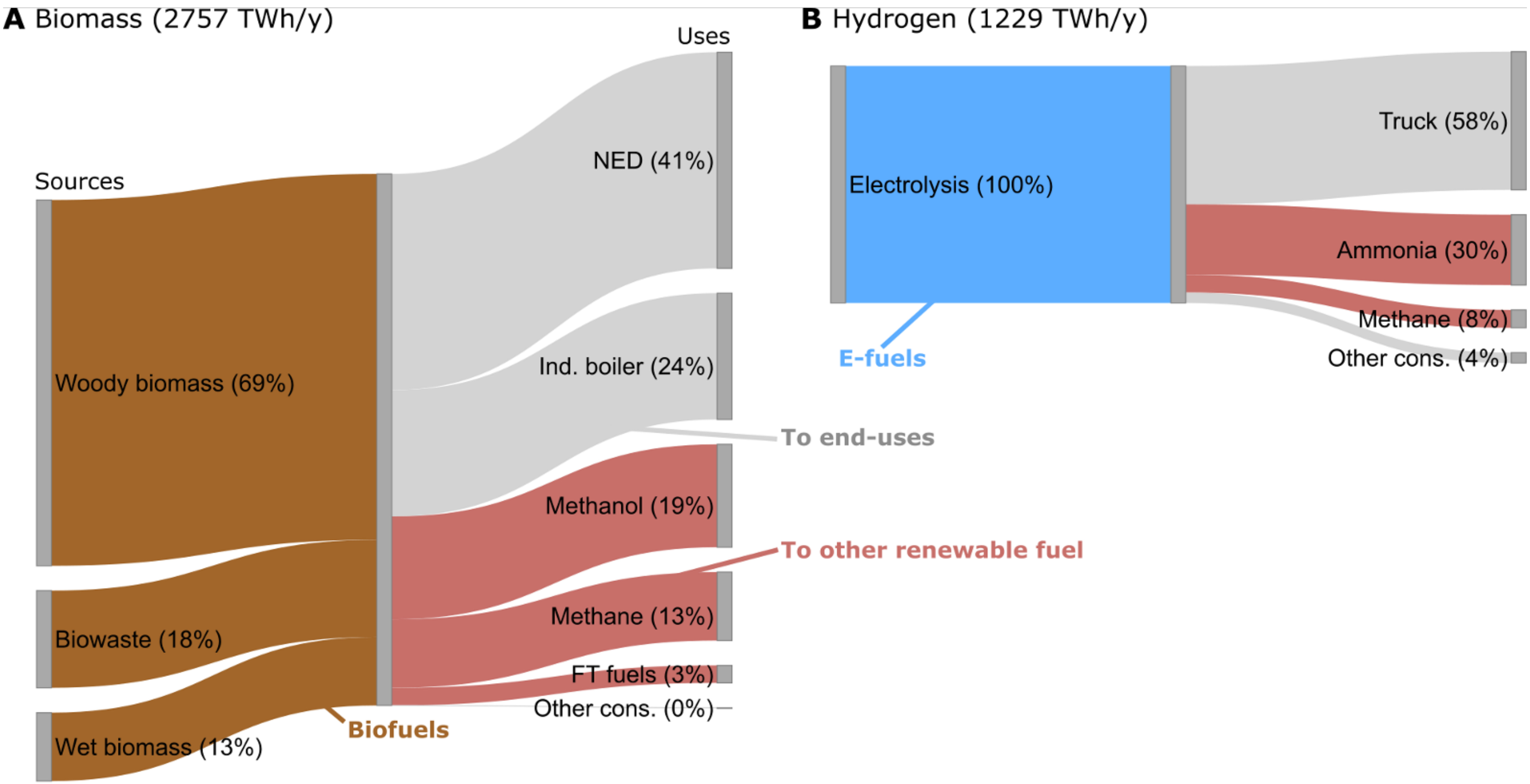
Networks
1. Electricity
2. Gas
3. Hydrogen

Freight
1. FT fuels
2. Methanol
3. Ammonia
4. Wood
5. CO_2

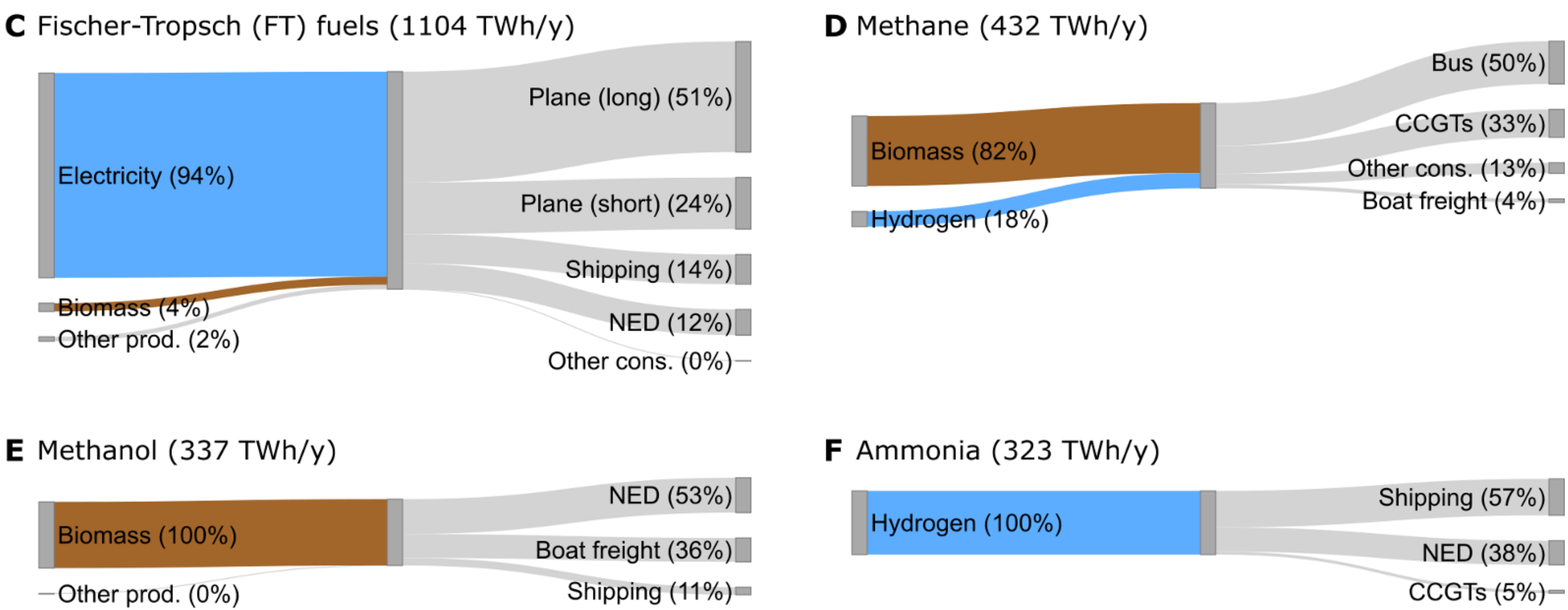
Europe relies on high wind, solar and biomass productions



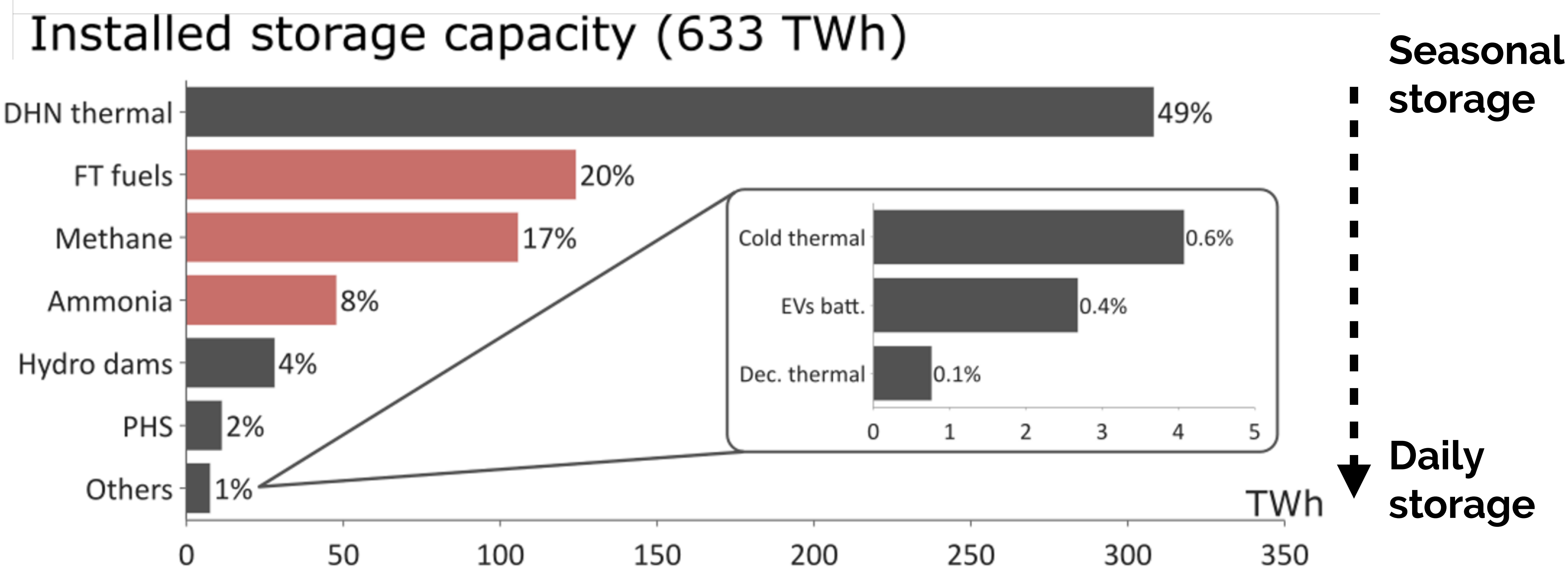
Biomass and e-Hydrogen are the 2 main sources of RE fuels



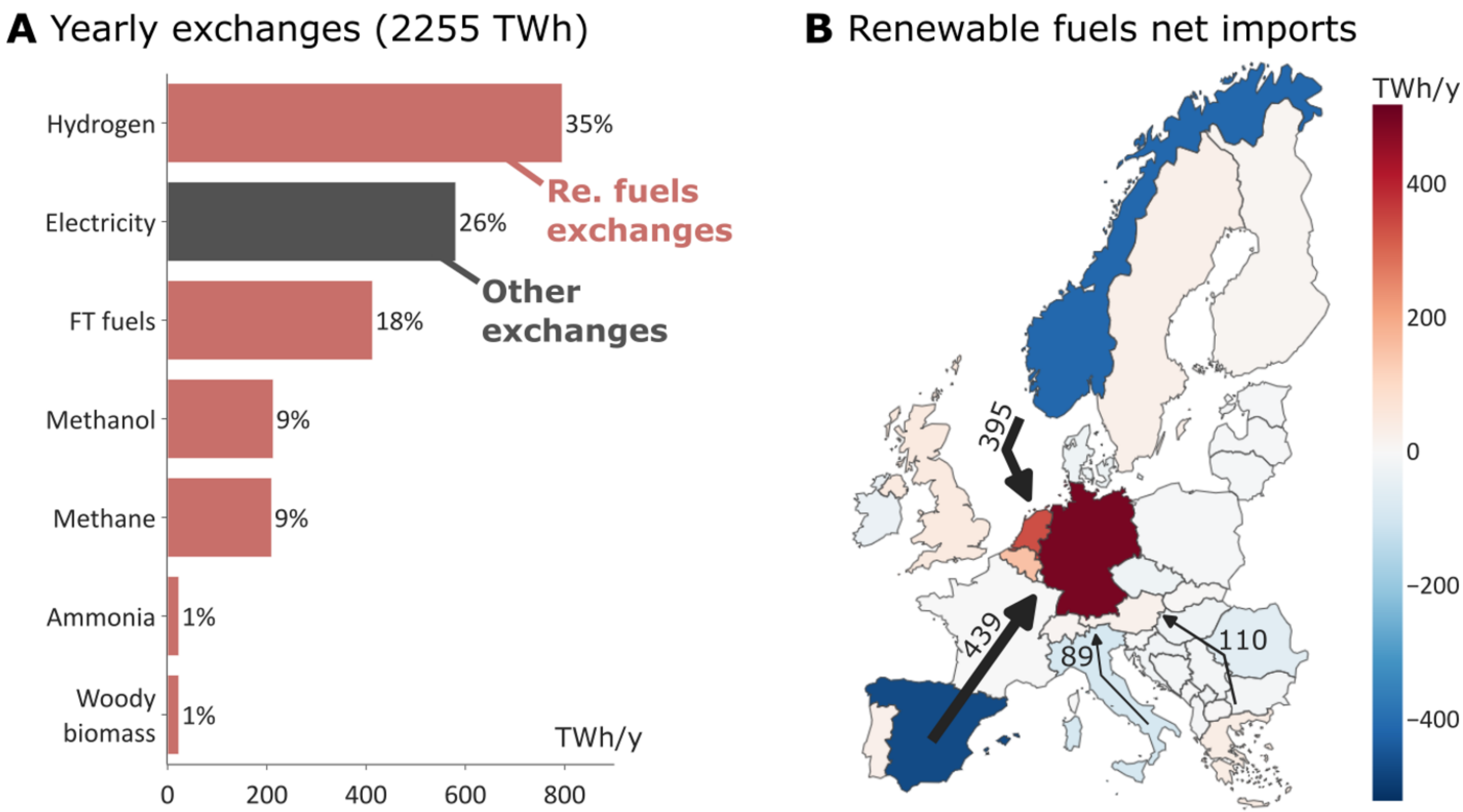
Key in hard-to-abate sectors: industry, heavy transport, flexibility



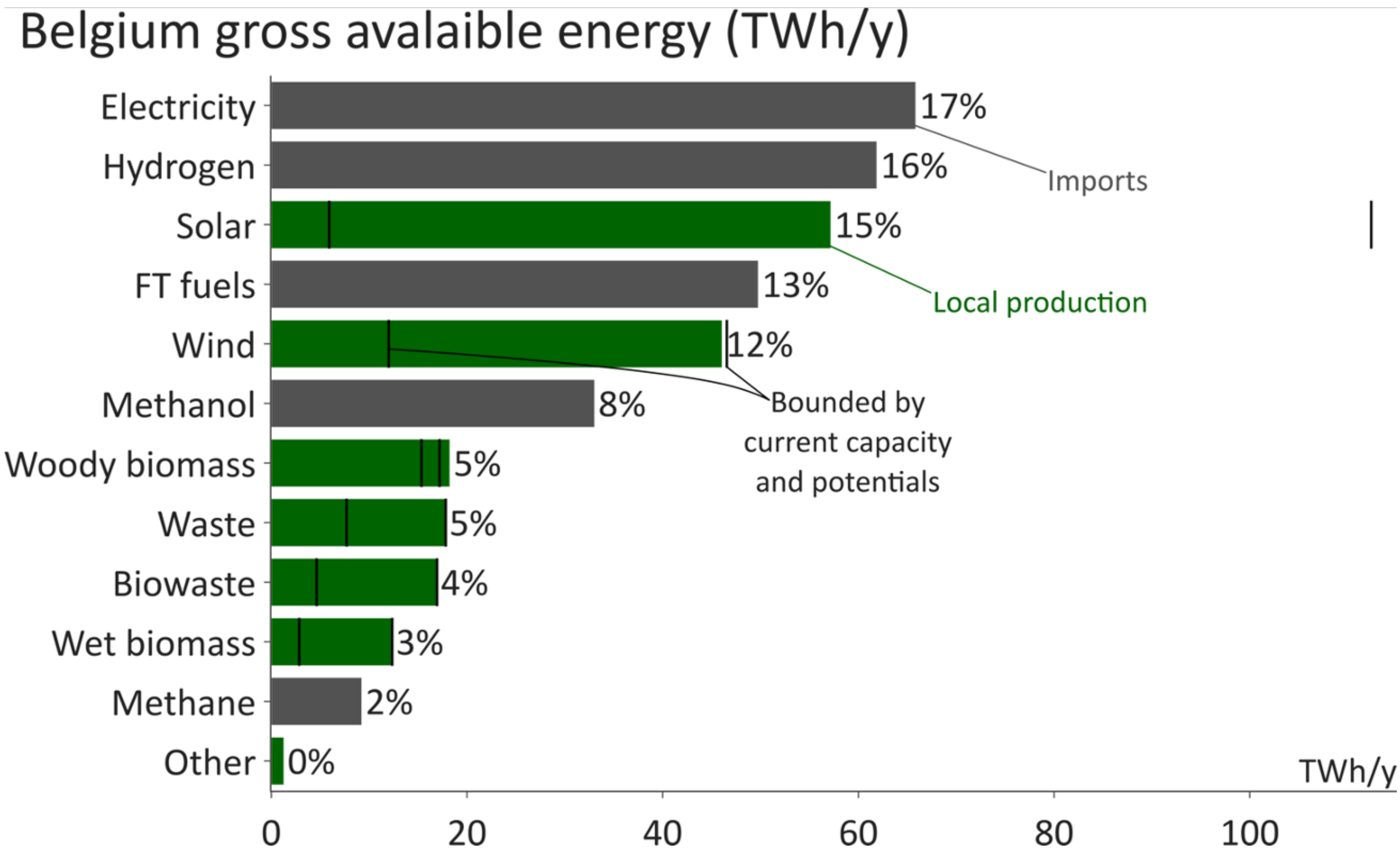
RE fuels represent 44% of the installed storage capacity



RE fuels transport the bulk energy to high consumption places



Belgium imports 56% of its energy, all from other European countries



WP1 WP2

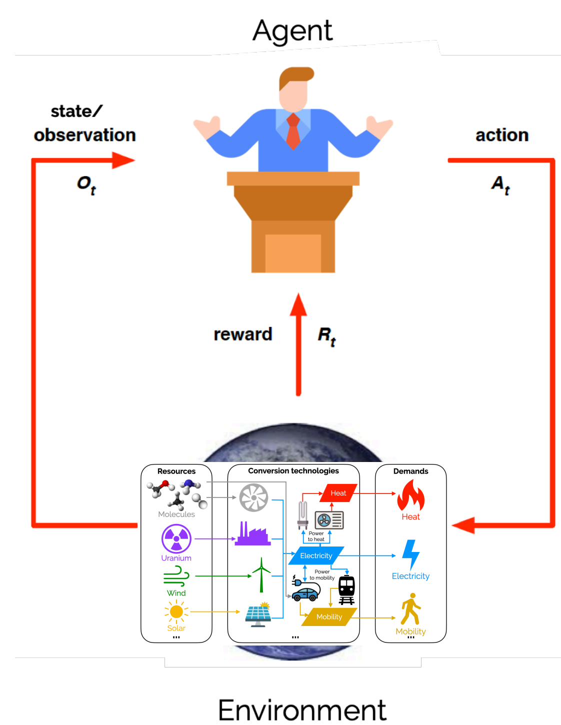
Whole-energy system model

ENERGYScope

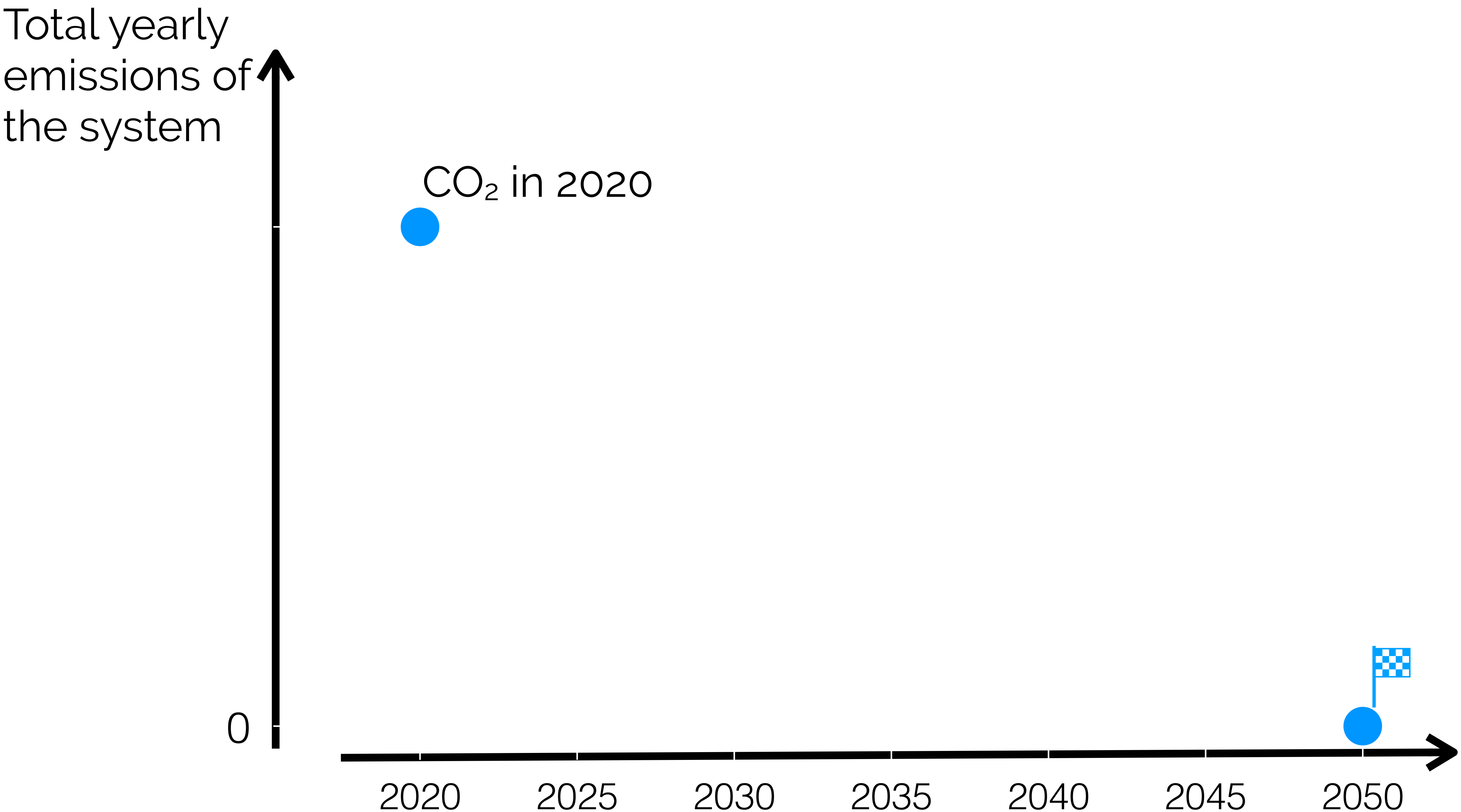
Biomass characterization

Boundary conditions for Belgium

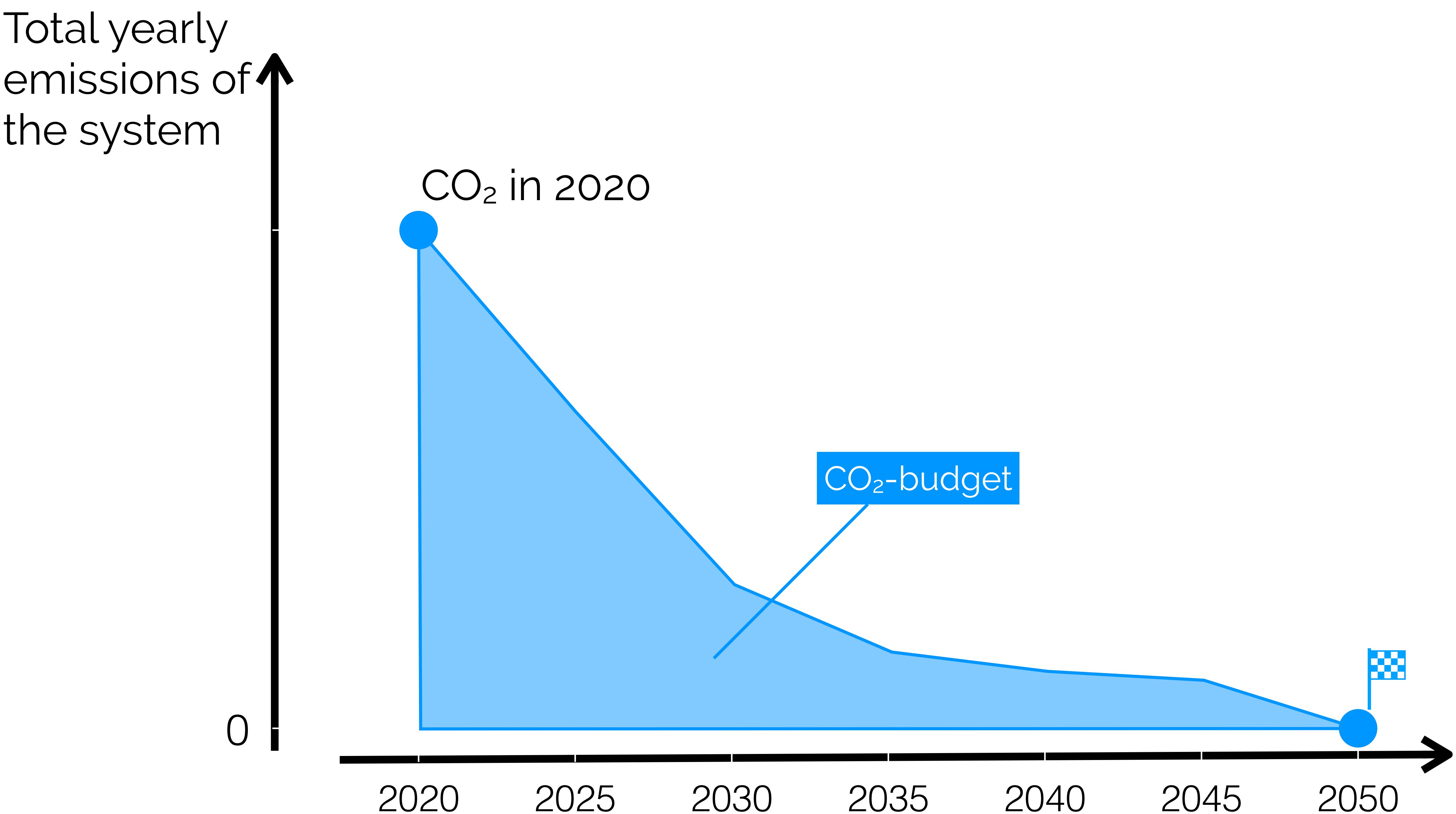
Pathway exploration under uncertainties



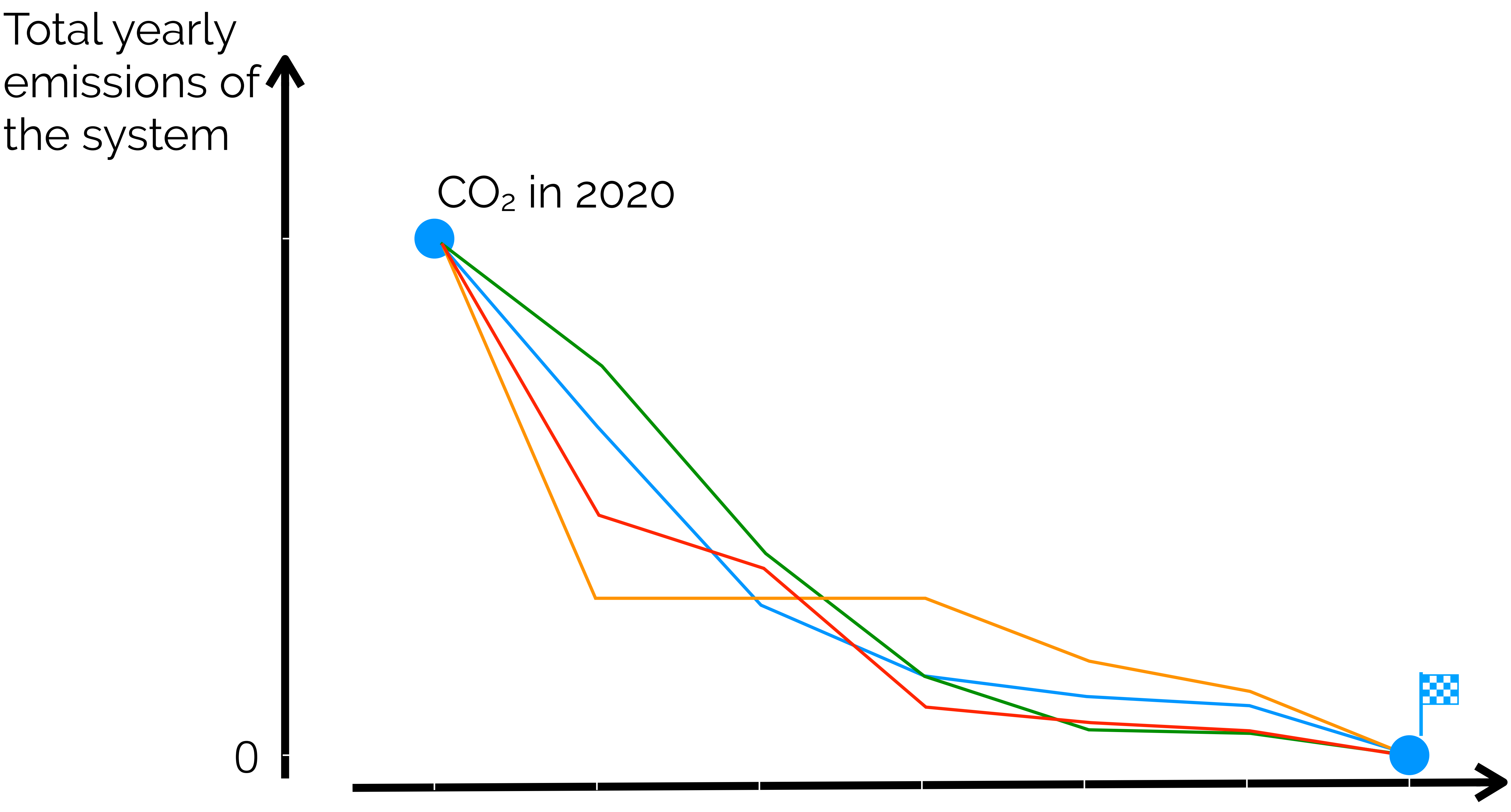
From where we are to where to go,...



… a transition with a target CO_2-budget in line with the +1.5° global objective…



… with no prescribed CO_2-trajectory



Myopic foresight to mimic short-sightedness of the agent

Perfect foresight (PF)

Complete knowledge on the whole horizon

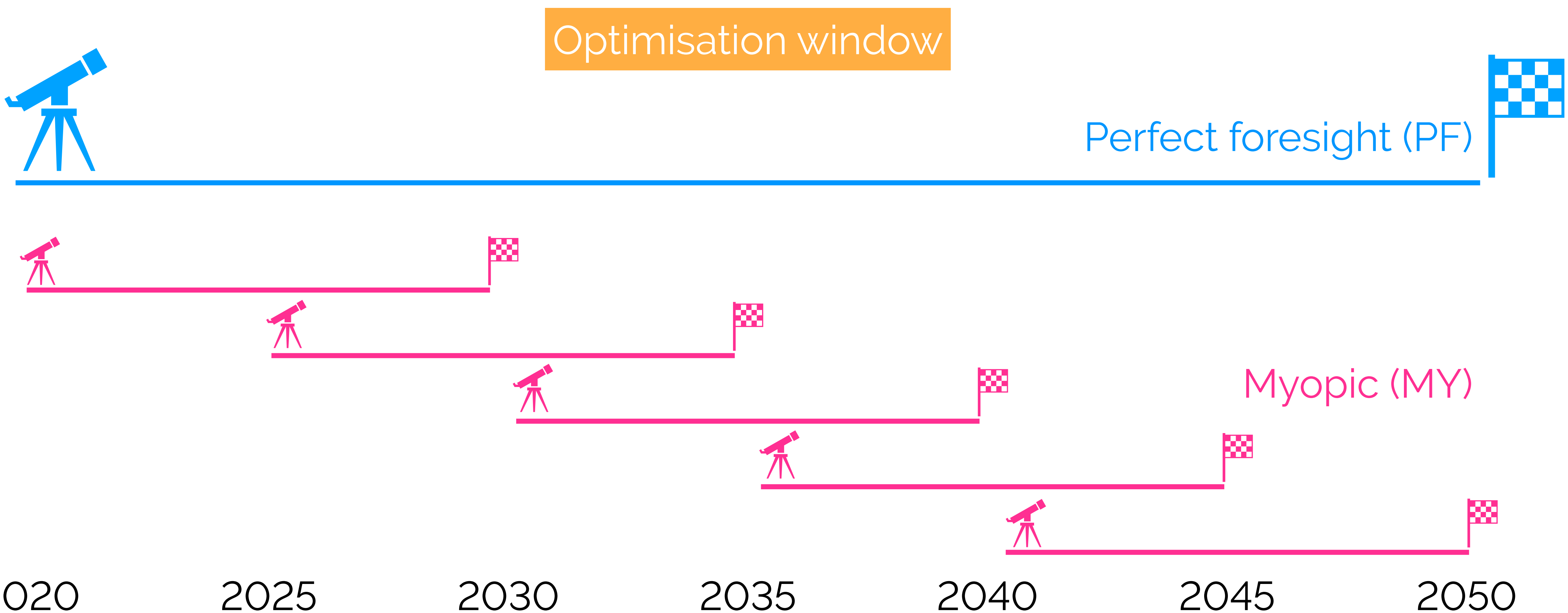
Global optimization of all the time-periods

VS

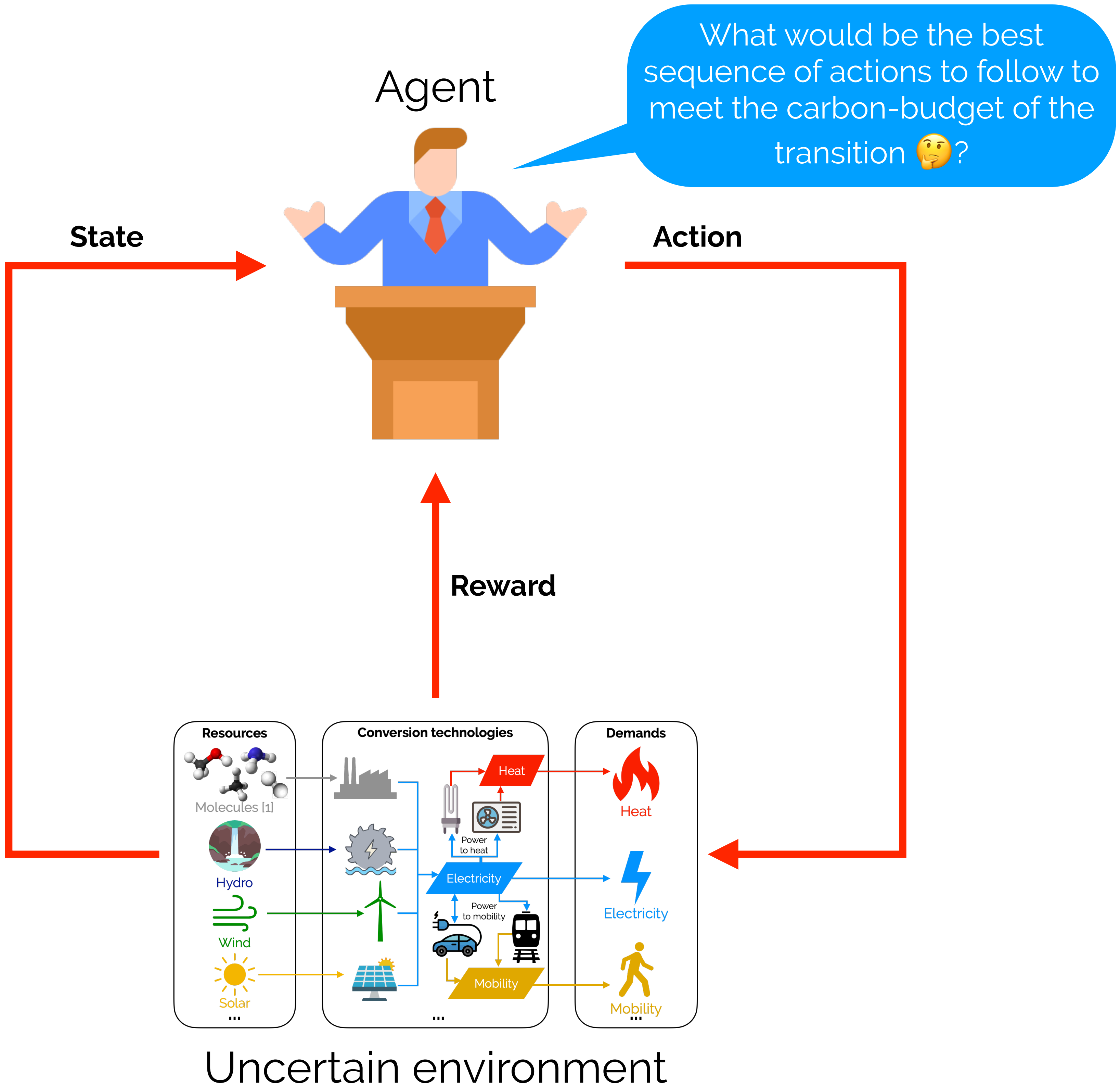
Myopic (MY)

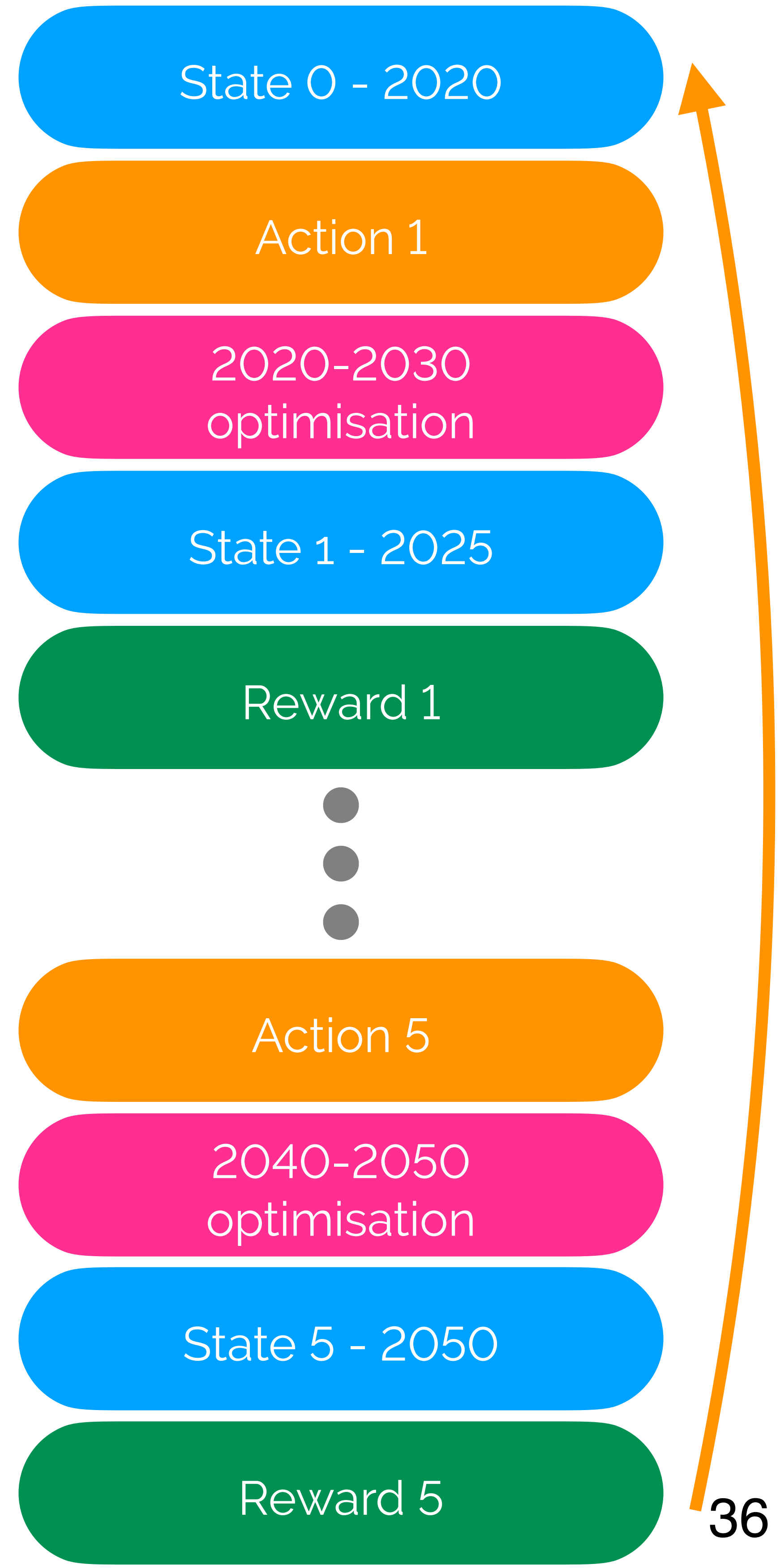
Limited knowledge on the whole horizon

Step-by-step optimization

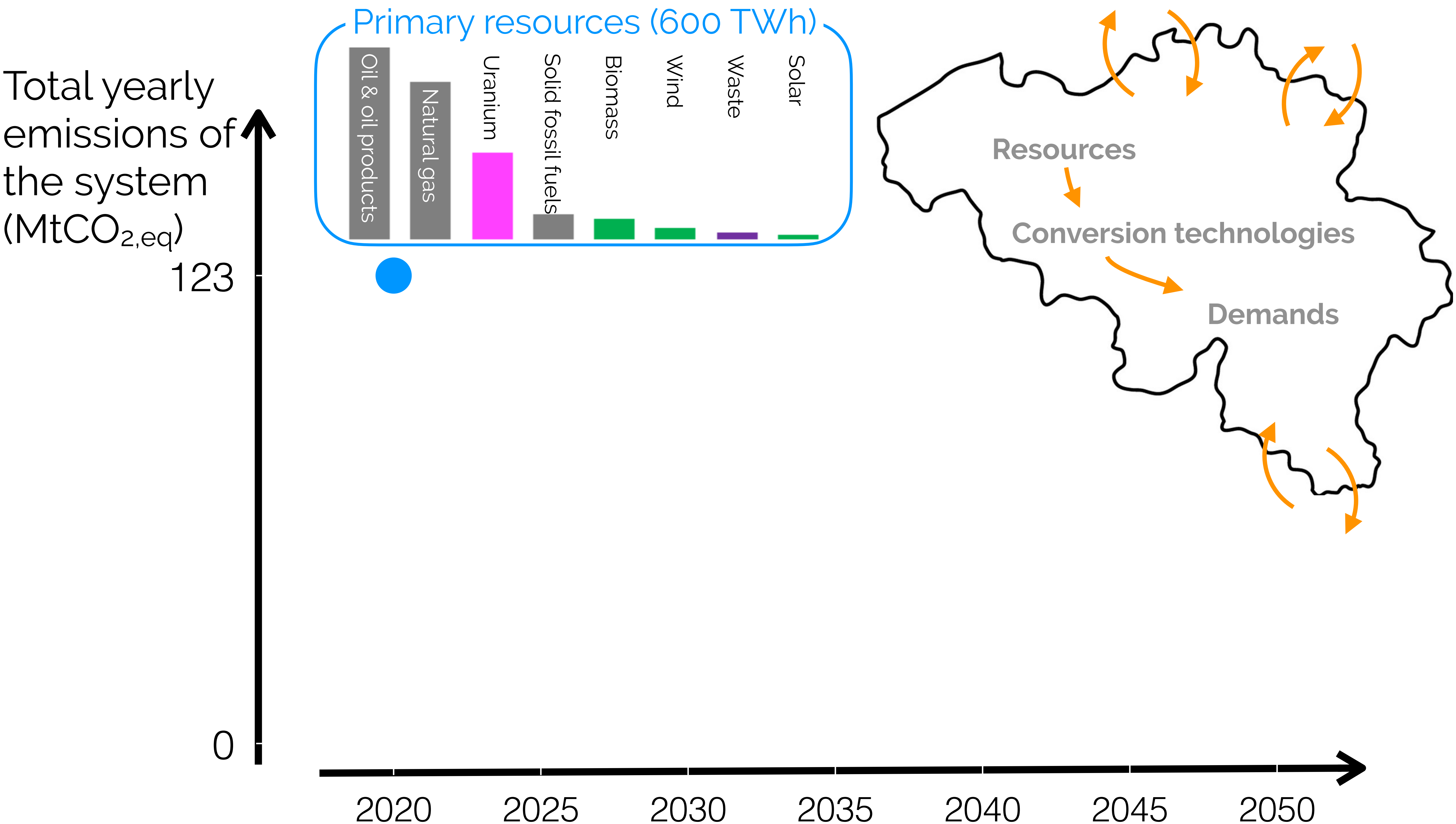


Towards an RL-based exploration of the policy towards sustainability

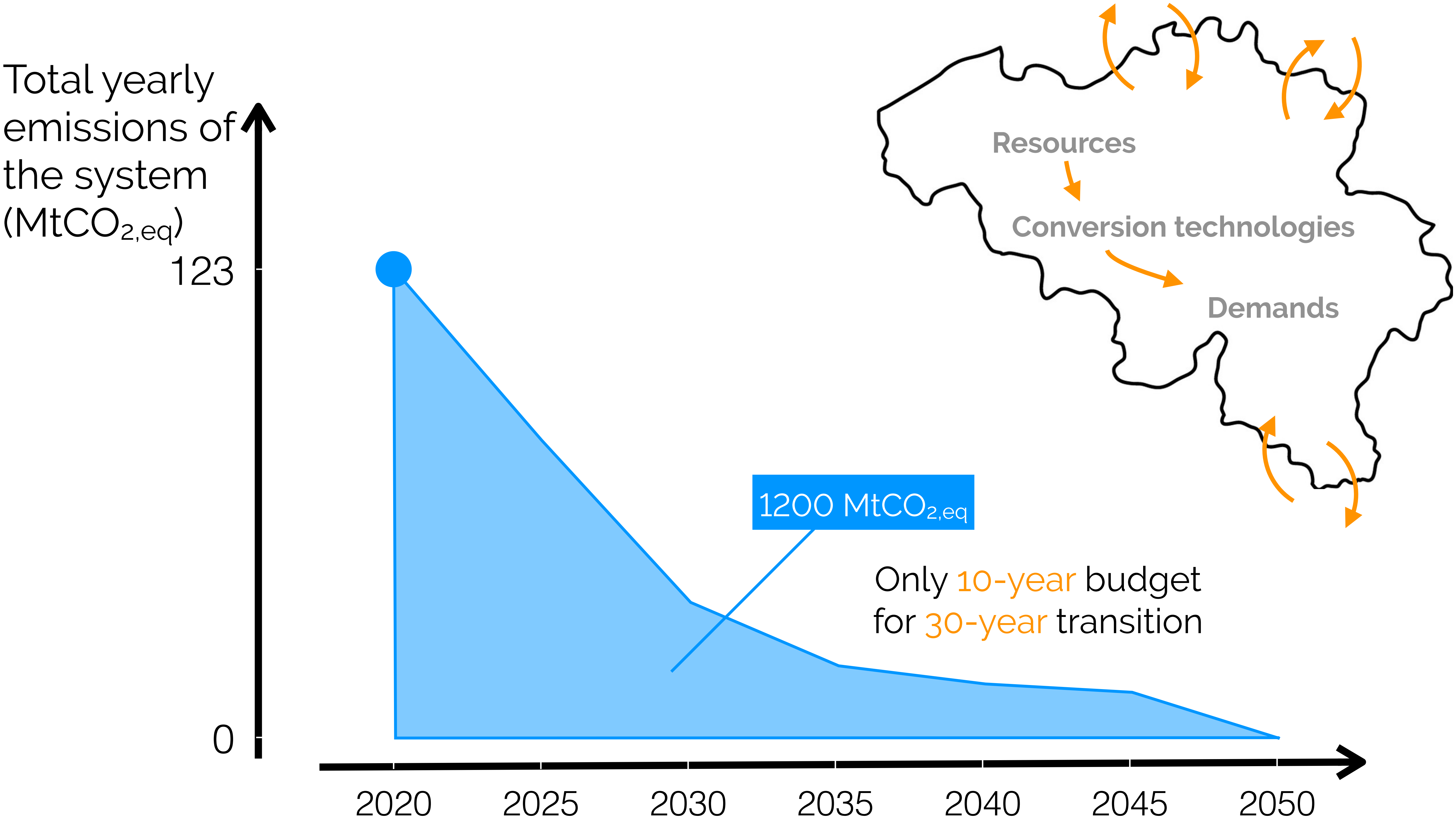




From the current Belgian energy system in 2020…

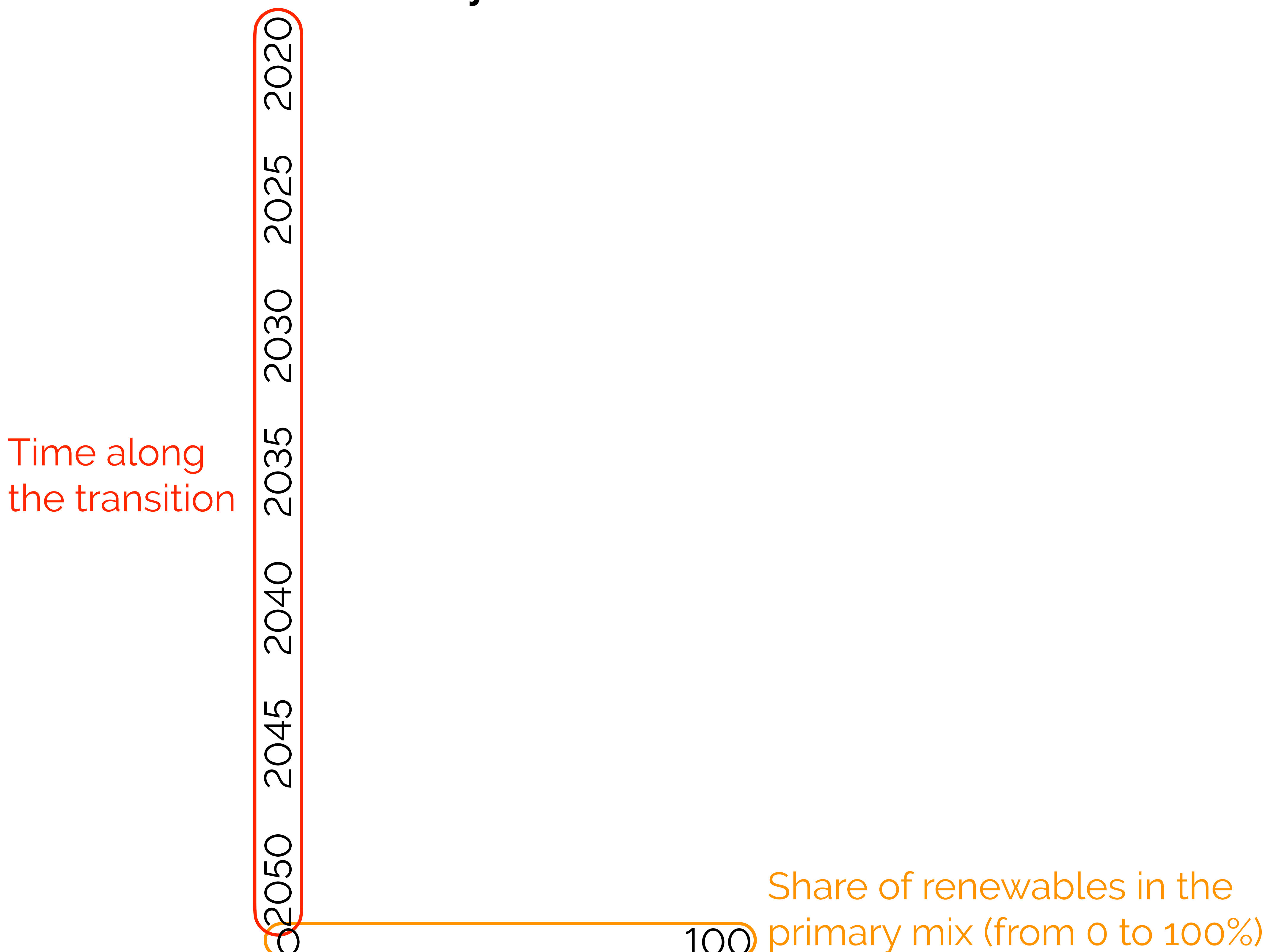


… to a transition with a CO2-budget target in line with the +1.5° global objective…



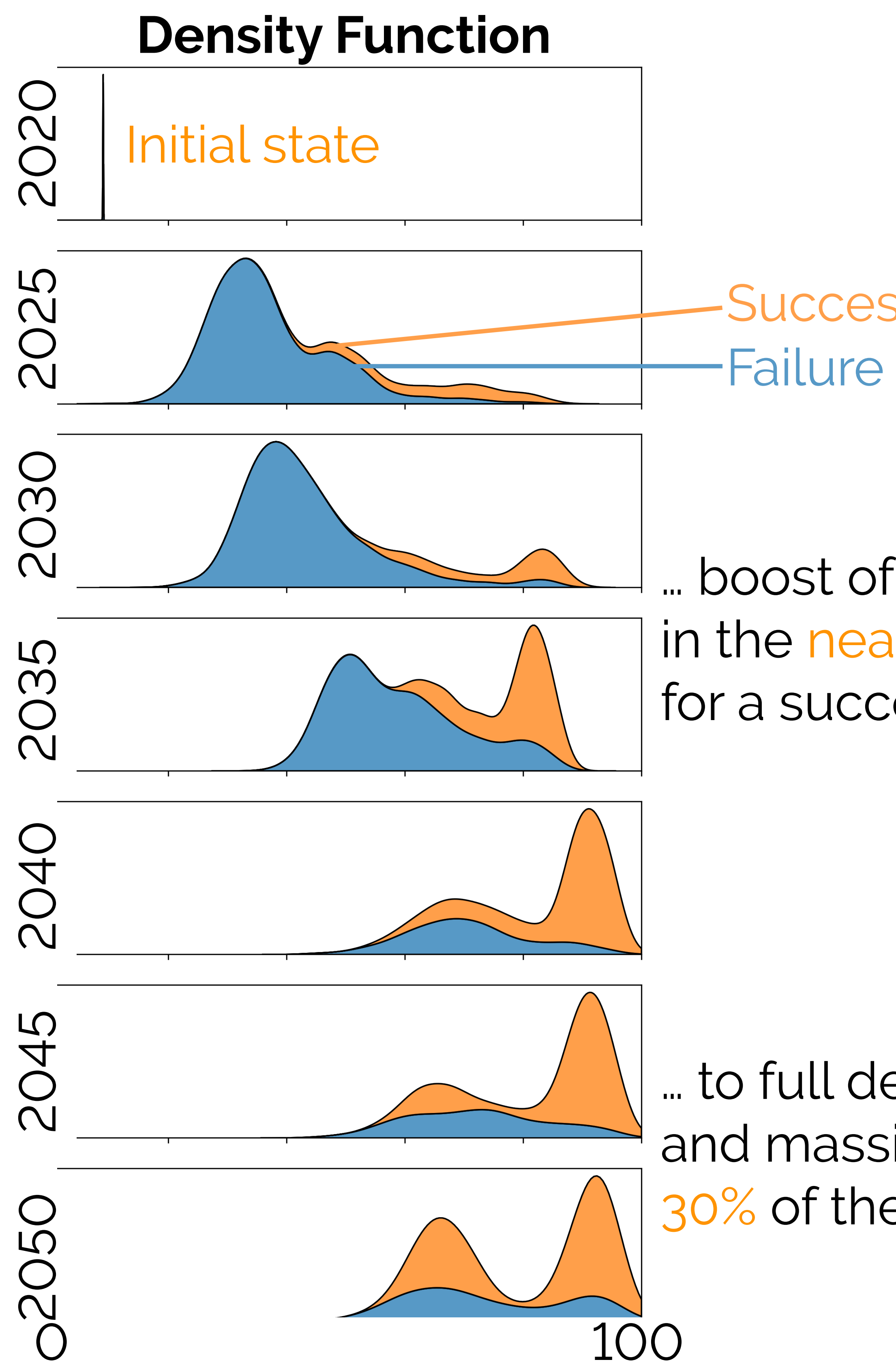
Wide exploration of the state space, during the learning phase…

Density Function



… renewables should penetrate intensively the primary mix in the near-term

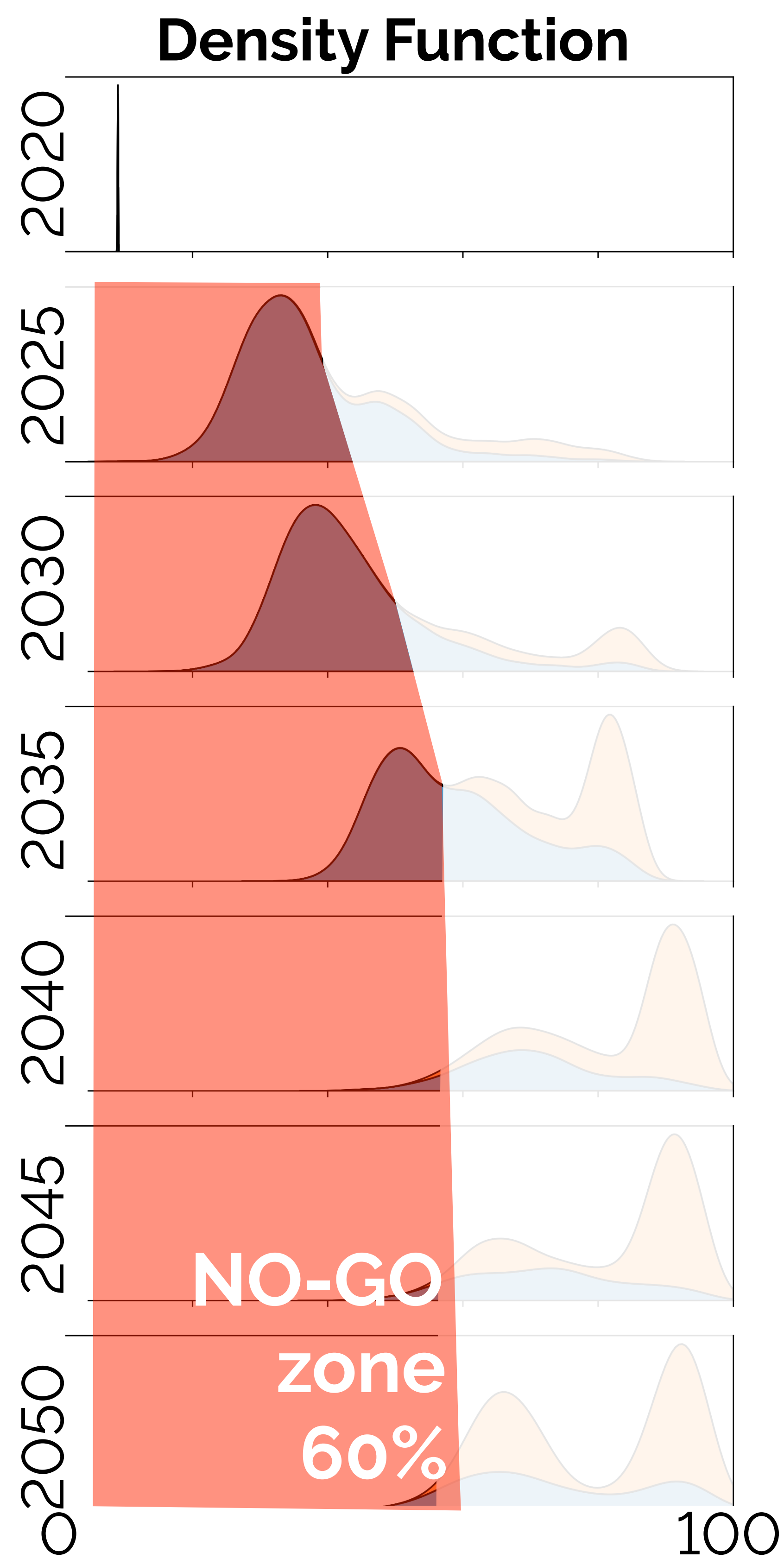
From 10% (mostly local biomass, PV and wind) in 2020…



… boost of integration of renewables in the near-term is needed to hope for a successful transition…

… to full deployment of local VRES and massive import of e-fuels (up to 30% of the mix)

… below near-term threshold, there is no way to succeed



Key take-away messages

WP1 WP2

The definition of local resources potential (e.g. biomass) implies a specific system and is not neutral or objective - it is political.

Biomass would be mainly used in high-temperature heat and non-energy demand.

A fossil and nuclear free, energy independent Europe is feasible with renewable fuels strategic in hard-to-abate sectors (e.g. industry, aviation, heavy transport), flexibility and energy exchanges.

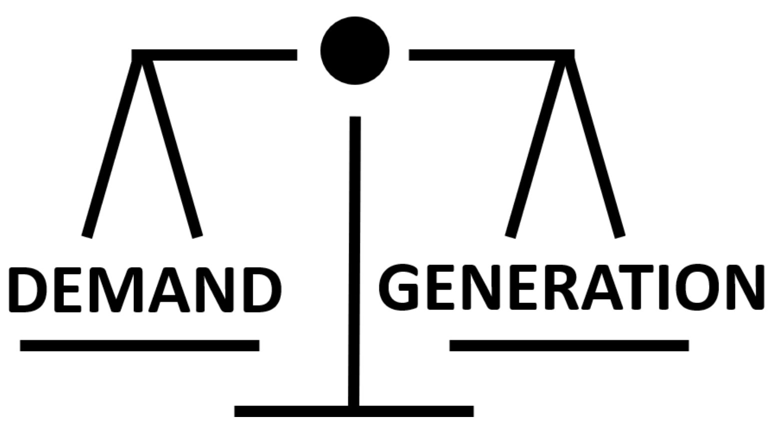
Belgium can rely on other European countries for imports of renewable energy.

Aiming at max +1.5˚C is very ambitious but we need to strongly act in the near-future to make it happen (sweet-spots).

WP3

Work out, for Belgium, the most economical electro- and synthetic energy carrier routes needed to face the climate change issues and **ensure the stability of the grid and the security of supply** in 2040 and beyond.

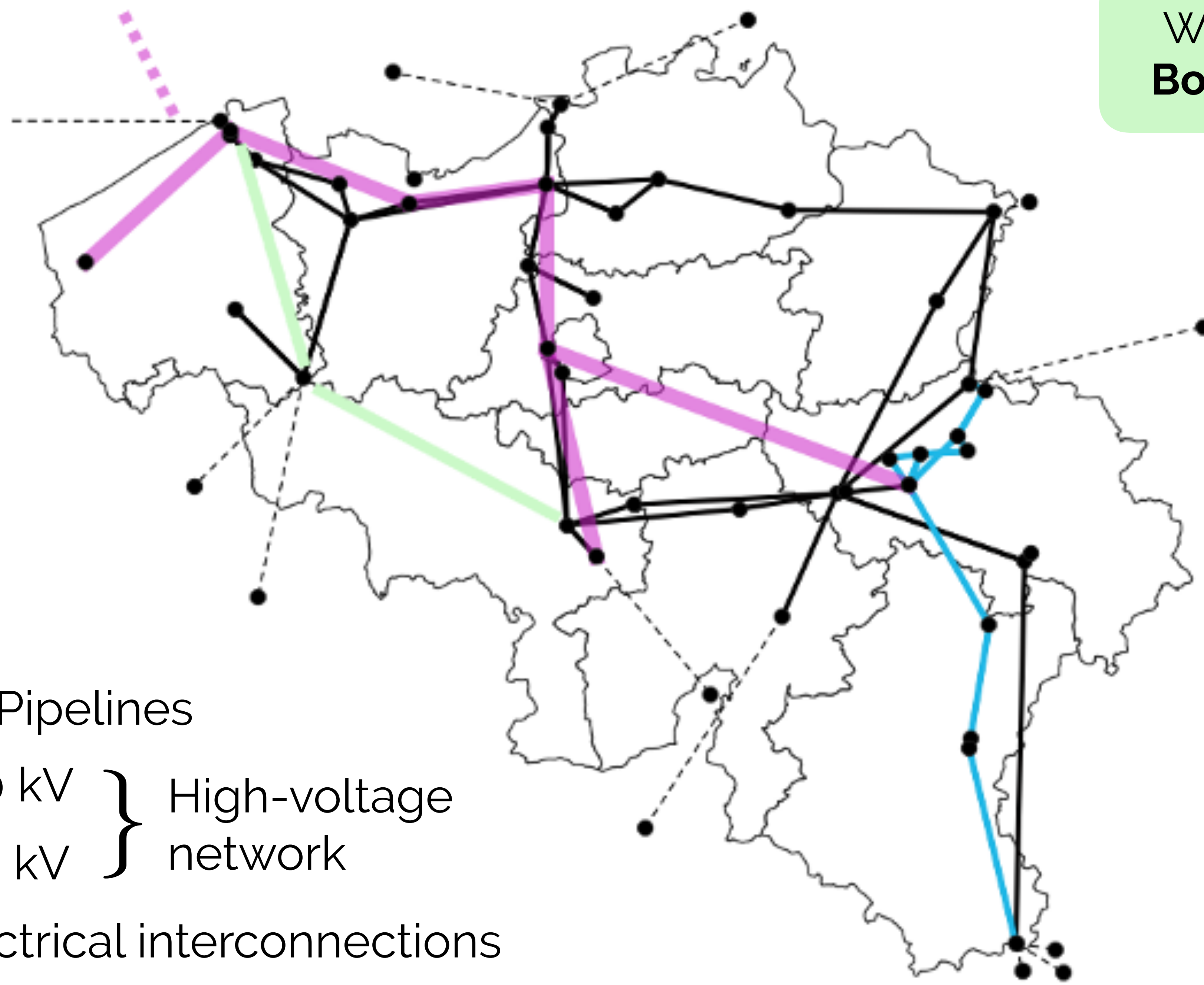
Grid adequacy



Rotor angle stability of synchronous machines

Case study: Belgium in 2030

With **Ventilus** and **Boucle du Hainaut**



H2 Pipelines

380 kV } High-voltage network

220 kV

Electrical interconnections

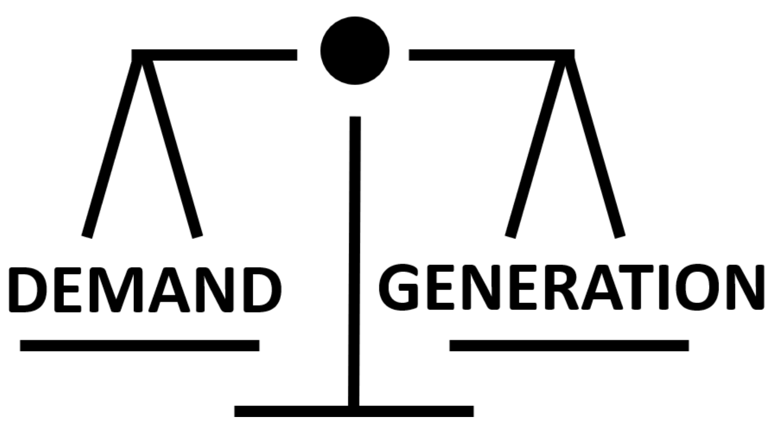
H2 Imports

Ventilus + Boucle du Hainaut

WP3

Assess the adequacy of the future Belgian power system in which electrofuels play a significant role

Grid adequacy



Rotor angle stability of synchronous machines

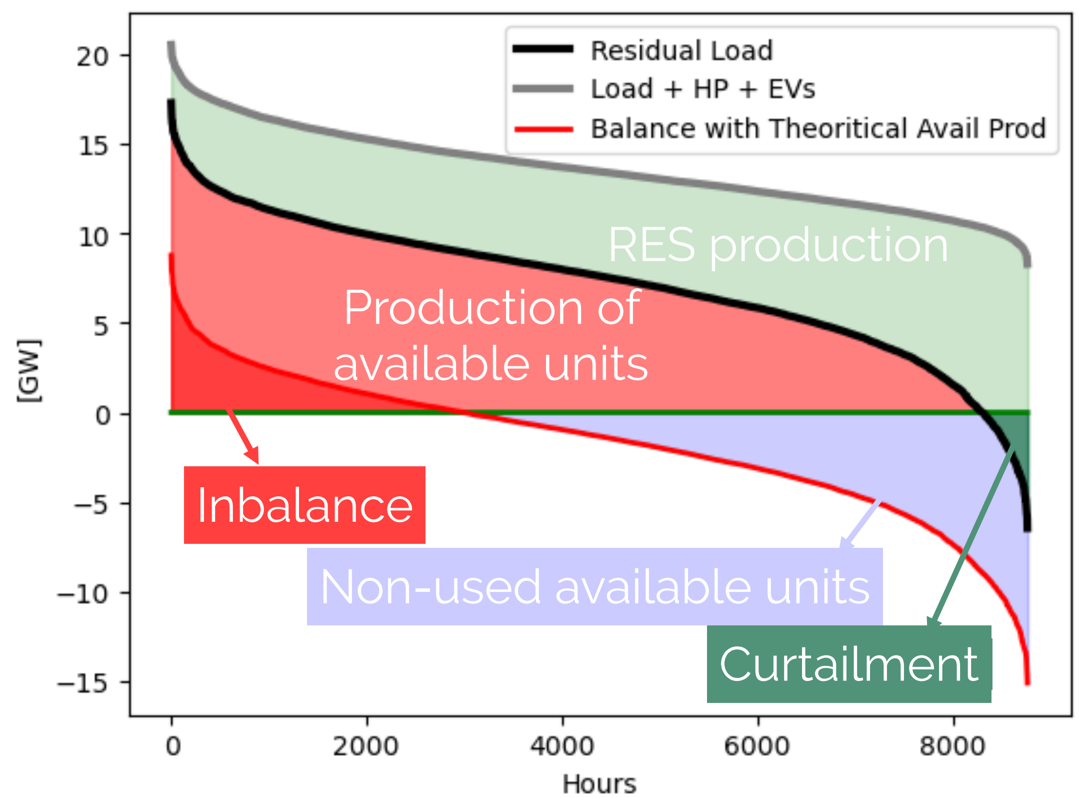
Adequacy assessment: Pre-results

2 GW nuclear + 1.8 GW new CCGTs in Liège

- Electric load - EVs - HPs	104.17 TWh 5.13 TWh* 2.9 TWh**	**Load** **112.2 TWh**
- Offshore WT - PV - Onshore WT	17.5 TWh (5.76GW - 44.5% LF) 14.7 TWh (14.1 GW - 11.8% LF) 11.3 TWh (5.3 GW - 23.3% LF)	
- Thermal Gen	72 TWh	**Gen** **125.6 TWh**
- Distributed thermal gen	10.1 TWh (1.9 GW - 60% LF)	

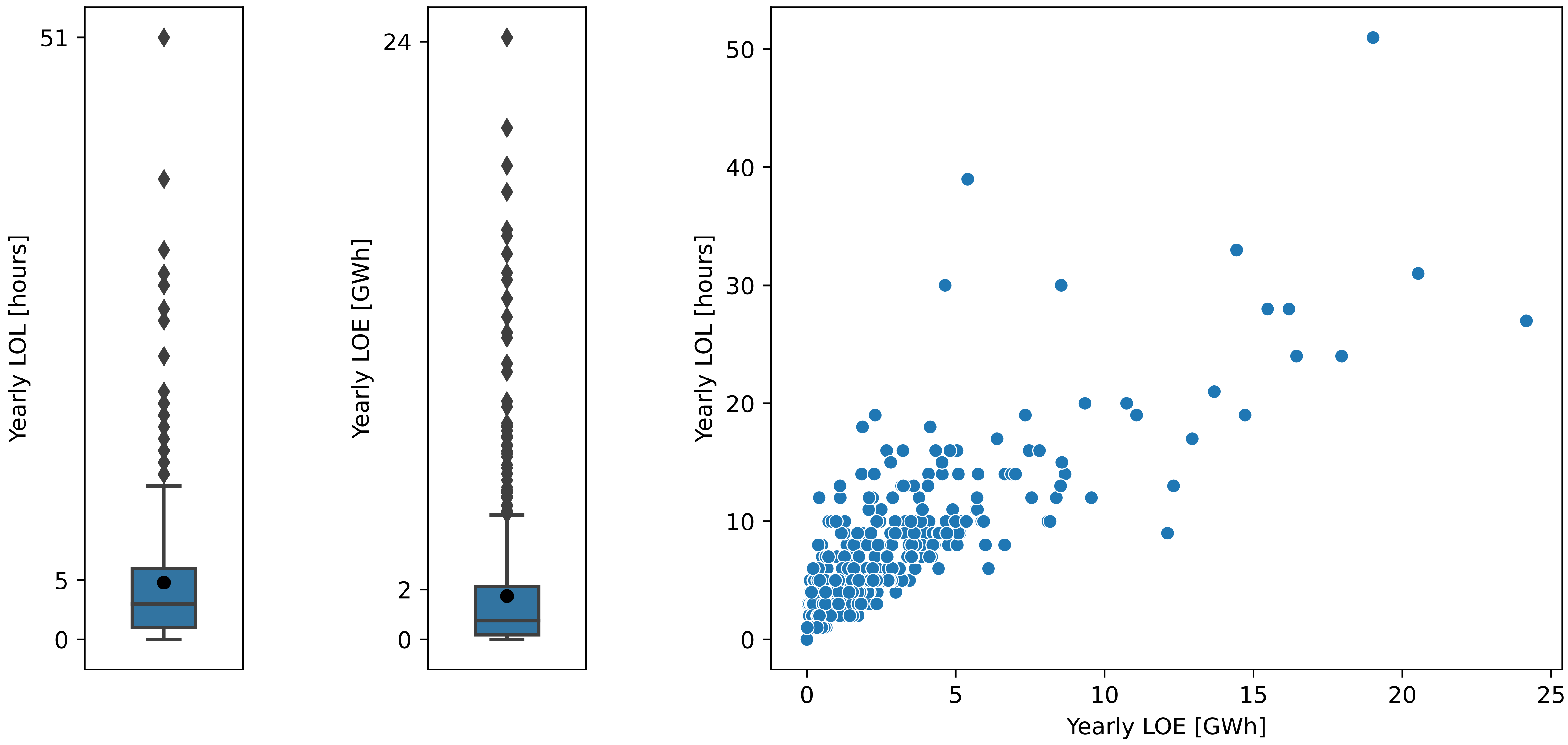
+ H2 demand of 800 kt/year = 26.6 TWh_{H2}/year (imports or locally produced) & 447 MW of installed electrolyzers

Monotonic curve



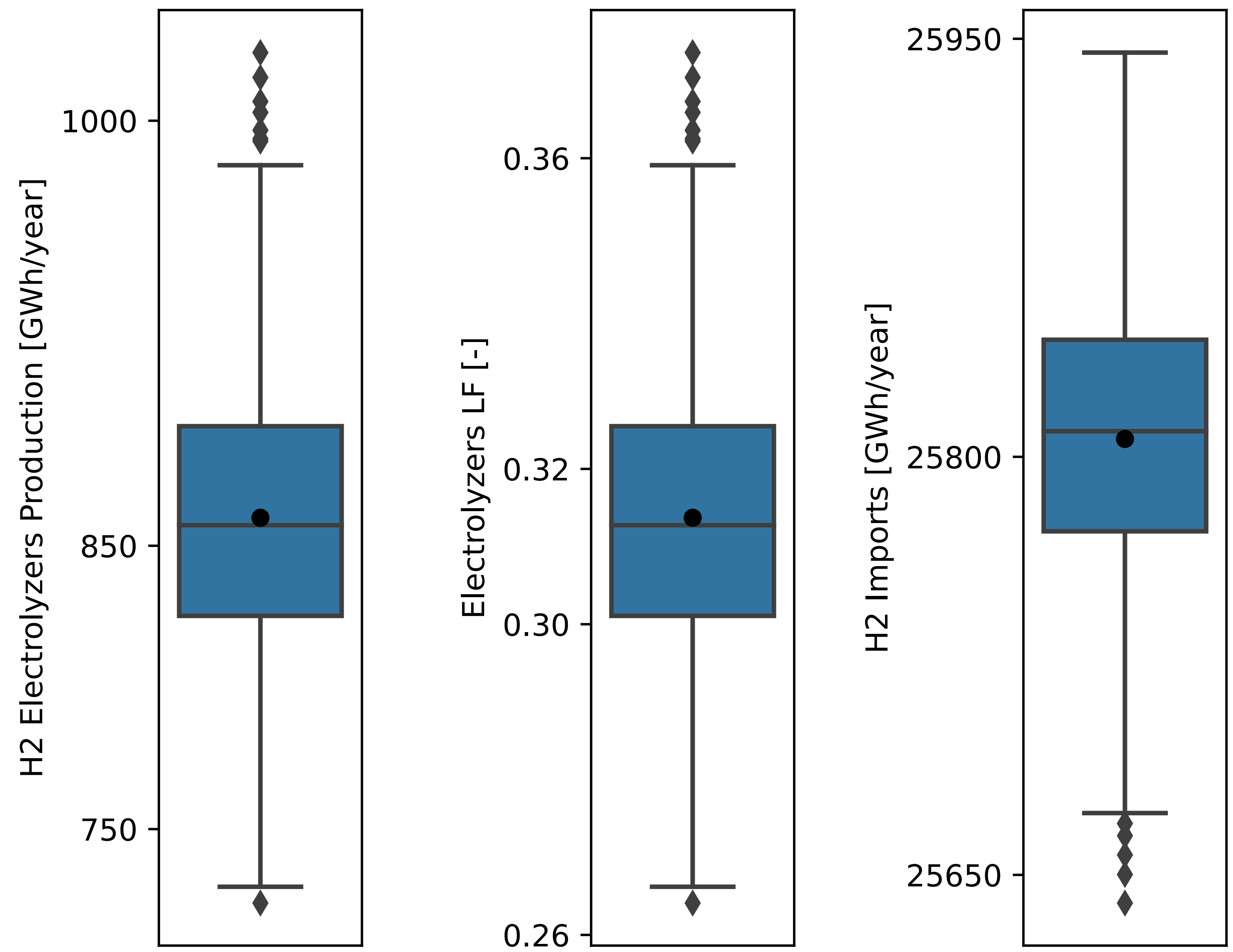
Although the yearly balance is satisfied,
flexibility means are necessary to shift the available energy
to hours lacking power.

Adequacy indicators: LOLE and LOEE



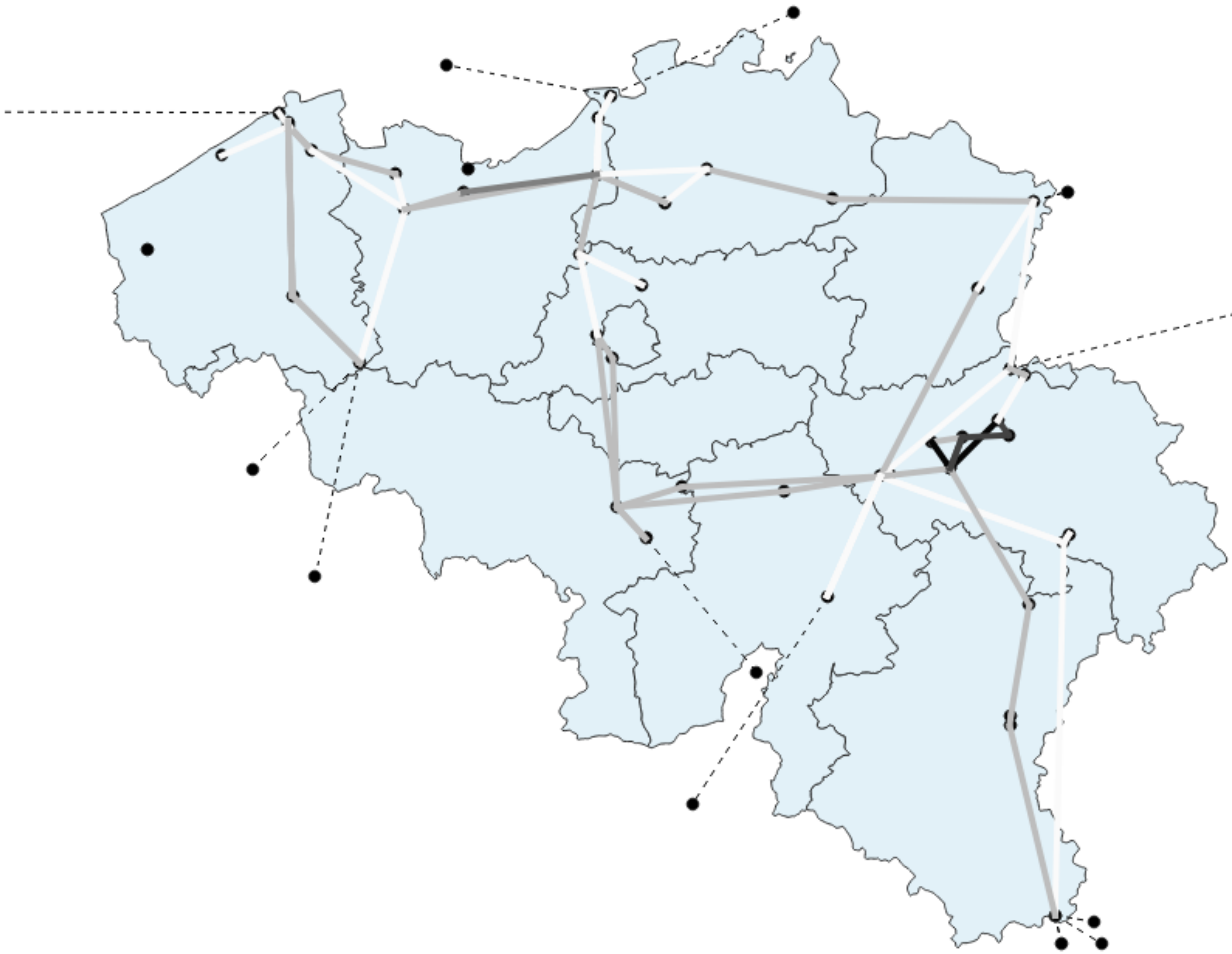
- 2GWh missing and power mismatch around 5 hours/year
- LOL and LOE are not fully correlated: LOE or LOL?
- Adding flexibility means: LOLE = 0.06 hours and LOEE = 0.002 GWh

Hydrogen production and imports



- Majority of hydrogen is imported: 0.86TWh (3%) from electrolyzers + 25.8 TWh (97%) from imports.
- Electrolyzers run at 31% during the year which is quite low (447 MW)

Loading of lines in the grid



The installation of the 2 new CCGTs in the area of Liège leads to an increase of the line loadings in that area. This observation might be overestimated due to the fact that the 150kV network is neglected.

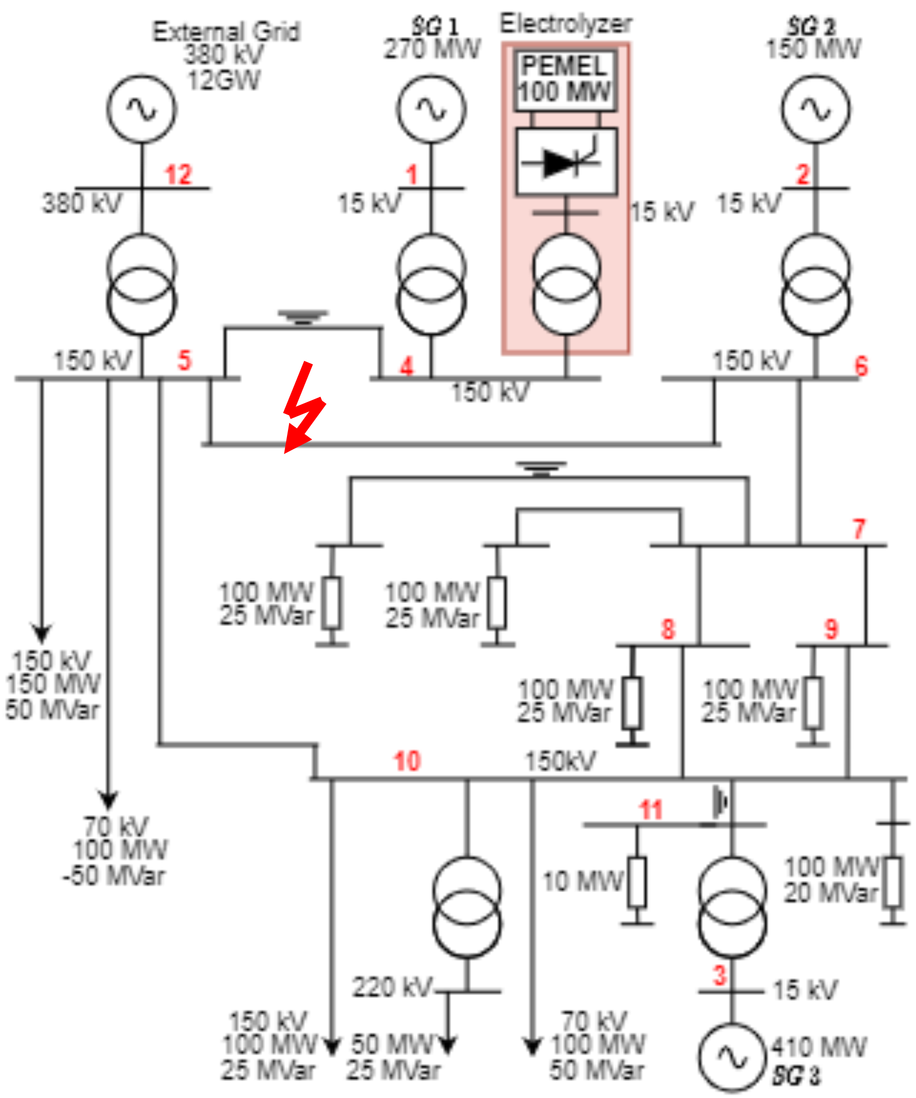
WP3

Study the impact of electrolyzers on rotor angle stability of synchronous machines: Small signal & Transient

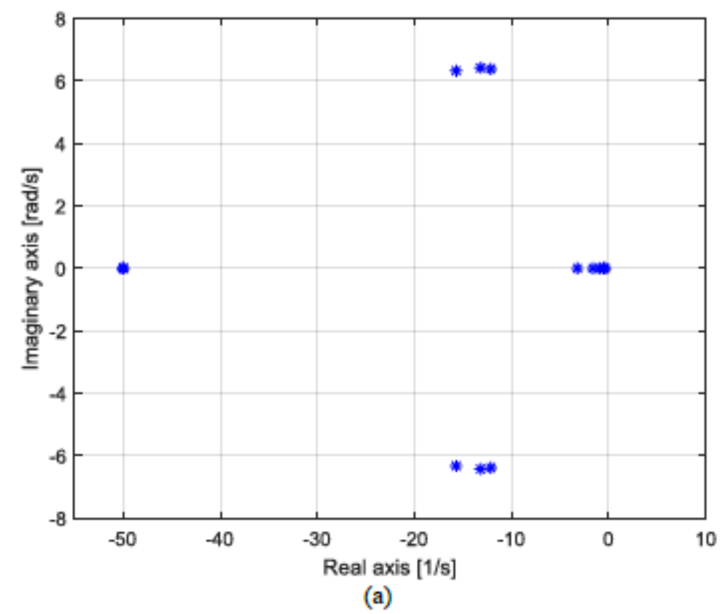
Grid adequacy

Rotor angle stability of synchronous machines

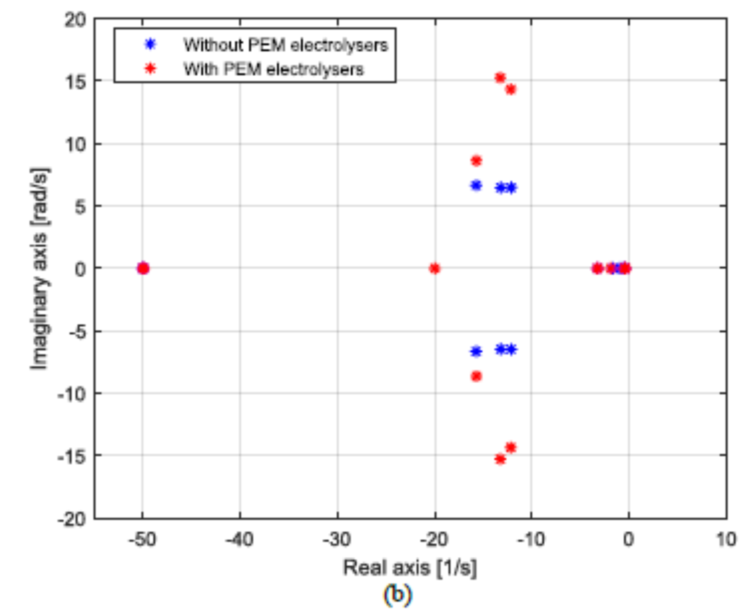
Small signal stability studied on local grid



Without electrolyzer



With electrolyzer

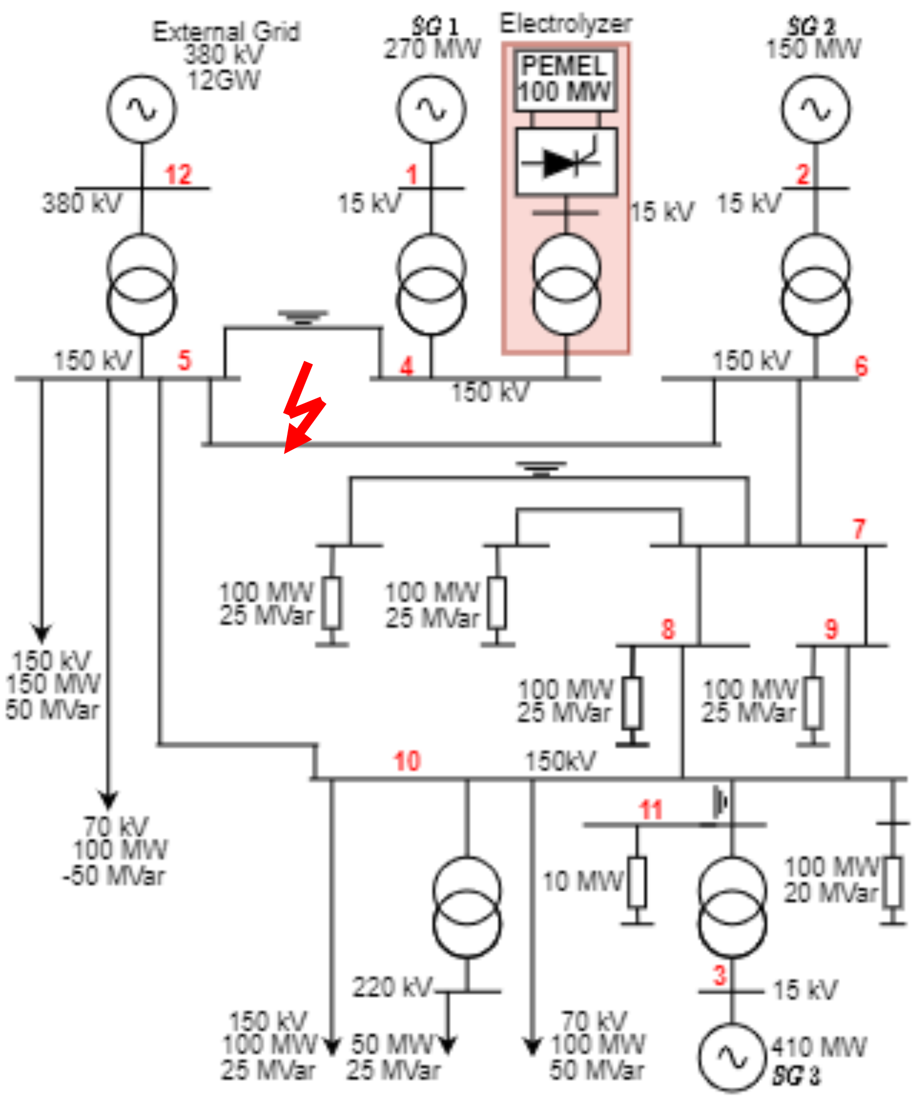


- Without electrolyzer: Obtained dominant modes are located in the left half-complex plane —> **stable**

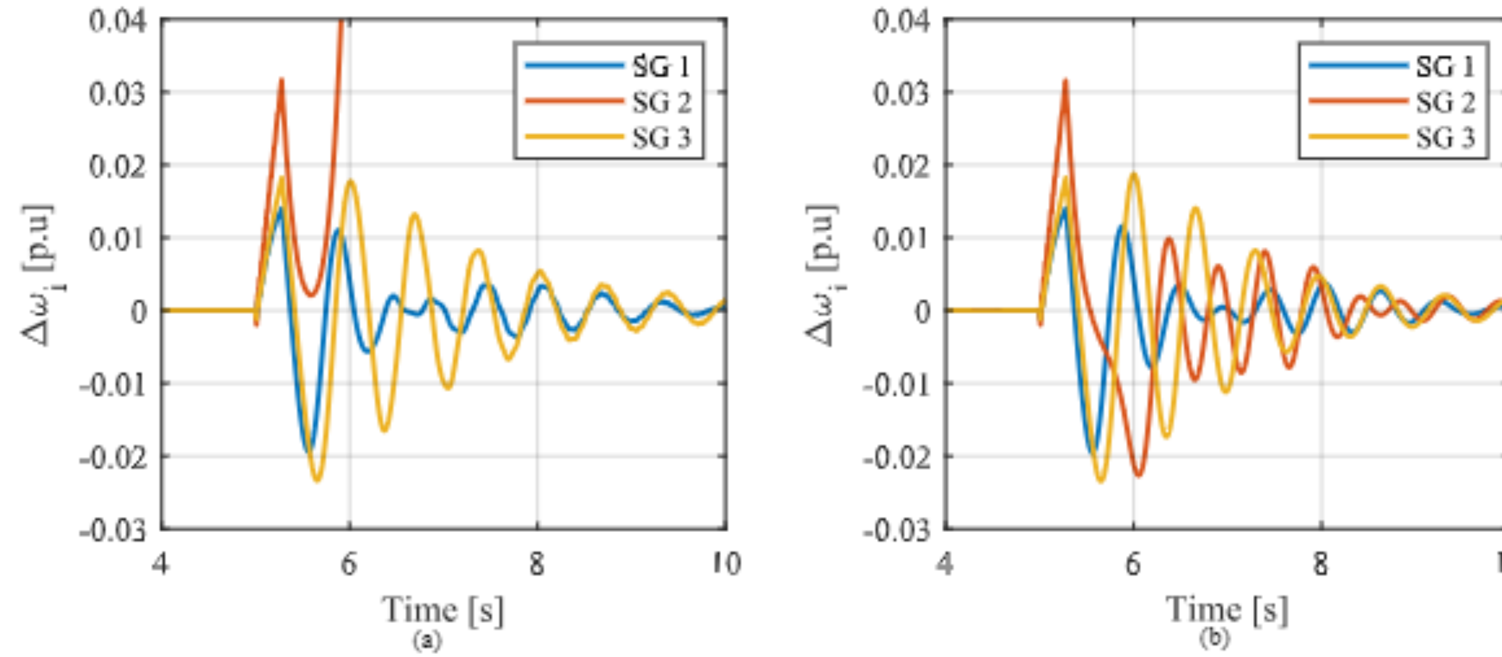
- With electrolyzer: Electrolyzer adds one mode and affects the electromechanical modes —> **stability maintained**

Transient stability studied on local grid

Short-circuit of 270 ms
@ Gouy - 150 kV grid



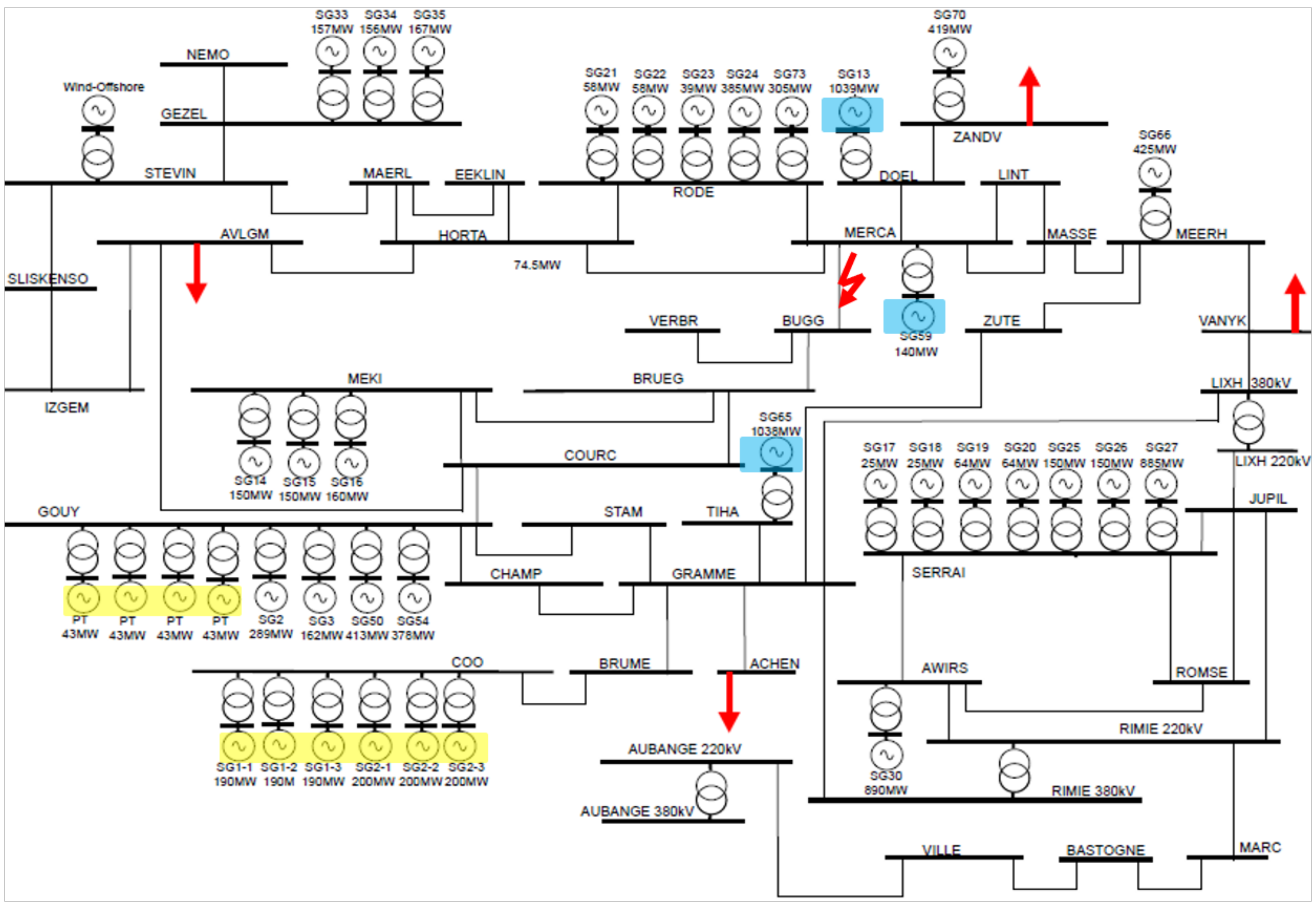
Without electrolyzer **With electrolyzer**



- Without electrolyzer: A generator loses synchronism when the electrolyzer is not connected —> **unstable**

- With electrolyzer: Synchronism is maintained by all generators —> dynamic responses of the relative rotor speed are **stable**

Transient stability studied on whole Belgian grid



Connection with neighbouring grids

Pumped-hydro storage power plant

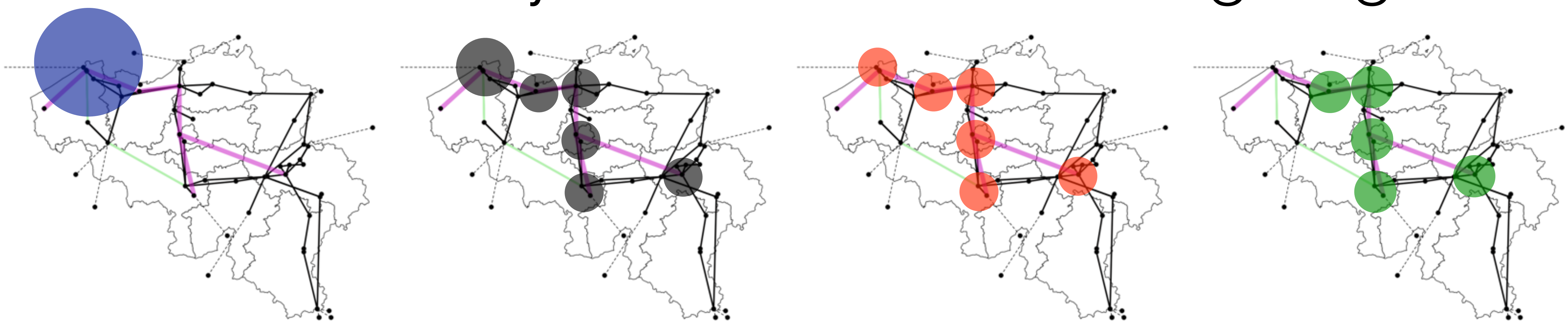
Operating group

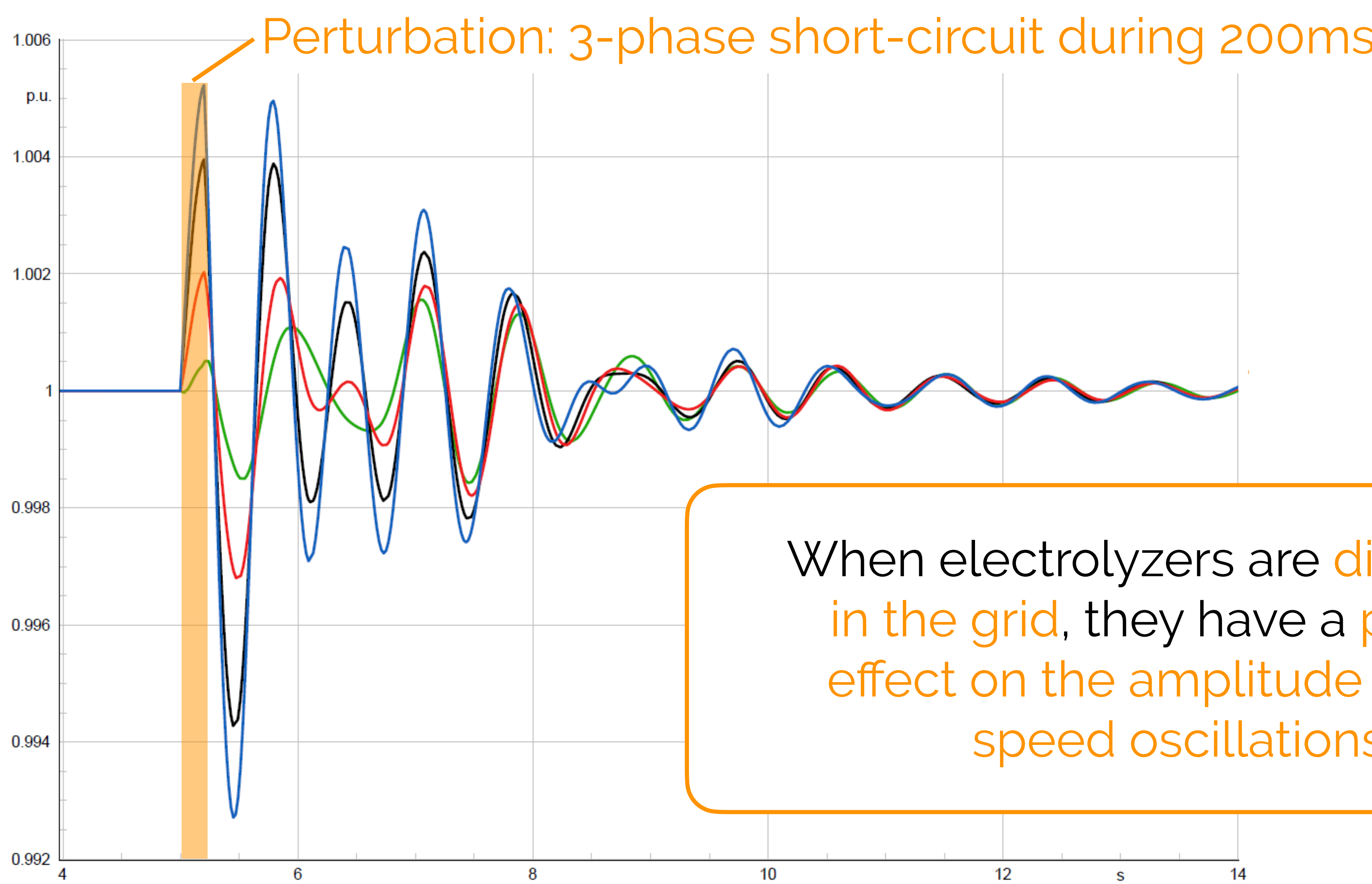
3-phase short-circuit 200ms

Large Disturbance

Short-circuit 200ms in the middle of the line Mercator-Buggenhout

Transient stability studied on whole Belgian grid





When electrolyzers are distributed in the grid, they have a positive effect on the amplitude of rotor speed oscillations.

Key take-away messages

WP3

Flexibility means can enhance significantly the adequacy indicators of a power system.

The system only uses its electrolyzers at 31% of the time producing 3% of the Belgian needs in 2030.

Very high line loadings appear near the new CCGTs located near Liège.

The electrolyzer affects the electromechanical modes of synchronous machines but they do not make the power system unstable.

The electrolyzers enhance the dynamic response of the synchronous generators under large disturbances.

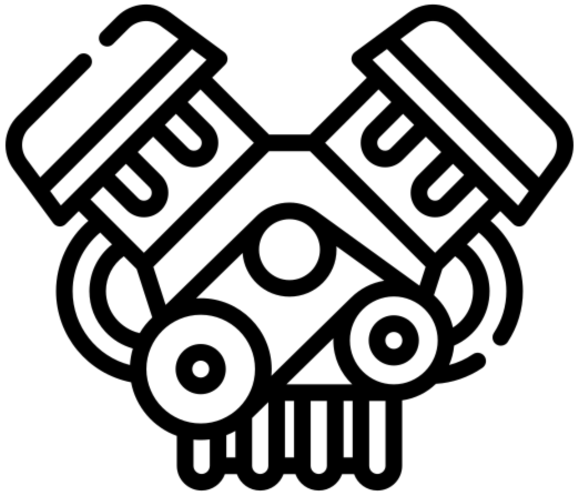
Rotor angle transient stability seems better when electrolyzers are distributed in the grid rather than centralized.

WP4

How can we efficiently use electro-fuels to retrieve the stored energy?

Gas turbines

Internal Combustion Engines



WP4

How can we efficiently use electro-fuels to retrieve the stored energy?

Gas turbines

Internal Combustion Engines

Gas turbines will play a key role in the energy transition in Belgium

Increasing share of **renewable production**

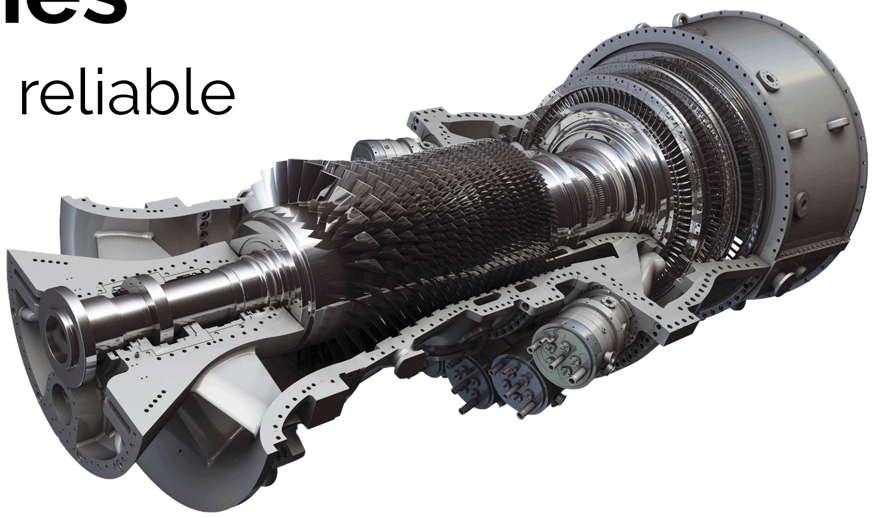
Nuclear phase-out in 2025 (4 GW) and 2035 (2 GW)

Need for peak-units

Need to substitute nuclear generation

Gas turbines

Fast, flexible and reliable

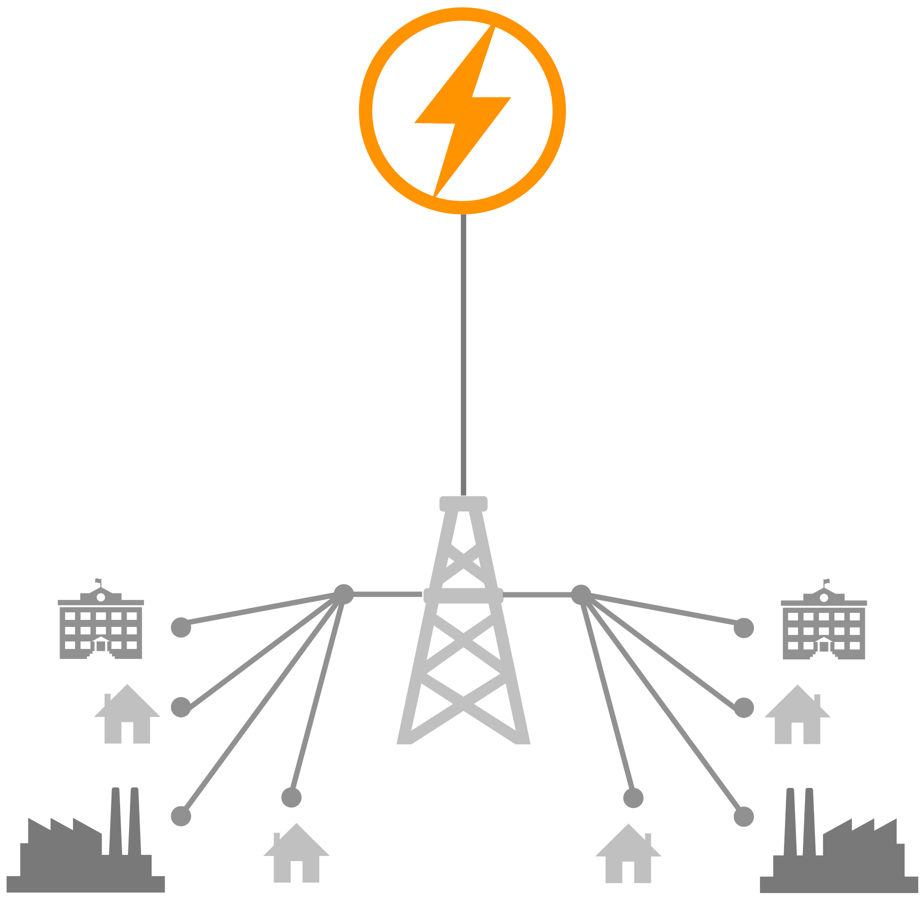


Capacity Remuneration Mechanism CRM:

Combined Cycle Gas Turbines power plants
2 GW existing plants
1.6 GW new plants

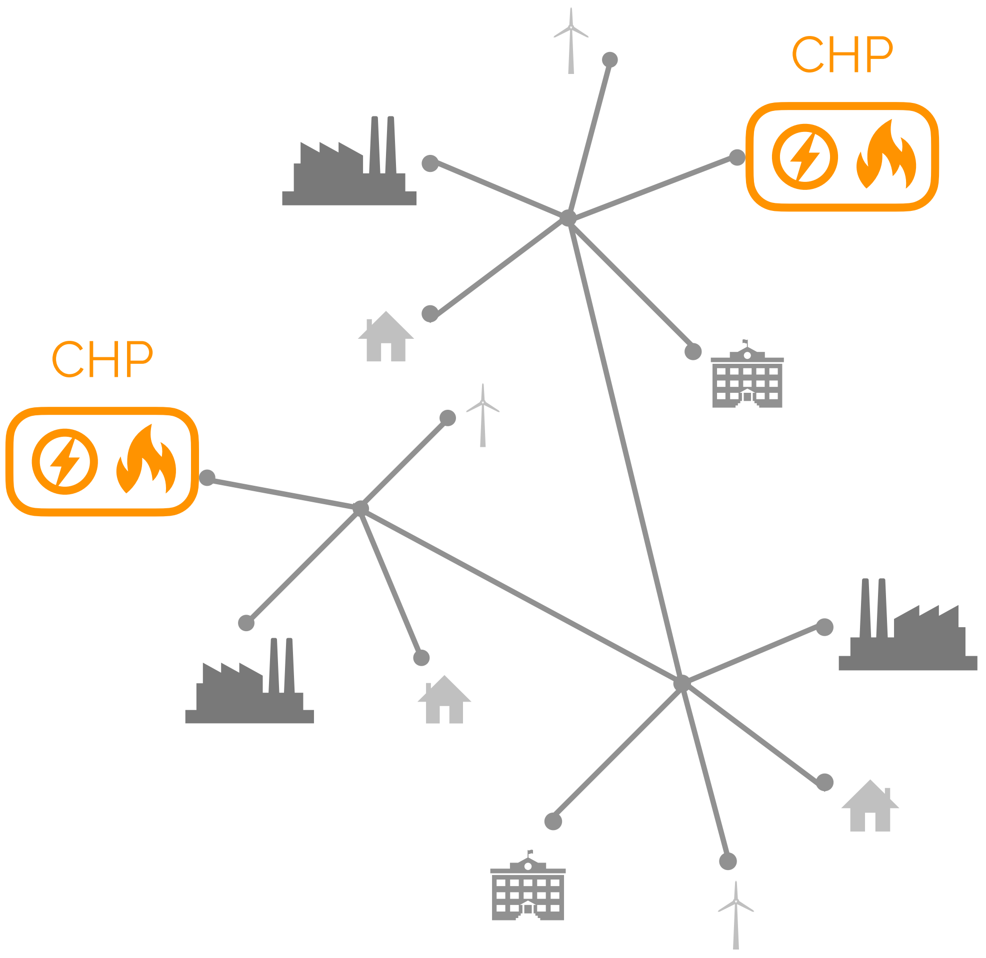
From small to large-scale gas turbines …

Large-scale CCGT plant



Micro Gas Turbines (mGTs)

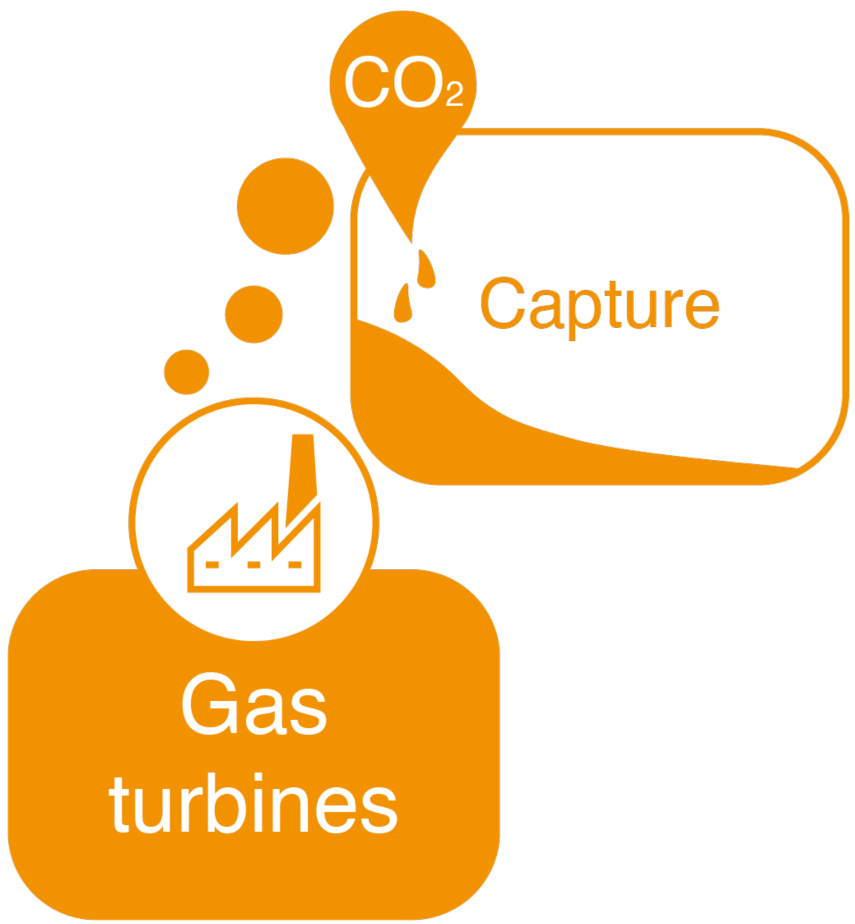
< 500 kWe

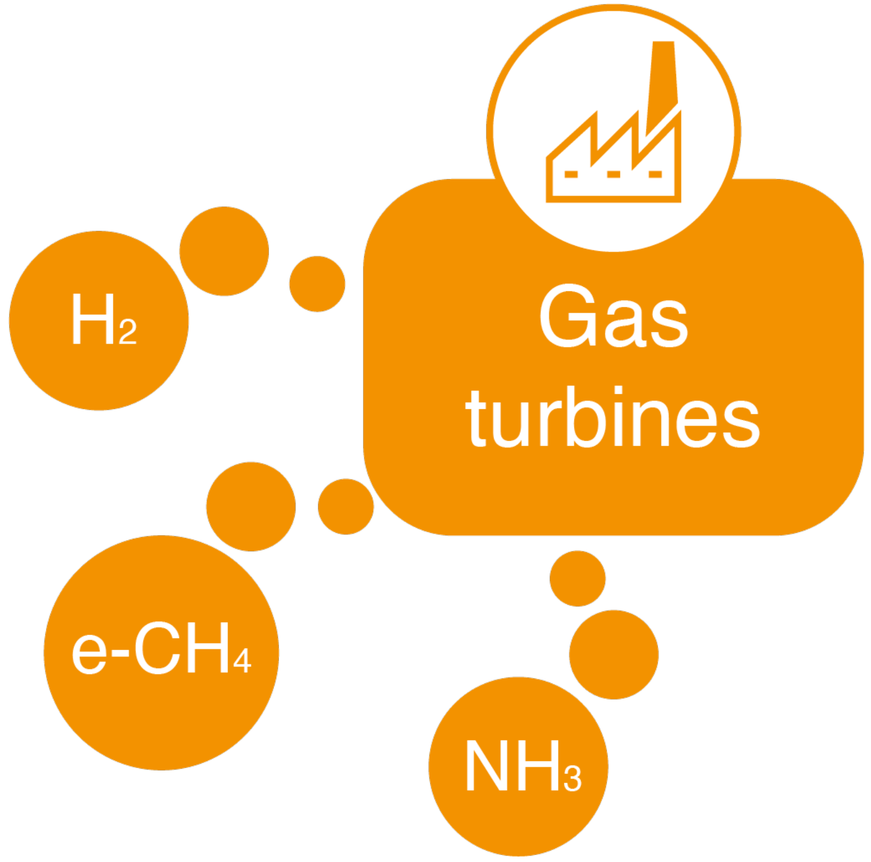


Towards low carbon gas turbines ....

CCUS

E-fuels





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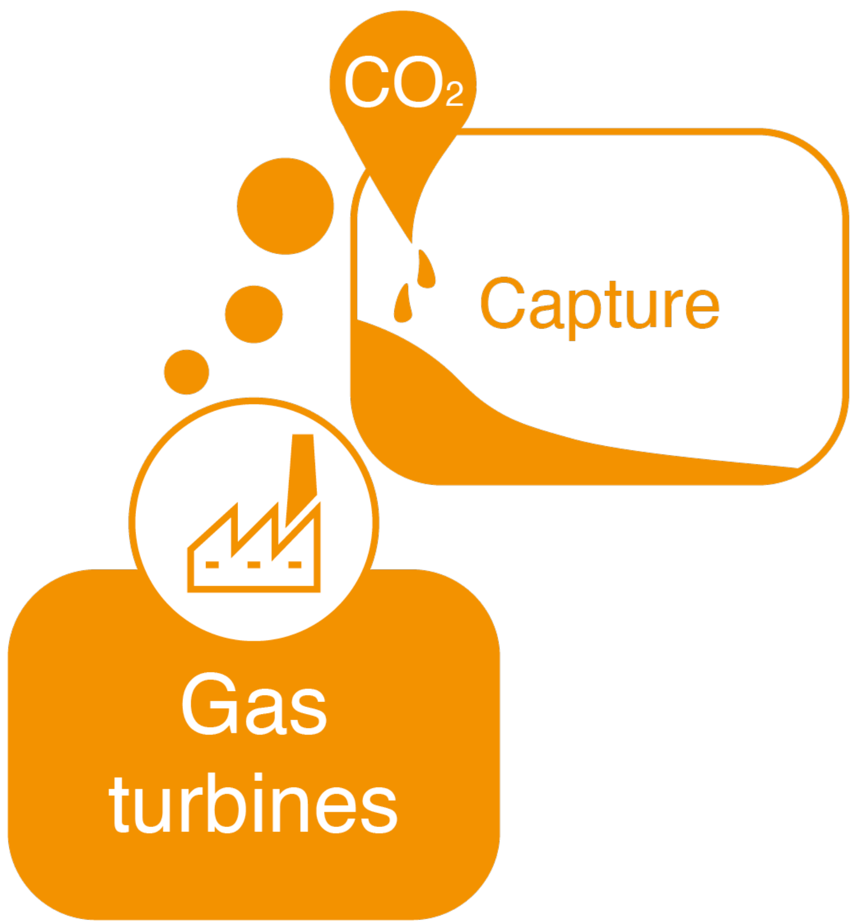
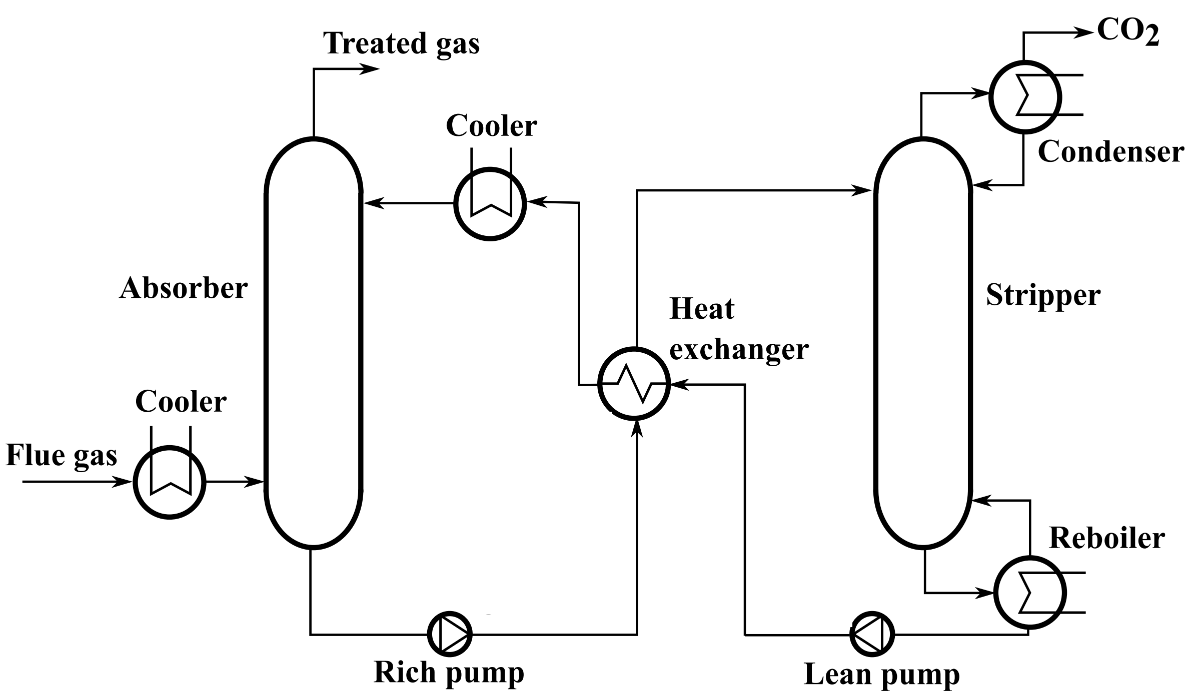


Is it feasible to apply Carbon Capture to Combined Cycle Gas Turbines?

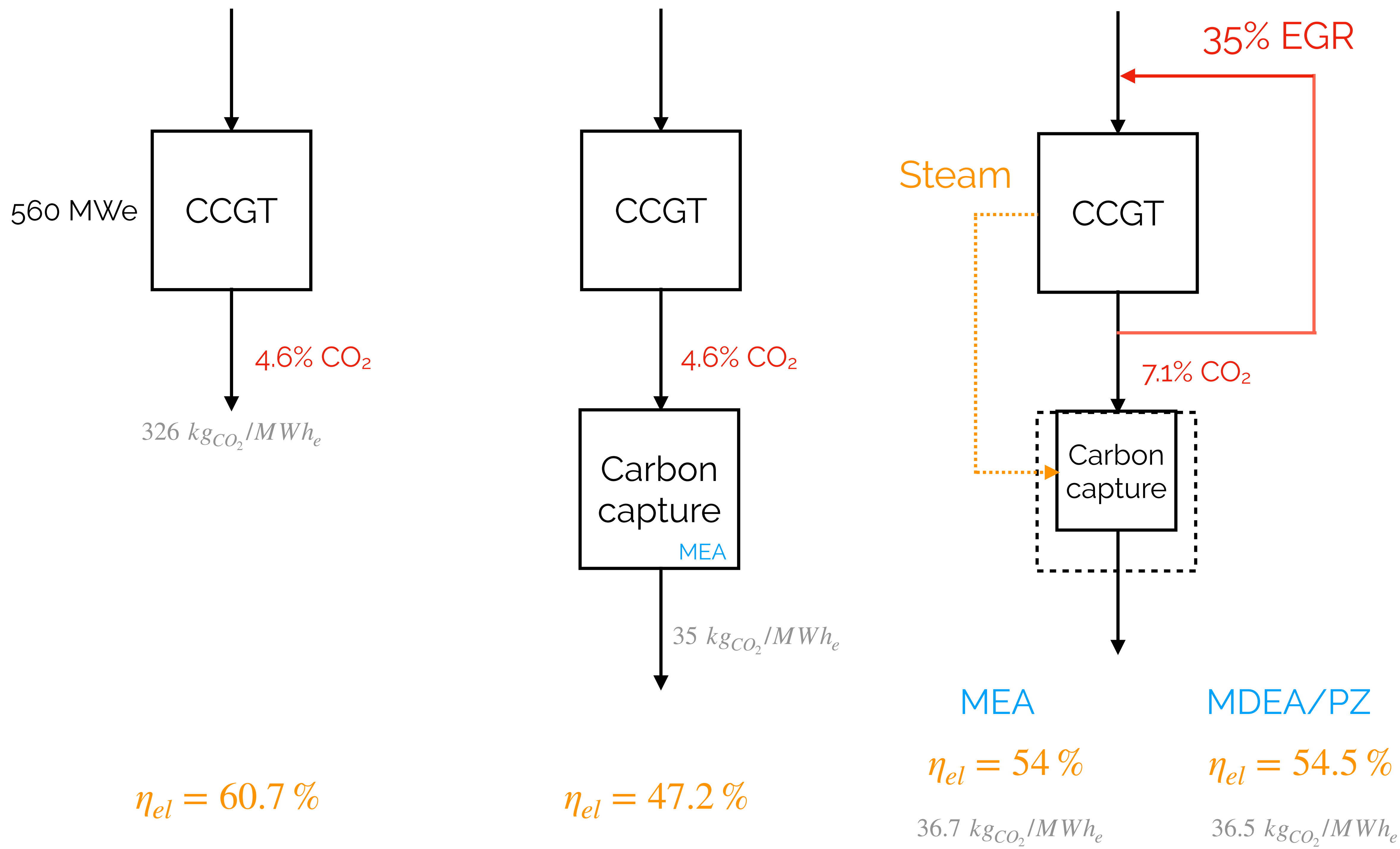
Objective:

- Evaluate the impact of applying carbon capture on CCGT performance
- Reduce the energy penalty induced by the carbon capture (EGR, advanced carbon capture systems, energy integration)

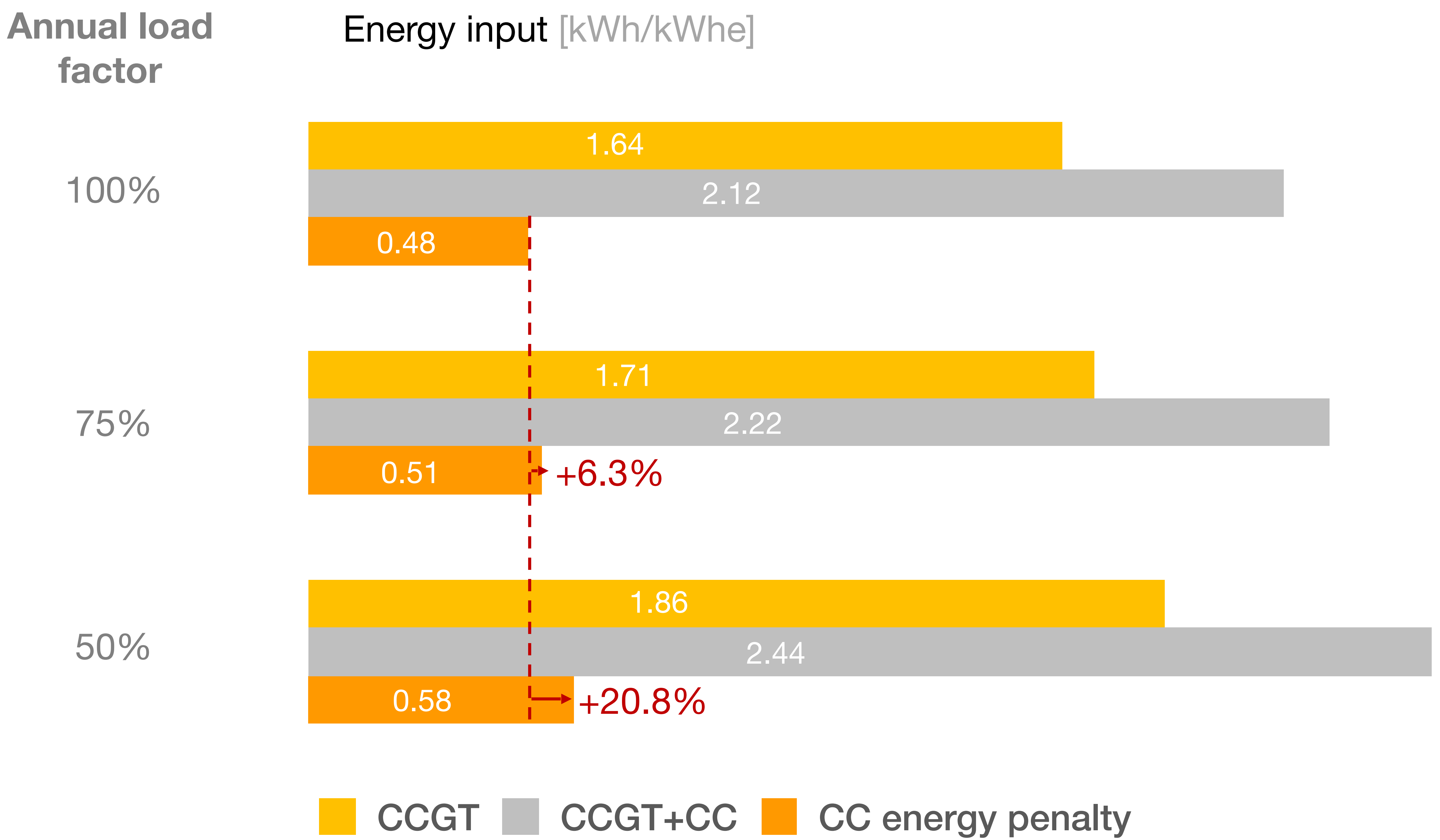
Amine(s)-based post-combustion carbon capture



Applying carbon capture induces a high energy penalty, but this can be reduced through adaptations



Flexibility required from the grid is penalizing from the carbon capture point of view

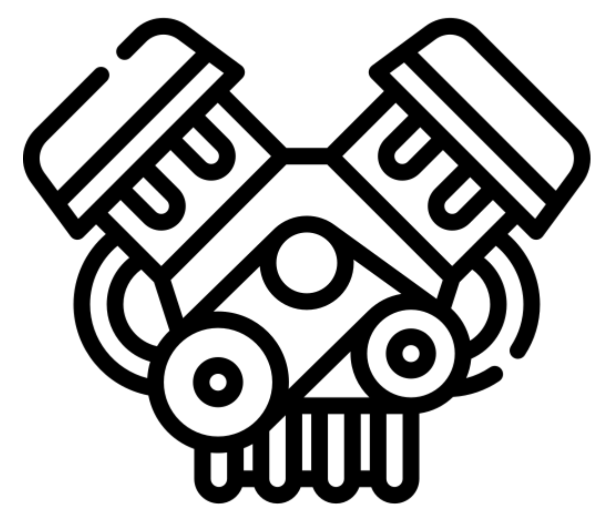


WP4

How can we efficiently use electro-fuels to retrieve the stored energy?

Gas turbines

Internal Combustion Engines



Internal combustion engines:
Keep the engine, change the fuel!

Cheap and **sustainable** (abundant materials and recyclable)

Flex-fuel

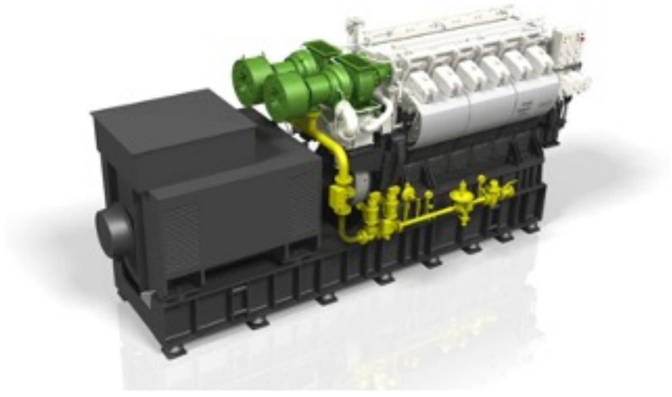
Zero-impact emissions

Efficiency still improving

Two main applications

Work - Mobility

Electricity - Power generation



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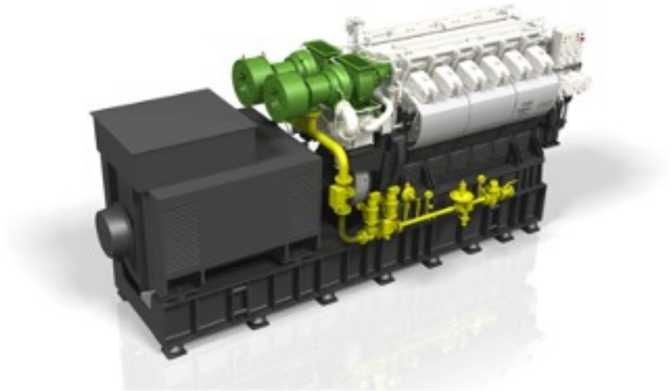
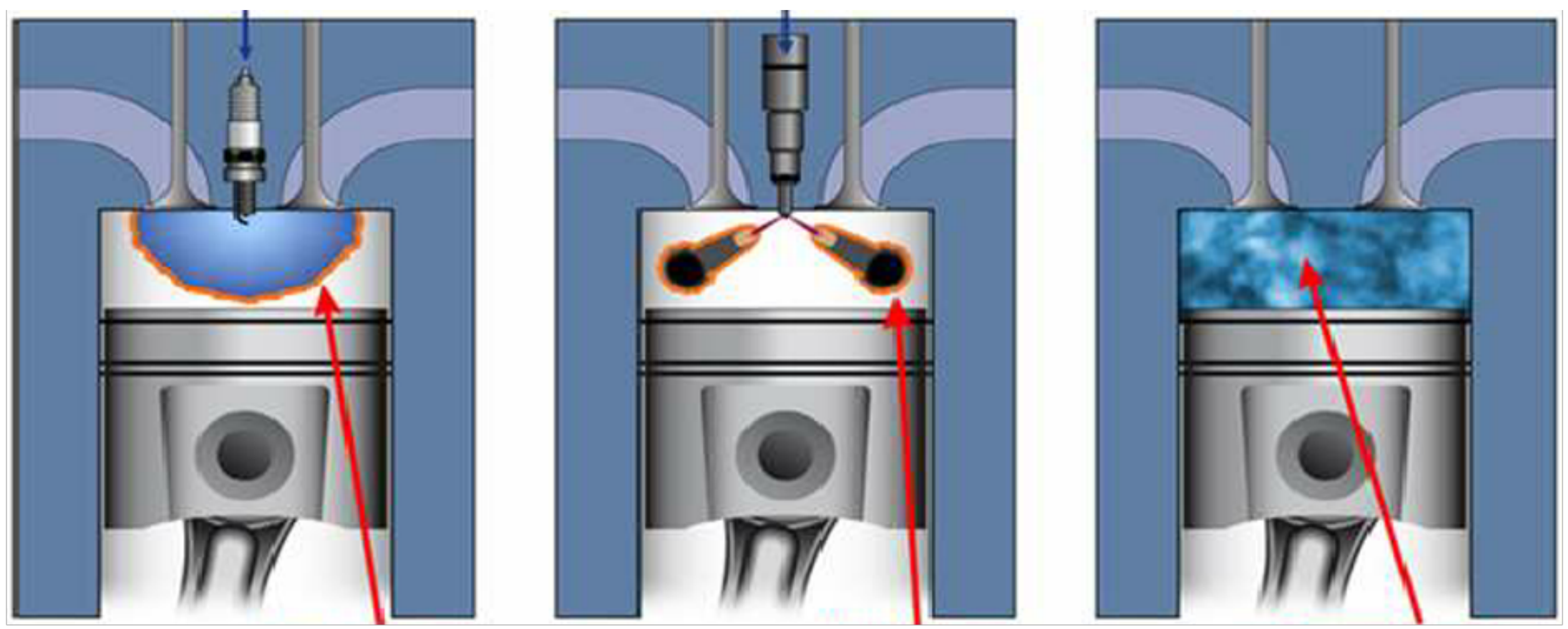


HCCI engine is a proper candidate to be deployed as CHP unit

Increase power density in HCCI engines

Spark ignition | Compression ignition | HCCI

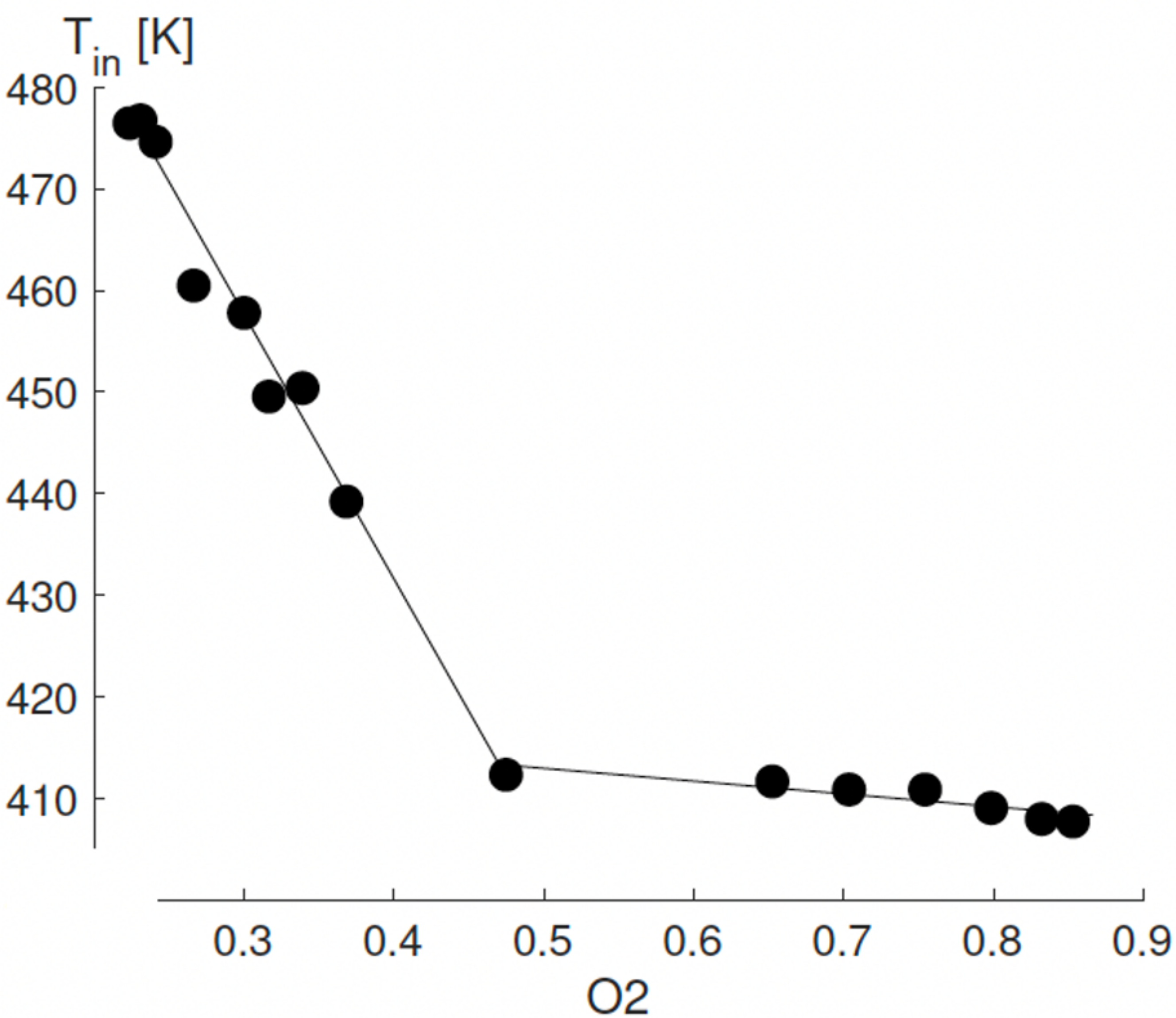


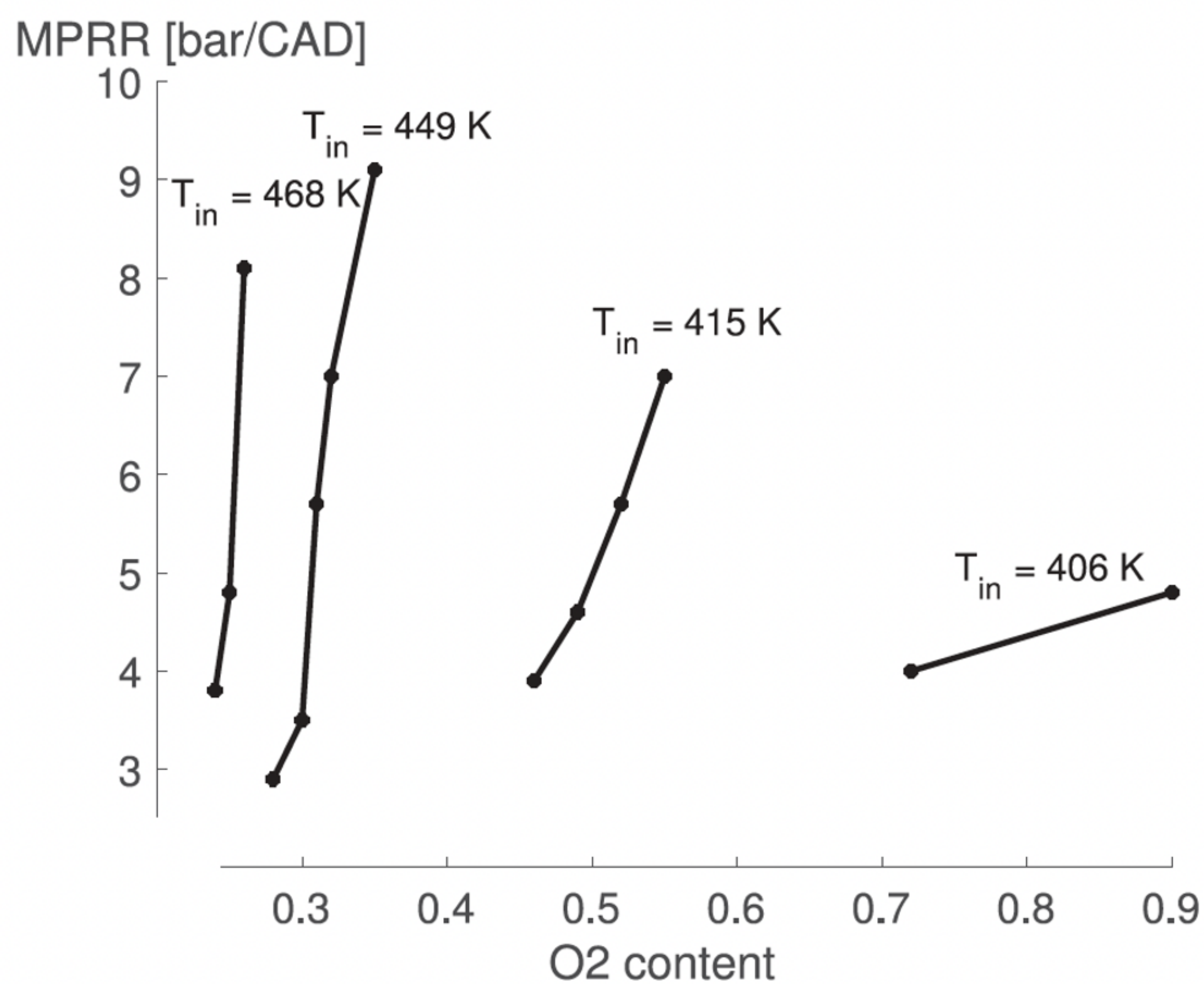
Hot flame region: NOx | Hot flame region: NOx and PM | LTC: low emissions, high efficiency

Combustion enhancement techniques: blending e-fuels, mixture and thermal stratification (WDI,glowplug), oxy-fuel combustion

Adding O2 allows for a decrease of intake temperature of around 80 degrees

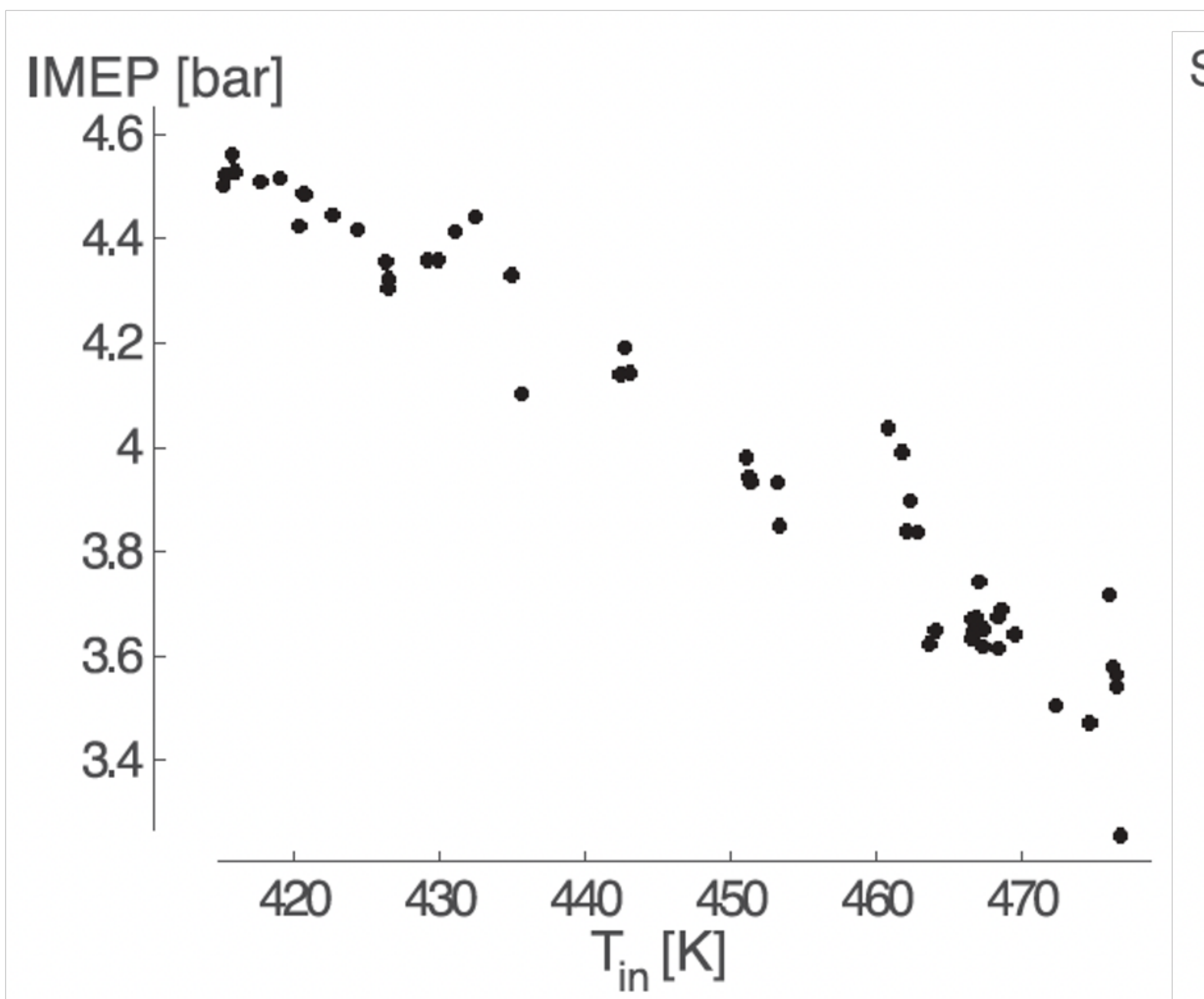
While keeping the value of MPRR below 9 bar/CAD

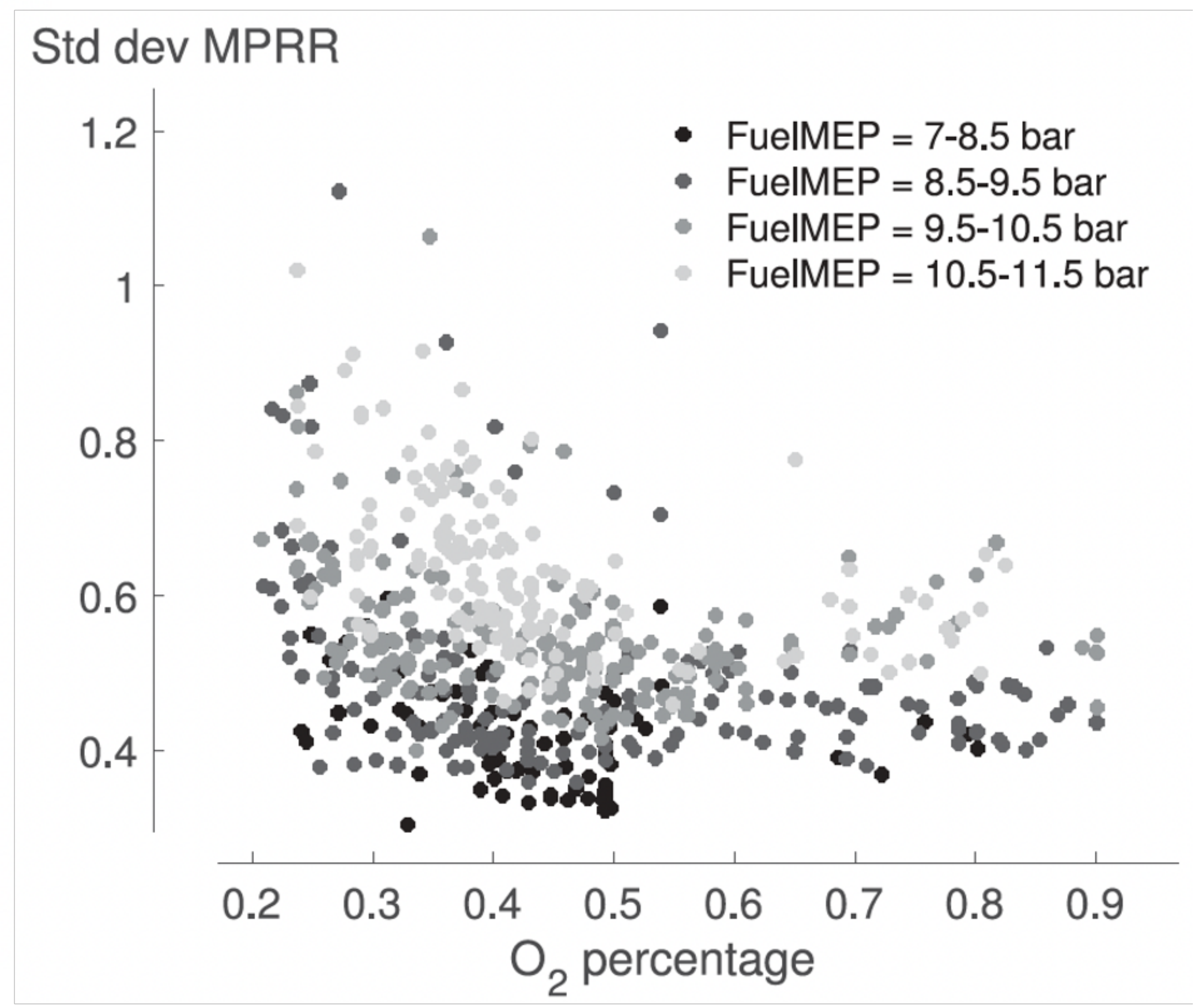




The decrease of intake temperature allows for an increase of IMEP and combustion stability

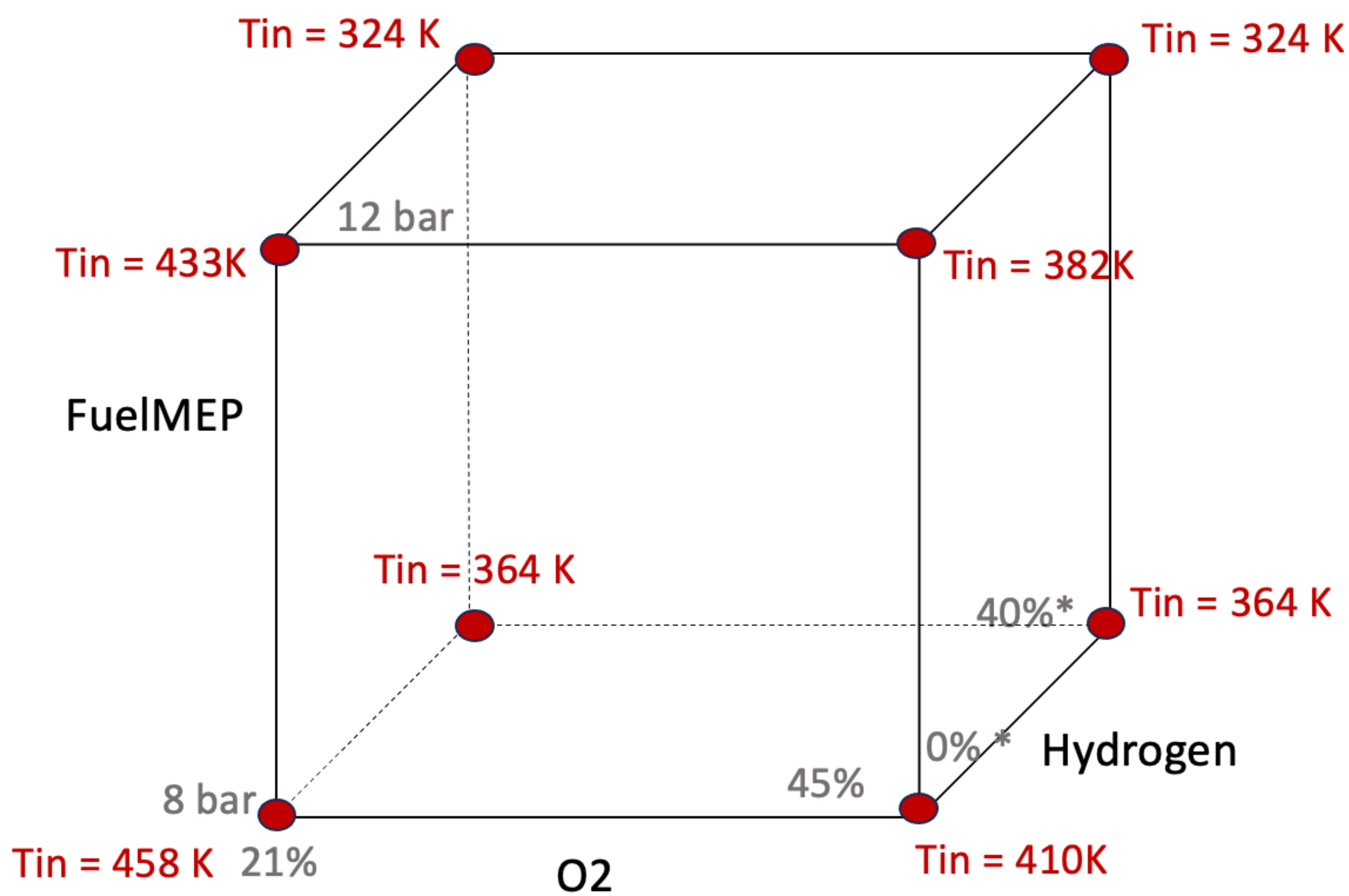
Standard deviation of MPRR has been chosen as measurement of combustion stability



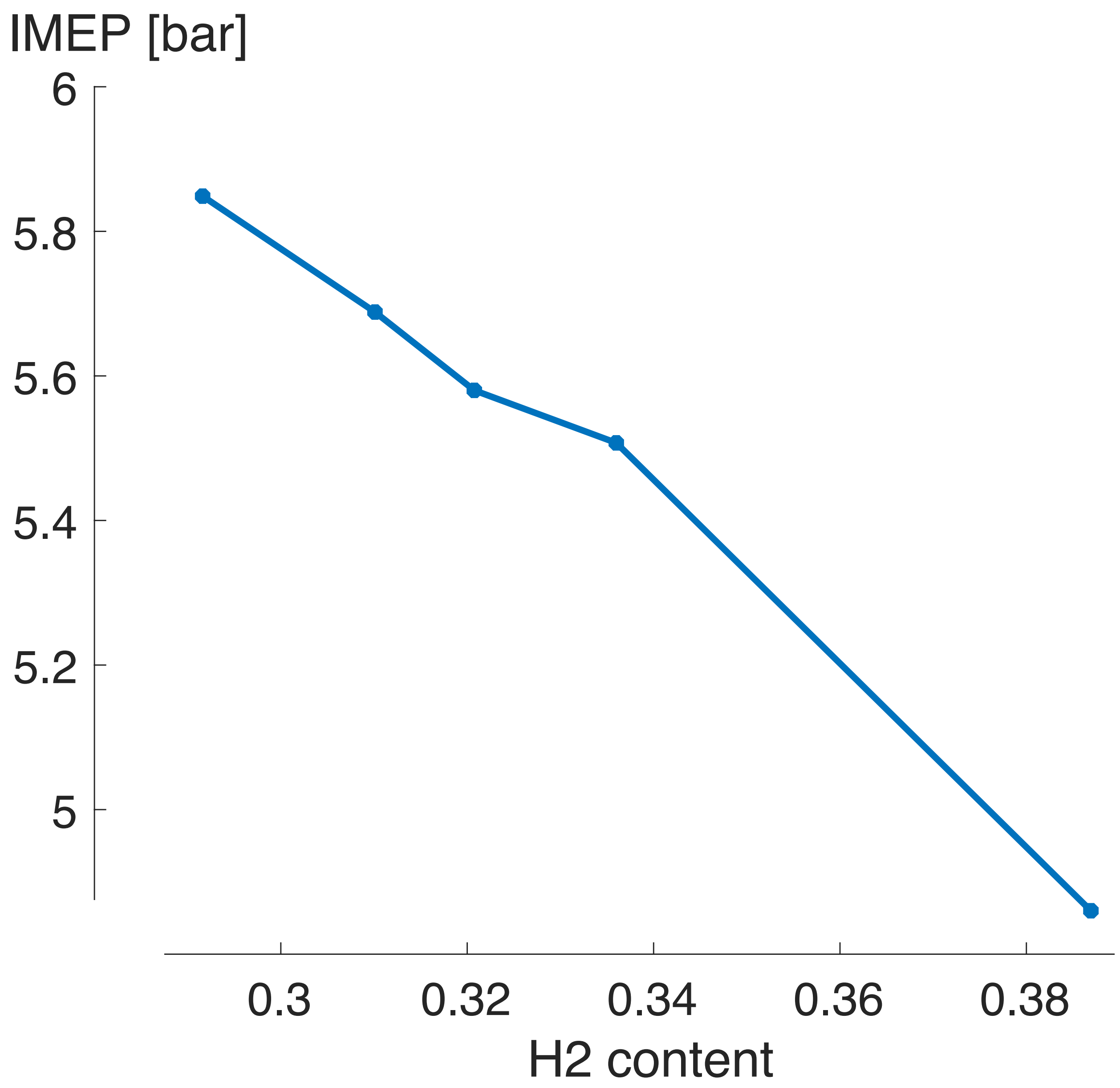


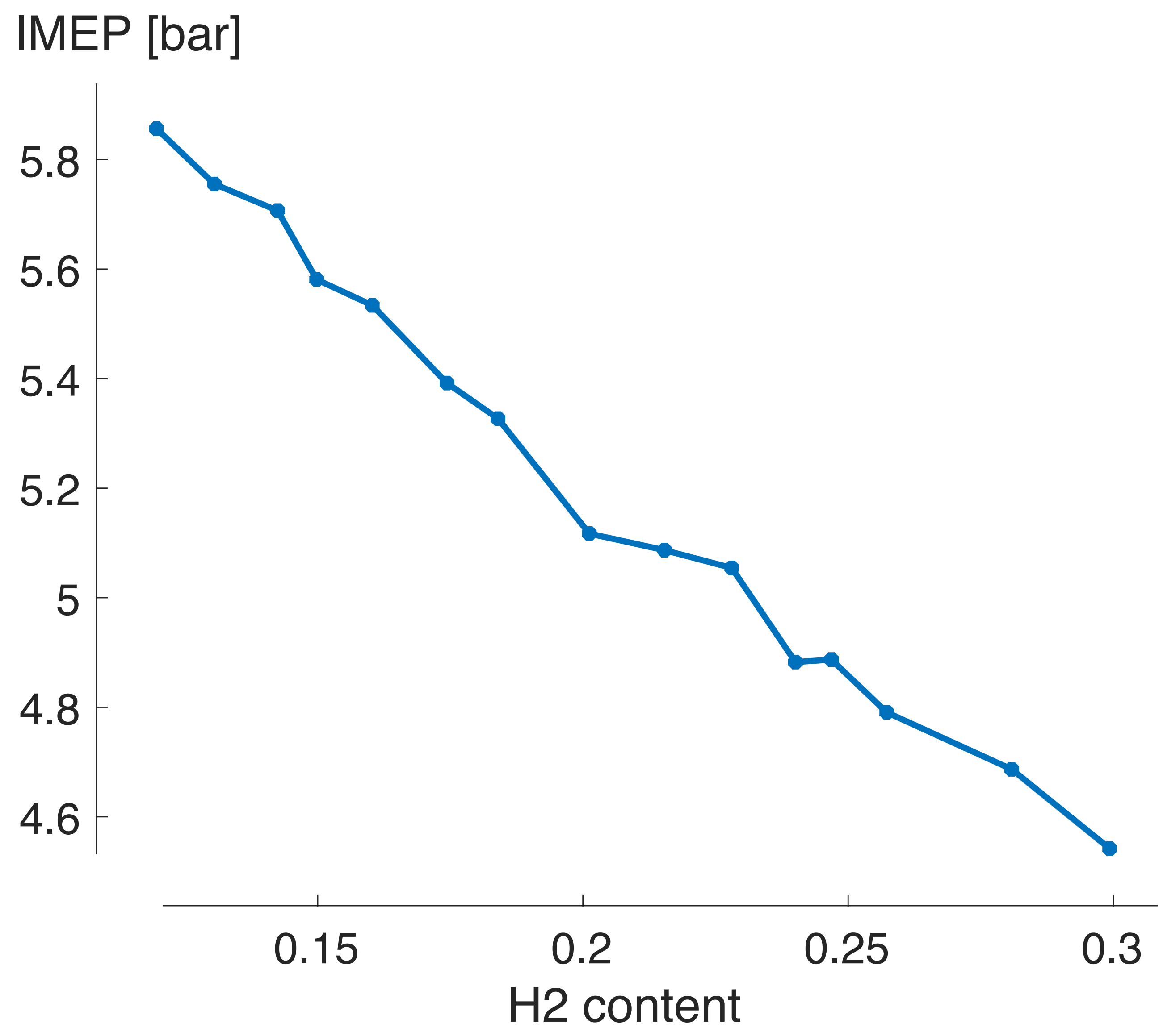
At high H2 content adding oxygen does not make any difference

Blending hydrogen and methane is interesting in the context of a fuel flexible CHP unit



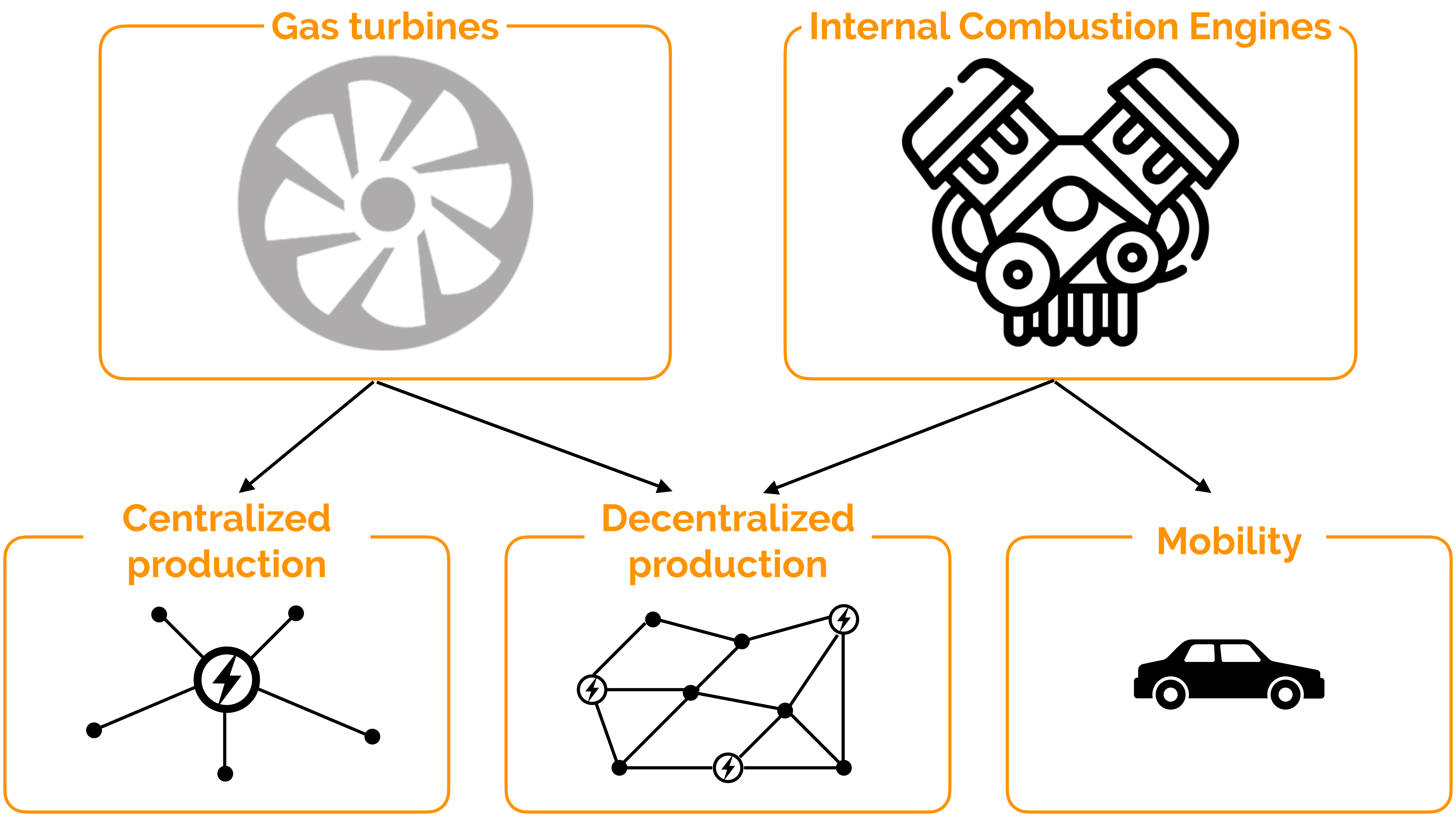
Adding a lot of hydrogen at low temperature has no higher benefits than adding less hydrogen at higher intake temperature





WP4

How can we efficiently use electro-fuels to retrieve the stored energy?



Key take-away messages

WP4

Technological advances for each application

No technical limitation has been identified for each low-carbon application

BEST solution depends on the specific case, application, circumstances, economics, policies, …

Progress of the BEST project

Joint Workshop of the BEST and PROCURA projects
March 19, 2024
Brussels