Harnessing the Potential of Power-to-Gas Technologies

Insights from a preliminary analysis focused on Belgium

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Work done in collaboration with FLUXYS

Introduction

- Belgian nuclear power plants to be decommissioned by end of 2025. Low-carbon alternatives must be selected, make economic sense and promote energy security.
- Electrification often presented as only means of achieving deep decarbonisation of energy system, including transport and heating.
- Power-to-gas may play role by offering seasonal storage and supplying some of energy demand for transport and heating.

Problem Statement and Formulation

Which generation, conversion and storage technologies should be deployed, and in what quantities, to supply load at minimum cost whilst satisfying technical constraints and pre-specified policy targets?

Input

- Technology costs and performance
- Renewable resource quality and availability
- Future electricity, gas and hydrogen demands
- Regional wholesale electricity and gas prices
- Hydrogen industry and transport prices
- Policy targets (CO_2 and energy import quotas)

Formulation

Central Planner
(system cost minimization)

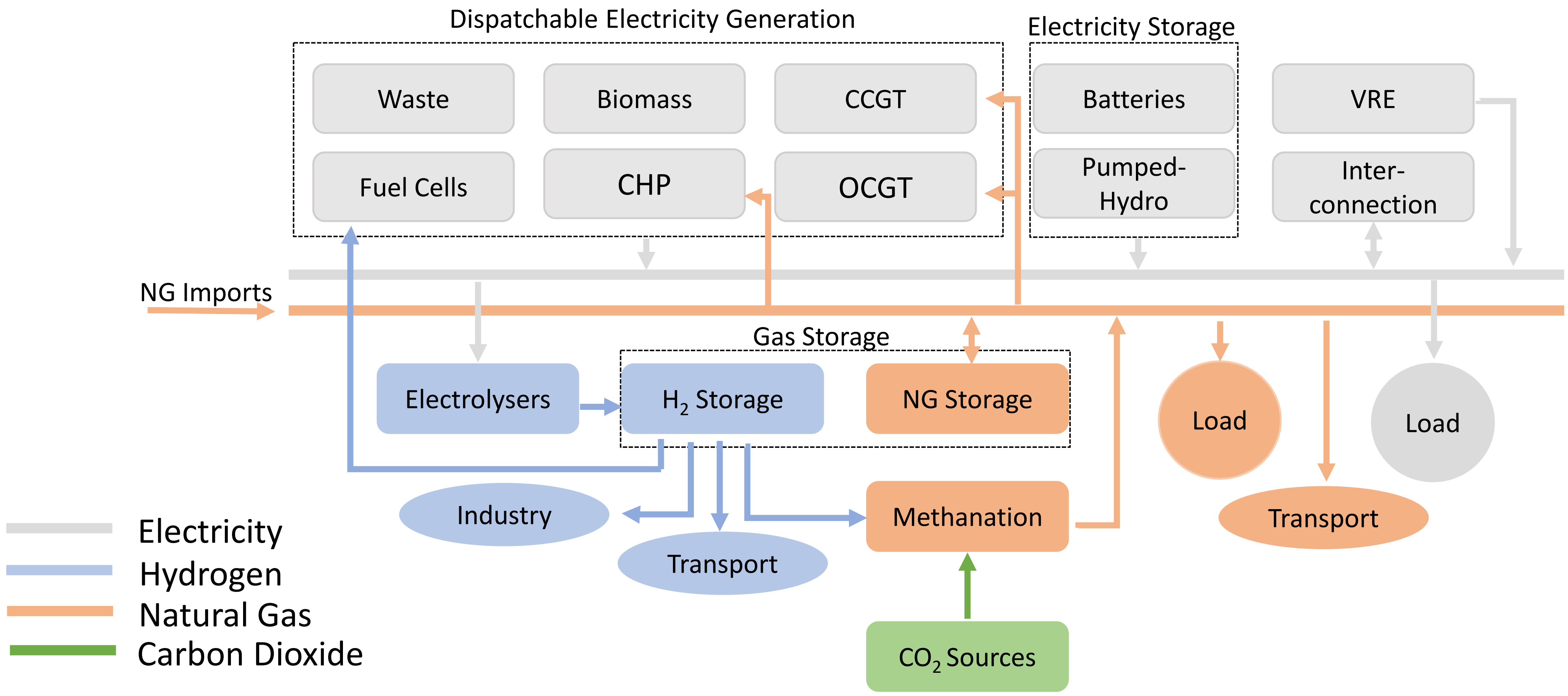
Output

- Technology selection
- Technology capacities
- System and energy costs
- Energy flows
- CO_2 emissions

Model Assumptions

- Joint electricity and gas system planning, plants are aggregated by technology.
- No congestion in networks, electricity, gas and hydrogen demands are spatially-aggregated.
- Multi-year investment horizon with hourly resolution, “overnight” technology deployment.
- Perfect foresight and perfect competition.

System Configuration



First Scenario

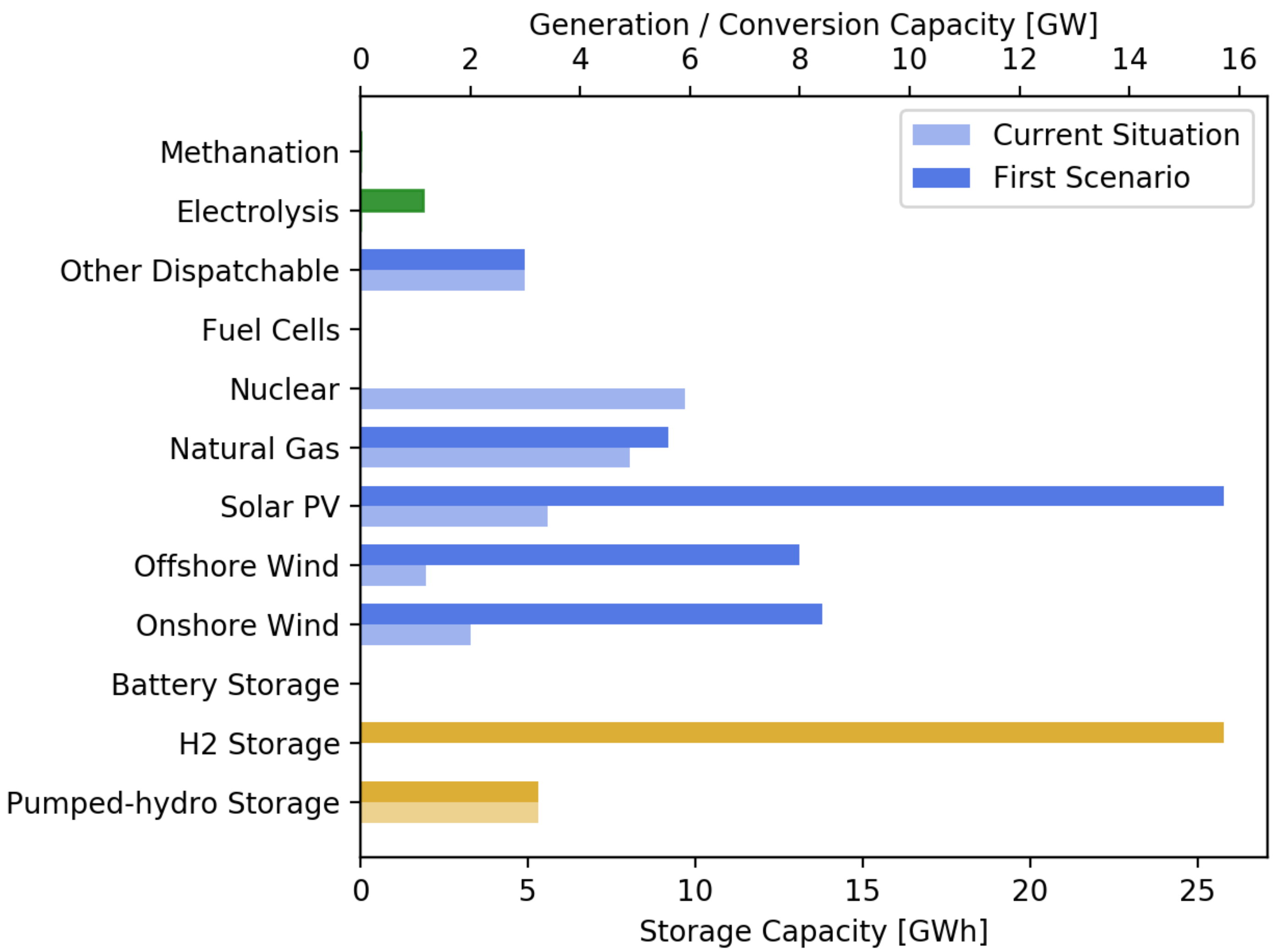
Constant Carbon Dioxide Emissions and Nuclear Phase-Out

1. 38 Mt annual carbon dioxide emissions budget for electricity and gas systems, defined as difference between CO_2 emitted and absorbed, excluding CO_2 emitted by cars running on CNG.
2. Belgian RES potential of solar PV is 40 GW.
3. CAPEX of 1400 €/kW$_e$ (electrolysers), 600 €/kW$_{H2}$ (methanation), 1000 €/kW$_e$ (fuel cells).
4. RES potential of onshore and offshore wind is 8.4 GW and 8 GW, respectively.
5. Peak electrical load of 13.5 GW and annual electricity consumption of 86.4 TWh.
6. Peak gas load of 40.1 GW and annual (non-power) gas consumption of 135.7 TWh.
7. Hydrogen/CNG transportation market of 250k/500k cars (approx. 2.7/5.4 TWh) and industry hydrogen demand of 1 GWh/h.
8. Import capacity of 6.5 GW, no more than 10% of annual electricity consumption can be imported.
9. Mean electricity and natural gas import costs of 36.9 €/MWh and 11.8 €/MWh, respectively.
10. Capacities of 1.3 GW/5.3 GWh of pumped-hydro storage and (in/out) 3.5/7 GW/8 TWh of natural gas storage.
11. Carbon tax of 80 €/t of CO_2 for emissions from power generation and none for other emissions.
12. Zero initial capacity for RES and gas-fired power plants. 0.3 GW, 0.9 GW and 1.8 GW of waste, biomass and combined heat and power plants, respectively.
13. CAPEX of 1100 €/kW and 2500 €/kW (on/offshore wind), 1000 €/kW (solar PV), 200 €/kWh (batteries), 5 €/kWh (hydrogen storage).
14. Value of lost load of 3000 €/MWh and 500 €/MWh for electricity and gas demands, respectively.
15. Price of hydrogen for industry and transportation of 0.15 €/kWh and 0.3 €/kWh, and CNG price of 0.2 €/kWh.

Installed Technologies, Capacities[1] and Costs

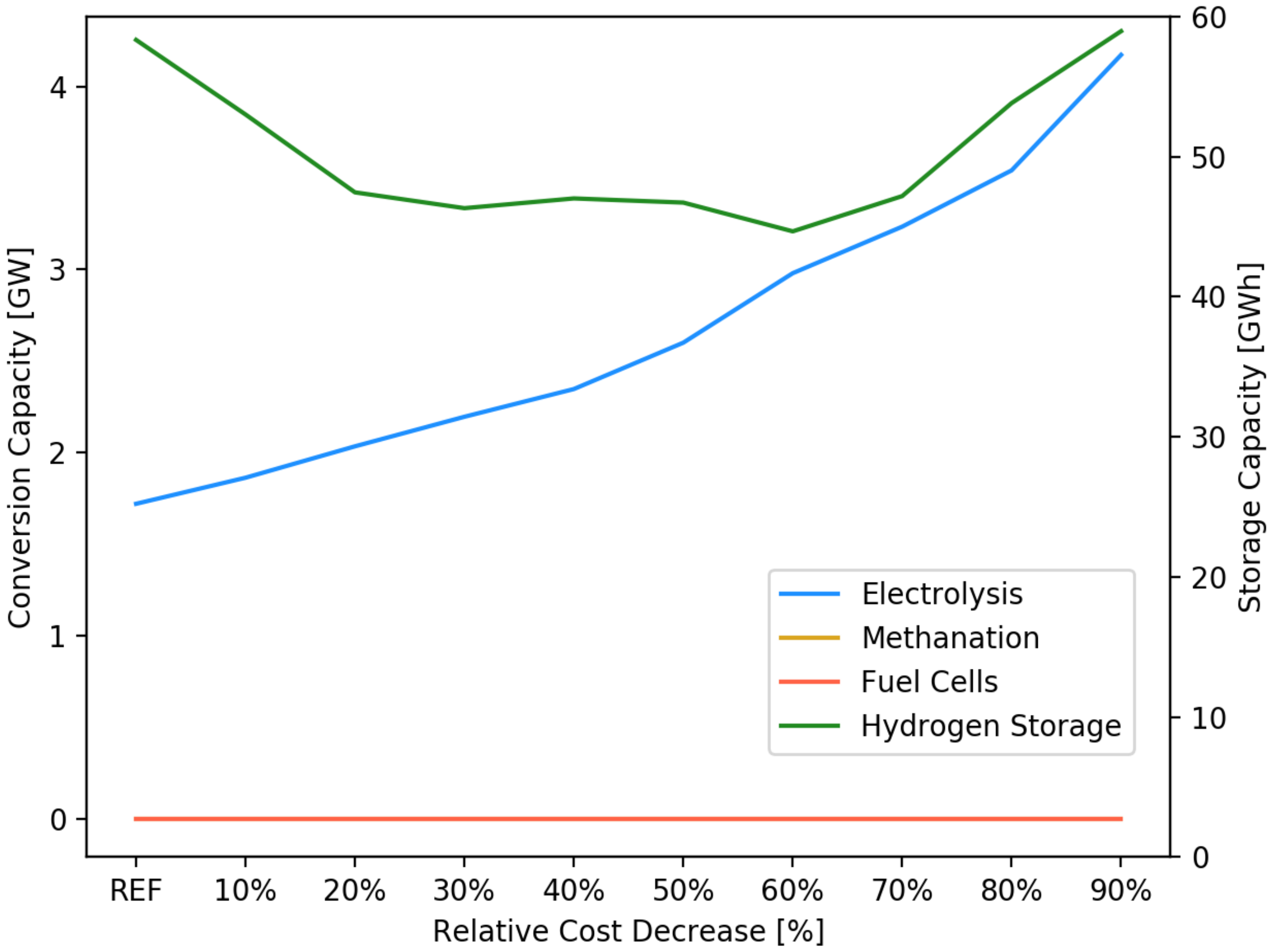
System Cost:
8.4 B€

Energy Cost:
36.5 €/MWh



1: Ratio between energy and power capacity of batteries is equal to 2.

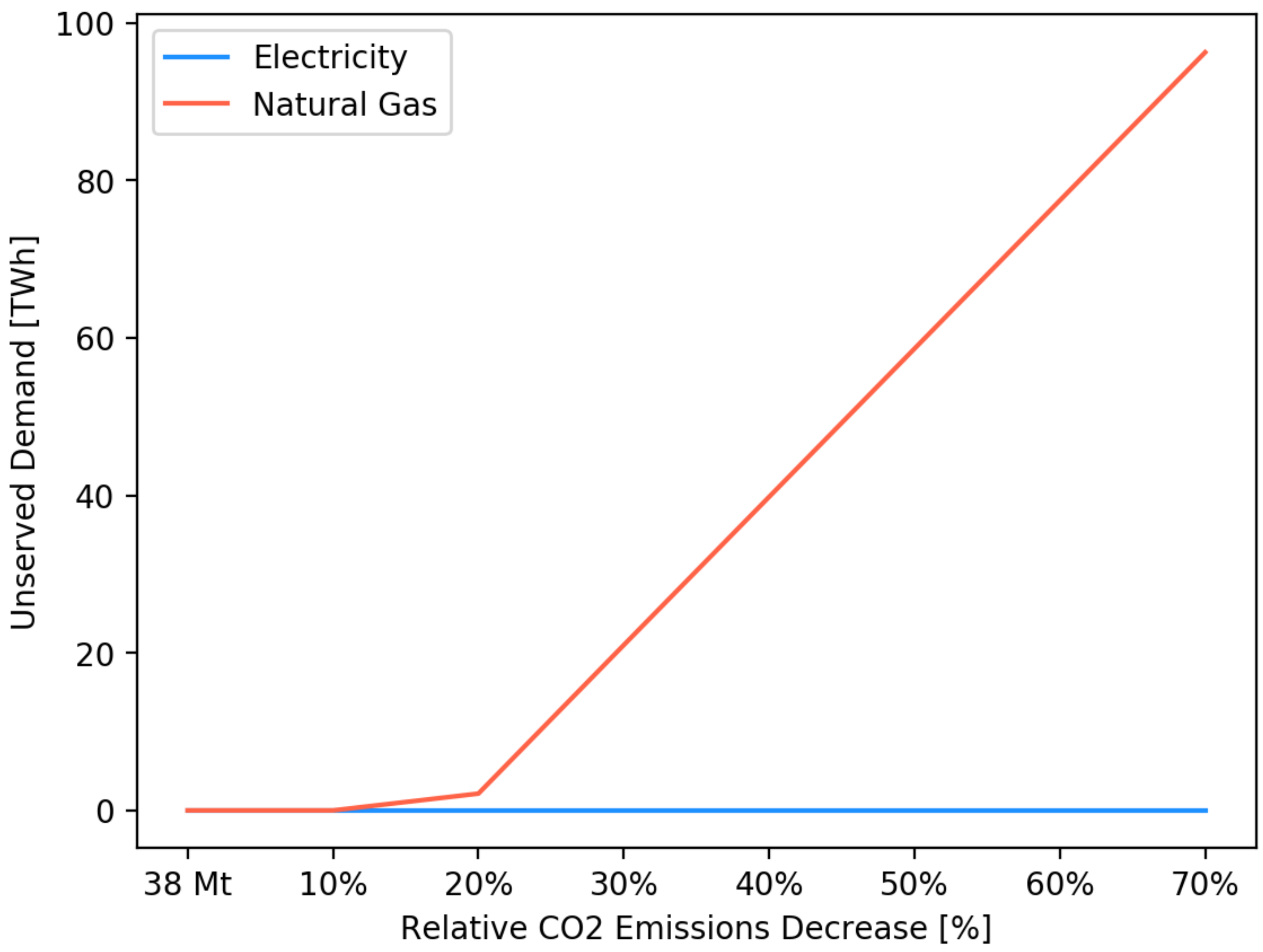
Sensitivity Analysis on Power-to-Gas and Fuel Cell Costs



Energy not Served vs Carbon Budget

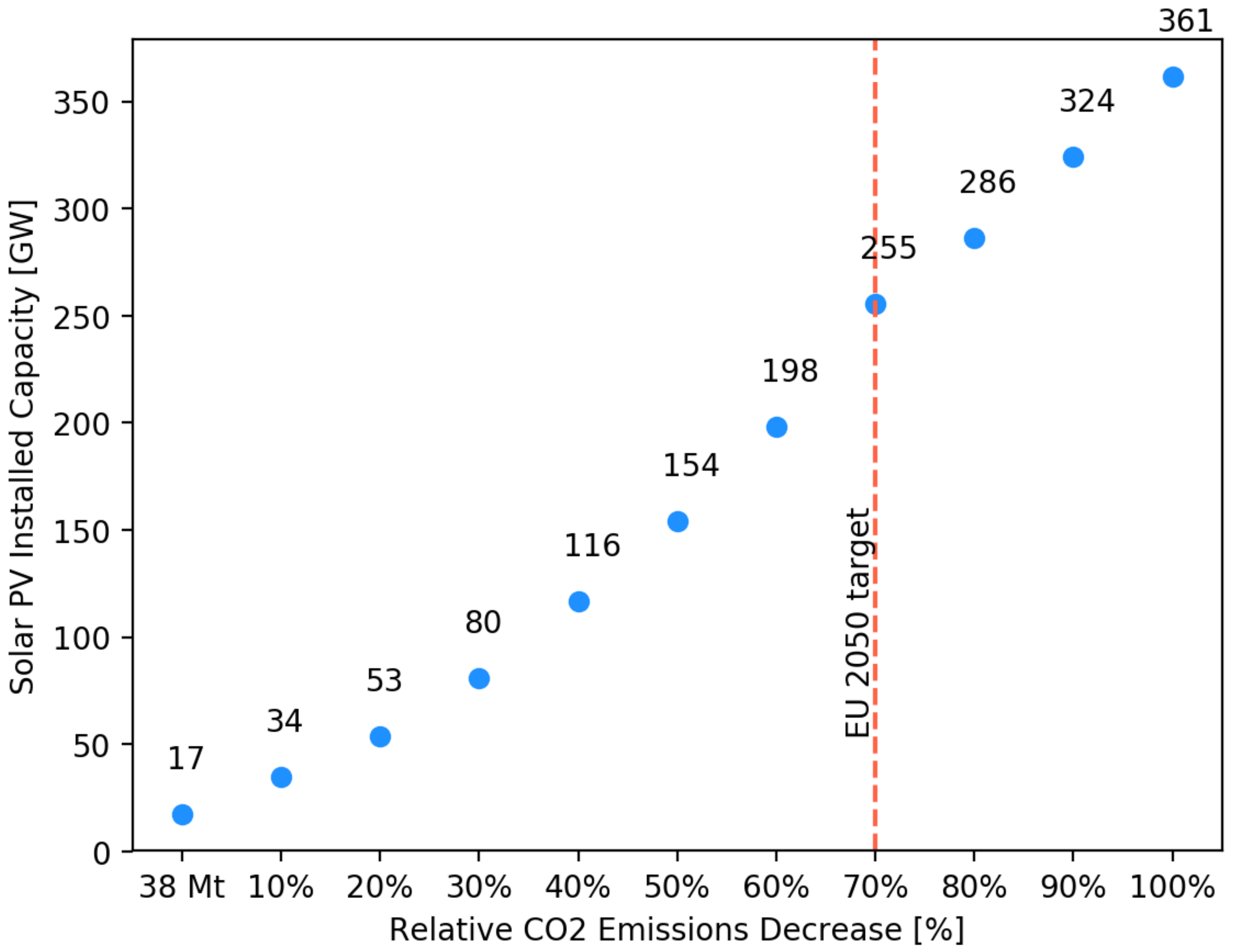
Electricity VoLL[2]:
3000 €/MWh

Gas VoLL:
500 €/MWh



2: Value of Lost Load (VoLL).

Solar PV Capacities for Zero Shedding vs Carbon Budget[3]

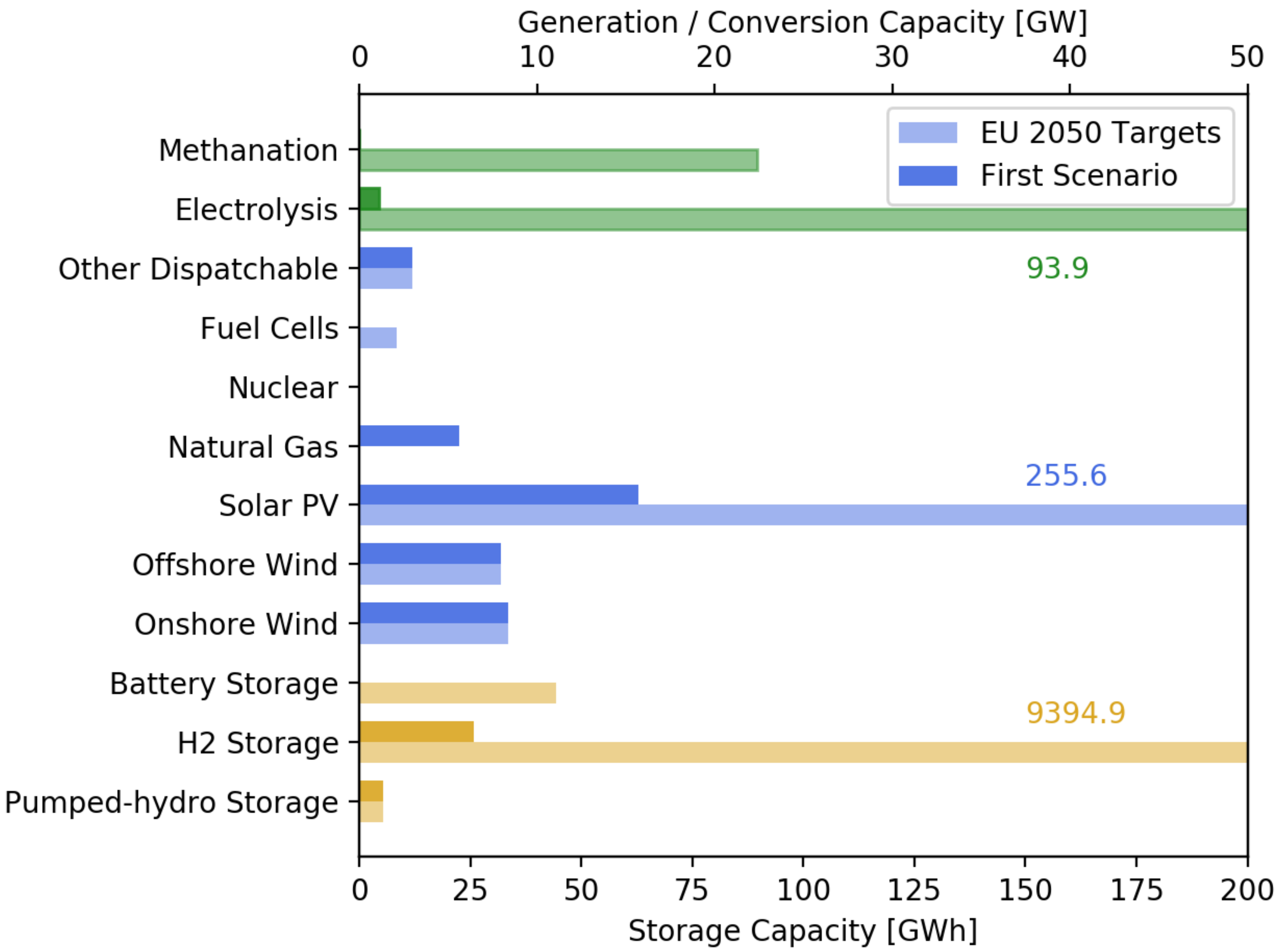


3: Load shedding not allowed, imposed as hard constraint.

System Design for European 2050 Targets

System Cost[4]:
43.1 B€

Energy Cost:
186 €/MWh



4: Power-to-gas and fuel cell costs are half those from first scenario.

Land Area and Storage Volume Requirements

Assuming that 100 MW of solar PV require 1 km^2 of land, whilst 10 MW of wind turbines span 1 km^2

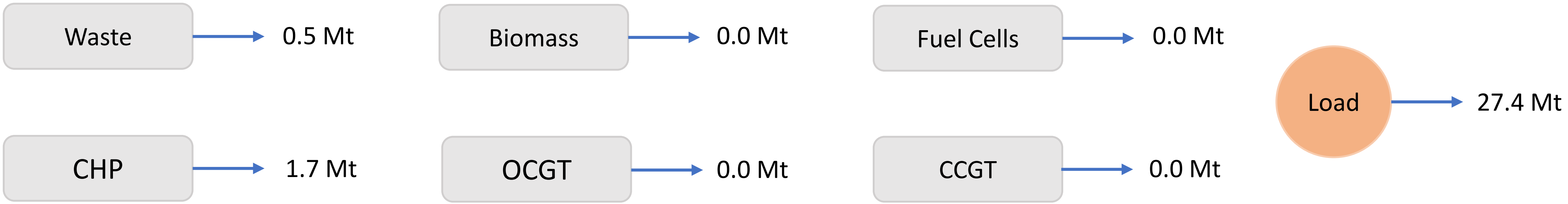
Solar PV Surface Area	Onshore Wind Surface Area	Offshore Wind Surface Area
2556 km^2	840 km^2	800 km^2

Assuming (gaseous) hydrogen compressed at 700 bar has an energy density of 1657 kWh/m^3,

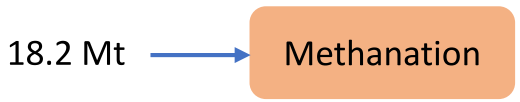
Hydrogen Storage Volume	Side Length of Equivalent Cube
5.7 Mcm	178 m

Carbon Dioxide Budgeting

Carbon Dioxide Emissions



Carbon Dioxide Consumption



Net Carbon Dioxide Budget

$$0.5 + 1.7 + 27.4 - 18.2 = 11.4 \text{ Mt}$$

Carbon Dioxide and Water Needs for Power-to-Gas

The electrolysis process requires water. In total, 127 TWh of hydrogen are produced, which corresponds to

Water Volume for Hydrogen Production	Side Length of Equivalent Cube
34.4 Mcm	325 m

The methanation process consumes CO_2. In total, 92 TWh of synthetic methane are produced, which requires

Mass of Carbon Dioxide Required	Emissions from cement industry in Belgium
18.2 Mt/y	3 Mt/y

Other Scenarios

In future work, the following scenarios can be explored:

- Relaxing constraint on electricity imports.
- Reducing electricity and gas demand.
- Importing green gas.
- Updating the assumption on carbon dioxide inputs.
- Modelling the networks, which will uncover under applications of power-to-gas.

References

- M. Berger, D. Radu, R. Fonteneau, G. Detienne, T. Deschuyteneer, D. Ernst, "Centralised Planning of National Integrated Energy System with Power-to-Gas and Gas Storages", MedPower 2018. Link to the paper: http://hdl.handle.net/2268/228999

- MultiCarrier Planning repository GitHub: https://github.com/MathiasPBerger/MultiCarrierPlanning