WP5 Dutch Case study

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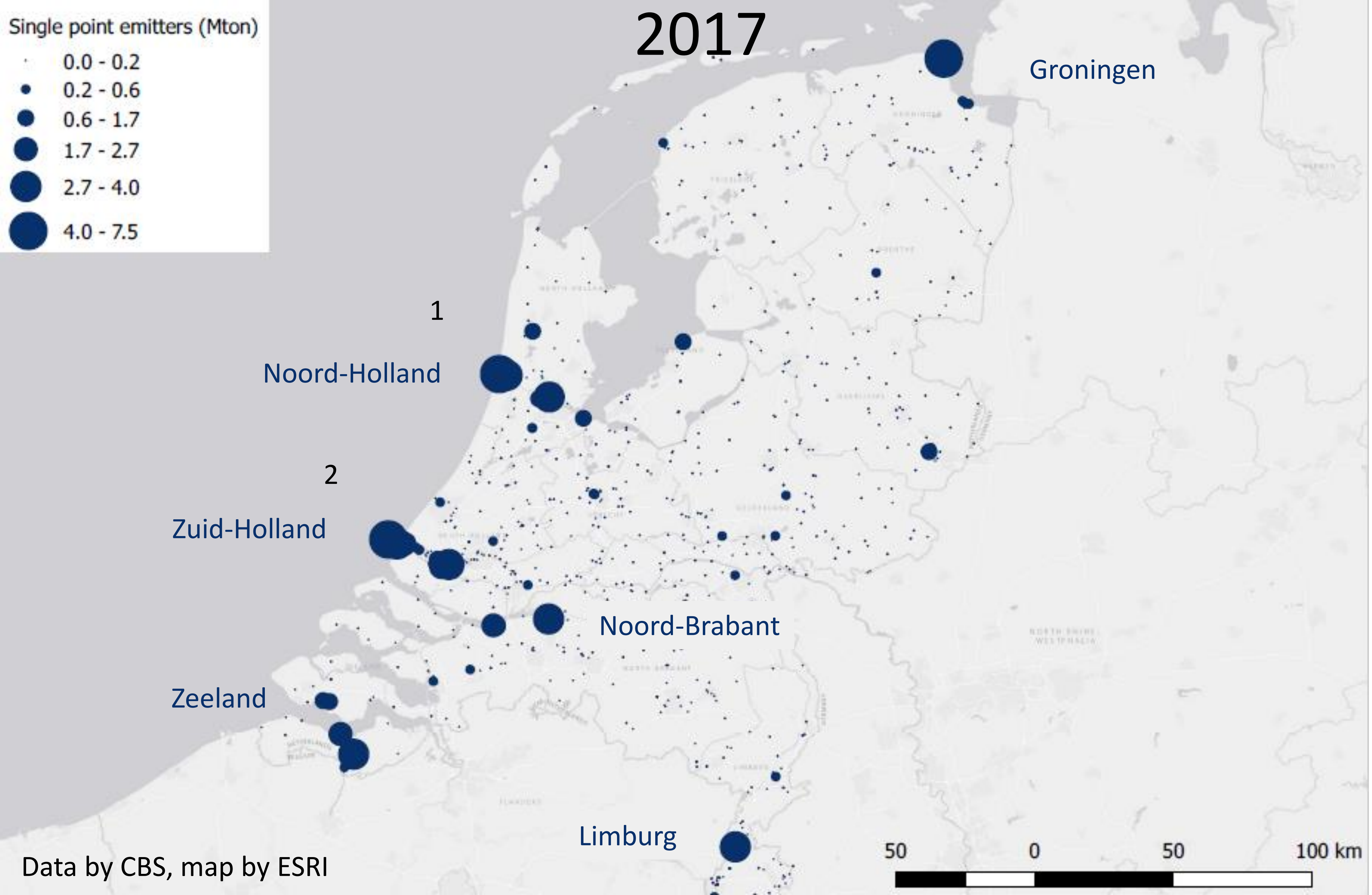
UU: **Lukas Weimann**, Gert Jan Kramer, Matteo Gazzani

19 June 2020

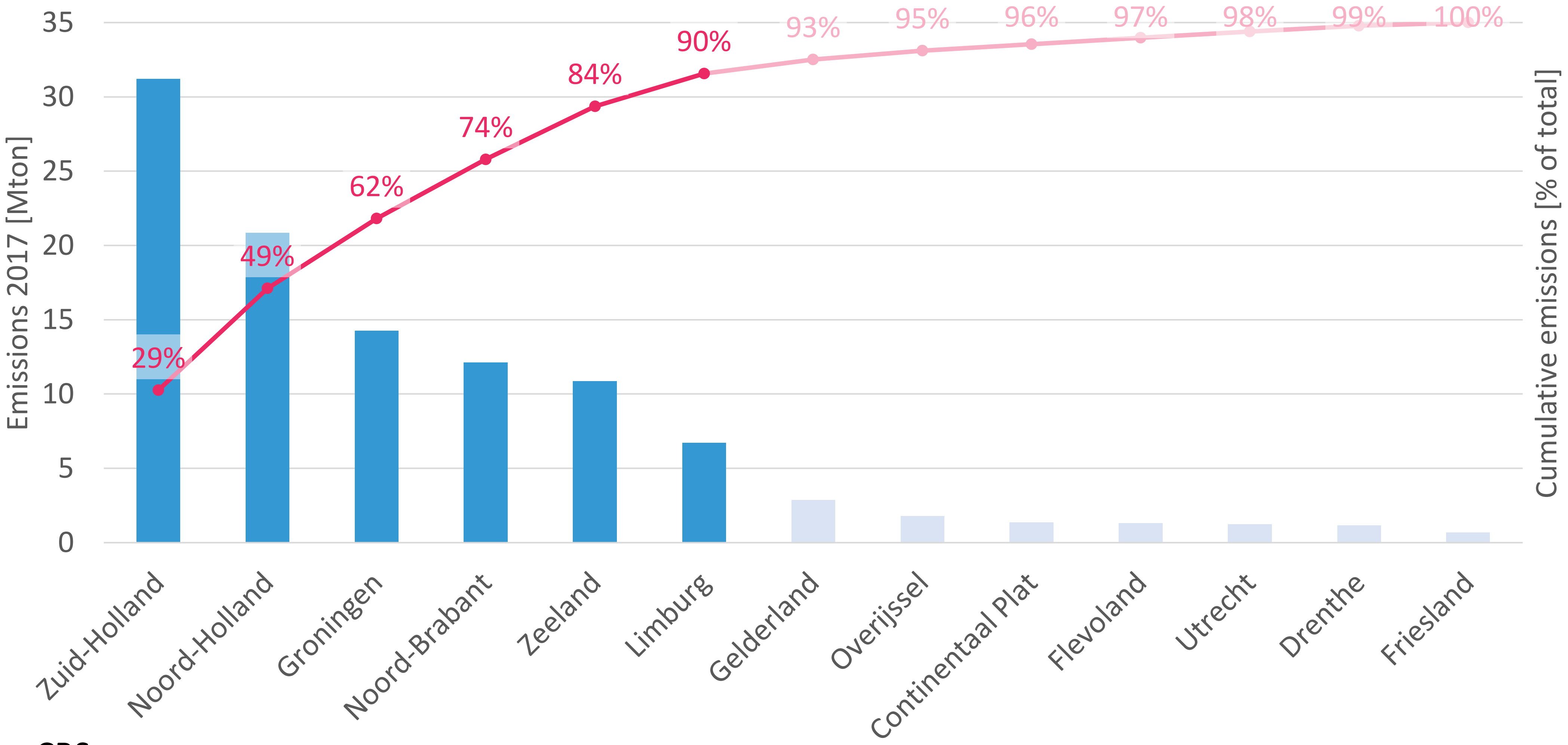
2017



Data by CBS, map by ESRI

CO_2 emissions per province (2017)

related to industry, waste incineration and electricity production



Source: CBS

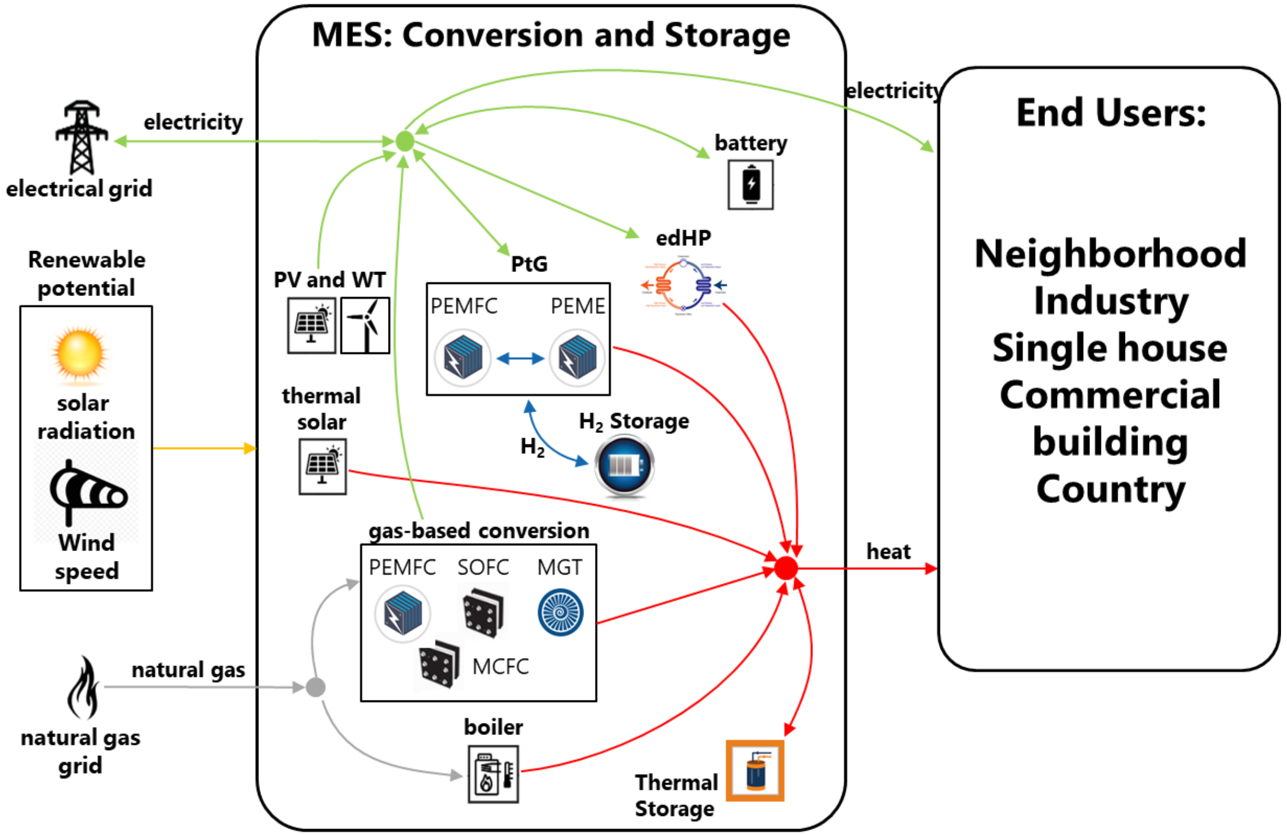
The Dutch case study

- Multi-energy systems tool (UU)
  - Feasibility of clean hydrogen from renewables for industry
  - Decarbonization of the Dutch steel industry

- Chain tool framework (TNO)
  - Chemical industry in Rotterdam
  - Decarbonization of the Dutch industry and electricity sector

Modeling framework (MES – tool)

- Developed and applied by ETH and UU
- Mixed integer linear programming (MILP)
- Optimization of multi-energy systems (MES)
- Focus on conversion technologies



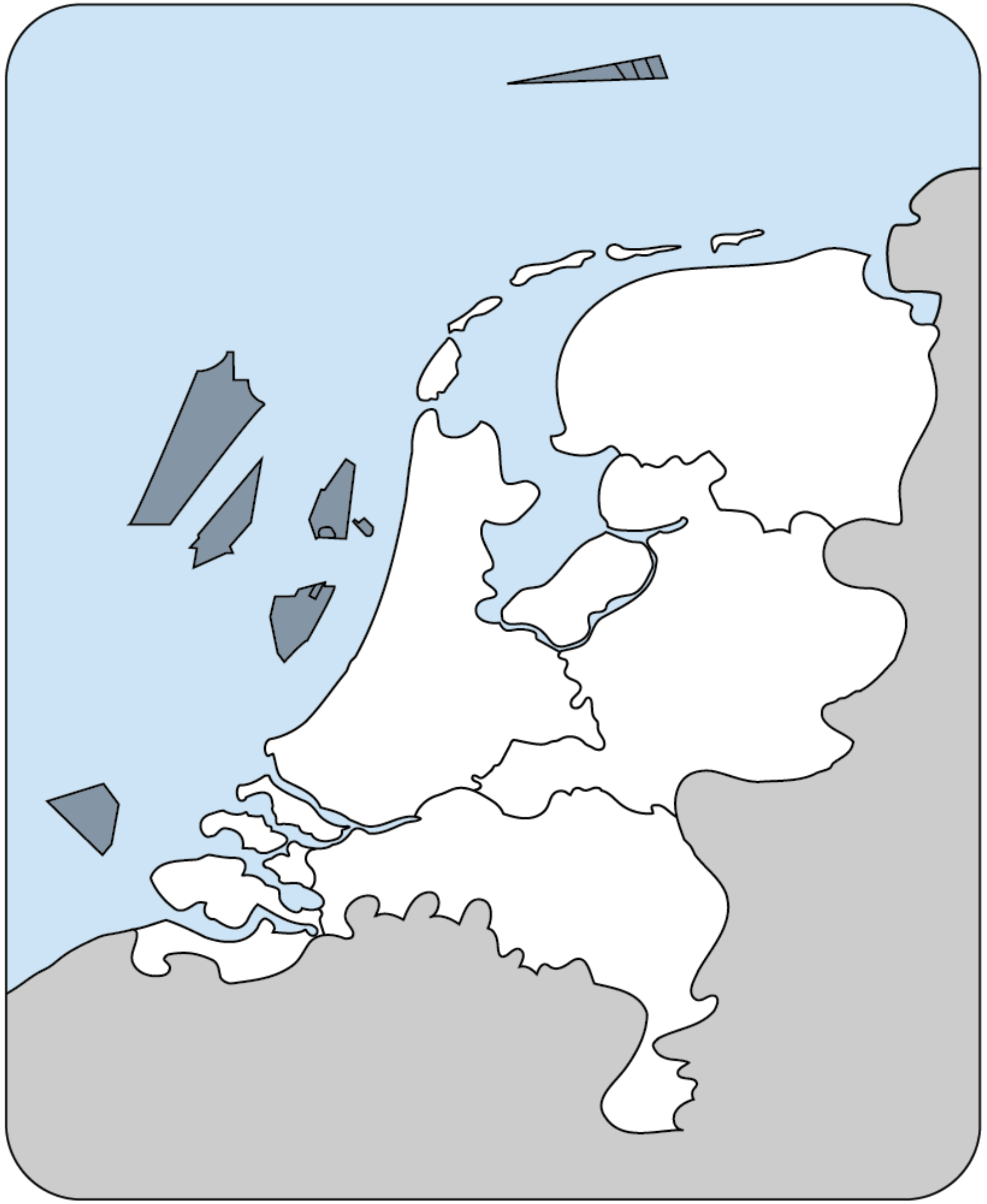
Gabrielli *et al.*, Appl. Energy 2018 (219) & Appl. Energy 2018 (221)

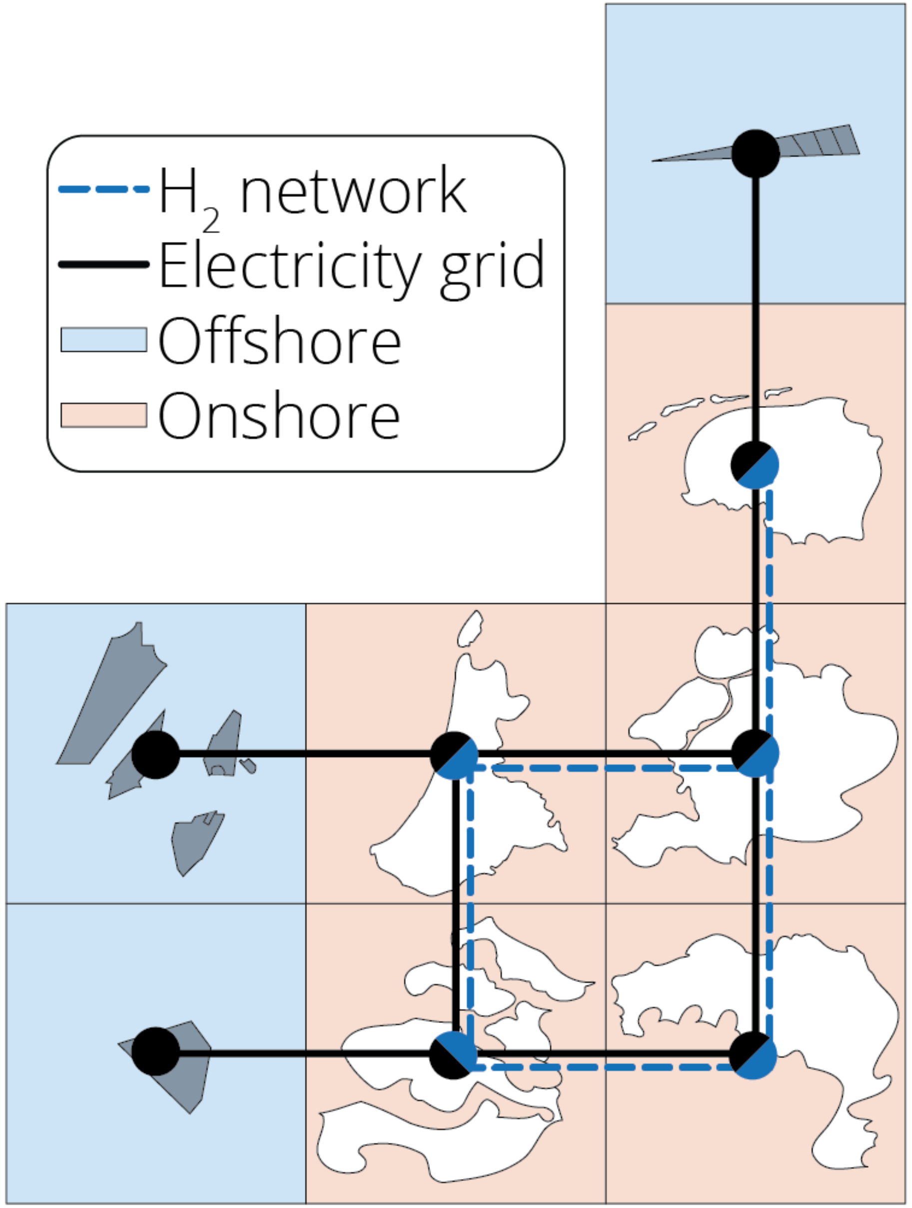
ELEGANCY

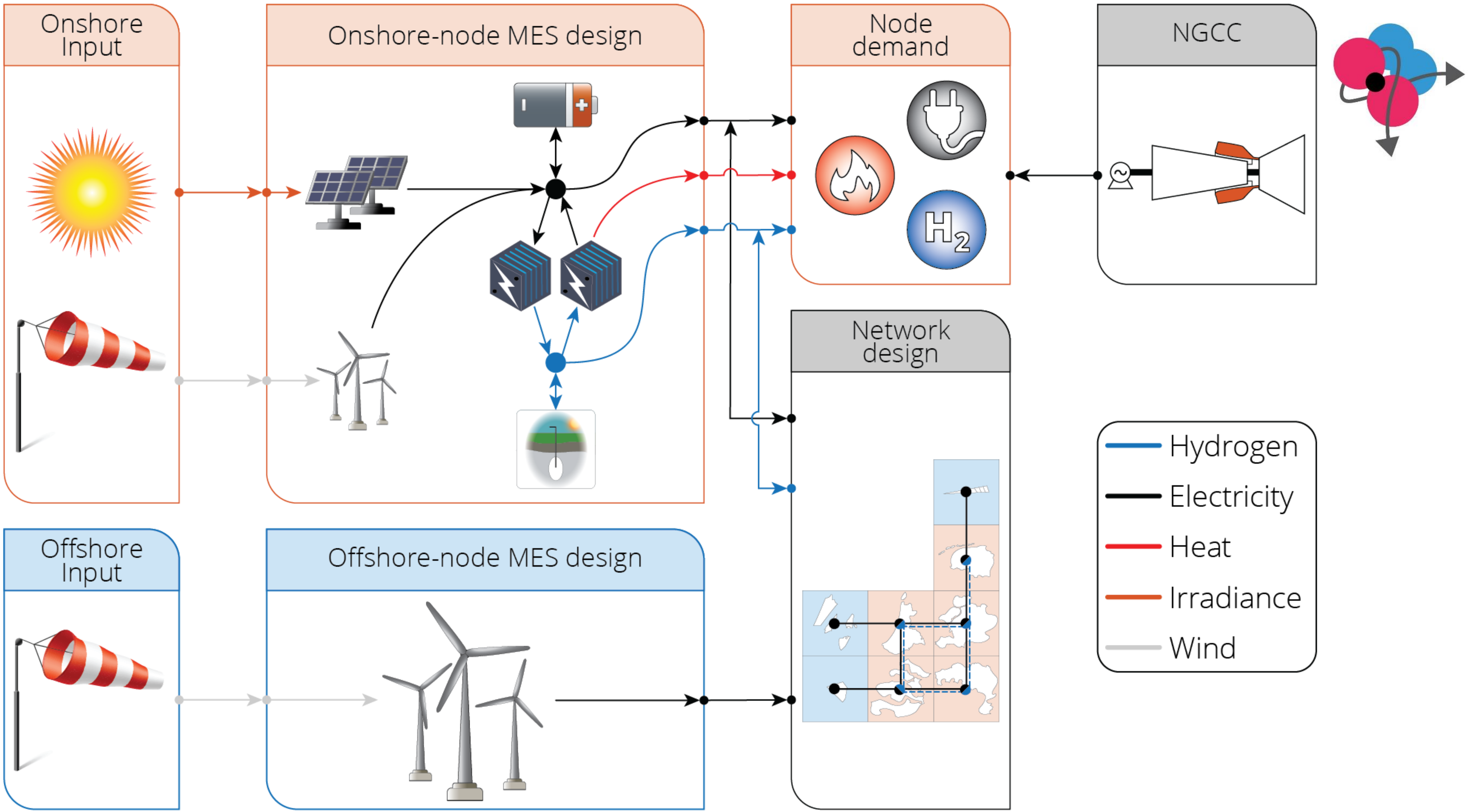
Feasibility of hydrogen from renewables for industry

Clean hydrogen from renewables for industry?

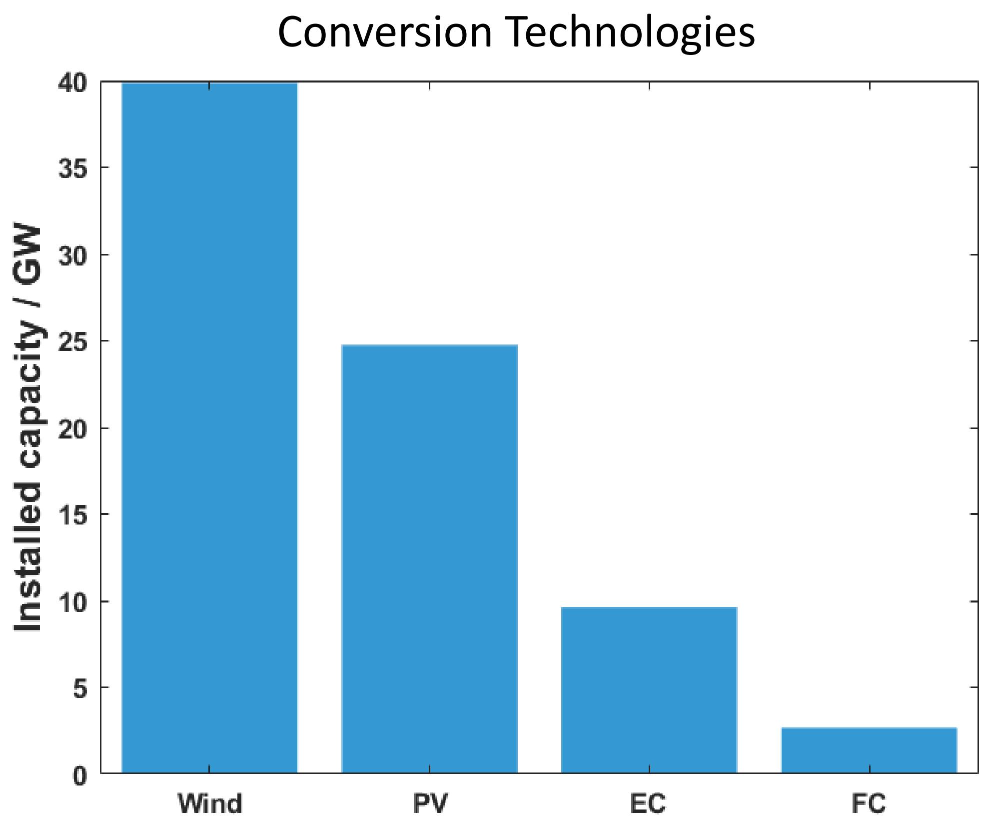
- Can the Netherlands supply the industrial demand with hydrogen from renewables? (technical feasibility)
- Would the application of H_2 for dispatching renewable energy generation benefit from increased scale due to industrial demand?
- How much would it cost? (economic viability)

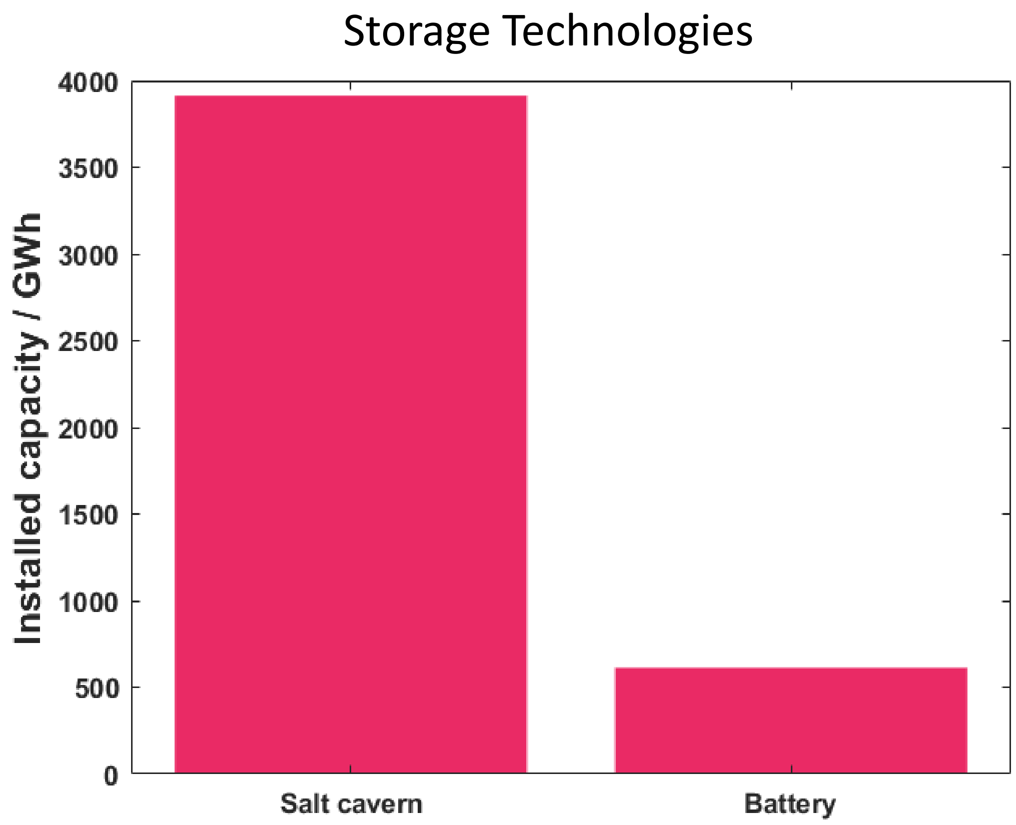



H_2 network
Electricity grid
Offshore
Onshore


Onshore Input
Onshore-node MES design
Node demand
NGCC
Network design
Offshore Input
Offshore-node MES design
Hydrogen
Electricity
Heat
Irradiance
Wind

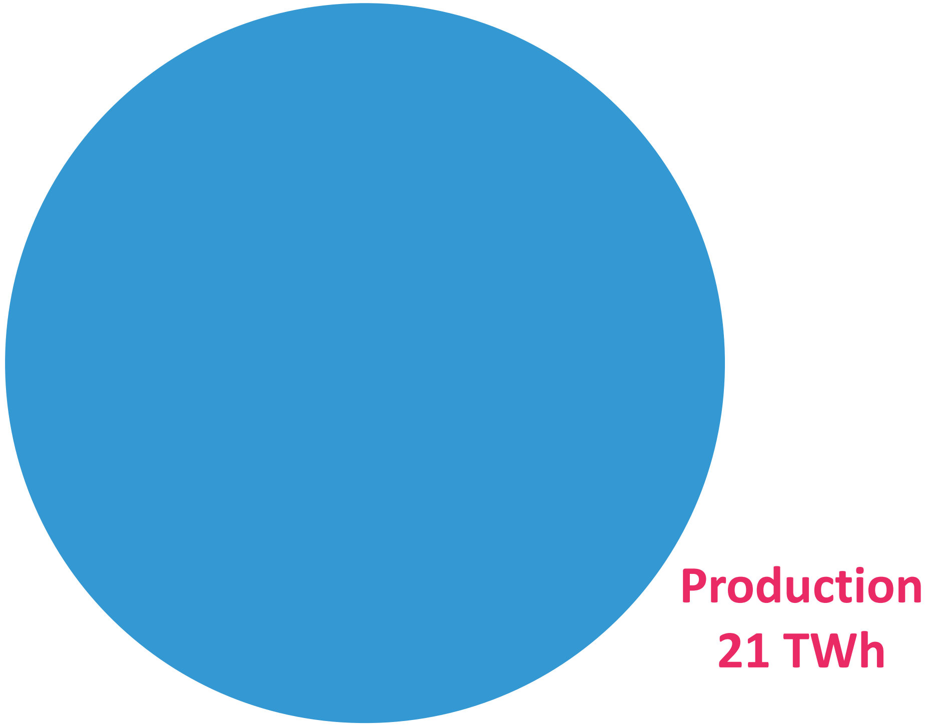
Can the Netherlands supply the industrial demand with hydrogen from renewables?





Average E-demand: 12.4 GW (18.6 GW peak)
Average H_2-demand: 2.2 GW (2.2 GW peak)

Would the application of H_2 for dispatching renewable energy generation benefit from increased scale due to industrial demand?



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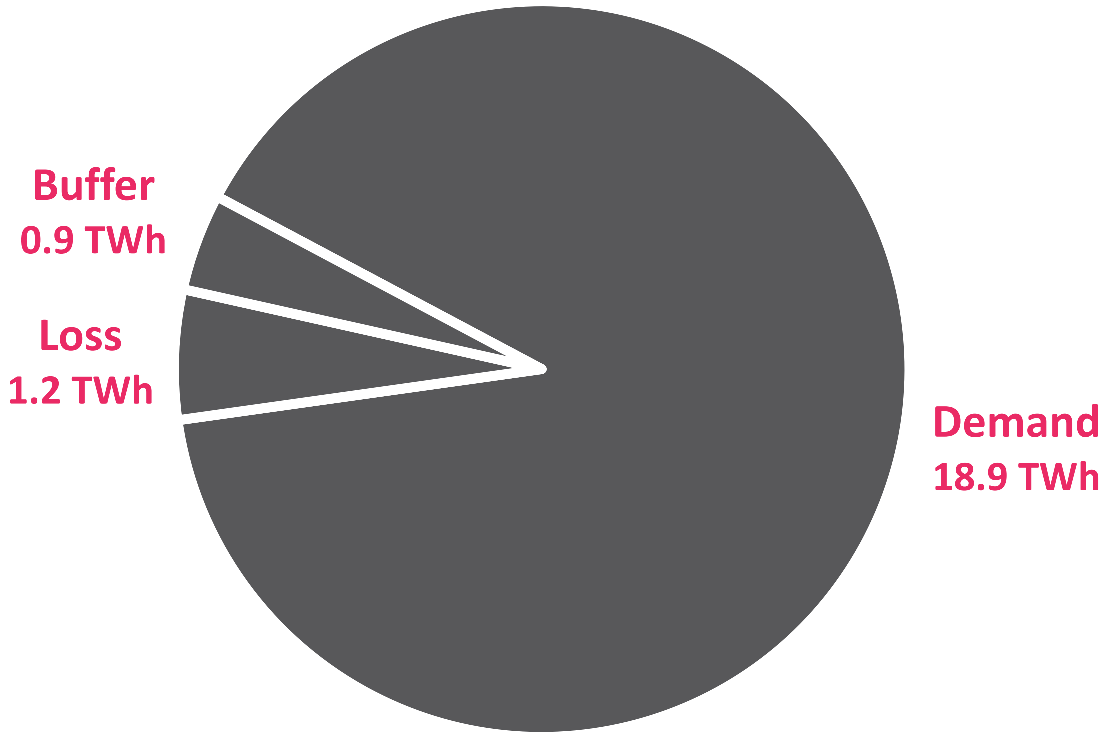

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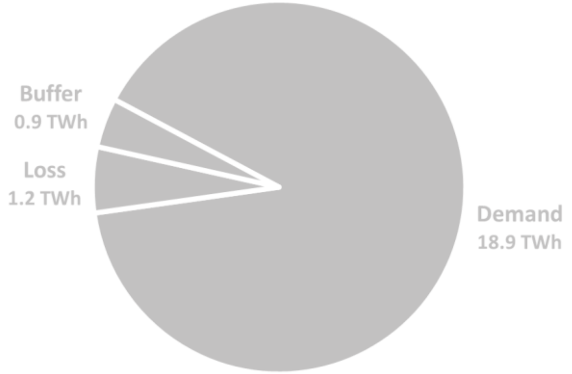


	No H_2 demand	Industrial H_2 demand
Fuel cell output [GWh/y]	4.78	0.47
Share of E-demand [%]	4.4	0.4

Preliminary results

How much would it cost?

	No H_2 demand	Industrial H_2 demand
System cost [bil-EUR/y]	33	40
Added cost [bil-EUR/y]	-	7
H_2 cost [EUR/kWh]	-	0.4
H_2 cost [EUR/kg]	-	13.3

Preliminary results

H_2 becomes cheaper if 0-emission constraint is relaxed.
However, **to be compatible with conventional H_2**, electricity must have a carbon footprint of **less than ~170 g/kWh$_e$**, which corresponds to **45+% renewable share**.

ELEGANCY

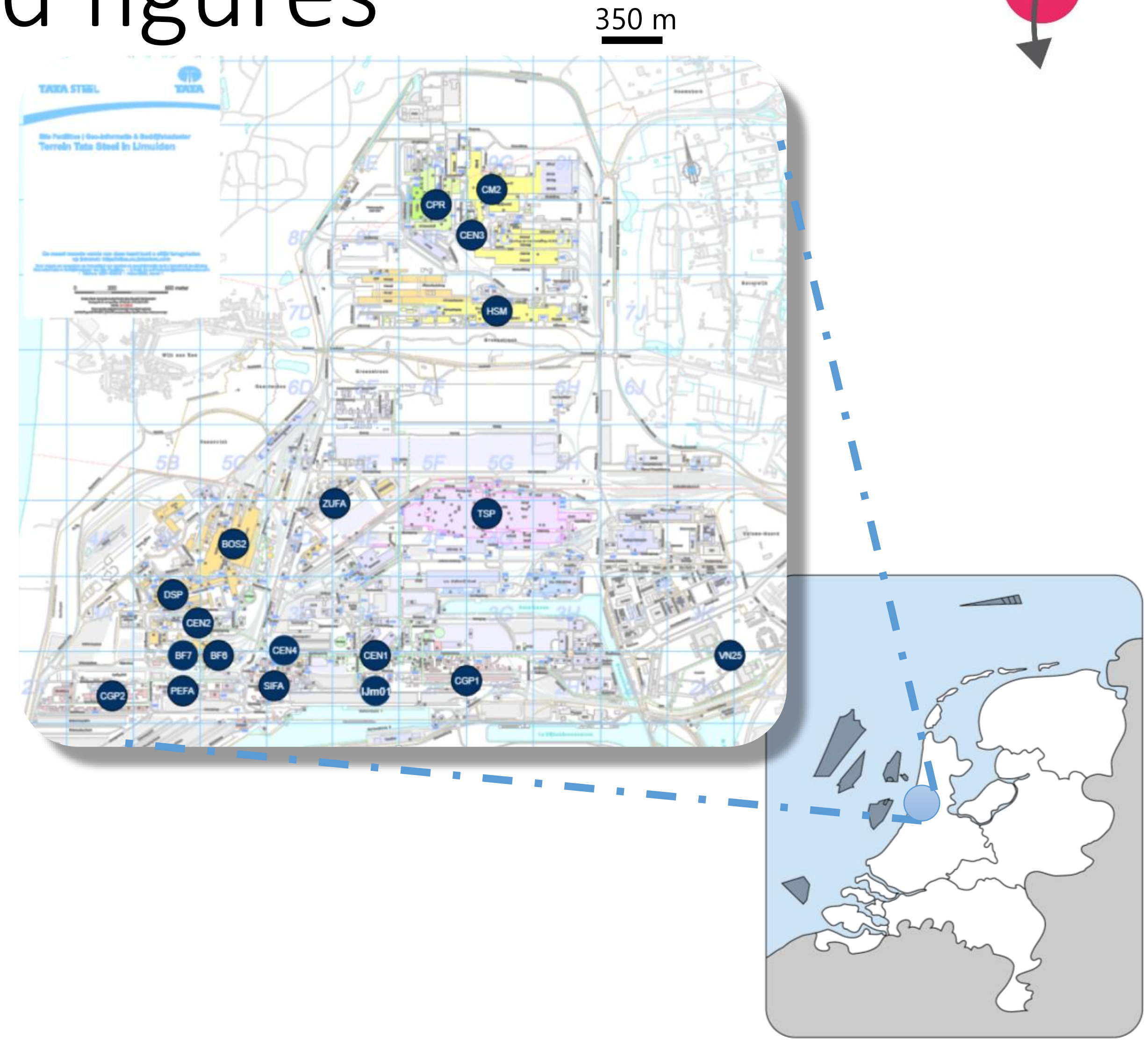
Decarbonization of the Dutch steel industry

Challenges of the steel industry

- Low profit margins and strong competition from China
- Long equipment lifetime
- Energy intensive processes with limited capacity for renewables on-site
- High level of process-integration
- Power island (high autarky) as preferred configuration

TATA Steel: key facts and figures

- 7.2 Mton steel per year (4% of European steel production)
- 13 Mton $CO_{2,eq}$ per year (7% of total Dutch emissions)



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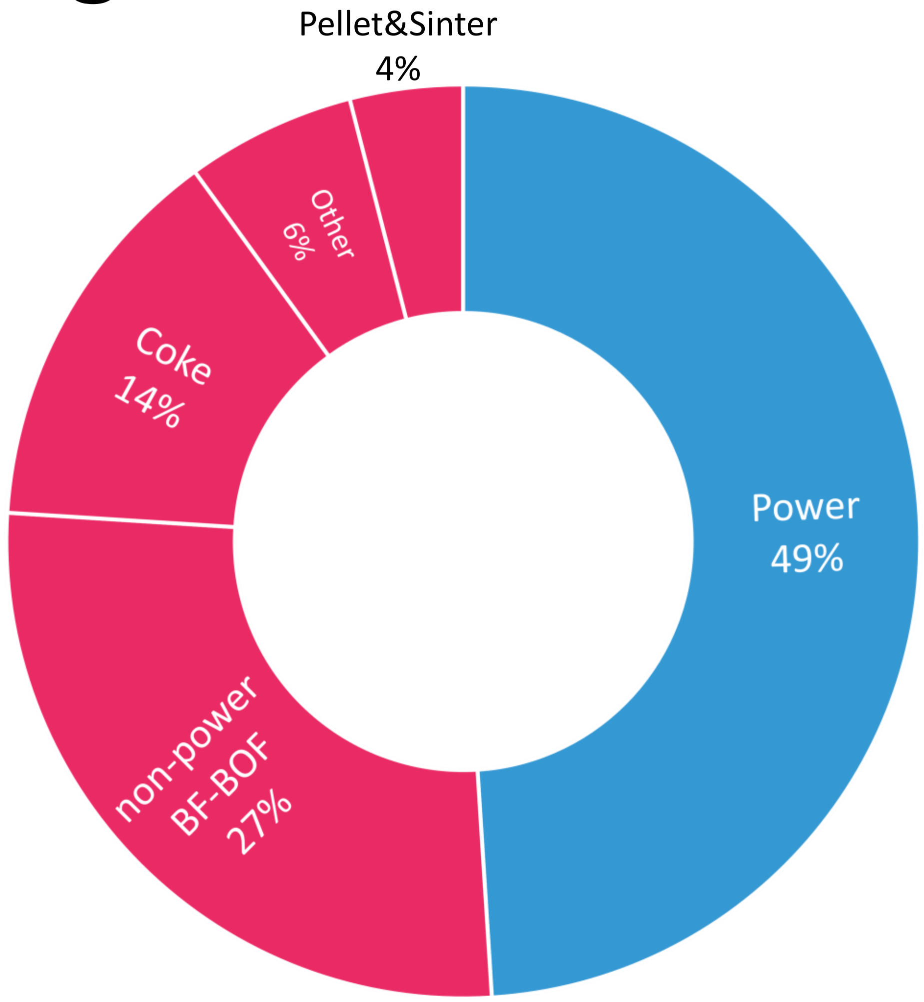
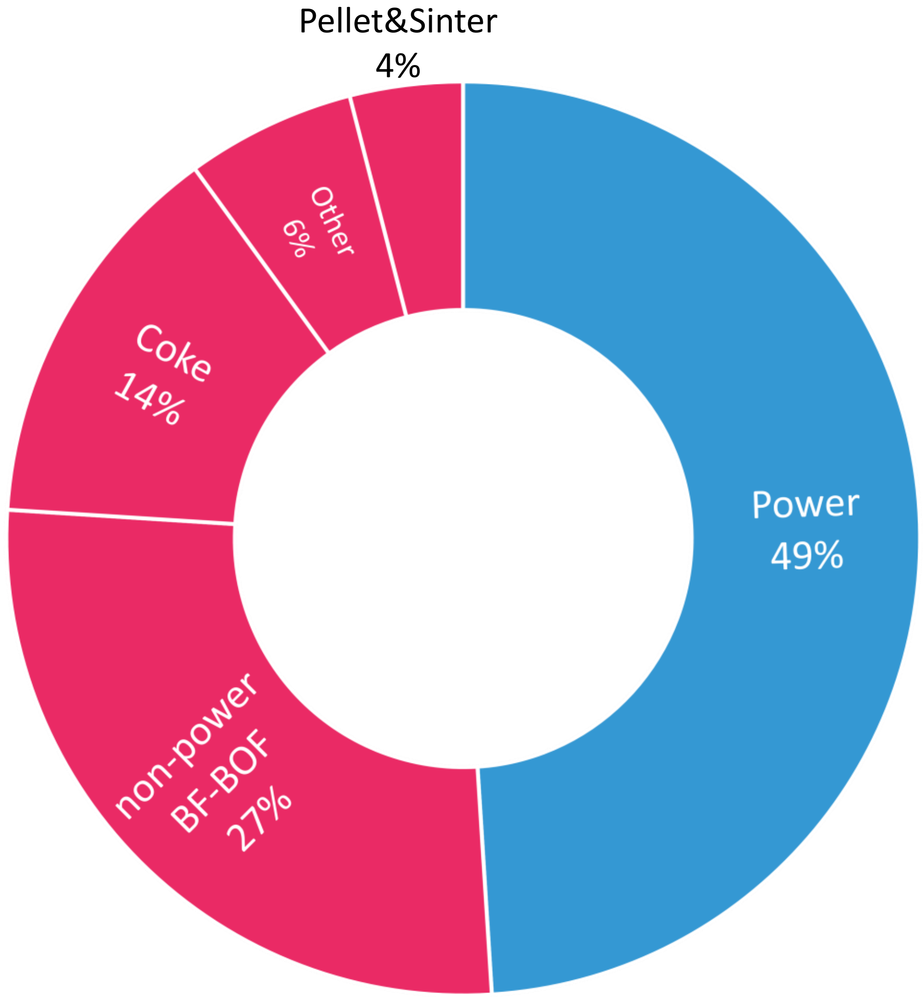


Origin of CO_2 emissions

Keys *et al.*, Decarbonisation options for the Dutch steel industry, 2019, MIDDEN project

Research objective

Investigate the impact of measures to decrease process emissions on the energy system



Origin of CO_2 emissions

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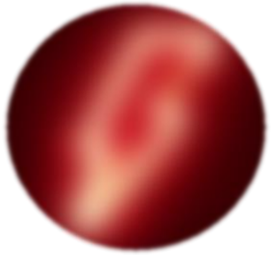
Decarbonization routes

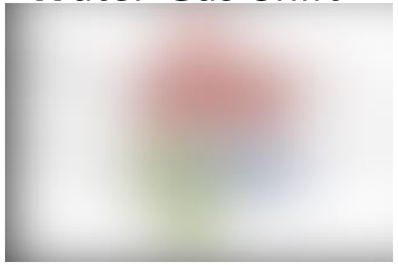
Conventional steel making

Electrification of Heat



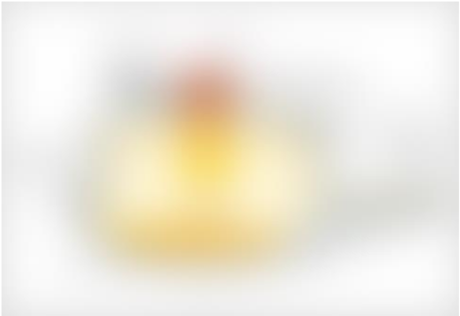
Post-combustion capture

Sorption **E**nhanced **W**ater-**G**as-**S**hift



Novel ways of steel making

Electric Arc Furnace

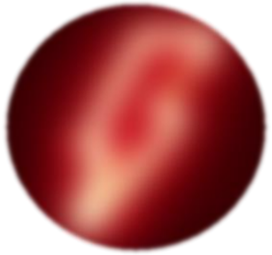
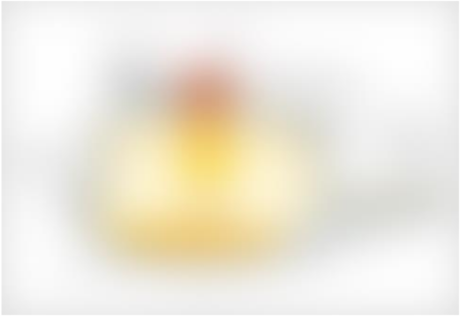


Hisarna

Direct Reduction through Hydrogen

Images blurred in open-access version for copyright reasons

Decarbonization routes

Electrification of Heat	Electric Arc Furnace	Hisarna
		
• Maximum electrification of heat	• Replacement of one BF (3 Mt/y)	• Replacement of one BF (3 Mt/y)

	Electrification of Heat	Electric Arc Furnace	Hisarna
Electricity	5%	5%	15%
Natural gas	10%	20%	5%
Heat		35%	35%

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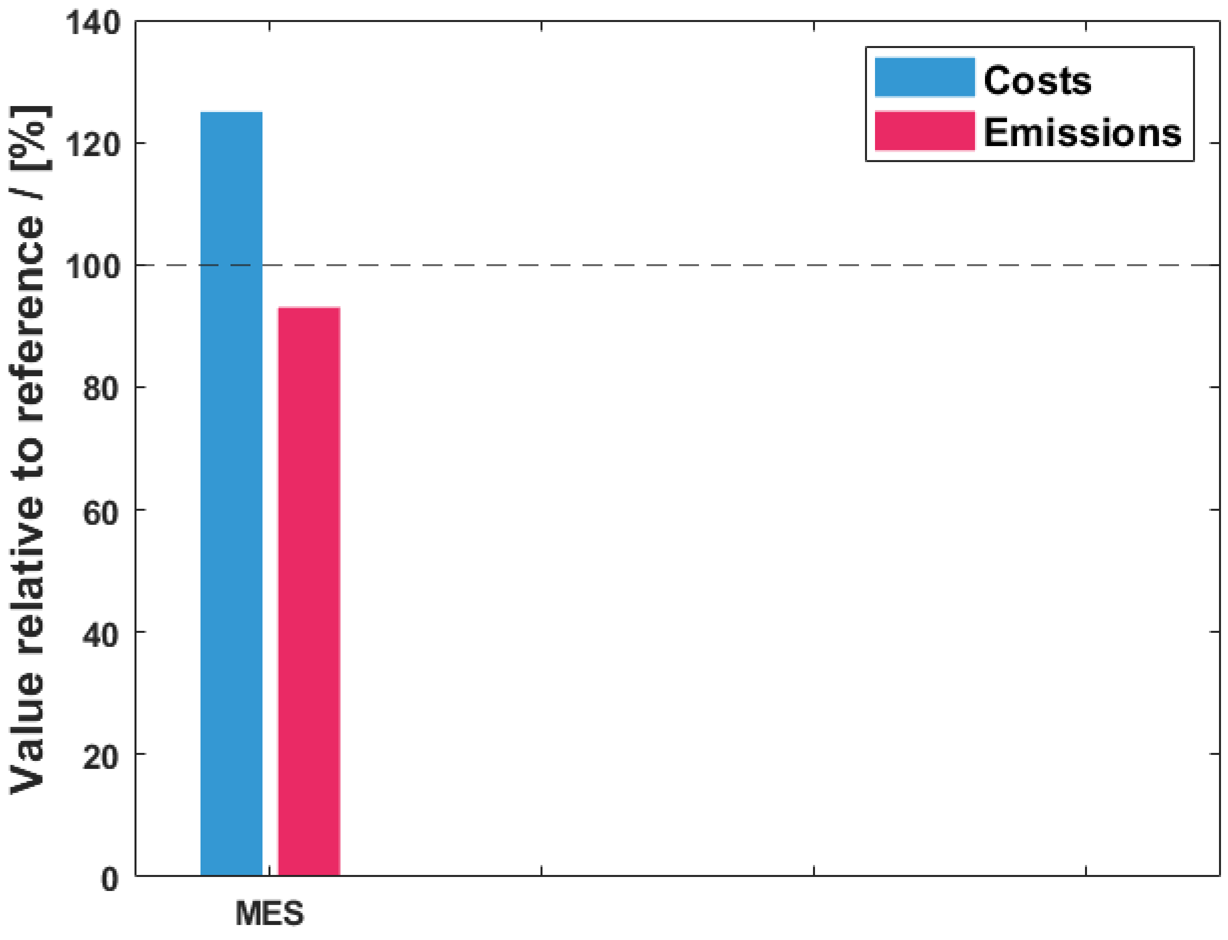
... and their effect on the energy system



Reference: current energy system of TATA steel, simulated in MES-tool

MES: Energy system redesigned to minimize emissions

Emissions for electricity from grid: 371 g/kWh

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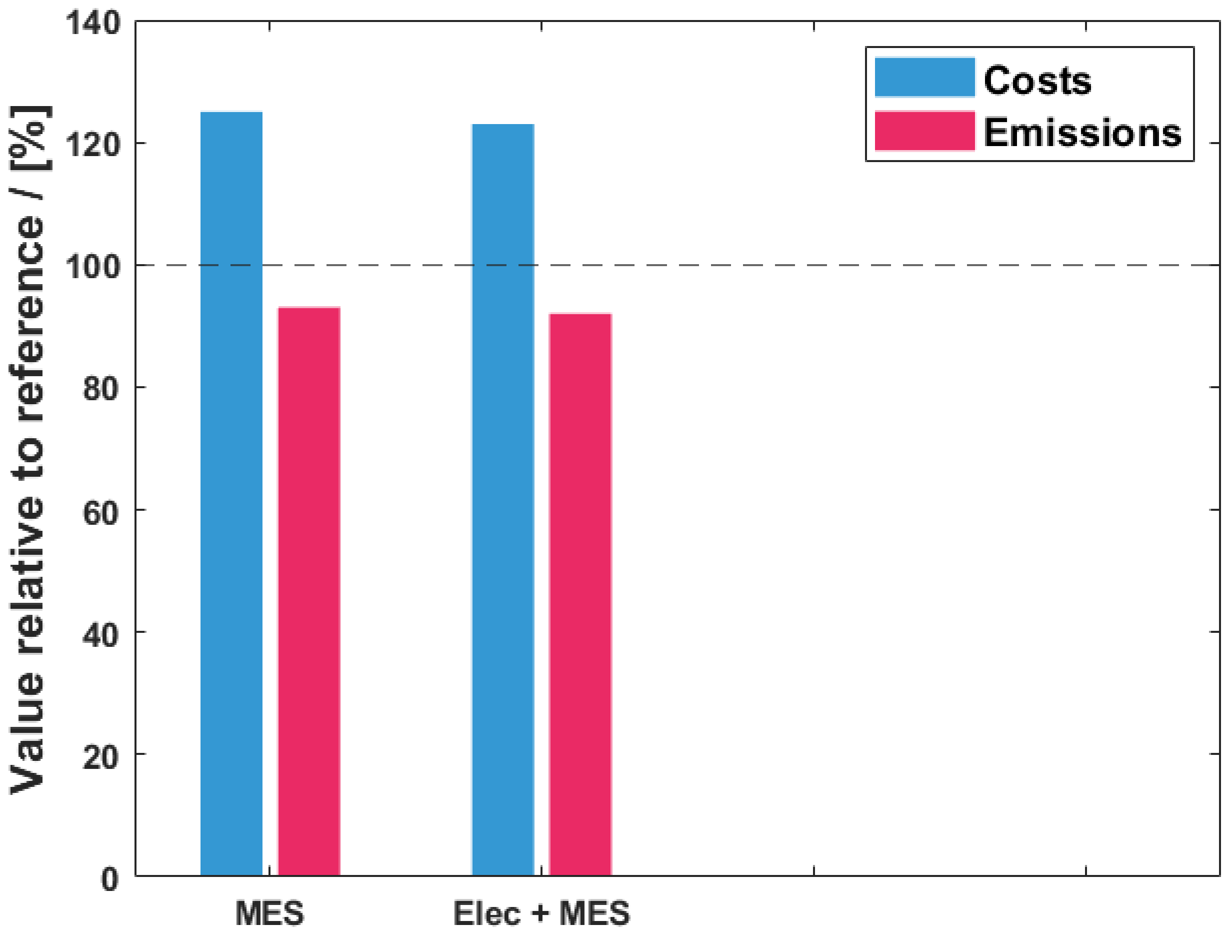

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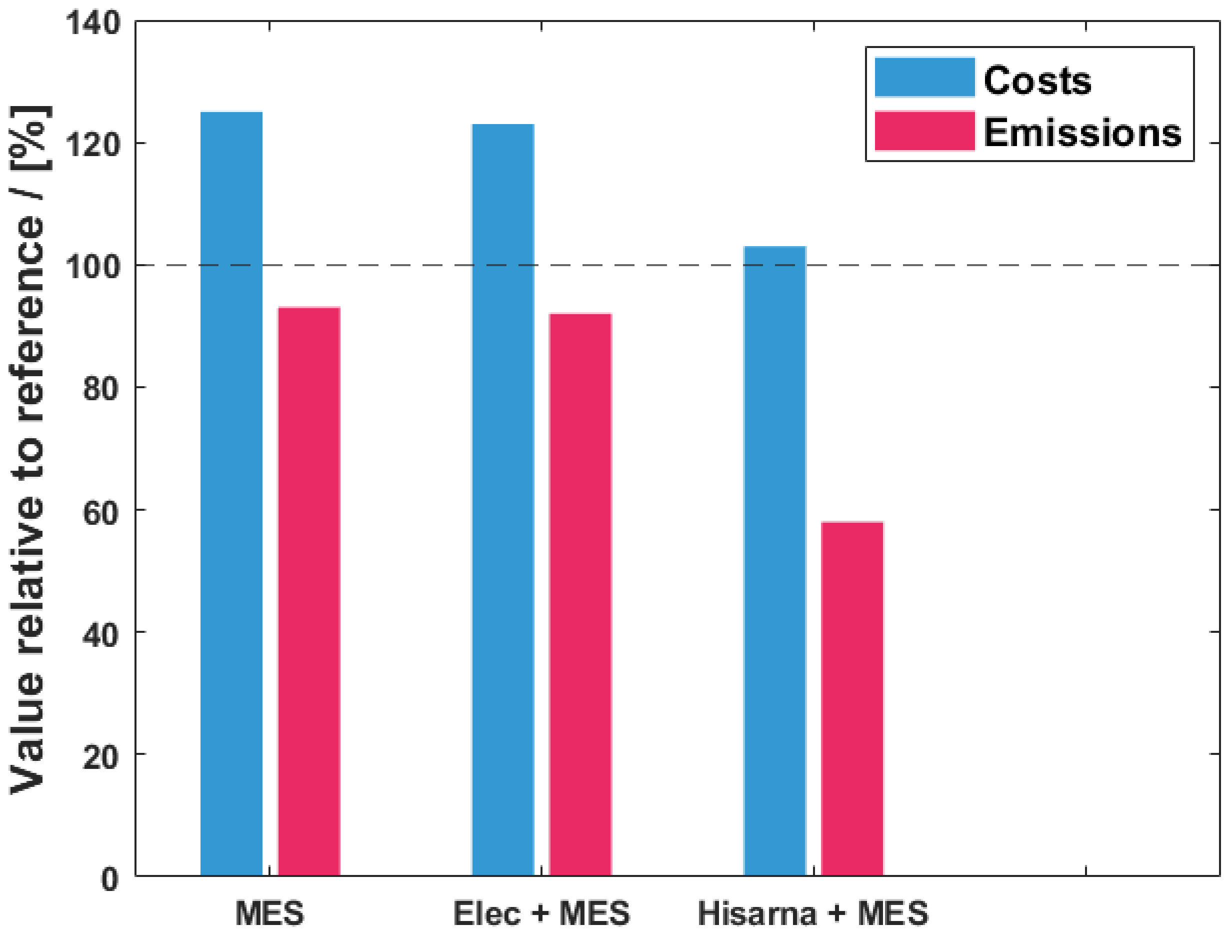

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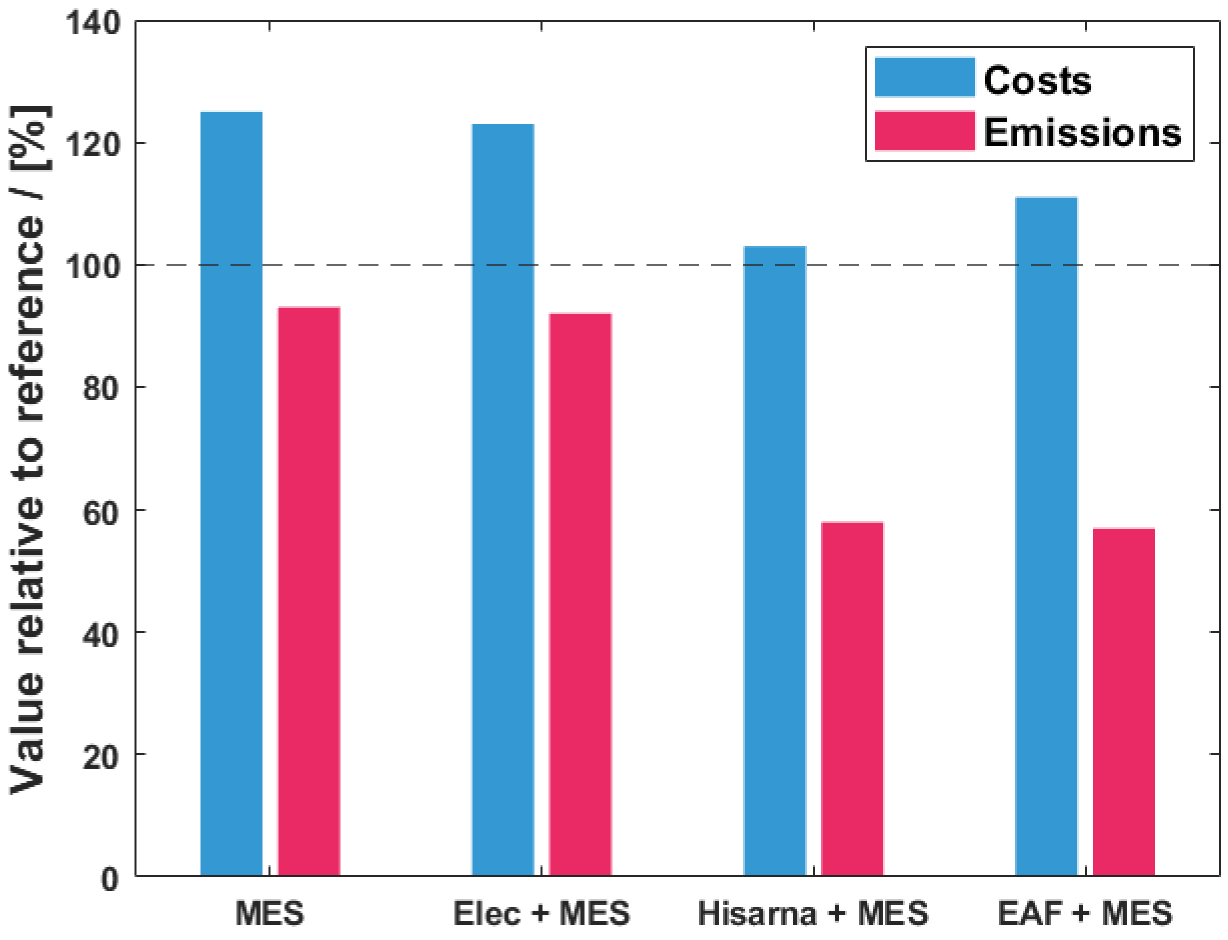

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How can the steel industry go for deep decarbonization?

1. Increase capacity of renewables, e.g. off-site
2. Tap into green national grid

How can the steel industry go for deep decarbonization?

1. Increase capacity of renewables, e.g. off-site
2. Tap into green national grid

3. Apply CCS to C-rich gas products of current steelworks processes (e.g. SEWGS, post-combustion)

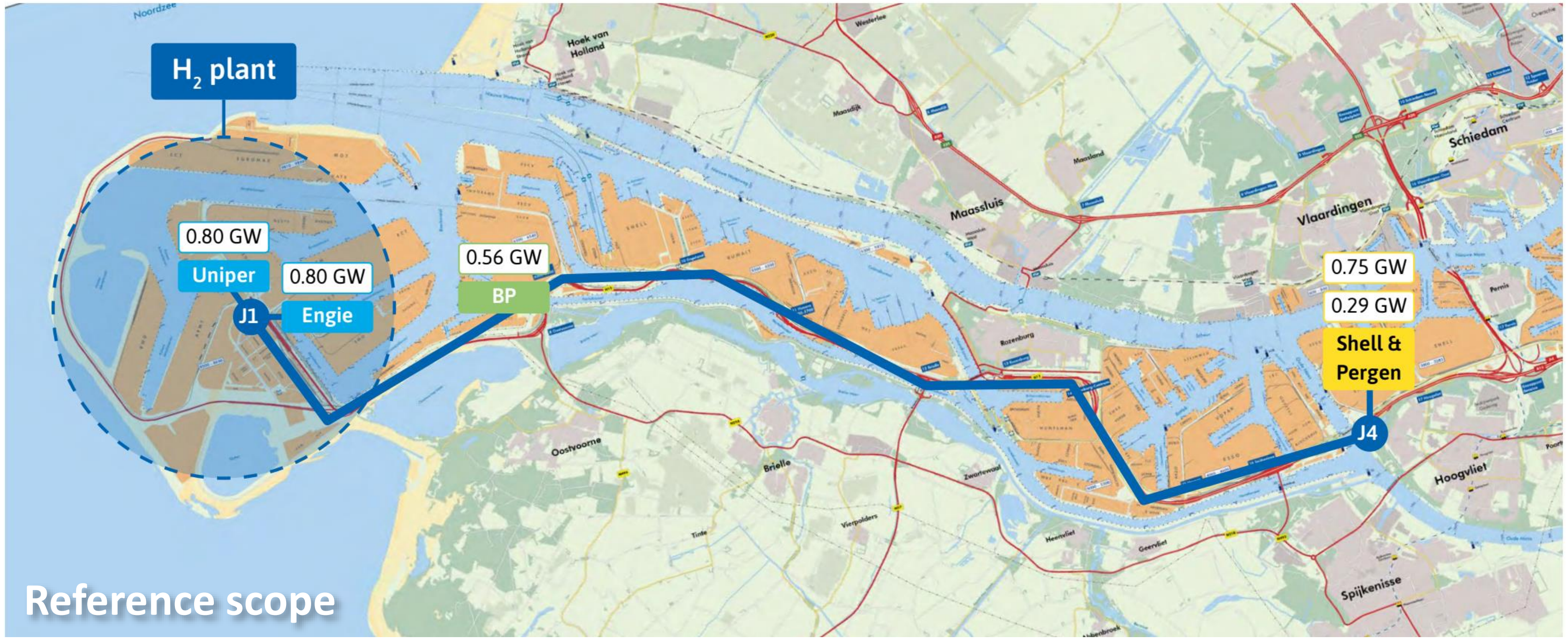
4. Use new steelworks processes empowered by CCS (Hisarna, direct reduction with blue H_2)

5. Use hydrogen from renewables

ELEGANCY

Decarbonization of the Rotterdam area using hydrogen

Decarbonization of refineries in Rotterdam is feasible and straight-forward in terms of spatial planning



Reference to H-vision 1:
https://www.deltalinqs.nl/h-vision-en
https://blog.sintef.com/sintefenergy/elegancy-tno-h-vision-project/

Decarbonization of the Dutch industry and electricity production using the Elegancy chain tool

Dutch energy system from 2025 on – overview and key figures

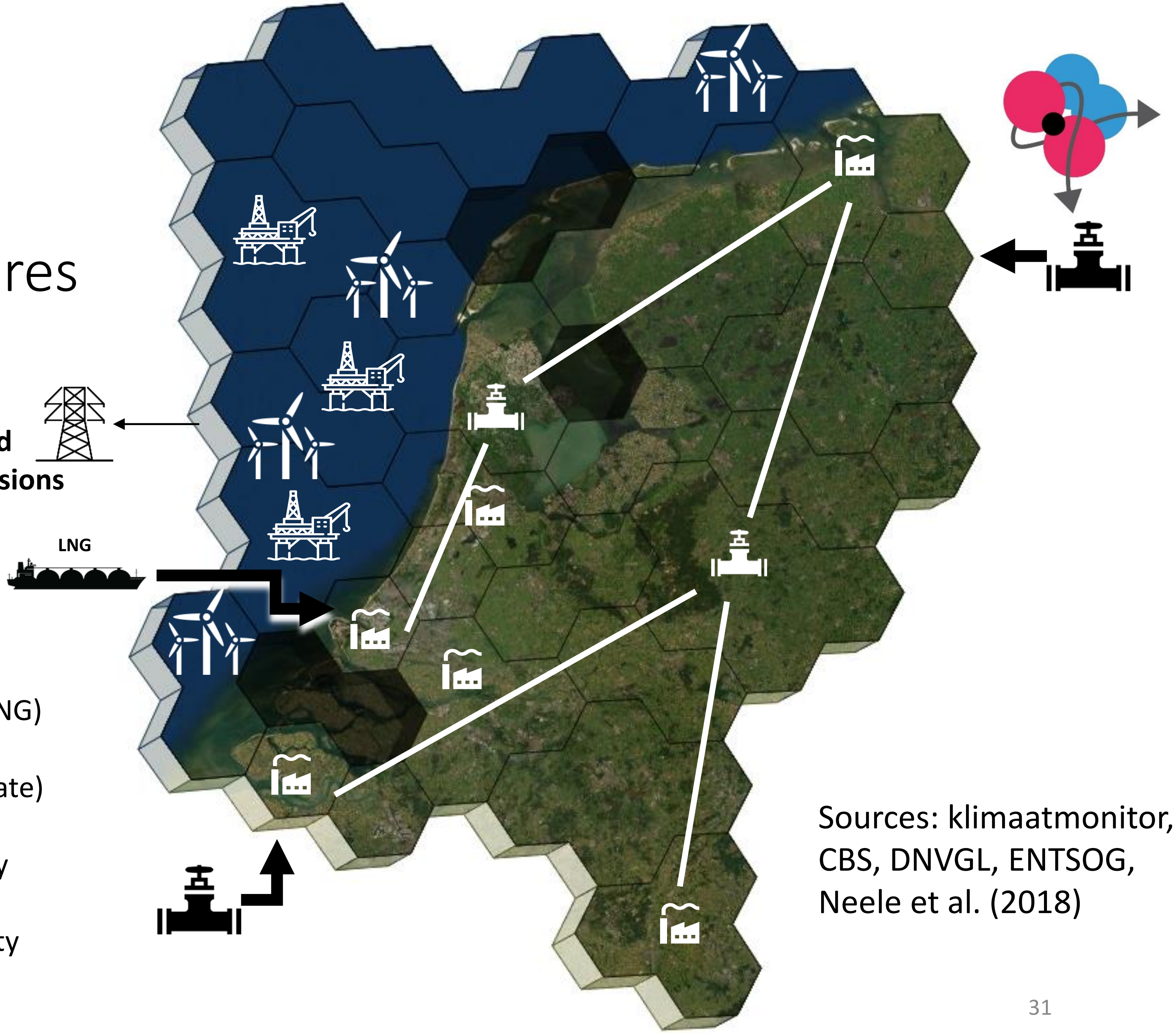
55 TWh/a **electricity demand**
115 TWh/a industrial **heat demand**
50 TWh/a hydrogen **feedstock demand**
6 Mton/a **CO_2** waste incineration **emissions**

95 TWh/a offshore **gas production**
890 Mton **CO_2 storage** capacity

Existing **gas** and **hydrogen** backbone
375 TWh/a **gas import** capacity (incl LNG)

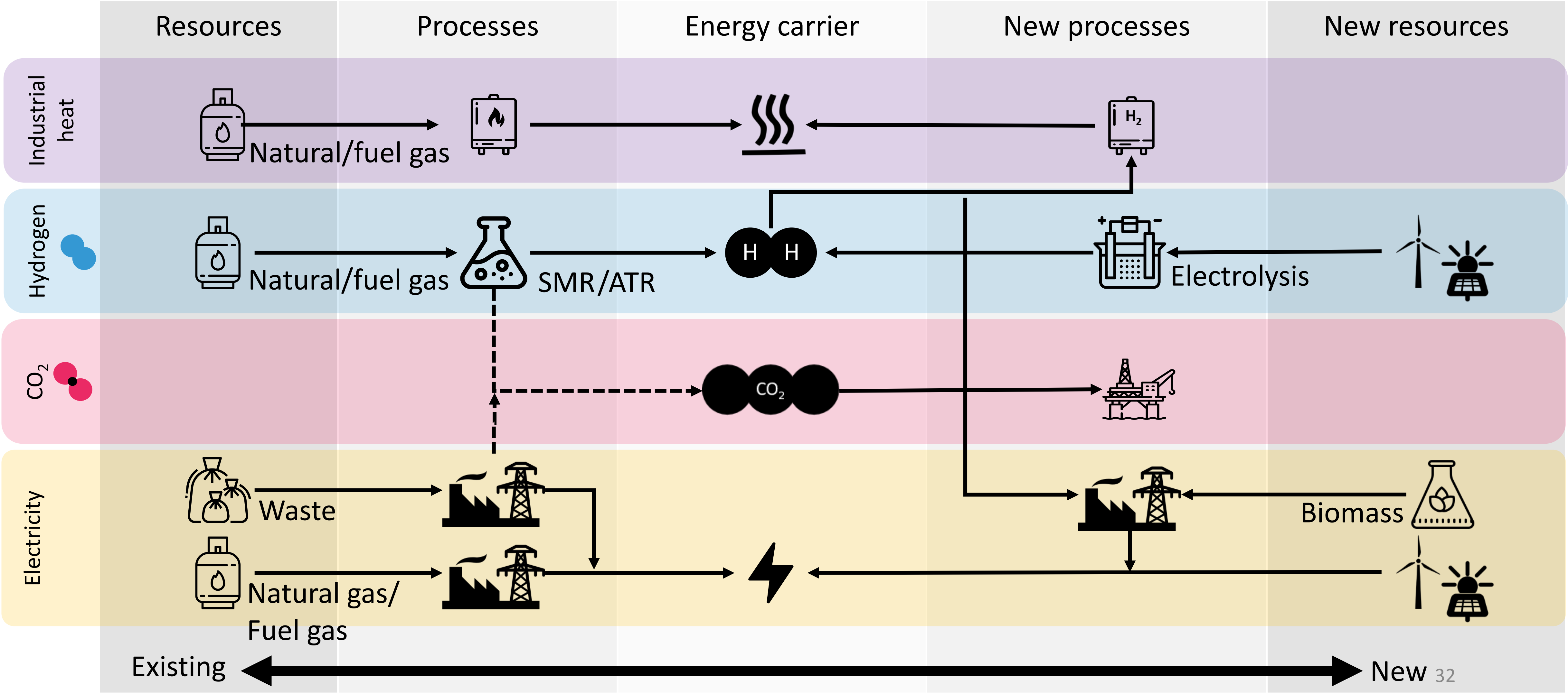
Existing electricity network (copper plate)
45 TWh/a **electricity demand**
Onshore wind/PV – increasing capacity

Offshore wind – increasing **RES** capacity

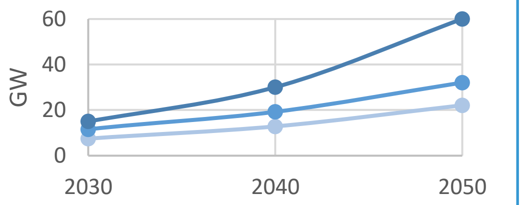
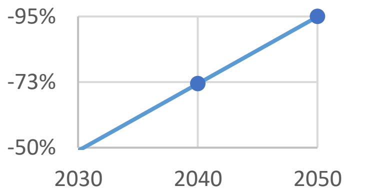
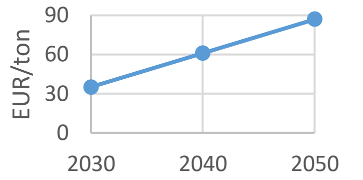


Sources: klimaatmonitor, CBS, DNVGL, ENTSOG, Neele et al. (2018)

Different decarbonization tactics are on the table for the industry and electricity sector



National case scenario’s

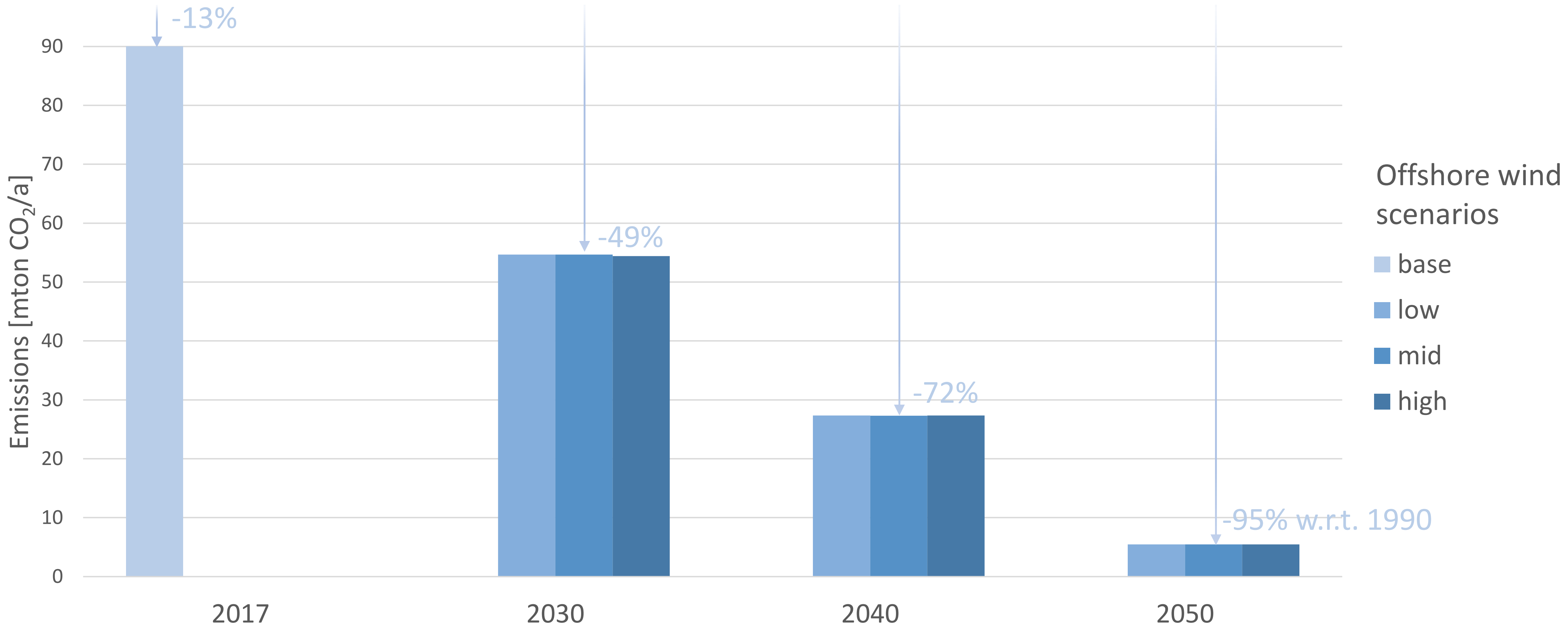
Offshore wind scenarios (low/mid/high)*	Emission reduction targets	Electricity price	Gas price	CO_2 price
		constant €57/MWh	constant €28/MWh	

Optimization based on following KPI’s:
CAPEX, OPEX, resource cost and emission cost

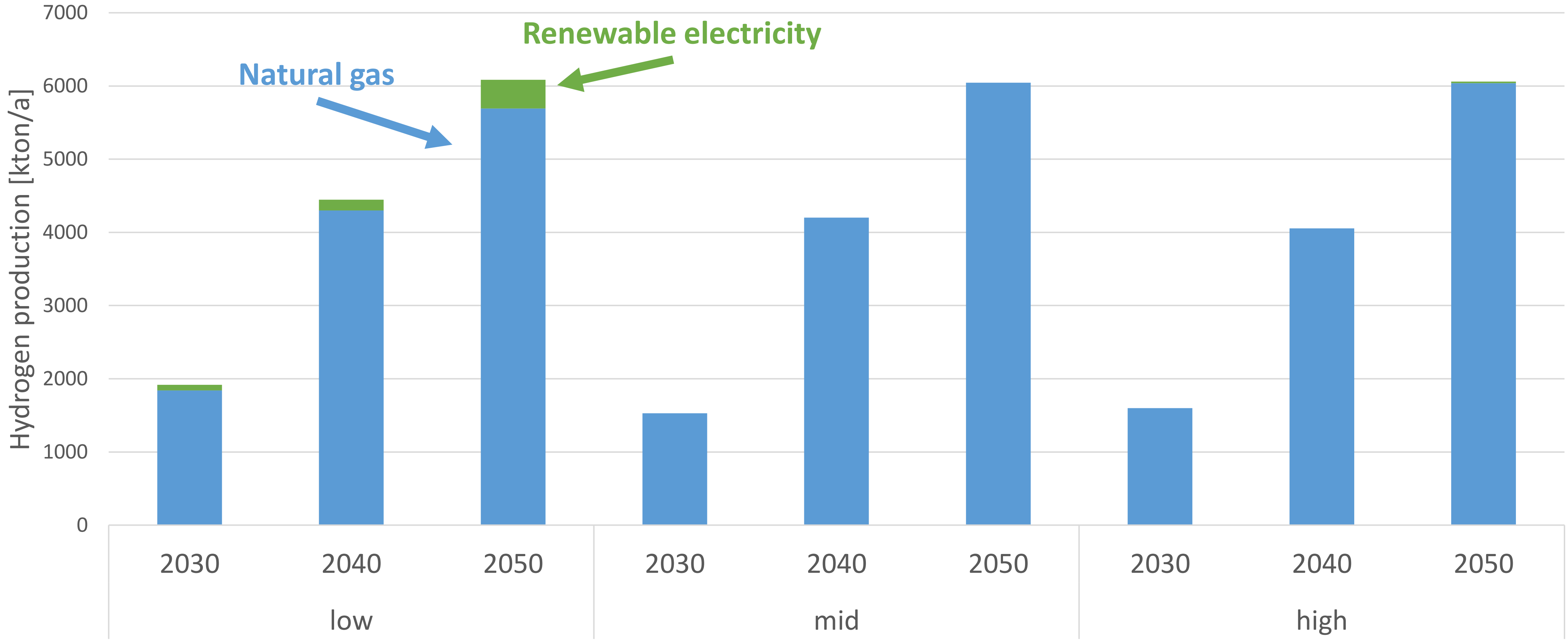
Optimized spatial network

*Corresponding to scenario’s II, III and IV from “De Toekomst van de Noordzee”, PBL (2018)

Emission reduction targets can be achieved using hydrogen under all scenarios



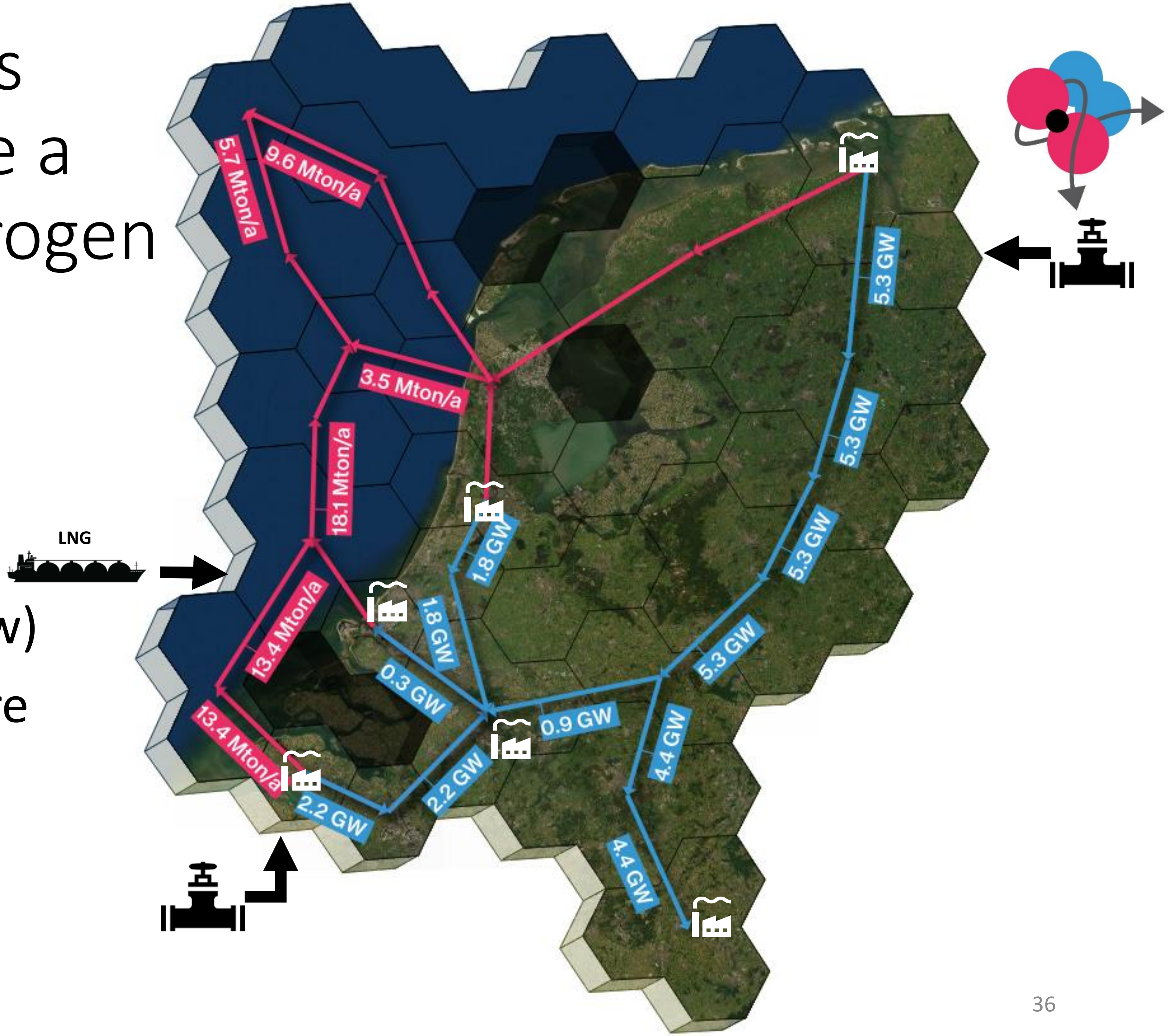
Based on the chain tool methodology without market dynamics, hydrogen from renewable electricity will only play a minor role?



Existing Dutch gas infra can facilitate a transition to hydrogen

Snapshot 2050

- CO_2 infrastructure (new)
- Hydrogen infrastructure



Results of the Dutch case study – key take-aways

- Deep decarbonization of the industry requires CCS on the short term
- Dutch offshore gas field capacity for CO_2 storage provide sufficient capacity
  - to support a blue hydrogen transition while decarbonizing the (petro-) chemical industry and waste incineration up to 95% in 2050 (w.r.t. 1990)
- Existing gas transmission infrastructure is sufficient
  - to accomodate this transition, with the exception of currently absent CO_2 infrastructure
- Market dynamics are required to paint a more representative picture
  - Of the hydrogen market in terms of different production methods

2020 2030 2040 2050 ?

Image sources

- Slide 22
  - http://homework.uoregon.edu/pub/class/climate_change/ccs.html
  - Gazzani *et al., International Journal of Greenhouse Gas Control, 2015 (41), 249-267*
  - *https://teara.govt.nz/en/diagram/5885/electric-arc-furnace*
  - *https://ieaghg.org/docs/General_Docs/Iron%20and%20Steel%202%20Secured%20presentations/2_1330%20Jan%20van%20der%20Stel.pdf*
  - *Steel Institute VDEh, European Steel: The wind of change, 2018*