INTERPLAY OF A NETWORK OF HYDROGEN REFUELLING STATIONS (HRS) FOR HEAVY-DUTY VEHICLES (HDV) AND THE POWER SYSTEM IN GERMANY IN 2050

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Strommarkttreffen, Berlin (5. Juli 2019)

Quelle: http://www.klimaexpo.nrw/mitmachen/projekte-vorreiter/vorreitergefunden/vorreitermobilitaet/; https://nikolamotor.com/tre

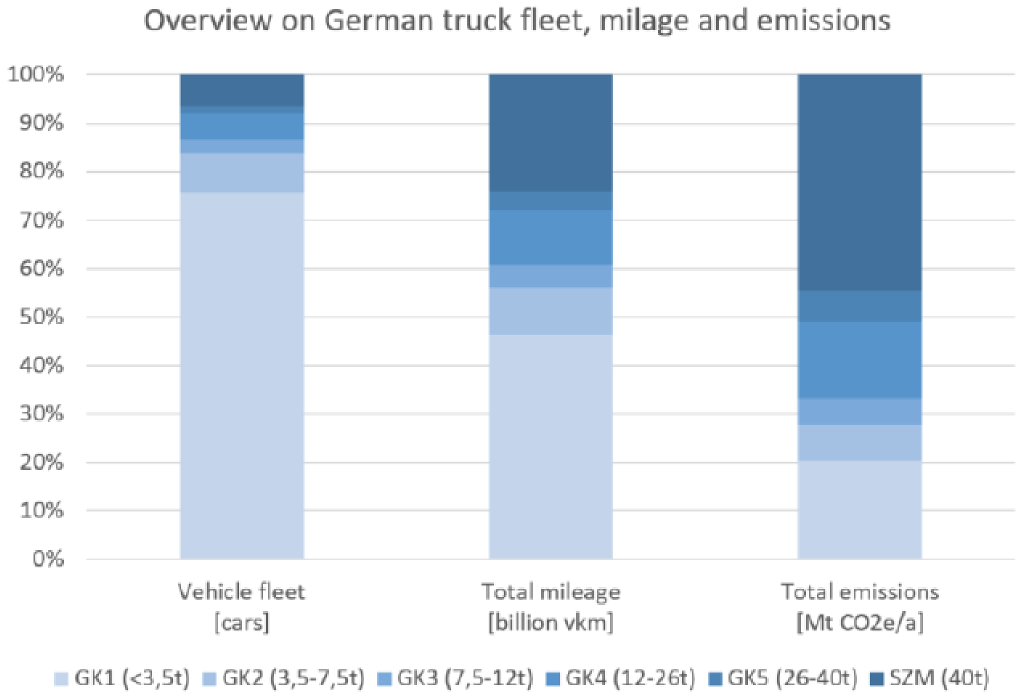
Focus: Reducing GHG emissions from German road freight transport

Role of HDV in the Transport Sector

- Of today's **170 Mt/a CO_2** emissions in transport, **40 Mt** are caused by heavy commercial vehicles (>3.5t)
- Growth of road freight transport volume
- Limited relocation potential on rail

Take-Away Message

- Especially **heavy trucks (40t)** cause disproportionately high emissions due to typically high mileages and vehicle weight.



Previous Work: A Viable Network of Hydrogen Refuelling Stations

HRS locations were determined using a Node-Capacitated Fuel Refuelling Location Model (NC-FRLM) that minimizes the number of stations to cover the hydrogen demand.

Inputs

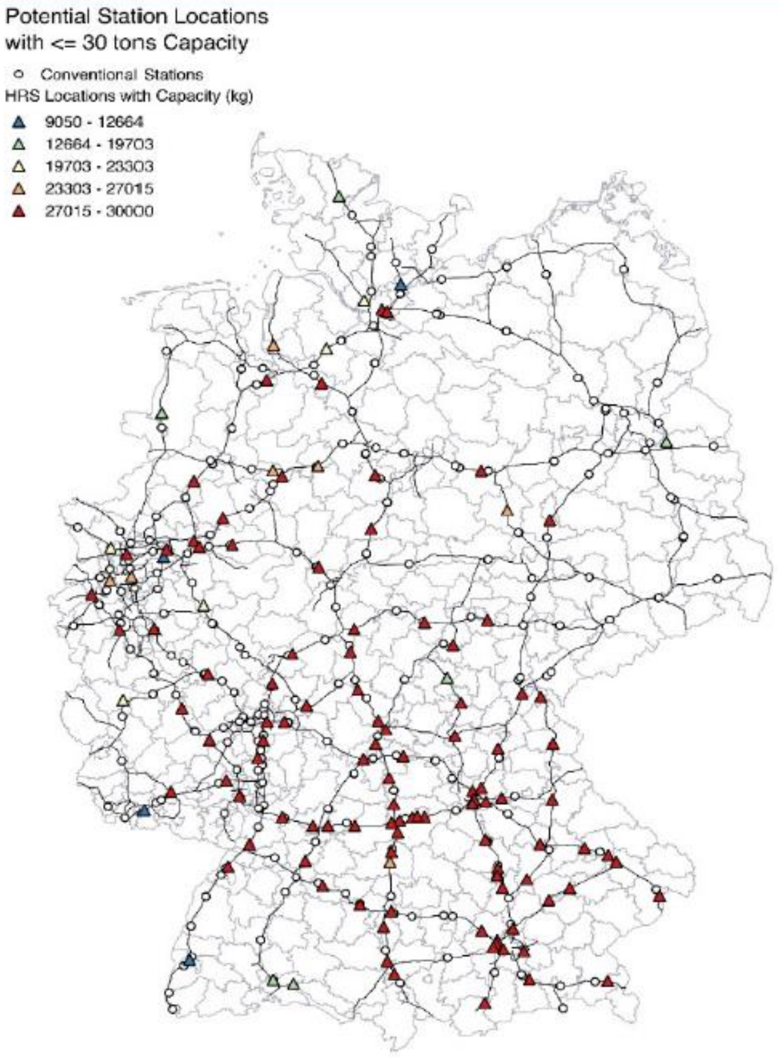
- HDV traffic density per section in the German highway network from a traffic census (BASt)
- Forecast of HDV traffic volume until 2050 (IEA)
- Driving profiles (origin-destination) for NUTS3 regions
- Technical parameters (e.g. range and consumption rates)
- Assuming 100% market diffusion of FC-HDV
- Discrete set of station sizes and sites *(7.5t, 15t, 30t)*

Outputs

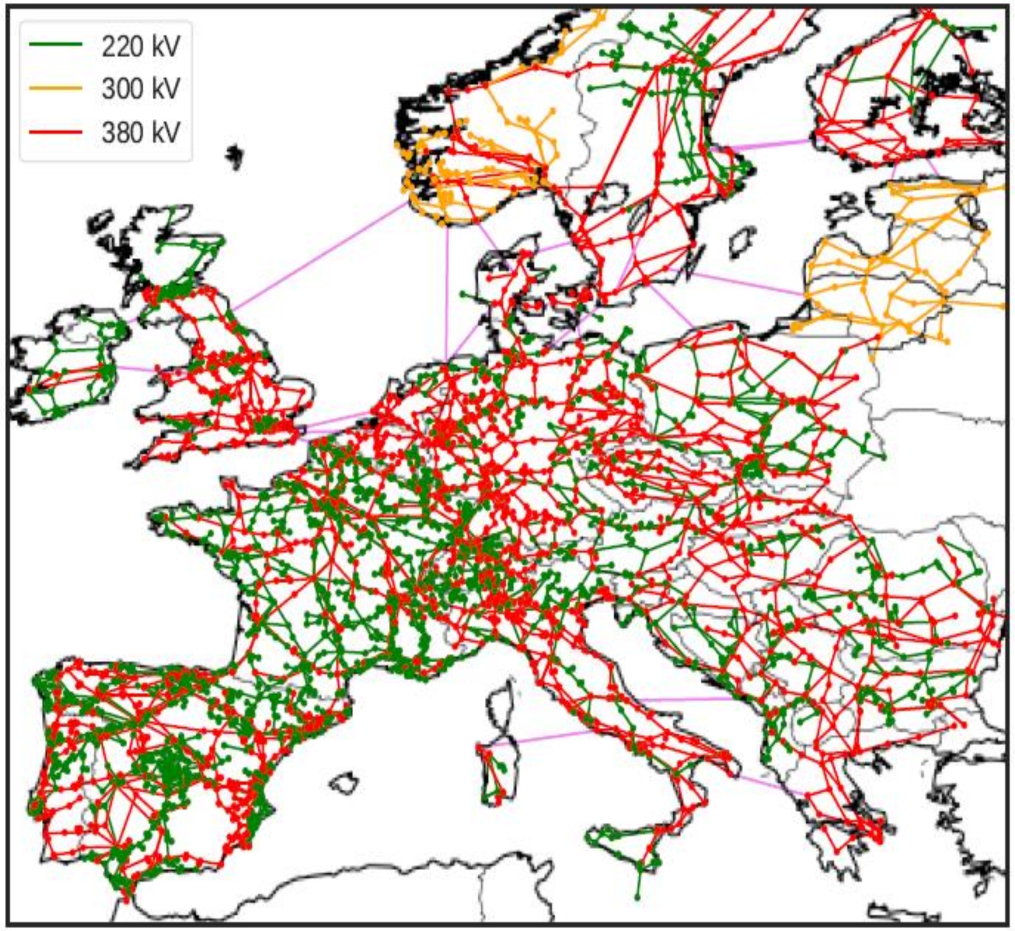
- Minimum viable set of HRS locations and sizes to serve HDV hydrogen demand **with onsite electrolysis**.

Results (2050)

- HRS network for FC-HDV-based road freight traffic consists of **142 stations** with maximum capacity of 30t/d.
- **Number of required HRS** depends on maximum capacity.



Methodology: Open Energy System Modelling with PyPSA-Eur



- Grid data based on **GridKit** extraction of ENTSO-E interactive map
- **powerplantmatching** tool combines open databases using matching algorithm DUKE
- Renewable energy time series from open **atlite**, based on Aarhus University REatlas
- Geographic potentials for RE from land use databases processed with **glaes**
- Optional: time series aggregation with **tsam**
- Basic **validation** performed in Hörsch et al 'PyPSA-Eur: An Open Optimisation Model of the European Transmission System'

Methodology: Open Energy System Modelling with PyPSA-Eur

Find the long-term cost-optimal energy system, including investments and short-term costs:

$$\text{Minimise}\left(\textbf{Yearly system costs}\right) = \sum_{n}\left(\textbf{Annualised capital costs}\right) + \sum_{n,t}\left(\textbf{Marginal costs}\right)$$

Model Scope

- German extract of European model
- Temporal resolution of **2 hours** (4380 snapshots)
- Spatial resolution of **333 nodes**
- max. **30 Mt/a** CO_2 emissions

Experimental Setup

- greenfield optimisation
- power plants are extendable
- excluding nuclear and coal power plants
- transmission grid is extendable
- HVDC links route options from TYNDP
- hydrogen and battery storage options

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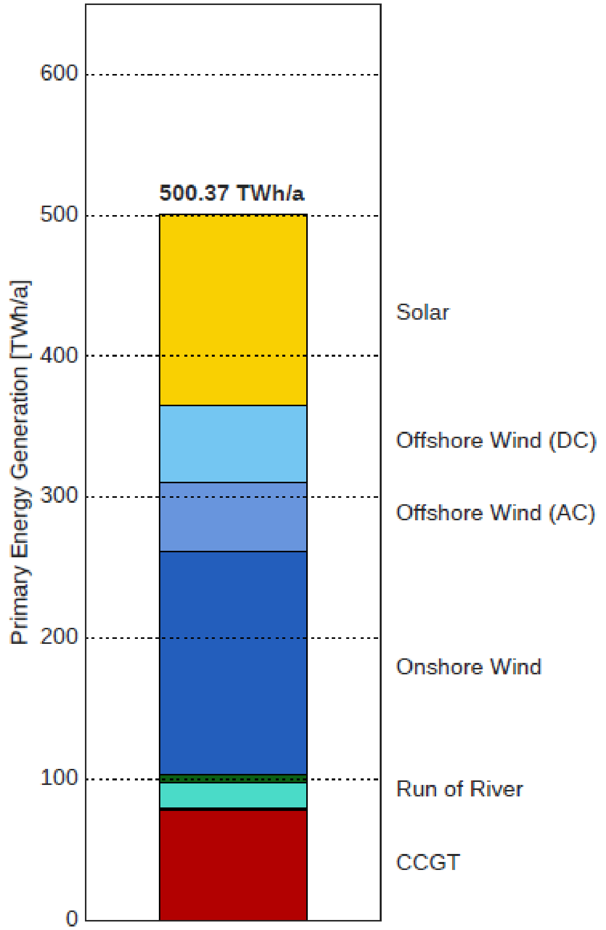
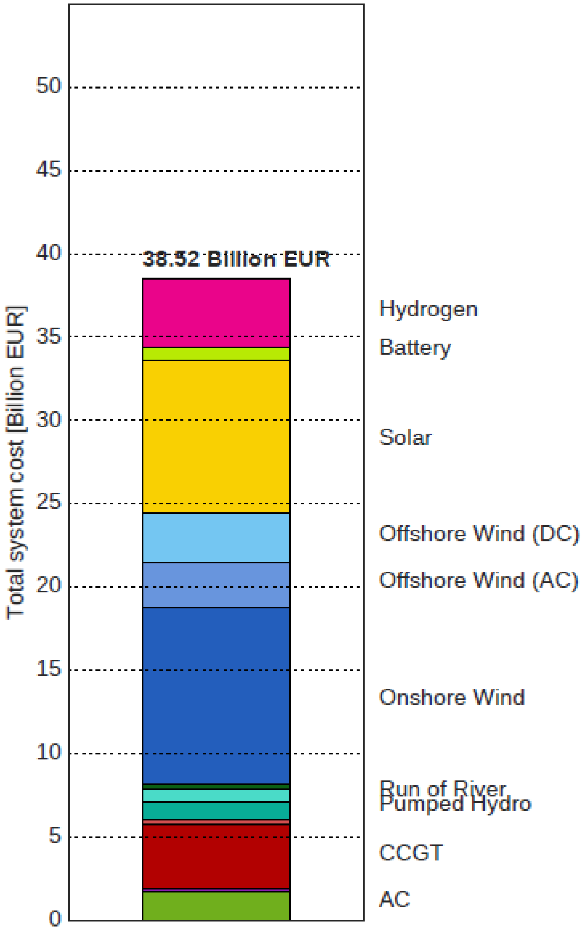
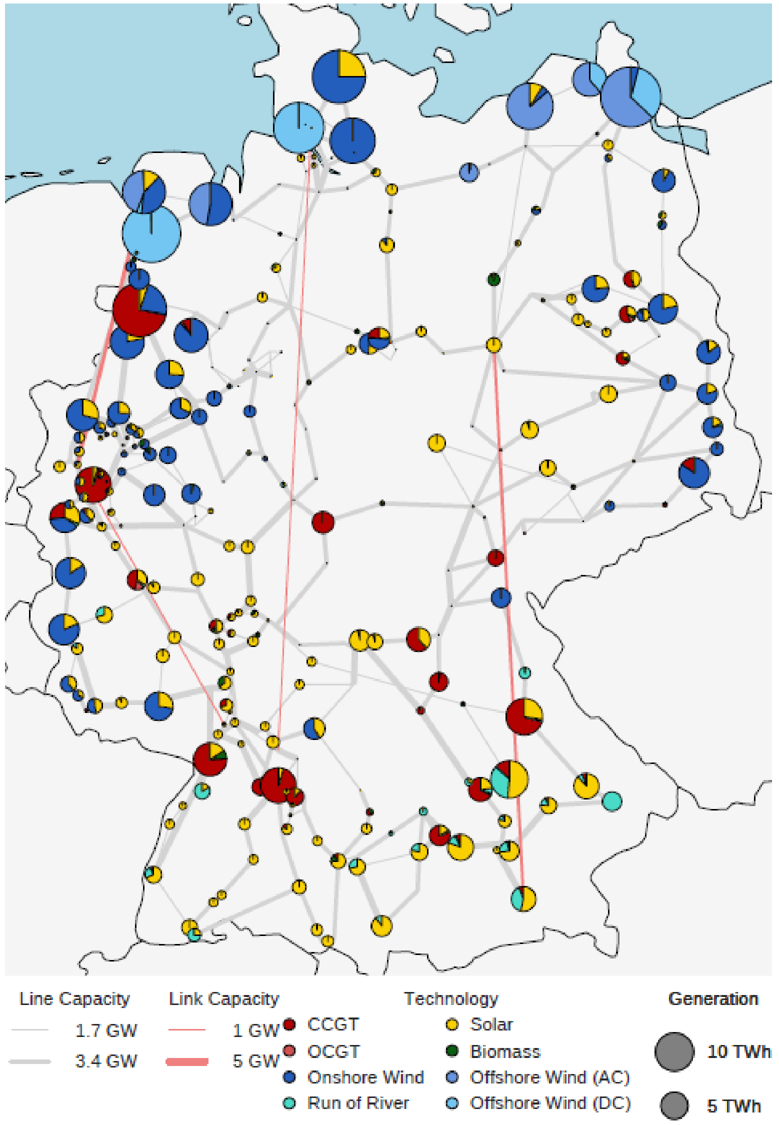
The German Power System without HRS (30 Mt/a CO_2-Cap)





76.98 EUR/MWh



Two HRS Dimensioning Scenarios for Power System Integration

Scenario:

System-Ignorant Investment in HRS

- locally optimal station size
- minimise capital expenditures (CAPEX)

Scenario:

System-Aware Investment in HRS

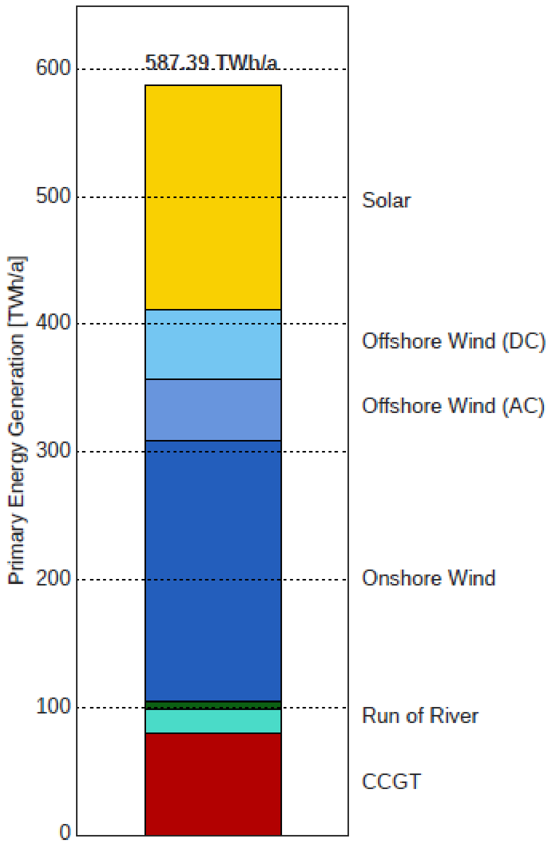
- globally optimal station size
- serve to minimise total system costs

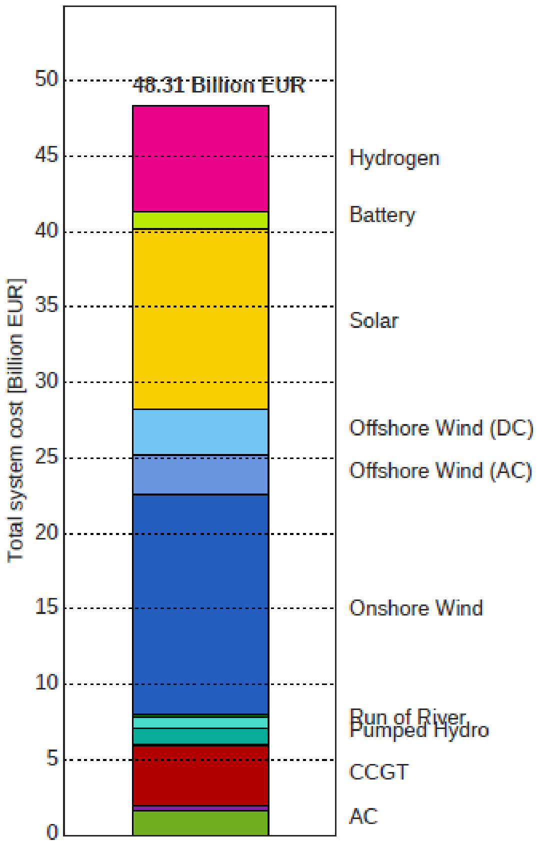
In both scenarios...

- local hydrogen demand must be met,
- no reconversion of hydrogen to power is allowed at HRS,
- maximum hydrogen storage capacity is 30 tonnes (1000 MWh),
- connection cost of electrolyser is proportional to distance to nearest (U-)HV-substation,
- CO_2-emissions for electricity sector plus refuelling infrastructure must not exceed 30 Mt/a.

How Does Total System Cost Change with More Flexible HRS?

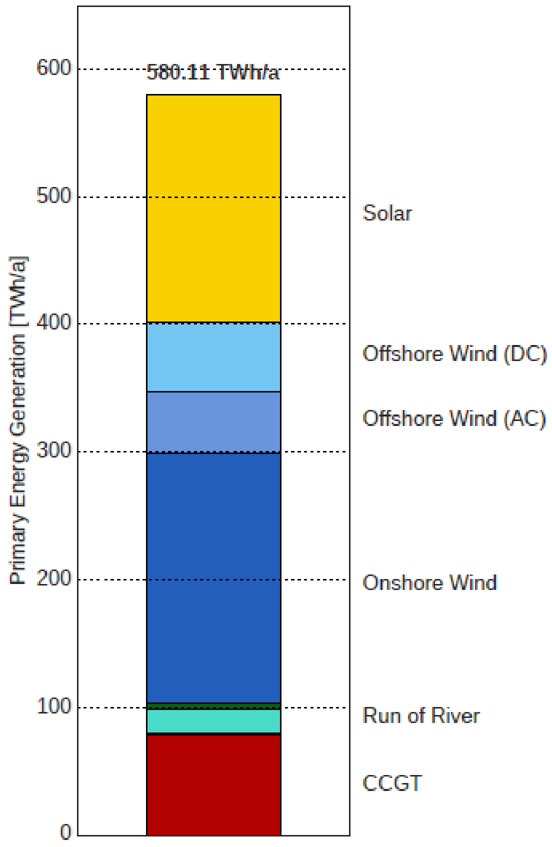
System-Ignorant HRS

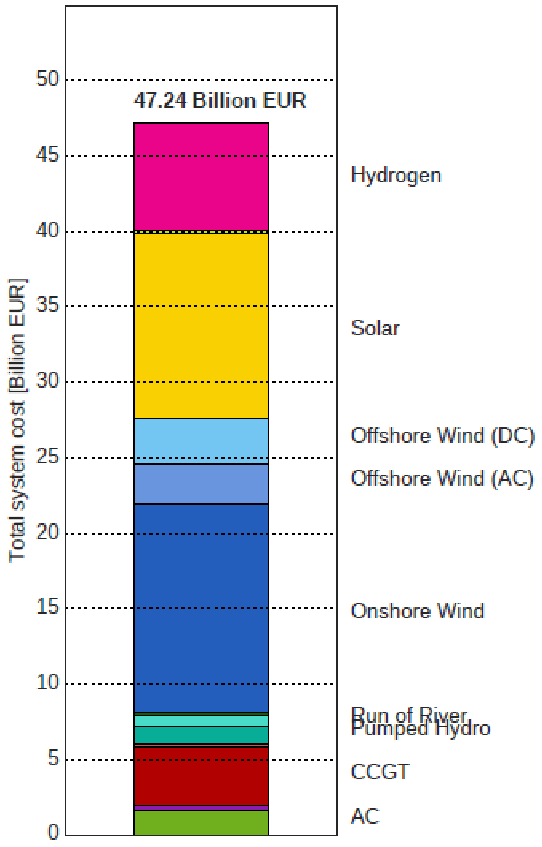




Average: **82.25 EUR/MWh**

System-Aware HRS

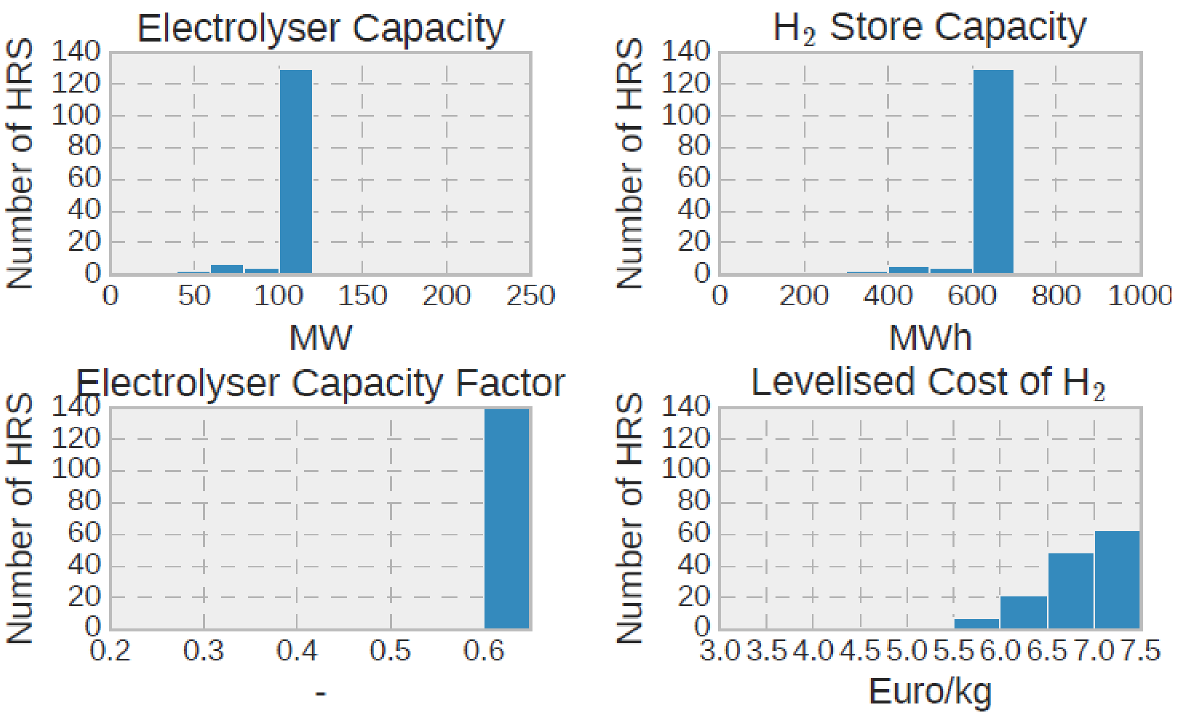




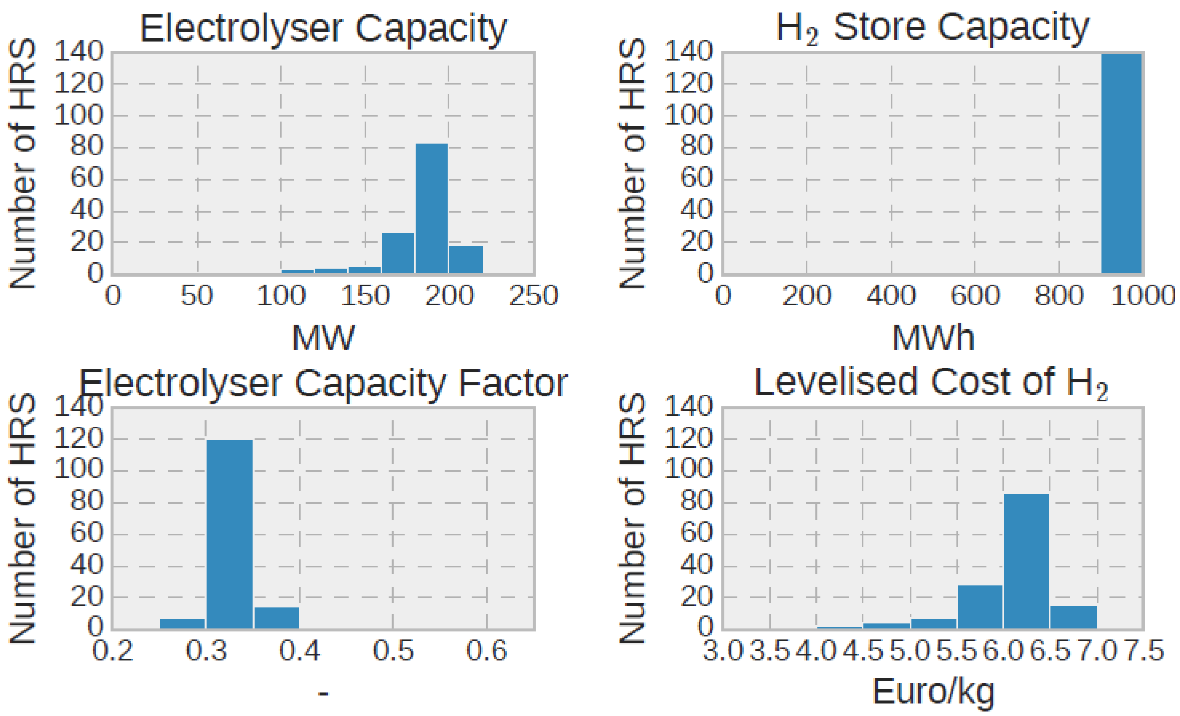
Average: **81.43 EUR/MWh**

Let's look at this from another perspective...

System-Ignorant HRS

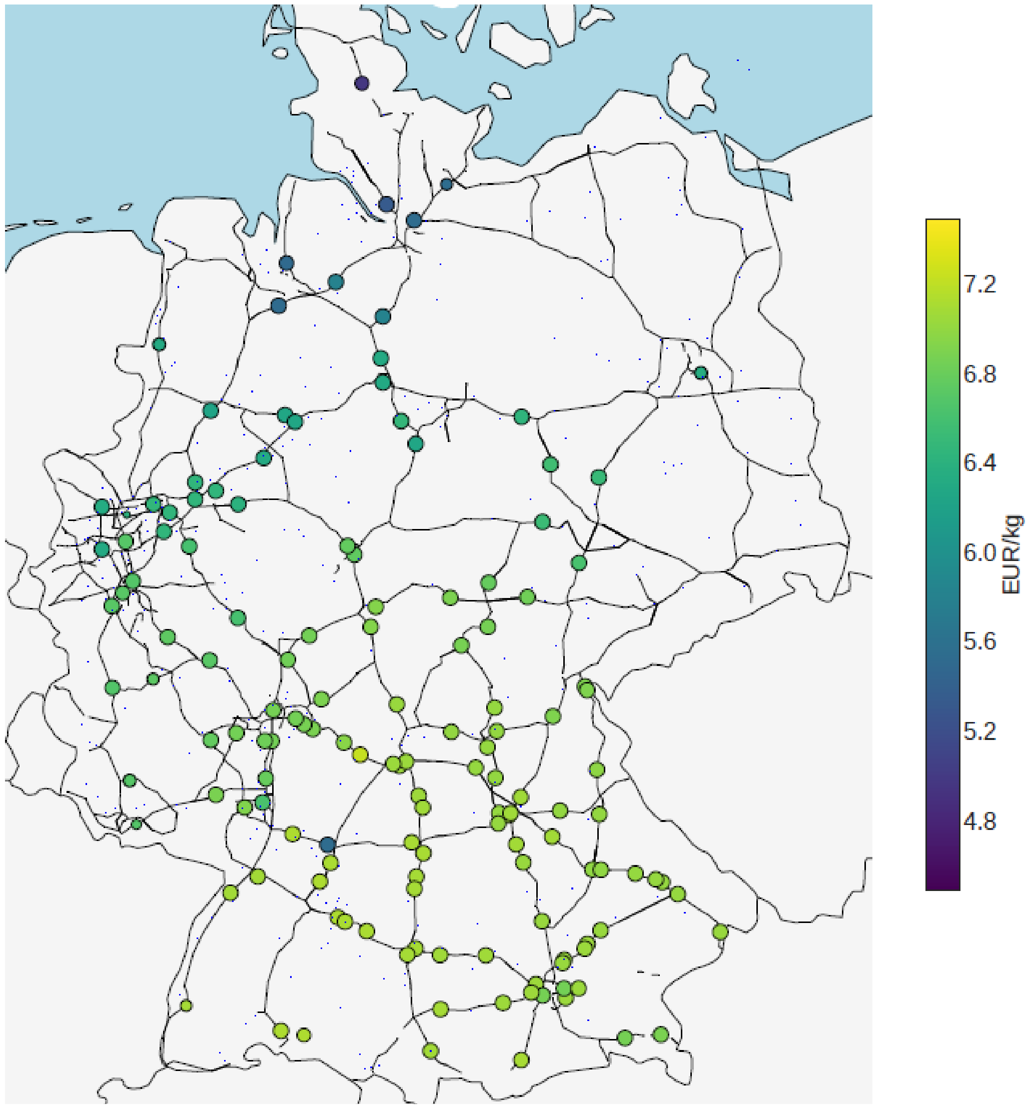


System-Aware HRS

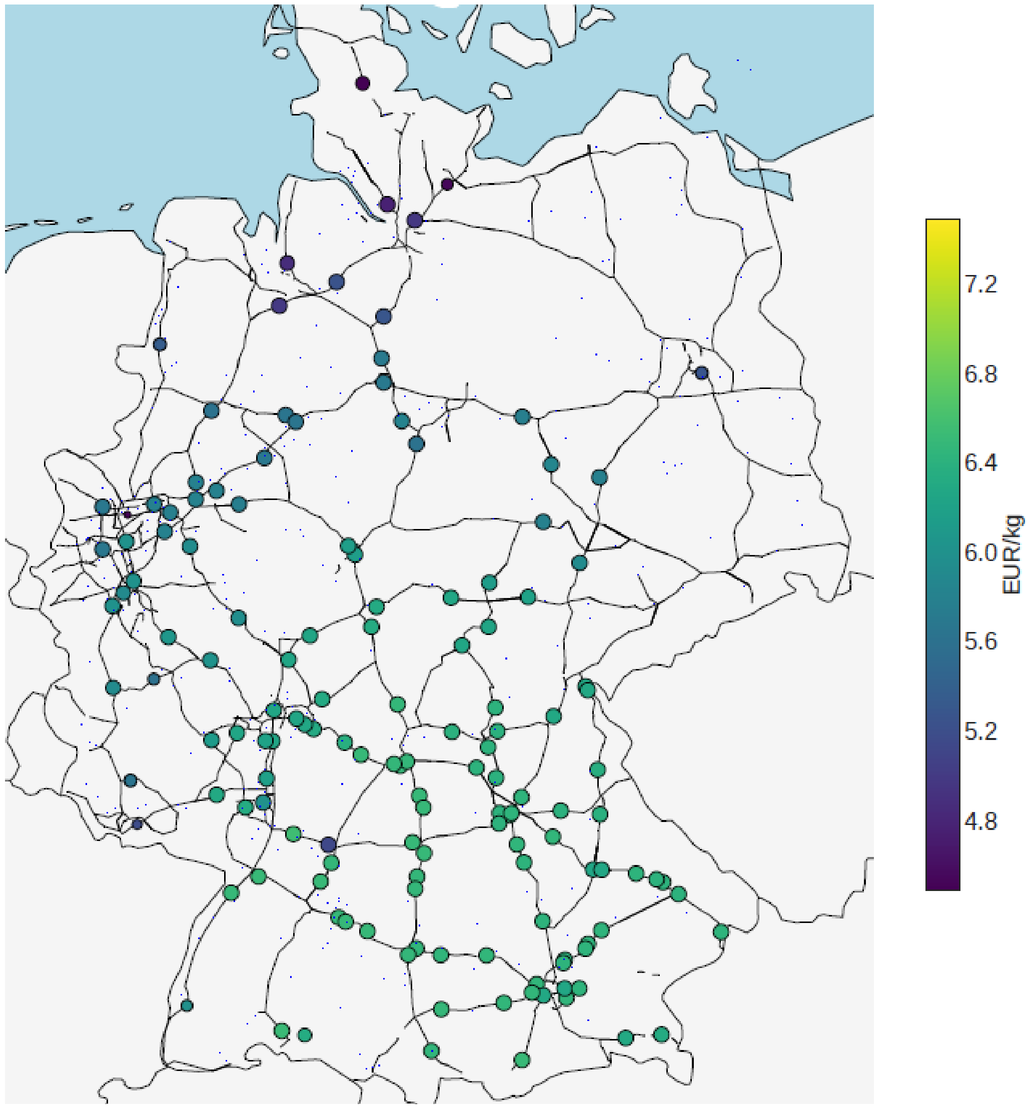


Levelised Cost of Hydrogen – A North-South Divide

System-Ignorant HRS



System-Aware HRS



In a Nutshell...

	Without HRS	System-Ignorant	System-Aware
Annual Electricity Demand [TWh]	463	537	537
– Hydrogen Refuelling	–	74	74
LCOH [EUR/kg]	–	6.66	5.97
– CAPEX Share [%]	–	9.6	20.0
Electrolyser Capacity Factors [-]	–	0.61	0.33
Total System Cost [EUR/MWh]	77.0	82.3	81.4
Total System Cost [bn EUR]	38.5	48.3	47.2
– HRS Electrolysis	–	1.0	1.8
– HRS Storage	–	0.2	0.3
– Other Storage (Battery, Hydro & Hydrogen)	6.0	8.0	6.4
Generation Fleet [GW]	304	381	383
HRS Electrolysers [GW]	–	13.9	25.6
HRS Hydrogen Storage [GWh]	–	93	142

What are the Take-Away Messages?

1. A **node-capacity limit** has a major impact on the number of refuelling stations required.
2. **Levelised Cost of Hydrogen (LCOH) vary regionally** depending on local cost of electricity production.
3. **System-aware dimensioning** of hydrogen refuelling infrastructure reduces LCOH (0.7 EUR/kg_{H_2}) as well as total system cost (1 Billion EUR/a).
4. **Co-optimization of multiple energy sectors** is important for planning to exploit synergies and cost reduction potentials.
5. **Nodal pricing** can forward useful information about total system cost.

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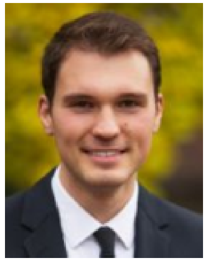

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