Results from the German case study

Stefan Flamme, Daniel Benrath, Sabrina Glanz, Franziska Hoffart

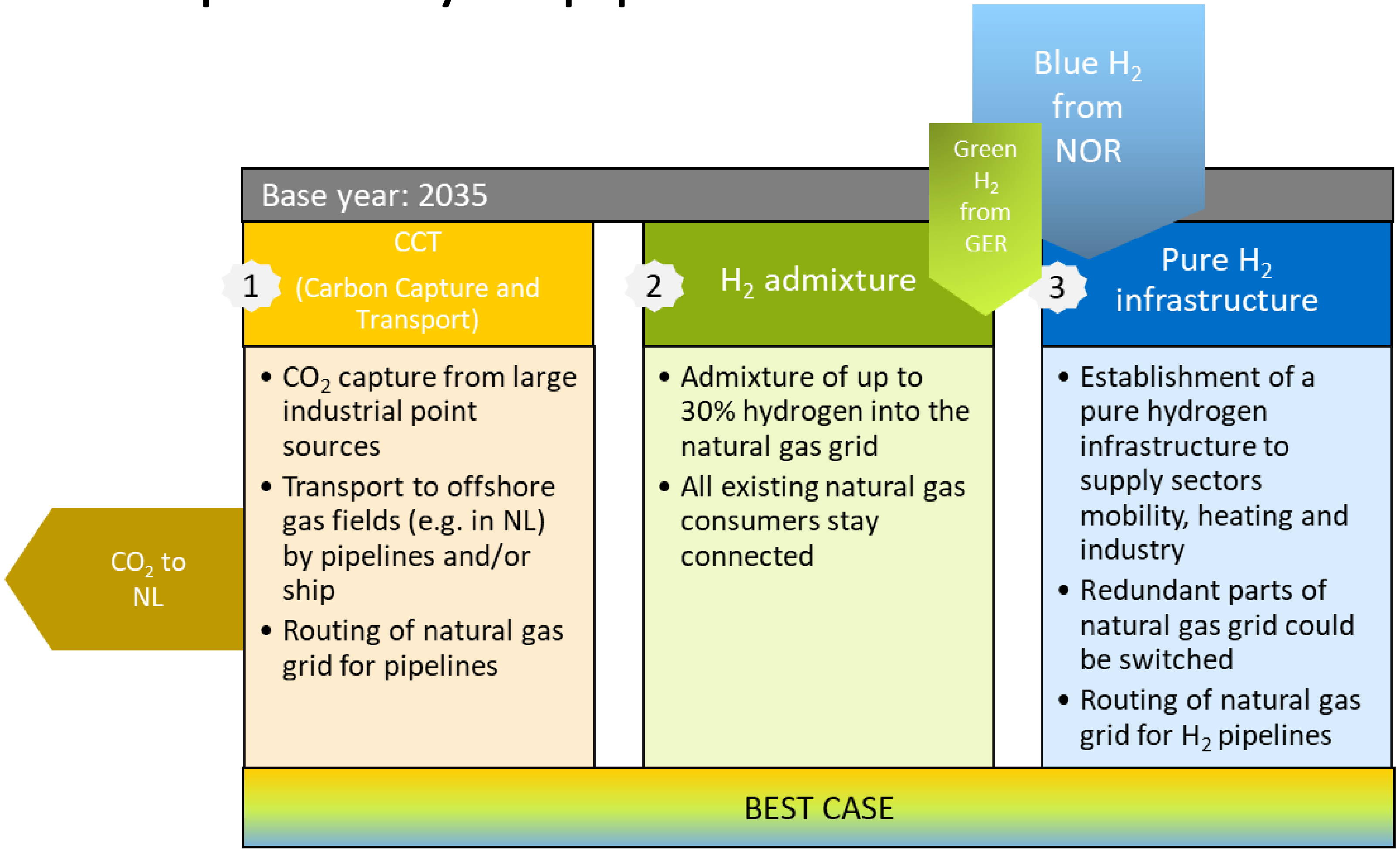
Ruhr-University Bochum, Germany

ELEGANCY Final Webinar Series

Webinar 2 06-19-2020

Table of contents

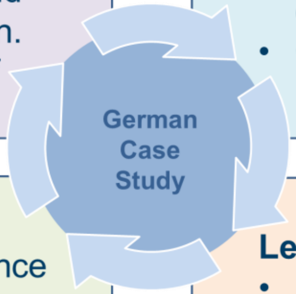
0. The Infrastructure Options and the Interdisciplinary Approach



0. The Infrastructure Options and the Interdisciplinary Approach

Technical approach:
- Aim: evaluation of the three infrastructure options in terms of their CO_2 reduction potential and abatement costs, on which basis a best case scenario could be designed
- Approach: GIS-based model for the three infrastructure options, consisting of future framework conditions and specific data on the H_2/CO_2 sites under consideration. The infrastructure is planned based on the routing of the natural gas network.

Macroeconomic approach:
- Aim: to assess the conditions that foster or hinder the transition towards a low-carbon economy by evaluating the different infrastructure options
- Approach: stakeholder-centred economic analysis that provides macroeconomic descriptive scenarios for decision making
- Criterion for evaluating the infrastructure options: political and economical realisability



Sociological approach:
- Aim: to identify chances and risks for public acceptance of the options and to work out possible approaches to their implementation
- Approach: mixed-methods-design including interviews with stakeholders and quantitative online survey
- Focus: state of awareness and knowledge, technology perception/evaluation, factors influencing the acceptance

Legal approach:
- Aim: regulatory framework relevant for infrastructure options (restrictions, costs, barriers, support) in current law and in legal perspective
- Approach: analysis of existing law; systematic lines and legal constraints for further development
- Focal points: special rules for H_2 and CO_2 transport; re-use of existing infrastructure; cross border frictions

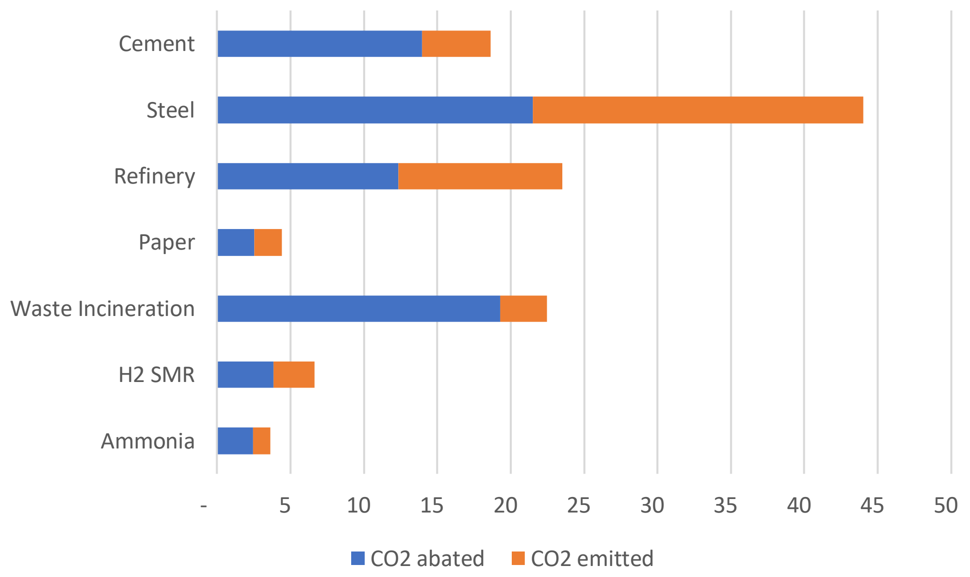
2. Carbon Capture and Transport (CCT)

➢ Determination of Abatement Potential

- Industrial CO_2 sources (mostly from E-PRTR)
- Calculations based on specific data on CCS at an exemplary site
- Data on CO_2 compression aligned to 110 bar

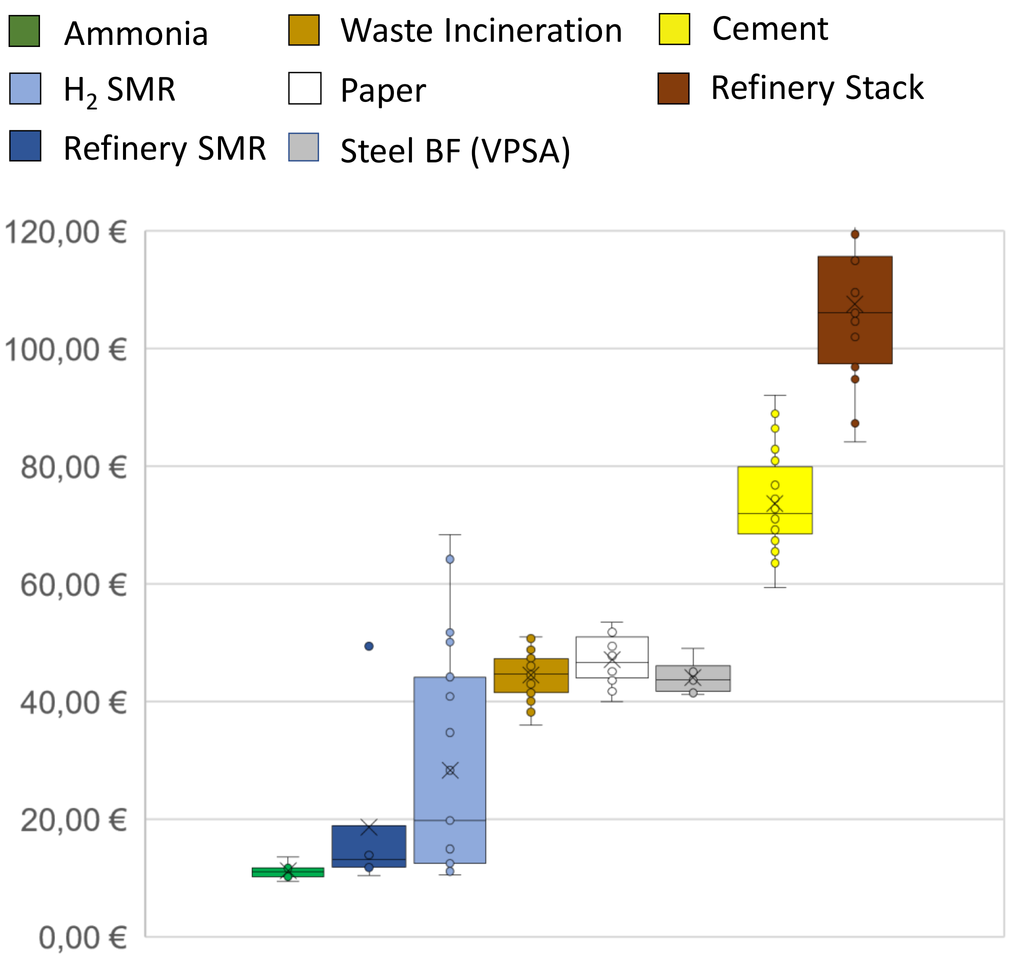
➢ Determination of Abatement Costs and CO_2 Amounts Avoided

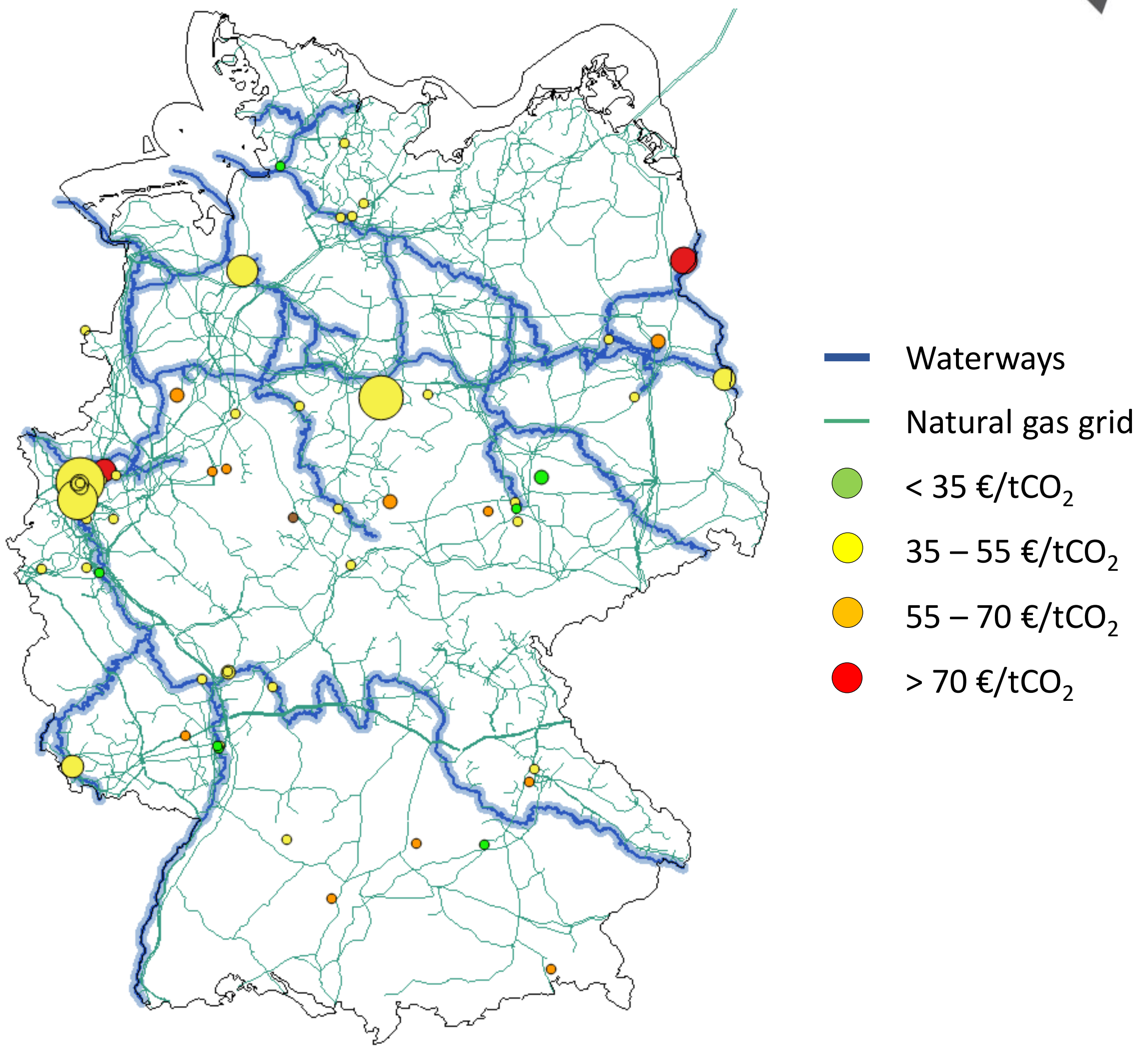
- Post combustion capture with amine scrubbing or VPSA, except for pure CO_2 streams in hydrogen applications
- Scaling factor for Capital Costs (~0,7)
- All costs adjusted to $€_{2015}$
- Base Case:
  - Electricity: 55 €/MWh, 267 gCO_2/kWh_{el}
  - Natural gas: 28 €/MWh, 201 gCO_2/kWh



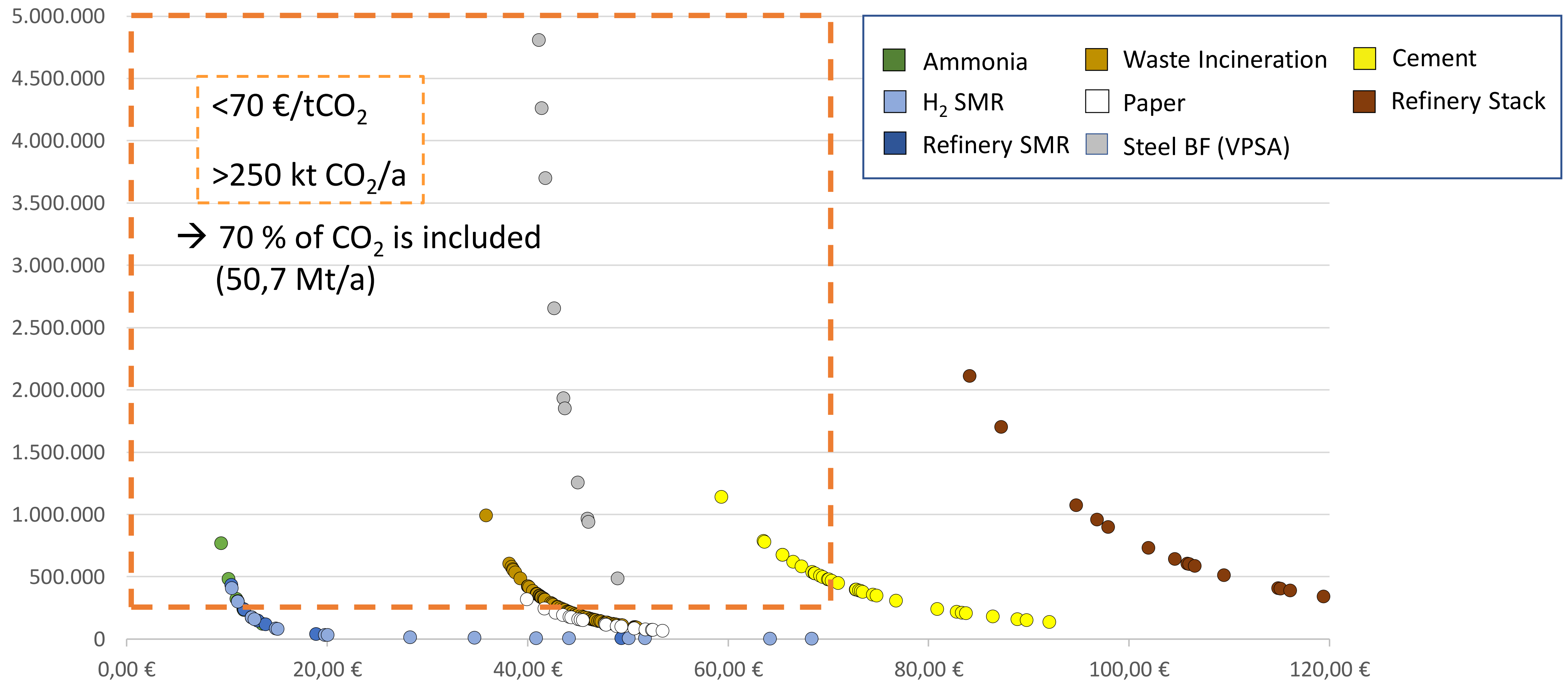
CO_2 abated: 76 Mt/a
emitted: 47 Mt/a
(total: 123 Mt/a)

CO_2 Abatement Costs





Selection of Sources for CCS

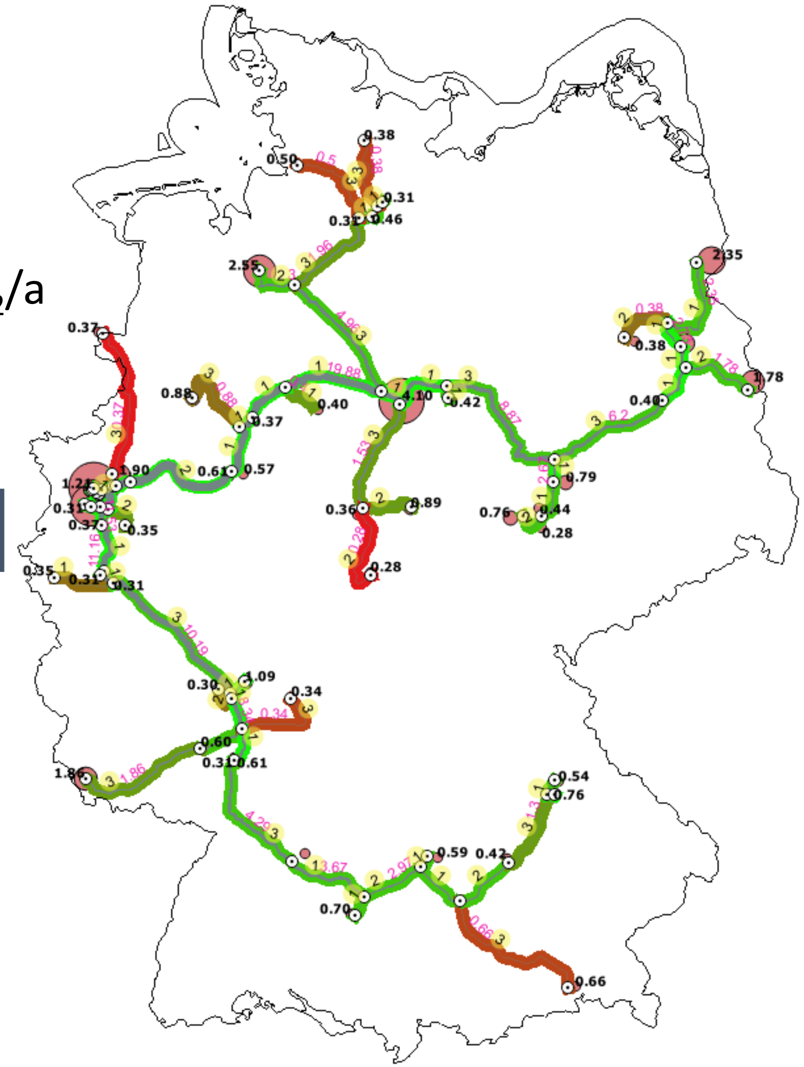


CO_2 Pipeline Modeling

50,7 Mt CO_2/a

5,96 €/tCO_2

CO_2 to NL



- Quadratic functions for investment costs of pipeline depending on diameter and length (Parker and IEAGHG)
- Haaland-approximation of Darcy friction factor for pressure losses:

$$\frac{1}{\sqrt{f}} = -1.8 \log\left[\left(\frac{\varepsilon/D}{3.7}\right)^{1.11} + \frac{6.9}{\mathrm{Re}}\right]$$

- Load Factor 0.9
- Operating Pressure: 110 - 86 bar
- Booster station in every section of pipeline with losses >1.5 bar
- Cost optimization of every section adjusting the transport velocity (1 to 4 m/s) with a solver to find cost minimum between diameter and number of booster stations (max. 3 per section)

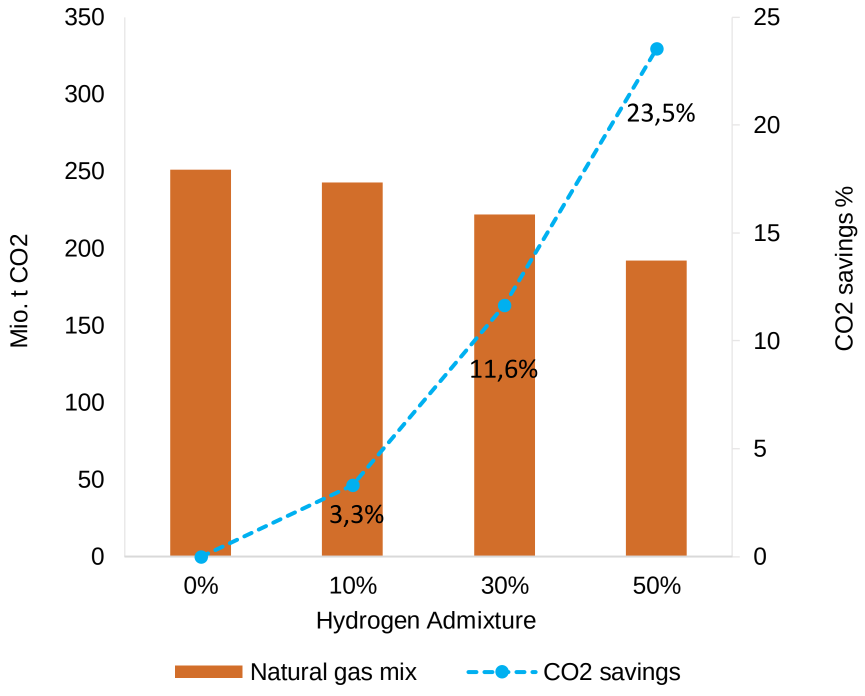
2. Hydrogen Admixture

- Higher amounts of green gases in the natural gas grid are considered as external developments
- Blue hydrogen from Norway will only be used to flatten the curve of admixture when necessary
- Determination of potential
  - Amounts of hydrogen needed for 10, 30 and 50% in natural gas grid (energy content of the grid must be maintained)
  - CO_2 saving potentials
- Determination of costs
  - Determination of costs for the admixture levels in distribution and transport infrastructure based on DVGW studies

Option 2 – Hydrogen Admixture: Potential Analysis

Hydrogen admixture level	Amounts of hydrogen admixed	Total volume flow increase of mixture	CO2 saving potential
10%	27 TWh/a	7%	8 Mt/a
30%	95 TWh/a	26%	30 Mt/a
50%	191 TWh/a	53%	60 Mt/a

Surplus electricity in 2035: >100 TWh/a



CO_2 saving potential by hydrogen admixture level

Option 2 – Hydrogen Admixture: Costs of Infrastructure Adjustments

Level	Distr.	Transp.	SUM
Replacement Investments	*95,5*	*50*	*145,5*
Extraordinary costs H_2 admixture	3,2	9,6	12,8
Methanization	0	0,1	0,1
Methanization porous UGS	-	1	1
SUM extra costs	**3,2**	**10,7**	**13,9**

2020 to 2035: Costs to reach 25% H_2 in transport network and 50% in distribution network [x 10^9 €] [DVGW]

3. Pure Hydrogen Infrastructure

➢Hydrogen demand determination for the target year 2035

- Inventory of the current status within the targeted sectors
- Meta study → specific data
- Forecast for 2035 via meta study and trend calculation
- Distribution of the data on NUTS 3 level
- 0,97 $kgCO_2/kgH_2$ (Norwegian case study)

➢Pipeline infrastructure planning

- Hotspots to be connected to a first pipeline
- Pipeline modelling based on the same approach as for CO_2 pipelines

Mobility Sector

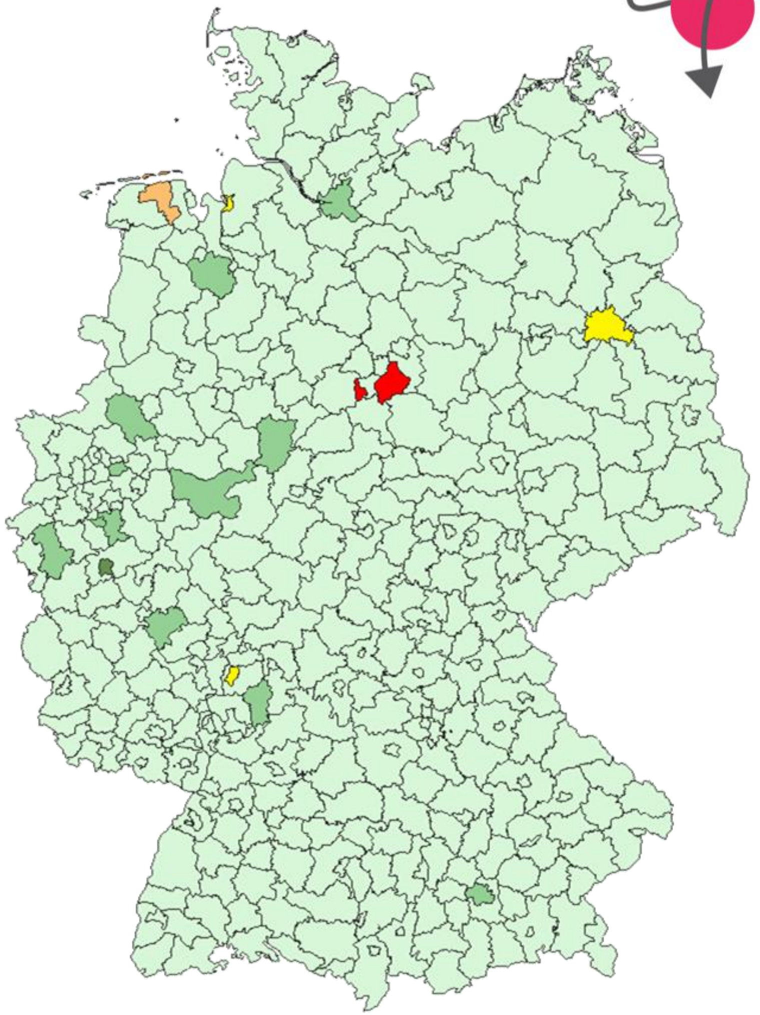
MOBILITY

Fuel cell vehicles

- Passenger cars
- Public transport
  - Buses
  - Trains
- Freight transport
  - Rail freight transport
  - Truck freight transport

Methodology for NUTS-3

- Meta study and trend functions for the overall hydrogen demands in the subsectors
- Determination of a distribution factor based on specific localized data, e.g.:
  - Current fleet numbers
  - Mileage or passenger volumes
  - Fuel consumption
  - Share of diesel vehicles (to be replaced)
  - Population density
  - Federal financial aids
  - GDP & income



Mobility demands in 2035:
25 TWh/a
-21 Mt CO_2/a

Heating Sector

HEATING

District heating networks

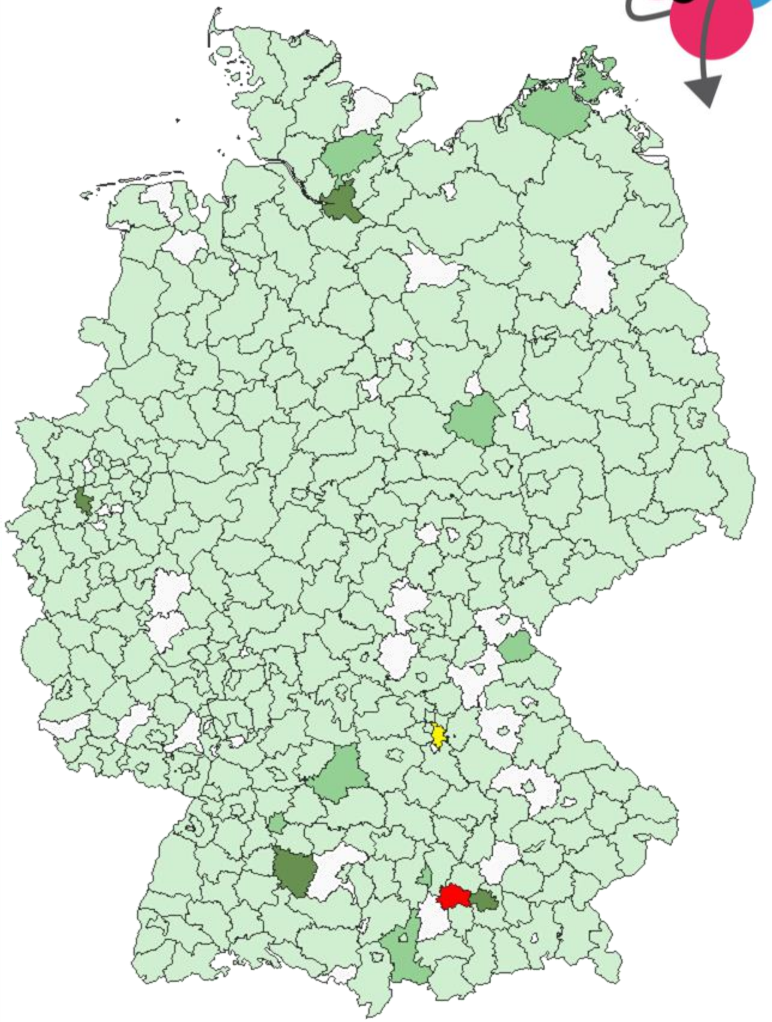
- Hydrogen-powered combined heat and power units (CHP)

- *Housing, small business and industrial heating*

Methodology for NUTS-3

- Determination of future hydrogen distribution based on reported CHP plant sites and their capacity

- *Determination of future hydrogen distribution by statistical data on district heating*



Heating demands in 2035:
27 TWh/a
-6 Mt CO_2/a

Industry Sector

INDUSTRY

Assessment of current hydrogen producers/consumers

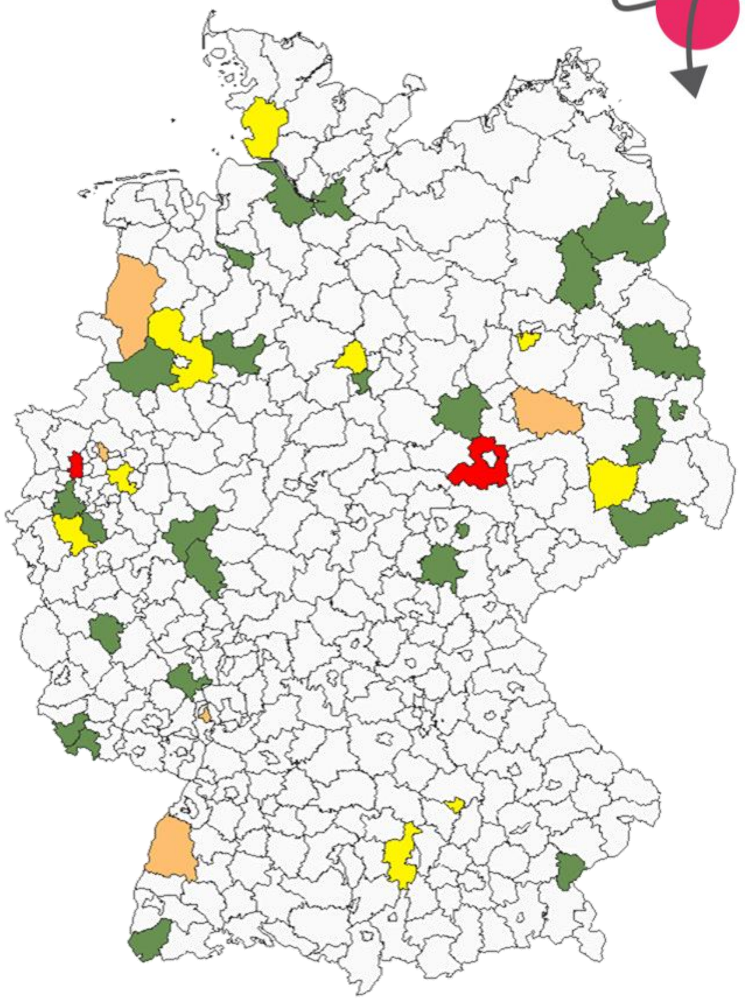
- Merchant, captive, (by-product)

Steel production

- Hydrogen as a reducing agent in blast furnaces (BF)
- Hydrogen-operated direct reduction plants
- *Perspective 2035-2050: BF converted into EAF with hydrogen direct reduction*

Methodology for NUTS-3

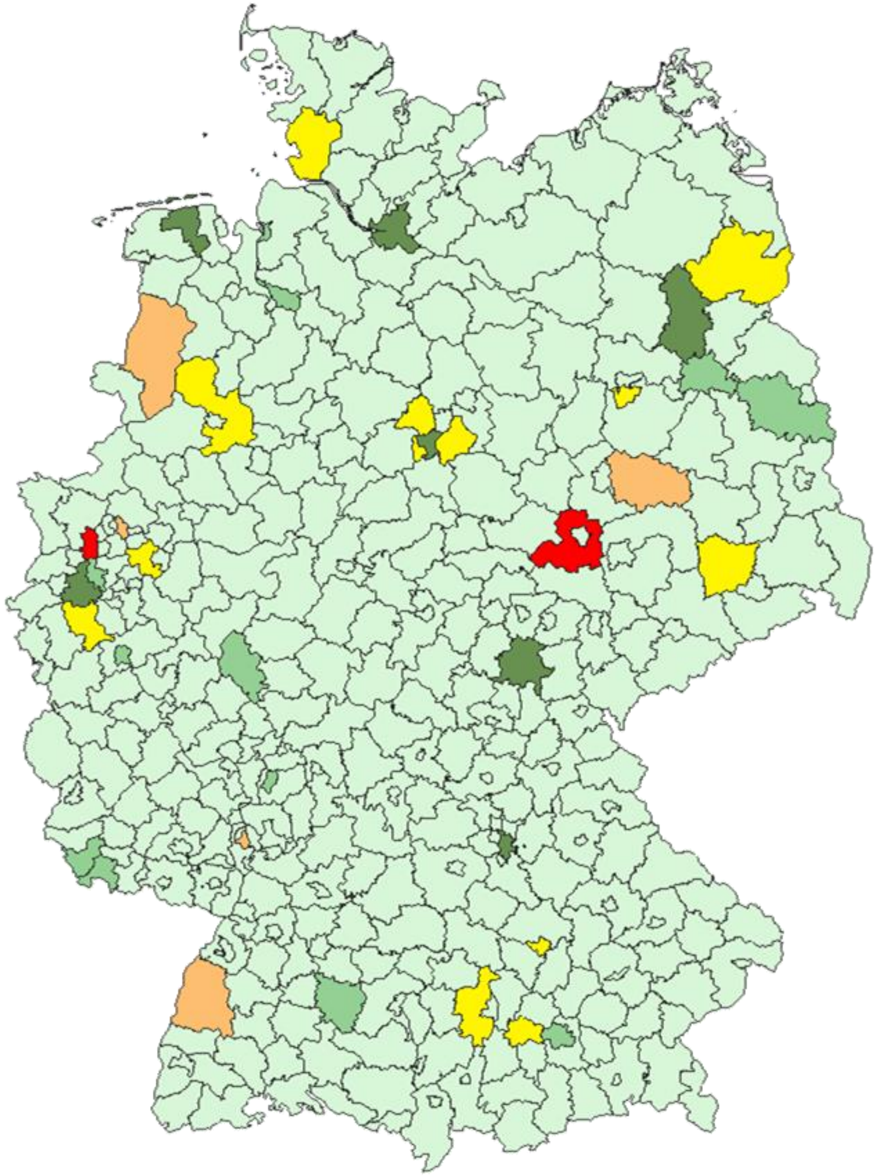
- Determination of future hydrogen demands for hydrogen industry by data on the actual hydrogen consumption
- Determination of hydrogen demands in the steel industry using hydrogen demand per ton of steel as reducing agent in BF and for EAF



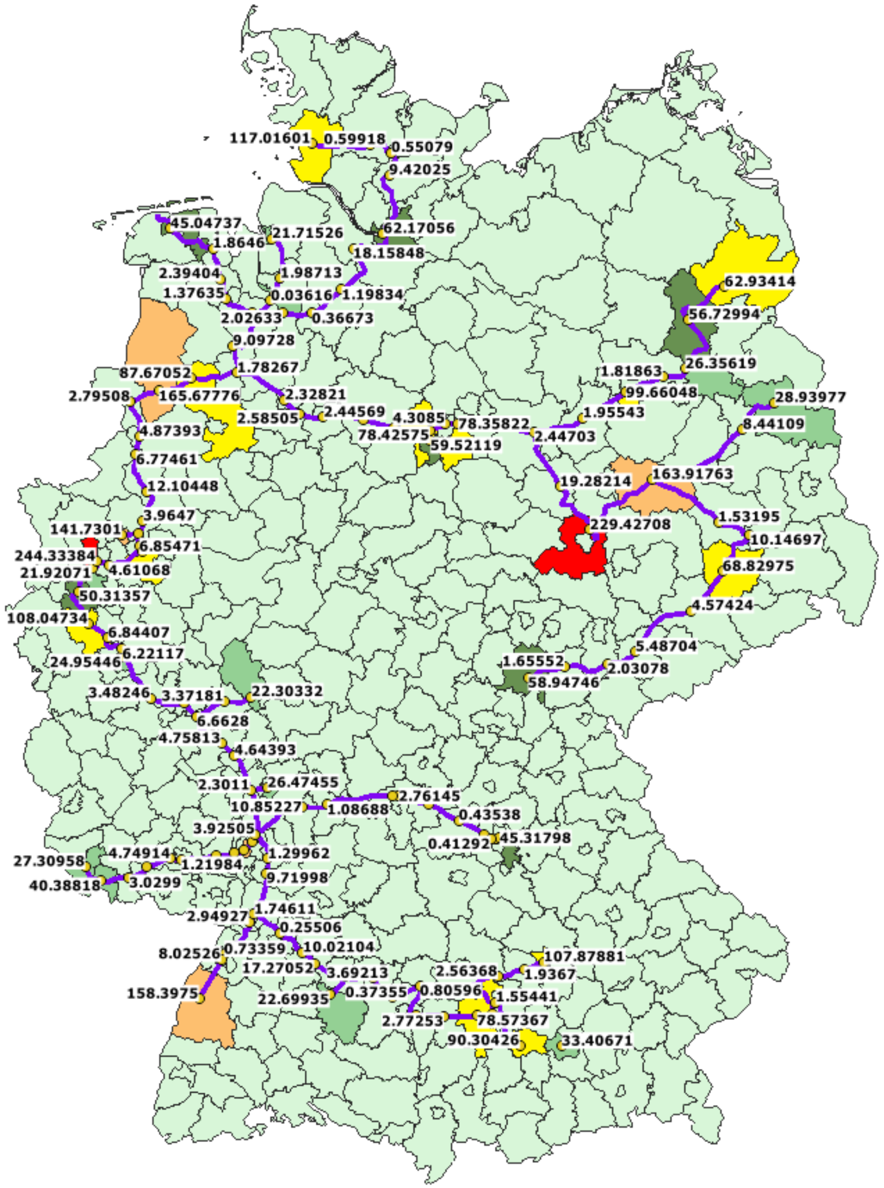
Industry demands in 2035:
85 TWh/a
-37 Mt CO_2/a

German Hydrogen Demands for 2035

Sector	2035 H_2 demands	*CO2 saving potential*
Mobility	25 TWh/a	*21 Mt/a*
Heating	27 TWh/a	*6 Mt/a*
Industry	85 TWh/a	*37 Mt/a*
TOTAL	137 TWh/a	*64 Mt/a*



Hydrogen Pipeline Modeling



- Pipeline routing primarily connecting hot spot areas (58,3 TWh/a)
- With regions on the way also being connected, around 110 TWh/a can be supplied (over 80% of calculated demand)
- Pipeline modelling is based on the same assumptions and calculations as CO_2 pipelines, with exception of cost functions for pipes and compressors (exponential & quadratic)
- Pressure: 100 - 30 bar, then recompression (much more expansive than pumping CO_2)
- First re-pressurization at transfer station from Europipe
- Probably no further recompression could be the most cost-effective solution

Work in Progress within the Technical Modelling

- CO_2 shipping
- H_2 pipeline optimization with solver (like CCT option)
- Option of using "redundant" parts of the natural gas grid
- "Replacement costs" for hydrogen applications
- Best-case:
  - CO_2 sources with mid/long term perspective (-> ship/pipelines)
  - Admixture of up to 30% hydrogen into natural gas grid
  - Hydrogen pipelines as backbone, most likely similar to the pure H_2 option

4. Macroeconomic and sociological insights on H_2/CCS infrastructure implementation

Factors	**Interdisciplinary insights**
Stakeholder dynamics	**Stakeholder dynamics** are a **central factor** for a successful infrastructure implementation from an economic and sociological perspective.
Technological feasibility	**Progress and availability** of technology play a **minor role** for the investment in infrastructure, whereas **openness towards technology** as well as the **political and legal framework** are **essential**. Maturity of a technology is important for social acceptance.
CCS technologies	For CCS, the **relation to fossil energy** and its phase out **mainly determines** the economic **feasibility** and the **social acceptance**.
H_2 technologies	For **investments** in **hydrogen** technologies, the **legal and political framework** is **important**. However, for the **success** of hydrogen technologies **both total demand** and its **perception** as ‘green’ energy carrier are **decisive**.
Infrastructure modifications	**The smaller** the **overall level of** a countries **low-carbon transformation**, the **less feasible** it is to implement **extensive infrastructure** modification. The **smaller the degree of modification**, the **higher is the social acceptance** and the chances of a successful implementation.

Macroeconomic and sociological insights on H_2/CCS infrastructure implementation

- **Bottom-up commitment** of the economy and society is **not sufficient** as long as the **political intention** is **missing**.
- **Political intension** and strategies are **necessary** but **not sufficient** for a German H2-CCS chain. **Economic & societal** commitment is **also required**.

Evaluation by survey within the German population:

- **Neutral to positive** evaluation of H2-CCS chains
- **Risks** of the technologies **are perceived higher than benefits** and benefits are perceived more ambivalent
- **CCS** technology is evaluated **rather sceptical**
  - ➢ CCS is evaluated **more positive** if the technology is **located outside Germany** than if the technology is located in/close to Germany
- In contrast, **hydrogen** technology and hydrogen as energy carrier **is mostly evaluated positively**
  - ➢ In **combination with hydrogen** technology, also **CCS is more accepted**
- The **storage** of both CO_2 and H_2 is the **biggest hurdle** in terms of technology and infrastructure acceptance
- Furthermore, **transparency of information** and **citizen participation** during the implementation process are **important** instruments to achieve broad acceptance and to avoid NIMBY effects

5. Legal Aspects

For all H2-CCS infrastructure options, there are deficiencies in the legal regime and legal action is necessary.

- CO_2-pipelines: There is a workable **base to start projects**, but for network operation, there are **conflicts** which demand **legislative action** and some provisions even hinder CO_2-pipelines. Further **legal coordination**, **clarification** and **operational details** are needed to implement working pipeline networks.

- H_2-injections: **Large scale injections** have to be **coordinated**, but the existing **law is not fit** for its challenges. **Complex interventions** within the existing framework are **necessary** to allow large scale injections.

- H_2-pipelines: There is **no specific regime** for dedicated **H_2-pipelines** and the **legal uncertainty** creates **barriers for investments**. These barriers can easily be removed by **clarifying** the legislation.

6. Best-Case Option & Common Analysis

Approach of the common analysis

- Identification of relevant potentials and risks from different disciplinary perspectives
- Reflection on measures to realize potentials and to mitigate risks
- Interdisciplinary analysis of interconnections and conditions

Technical

Macro-economic

Best-Case 2035:

Combination of a natural gas grid with admixed hydrogen, a separate, expandable infrastructure to supply hydrogen hotspots and CCT for industrial sources with mid/long term CO_2 emissions
- synergies between the options need to be found and implemented -

Social

Legal

Workshop of German Case Study

- On July 28th as webinar
- More detailed information and results from all disciplines
- Language will be German due to local stakeholder focus
- For information and registration: Daniel.Benrath@rub.de

Thanks for your attention ☺

Acknowledgement

ACT ELEGANCY, Project No 271498, has received funding from DETEC (CH), BMWi (DE), RVO (NL), Gassnova (NO), BEIS (UK), Gassco, Equinor and Total, and is cofunded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712.