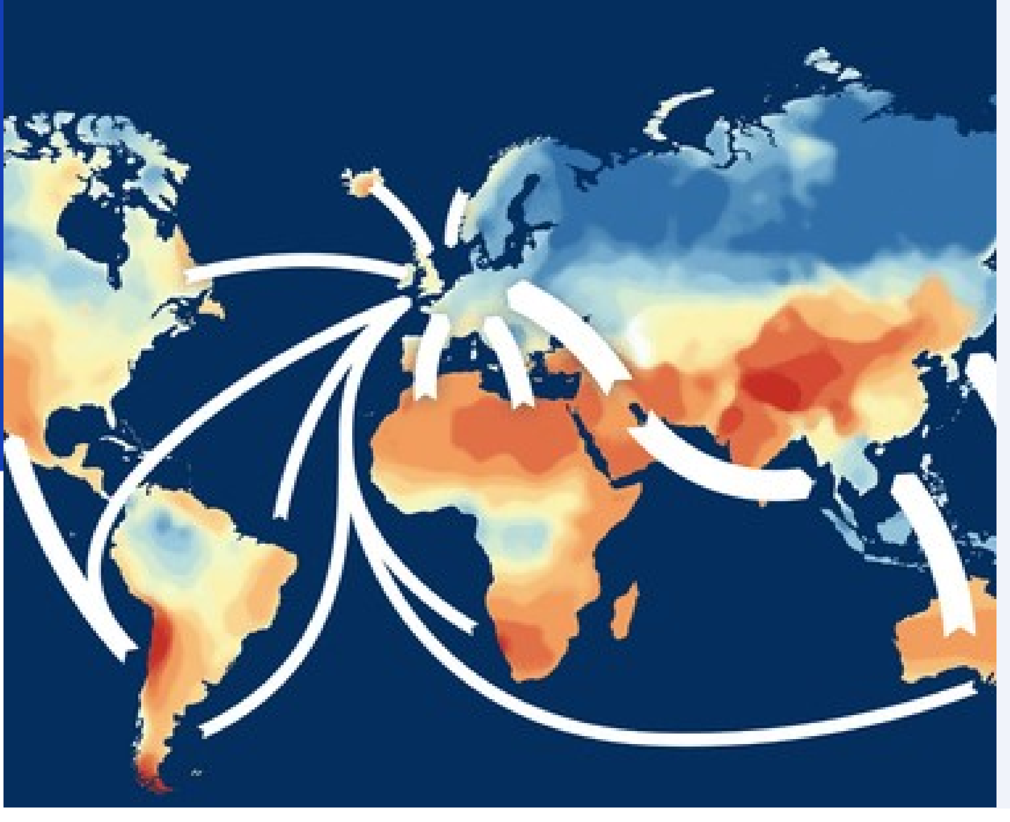
SHIP>NL sessie V 2024

Drs. M.C.M. Rijkers

Start presentation

TNO innovation for life

Agenda SHIP>NL sessie V 22 mei 2024



1. Welkom
2. Reflectie: World Hydrogen Summit 2024 |
   Carla Robledo, Min.EZK
   David Koole, RVO
3. Deep dive: How green is your imported hydrogen? |
   Alessandro Arrigoni, JRC
   Thomas Hajonides & Thomas Hennequin, TNO
4. Afsluiting & Borrel

Huisregels

- Telefoon op ‘stil’; laptop gesloten
- Vragen? Steek je hand op!
- De moderator zorgt ervoor dat je vraag beantwoord wordt (eventueel achteraf).
- Slides worden na de sessie gedeeld en zijn te vinden op SHIPNL: Sustainable Hydrogen Import Program Netherlands | Nationaal Waterstof Programma
- We bespreken uiteraard geen marktgevoelige zaken.
- Chatham house rules: De besproken informatie mag gedeeld worden, maar zonder de spreker te onthullen.

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Meerjarig kennisprogramma met 5 lijnen

- **In deze sessie:**

1 Technisch economisch	2 Beleid	3 Markt	4 Internationaal	5 Omgeving
▪ Inzicht in importketens productie-conversie-transport-opslag-reconversie-gebruik ▪ Vraagontwikkeling, scenario's ▪ Infrastructuur & systeemintegratie: corridors, benutten bestaande infra. ▪ Technology assessments, R&D	▪ Impact van 'Fit for 55', REDII, Delegated acts, ETS/CBAM, etc. ▪ Impact van certificering en CO2 allocatie: emissiefactoren, LCA ketenanalyse, etc. ▪ Financiering en stimulering (EU & NL): IPCEI, PCI, TEN-E, JTF, EIB, Horizon Europe, MOOI, DEI, MIEK, SDE++, etc	▪ Marktmodellen: bilaterale contracten, vrije handel, waterstofbeurs ▪ Internationale handelsstromen: verwachte vraag- en aanbodvolumes en transportstromen ▪ Importtarieven, trade agreements en handelsbeperkingen, WTO, etc.	▪ Samenwerking met omringende EU/niet-EU importlanden om corridors te ontwikkelen ▪ Concurrentie met omringende EU/niet-EU importlanden ▪ Geopolitieke aspecten: strategische voorraden, afhankelijkheid, politieke stabiliteit van exportlanden	▪ Ruimtegebruik van ketenelementen ▪ Veiligheid: brandbaarheid, zorgwekkende stoffen, risicocontouren, etc ▪ Milieu: stikstof, lekkage ▪ Maatschappelijke acceptatie ▪ MVO / samenhang met SDG's in exportlanden

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Actualiteiten | tour de table

TNO innovation for life

Reflectie World Hydrogen Summit 2024

- Carla Robledo, Min.EZK
- David Koole, RvO

Ministerie van Economische Zaken en Klimaat

Terugblik World Hydrogen Summit & Exhibition 2024

SHIP 22-05-2024

Doelen tijdens de WHS

De dialoog tussen exporterende en importerende landen versterken

De ontwikkeling van corridors bevorderen

Aandacht vragen voor vraag creatie en het gebrek aan FID's

Certificering bevorderen

Infrastructuurontwikkeling in exporterende landen te bevorderen

Buitenlandse investeringen aantrekken om de waterstofketen te ontwikkelen

Beleidsprioriteiten

Tijdige ontwikkeling van de regionale infrastructuur
+
Gecoördineerde regionale importstrategie

Een transparante en eerlijke internationale waterstofhandel
+
Nederland als belangrijke hub in Noordwest Europa positioneren

Actieve diplomatie gericht op leveringszekerheid waterstofvolumes
+
Diversificatie van leveranciers en dragers

1 Intra-EU Samenwerking

2 Multilaterale Samenwerking

3 Partnerschappen met non-EU Landen

1. Versterking van Intra-EU samenwerking

NL-NOR-DE SESSIE –PIJPLEIDING CORRIDOR

MOU BRANCHEORGANISATIES BE-DE-NL

2. Multilaterale samenwerking

- Publiek-privaat dialoog tussen exporterende en importerende landen bevorderd via **2e IHTF Ministeriele-CEO rondetafel**

- Corridor studie gepresenteerd

- 4 belangrijke voorwaarden geïdentificeerd:
  1. Behoefte aan lange-termijn zekerheid aan de vraag kant
  2. Dringend behoefte aan de vaststelling en interoperabiliteit van normen en certificatieschema's voor effectieve handel
  3. Capaciteitsopbouw en kennisdeling nodig
  4. Ontsluiting van financiering, vooral in ontwikkelingslanden

3. Strategische partnerschappen met landen buiten Europa versterken

ACTIEPLAN NL-MAR 2024-2025

TRANSATLANTISCHE SESSIE MET VK-CAN-VS-NL-DE

MOU NLHYDROGEN EN H2CHILE

PRESENTATIE CERTIFICERING STUDIE MET UY&CL

KENNISDEELSESSIES MET O.A. EGYPTE, JAPAN, EN BEZOEK AAN BEURS

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Supplier-offtaker matchmaking event

Derde editie van supplier-offtaker matchmaking

- 22 suppliers & 19 offtakers (incl. terminals)
- >10 suppliers op wachtlijst

Suppliers:

- Uit: VS, Canada, Spanje, Duitsland, Saoedi-Arabië, Oman, India, Brazilië, Australië, Namibië, Portugal en ook Nederland
- Ammoniak dominant, methanol en gasvormig waterstof ook. LOHC, LH2 en SAF minder
- Verwachte volumes verspreid van tien tot enkele honderden ktpa H2
- 2027-2028 meeste COD

Offtakers:

- Beperkte deelname eindgebruikers
- 2027-2029 verwachte start import
- Verspreid van 5 tot 200 ktpa H2

Dank!

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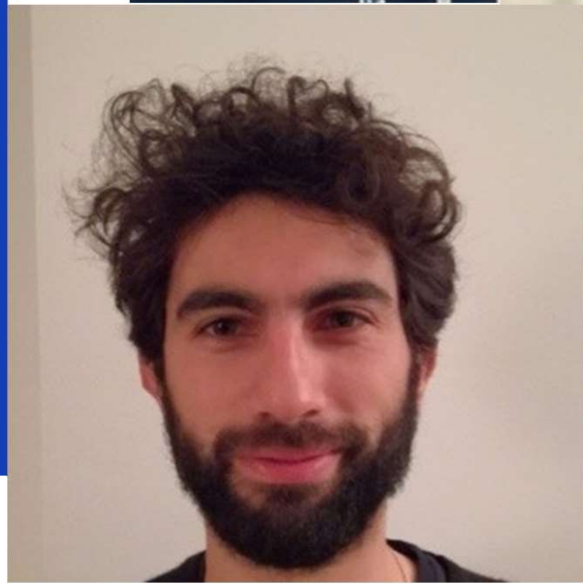
How green is your imported hydrogen?

- Alessandro Arrigoni | Joint Research Centre EU
- Thomas Hajonides | TNO
- Thomas Hennequin | TNO



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How green is *your* imported hydrogen?
Thomas Hajonides & Thomas Hennequin (TNO)
Alessandro Arrigoni (JRC)
innovation for life

Introduction: your hosts of today

Thomas Hajonides van der Meulen

Consultant at TNO
Energy supply chains

Thomas.Hajonides@tno.nl

Thomas Hennequin

Scientist at TNO
Life-cycle assessment

Thomas.Hennequin@tno.nl

Alessandro Arrigoni

Scientific officer at JRC
Sustainability of H_2 technologies

Alessandro.Arrigoni-Marocco @ec.europa.eu

Introduction:

Menti.com

You!

7719 8827

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Agenda

Goal of session:

Share different perspectives on the trade-offs between environmental impact (GHG) and costs (LCoH).

We therefore:

1. Present insights
2. Facilitate discussion
3. Draw conclusions

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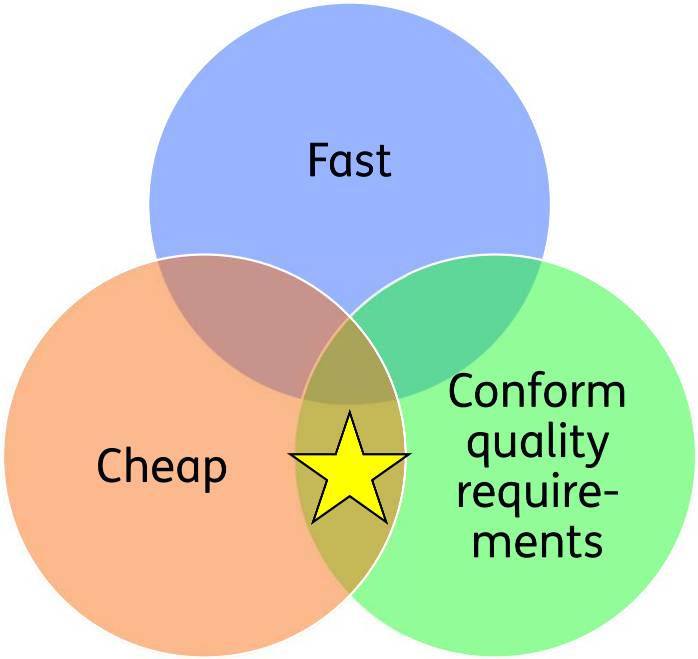
Agenda

Presentation TNO 15.40 – 16.00	• TNO H2SCM basics • **Key results**: LCoH2 vs CO2eq • Some LCA basics • **Key results**: Relation to RED-III CO2eq treshholds, and grey hydrogen
Discussion 16.00 – 16.20	• Reflection round with Menti • Discuss trade-offs cost-CO2eq-quantity
Presentation JRC 16.20 – 16.35	• The full picture of environmental impact: From CO2eq to all 18 environmental impact categories
Discussion 16.35 – 17.00	• How to decide about the import routes to invest in? • An open access approach

Introducing the focus of todays session



Q: What does 'conform quality standards' mean to *you?*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For me, the following factor is KEY in selecting a hydrogen (derivative) import route:
40 responses
use of space in nl
costs incl from regulatio
local supoort
ease of transport
environmental performance
security of supply
public risk
co2 reductie
costs
safety
quantity
emissions
economic
carbon emissions
cost
toxicity
policy stability
political stability
infrastructure
price stability
scalability
supply
co2 performance
availability date

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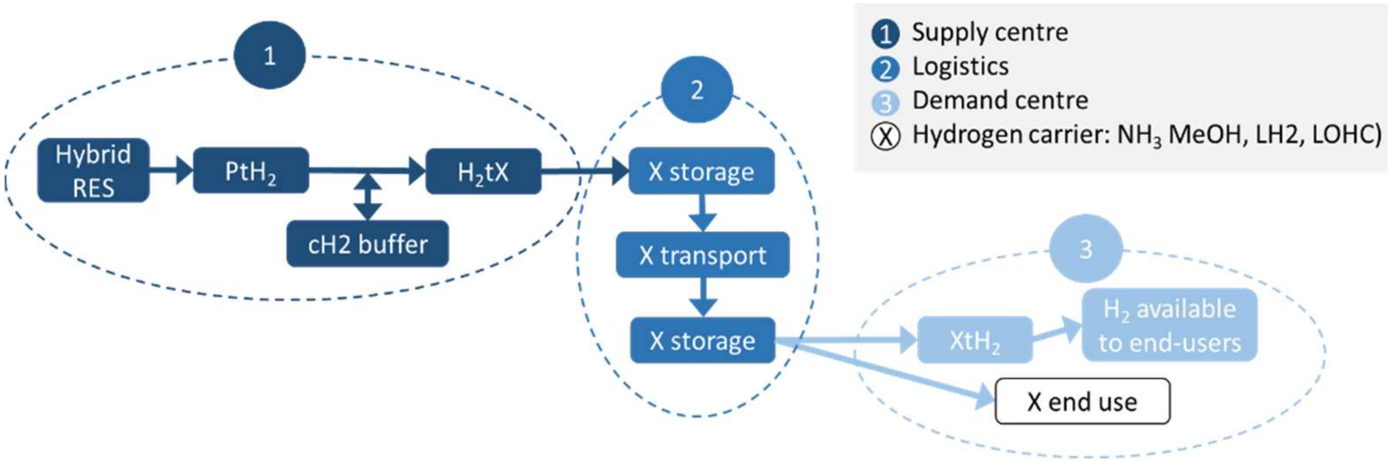
Let's do pairwise comparison: which RELATIVE value do you assign? cost, CO2eq, quantity?

20

A very brief introduction to
hydrogen import cost analysis using TNOs H2SCM



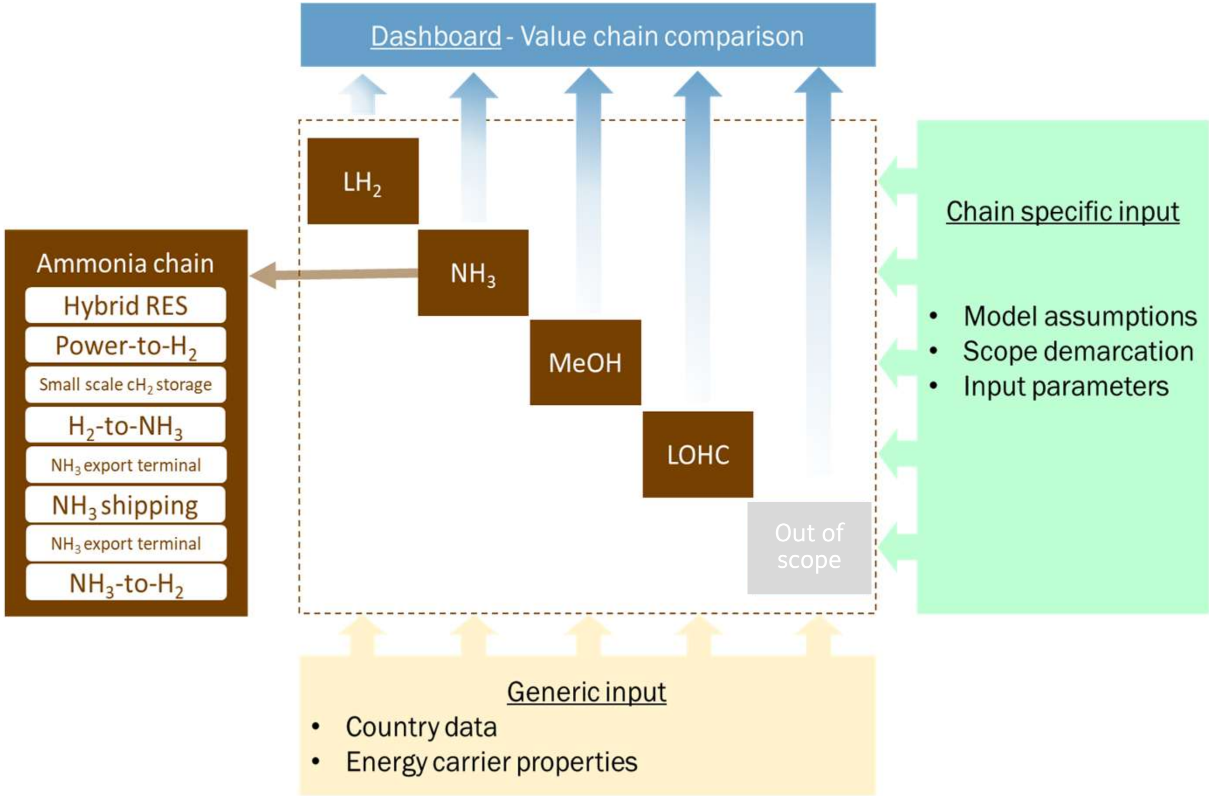
The KPIs for 2020-2030-2040:

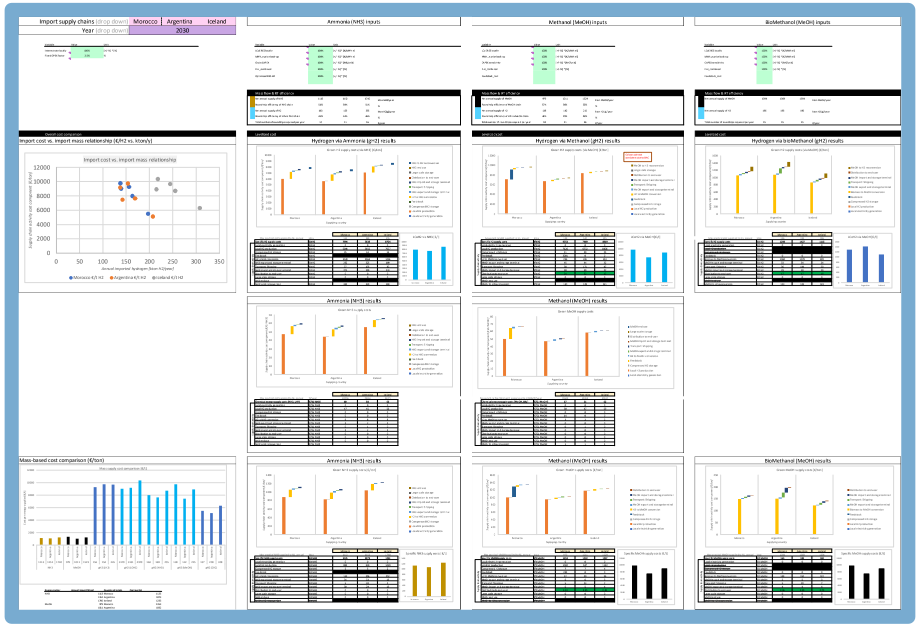
- **Technical** Energy & material flows
- **Economic** CAPEX, OPEX per chain element
- **Environmental** CO2eq per chain element
- **Assets required** e.g. PtH$_2$ stacks, ships

From ‘islanded PtX production hub’ … to central bunker hubs in Dutch ports.

SHIPNL Sessie V 22 mei

A very brief introduction to hydrogen import cost analysis using TNOs H2SCM





A very brief introduction to
hydrogen import cost analysis using TNOs H2SCM

5 carriers LH_2, NH_3, e-MeOH, bio-MeOH, LOHC
12 countries (archetypes)
3 time horizons
= 180 hydrogen (import) value chains

Parameter	Archetype U	Archetype M	Archetype I
Example:	*UK*	*Morocco*	*Iceland*
RES type	OffWind+PV	OnWind+PV	Geo+hydro
RES FLH	52%	60%	93%
RES LCoE	54 €/MWh	34 €/MWh	88 €/MWh
RES CO2e	22 kg/MWh	32 kg/MWh	60 kg/MWh
Travel time	44 d	11 d	10 d
Interest rate	6%	10%	5%

Please note that all ‘country names’ should be considered ‘examples of archetypes’.

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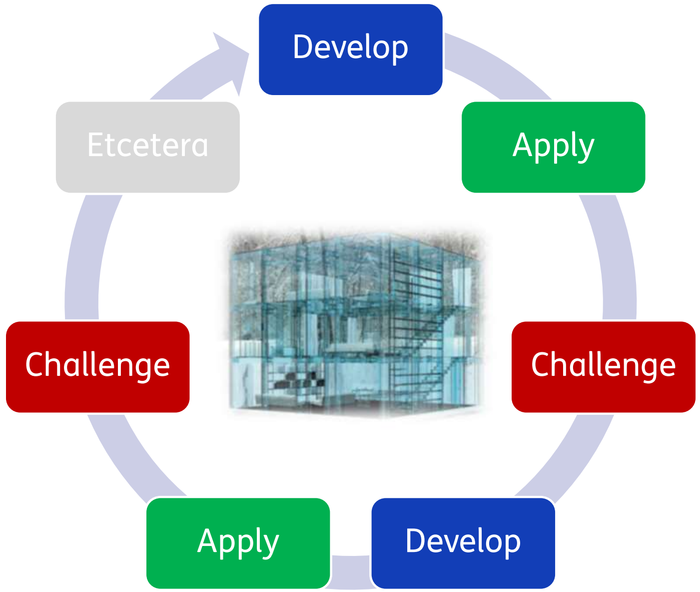
A very brief introduction to hydrogen import cost analysis using TNOs H2SCM

<u>Our fundamental principles</u>

1. Transparent analysis methods

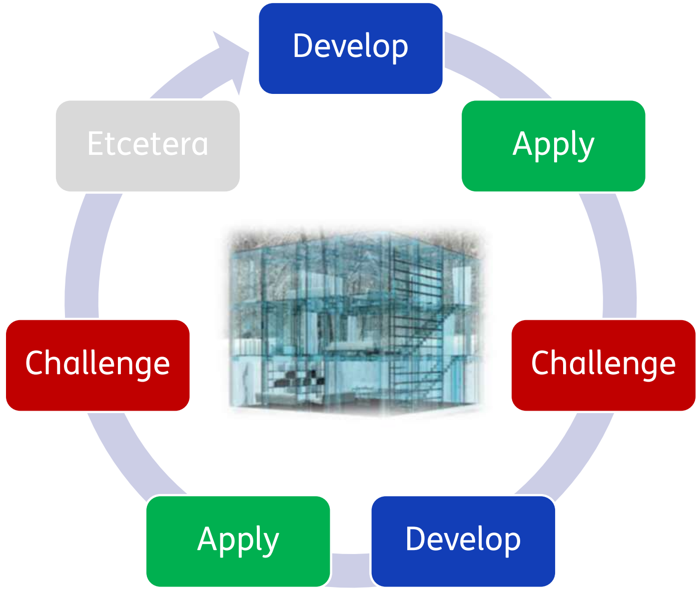
2. Usage of modular building blocks



A very brief introduction to hydrogen import cost analysis using TNOs H2SCM

Our current efforts

- ❑ Make the H2SCM "open access"
- ❑ $LCoH_2$ model alignment & knowledge sharing in IEA TCP Task 50 with e.g. Fraunhofer ISE, CSIRO, Monash Univ. Tokyo Univ, SINTEF, JRC and share the learnings with you.

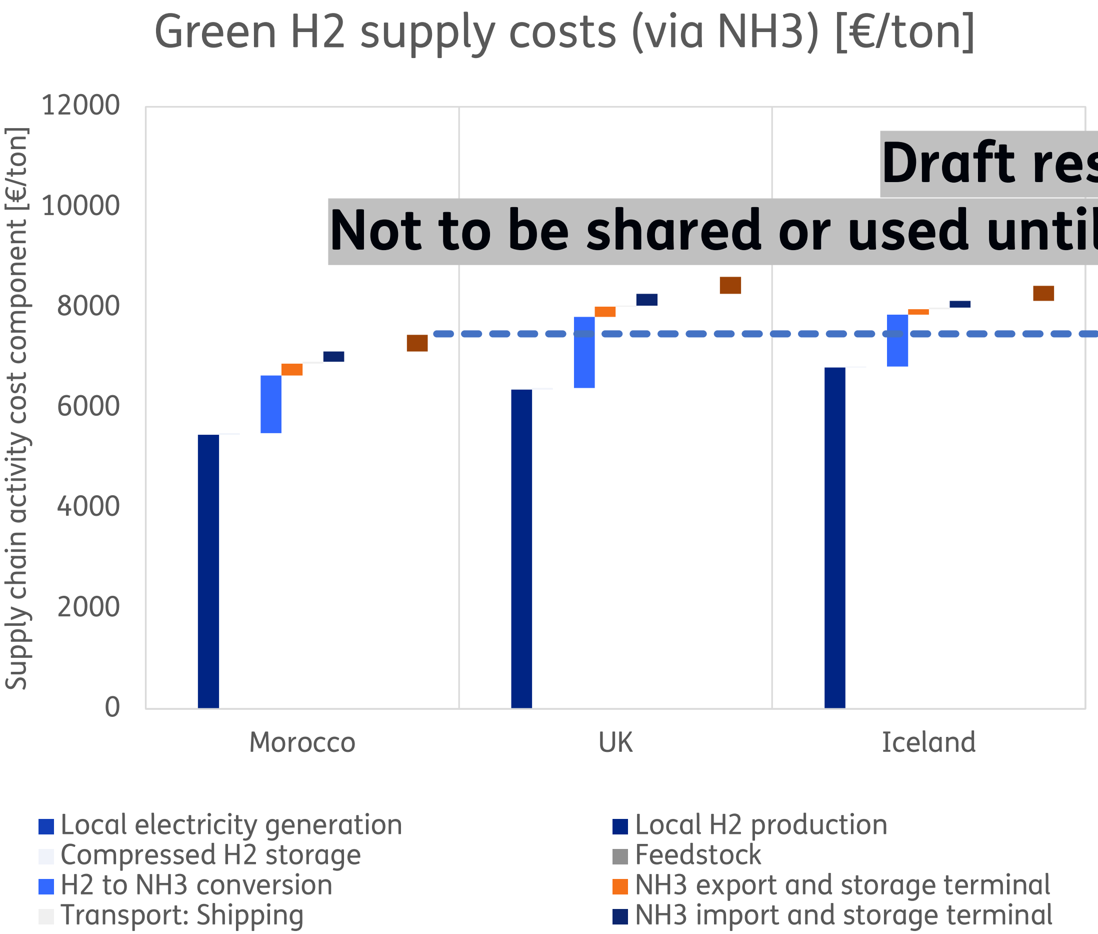


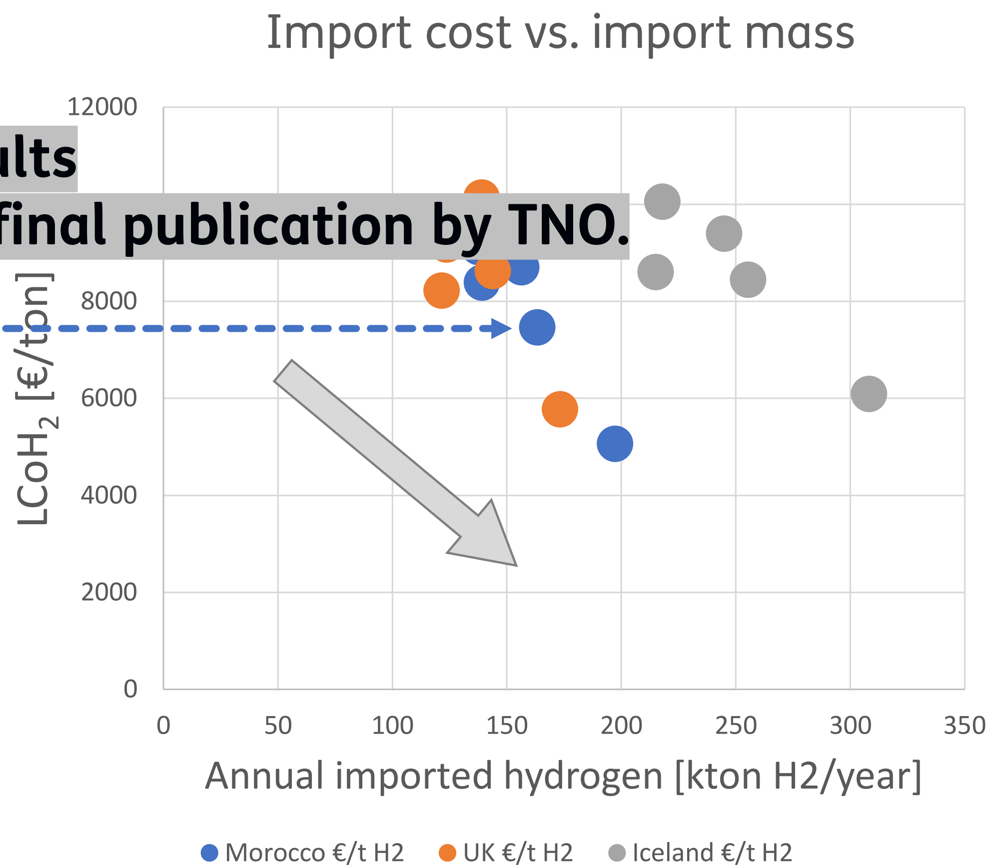
We need a 3 dimensional perspective:

- **Quantity [ton H_2/year]**
- **Cost [€/ton H_2]**
- GHG emissions [CO2e/ton H_2]

$$Levelized\ cost\ \left(\frac{€}{ton}\right) = \frac{total\ cost\ of\ ownership}{total\ product\ delivered}$$

We need a 3 dimensional perspective:





Draft results

Not to be shared or used until final publication by TNO.

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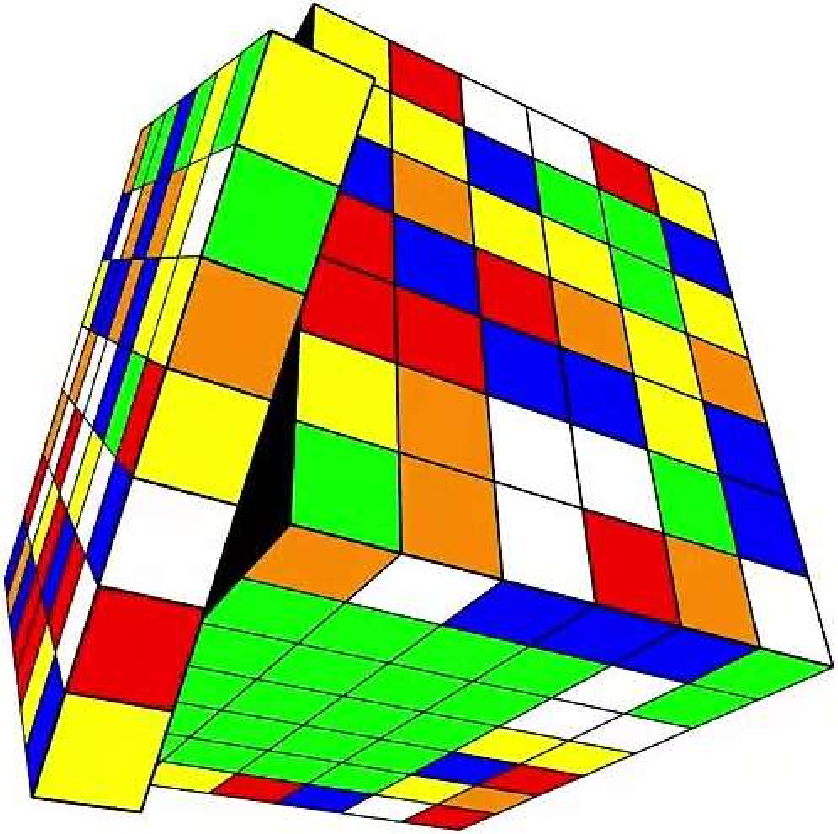
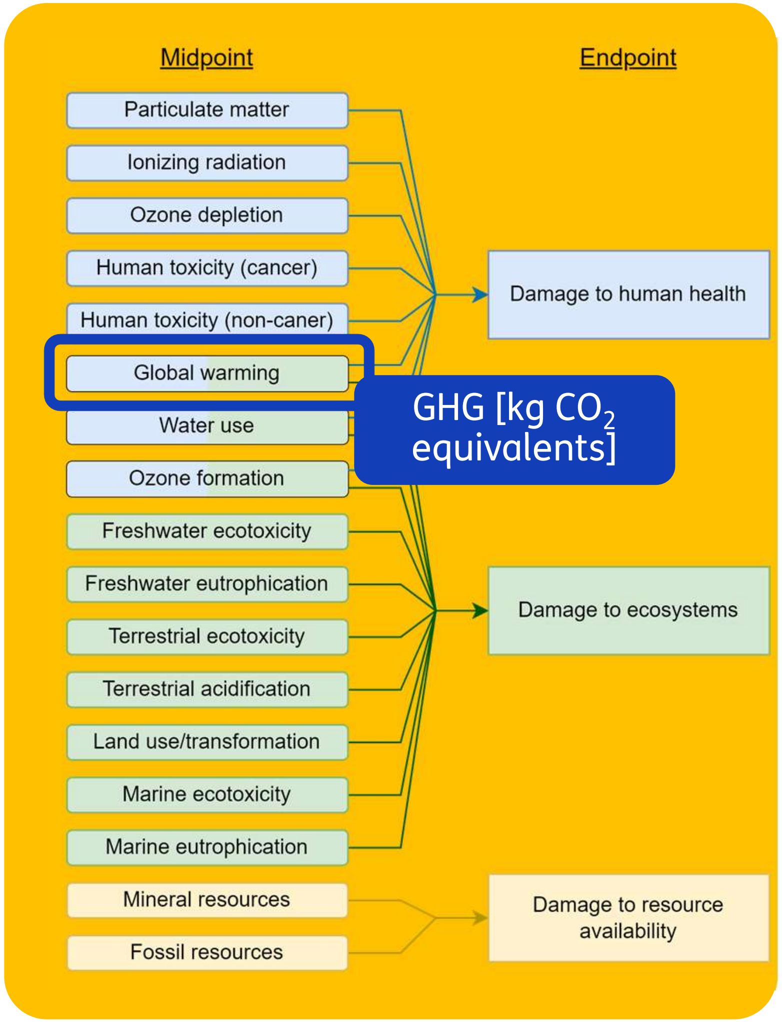
We need a 3 dimensional perspective:

- Quantity [ton H_2/year]
- Cost [€/ton H_2]
- **GHG emissions [CO2e/ton H_2]**



A 1 minute introduction into life-cycle assessment

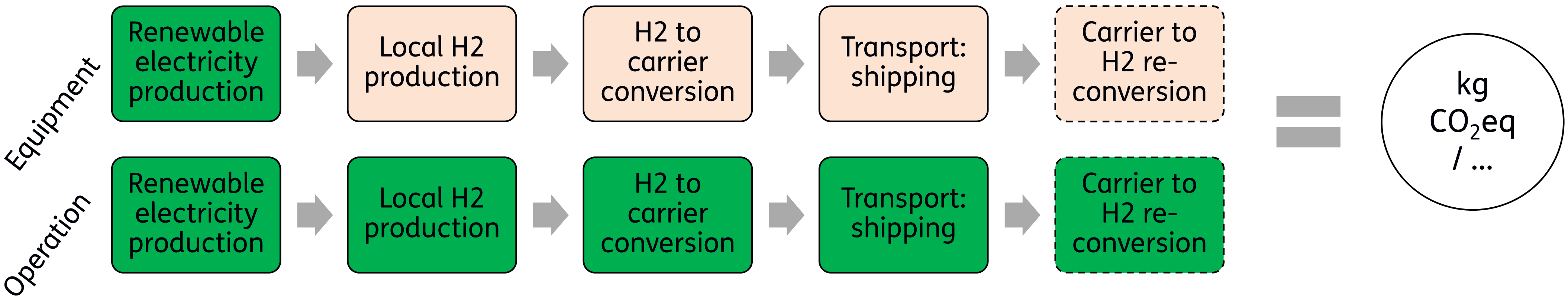


TNO scope

JRC scope

What about our scope?

- ❑ The idealist: “Include all!”
- ❑ The realist: “Include key elements, complying with RED-III”



Let's dive into detail using two stories:

How do renewable hydrogen (g) import chains perform compared to grey H_2?
(12000 kg CO2e/t H2)

Which renewable ammonia and methanol import chains comply with the RED-III?
(28 kg CO2e/GJ)

How do renewable hydrogen import chains perform compared to grey H_2?

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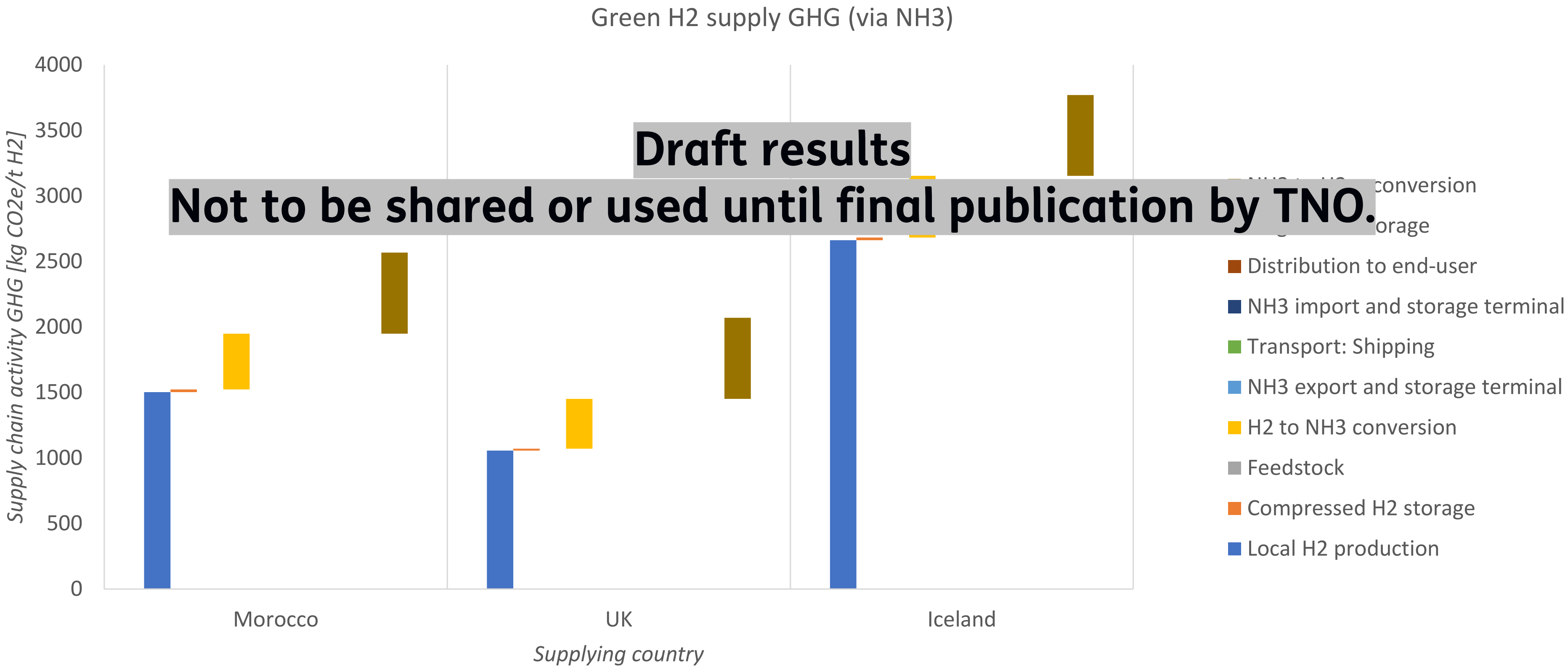
GHG CO2e emissions of hydrogen import via ammonia (NH_3)



How do renewable hydrogen import chains perform compared to grey H_2?

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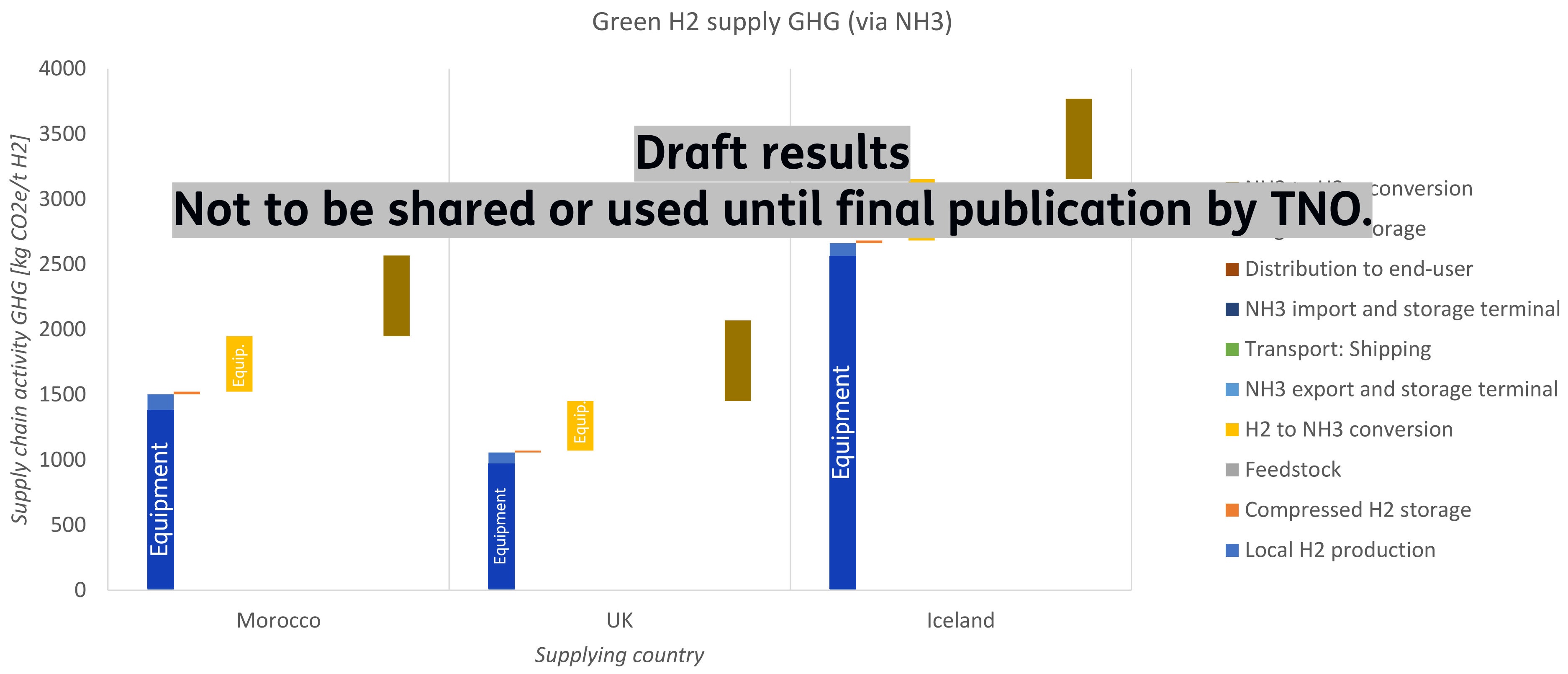

Draft results

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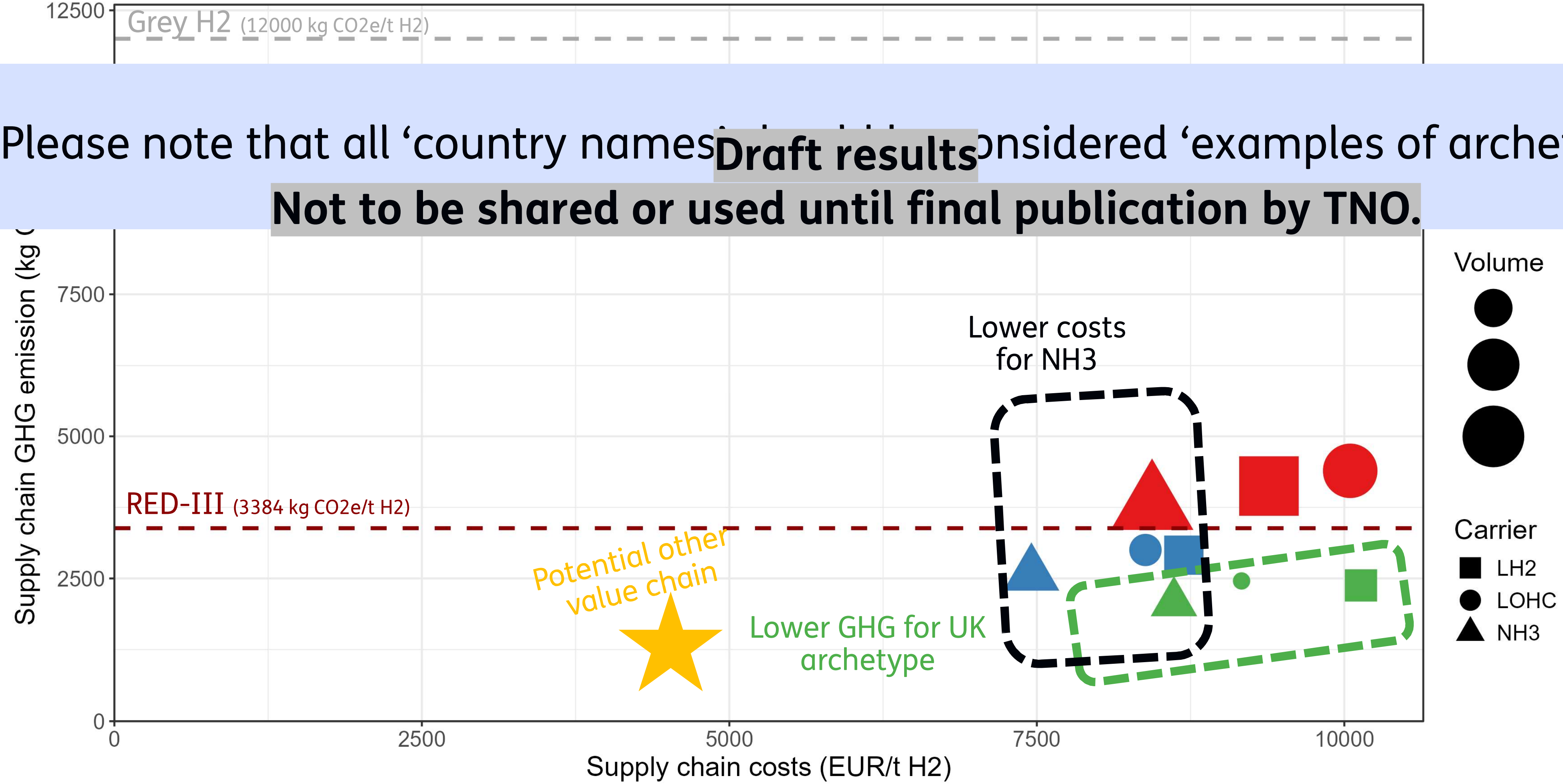
How do renewable hydrogen import chains perform compared to grey H_2?

Trade offs: GHG vs costs vs volume



Please note that all 'country names' should be considered 'examples of archetypes'.

Draft results

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Which renewable ammonia and methanol import chains comply with the RED-III?

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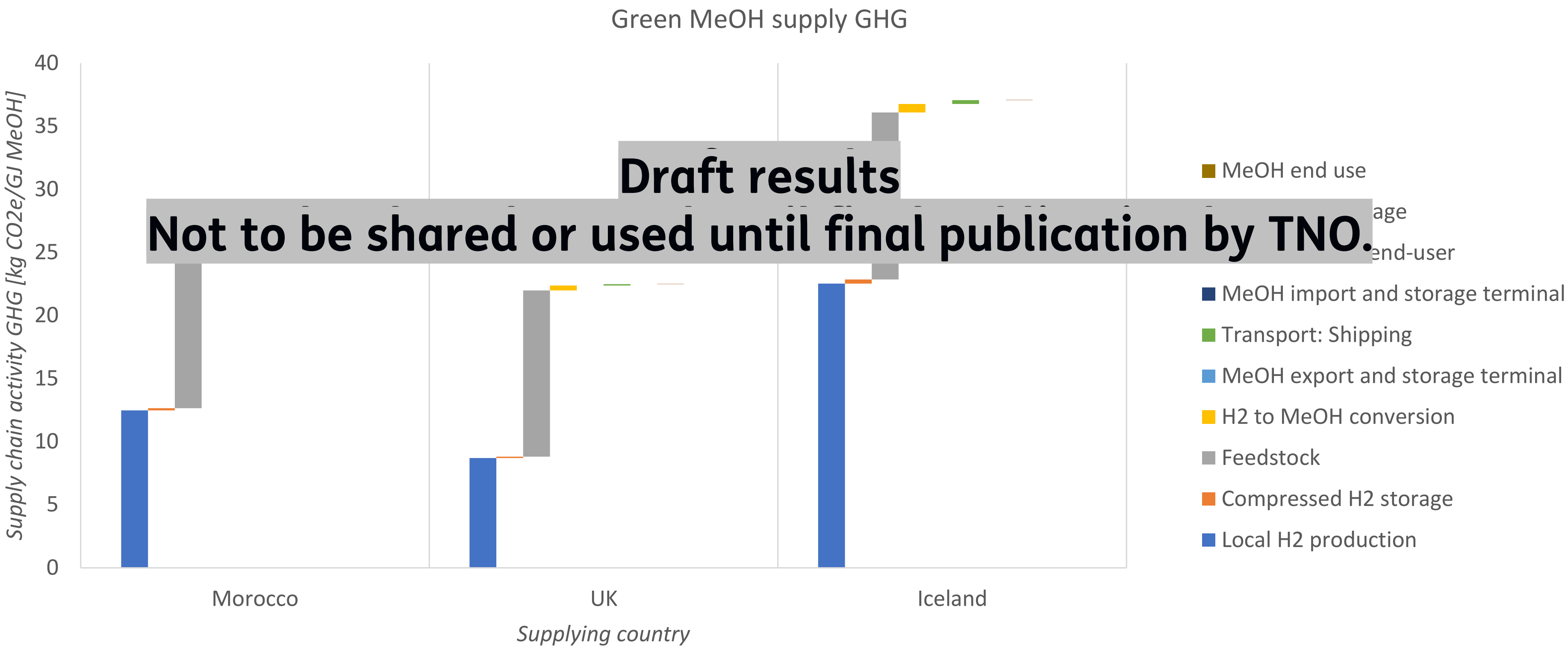
GHG methanol (MeOH)



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Which renewable ammonia and methanol import chains comply with the RED-III?

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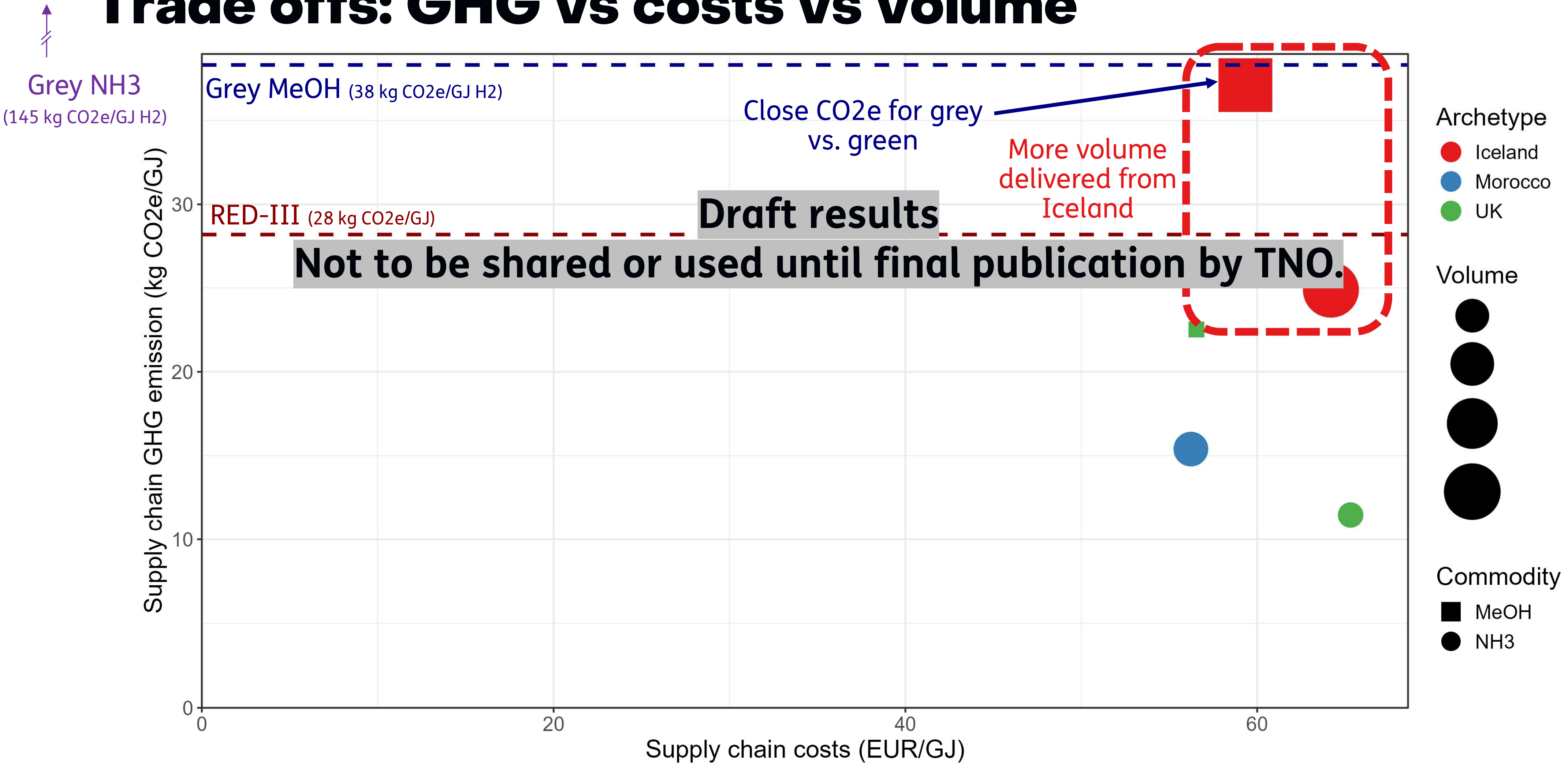
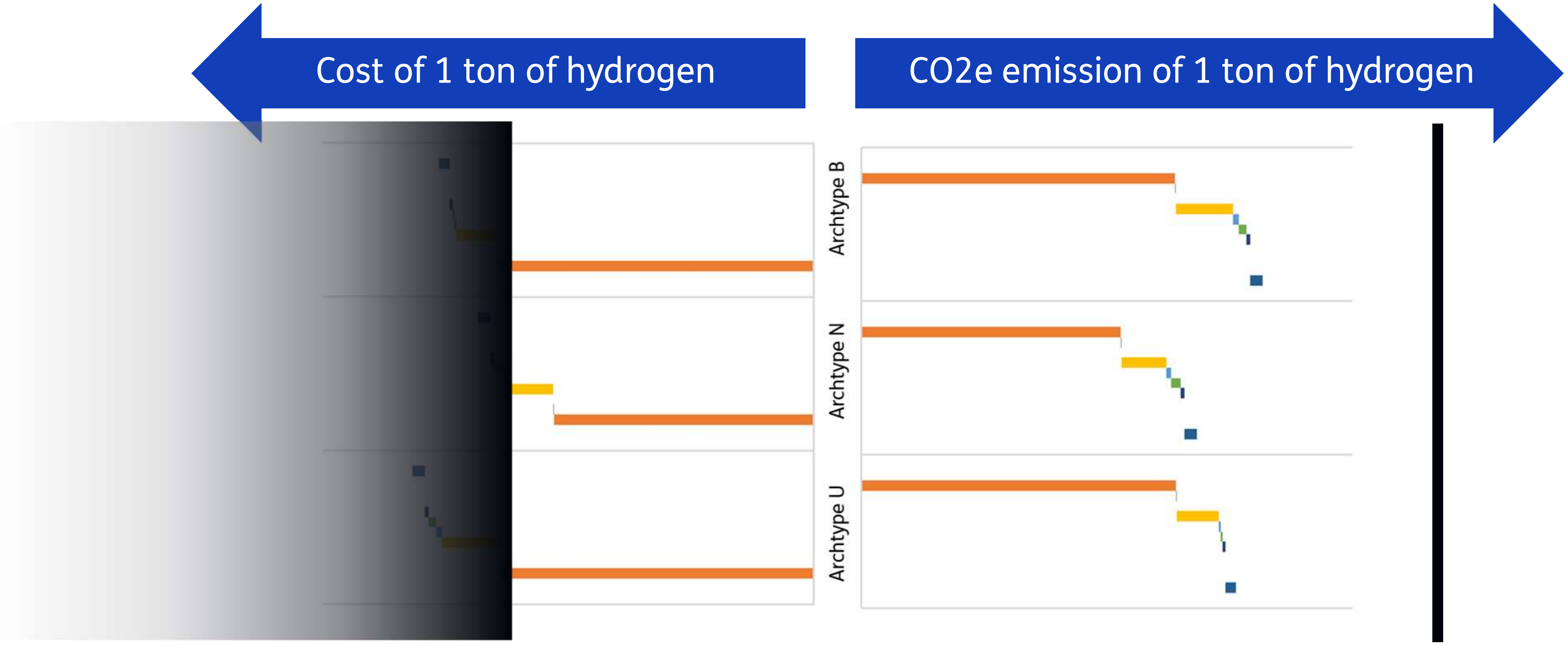
Trade offs: GHG vs costs vs volume



Our solution space of value chain design requires a balance between hydrogen costs and CO2e emissions.

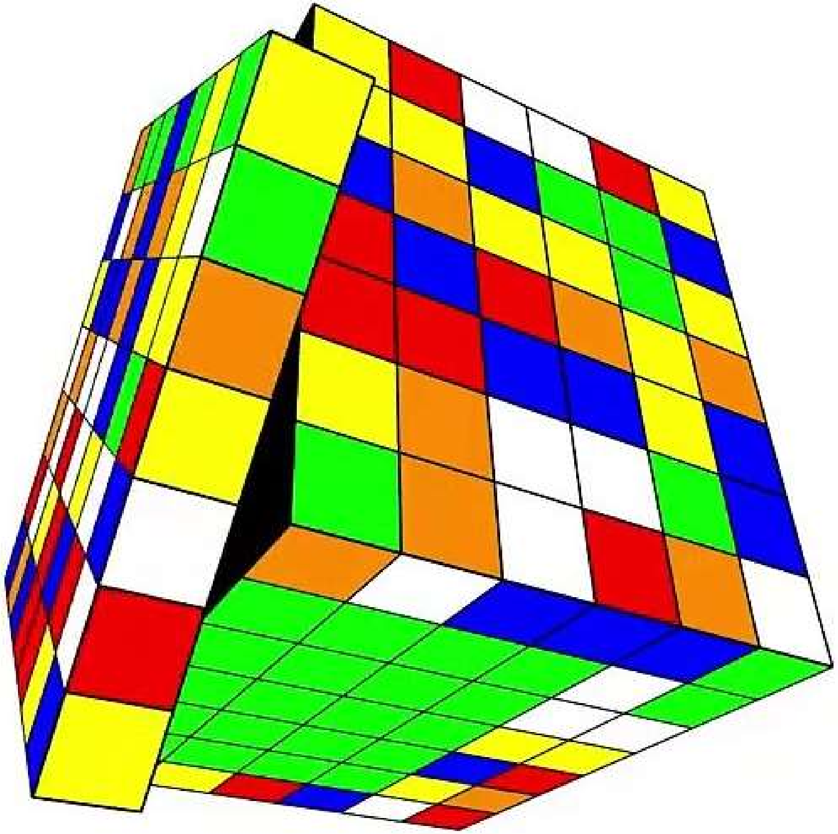


Acceptable supply costs (=price!)

Max. GHG emissions conform regulations

We need a 3 dimensional perspective

- Quantity [ton H_2/year]
- Cost [€/ton H_2]
- GHG emissions [CO2e/ton H_2]



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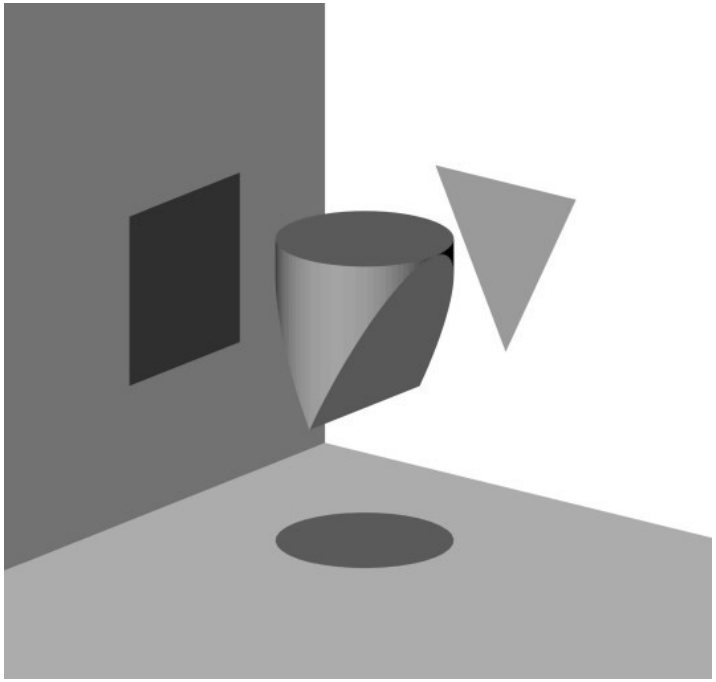
Our solution space of value chain design requires a balance between hydrogen costs and CO2e emission, and we need (very) large quantities.

Q: How?

Individual reflection



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Discussion on trade-offs

Q1

What is minimal carbon intensity *worth* to you?

Q2

What are we missing that complicate the trade-off even more?

ESG, security of supply, existing trade relationships, …

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Agenda

Presentation TNO

15.40 – 16.00

- TNO H2SCM basics
- **Key results**: LCoH2 vs CO2eq
- Some LCA basics
- **Key results**: Relation to RED-III CO2eq treshholds, and grey hydrogen

Discussion

16.00 – 16.20

- Reflection round with Menti
- Discuss trade-offs cost-CO2eq-quantity

Presentation JRC

16.20 – 16.35

- The full picture of environmental impact: From CO2eq to all 18 environmental impact categories

Discussion

16.35 – 17.00

- How to decide about the import routes to invest in?
- An open access approach

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Environmental LCA comparison of hydrogen delivery options within Europe

Den Haag, 22 May 2024

contact information
alessandro.arrigoni-marocco@ec.europa.eu

European Commission

SHIP>NL Sessie V 22 mei

Joint Research Centre

Our purpose

The Joint Research Centre provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society.

European Commission

Introduction

REPowerEU
with Clean Energy

2030

- **10 Mt** domestic renewable H_2 production
- **10 Mt** renewable H_2 imports

? ***which is the cheapest way to deliver the renewable H_2?***

[JRC Assessment of Hydrogen Delivery Options, 2022]

? ***is it also the most sustainable way to deliver it?***

Goal of the study

What is the most environmentally sustainable option of ***delivering of 1 Mt/y of renewable H_2 to a single industrial customer*** *via a direct transport pathway (via ships or pipelines)*

delivery options

- **Compressed H_2 (C-H2)**
- **Liquefied H_2 (L-H2)**
- **Ammonia (NH_3)**
- **Liquid organic H_2 carrier (LOHC)**
- **Methanol (MeOH)**
- **Synthetic natural gas (SNG)**
- ***Reference: on-site SMR/electrolysis***

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Method

- **Assessment method:** Attributional prospective LCA
- **Functional unit:** 1 kg H_2 delivered (30 bar, 99.97% purity)
- **Impact assessment method:** Environmental Footprint (16 impact categories)
- **Inventory**: JRC calculations*, ecoinvent 3.9, scientific literature
- **Time horizon**: 2030+
- **System boundaries**: from cradle to gate

**Ortiz Cebolla et al. 2021. Assessment of Hydrogen Delivery Options*

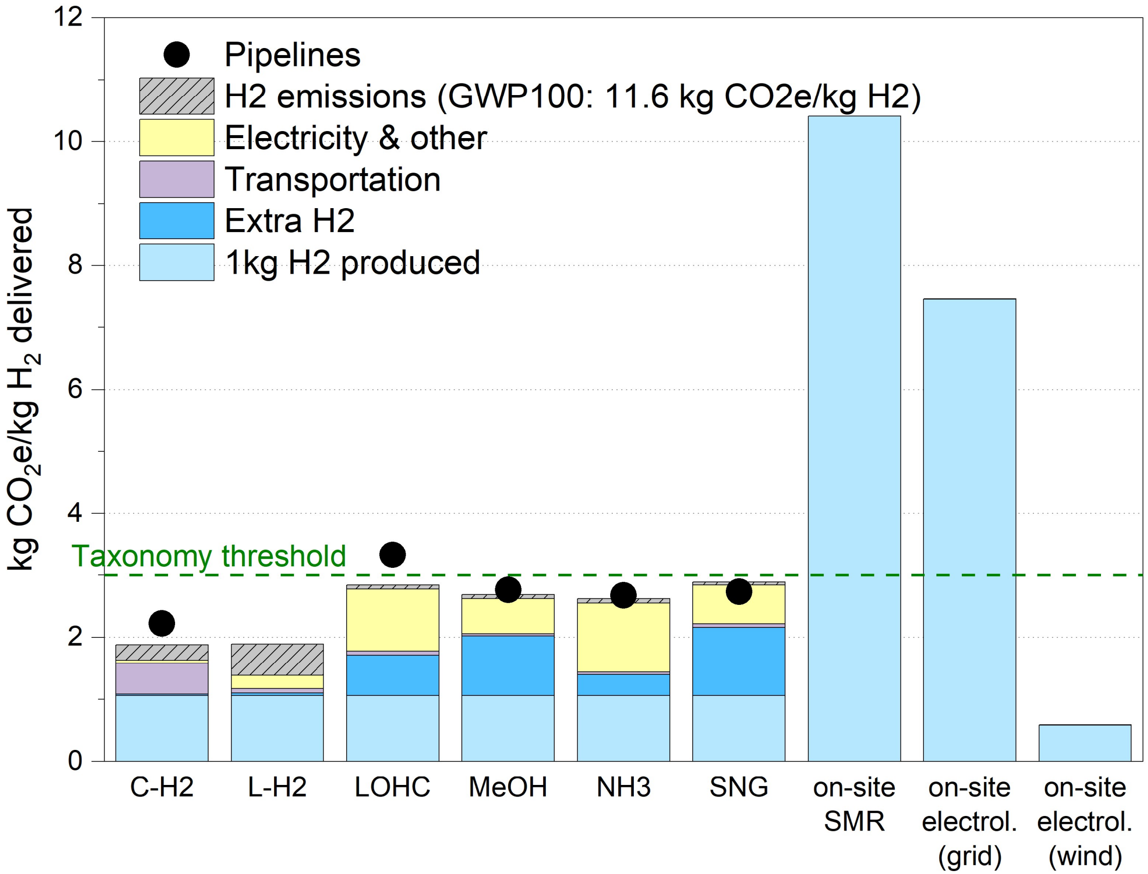
European Commission

Main assumptions [2030+]

- **Renewable H_2:** electrolysis [50 kWh/kg H_2] via solar electricity [a]
- **Electricity grid:** mixes of 2030 in line with EU Fit for 55 plan [b]
- **Storage:** both at production and use sites to guarantee constant H_2 supply
- **Ships:** powered by biodiesel
- **CO_2 for carriers** (i.e., MeOH, SNG): sourced from direct air capture (DAC)
- **Heat for processes** (e.g., DAC, LOHC unpacking): from extra renewable H_2
- **H_2 Global Warming Potential over 100 years**: 11.6 kg CO2e/kg H_2 [c]

[a] *Hydrogen Council. 2021. Hydrogen decarbonization pathways. A life-cycle assessment*
[b] *E3Modelling, "Fit for 55" MIX Scenario. Summary Report: Energy, Transport and GHG Emissions, 2021*
[c] *Sand et al. A multi-model assessment of the Global Warming Potential of hydrogen. Commun Earth Environ 2023*

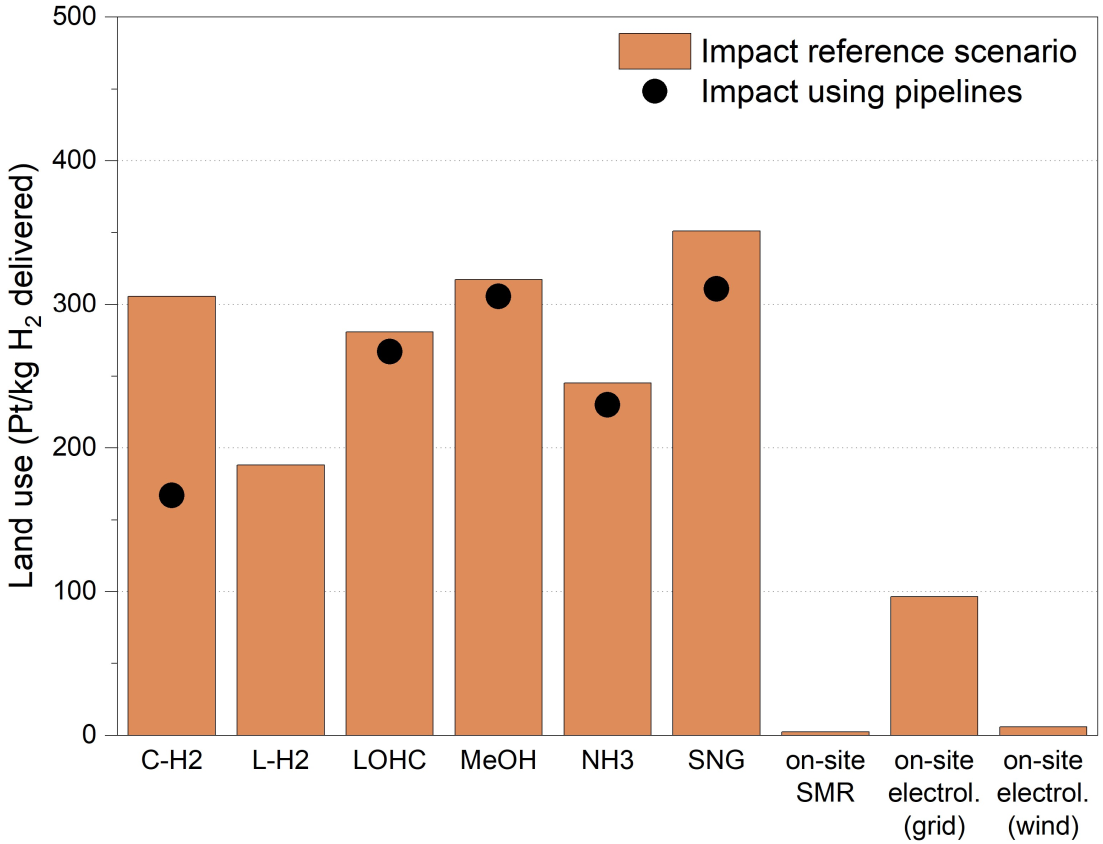
Results: Climate change potential impact



Extra H2: H_2 to make up for losses, and H_2 used for heat

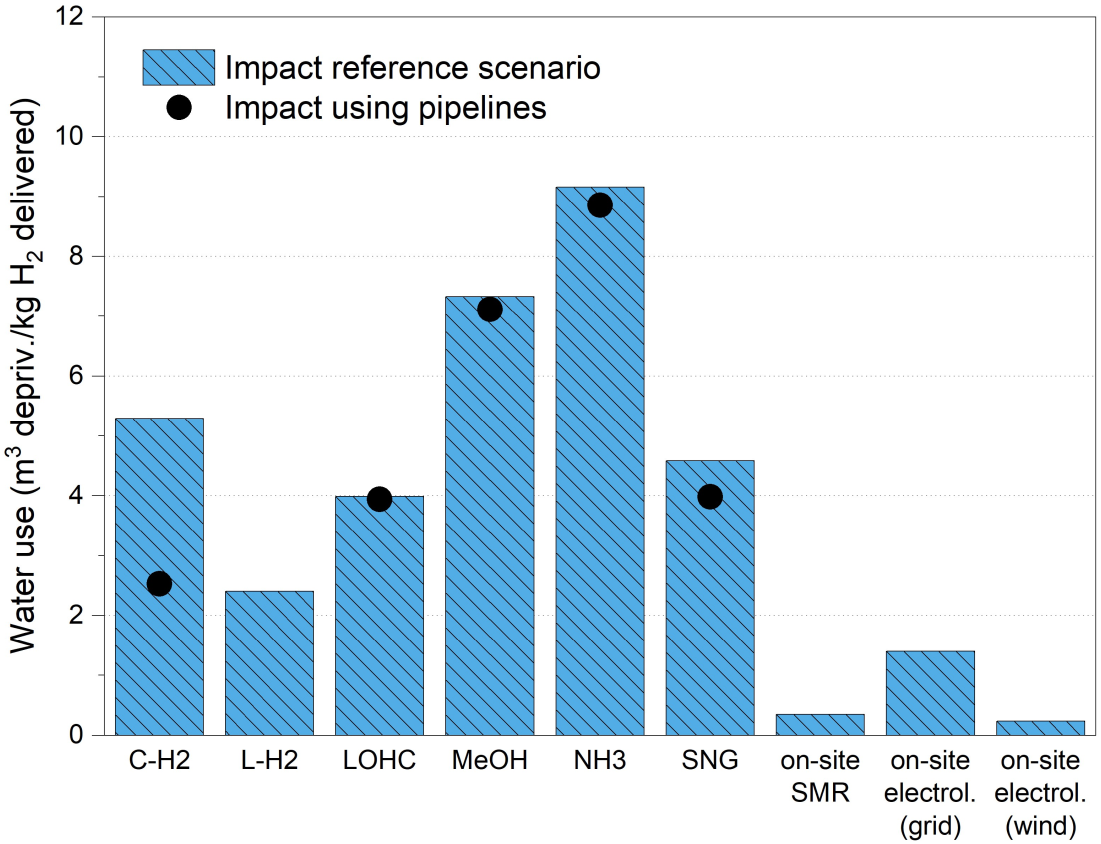
- **H_2 delivery** from a location where renewable energy is cheaper would generate a **lower climate impact** than producing hydrogen on-site via either SMR or electrolysis powered by the grid mix
- The transportation advantage of packing H_2 into a more **manageable carrier** does not seem to translate in a GHG advantage, due to the energy required to pack and unpack the carrier

Results: Land use potential impact



Impact can be ascribed to land used for solar power generation and to grow biomass for biodiesel

Results: Water use potential impact



Impact is mainly due to the water consumed for electrolysis, for electricity production, and for cooling processes.

Impact depends on the location where water is consumed: using freshwater in Portugal is 40 times higher than in the Netherlands, due to the different availability of water resources.

Results: Normalization and weighting

Absolute results were normalized and weighted to obtain a single impact score according to the EF method.

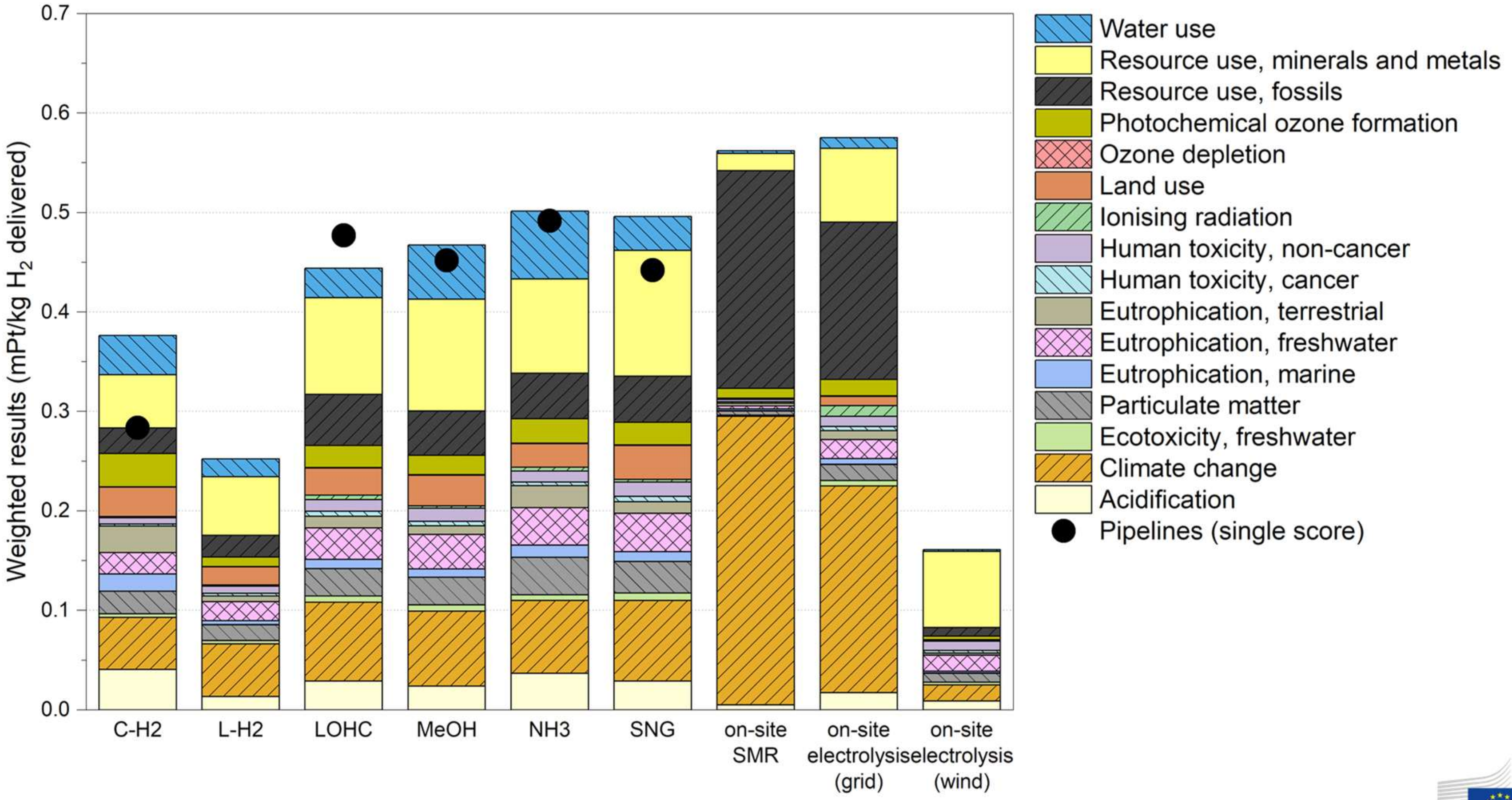
Normalization compares the magnitude of the impact with respect to the global impact on a per capita basis.

Normalized results are multiplied for the a set of **weighting factors** that are intended to represent the relative importance of each environmental impact category considered.

Impact category	Weighting factor (%)
Climate change	21.06
Ozone depletion	6.31
Ionising radiation	5.01
Photochemical ozone formation	4.78
Particulate matter	8.96
Human toxicity, non-cancer	1.84
Human toxicity, cancer	2.13
Acidification	6.20
Eutrophication, freshwater	2.80
Eutrophication, marine	2.96
Eutrophication, terrestrial	3.71
Ecotoxicity, freshwater	1.92
Land use	7.94
Water use	8.51
Resource use, fossils	8.32
Resource use, minerals and metals	7.55

***Source*: Sala, Cerutti, and Pant (2018)**

Results: Single score



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Conclusions

Results are referred to a **well-defined geographical context and time horizon**, and they are driven by the **numerous assumptions** made throughout the study

- The **least environmentally impactful option** of supplying hydrogen is to produce it on-site via efficient renewable sources, followed by shipping of liquid hydrogen and compressed hydrogen by pipeline
- Energy required to pack and unpack hydrogen into more **suitable carriers** (i.e., ammonia, LOHC, methanol, and SNG) makes this option **less attractive in terms of environmental impacts**
- The **renewable energy infrastructure** (i.e., solar panels manufacture) plays a critical role in the environmental performance of the hydrogen delivered
- Limiting the scope of the assessment to GHG emissions can lead to unintended consequences in terms of other environmental impacts

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Recommendations

- **Prioritizing on-site hydrogen production utilizing local abundant renewable sources** when viable**;**
- **Focusing research and development efforts on** hydrogen transportation methods, such as **pipelines for compressed hydrogen and maritime transport for liquid hydrogen;**
- **Reducing the environmental impact of the infrastructure used for renewable electricity production**, namely solar PV panels
- Optimizing energy efficiency throughout the supply chain of chemical carriers involved in hydrogen distribution, with special attention to the delivery phase;
- Preventing hydrogen losses along the delivery chains
- Perform environmental LCAs to determine the best hydrogen supply chain for each specific scenario

Thank you
and keep in touch

alessandro.arrigoni-marocco@ec.europa.eu

Link to the new report

https://publications.jrc.ec.europa.eu/repository/handle/JRC137953

EU Science Hub
joint-research-centre.ec.europa.eu

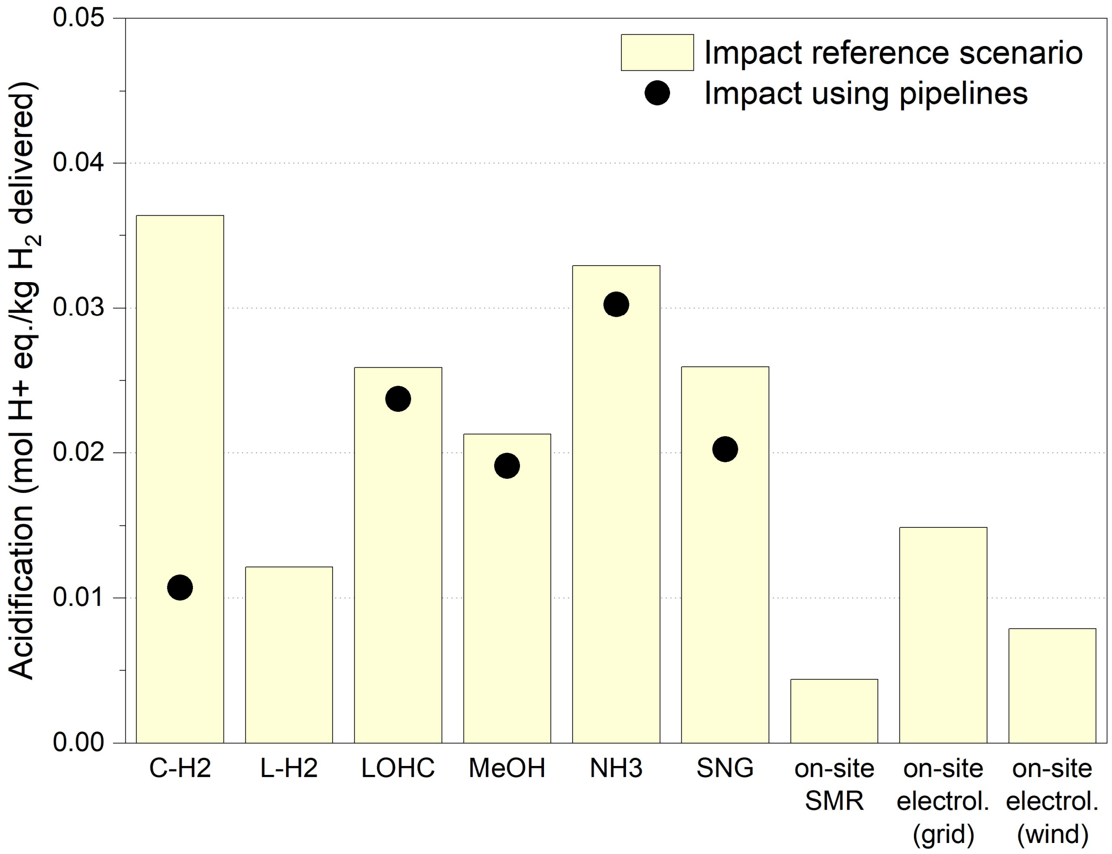
- @EU_ScienceHub
- EU Science Hub – Joint Research Centre
- EU Science, Research and Innovation
- EU Science Hub
- @eu_science

European Commission

Future work

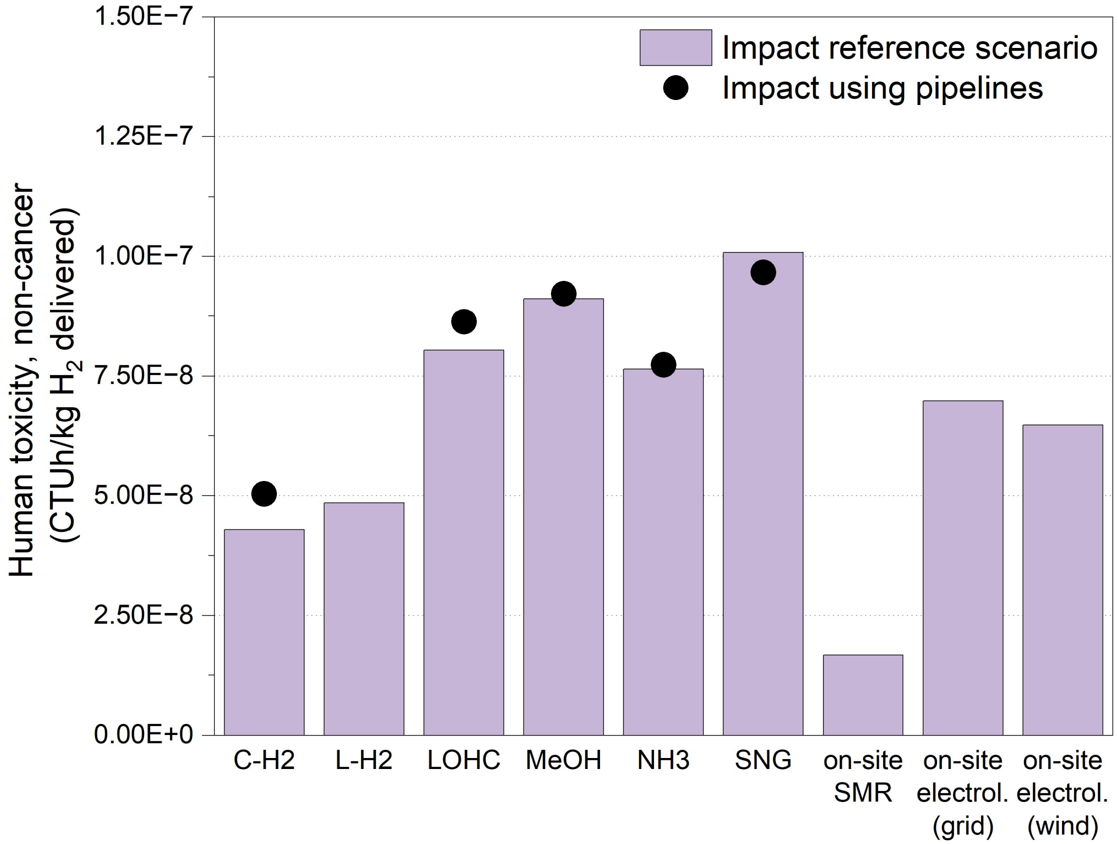
- Monitor technologies to regularly update the results and reduce uncertainty
- Develop more robust tools for investigating the potential environmental impact of uncertain future activities
- Extend the research to different geographical locations, time horizon (e.g., 2050+), and additional means of transportation (e.g., trucks and trains)

Results: Acidification potential impact



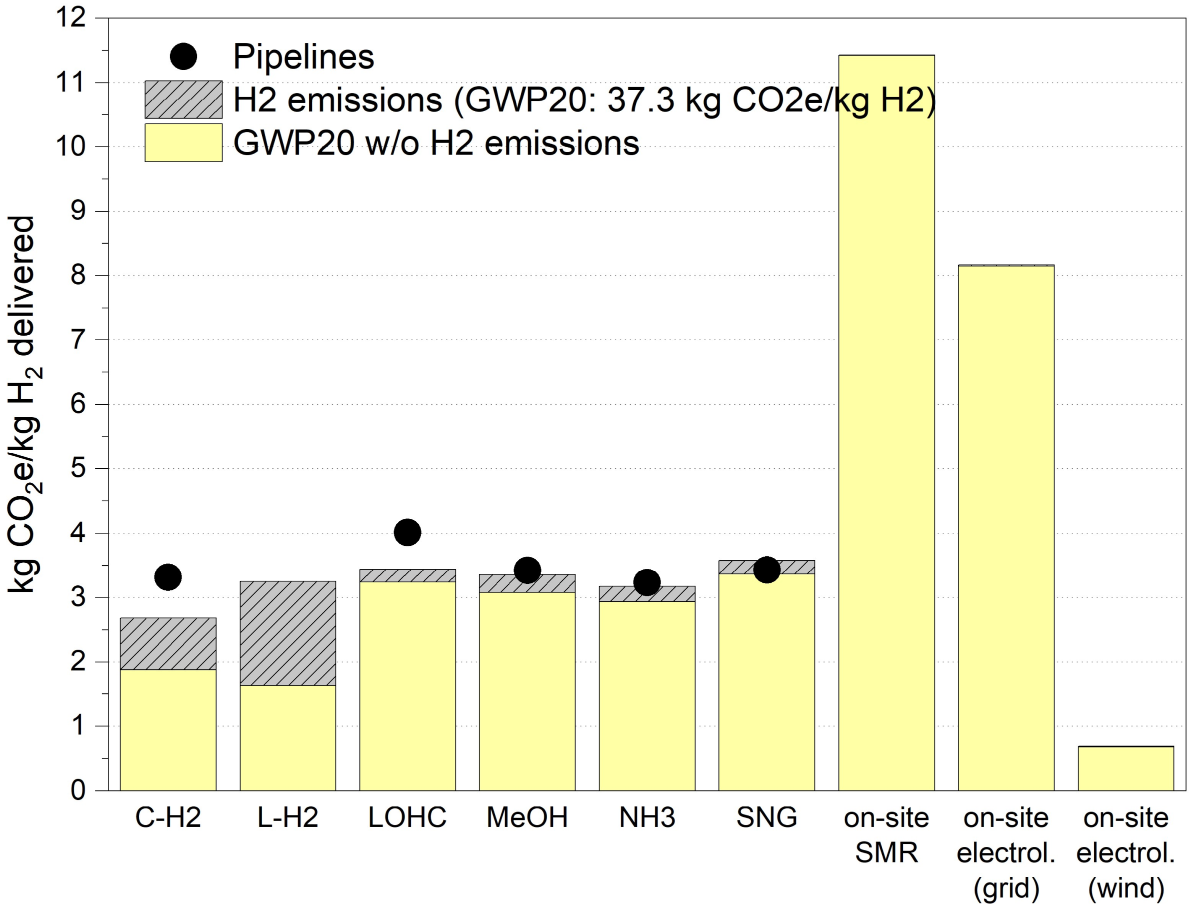
Main impacts from sulphur dioxide and nitrogen oxide emissions from biodiesel use and solar panel manufacture (sulphur dioxide from burning fossil fuels)

Results: Human toxicity potential impact

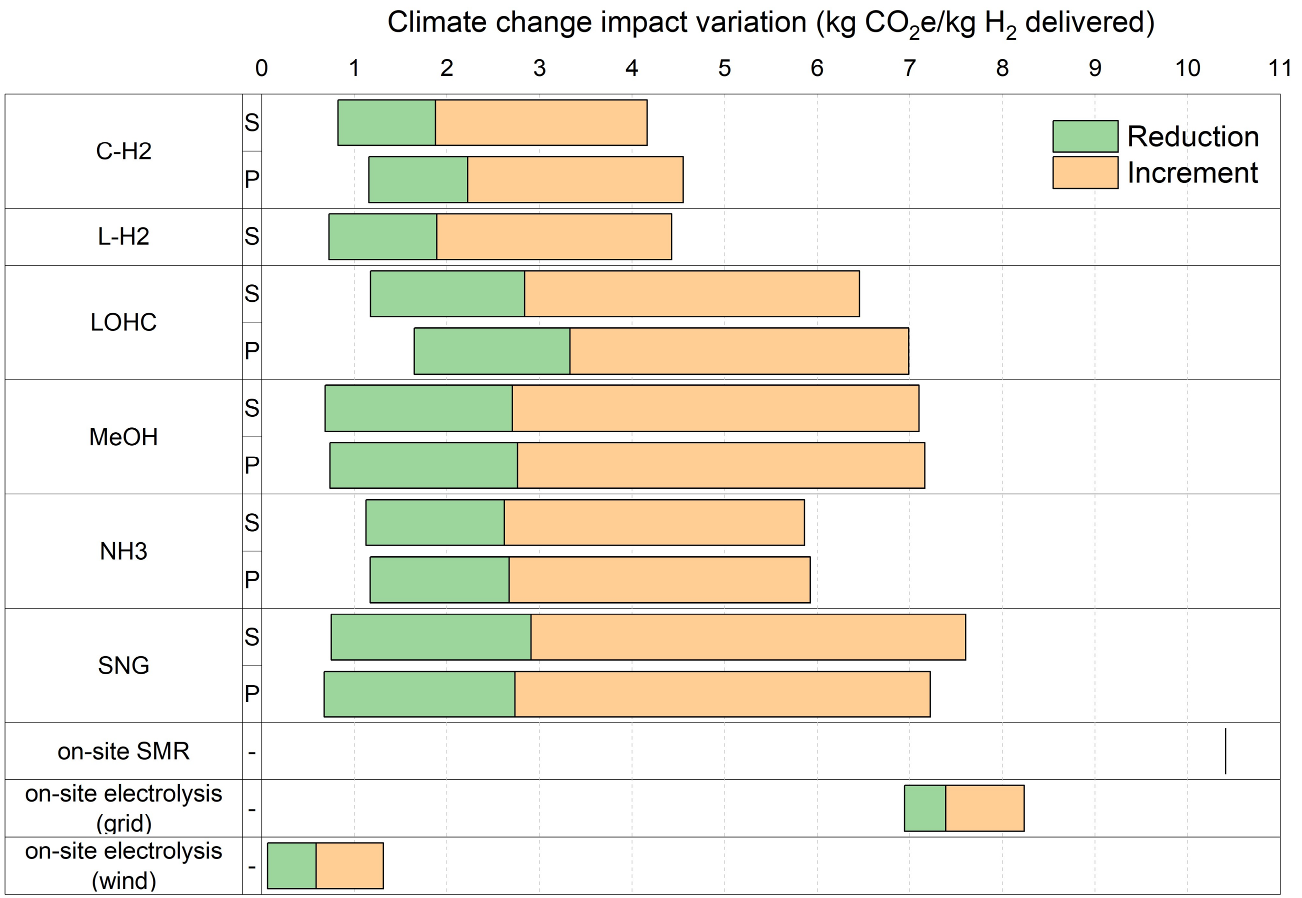


The impact could be attributed to several processes, including the production of photovoltaic cells (silver emissions) and the treatment of copper slag (arsenic emissions) for electricity generation.

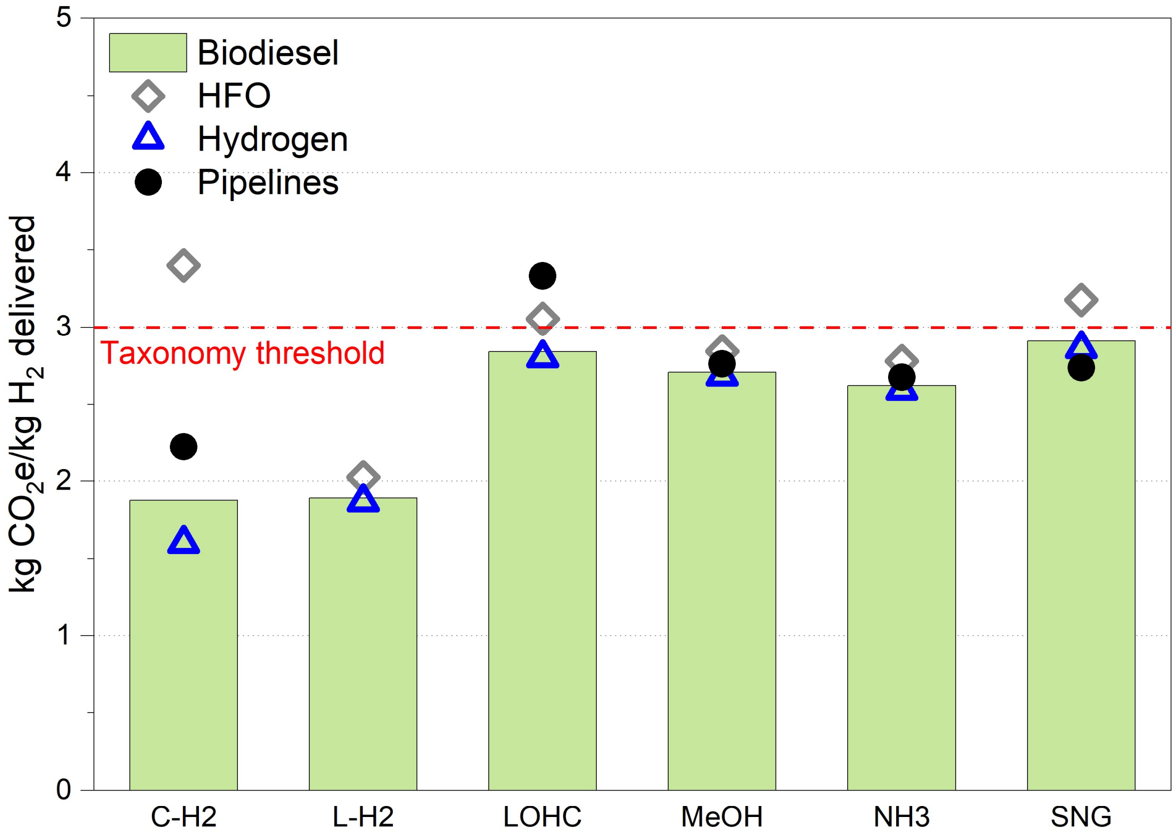
GWP20 results



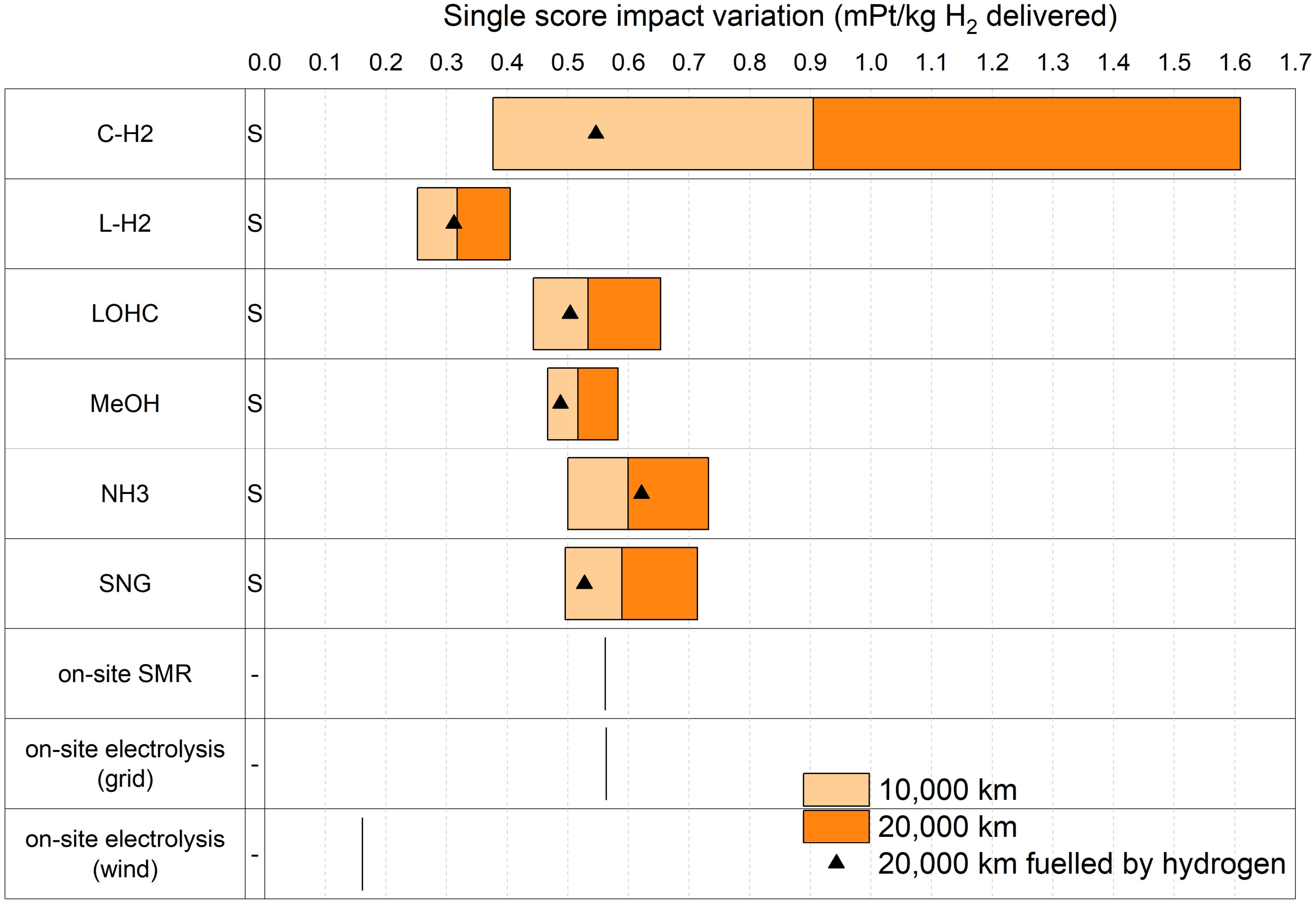
Sensitivity analysis
Renewable electricity generation



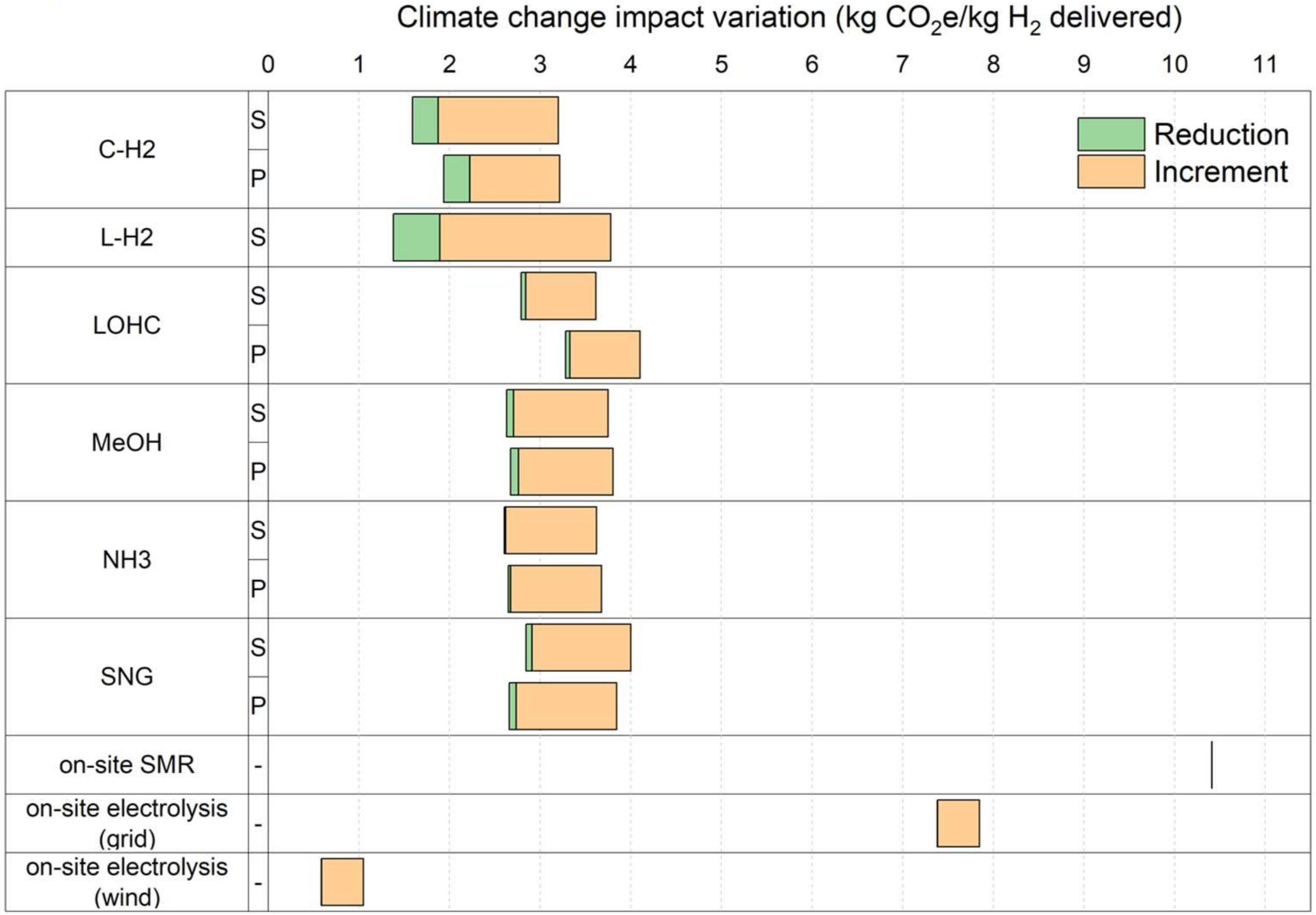
Sensitivity analysis
Shipping fuel



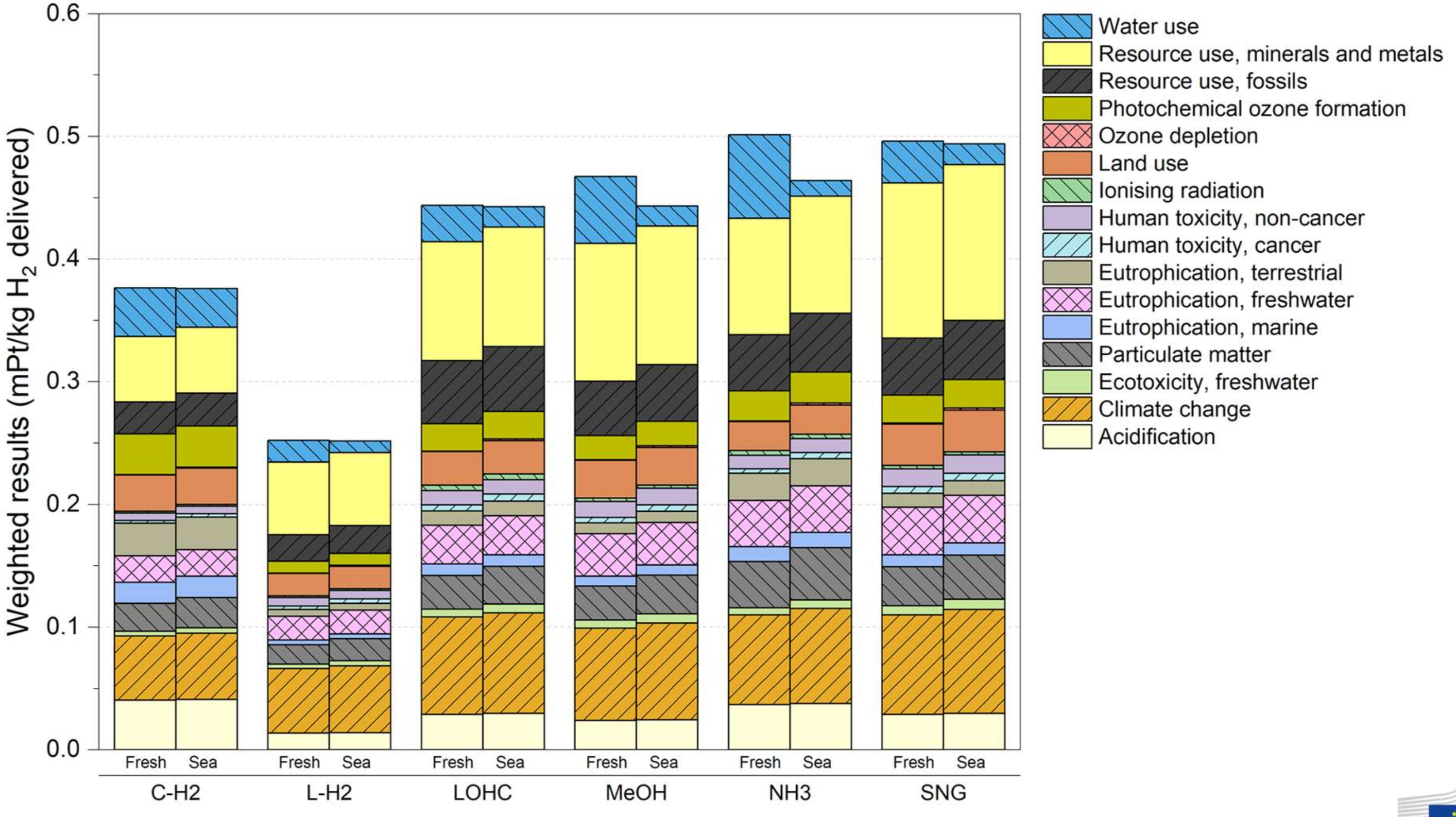
Sensitivity analysis
Distance



Sensitivity analysis
Hydrogen losses



Sensitivity analysis
Water source: freshwater vs. seawater



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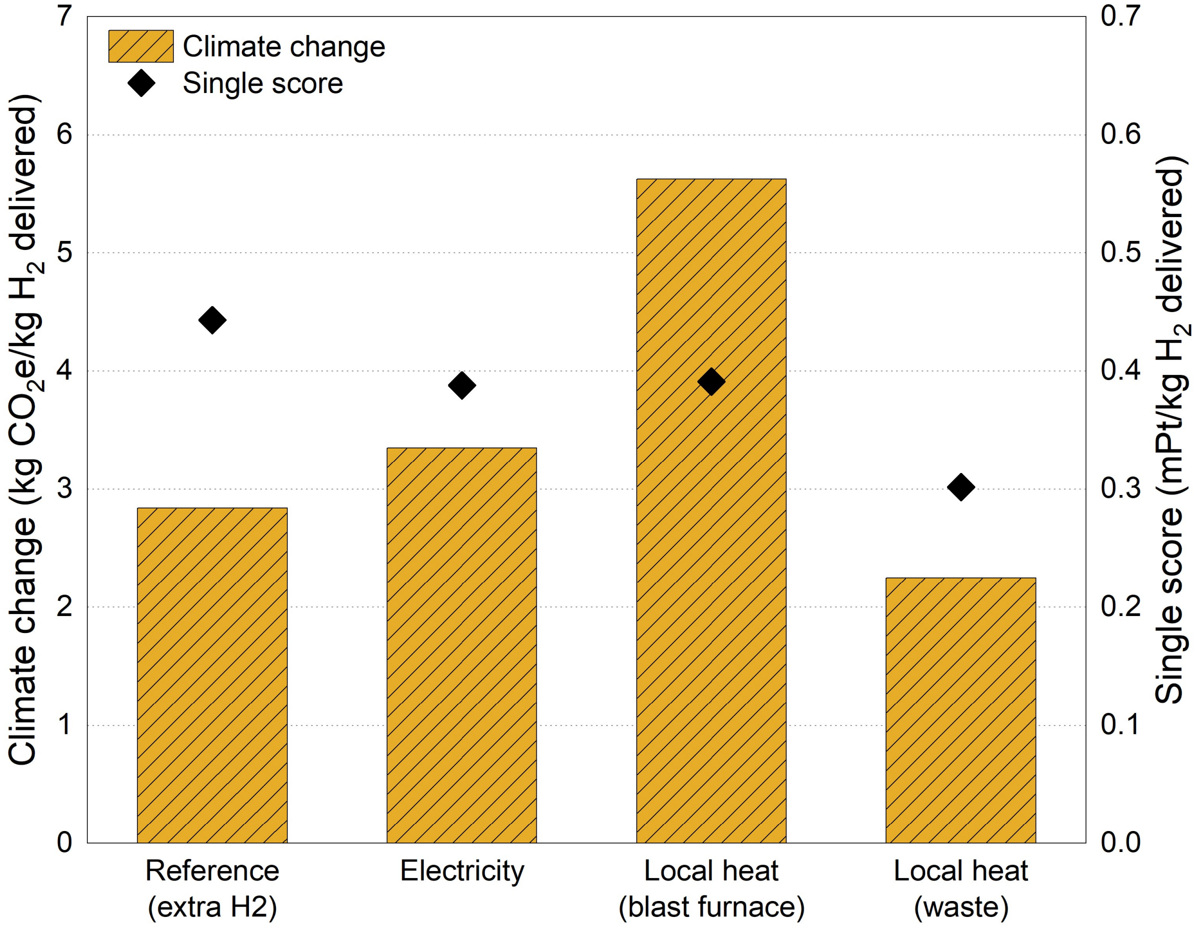
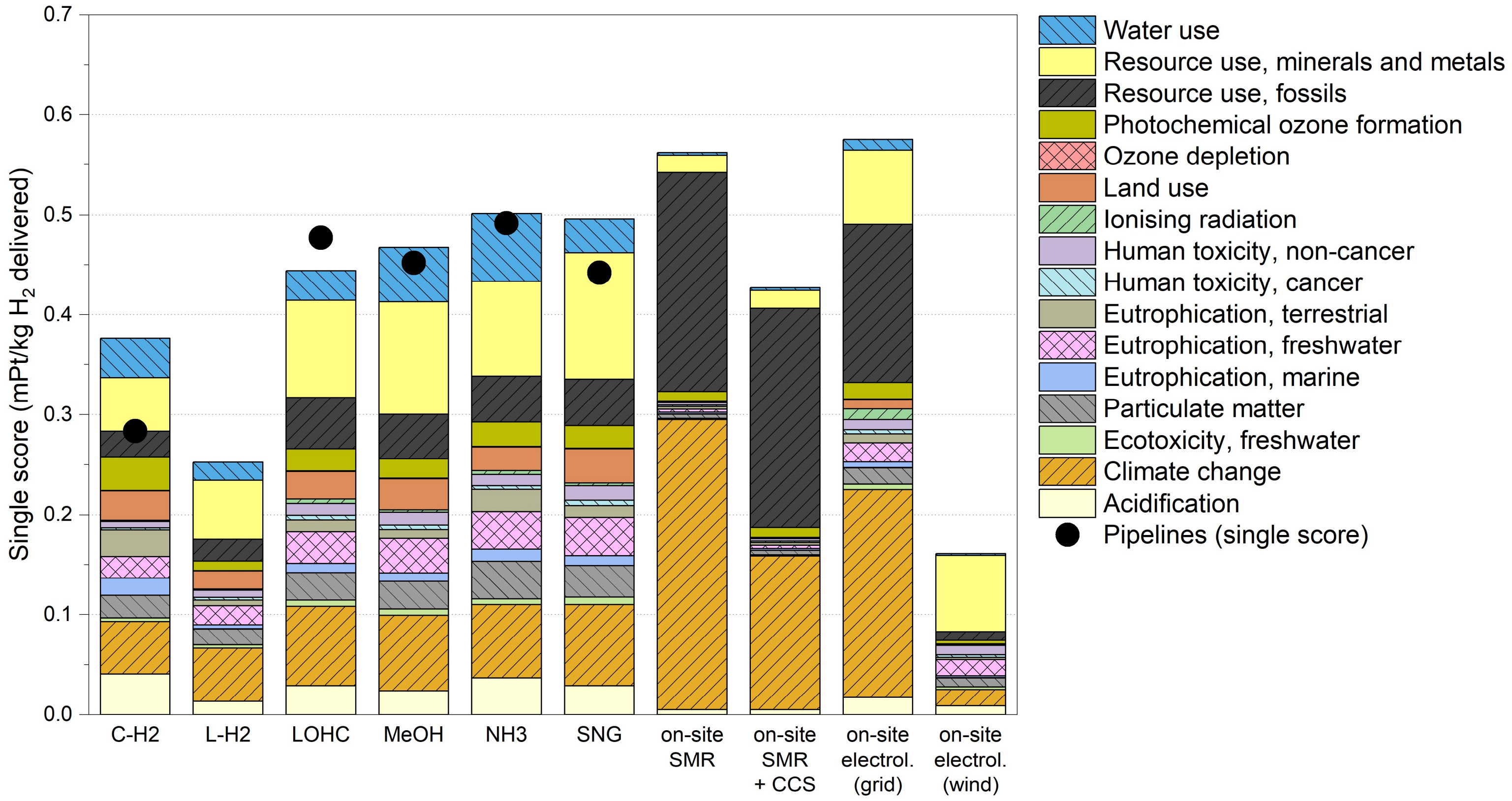
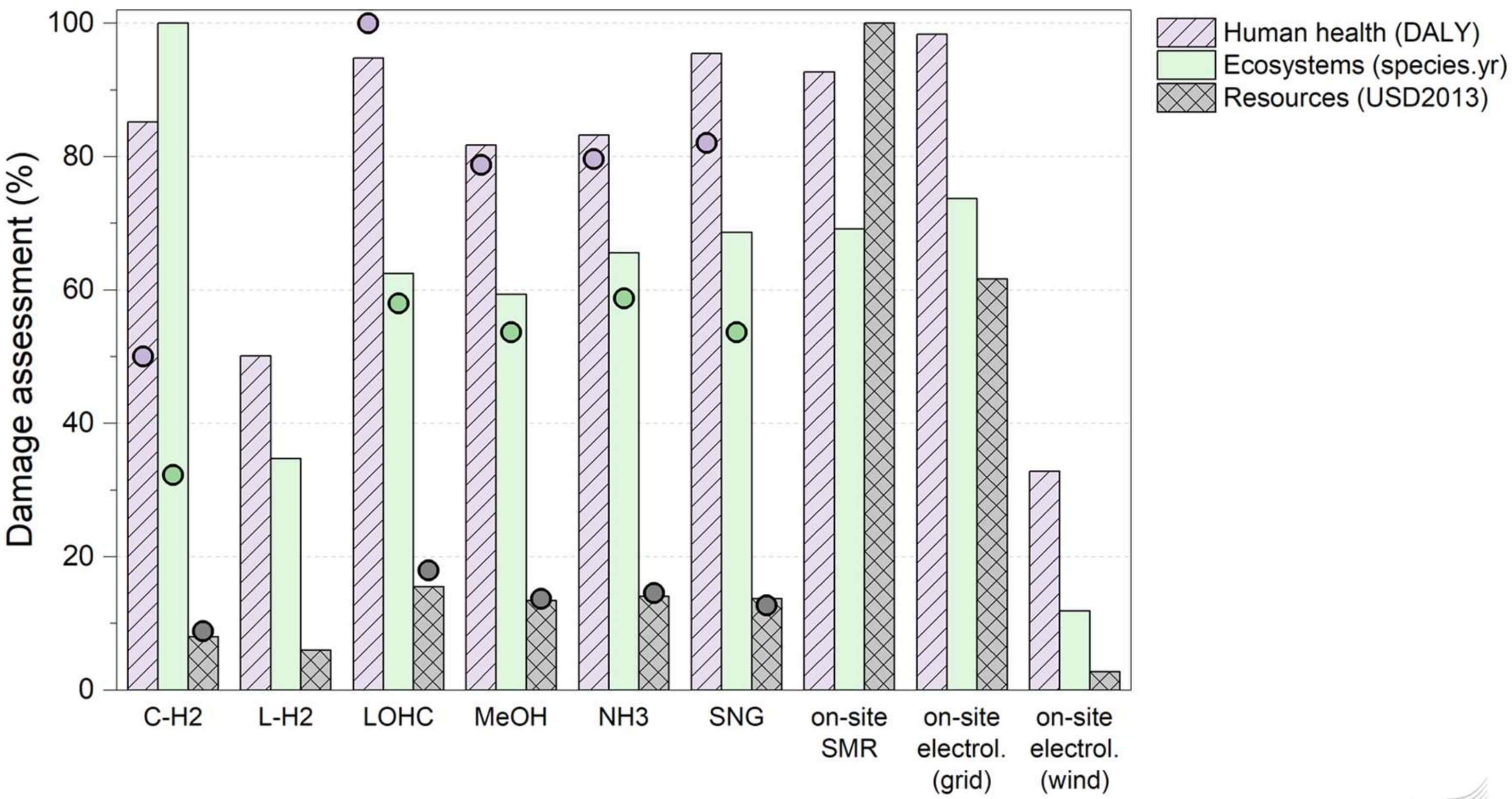
Sensitivity analysis
Energy for unpacking



Sensitivity analysis
Carbon capture and storage



Sensitivity analysis
Impact assessment method



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Agenda

Presentation TNO

15.40 – 16.00

- TNO H2SCM basics
- **Key results**: LCoH2 vs CO2eq
- Some LCA basics
- **Key results**: Relation to RED-III CO2eq treshholds, and grey hydrogen

Discussion

16.00 – 16.20

- Reflection round with Menti
- Discuss trade-offs cost-CO2eq-quantity

Presentation JRC

16.20 – 16.35

- The full picture of environmental impact: From CO2eq to all 18 environmental impact categories

Discussion

16.35 – 17.00

- How to decide about the import routes to invest in?
- An open access approach

TNO innovation for life

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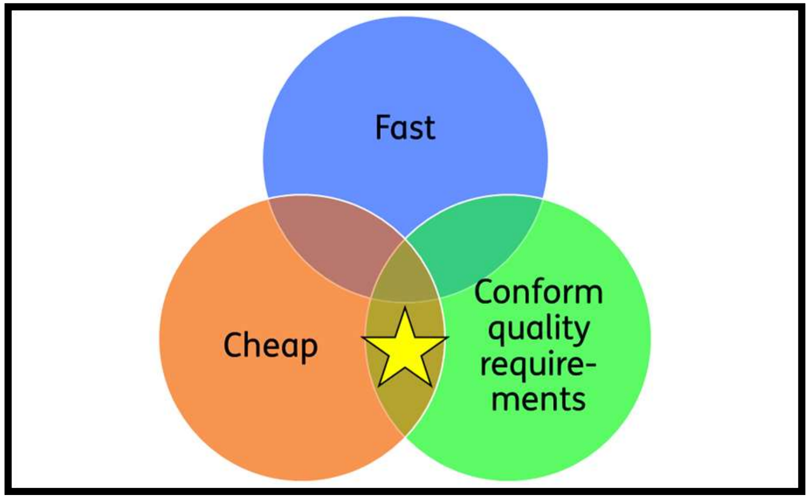
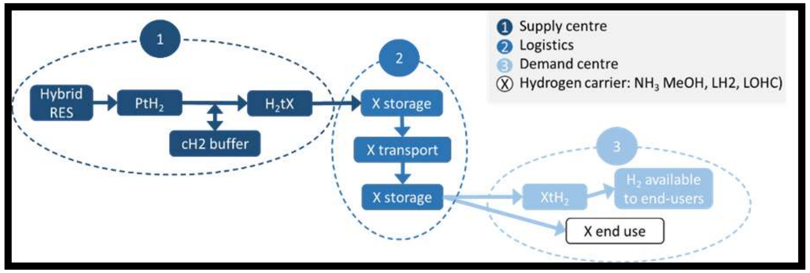
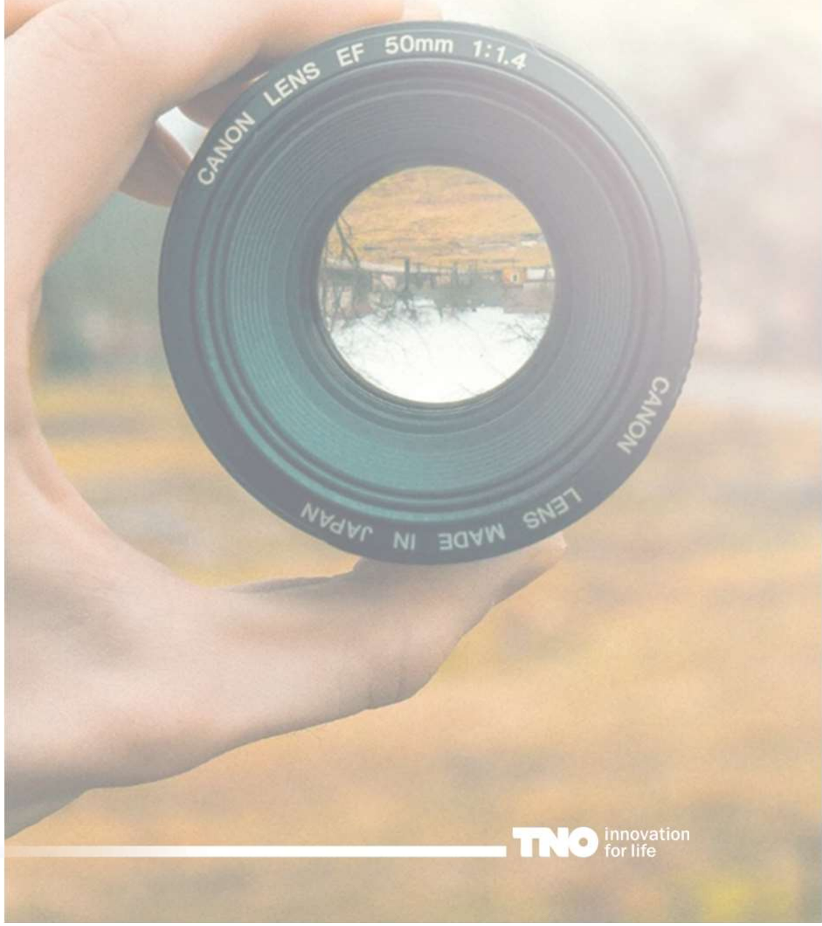
Q: How to decide which import routes to invest in from a low cost ánd low environmental impact POV?







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We have a plan – you are invited

Are you with us?

- Which chains to explore?
- Which configurations and input assumptions?
- And what information to share?

Session Q3 ‘24	Session Q4 ‘24
Import cost of H_2	CO_2e of imported H_2

Open access tooling to challenge, play around and agree (to disagree) with a Community of Practice.

Thank you for your participation

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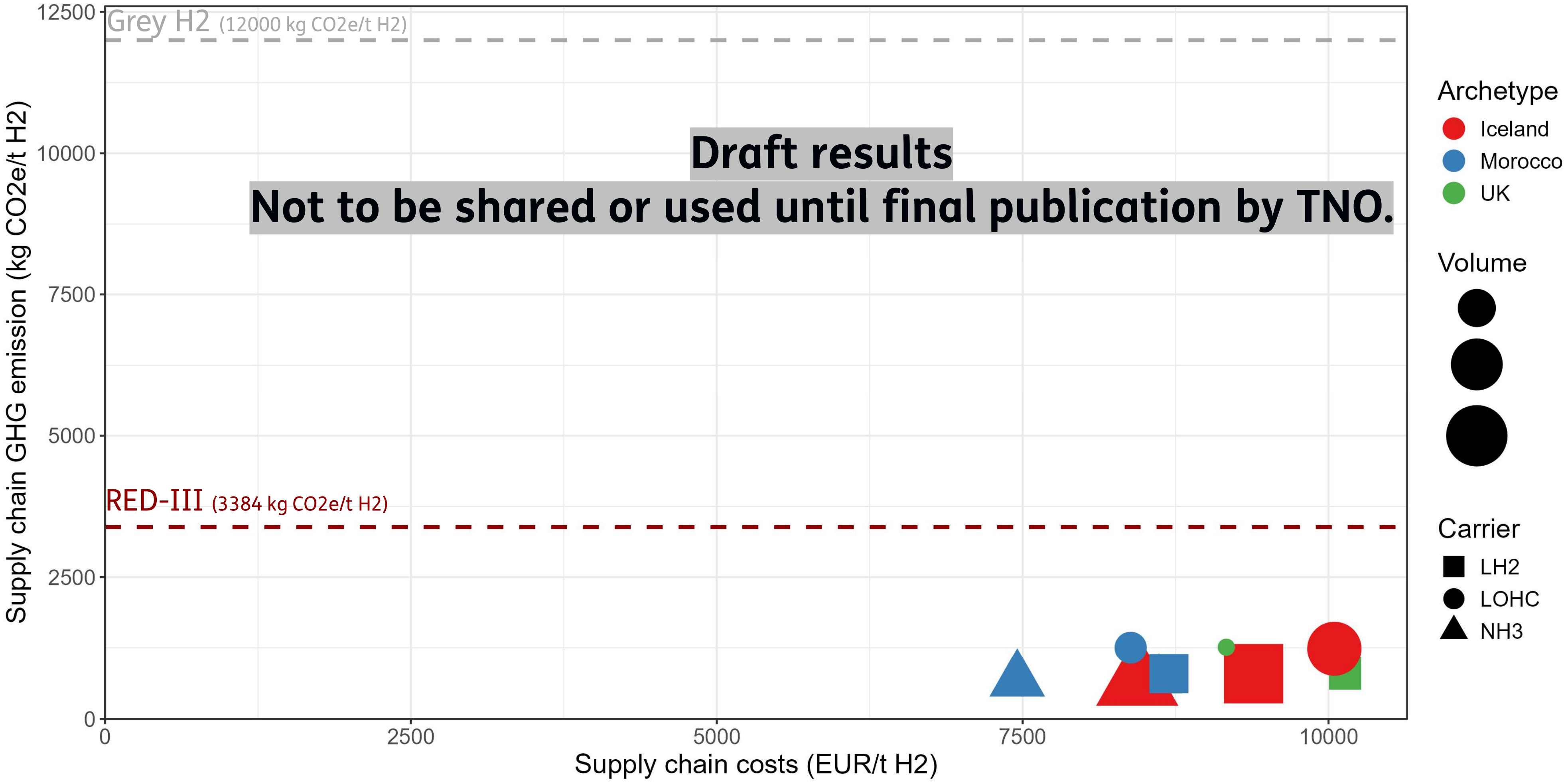
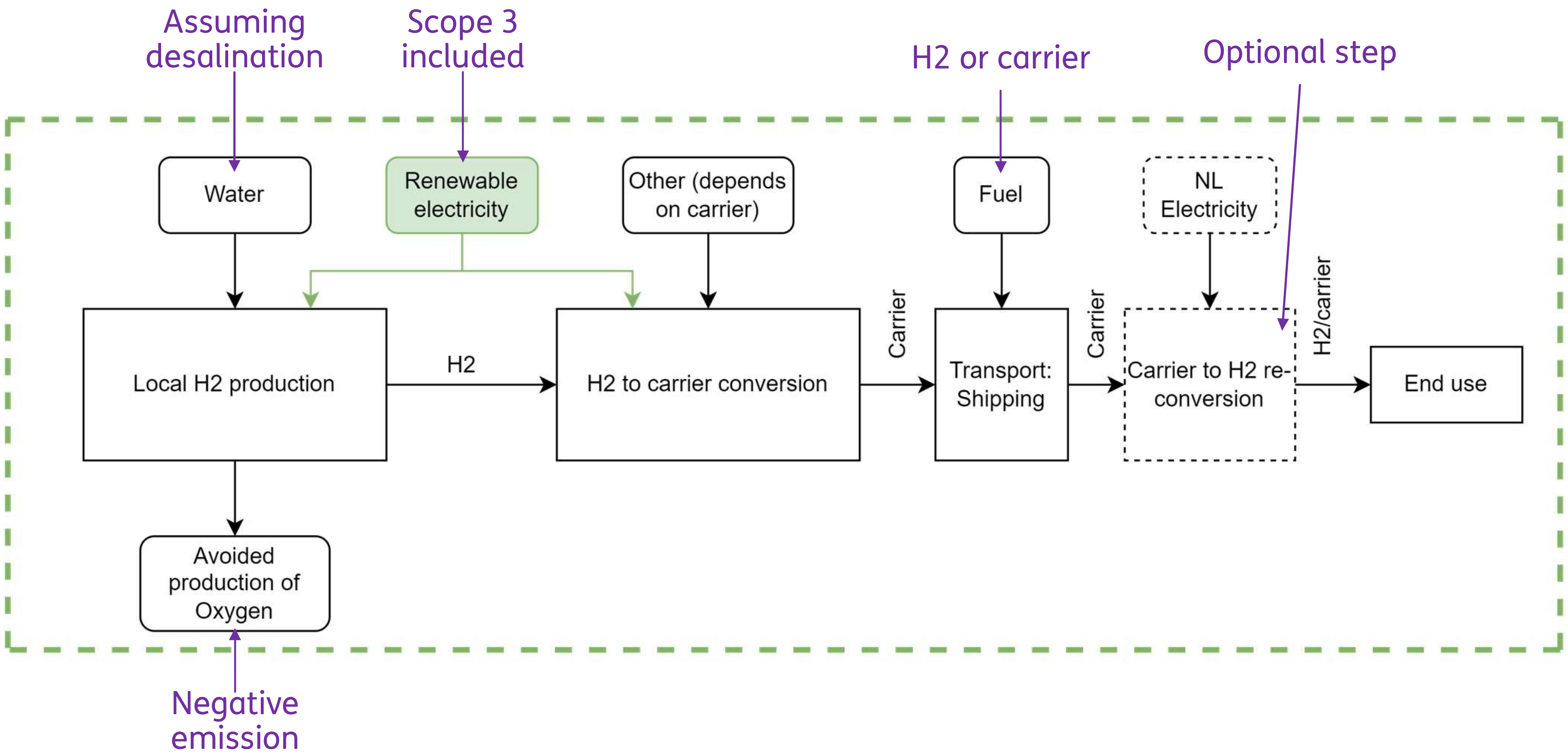
How do renewable hydrogen import chains perform compared to grey H_2?

Trade offs: GHG vs costs vs volume (excl. equipment)



ation

What about the CO2e emissions beyond production?



Other assumptions

Please feel free to challenge these assumption too!

- Emissions associated with the infrastructure (scope 3) of renewable electricity production are included (e.g. PV panel or windmill production)
- Emissions associated with other infrastructure (scope 3) are excluded (e.g. H2 storage tanks, construction of electrolysis plants)
- Back-up power is needed to keep the electrolysis in hot stand by, due to the intermittency of renewables. Lithium-ion batteries were assumed to be used.
- Fugitive H2 emissions are not modeled.
- Carbon cycles of captured CO2 (for MeOH production) were assumed to results in net zero emissions. GHG emissions associated with the capture itself (e.g. power consumption) are modelled.
- Green H2 production sites were assumed to be off-grid, leading to the need for batteries and water desalination.
- Heat needed in several processes (e.g. LOCH dehydrogenation) is provided with H2
- Low temperature alkaline electrolysis is modeled. Proton exchange membrane (PEM) electrolysis will also be considered

Volgende kennissessie

Volgende online sessie woensdag 19 juni a.s.:

- 16.00-17.00 Deep Dive: Methanol in shipping
  Martijn Kom | Boskalis

Agenda 2024

Datum	
Woe 10 juli	F2F
Woe 18 september	F2F
Woe 16 oktober	Online
Woe 20 November	F2F
Woe 18 december	Online

SHIP>NL Sessie V 22 mei

Hartelijk dank voor uw aandacht

Vragen? Neem gerust contact met mij op:

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+31 6 23 34 65 16

De slides van alle sessies zijn te vinden op:
SHIPNL: Sustainable Hydrogen Import Program Netherlands | Nationaal Waterstof Programma