



Spatial-economic analysis of low-carbon hydrogen supply to the European market

Construction of an international merit-order of low-carbon hydrogen

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Outline

1. Low-carbon hydrogen supply
2. Construction of an international merit-order of hydrogen supply to Europe
3. Results
4. Conclusions

Low-carbon hydrogen supply

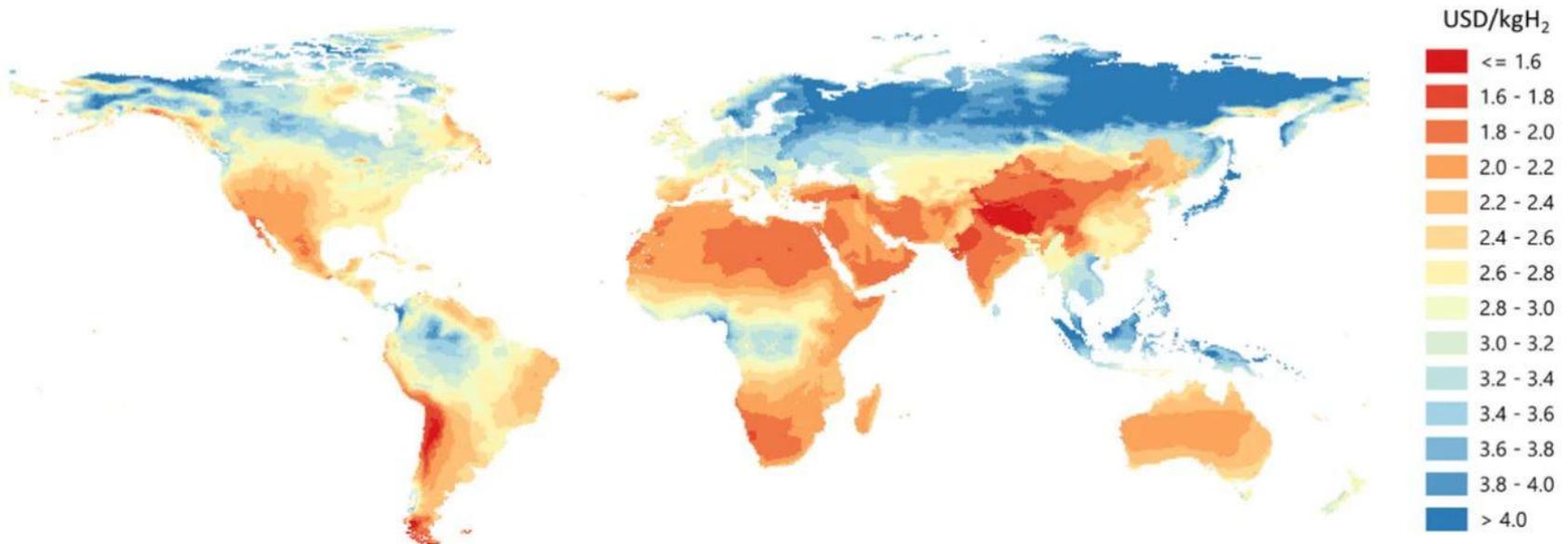
Hydrogen production

- SMR is globally the most used option (95%), with natural gas as the most common used energy input in the EU. Most important cost components are natural gas costs, investment costs and costs of emitting/storing carbon (Collodi et al., 2017)
- Several electrolysis techniques exist, with proton exchange membrane (PEM) electrolysis seen as most suitable for hydrogen production with renewable electricity (FCH, 2017)
- The costs of electricity input makes up a large amount of the total long-term hydrogen costs (Michalski et al., 2017), hence electrolysis production is most competitive where the production costs of renewable electricity are lowest (van Renssen, 2020; Timmerberg & Kaltschmitt, 2019)

Potential production areas

Costs of renewable electricity are largely determined by favourable conditions as solar irradiation and wind speed

Hydrogen costs from hybrid solar PV and onshore wind systems in the long term



Source: IEA; Future of hydrogen (2019)

Low-carbon hydrogen supply

Hydrogen transport

- Options for hydrogen transport include gaseous hydrogen through pipelines, liquefied hydrogen per ship and liquid ammonia as a hydrogen carrier per ship. The most suitable option depends on distance and ratio onshore/offshore

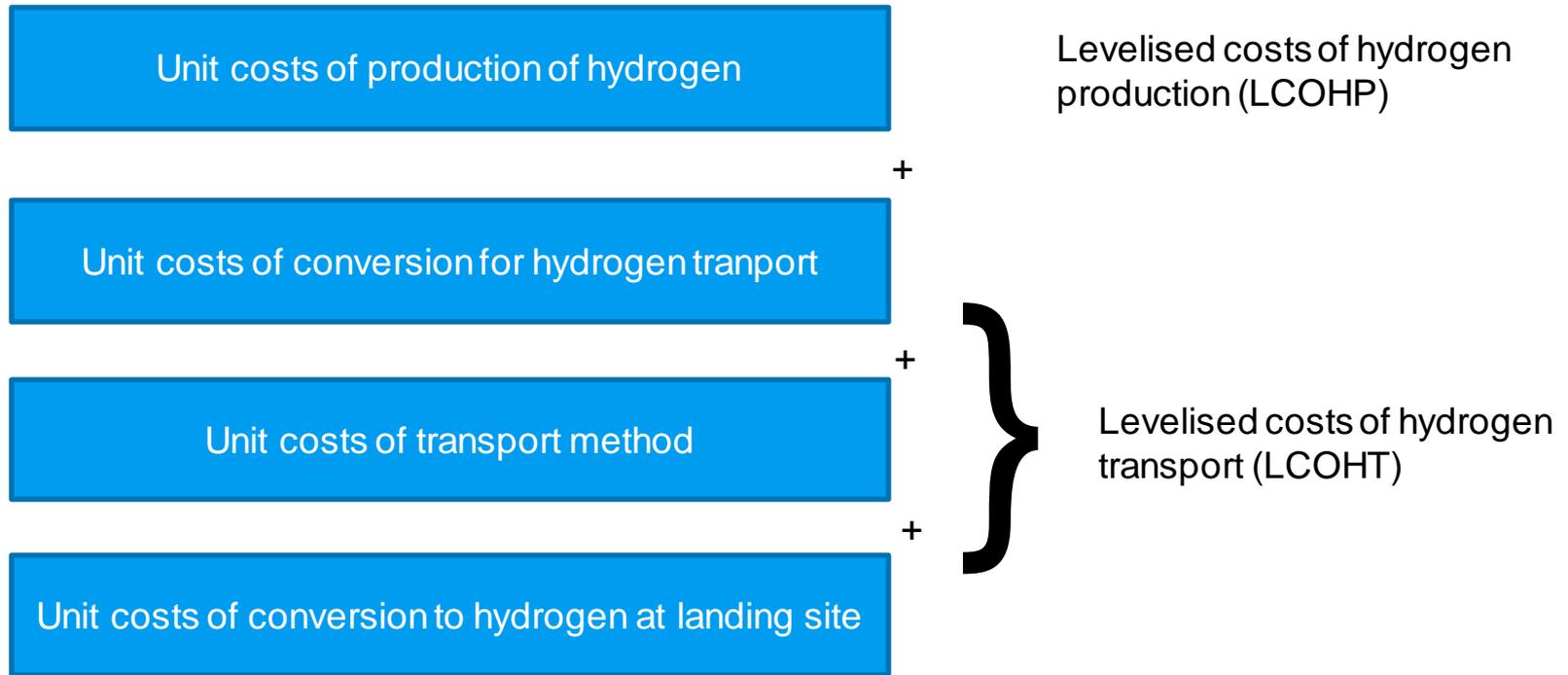


What is the most competitive supply route of low-carbon hydrogen to North-west Europe?

Construction of an international merit-order of hydrogen supply to Europe

- We construct a merit-order for low-carbon hydrogen supply to the port of Rotterdam, which is taken as the entry to the North-West European market, based on the levelised costs of hydrogen supply (LCOHS)
- We determine the long-term unit production costs for low-carbon hydrogen production, given spatial economic conditions in different regions
- Based on national hydrogen strategies we analyse hydrogen produced through SMR with CCS in Norway and hydrogen produced through PEM-electrolysis in Australia, Chile, Morocco, Norway and Saudi Arabia
- Subsequently, we calculate which transportation method is most suitable for each of the identified regions, enabling us to construct a long-term unit cost of supplying low-carbon hydrogen from each selected region
- As benchmark, we include the hydrogen production in Rotterdam for both techniques

Levelised costs of hydrogen supply (LCOHS)



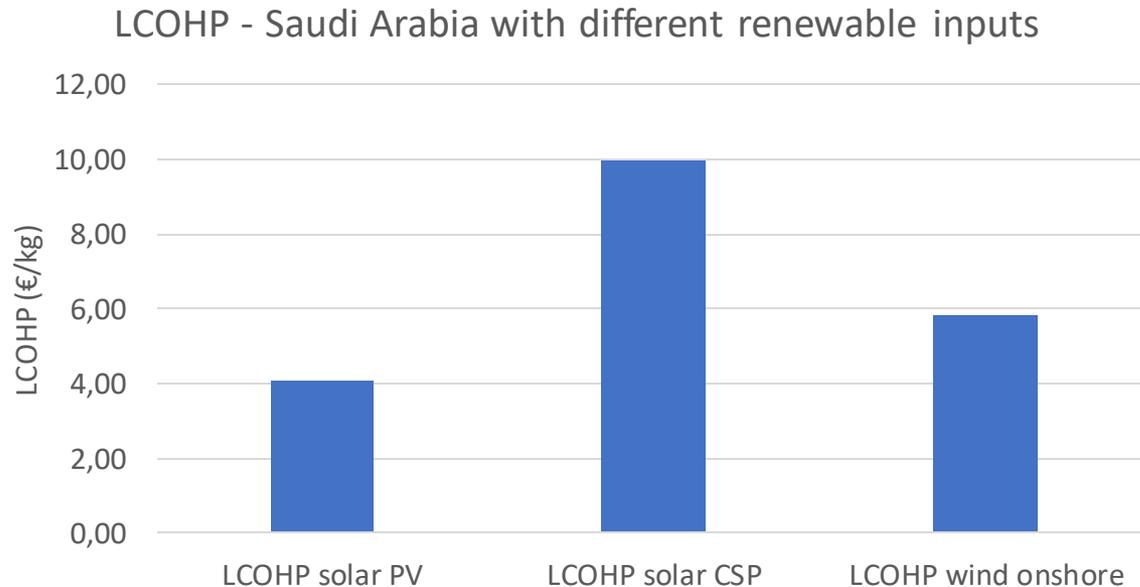
Total unit costs of supply (LCOHS)

$$LCOHS_i = \frac{LCOHP_i}{l_i^x} + LCOHT_i$$

Loss of hydrogen during transport

LCOHP per technique, per country

For each country, the information on the LCOE and capacity factor are used to calculate the LCOHP. From these, the technique with the lowest LCOHP is selected for that country

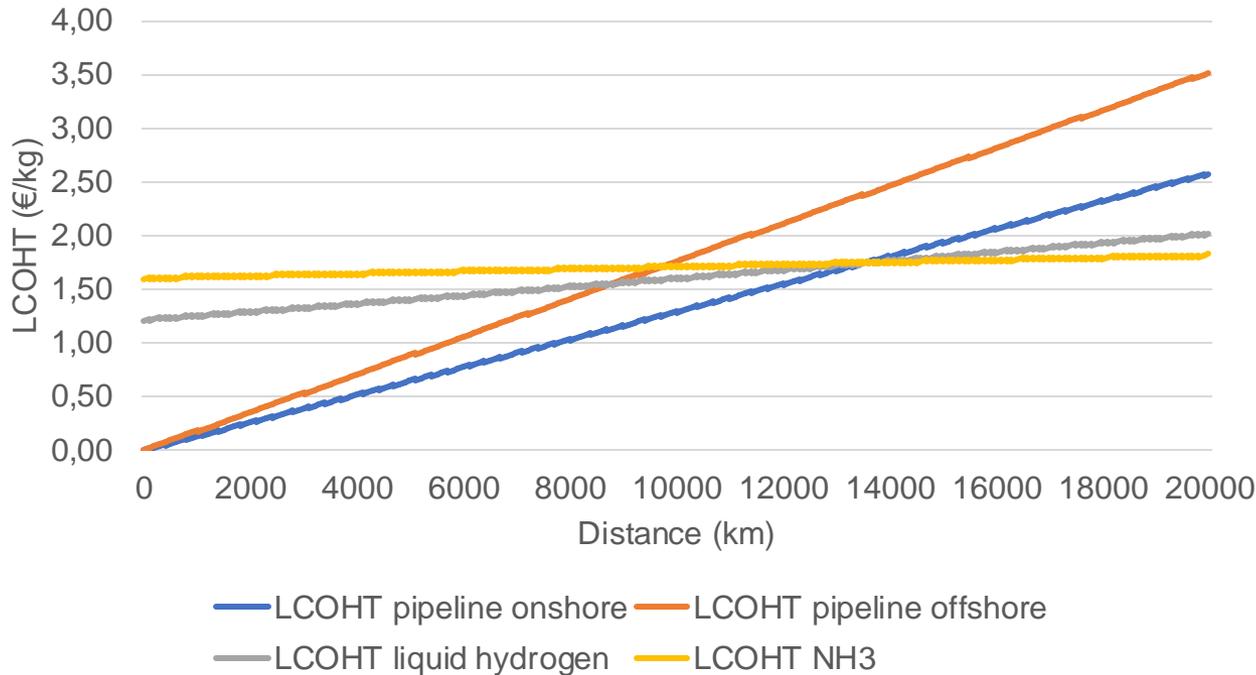


Here, we select solar PV as renewable electricity input for Saudi Arabia

LCOHT for different distances

Assuming optimal utilisation of transport methods

Comparison LCOHT

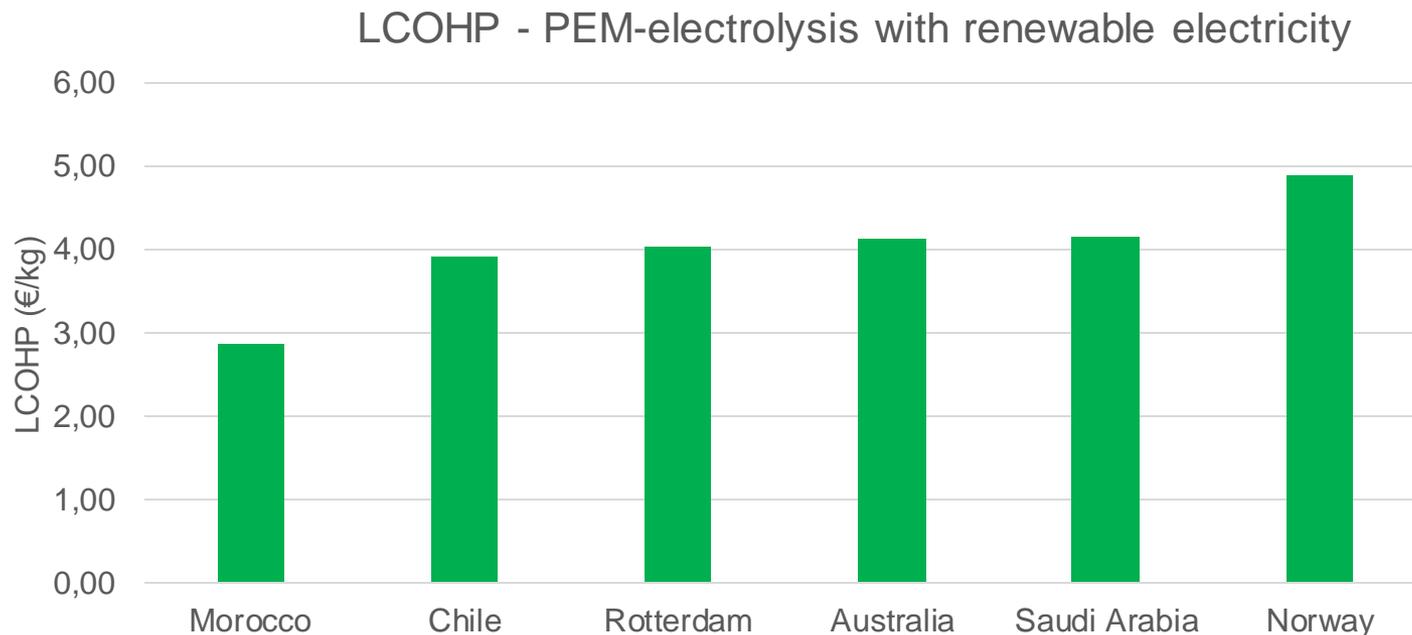


Based on:

Electricity price (€/MWh)	45
H2 price (€/kg)	3
Gas price (€/MWh)	20
Carbon price (€/ton)	40

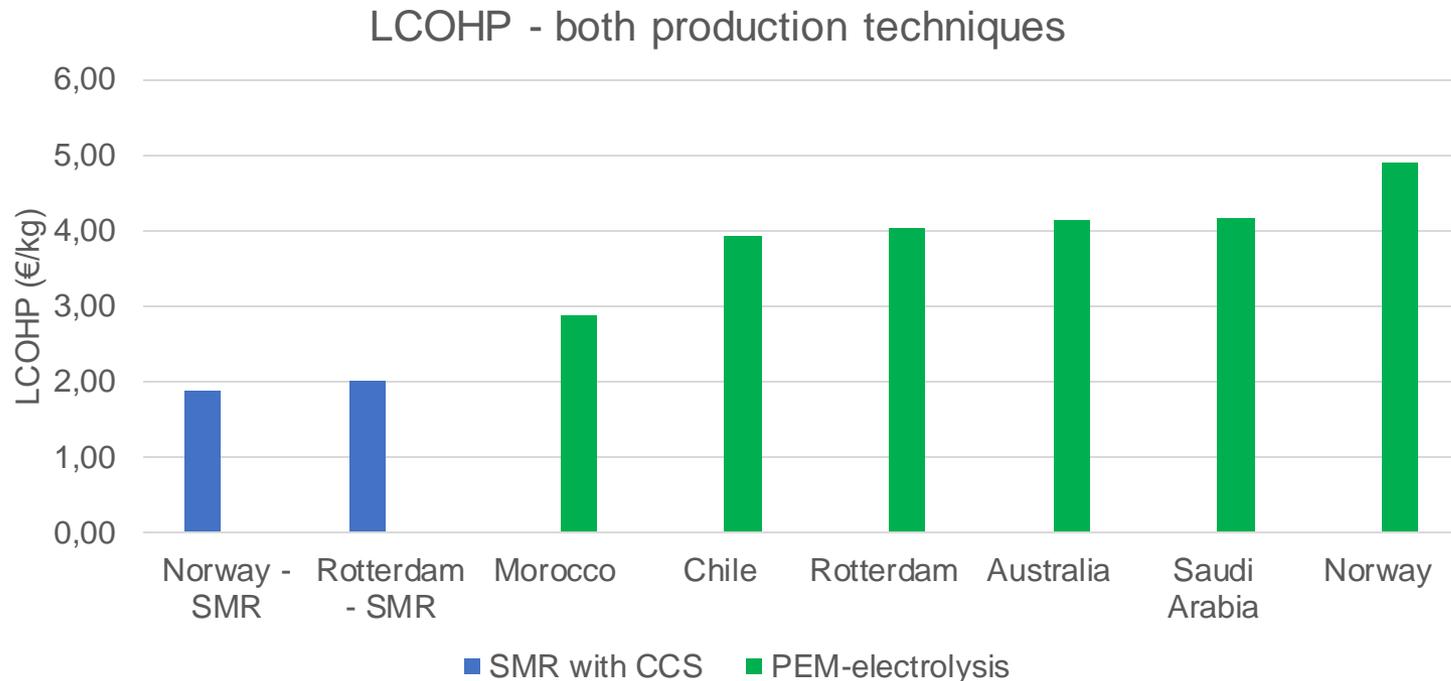
Shipping of liquid hydrogen and ammonia have high upfront costs, but become competitive over larger distances

Levelised costs of hydrogen production (LCOHP) for PEM-electrolysis using renewable electricity



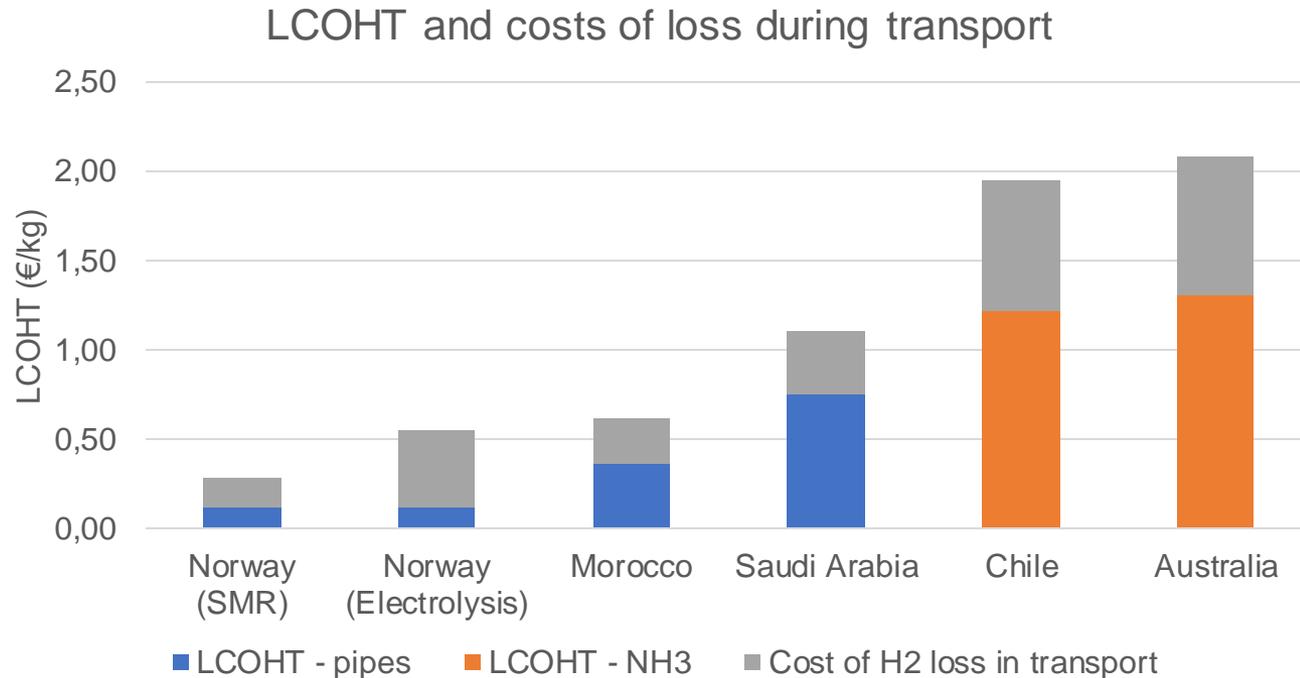
Production of hydrogen using renewable electricity is most competitive in Morocco, with a LCOHP of below 3 €/kg

Levelised costs of hydrogen production (LCOHP) for both SMR with CCS and PEM-electrolysis



Production of hydrogen using renewable electricity is not competitive compared to SMR with CCS production, which have a LCOHP of under 2 €/kg

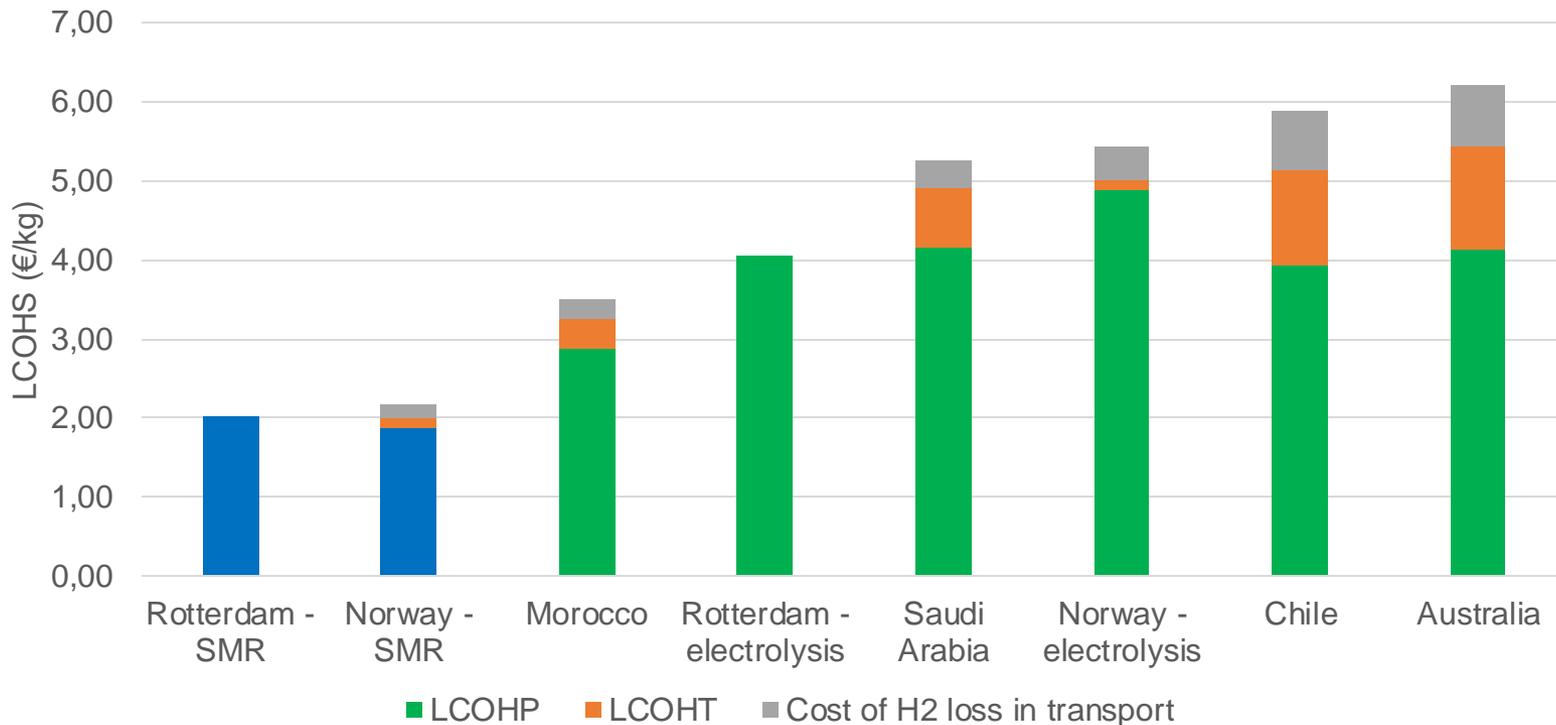
Levelised costs of hydrogen transport (LCOHT) including costs of hydrogen loss during transport, per country



For the larger distances, transport as ammonia is most competitive for that region

High LCOHT for larger distances can potentially be a driver for global price differences

International merit-order of hydrogen supply

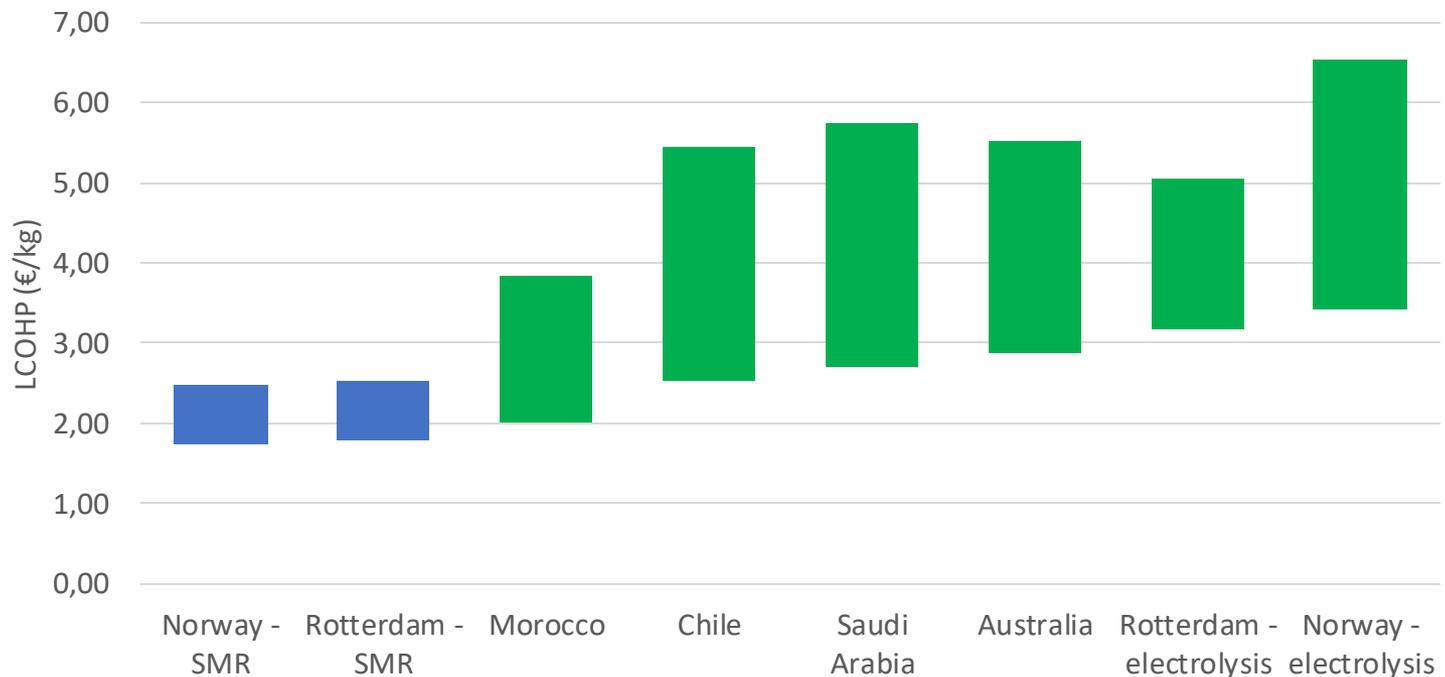


Hydrogen produced through SMR with CCS in Rotterdam is the most competitive

If one only considers PEM, supply from Morocco is cheaper than production in Europe

Levelised costs of hydrogen production (LCOHP)

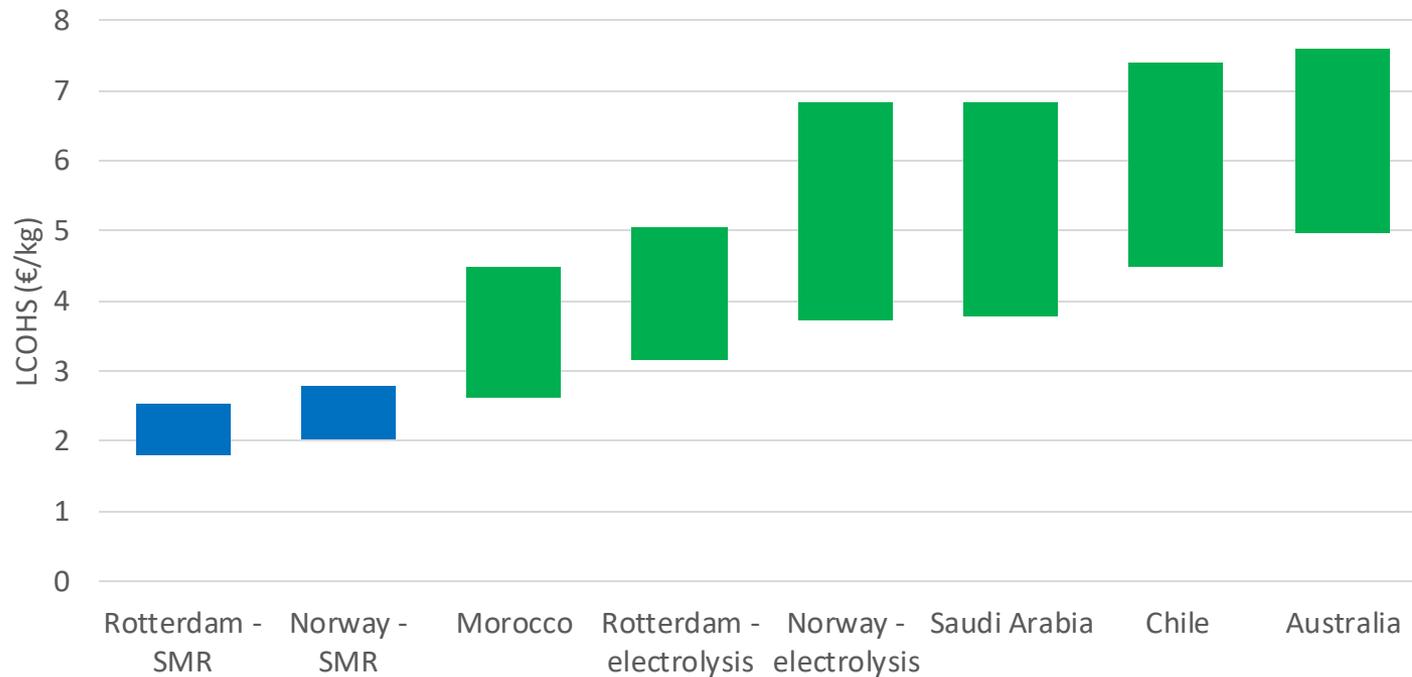
Sensitivity analysis



In an innovative scenario, the production costs of electrolysis could become more competitive. This mainly affects regions with lower capacity factors.

International merit-order of hydrogen supply

Sensitivity in production costs



If transport costs are included, the merit-order is not altered from the first outcomes. Especially import from further distances remains uncompetitive

Conclusions

- Production of hydrogen using renewable electricity is most competitive in Morocco
- Production of hydrogen using renewable electricity is not competitive compared to SMR with CCS production
- For larger distances, transport as ammonia is most competitive for that region
- High LCOHT for large distances can potentially be a driver for global price differences
- Hydrogen produced through SMR with CCS in Rotterdam is the most competitive
- If one only considers PEM, supply from Morocco is cheaper than production in Europe
- Cost reductions in electrolyzers do make this option more competitive, but does not alter the international merit-order
- Higher capacity factors of renewables could change the merit-order



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