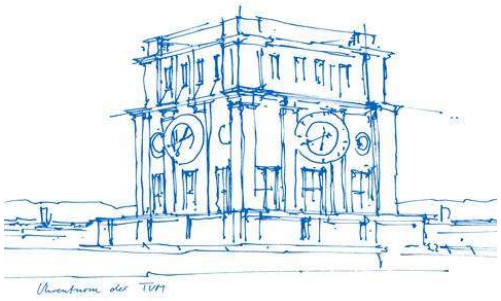
IAEE, 2021

Is There a Winner:

A Study of Competition Among Hydrogen Technologies

Svetlana Ikonnikova*, Bridget Scanlon, Sofia Berdysheva

Center for Energy Economics,
TU Munich, School of Management



CEM

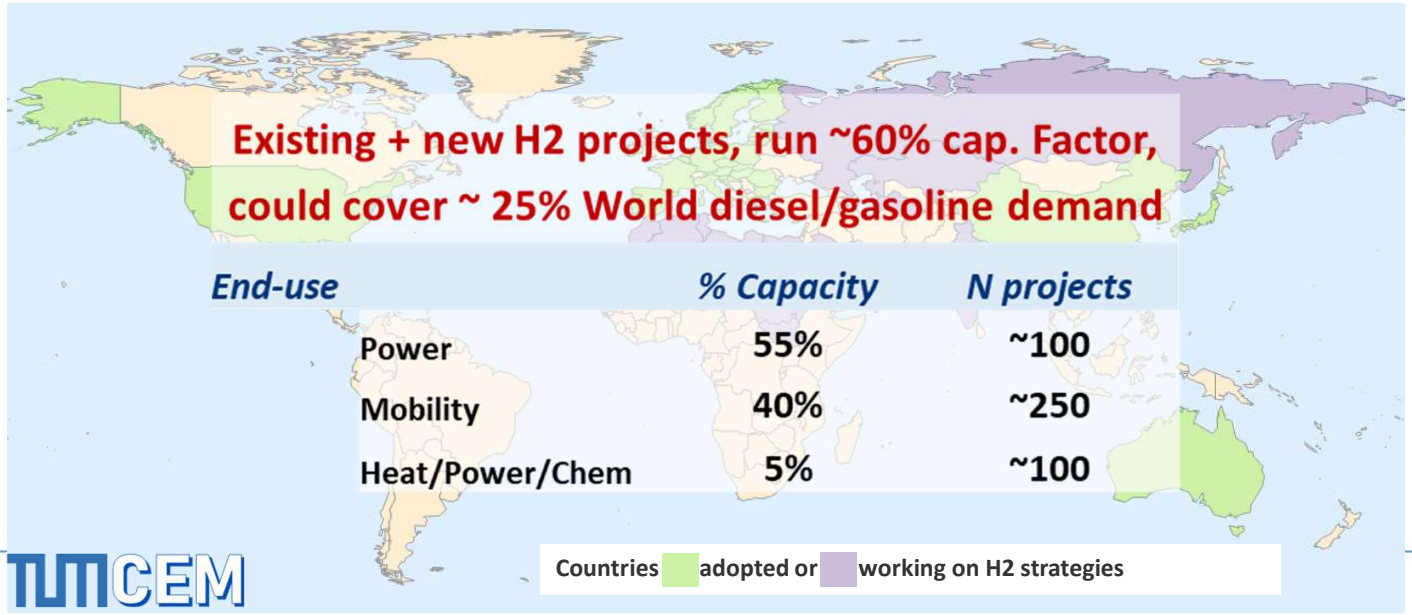
Support energy transition with research and education

Plan for Today

- Data analysis and overview of the techno-economic analyses:
  - Demand for H2, incl. blue vs. green technologies in regional and global markets
- Motivation and Research Questions
- Competition model
  - Setup and assumptions
  - Solution: The role of exogenous parameters
  - Results
- Conclusions and Directions for Further Research

Hydrogen is a New Global Energy Player

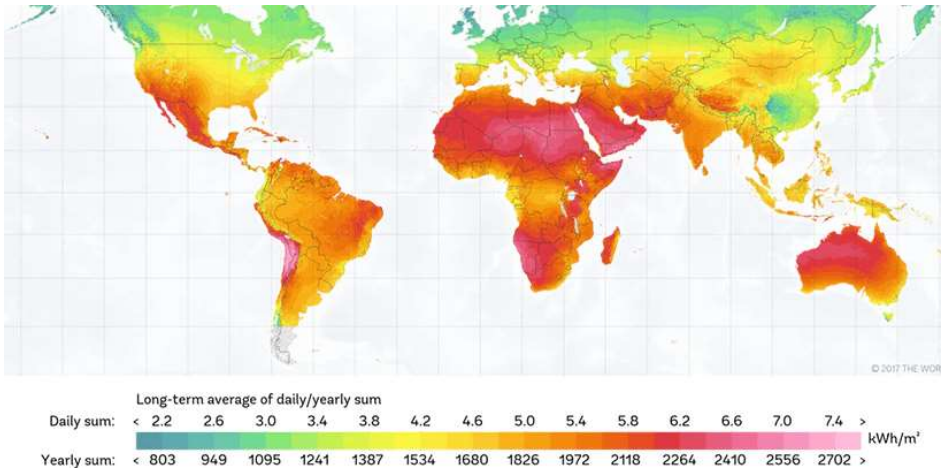
- The increasing number of countries adopts strategies on GHG emission reductions and linked to them regulations focused on energy supply, especially RES and hydrogen (H2)
  - In July 2020, the EU has released its Strategy on Hydrogen aligned with and supporting its Strategy on Energy System Integration and the goals for carbon neutrality by 2050.



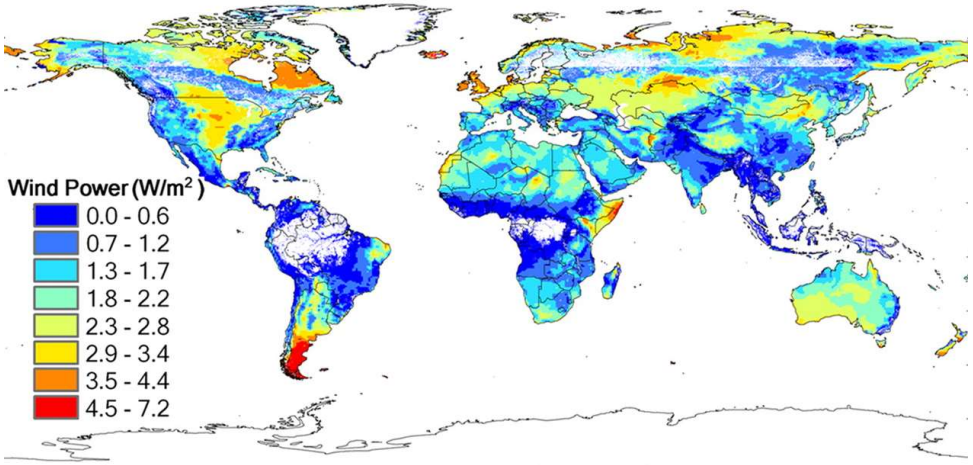
Sources: IEA, CEM

Energy Data Analysis: RE Generation Potential

- Reduction in fossil energy consumption would require an increase in wind & solar (+ other RE) resource use
- The existing assessment of the wind & solar generation potential, reveal the uneven global production potential distribution (ArcGIS project compiling data from WindGIS, Solar Atlas and 10+ pubs)



https://doi.org/10.1016/j.jclepro.2018.10.239



Xi Lu et al. PNAS 2009;106:27:10933-10938

The Role of Hydrogen in the Energy Transition

- Assessment of the wind & solar generation potential reveals:
  - The distribution of RE resources is not proportional to local consumption => countries / regions with **RE deficit**
    - The major economies, incl. Germany, China, Japan, India are likely to become **RE-importers**
  - For some regions the challenge is in water-energy nexus

But in total there is at least 3x of the World Energy Demand

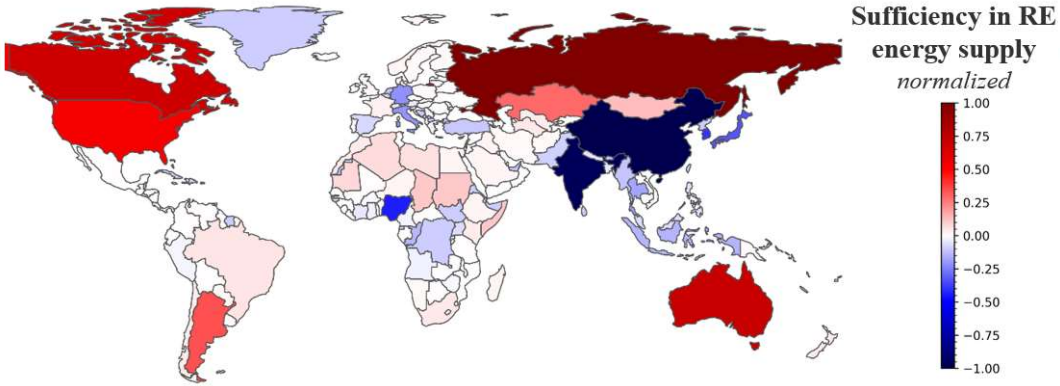


Figure 3. Mapping the difference between wind and solar energy generation potential and countries' 2019 primary energy consumption normalized to the maximum (for positive) and minimum (for negative) values.

Water Challenges and Opportunities (Desalination)

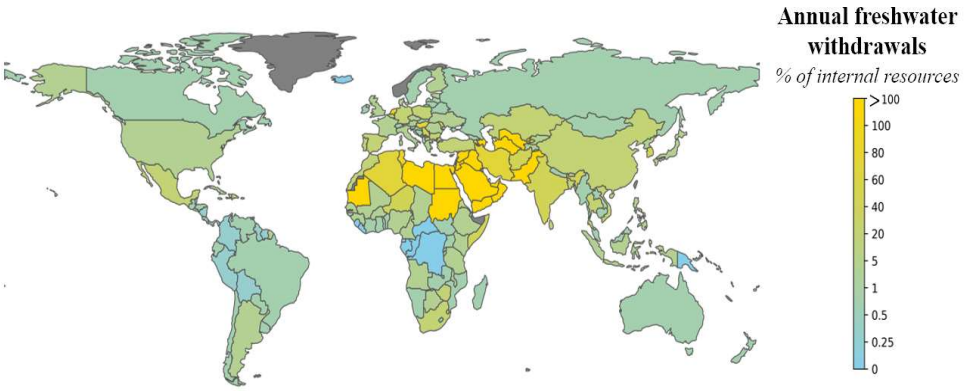


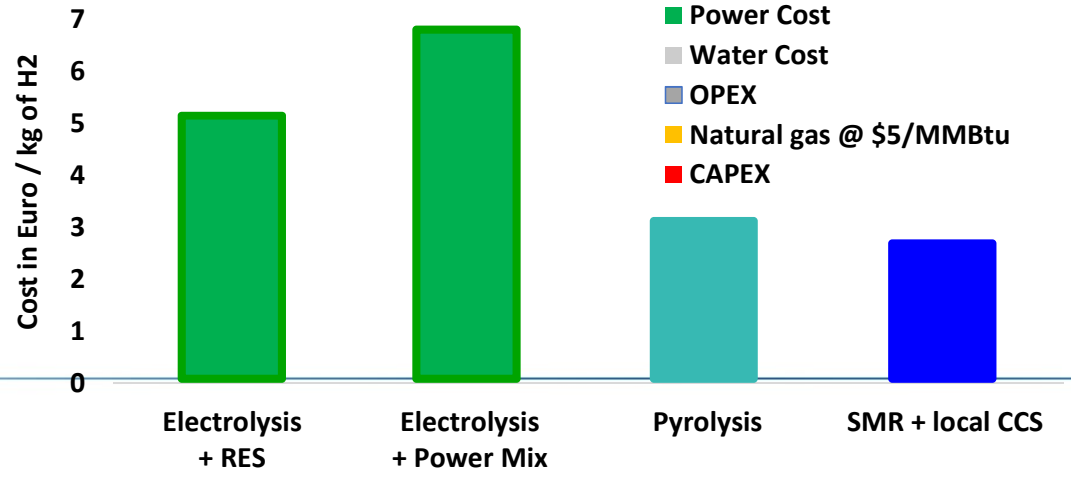
Figure 6. A map of the internal water resource use indicating the countries with potential water scarcity issues, based on 2017-2019 data reported in the World Bank Database.

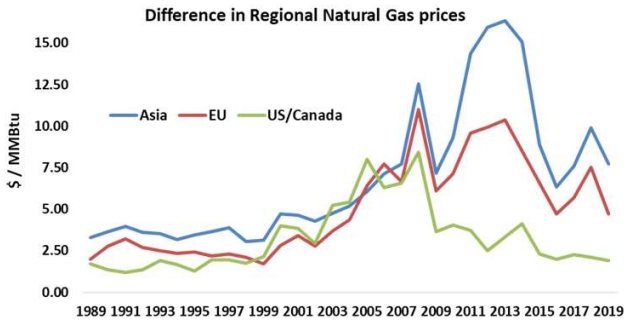
H2 cost structure and the role of CO2 policy

➢ The announcement of the long-term support to H2 led to technological race

- The increasing number of techno-economic analyses focuses on H2 technology efficiency η and prices of feedstock
- However, such project economics studies ignore the interfuel substitution effects, arbitrage, and regional differences
  - $2H_2O \rightarrow 2H_2 + O_2$: $MC_{H_2} \sim p_e \cdot \eta_e + p_C \cdot 0$
  - $CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2$: $MC_{H_2} \sim p_{NG} \cdot \eta_{NG} + p_C$
  - $CH_4 \rightarrow C + 2H_2$: $MC_{H_2} \sim p_{NG} \cdot \eta_{NG} \pm p_C$

based on Tlili, et al., 2019
Timmerberg et al., 2020





Research Questions

- Interested in how the emerging local and global H2 markets, we study:

  1. How will the competition between different H2 technologies may develop given that natural gas and power prices are interrelated in many regions? ***Could green H2 win the increasing market share squeezing out the blue H2 driven only by technology efficiency (without additional policy support)?***

  2. Which policy instruments are more efficient to promote green H2? ***How the policy efficiency may be affected by the resource prices and availability?***

- Since H2 technologies are still in their infancy, we are interested to develop adaptable, updatable, and expandable framework for the analysis of the emerging H2 markets.

Model Setup

- Most techno-economic assessments for green H2 technologies, assume $p_e = MC_{RES}$ for the price of electricity, yet the retail power price suggest that the price of RE is linked to the grid price
- We refer to the merit order and test the hypothesis that year-average power price is a function of natural gas prices as well as RE generation:

$$\boldsymbol{MC_t^g \sim p_e^t \left(K_{RES}^t, p_{ng}^t\right) \cdot \eta_e = \eta_e^t \cdot \left(\alpha_{t_e} + \frac{\beta_t}{K_{RES}^t} p_{ng}^t + \gamma_t K_{RES}^t\right)}$$

- Seeing natural gas as a global commodity, we set its price be independent on the local power demand in the short-term, with

$$\boldsymbol{MC_t^b \sim \eta_{ng}^t \cdot p_{ng}^t}$$

- In the long-term, the large-scale adoption of renewables and substitution of NG by H2 in other sectors may affect the NG price.

Demand and Regulation Parameters

- In the view of the discussed regulations, we assume that consumers may develop different willingness to pay for H2 dependent on its color.
- We introduce a differentiated demand function that also allows for capturing the potential effect of “green H2 certificates” or other factors affecting public preferences:

$$P_{H2} = (a_t - b_t \cdot q_{blue} - g_t \cdot b_t \cdot q_{green})$$

- We consider competition *a-la Cournot* to analyze investment strategies of green and blue H2 producer groups.
- In the profit function we neglect fixed cost with the reference to regulation and/or sunk cost argument

Solution

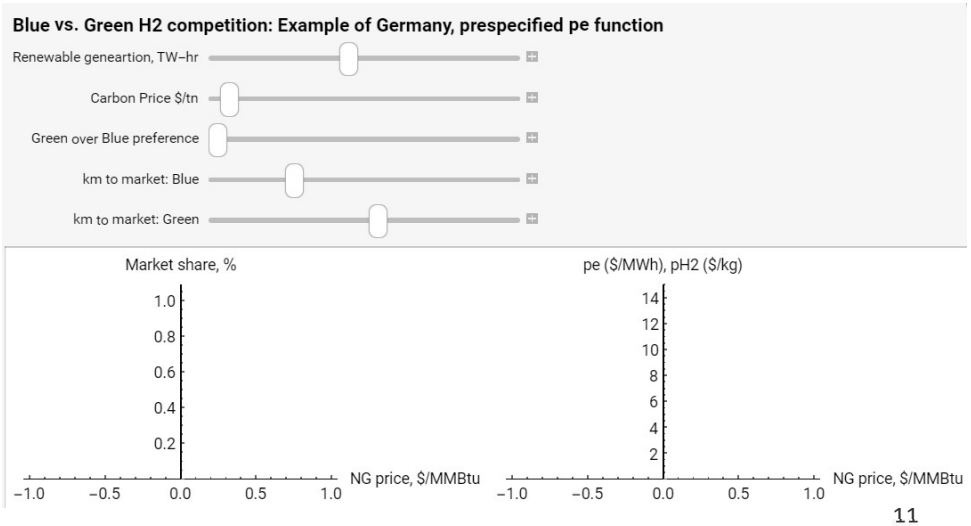
- The limiting assumption on the Cournot competition with only two producer groups, is later relaxed.
- Profit maximization for green and blue H2 producers results in the quantity-based reaction functions and optimal supply functions *both dependent on natural gas and* K_{RES}:

$$q^g = \frac{a + p_C - 2 \cdot \alpha \cdot \eta_e + 2 \cdot \gamma \eta_e \cdot K_{RES}}{3g} + \left(-2\beta \cdot \eta_e + \eta_g \cdot K_{RES}\right) \cdot \frac{p_{ng}}{3gK_{RES}}$$

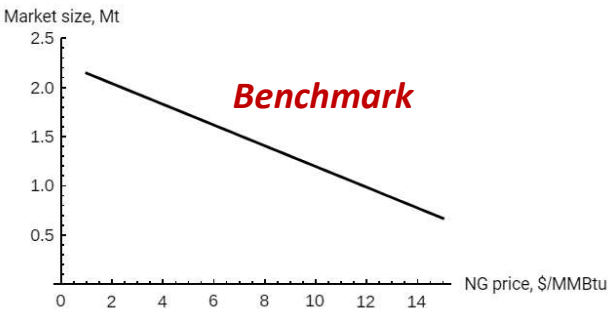
- Positively linked to carbon price/tax
- Positively linked to efficiency
- Sensitivity to the demand parameters / certification option
- Not trivial link to K_{RES} (power price coefficient sensitive)
- Non-trivial relationship to natural gas price: a decrease in natural gas price could outweigh p_C or K_{RES} effects

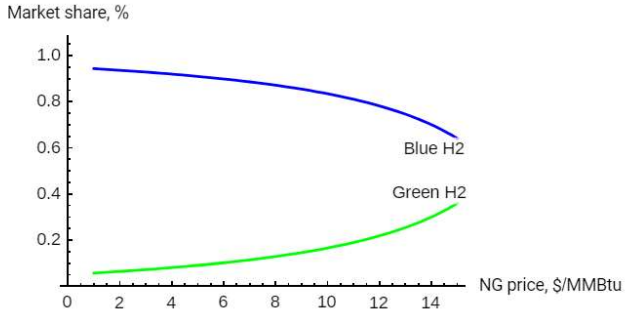
Results

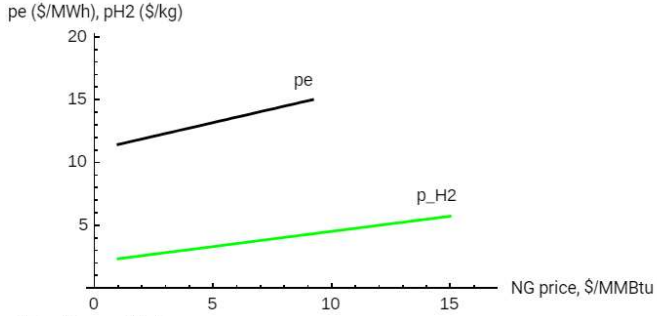
- Focusing on the dynamics carbon and natural gas prices, along with the increasing share of RE generation, we run a set of scenarios to see the interactions between those variables.
  - The increase in the renewable generation is likely to reduce price of power, making less dependent on natural gas prices
  - A drop in natural gas demand may translate into a drop in p_{ng} (when the demand decline is a global phenomenon), then efficiency of policy measures and investments would decrease.

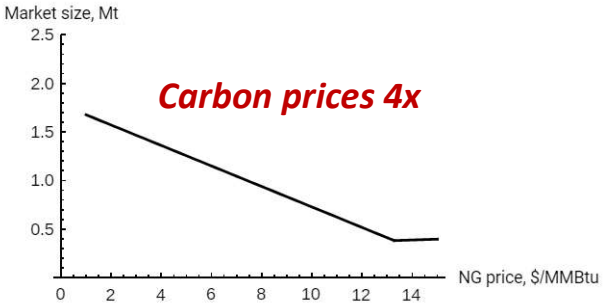


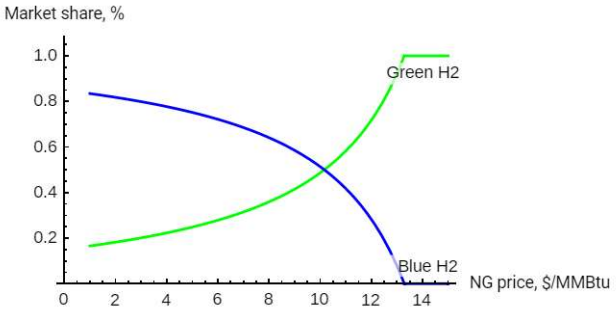
Scenarios of Blue and Green H2 Market Sharing: Germany

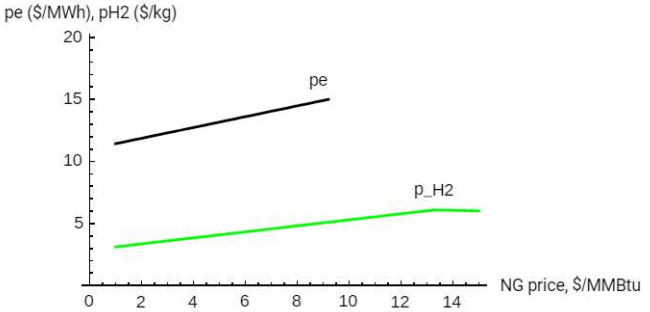


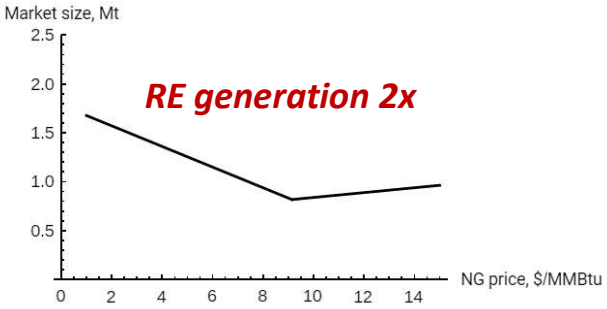


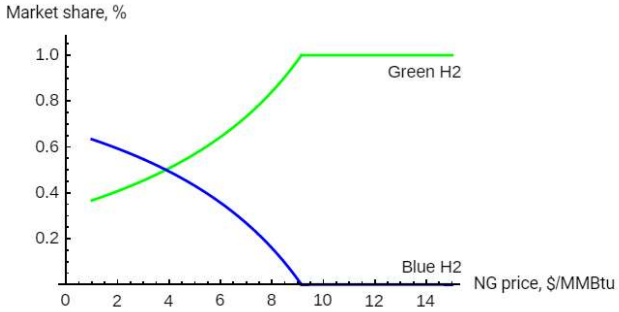


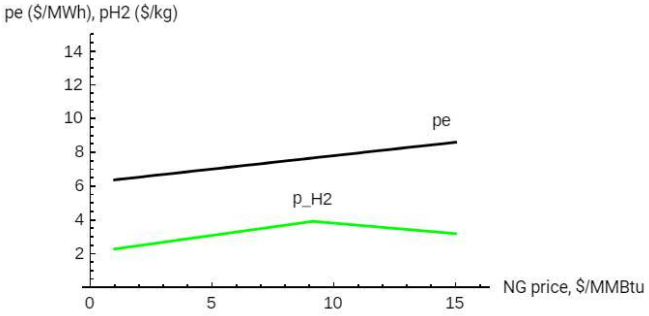












The Role of Hydrogen in the Energy Transition

- Hydrogen is critical to store large quantities of energy for long periods of time, manage intermittency
- Hydrogen (and ammonia) is preferable form for transport of renewable energy (vs. international power system)
- Abstracting away from investment cost (with mid- and long-term in mind, PP financial support), the analysis of the current MC of renewable energy and wholesale natural gas prices reveals, that green H2 is not the least cost input in a number of regions with RE-export potential

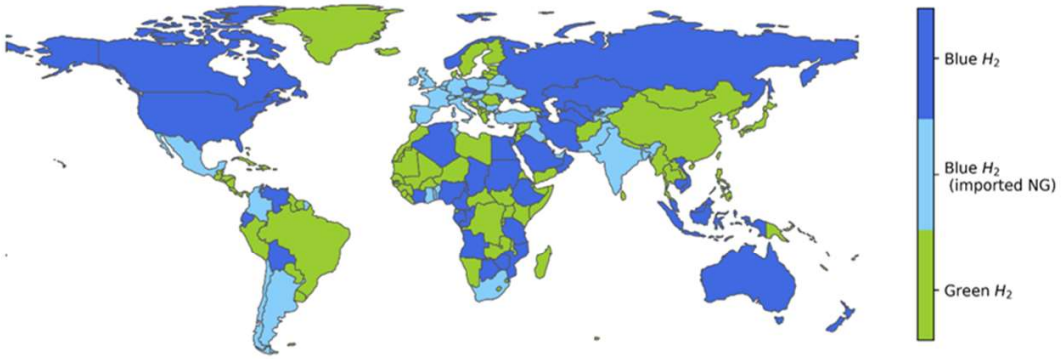


Figure 4. A map of the least marginal cost hydrogen technology based on 2019 wholesale natural gas prices and assuming ~$35/MWh cost of green hydrogen, equivalent to ~2$/kg of H2.

Conclusions and Further Research Questions

- Our analysis reveals the importance of:
  - Effect of increasing RE capacity and generation on H2 competition
  - Regional energy prices and policies for promotion of the green H2
  - Regional arbitrage opportunities
- Our model abstracted away from how marginal cost may be affected by the developments in demand
  - In UK, H2 is used for heating competing with natural gas => reducing demand for NG => reducing p_{ng} => making blue H2 more attractive
- Regional energy prices, RE capacity, carbon regulation, and distance to market affect the market sharing and suggest the price differentials around the world:
  - Blue H2 or NG delivered from Russia (>10,000km) vs. Green H2-based Ammonia from Middle East are likely to compete for residual EU demand for H2
- We find that the adoption of green H2 is the most affected by the share of RE, it remains to be tested the affect of carbon tax on the demand preferences.
- We confirm that the resource (RE and natural gas) availability and affordability will play a critical role.