Technische Universität Berlin

THE GLOBAL HYDROGEN MARKET 2050

A MODEL-BASED COMPARISON OF PATHWAYS AND POLICY CONSTRAINTS

Jefferson Riera, Lukas Barner, Franziska Holz
Lennart Rathje, Robin Sogalla, Christian von Hirschhausen

Fachgebiet Wirtschafts- und Infrastruktur Politik (WIP)

Today ~95% of hydrogen production comes from fossil fuels…

through steam reforming (SMR) of natural gas and coal.

- Hydrogen is primarily produced and used on site by the industrial sector
- Purpose: ammonia production and oil refining

So far there is no significant hydrogen production from renewables.

International Trade of Hydrogen?

Asian market will likely be the largest consumer of hydrogen → opens doors for exporting countries with low-cost electricity and with high-capacity factors.

Australia (south): significant renewable generation capacity and limited interconnection with the rest of the country.

- Exports to Japan, South Korea, China, and Singapore

Chile: one of the best solar resources in the world (Atacama Desert)

- low-cost, high-capacity renewables → low-cost hydrogen production for Asia

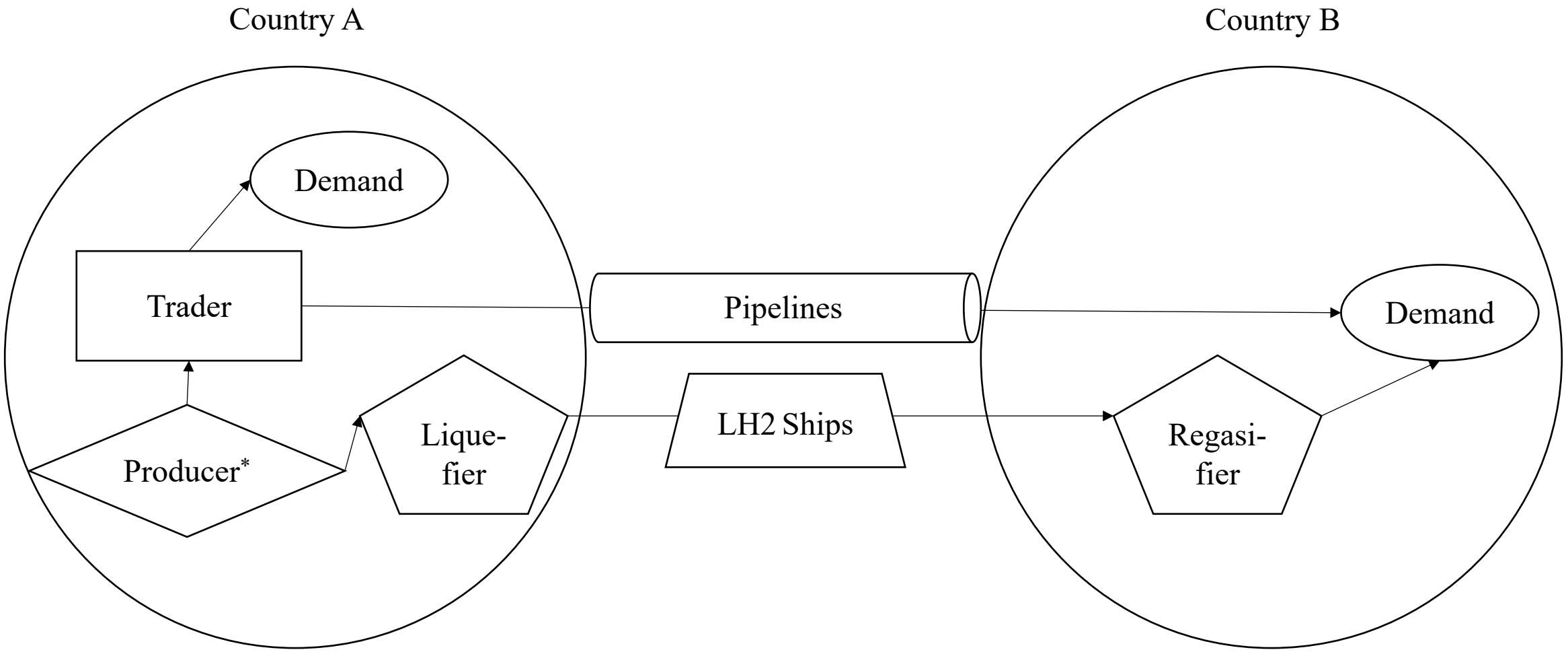
Norway: Hydrogen can be produced by hydropower, offshore wind, and natural gas

Saudi Arabia: combination of complementary wind and solar PV to generate hydrogen, potentially transported as ammonia

GH2-MOD (current iteration)

- Static model of the year 2050
- Deterministic
- Ten regions
- Transport of hydrogen as liquid and gas
- Includes market power
- Models different player in the value chain

Hydrogen Economy: Value Chain and Actors



* Production via SMR or Electrolysis

Producer's (Electrolysis) Optimization Problem

$$\max_{SALES_E^E} \left(\pi_{n(e)}^E SALES_E^E - c_e^E SALES_e^E\right) \quad (1)$$

s.t.

$$SALES_e^E \leq CAP_e^E \qquad (\alpha_e^E) \quad (2)$$

$$SALES_e^E \leq CAP_e^{EReg} \qquad (\beta_e^E) \quad (3)$$

$$SALES_e^E \geq 0 \quad (4)$$

Market Clearing

$$0 \leq SALES_e^E - PURCH_{t_e(e)n(e)}^{T_e \leftarrow E} - \sum_{l \in L_e(e)} PURCH_l^{L_e \leftarrow E} \quad \forall e \qquad (\pi_{n(e)}^E) \quad (5)$$

Producer's (Electrolysis) Optimization Problem

$$\max \left(\pi^{E}_{n(e)} SALES^{E}_{E} - c^{E}_{e} SALES^{E}_{e}\right) \quad (1)$$

s.t.

$$SALES^{E}_{e} \leq CAP^{E}_{e} \qquad (\alpha^{E}_{e}) \quad (2)$$

$$SALES^{E}_{e} \leq CAP^{ERes}_{e} \qquad (\beta^{E}_{e}) \quad (3)$$

$$SALES^{E}_{e} \geq 0 \quad (4)$$

Market Clearing

$$0 \leq SALES^{E}_{e} - PURCH^{T_e \leftarrow E}_{t_e(e)n(e)} - \sum_{l \in L_e(e)} PURCH^{L_e \leftarrow E}_{l} \quad \forall e \quad (\pi^{E}_{n(e)}) \quad (5)$$

Same type of optimization problem under constraints and market clearing conditions for all other players, including producer (SMR)

Producer's (Electrolysis) KKT

$$0 \leq -\pi^{E}_{n(e)} + c^{E}_{e} + \alpha^{E}_{e} + \beta^{E}_{e} \perp SALES^{E}_{e} \geq 0 \qquad (6)$$

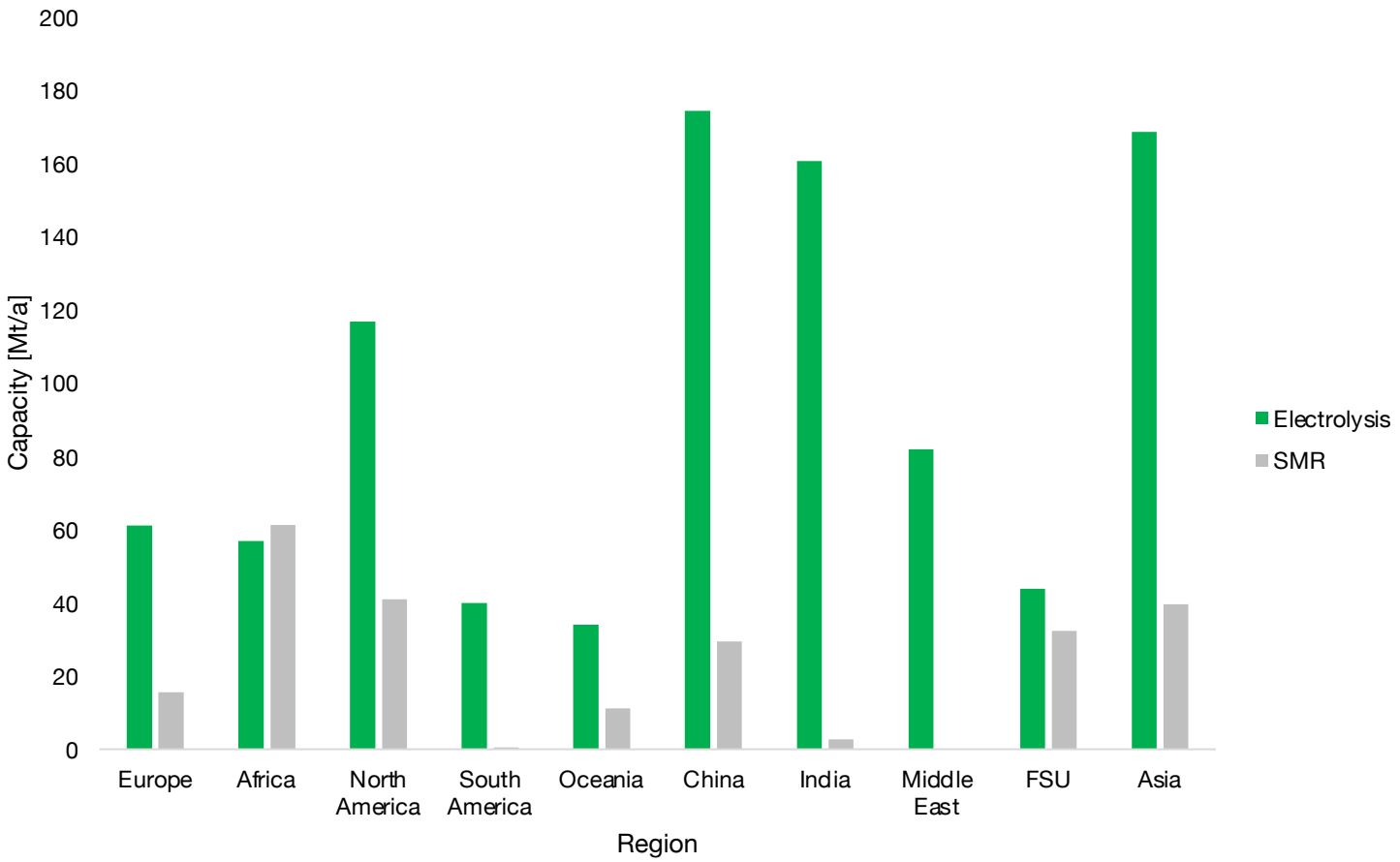
$$0 \leq CAP^{E}_{e} - SALES^{E}_{e} \perp \alpha^{E}_{e} \geq 0 \qquad (7)$$

$$0 \leq CAP^{EReg}_{e} - SALES^{E}_{e} \perp \beta^{E}_{e} \geq 0 \qquad (8)$$

Market Clearing

$$0 \leq SALES^{E}_{e} - PURCH^{T_e \leftarrow E}_{t_e(e)n(e)} - \sum_{l \in L_e(e)} PURCH^{L_e \leftarrow E}_{l} \perp \pi^{E}_{n(e)} \geq 0 \qquad \forall e \qquad (9)$$

Hydrogen Production Capacity (2050)



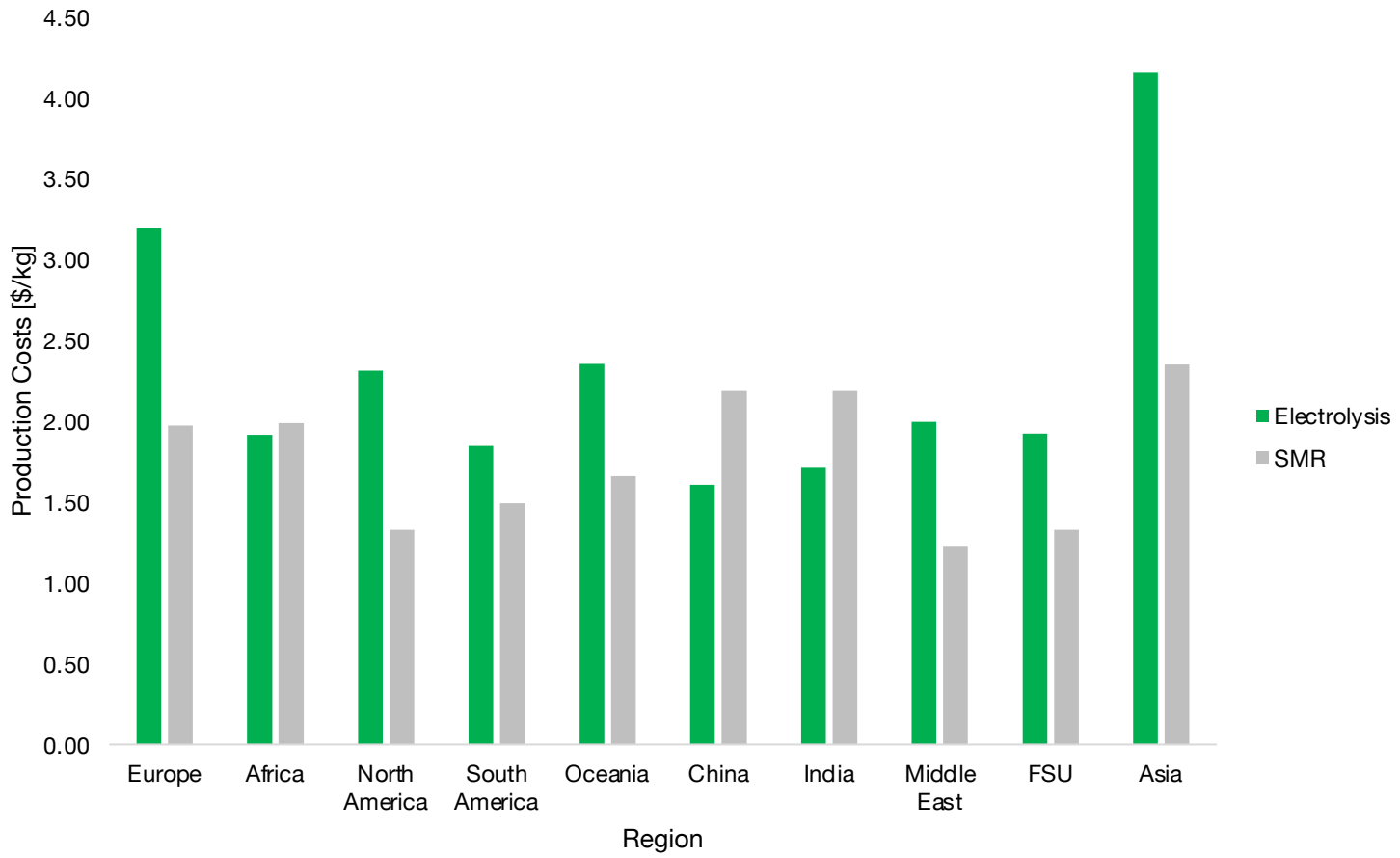
Electrolysis capacity significantly larger than SMR

Largest capacities:

1. Rest of Asia
2. China
3. India

Source: Löffler et al. 2017; Burandt et al. 2018

Production Costs



Production via electrolysis is generally more expensive than that by SMR

Exceptions:

1. China
2. India
3. Africa

Highest

Rest of Asia (Electrolysis– $4.16/kg)
SMR – $2.353/kg)

Lowest

China (Electrolysis – $1.61/kg)
Middle East (SMR– $1.23/kg)

Source: Heuser et al. (2019); Brändle et al. (2020); IEA 2019

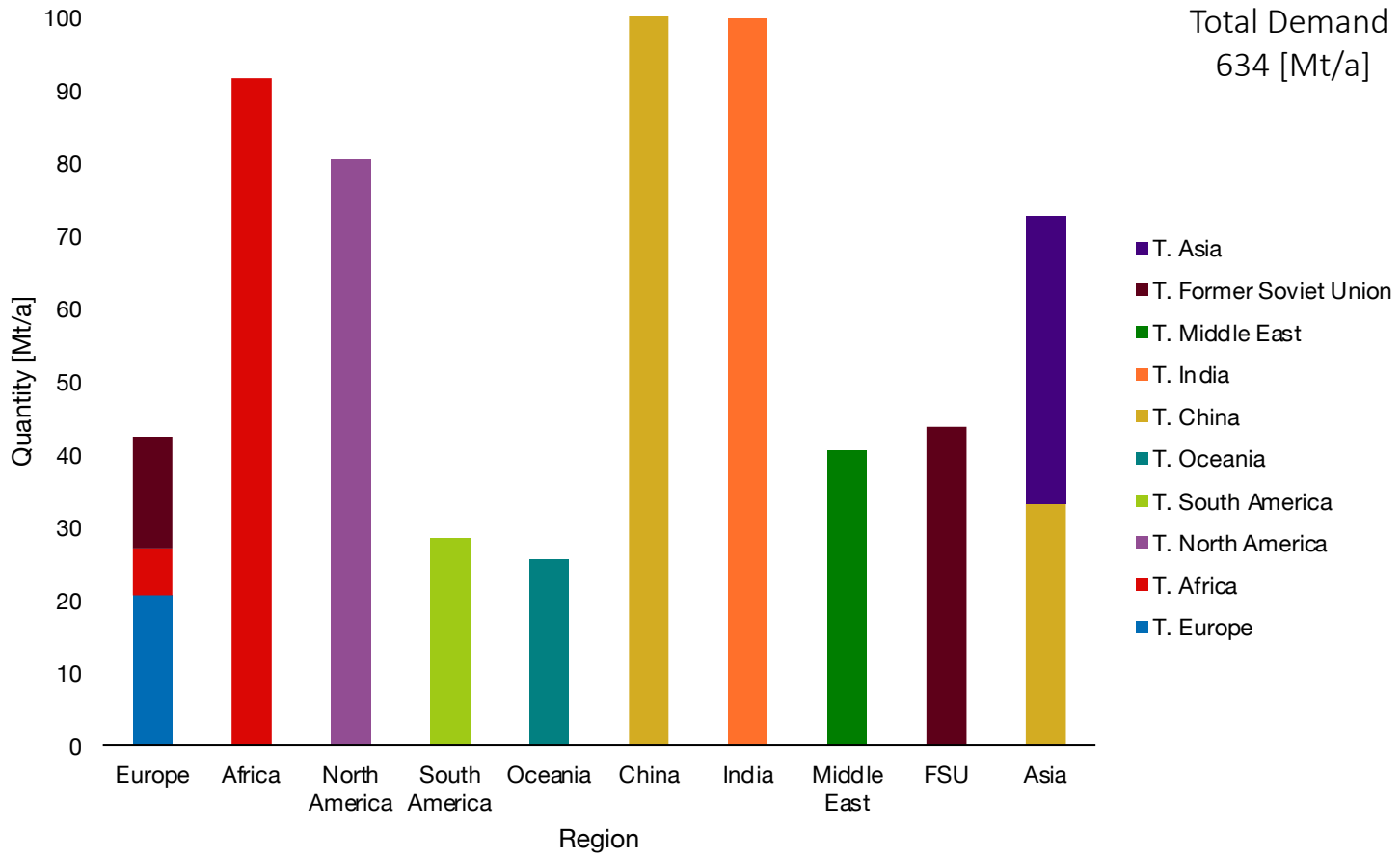
Other Data Inputs

- Liquefaction / Regasification capacities and costs
- Transportation costs (shipping vessels and pipelines)
- Loss rates

Source: Heuser et al. (2019); Brändle et al. (2020); IEA 2019

Perfect Competition

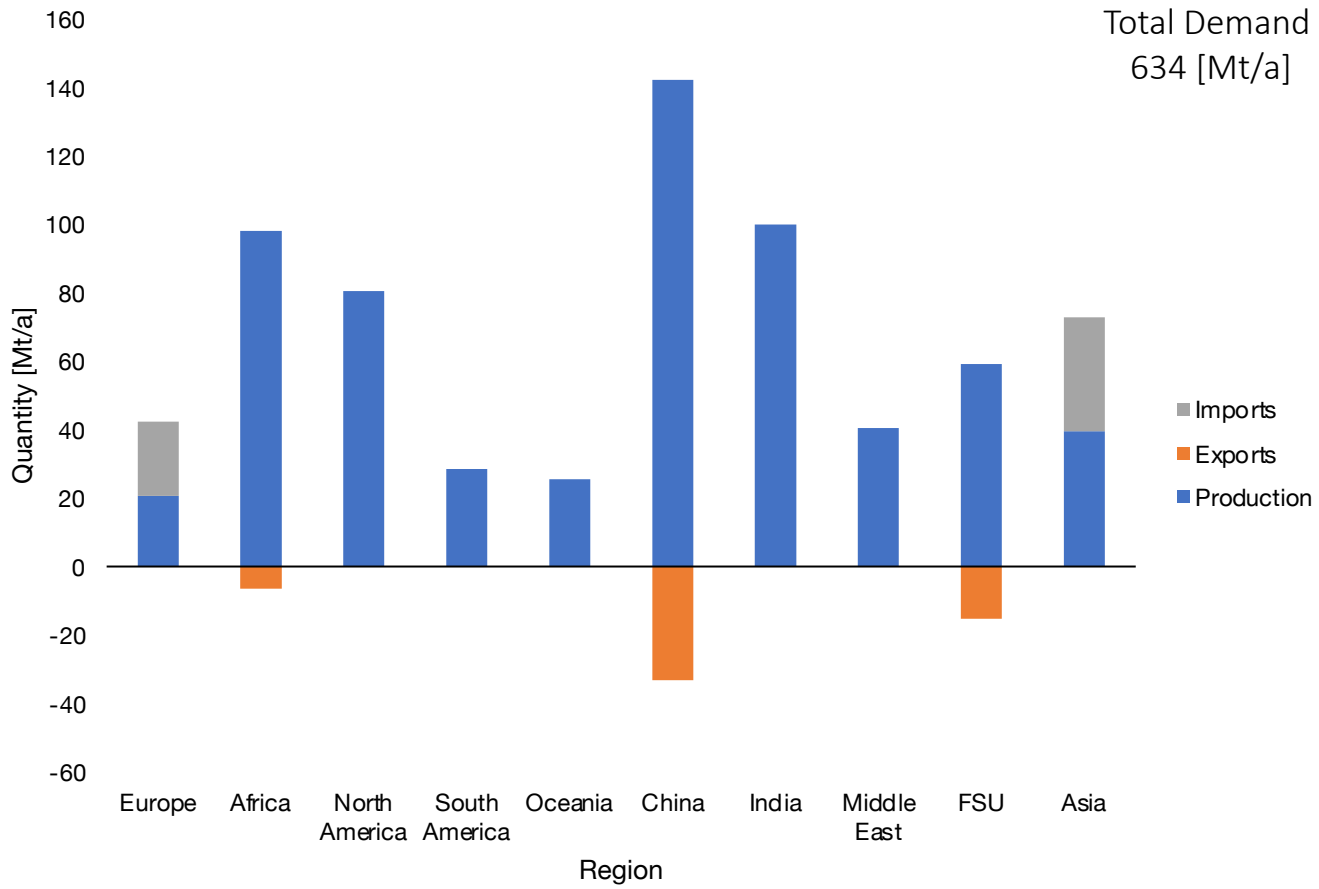
Hydrogen Demand – Perfect Competition



Nearly half of Asia's hydrogen demand is met by China

Half of European demand is met by the Former Soviet Union and Africa

Hydrogen Production – Perfect Competition

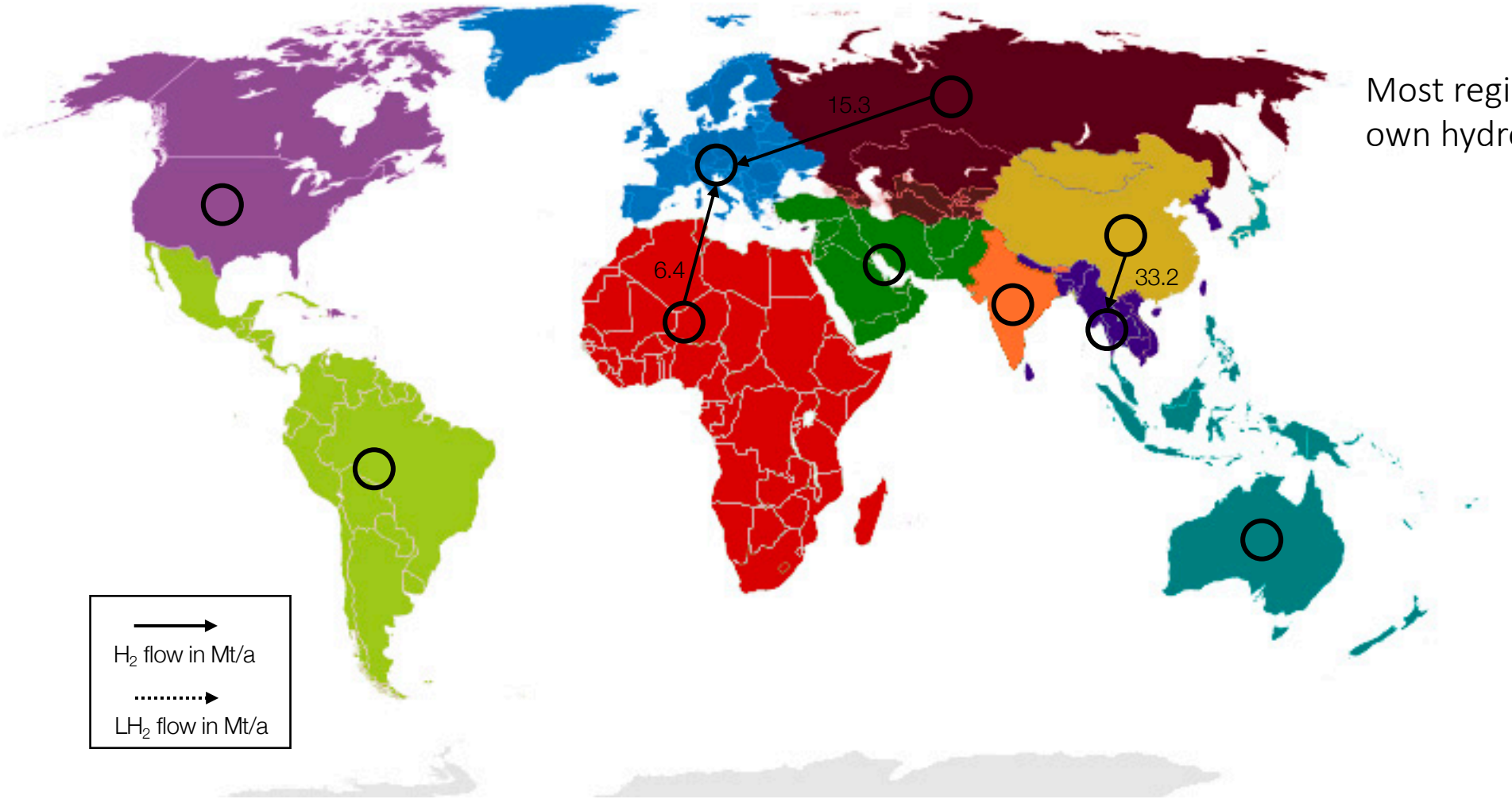


Rest of Asia and Europe are sole importers

Africa, China and the Former Soviet Union are exporters

Electrolysis: 404 Mt/a
SMR: 230 Mt/a

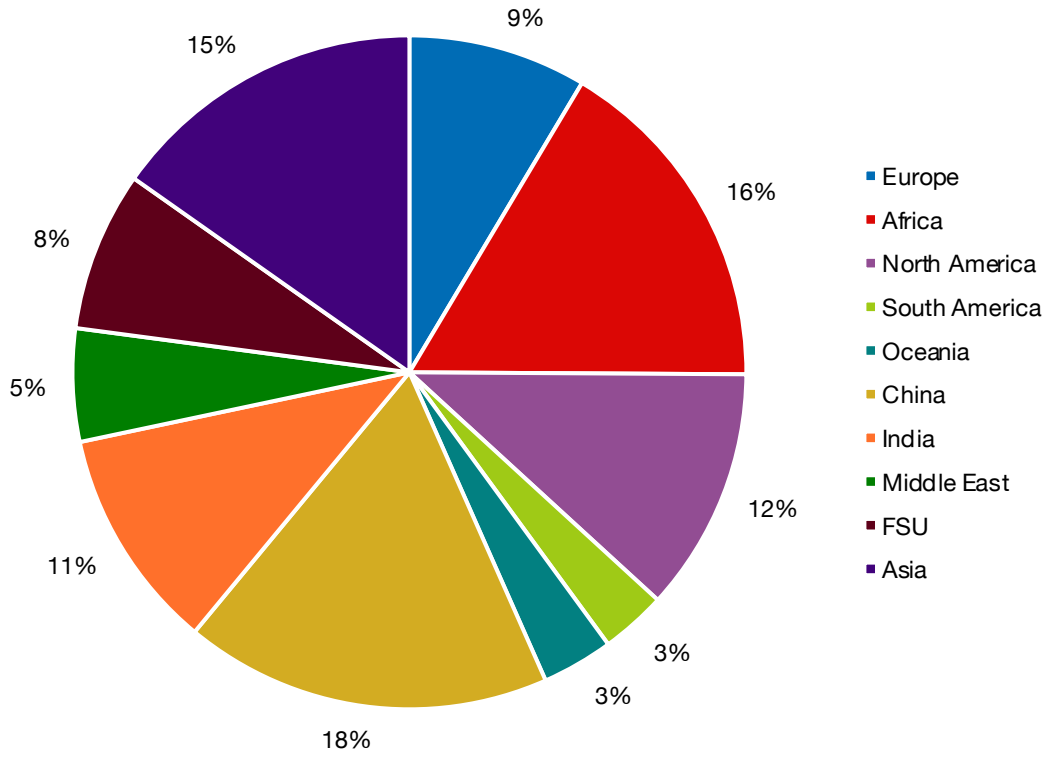
Market Power – Flows



Most regions produce to meet their own hydrogen demands

Market Power

Hydrogen Demand – Market Power



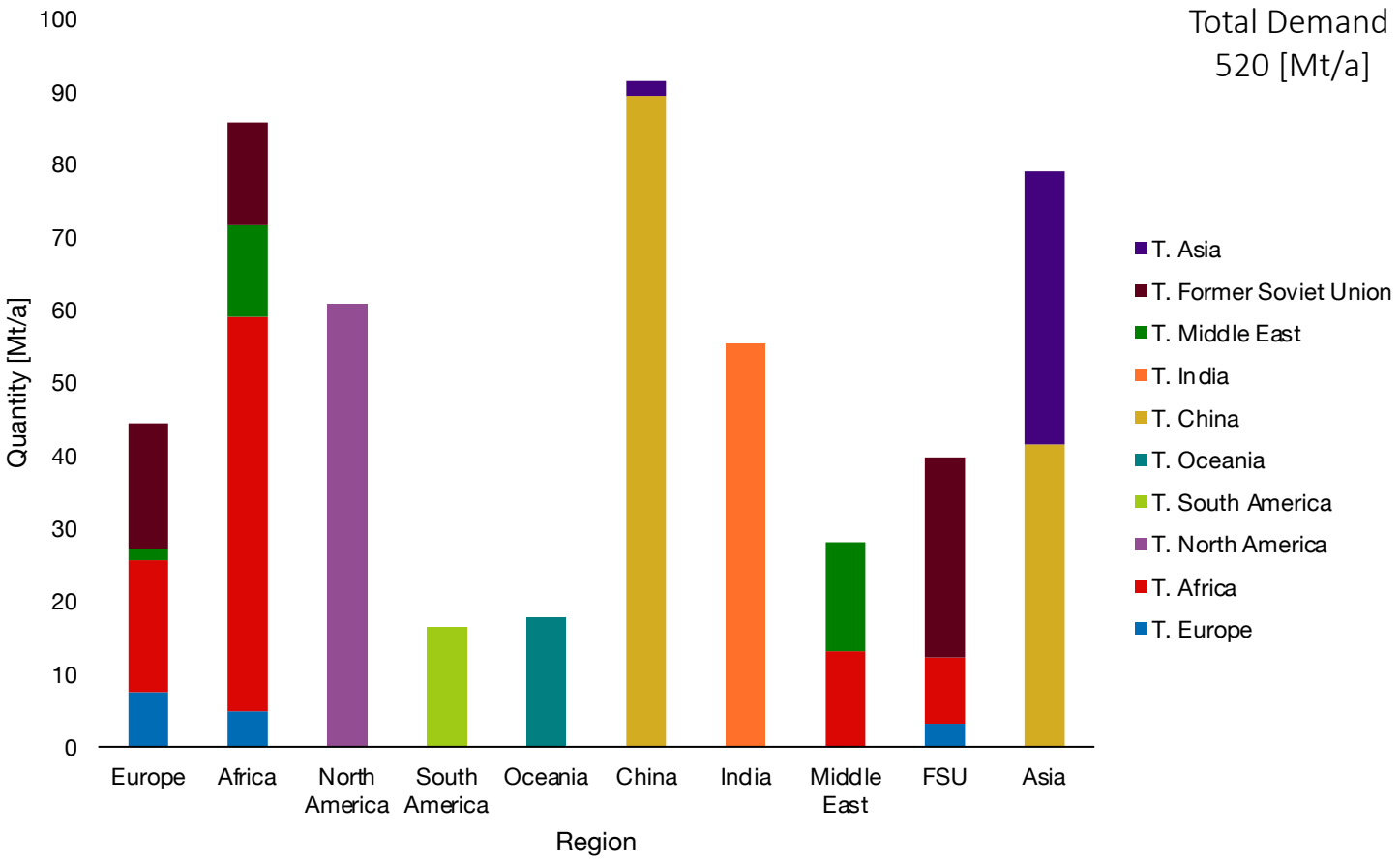
Global Hydrogen Demand: 520 Mt/a

Largest hydrogen demand:

1. China
2. Africa
3. Rest of Asia

Makes up 50% of global demand

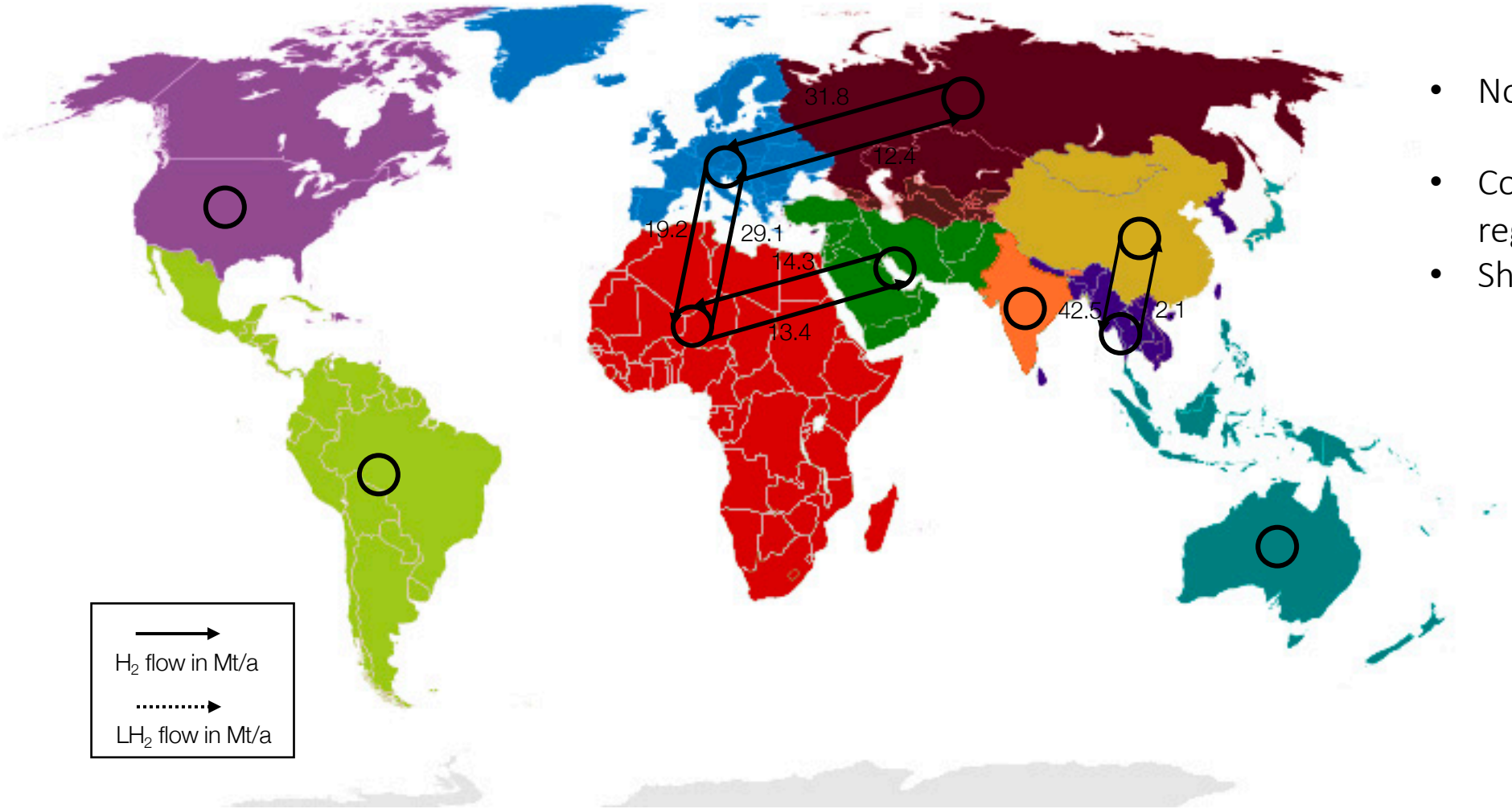
Hydrogen Demand – Market Power



- Total demand cut by ~ 20%

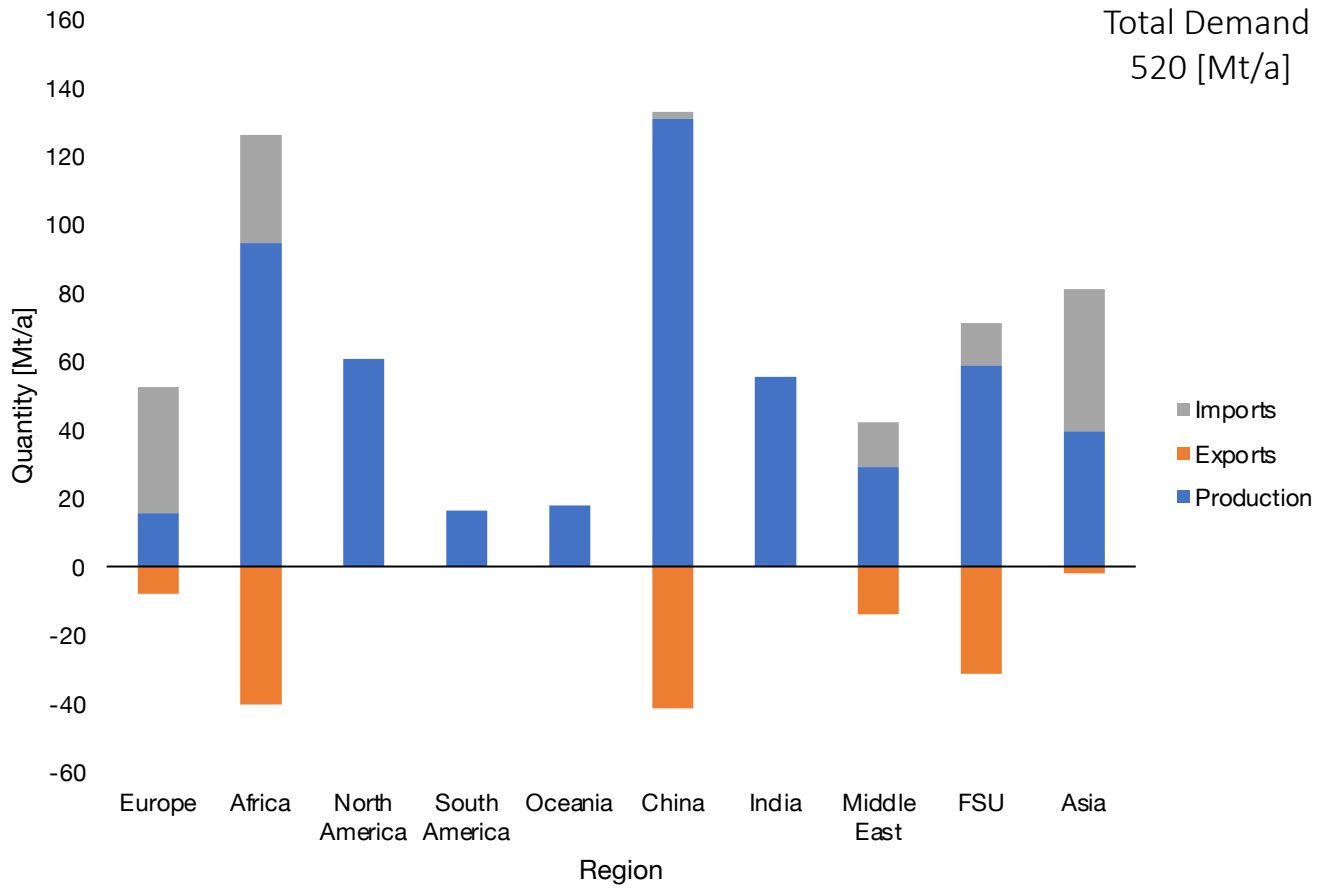
- India's demand cut in half
- African hydrogen penetrates new markets
- Europe relies mostly on imports to meet demand

Market Power – Flows



- No trade in liquid H_2
- Costs of liquefaction/ regasification too high
- Shipping costs also too high

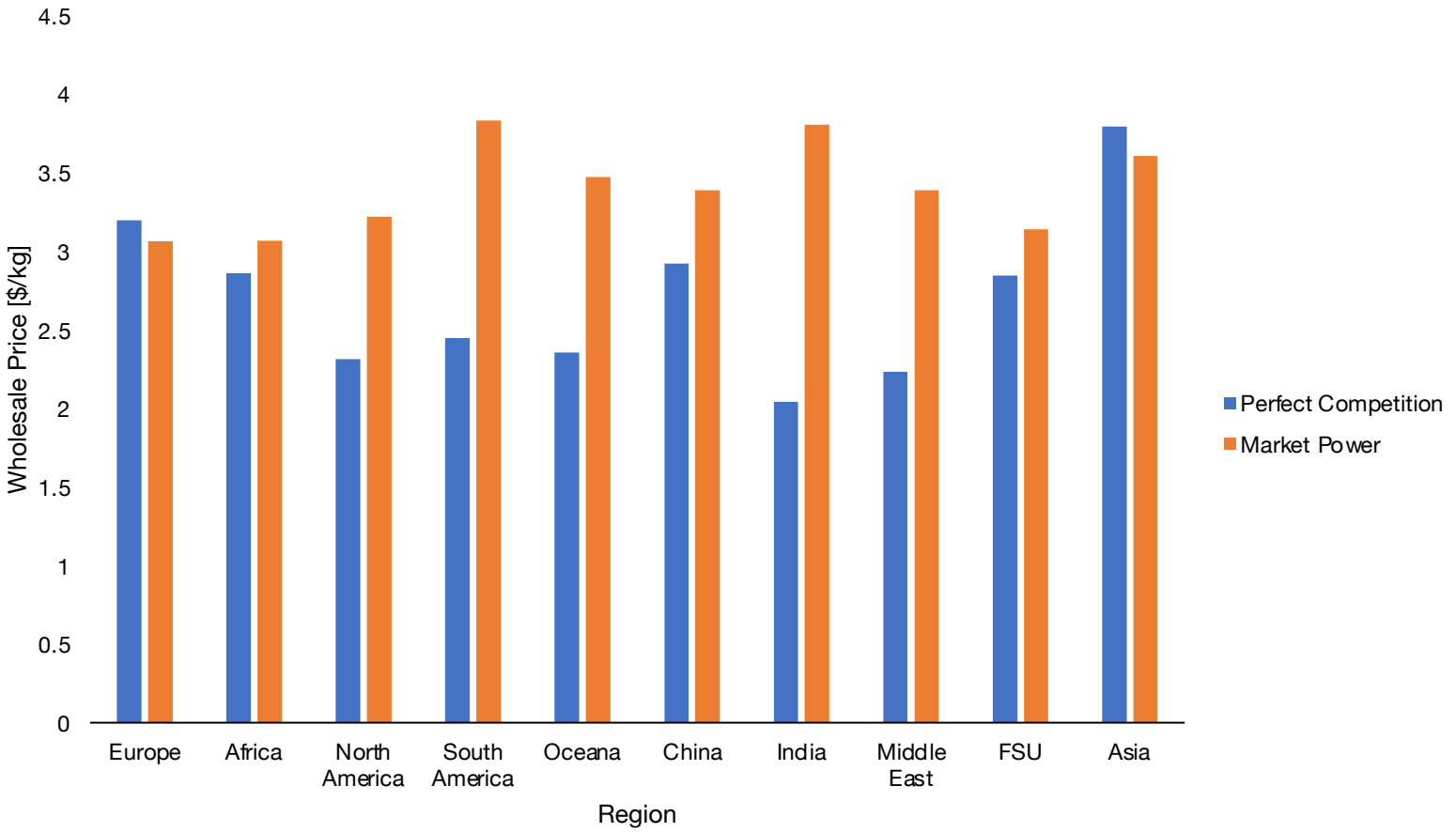
Hydrogen Production – Market Power



China's production accounts for a fourth of global production

Strategic trading, countries import and export to take advantage of external hydrogen prices.

Hydrogen Prices



Prices are generally higher with market power

Weighted Global Price

Perfect Competition: $2.72/kg

Market Power: $3.36/kg

Future Work

Model Expansion

- Multi-period framework
- Addition of storage operators
- Addition of ammonia as a hydrogen carrier
  - Hydrogenator and Dehydrogenator players
- Spatial disaggregation of regions

Hydrogen Economy: Value Chain and Actors