Hydrogen use in aviation from a macroeconomic perspective: Motivation, methods and current research directions

4th International Hydrogen Aviation Conference (IHAC 2023)

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2. Macroeconomic Perspective on Hydrogen in Aviation
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Hydrogen in Aviation – An Overview

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Motivation for hydrogen use in aviation and application options

- Aviation responsible for 2.1% of global carbon dioxide (CO_2) emissions in 2019 but number of passengers expected to rise so that emissions could triple until 2050 (ATAG, 2020; Gnadt et al., 2019; Gössling & Lyle, 2021)
- Electrification unlikely for aviation due to low energy density of batteries (Bauen et al., 2020; Eisenhut et al., 2021)
- Green hydrogen (H_2) as promising pathway to decarbonize aviation (Gunasekar et al., 2020; Yusaf et al., 2022)

Fuel-cell powered

- Electric propulsion powered by a fuel cell and H_2 storage
- Appropriate for short-range and commuter flights
- Realistically available from 2035

Direct combustion of H_2

- Combustion turbines powered by H_2
- Liquid H_2 necessary
- Appropriate for short- and mid-range flights (up to long-range)
- Realistically available from 2040/2050

Power-to-liquid (PtL) fuel

- Combustion in conventional turbines
- Blending with conventional jet fuel possible
- Appropriate for all distances
- Already available, but at small scale

Hydrogen in Aviation – An Overview

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Growing literature on hydrogen-powered aviation

	Environmental potential	Technological challenges	Techno-economic analyses
Fuel cell powered electric propulsion	▪ Highest potential for total climate impact reduction (Clean Sky 2 JU and FCH JU 2, 2020)	▪ Modifications in aircraft design (Schröder et al., 2021; Suewatanakul et al., 2022) ▪ Integration of H_2 tanks into aircraft (Gomez & Smith, 2019; Nicolay et al., 2021) ▪ On-ground infrastructure required (Hoelzen et al., 2022)	▪ Lack of cost competitiveness of green H_2 (Hoelzen et al., 2022) ▪ Variation in supply costs, depending on local conditions and supply chain design (Hoelzen et al., 2022; Batteiger et al., 2022) ▪ Cost reductions expected (Yusaf et al., 2022) ▪ Long-term competitiveness depends on policy instruments (Dahal et al., 2021)
Direct combustion of liquid hydrogen (LH_2)	▪ Reduction of CO_2 and overall climate impact (Silberhorn et al., 2022) ▪ Decrease of life cycle impact (Bicer & Dincer, 2017)		
Hydrogen-based power-to-liquid (PtL) fuels	▪ Reduction of CO_2 emissions (Breuer et al., 2022; Ballal et al., 2023) ▪ More sustainable than biofuels (Dray et al., 2022; Batteiger et al., 2022)	▪ Advancement of technical maturity and process efficiency (Drünert et al., 2020; Batteiger et al., 2022)	

Macroeconomic dimension of H_2-powered aviation underexplored

Macroeconomic Perspective

Why we should consider the macroeconomic dimensions of H_2-powered aviation

Shift in sectoral linkages

- New industries involved in green H_2 supply chain
- Loss of relevance for fossil industries
- Different options for green H_2 supply chain design

Potential for new employment

- New jobs along the supply chain
- Substitution of jobs in fossil sectors
- Changing qualifications and job requirements (e.g., refueling, aircraft manufacturer)

New trade opportunities

- Larger part of supply chain can be covered domestically
- Substitution of fossil dependencies and establishment of new trade relations
- Opportunity for developing countries

Design of policy framework

- Cost deficit makes green H_2 unattractive at the moment
- State interventions can compensate for cost deficit
- Effectiveness of different instruments uncertain

Effect on macro level indicators

- Effects also on economy-wide level (particularly through multiplier effects)
- Impact on GDP, trade balance, public spendings
- Non-economic indicators on macro-level (e.g., emissions)

Application of macroeconomic tools and methods to study these effects

Deep Dive – Recent Research

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Participation in "Sustainable and Energy Efficient Aviation (SE²A)"

Project name

„Hydrogen in Sustainable Aviation: Macroeconomic impacts and state intervention"

SE²A
Forward. Foresight. For flight.

Duration

12/2021 – 12/2023

Research goals

- Construction of a macroeconomic database and modelling framework with focus on the German aviation sector
- Analysis of H_2 supply chains and integration of H_2-based alternatives into the framework (focus on fuel perspective)
- Simulation and evaluation of different fuel scenarios and policy instruments

Project publications

energies — MDPI

Review

Fostering Macroeconomic Research on Hydrogen-Powered Aviation: A Systematic Literature Review on General Equilibrium Models

Tobias Mueller [1,2,*] and Steven Gronau [1,2]

Mueller & Gronau (2023)

ELSEVIER — Available online at www.sciencedirect.com — journal homepage: www.elsevier.com/locate/he — HYDROGEN ENERGY

Deep Dive for today

Hydrogen-powered aviation in Germany: A macroeconomic perspective and methodological approach of fuel supply chain integration into an economy-wide dataset

Steven Gronau [a,*], Julian Hoelzen [b], Tobias Mueller [a,c], Richard Hanke-Rauschenbach [b]

Gronau et al. (2023)

Deep Dive – Recent Research

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Deep Dive: Recent project publication (I/II)

Motivation

- No comprehensive and recent dataset for Germany
- Green H_2 currently not part of National Accounts

Research objectives

- Comprehensive dataset for Germany and status-quo analysis of aviation
- Integration of green H_2 into dataset

Methodological approach

- Social Accounting Matrix (SAM)
- Analysis of liquid H_2 supply chain and cost allocation

Macroeconomic indicators

17% Imports | **79%** Domestic | **4%** Taxes

31.7 Bn. € Supply

=

31.7 Bn. € Demand

44% Inter-sectoral | **26%** Households | **30%** Exports

9.9 Mio. t Kerosene

65,073 (direct) Employees

2.1 Mio. Total flights


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HYDROGEN ENERGY

Hydrogen-powered aviation in Germany: A macroeconomic perspective and methodological approach of fuel supply chain integration into an economy-wide dataset

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Main sectors supplying input for aviation:

Coke and oil products | Storage & transp. serv. | Maintenance general | Accommod. & restaurant | Renting (movables)

Main sectors demanding aviation services:

Travel agencies | Machines | Electr. and optic. devices | Express services | Motor vehicles

Deep Dive – Recent Research

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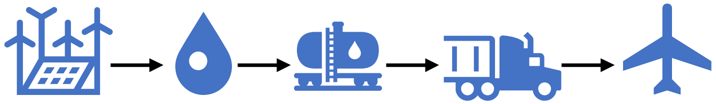
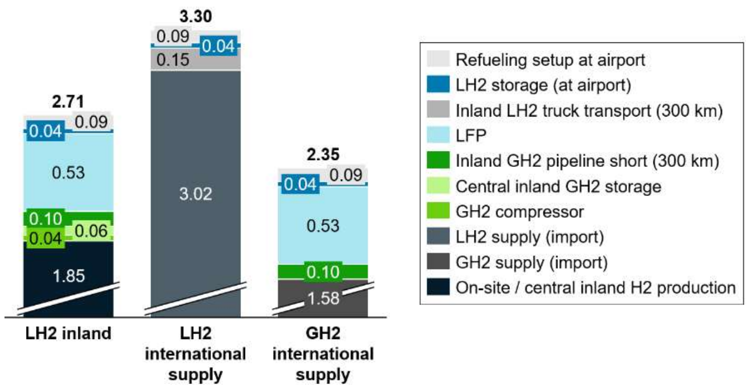
SAM creation and supply chain integration (II/II)

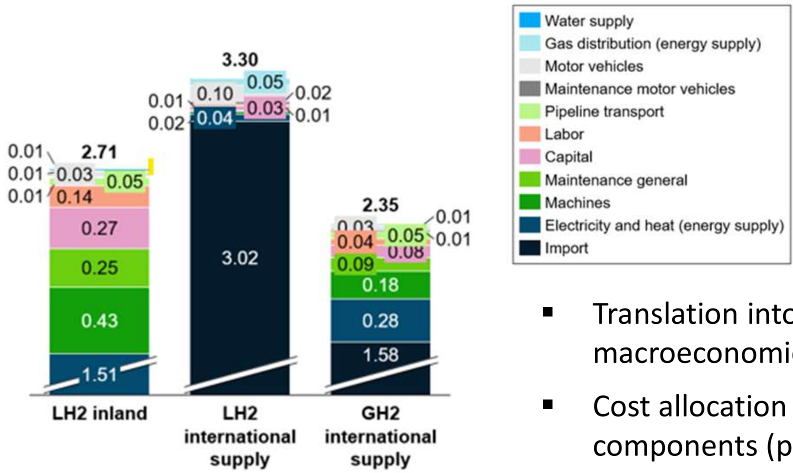
Consideration of 3 LH2 supply chain designs for 2050

1. LH2 inland production
2. LH2 import
3. Gaseous H2 (GH2) import



- Cost analysis of value chain options
- 10 techno-economic cost components





- Translation into 11 macroeconomic accounts
- Cost allocation to respective components (per kg H2)

Deep Dive – Current Work

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Overview of methods for macroeconomic impact assessment

- SAM as comprehensive and economy-wide data framework to depict linkages and transactions
- Illustrates production, trade, income generation and macro-level indicators (e.g., GDP)
- Serves as empirical backbone for macroeconomic simulation methods

	Activity	Commodity	Production factor	Agent	S-I	RoW	Total
Activity							
Commodity							
Production factor							
Agent		Receipts →		Expenditures ↓			
Saving-investment							
Rest of the world							
Total							

1 *Multiplier analysis*

- Effects of n … er sectors
- Effects on l … eholds
- Estimation method without prices or capacity constraints

Deep Dive for today

2 *General equilibrium modelling*

- Sophisticated method for modelling macroeconomic effects
- Considers price dynamics and elasticities
- Testing of different policies and scenarios

Deep Dive – Current Work

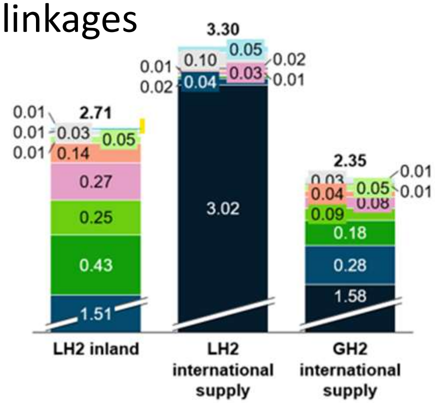
Multiplier analysis – LH2 supply chains in Germany

Approach of multiplier analysis

- Measurement of direct and indirect effects (ripple through the economy)
- Production and consumption linkages

LH2 supply chain

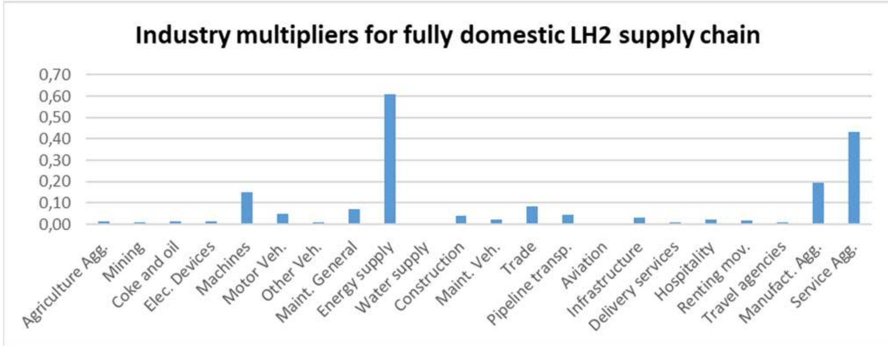
- Cost shares for setup from published paper
- Measurement of investment in LH2 supply chains in Germany (effects per 1€ investment)
- Focus on backward linkages in production and consumption effects



Multiplier analysis results

- Largest multipliers: fully domestic LH2
- Largest industrial effect for electricity
- Macro-level effect larger than kerosene

Macro-level multipliers				
	LH2 (dom)	LH2 (int)	GH2 (int)	Kerosene
Total production	1.86	0.22	0.61	0.66
Household income	0.79	0.09	0.26	0.16
GDP	0.99	0.11	0.33	0.19



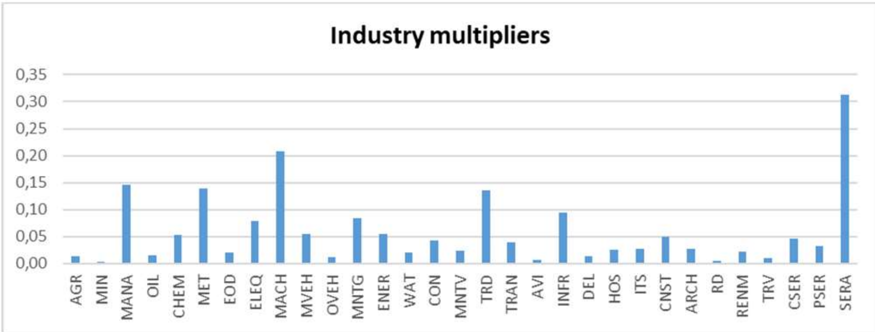
Deep Dive – Current Work

Hydrogen use for PtL in aviation

PtL supply chain analysis

- Most realistic supply chain design for Germany (LBST, 2022)
  - Off-shore wind energy
  - PEM electrolysis
  - Direct air capture
  - Fischer-Tropsch synthesis
- Extensive analysis of techno-economic cost components (data from the literature)

Multiplier analysis results



Macro-level multipliers	
Total production	1.81
Household income	0.90
GDP	1.09

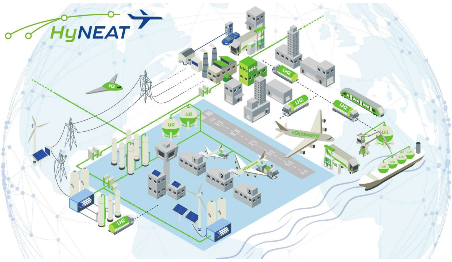
Next: General equilibrium modelling

- Comparative-static model for simulating PtL blending quotas in aviation (ReFuelEU)
- Consideration of different scenarios (PtL price pathways, supply options, quota increase)
- Evaluation of different policies for compensating price gap

Current work in progress

Outlook

Hydrogen Supply Networks’ Evolution for Air Transport (HyNEAT)



Project information

- *Duration*: 2022 – 2025
- *Funder*: German federal ministry of education and research
- *Participation*: 8 institutes from 5 universities
- *Website*: www.hyneat.de/en/

Research dimensions in HyNEAT

- Influence on energy transition
- Techno-economic analysis of LH_2 supply chains
- Macroeconomic analyses for selected countries
- Impacts on flight networks
- Life Cycle Analysis (LCA) of H_2 infrastructure

Selected countries: Germany, United Kingdom, Spain, Morocco, Saudi Arabia

Industry partners

Airbus, MTU Aero Engines, Deutsche Aircraft, Lufthansa Group, Hamburg Airport, Münster Osnabrück International Airport, Siemens Energy, Flughafen München, EWE, Linde, McKinsey & Company, DLR, Afrika-Verein der deutschen Wirtschaft

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Many thanks – any questions?

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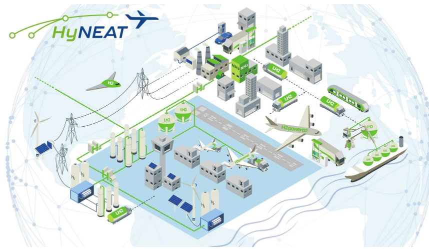

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