PSI Center for Nuclear Engineering and Sciences
Center for Energy and Environmental Sciences

Role of Electrification, Hydrogen and E-fuels on the Road to Climate Neutrality in Europe

European Climate and Energy Modelling Platform 2024 (ECEMP), Brussels

Meixi Zhang, Energy Economics Group, Laboratory of Energy System Analysis
Villigen, 16 October 2024

Adoption of ReFuel Aviation Regulation


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DIRECTIVE (EU) 2023/2413 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 18 October 2023

amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

Goal

- 2030: 6% SAF (1.2% RFNBOs)
- 2040:34% SAF (10% RFNBOs)
- 2050:70% SAF (35% RFNBOs)

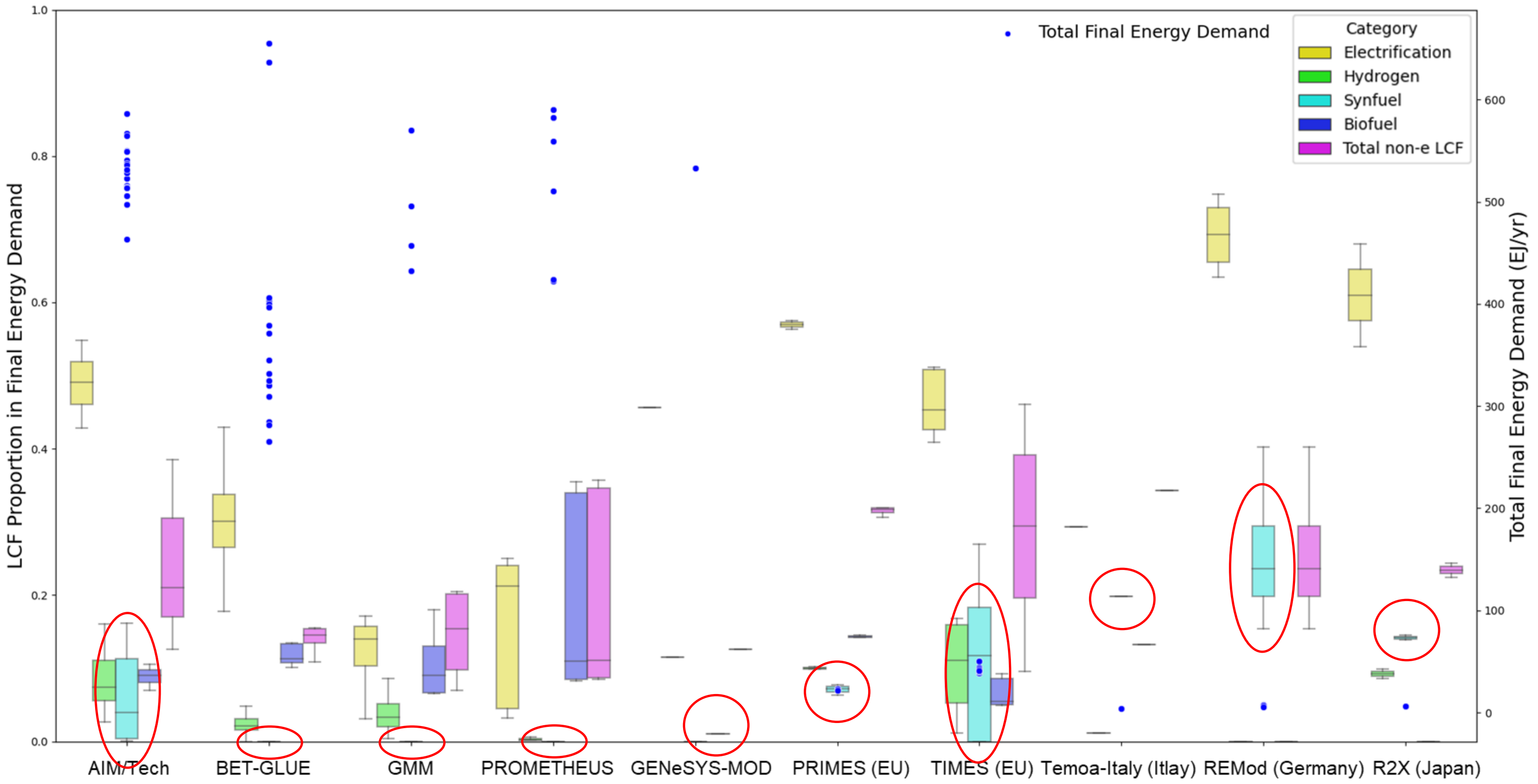
Current ratios: <0.05% of total EU aviation [1]

SAF: Sustainable Aviation Fuels
RFNBO: Renewable Fuel of Non-biogenic Origin

[1] “Sustainable Aviation Fuels.” EASA Eco, www.easa.europa.eu/eco/eaer/topics/sustainable-aviation-fuels. Accessed 10 July 2024.

What are the implications to the rest of the energy system led by the uptake of RFNBOs?

Large Variations in the Role of Low-Carbon Fuel in Net-zero Scenarios



Z. Liu, M. Zhang*, C. Bauer, R. McKenna (2024) The Role of Low Carbon Fuels in Integrated Assessment Models and Energy System Models: A Critical Review (under review) *co-first authors*

- The contribution of low-carbon fuels (*electricity, hydrogen, RFNBO, biofuel*) demand remains highly varied in 2050 net-zero emission scenarios of Energy System Models (ESMs) and Integrated Assessment Models (IAMs)
- All IAMs data form IPCC AR6 database

Synthetic Fuel Technology Representation in ESMs/IAMs as Drivers

Conversion Technologies: Liquid Fuels	TEMOA Italy	PRIMES	JRC-EU-TIMES	MESSAGEix	GCAM	TIAM-ECN	GMM	COFFEE	IMAGE	Poles	Merge-ETL	Genesys-mod	BET	IMACLIM-R	REMIND-MAgPIE	MEDEAS	PROMETHEUS	DNE21+	ReMOD	TIAM-UCL	EnergyPLAN	Calliope	AIM/Tech	R2X	WISEE
Coal	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	x					
Natural gas	x	x	x	x	x	x	x		x							x	x		x						
Biomass	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x			x	x			
Coal w/ ccs	x	x	x	x	x	x	x	x																	
Natural gas plant w/ ccs	x	x	x	x	x	x			x																
Biomass w/ ccs	x	x	x	x	x	x	x	x		x	x									x					
Green Hydrogen	x	x	x									x							x		x	x	x	x	x

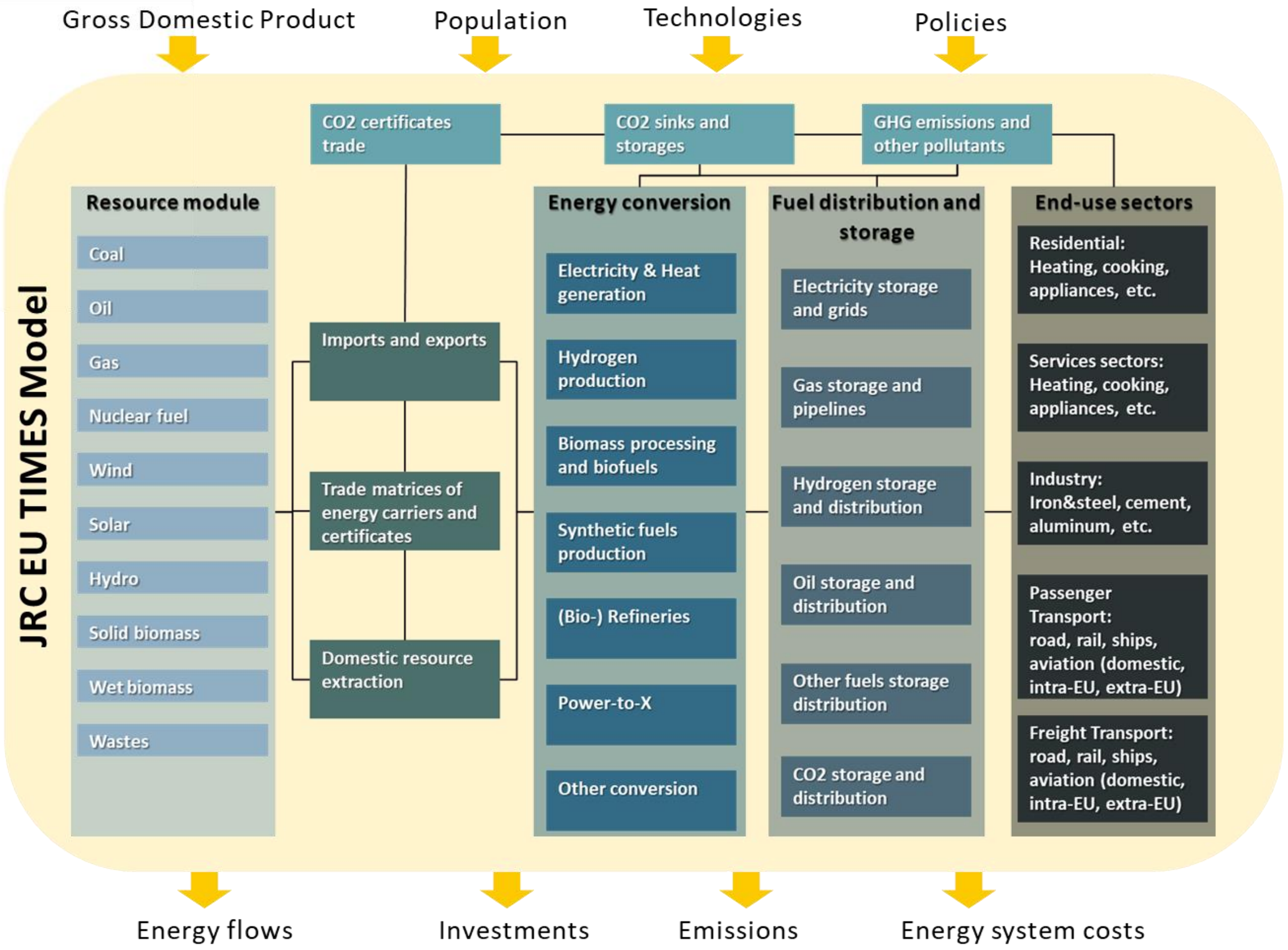
Annually
Seasonal
Weekly
Day/Night
Hourly

Z. Liu, M. Zhang*, C. Bauer, R. McKenna (2024) The Role of Low Carbon Fuels in Integrated Assessment Models and Energy System Models: A Critical Review (under review)*

- Models covering both a wide range of hydrogen and synthetic fuels, such as TEMOA-Italy and PRIMES, show a higher synfuel consumption.
- AIM/Tech with a high temporal resolution also shows a high consumption of synthetic fuels with similar levels of hydrogen.
- Models that include only fossil-fuel-based synthetic fuels show low synfuel production, as they play a negligible role in decarbonization.

Methodology

Enhanced JRC-EU-TIMES Model



Energy system cost optimization

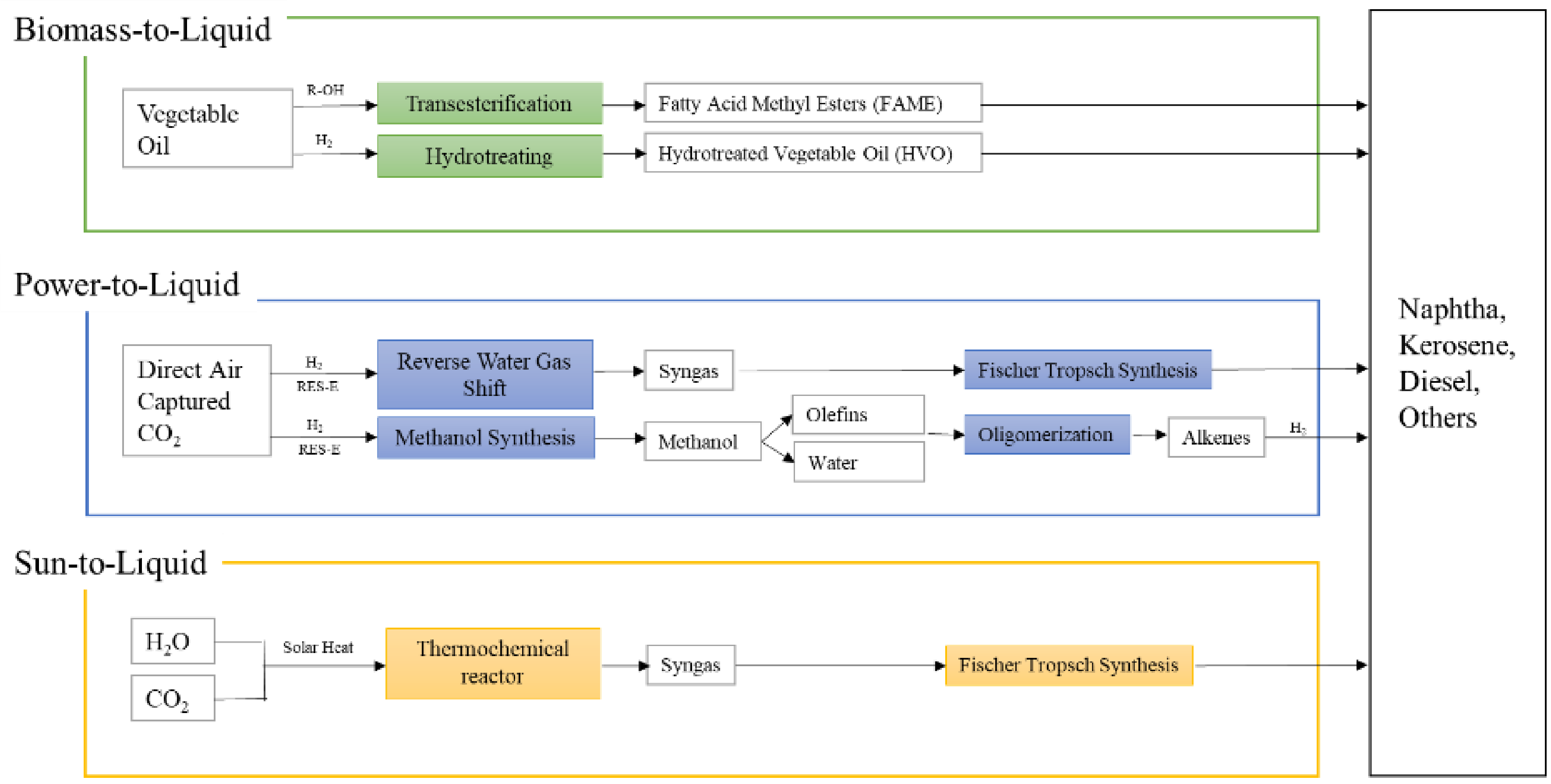
36 European countries

Time horizon 2050+

4 seasons, day/night/peak

- Comprehensive data input update (c.a. 70+ major databases used)
- Calibrated for 2019 (average deviation of 1.2%)
- Passing through some persistent developments after the COVID-19 Year 2020

Renewable Synthetic Fuels



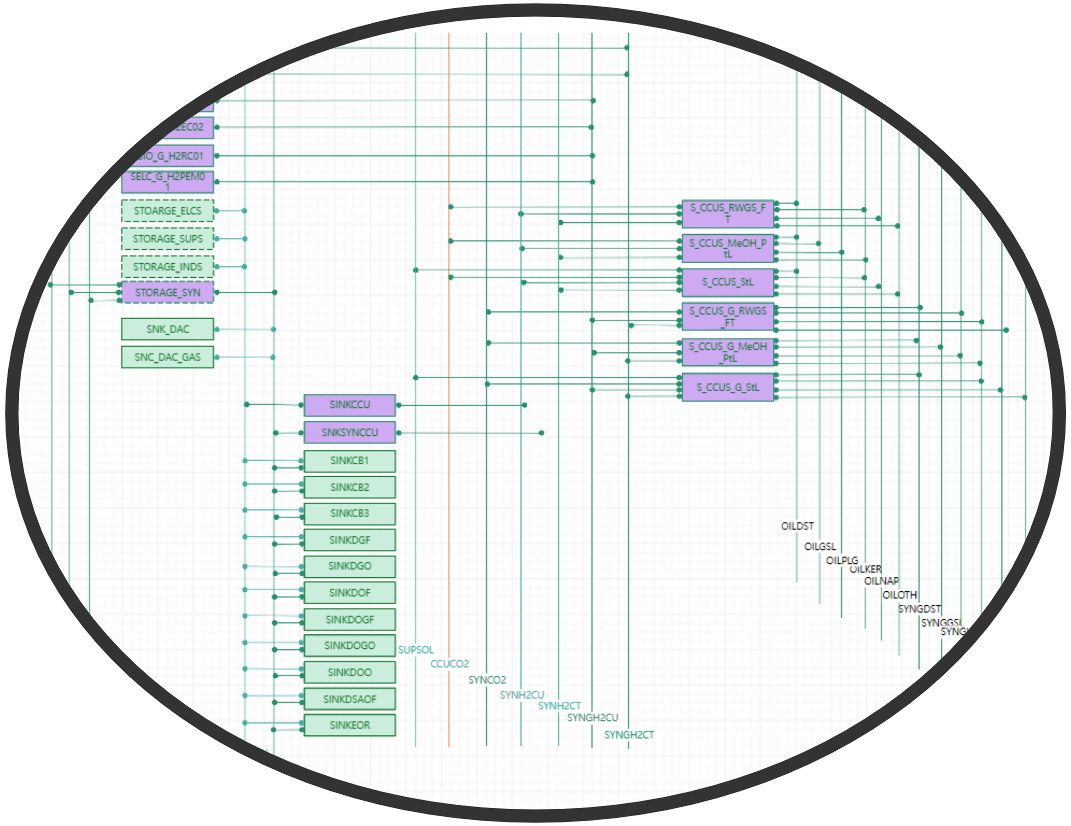
FT PtL		
Input		
commodity	value	unit
co2	3.80	kg
h2	0.51	kg
elc	0.53	kwh
EFF	69%	
AF	0.9	
Operating Hours (hr)	8000	
Capacity	1368	MW
CAPEX	1101	EURO/kW
FIXOM	73.9	MEURO
VAROM	1.5	MEURO
Life time	30	years

Methanol PtL		
commodity	value	unit
co2	3.18	kg
h2	0.45	kg
elc	0.83	kwh
EFF	76%	
Operating Hours	8000	
Capacity	1368000	kW/yr
CAPEX	1521.0	MEURO/kw
FIXOM	51.9	MEURO/kw
VAROM	23.5	MEURO/kw
Life time	30.0	

StL		
Input		
commodity	value	unit
co2	2.73	kg
h2	0.0	kg
MeOH	0.0	kg
solar		
EFF	1.0	
Operating Hours		
Capacity	1054.0	BPD
CAPEX	1135.8	MEURO
OPEX	39.9	MEURO
Life time	20.0	

Sample Slide with Purple Table

→ PtX module extension



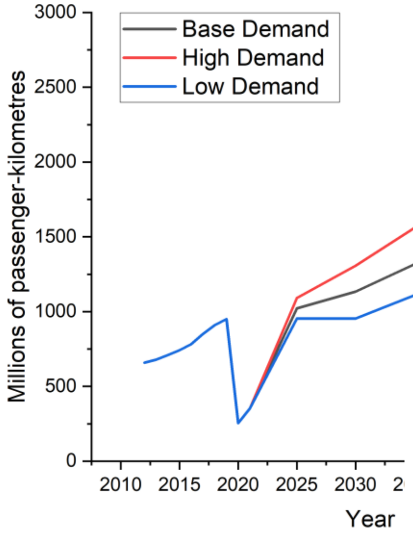
✓ Restructuring of the model to accommodate the supply chain and ensure the fuels are low-carbon

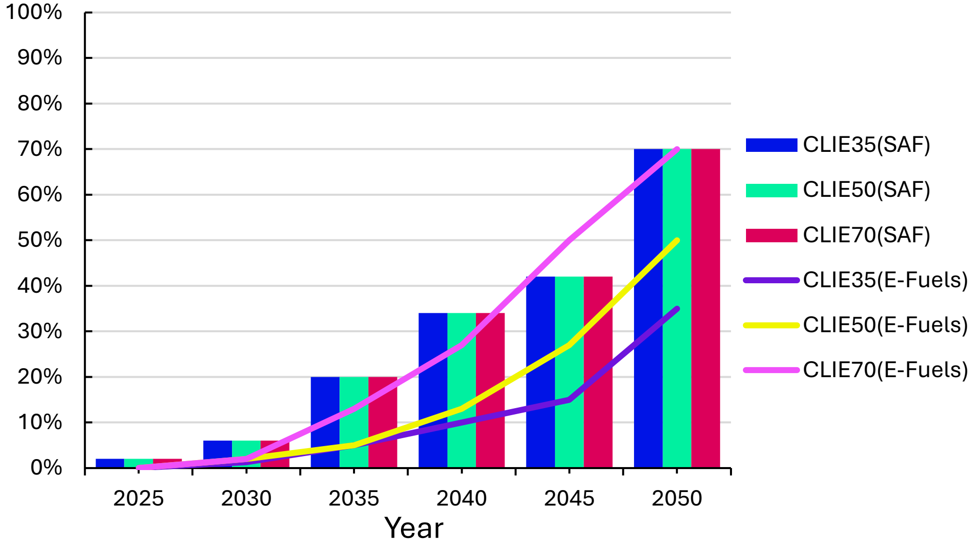
→ Policy Analysis

Scenario	EU-27
CLI (net-zero target scenario + policies in the legislation as of 1.1.2024)	• EED energy efficiency (EU2023/1791) • EPBD buildings performance standards (EU2018/844) • ETS (all revisions up to EU2023/959) • EU RED III renewable targets (up to EU2023/2413) • GHG effort sharing (up to EU2023/857) • Vehicle emissions standards (EU2019/631, EU2023/851) • Heavy vehicle emissions standards (EU2019/1242) • Coal phase out 2030 in DE, DK,FI,GR,HU,IE,IT,NL,PT,SI,SK,ES • Intra-EEA aviation in EU-ETS • NTC electricity capacities as in ENTSO-E TYNDP 2022 plan • Reduction of nuclear share in France • New nuclear plants those under construction/advanced planning • GHG emissions from 1990: -55% in 2030, -90% in 2040 • Net-Zero GHG emissions in 2050 at the EU-level • Individual net-zero GHG emissions targets of the member states • GHG emissions reduction scope as in the EU Climate Law - includes LULUCF and 50% of the international transport • Refuel aviation SAF mandates • EU-ETS-2 from 2030 (although incl. in 2023 revision of EU-ETS) • + 8GW new nuclear power (BG, CZ, RO, SI, SK, FI, FR)

Scenario Definitions

- 9 scenarios based on 3 variations of passenger aviation demand and 3 in e-fuel blending obligations
- All scenarios are net-zero emission target scenarios (CLIE)

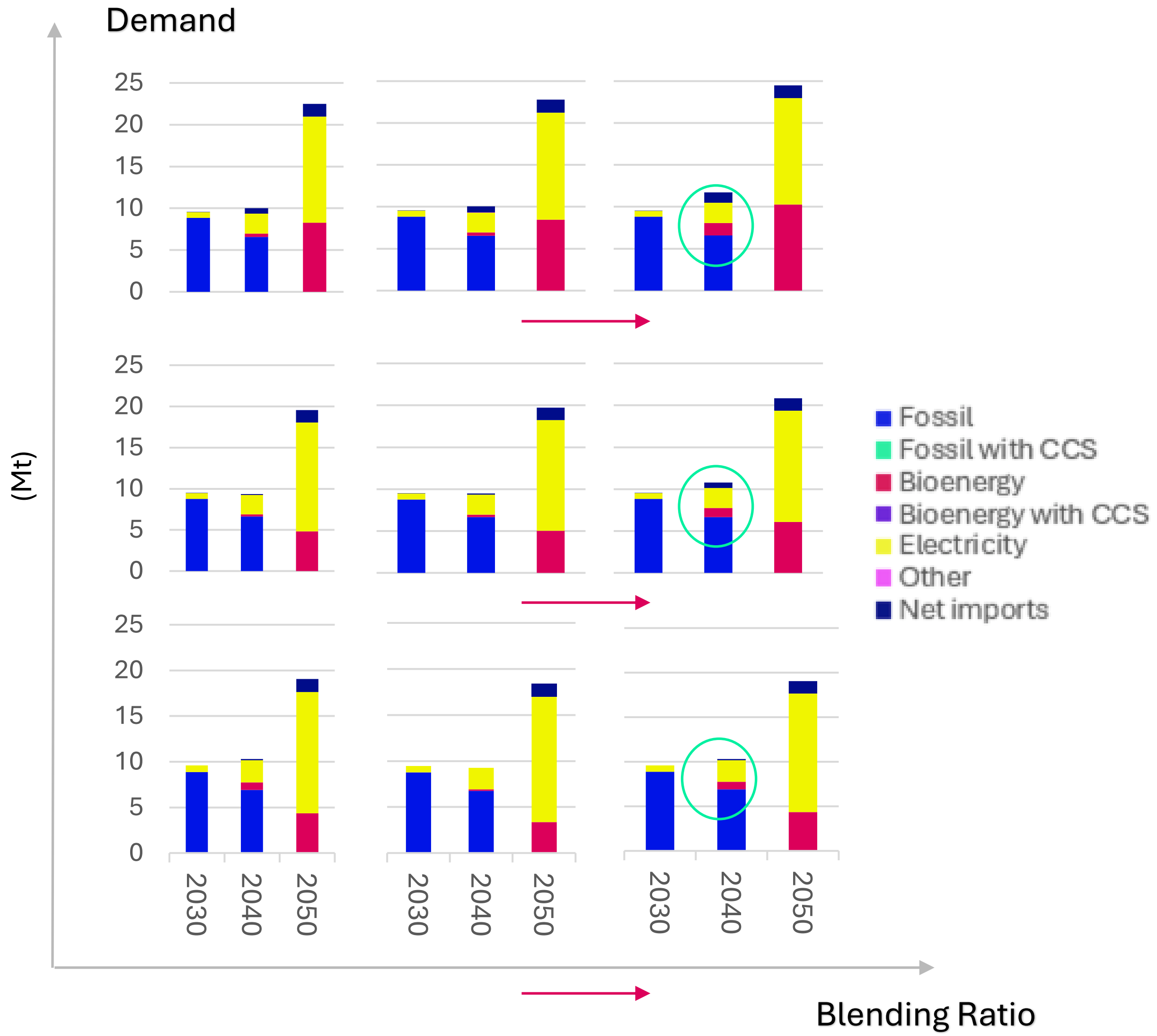


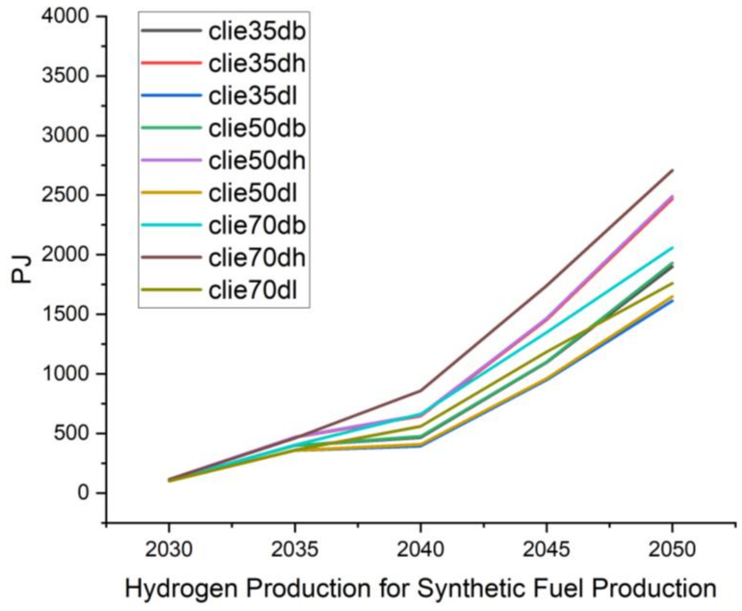


	Blend Ratio	Demand Level
CLIE	35	Basis
CLIE	35	High
CLIE	35	Low
CLIE	50	Basis
CLIE	50	High
CLIE	50	Low
CLIE	70	Basis
CLIE	70	High
CLIE	70	Low

Results

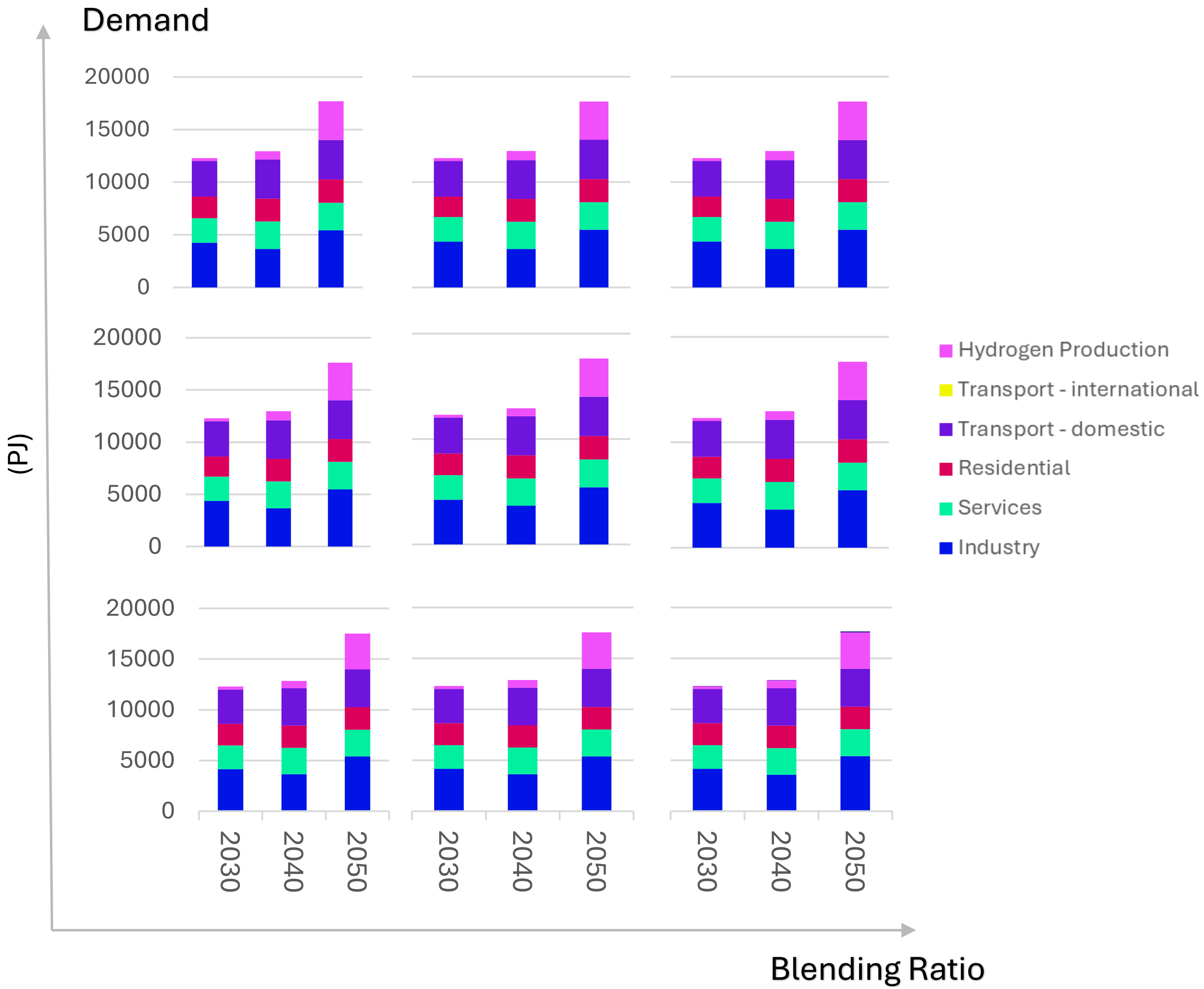
How and how much hydrogen should produced?

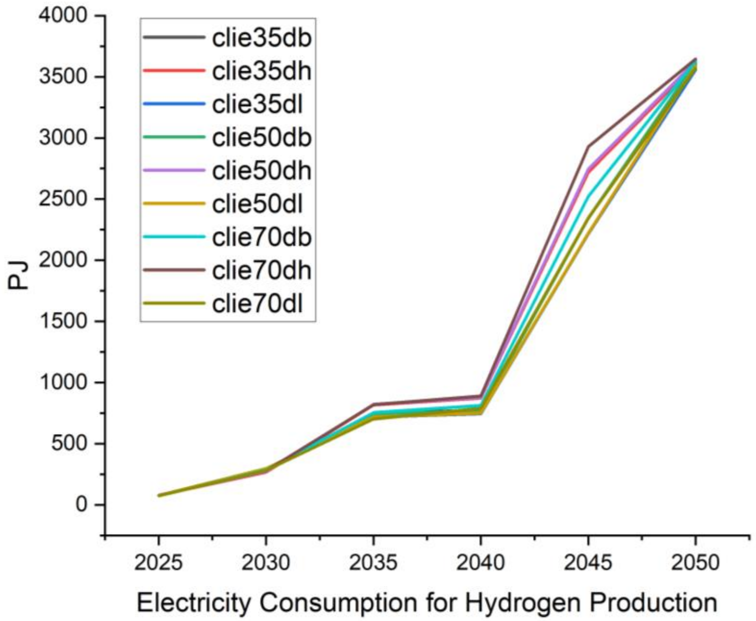




- The ratio of **feedstock remains similar** throughout all scenarios, a transition from gas to electricity
- **Bioenergy** taking a larger role in high-demand scenarios
- Bioenergy enters earlier in higher blending ratio scenarios

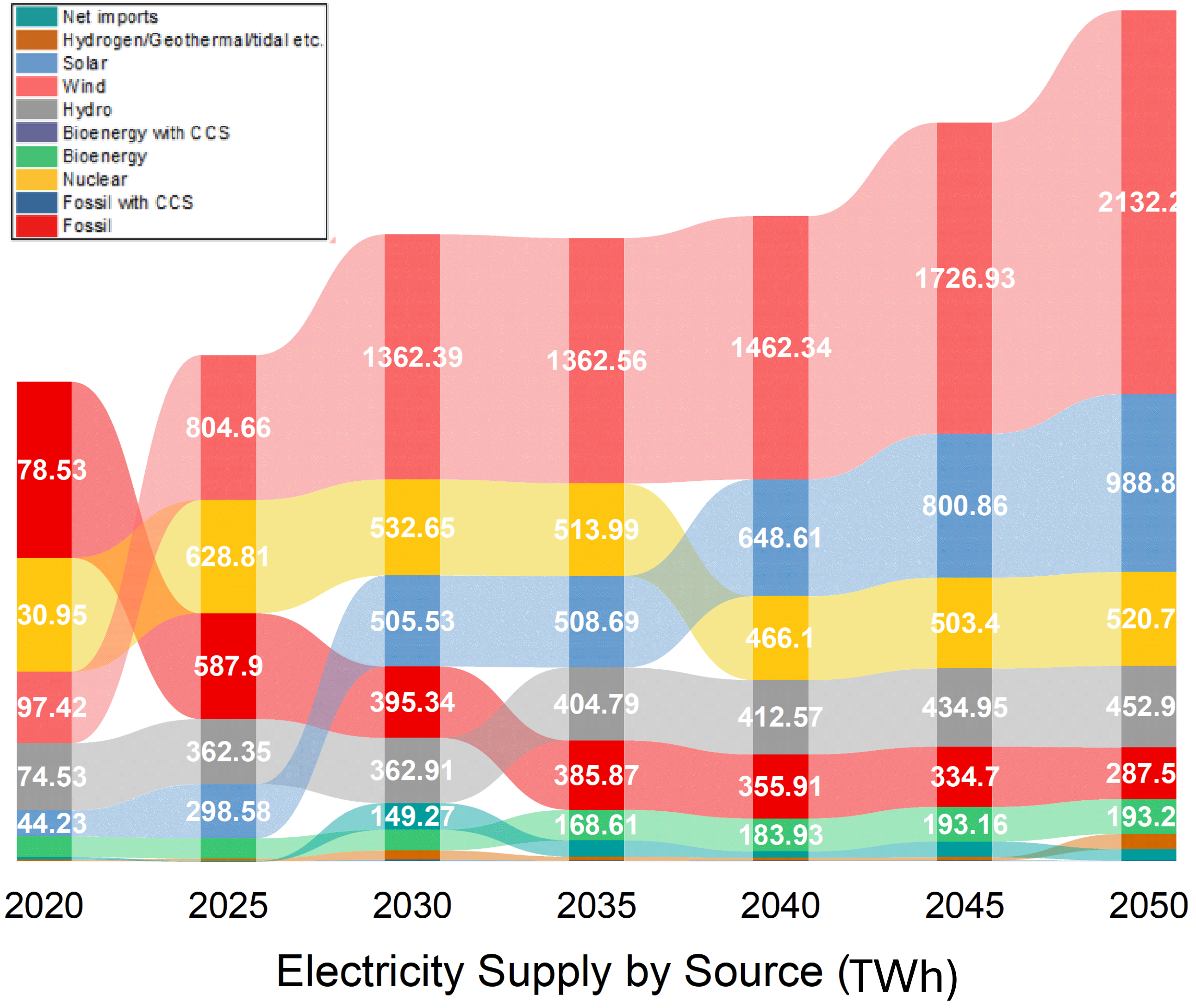
How much direct electricity for hydrogen production?

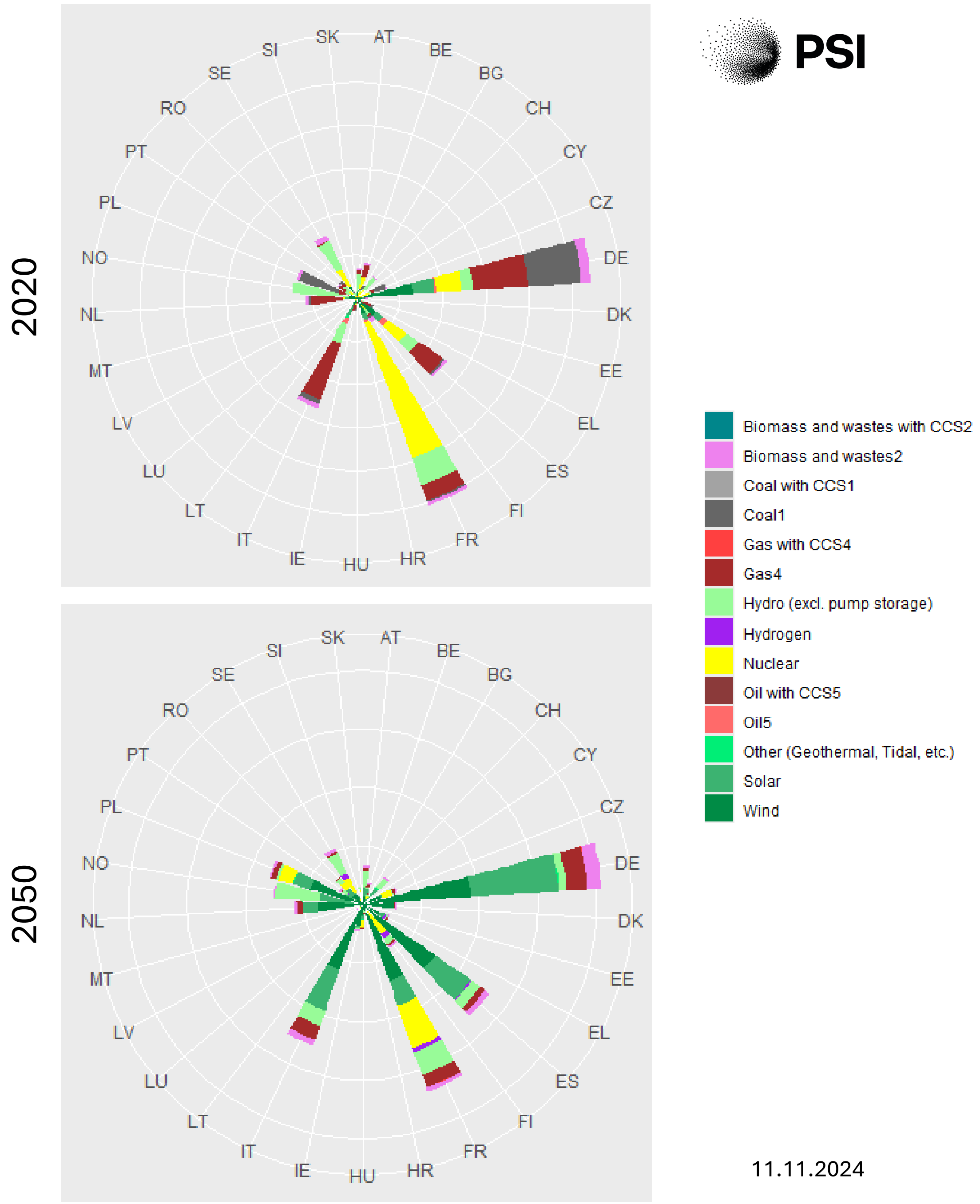




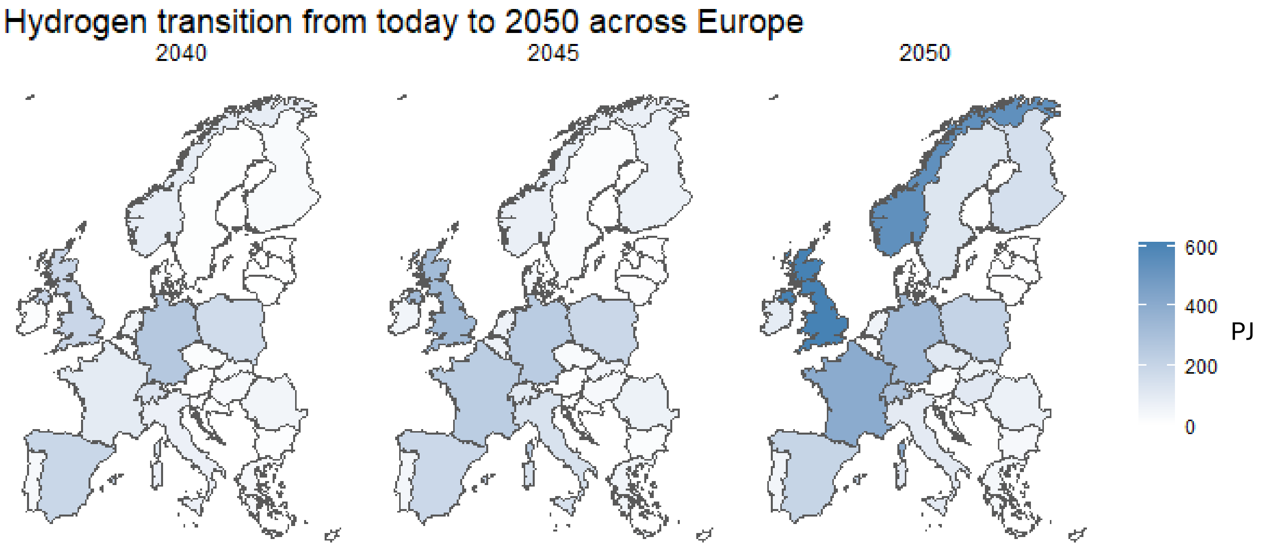
- **¼ of final electricity consumption** for all end-use sectors is required just for hydrogen production, no significant variation among scenarios
- Yet, the electricity demand accelerates drastically between 2040 and 2045 among all scenarios
- Hydrogen production (2025-2040) still produced from a mix of natural gas with CCS and biomass

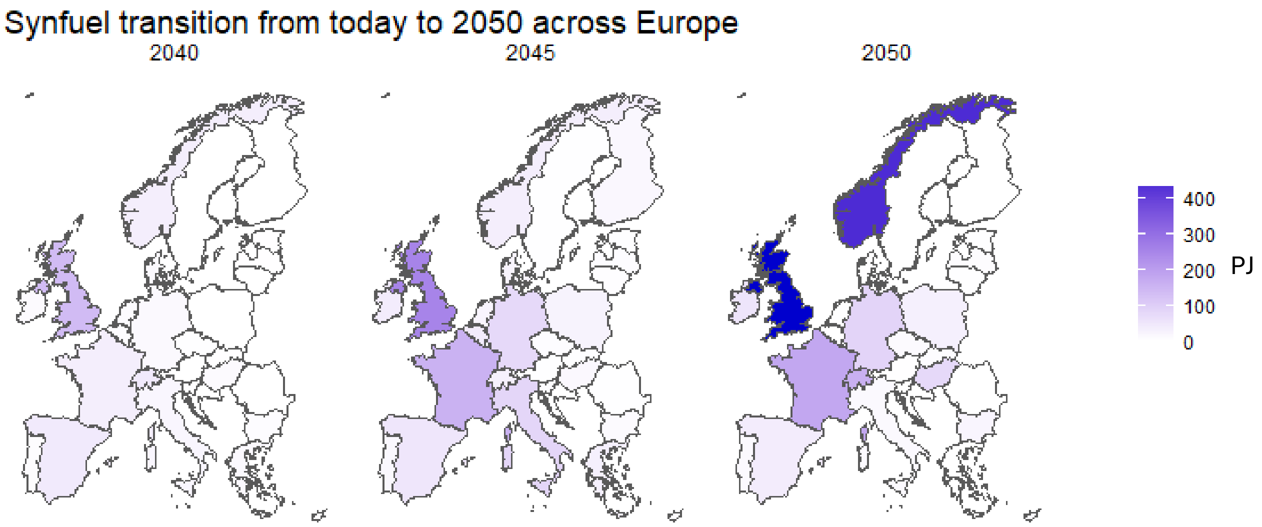
Electricity Supply by Energy Sources





Where are the low carbon fuels produced?





- The countries (NO, UK) that produce hydrogen are also strong players in electricity-based synthetic fuel production in Europe.
- European hydrogen production reaching c.a. 9Mt in 2030 and 18Mt in 2050.

What are the implications to the rest of the energy system led by the uptake of RFNBOS?

Conclusion

Uptake of low-carbon synthetic fuels will

- Consume renewable electricity that amounts to ¼ of all end-use electricity consumption
- Require over double all end-use green hydrogen consumption

Higher aviation demand and blending ratio variations

- Electricity demand does not scale up as drastically as for hydrogen as green hydrogen can also be produced by natural gas with CCS and biomass
- Bioenergy is utilized to satisfy higher hydrogen demand instead of more electricity-based hydrogen

With Lower demand

- The reduction of emissions from aviation is not sustainable through mere technical means, demand response continues to play a crucial role

Outlook

Parametric analysis

- Costs for the Direct Air Capture (DAC) costs and hydrogen production costs
- Extra-EU import flexibility for synthetic fuels requires some further scrutiny, particularly the techno-economic data of future aviation

Policy disentanglement

- Identify if any of the policies implemented could affect the effect of synfuel production.

Further Modeling Efforts

- More differentiated infrastructure modeling in expansion building (iDesignRES)

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Thank you for your attention!

Meixi Zhang
Villigen, 10.07 2024

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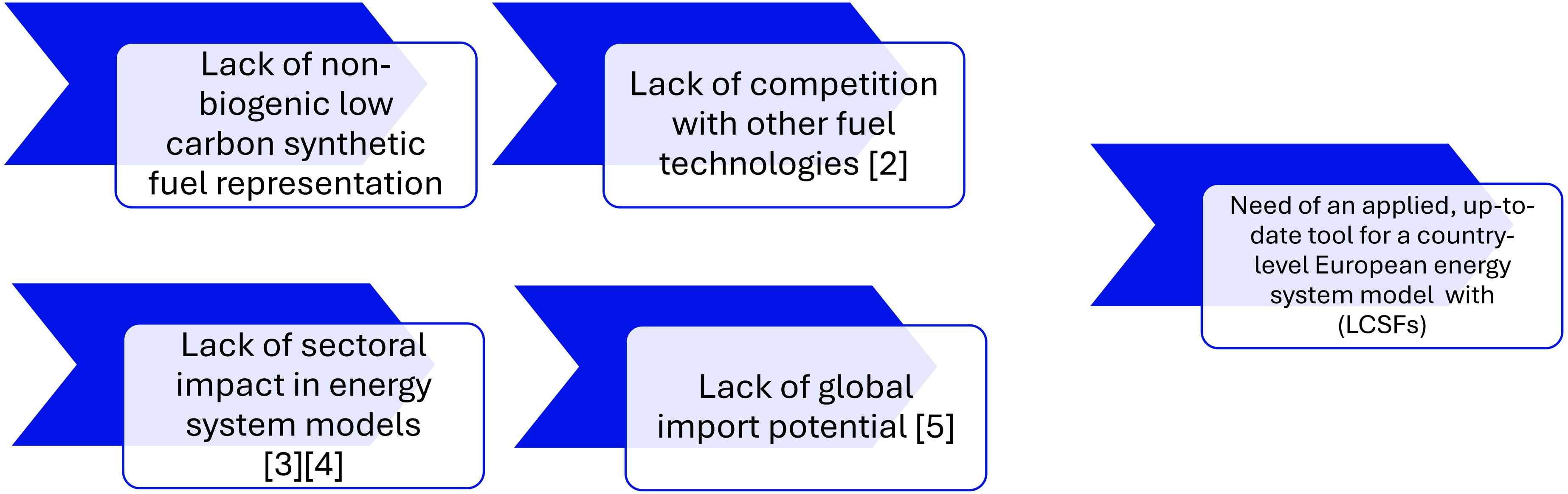
Appendix

Research Gap



[2] Sacchi, R., Becattini, V., Gabrielli, P. et al. How to make climate-neutral aviation fly. Nat Commun 14, 3989 (2023). https://doi.org/10.1038/s41467-023-39749-y
[3] Mignone, B.K., Clarke, L., Edmonds, J.A. et al. Drivers and implications of alternative routes to fuels decarbonization in net-zero energy systems. Nat Commun 15, 3938 (2024). https://doi.org/10.1038/s41467-024-47059-0
[4] Oshiro, K., & Fujimori, S. (2022). Role of hydrogen-based energy carriers as an alternative option to reduce residual emissions associated with mid-century decarbonization goals. Applied Energy, 313, 118803. https://doi.org/https://doi.org/10.1016/j.apenergy.2022.118803
[5] Blanco, Herib, et al. “Potential for hydrogen and power-to-liquid in a low-carbon EU energy system using cost optimization.” Applied Energy, vol. 232, Dec. 2018, pp. 617–639, https://doi.org/10.1016/j.apenergy.2018.09.216.

Presentation Outline

Introduction

- Relevance in current European legislative targets
- Research Question
- Literature review on low-carbon fuels in energy system modelling

Methodology

- Calibration, extension, and application of the JRC-EU-TIMES model

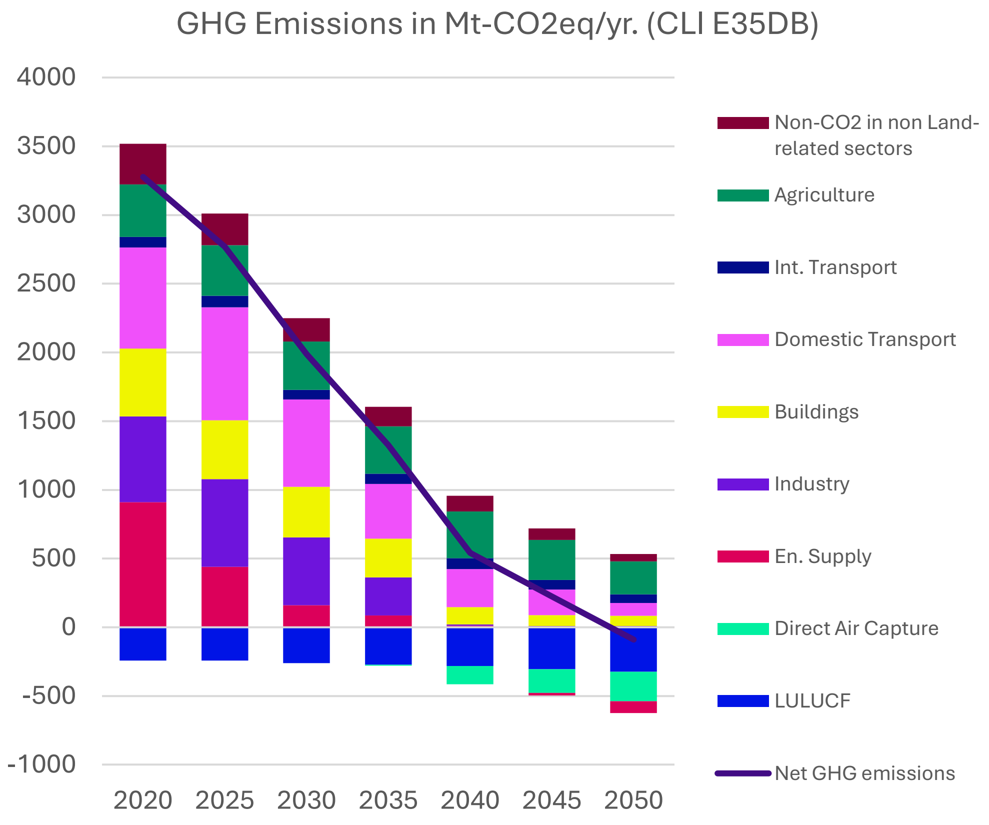
Results

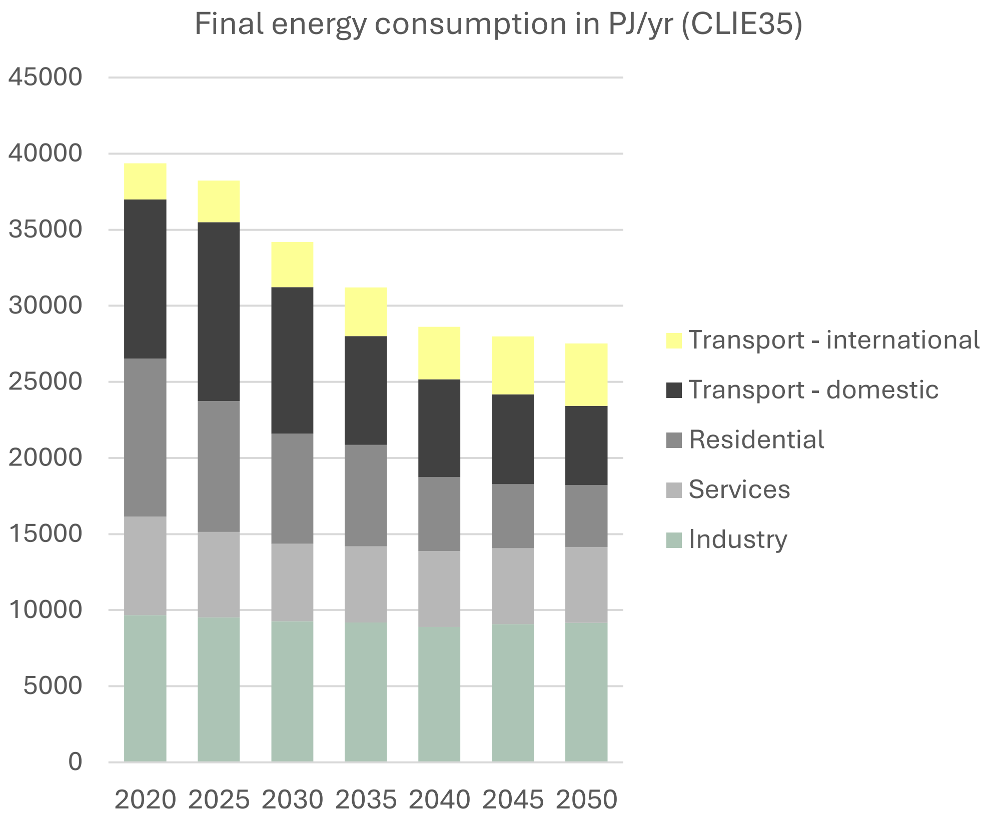
- EU net-zero emissions scenario with the contribution of synthetic fuels
- Scenario variations of systemic impact of synthetic fuels

Conclusion & Outlook

- Parametric analysis

A Net-zero Scenario led by Efficiency Gains





- Net zero achieved with a contribution of 49% of Land-Use and Land-Use Change Forestry emission removals and a substantial scale-up of Direct Air Capture (DAC) technologies from 2040.
- The domestic transport and services sector undergoes the most efficiency gains.