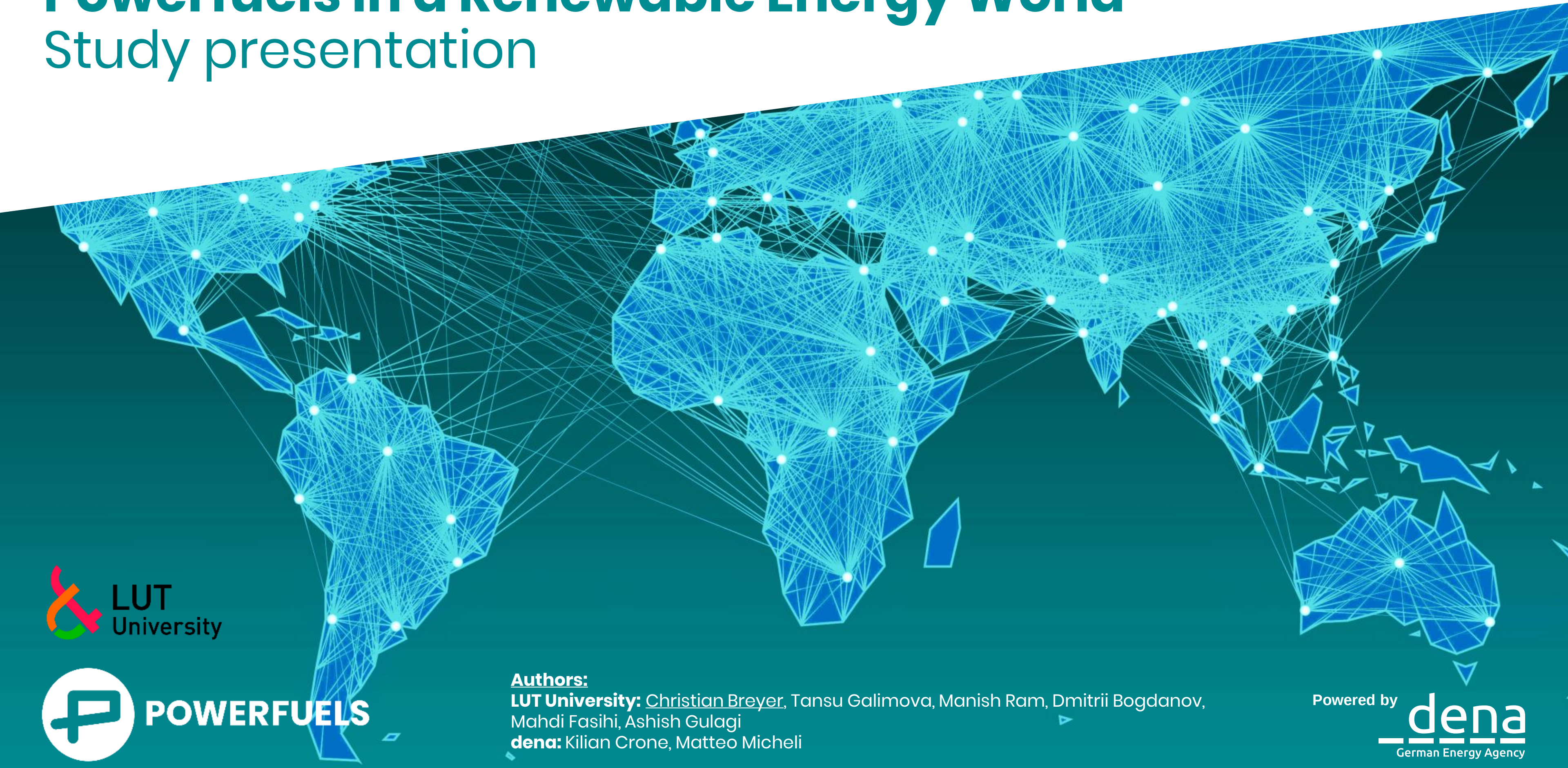
Powerfuels in a Renewable Energy World
Study presentation



LUT University

POWERFUELS

Authors:
LUT University: Christian Breyer, Tansu Galimova, Manish Ram, Dmitrii Bogdanov, Mahdi Fasihi, Ashish Gulagi
dena: Kilian Crone, Matteo Micheli

Powered by dena
German Energy Agency

Presenters and Agenda

1

Background and methods

Prof. Dr. Christian Breyer
LUT University
Professor for Solar Economy

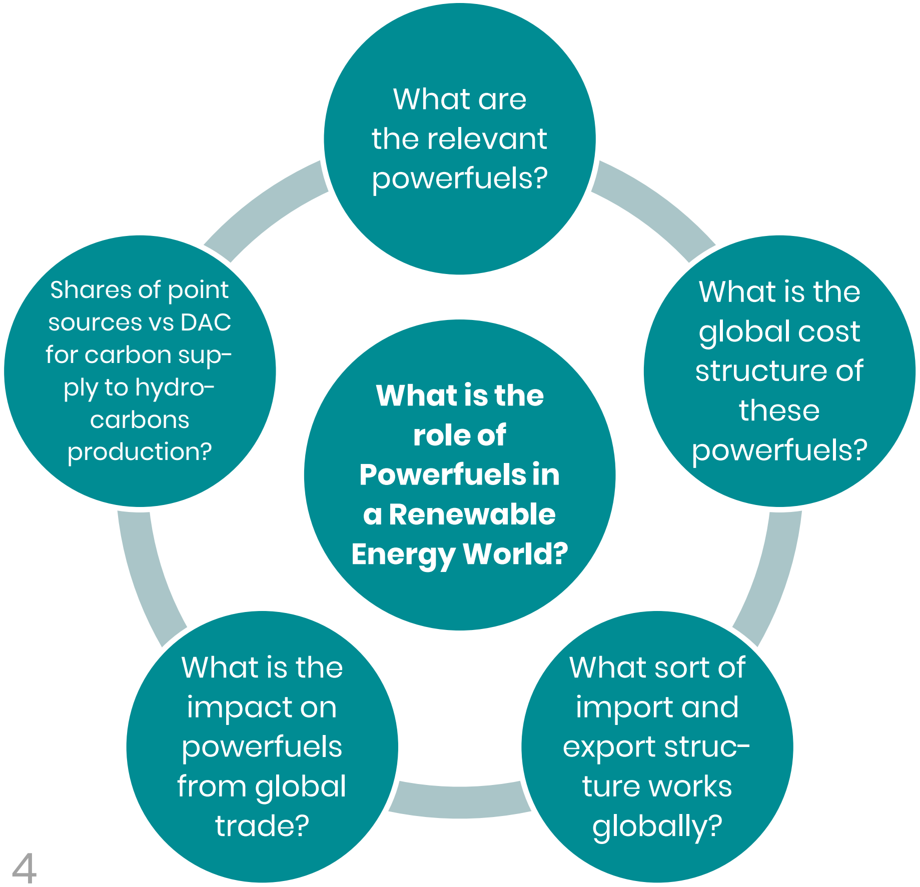
2

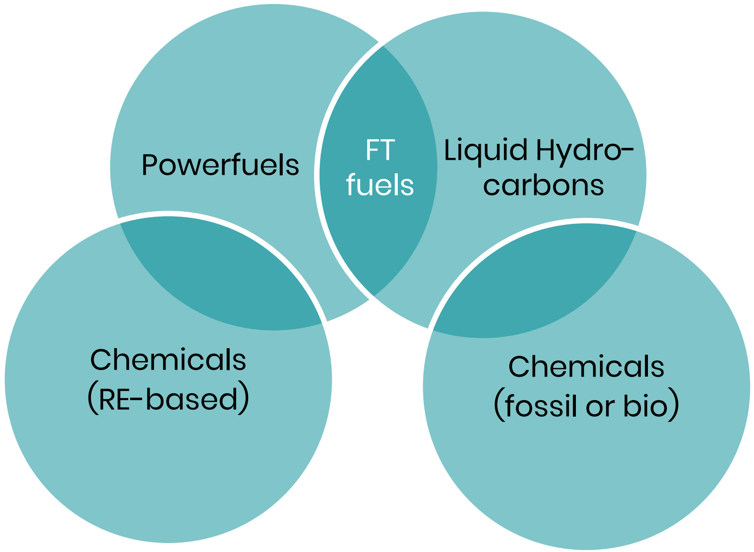
Key messages

Kilian Crone
dena
Team Lead, Global Alliance Powerfuels

Background and methods

Research question and definitions

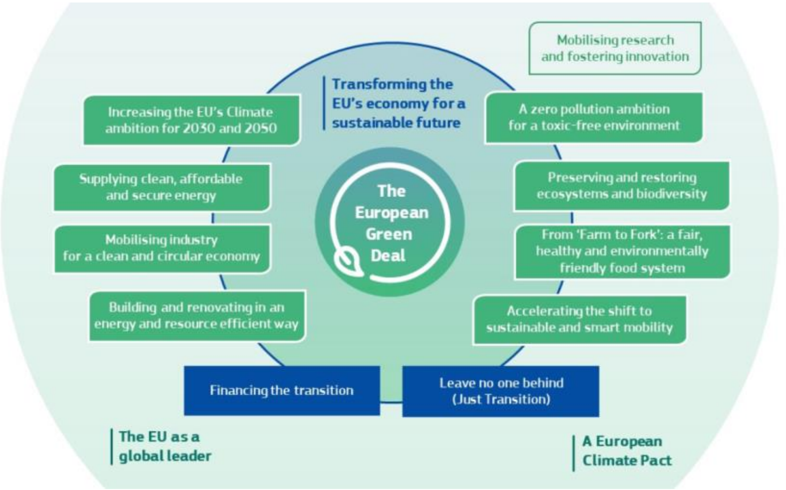




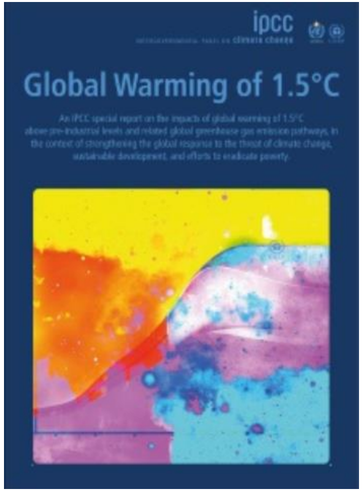
Powerfuels	renewable electricity based - synthetic natural gas (SNG), liquefied natural gas (LNG), Fischer-Tropsch fuels (FT-fuels), hydrogen (H_2), methanol, ammonia, and naphtha
FT-fuels	renewable electricity based - diesel, gasoline, kerosene, and naphtha
Liquid hydrocarbons	fossil fuels, biofuels, and FT-fuels
Chemicals	methanol, ammonia, and naphtha

LUT University

Background of Study: Targets



European Green Deal



Paris Agreement
("well below 2°C")

+ <u>What does it mean?</u>
  - (net) zero greenhouse gas (GHG) emissions by 2050 are mandatory
  - negative GHG emissions are costly, risky, with unclear responsibilities
  - thus zero GHG emissions is the real target for the energy system
  - this implies in particular GHG emission neutral powerfuels (fuels for transport, chemicals for industry)

LUT University

Background of Study: Existing Studies

					TFED share in 2050 *			
Source	Publication year	Unit		2050	fossils	biofuels	powerfuels	electricity
this study	2019	TWh/a		32542	0 %	1 %	63 %	35 %
Greenpeace [E]R	2015	TWh/a		19159	29 %	14 %	20 %	38 %
Greenpeace [E]R adv.	2015	TWh/a		14836	0 %	14 %	35 %	51 %
Teske, 1.5 °C	2019	TWh/a		17001	0 %	16 %	36 %	48 %
Teske, 2 °C	2019	TWh/a		14279	0 %	25 %	29 %	46 %
Jacobson et al.	2018	TWh/a		13113	0 %	0 %	33 %	67 %
Löffler et al.	2017	TWh/a		10414	0 %	15 %	44 %	41 %
Pursiheimo et al.	2019	TWh/a		23480	0 %	30 %	33 %	37 %
García-Olivares et al.	2018	TWh/a		28383	n/a	n/a	n/a	n/a
WWF / Deng et al.	2011	TWh/a	. . .	17741	0 %	74 %	0 %	26 %
World Energy Council	2019	TWh/a		33134	62 %	12 %	9 %	17 %
DNV GL	2019	TWh/a		30000	49 %	12 %	6 %	33 %
IEA, WEO StPS	2019	TWh/a		-	89 %	6 %	0 %	5 %
IEA, WEO SDS	2019	TWh/a		-	71 %	14 %	1 %	14 %
Luderer et al. B200	2018	TWh/a		31945	32 %	29 %	18 %	21 %
Luderer et al. B800	2018	TWh/a		36110	47 %	26 %	12 %	15 %
Shell, Sky	2018	TWh/a		40630	67 %	13 %	2 %	18 %
BP Energy Outlook	2019	TWh/a		-	89 %	7 %	0 %	4 %
ExxonMobil	2017	TWh/a		-	94 %	4 %	0 %	2 %
US DoE EIA	2017	TWh/a		-	98 %	0% **	0 %	2 %

*presented numbers apply to the transport sector alone

source: Khalili et al., 2019. Energies, 12, 3870

- Powerfuels in major **energy studies** are still very **often limited to hydrogen** only
- **RE-based chemicals** for the chemical industry are **not yet part of any** known **global study**
- Key models **lack methods to describe powerfuels**
- **Green Deal and** ambitious **IPCC targets are not yet well reflected** in most studies

LUT University

Unique Features of the Study

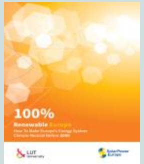
1. Covering the **fuel demand by powerfuels** in a sustainable economy
2. **Chemical industry** is fully **considered** within powerfuel demand
3. **Global trade** of powerfuels enabled for existing shipping options
4. **Full hourly resolution** of analyses based on 145 regions
5. **Latest cost insights** applied for all key technologies

LUT University

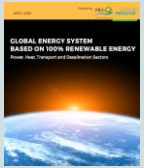
Applied Methods

Step 1
Framing, demand, fuels/chemicals

- Fully sustainable energy system by 2050
- LUT reports as basis for powerfuels demand and cost structure



link to report



link to report

Step 2
Cost structures and regional structuring

- Years 2030, 2040, 2050 are considered for 145 regions globally, aggregated to 92 regions
- LUT reports as basis for latest cost levels of solar PV, battery, CO_2 DAC
- Full hourly modeling, PV/Wind shares, operation modes of electrolysers, DAC, etc.

Step 3
Global trading

- All 92 regions are grouped into importers, exporters and neutral
- Relative export shares estimated as a function of export attractiveness, cost attractiveness, available area
- Import demand obtained as a function of relative cost levels and import shares of 0…100%

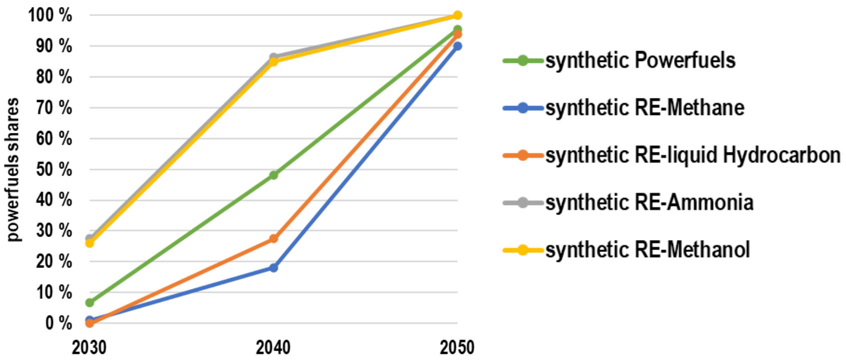
Step 4
Results analysis

- Global market for powerfuels: pre-trade and post-trade, volumes, values, trends over time and regions

LUT University

Main Assumptions: powerfuels, components

- Powerfuel shares (transport sector) according to LUT/EWG study
- Powerfuel shares (chemical industry) according to a progressive development
- Phase-in of LNG (marine) and FT fuels rather late and very intensive, earlier phase-in would be supportive
- Solar PV capex according to ETIP-PV
- Wind capex have downside potential, but wind industry lacks transparency in real cost numbers
- Battery capex approved by major industry players
- Water electrolyser capex have downside potential, in line with latest industry announcements
- CO_2 DAC capex have higher uncertainty, based on industry numbers



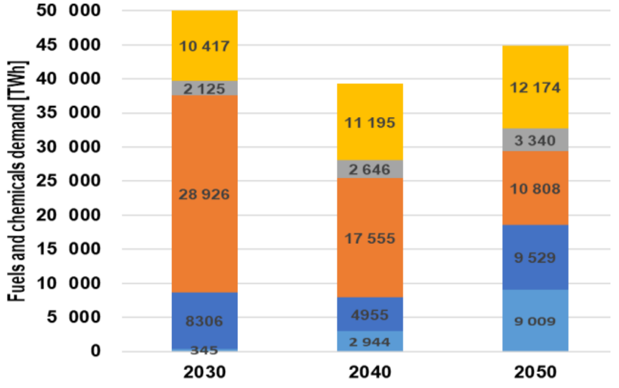
Name		2015	2020	2025		2050	units
PV fixed tilted PP	Capex	1000	432	336		166	€/kW,el
PV single-axis PP	Capex	1150	475	370		183	€/kW,el
Wind onshore PP	Capex	1250	1150	1060		900	€/kW,el
Battery utility-scale - storage	Capex	400	234	153	...	61	€/kWh,el
Battery utility-scale - interface	Capex	200	117	76		30	€/kW,el
Water Electrolysis	Capex	800	685	500		248	/kW,H2
CO2 direct air capture	Capex	1000	730	481		199	€/(tCO2*a)

Key messages

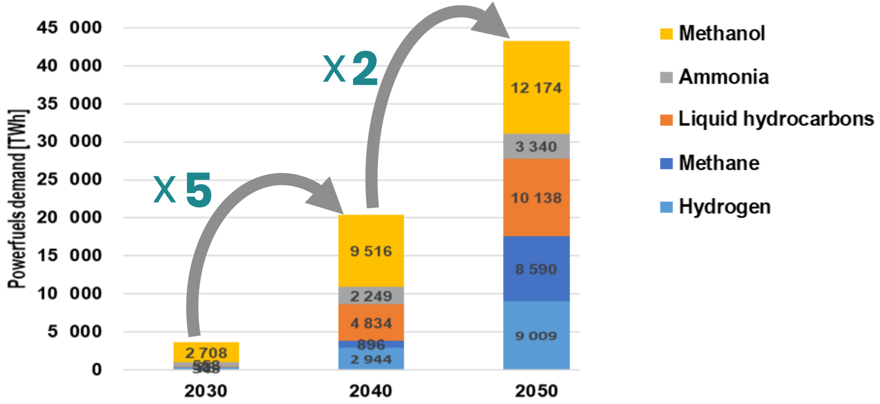
All powerfuels play a dominant role in a renewable 2050 global energy system

A global powerfuels market will **ramp up** in the **2020s** and emerge **across the world** in the **2030s**. Total fuels demand will decrease up to 2050, seeing a **well-established and stable powerfuels market in the long run**.

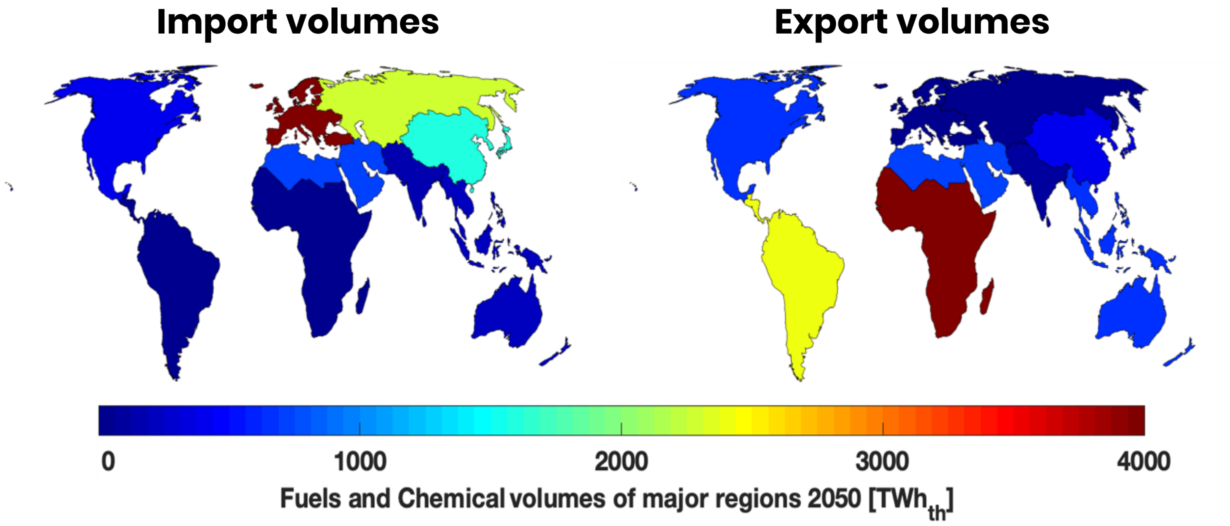
Bio, fossil and synthetic global demand



Synthetic global demand



A cost-optimized scenario means global trade of powerfuels

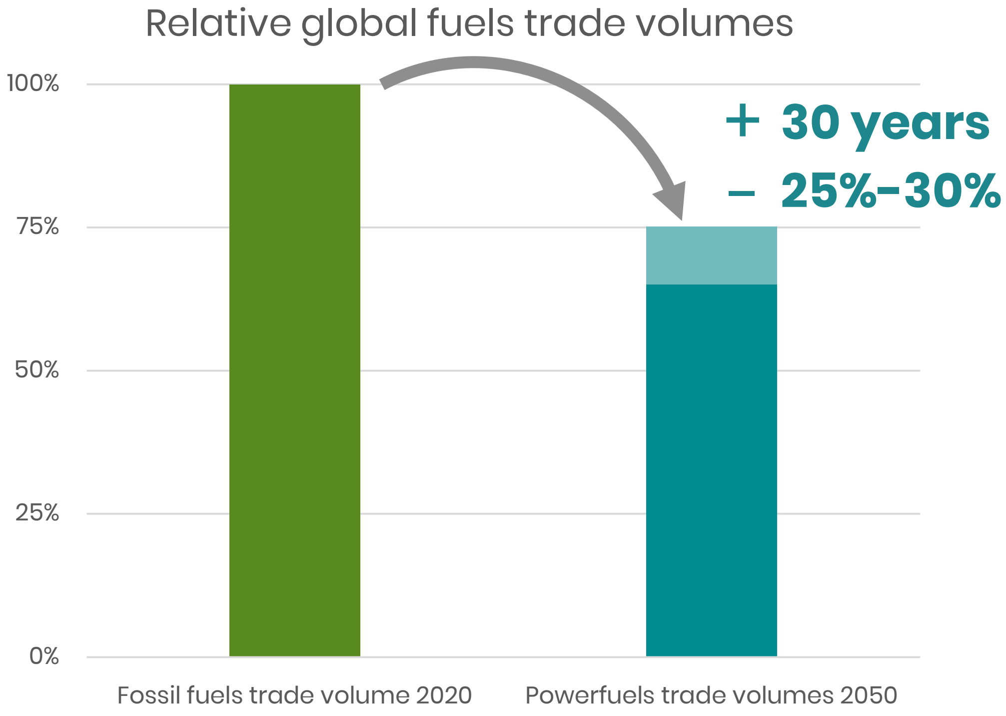


Key importers	Key exporters
Europe, Eurasia, Northeast Asia, and Canada (within N. America)	mainly South America, sub-Saharan Africa, and to a lesser extent the Middle East and North Africa

- Importers mainly reside in the northern hemisphere, while exporters mainly reside in the sunbelt region.
- Some regions are importers and exporters, such as North America (Mexico exporting, Canada importing).

LUT University

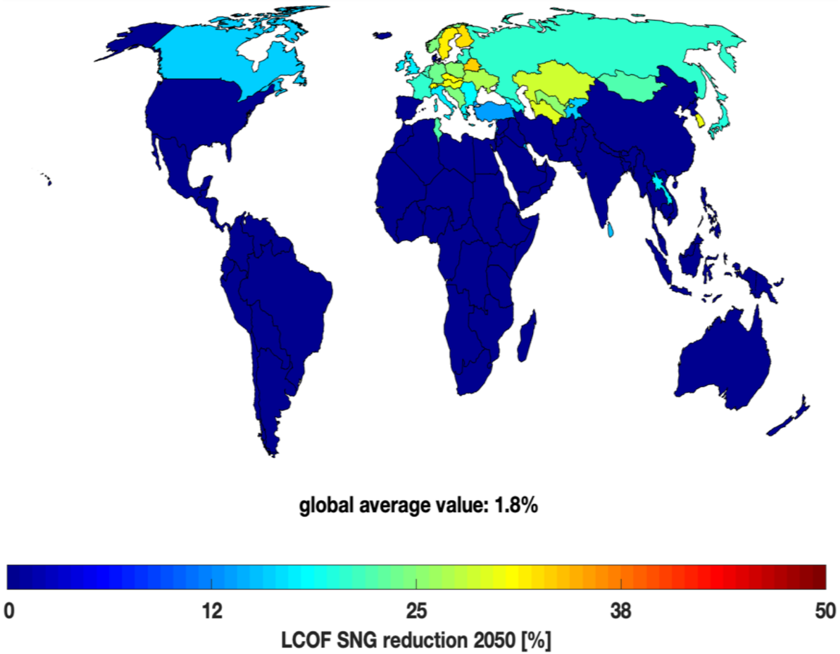
Powerfuels trade volumes will be much lower than the present average trade volumes of fossil fuels, especially crude oil

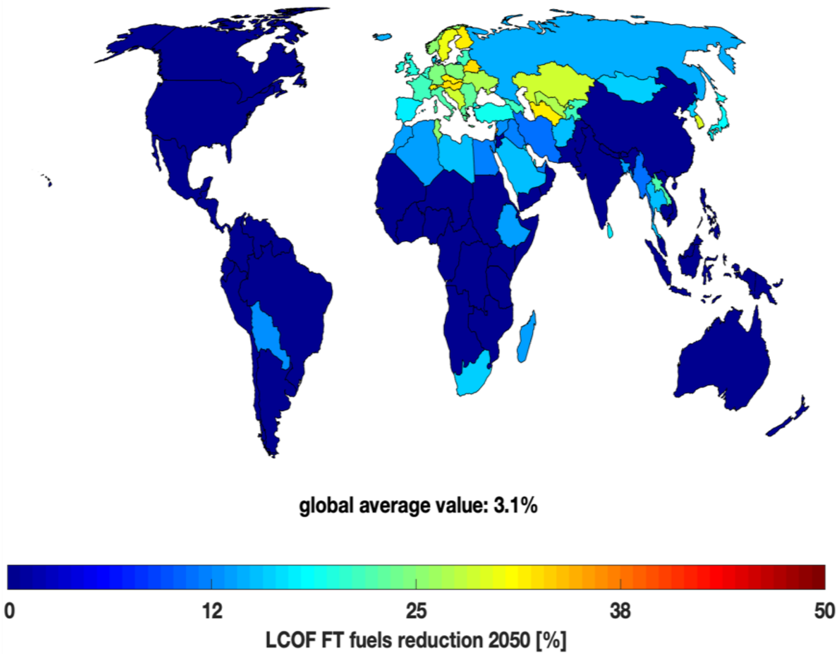


- Strong expansion of PV leads to higher levels of energy autarchy, and therefore significantly lower powerfuels trade volumes.
- Overall trade volumes of powerfuels in the order of 25-35% of present global fossil fuels trade volumes.

LUT University

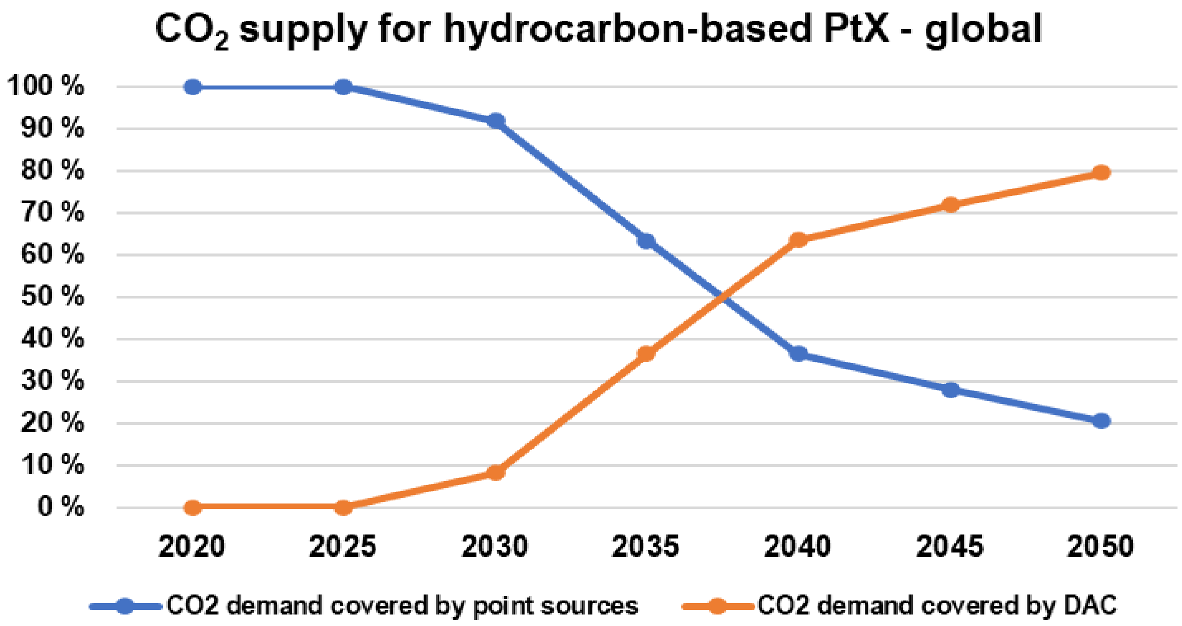
Europe benefits from global powerfuels trading, resulting in 15-30% cost reduction compared to a self-supply scenario





LUT University

CO_2 emerges as a valuable feedstock, with the CO_2 market transitioning from point sources to Direct Air Capture (DAC)



- DAC emerges as an essential technology for achieving net zero GHG emissions, providing 80% of all CO_2 feedstock in 2050.

Delaying the commercialisation of powerfuels would lead to high-risk and/or high-costs alternatives for achieving emissions reduction targets.

1 A **business-as-usual** scenario without powerfuels would result in **additional 140 $GtCO_2eq$ emissions by 2050 globally**, and up to 18.5 $GtCO_2eq$ in Europe.

2 These are the **result of a cost-optimised scenario**, i.e. all other pathways will come at higher cost (such as those w/o powerfuels).

3 **Alternatives** to powerfuels such as biofuels and CCS would exert **pressure on already highly vulnerable ecosystems**.

Powerfuels are an indispensable part of the global energy system, and **investments must start now.**

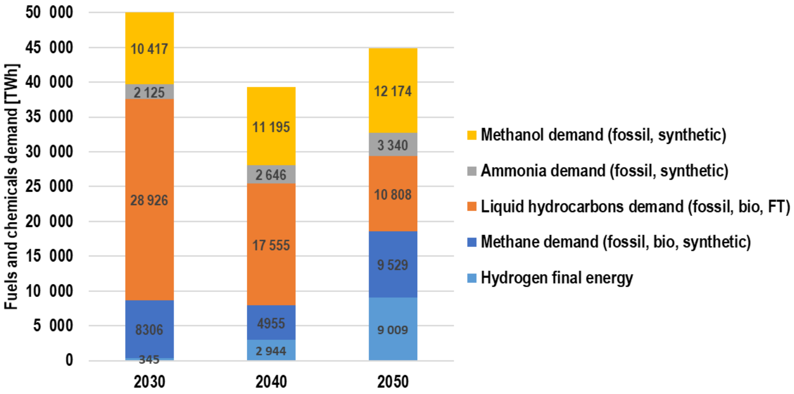
Investments in the early adoption of powerfuels can **lead** to **long-term, stable trading, and returns.**

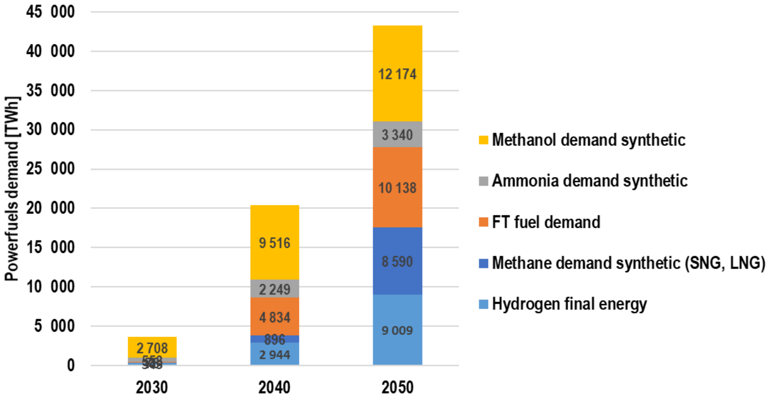
Powerfuels are a **cost- and risk-optimised solution.**

LUT University

Thank you for your attention!

Results

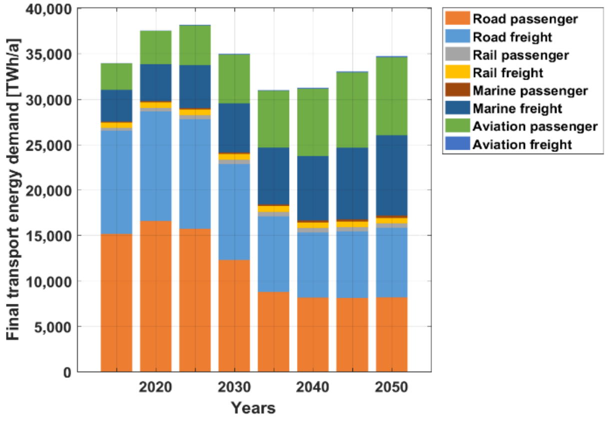


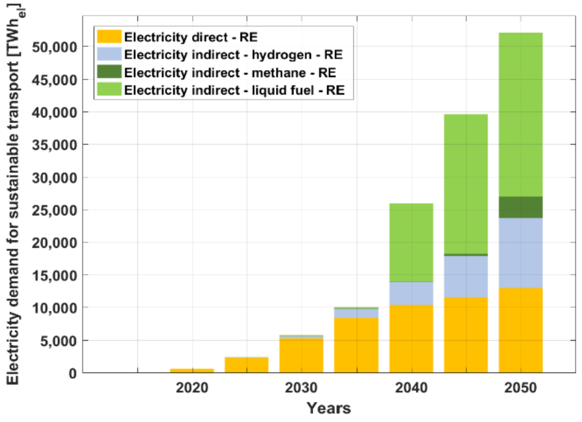


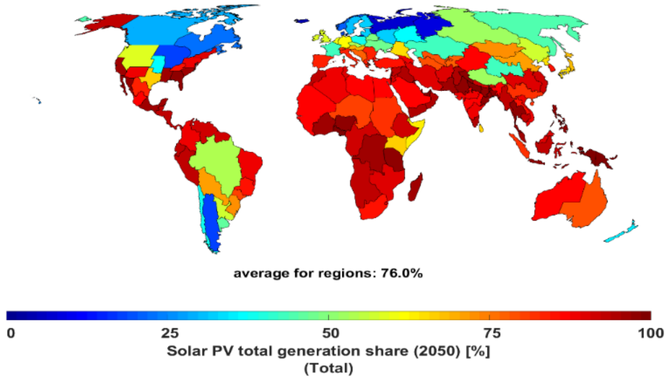
Fuels and Chemicals in general:
- steady growth of chemicals, whereas Methanol represents non-Ammonia chemicals feedstock equivalent
- liquid hydrocarbons are in steady decline, mainly due to electrification of road transportation
- Methane demand in decline until 2040 with increase towards 2050, with some uncertainty for substitution of Methane by Hydrogen

Powerfuels:
- first markets in 2030
- strong growth until 2040, continued until 2050
- less uncertainty for synthetic Chemicals
- highest uncertainty for Methane demand due to substitution by Hydrogen (heat) and Ammonia/Methanol (marine)
- sustainable bioenergy for Fuels

Input LUT/EWG report – selected results



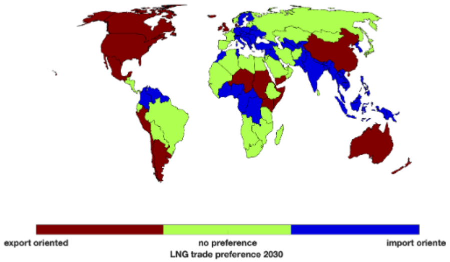


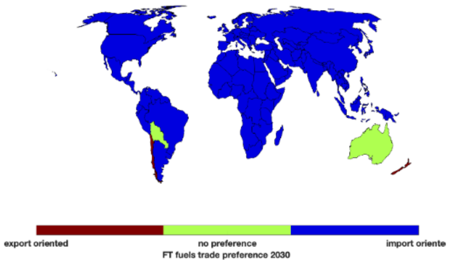


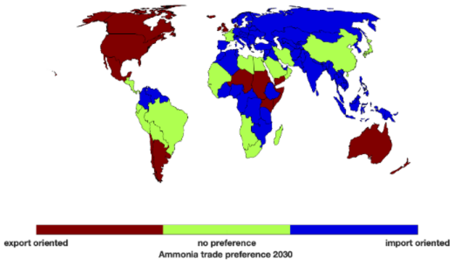
Key insights:

- final transport demand increases from around 50.8 million p-km to around 150.8 million p-km, and from around 110 million t-km to around 330 million t-km
- whereas, the final energy demand for overall transport increases slightly from 34,000 TWh/a in 2015 to 35,000 TWh/a by 2050, enabled by high efficiency of EV
- RE-based powerfuels produced by renewable electricity contribute around 62% of FED in 2050
- massive demand for FT fuels from 2040 onwards
- countries in the Sun Belt are almost fully dominated by solar PV

Trading 2030: powerfuels and chemicals

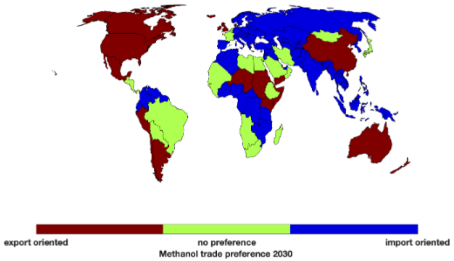




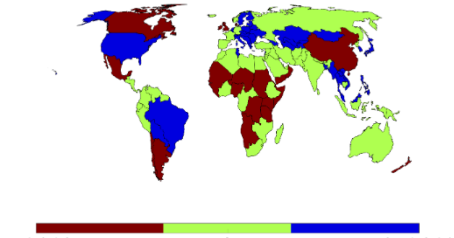


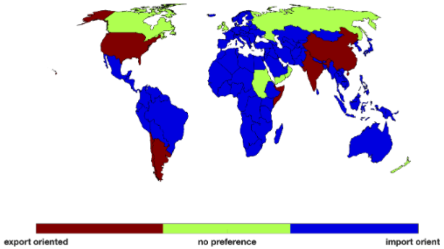
Key insights:

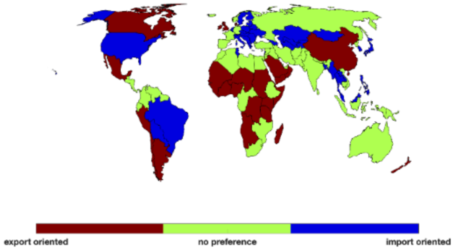
- consistent import attractiveness in Europe, but also many other regions all around the world
- export options for excellent wind sites, but also most excellent (and seasonally stable) solar sites
- Chile is the most important export site in 2030s
- countries of the Sun Belt will go increasingly for domestic self-supply, except FT fuels, the highest cost powerfuel and sustainable chemicals option listed here



Trading 2040: powerfuels and chemicals

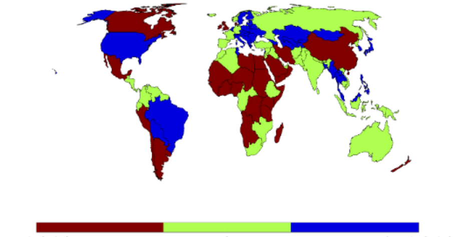




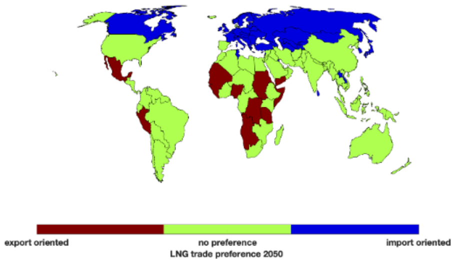


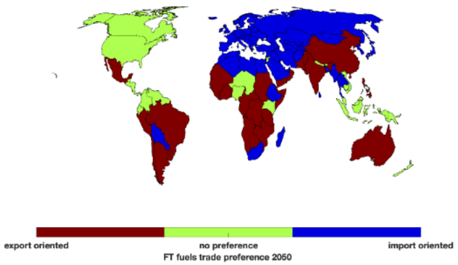
Key insights:

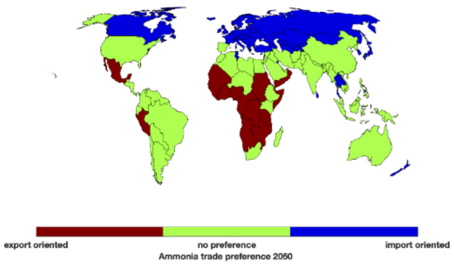
- consistent import attractiveness in Europe, but also many other regions all around the world
- export options for excellent wind sites, but also most excellent (and seasonally stable) solar sites
- almost all countries of the Sun Belt will go for domestic self-supply, except FT fuels, the highest cost powerfuel and sustainable chemicals option listed here



Trading 2050: powerfuels and chemicals

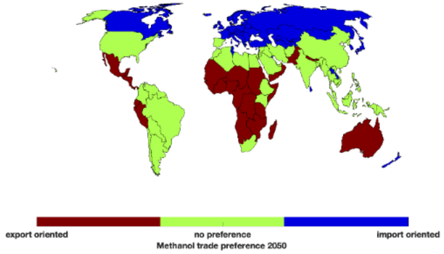




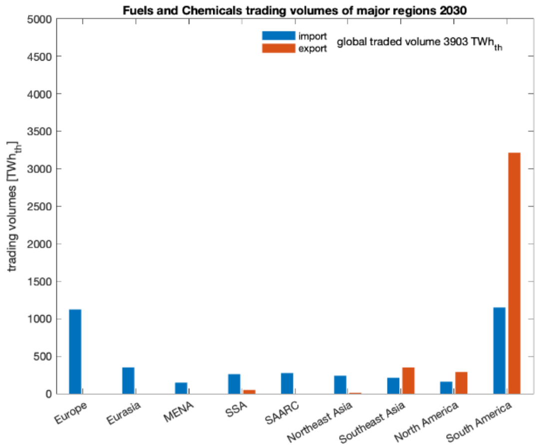


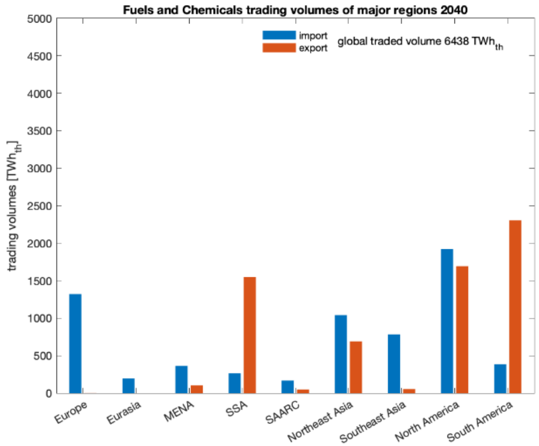
Key insights:

- consistent import attractiveness in northern hemisphere (Canada, Europe, Eurasia)
- export options for Latin America, sub-Saharan Africa, Australia
- almost all countries in the Sun Belt will go for domestic self-supply



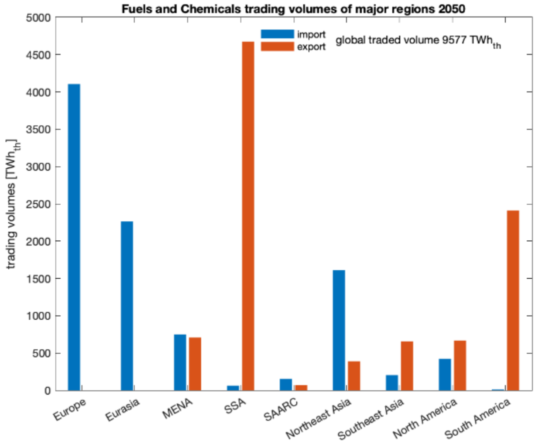
Volumes: powerfuels and chemicals



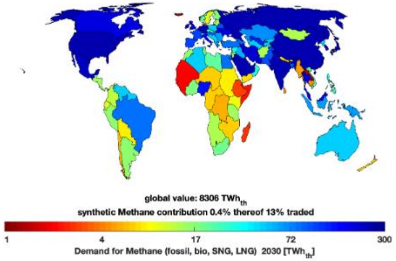


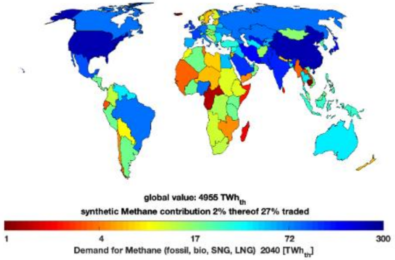
Key insights:

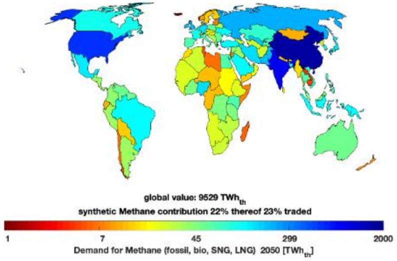
- **Europe shows continued import demand**
- **South America can export first, and remains in the market**
- **North America can balance within its region**
- **Sub-Saharan Africa continuously gains exporter market shares, benefiting from solar PV decline**
- **MENA region growth in export attractiveness, but less than generally expected**
- **SAARC shows strong domestic supply**



Global demand 2050: SNG/LNG and FT fuels

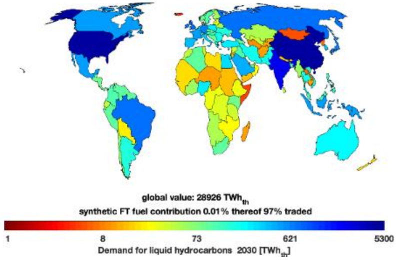


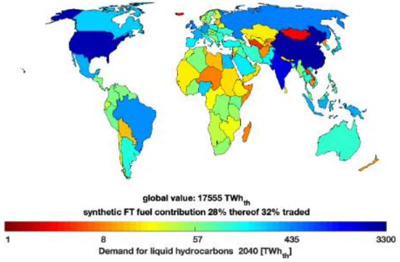


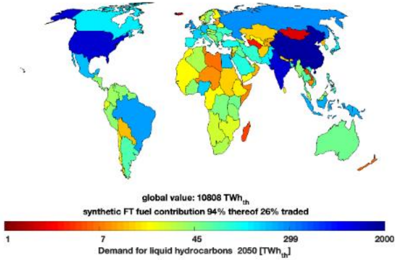


Key insights:

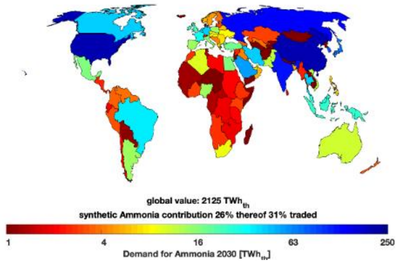
- liquid hydrocarbon demand in decline, due to electrification of road transportation
- SNG/LNG demand in decline until 2040, but followed by a demand increase, BUT with high uncertainty due to likely Hydrogen uptake
- powerfuel contribution to demand coverage increasingly growing
- traded volume around 20-30% of global demand
- relative market sizes seem to be surprisingly stable despite the strong demand growth in emerging and developing countries

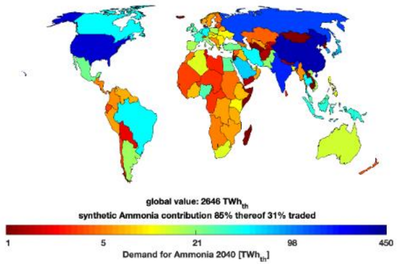


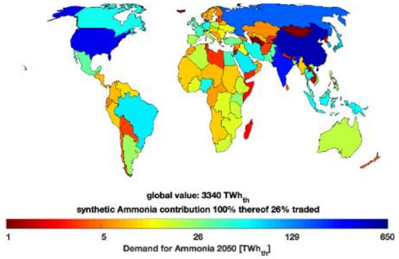




Global demand 2050: Ammonia and Methanol

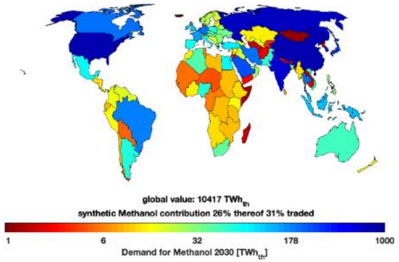


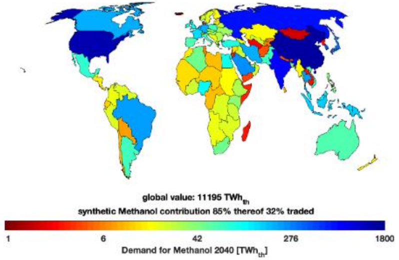


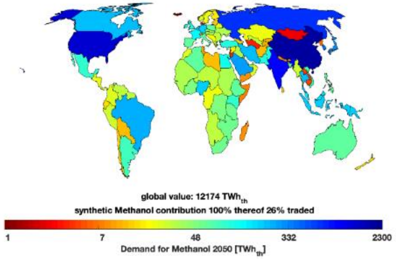


Key insights:

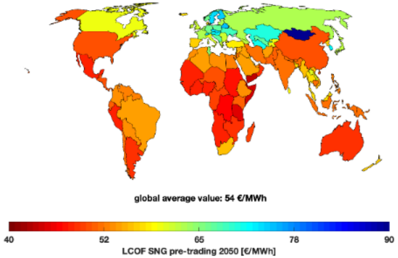
- Ammonia demand in stable growth
- Methanol demand in stable growth (here Methanol equivalent demand displayed)
- additional demand opportunity as a marine fuel
- stable RE-based chemicals phase-in expected
- traded volume around 25-35% of global demand
- relative market sizes seem to be surprisingly stable despite the strong demand growth in emerging and developing countries

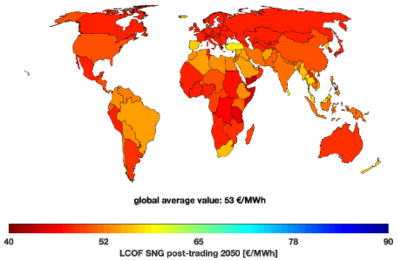


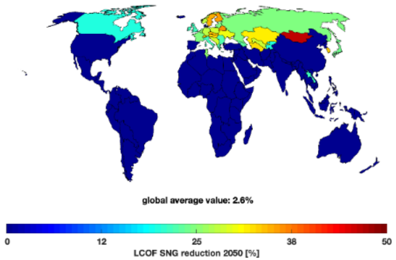




Trading 2050: SNG/LNG and FT fuels

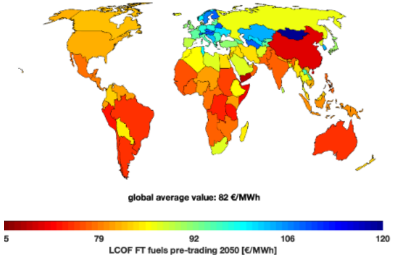


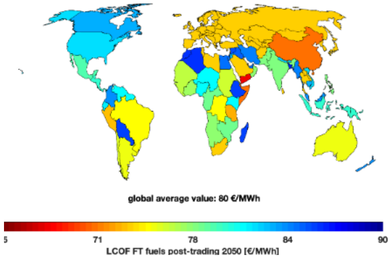


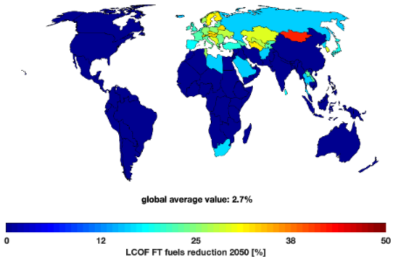


Key insights:

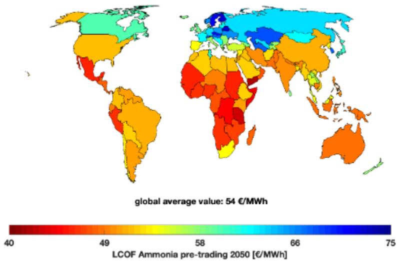
- main import regions are Europe and Eurasia
- cost reduction of world market rather small, as global average costs are reduced by about 3% (2050)
- importing countries benefit from 15-30% cost reduction of powerfuels
- global Sun Belt can switch to domestic self-supply
- SNG cost levels seem to be more homogenously distributed than FT fuels
- global market volume of trading 99 / 244 b€ for LNG / FT fuels
- traded volume of 23% / 33%
- shipping cost of 3.7 / 1.5 €/MWh
- MENA cost level seems to be at least partly latitude induced

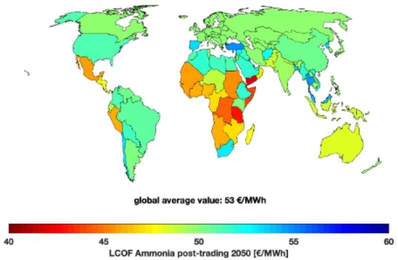


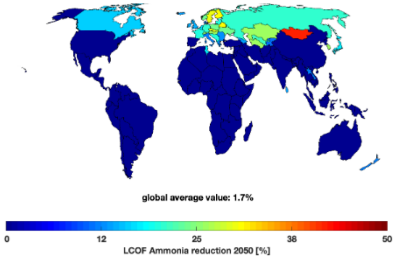




Trading 2050: Ammonia and Methanol

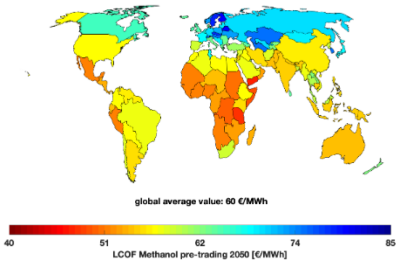


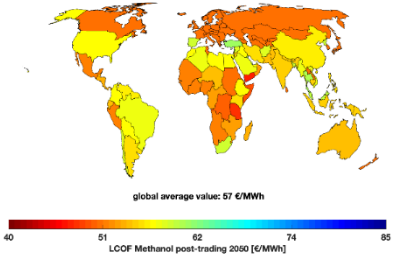


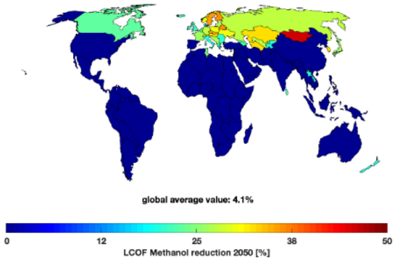


Key insights:

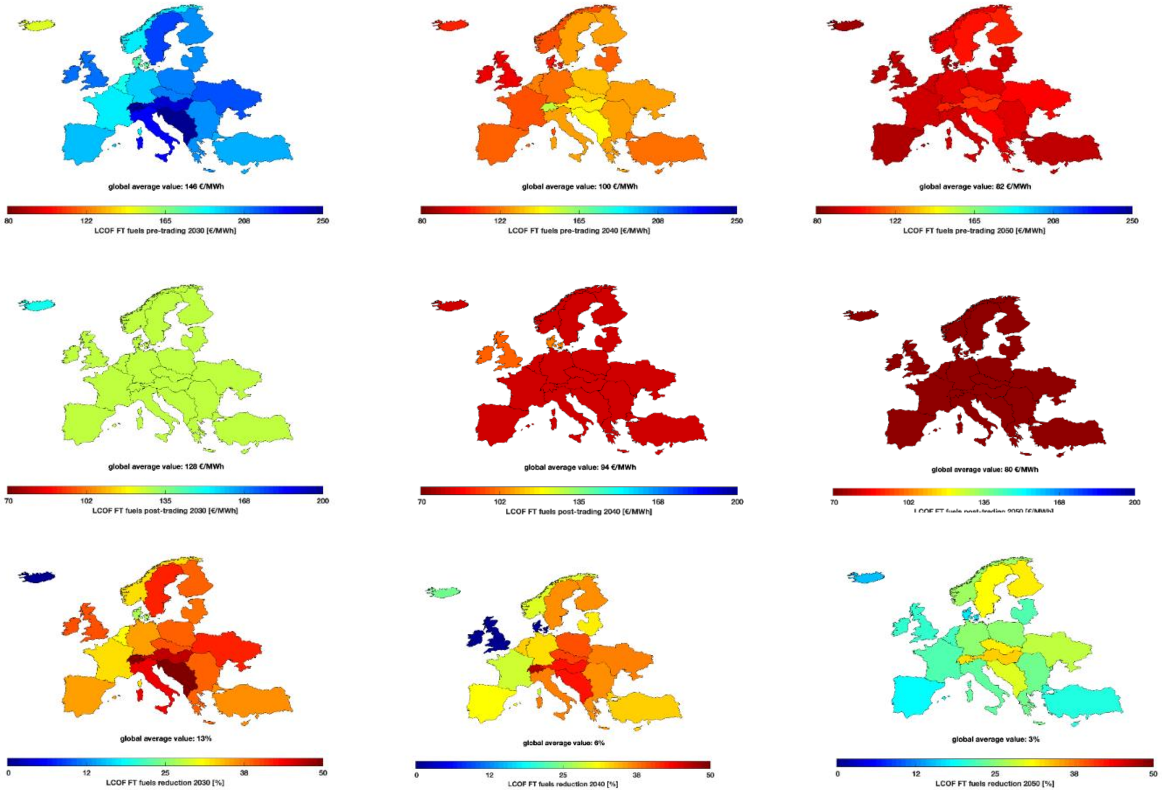
- main import regions are Europe and Eurasia
- cost reduction of world market rather small, as global average costs are reduced by about 1%-4% (2050)
- importing countries benefit from 15-30% cost reduction of chemicals
- global Sun Belt can switch to domestic self-supply
- chemicals seem to show a quite similar trade characteristic
- global market volume of trading 49 / 171 b€ for NH3 / MeOH chemicals
- traded volume of 29% / 28%
- Shipping cost of 5.0 / 3.7 €/MWh
- MENA cost level seems to be at least partly latitude induced



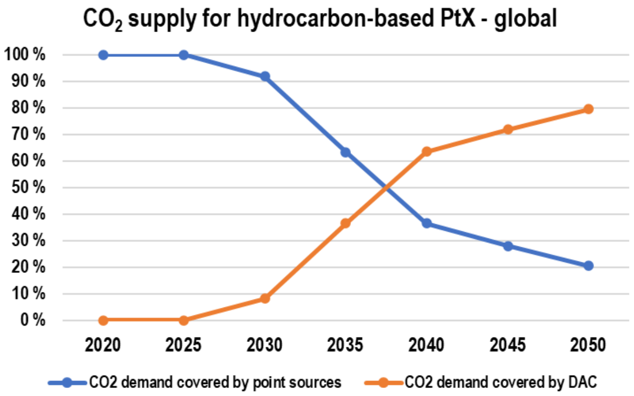


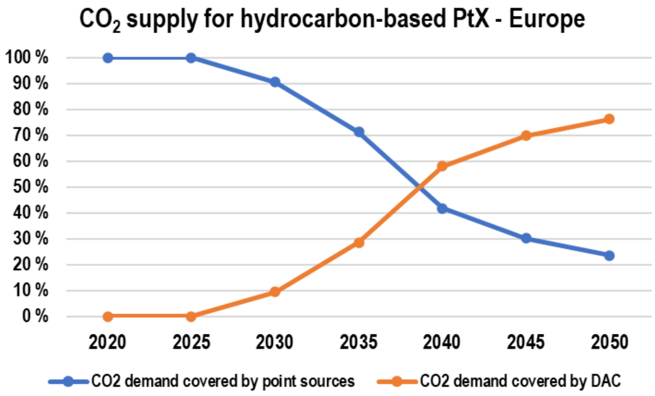


Focus Europe: example FT fuels



CO_2 Supply: Point Sources and DAC





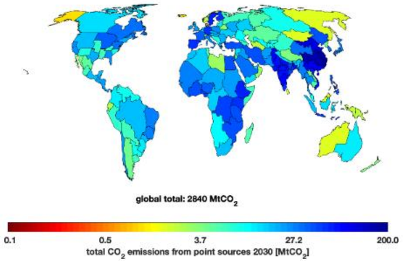
Fundamental assumptions:

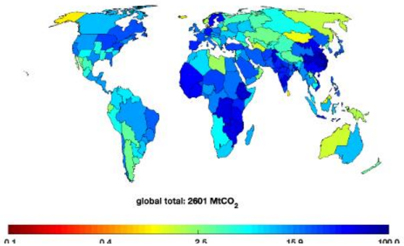
- CO_2 ONLY from sustainable/ unavoidable point sources of high full load hours, which are waste incinerators, pulp & paper mills and limestone fraction of cement mills
- CO_2 capture efficiency of 87% and CO_2 captured utilisation of 70% (match of CO_2 and synthesis sites)
- CO_2 as raw material needed for SNG, FT fuels, Methanol

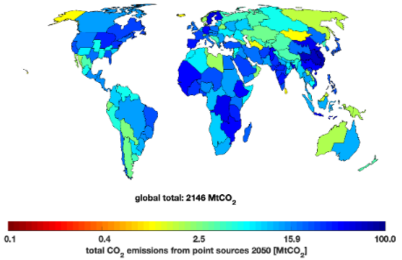
Key insights:

- DAC shall start to growth in 2020s and has to lift off by 2030
- DAC is an essential technology for any sustainable energy scenario
- 80% of all CO_2 raw material to be provided by DAC
- DAC technology phases in first for DACCU, then from 2040 onwards also for DACCS-EW

CO_2 from point sources and demand

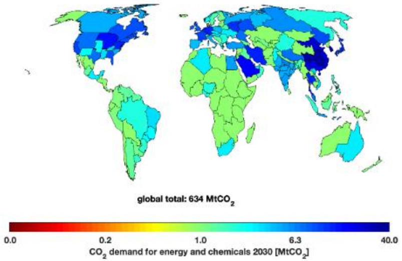


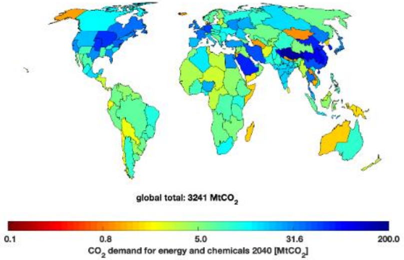


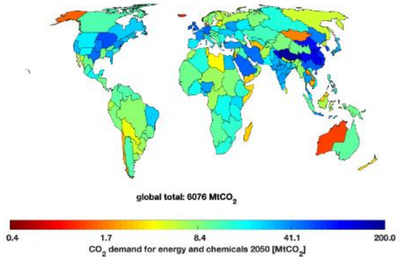


Key insights:

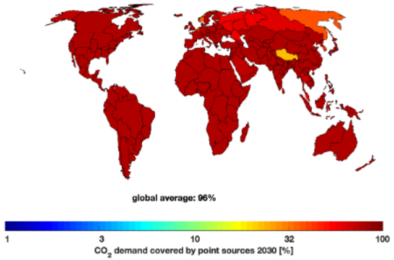
- used point sources are waste incinerators, pulp & paper mills, and limestone part of cement mills
- cement mills contribute the lion share
- CO_2 point sources availability declines due to demand decline in cement
- CO_2 raw material demand for SNG, FT fuels and Methanol for sectors power, heat, transport, industry, chemicals
- global sustainable CO_2 raw material demand exceeds in 2040 the supply potential of point sources

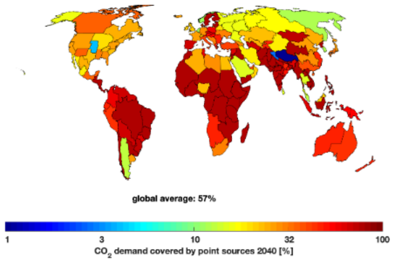


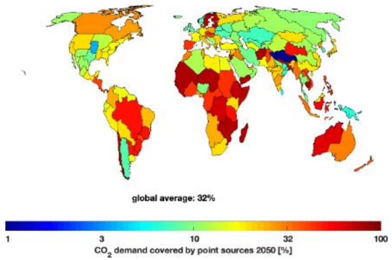




CO_2 supply from point sources and DAC

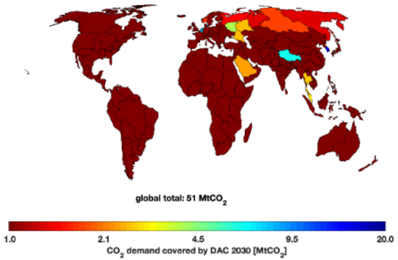


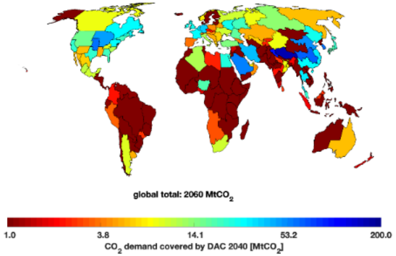


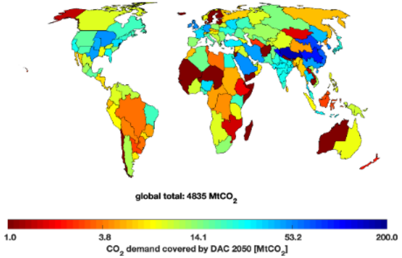


Key insights:

- CO_2 point sources are mainly sufficient in 2020s
- from 2030s onwards CO_2 point sources are not anymore sufficient
- in 2050 only exceptional regions have enough CO_2 point sources, in particular with strong pulp & paper industry, or late industrialisation (thus late cement demand) and low CO_2 for synthesis demand
- most industrialised regions in the world have a strong CO_2 DAC demand from 2030s onwards
- CO_2 DAC is the main sustainable CO_2 supply source from late 2030s onwards







Summary

- powerfuels and RE-based chemicals are an integral part of a zero GHG emission path
- overall Fuels and Chemicals market is shrinking from the present until 2040, mainly due to road transport electrification, and remains stable onwards
- market shares in 2050: SNG (25%), FT fuels (30%), Ammonia (10%), Methanol (35%)
- global trade for cost optimization much less than at present, since low-cost electricity is provided by solar PV, and most people in the world live in the Sun Belt, leading to self-supply
- key importing regions: northern hemisphere, in particular Europe, Eurasia, Canada
- key exporting regions: Latin America, sub-Saharan Africa, a bit MENA
- Europe can reduce cost for powerfuels and chemicals by about 15-30% compared to a domestic self-supply strategy, which would be also a policy option
- CO_2 point sources can contribute 20-30% of CO_2 raw material demand, qualifying DAC as an essential technology for achieving net zero GHG emissions