LONG-TERM HYDROCARBON TRADE OPTIONS FOR THE MAGHREB REGION AND EUROPE – RENEWABLE ENERGY BASED SYNTHETIC FUELS FOR A NET ZERO EMISSIONS WORLD

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Agenda

- Motivation
- Methodology
- Results
- Summary
Motivation

- Fossil fuels
  - increasing demand
  - diminishing resources
  - emissions

- Global warming, COP21 and national targets
  - to keep global temperatures "well below" 2°C above pre-industrial times
  - "endeavor to limit" them even more, to 1.5°C
  - emissions under a sustainable level

- Renewable Energy (RE) available, but energy system transformation is challenging
  - fluctuating RE and energy storage
  - 100% direct electrification impossible for mobility sector
Motivation

- Hydrocarbon fuels can be generated synthetically
  - Power-to-Gas an emerging technology
  - Power-to-Liquids technology ready for market

- RE-SNG or RE-diesel
  - non-diminishing resources
  - costs stable or declining
  - no costs for harmful emissions (CO$_2$, etc.)
  - drop in fuels for available infrastructure
  - energy storage
  - a step towards fuel security

- Excellent solar and wind energy in the Maghreb region can be used to power PtX systems for EU demand

- Generation potential in 2030 and 2040?

- Cost competitive?
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Methodology
RE-PtG-LNG Value Chain

Key insights:
- Substitution of the fossil hydrocarbon value chain by a RE basis
- Utilization of downstream fossil infrastructure
- Integrated heating system
- Water recycling

Dashed lines represent fluctuating flows
Continuous lines represent steady flows

Hybrid PV-Wind & Battery
Power-to-Gas
SNG Liquefaction
LNG Shipping
LNG Regasification

Long-Term Hydrocarbon Trade Options for the Maghreb Region and Europe – RE-based Synfuels
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Methodology

RE-PtL Value Chain

Key insights:
- substitution of the fossil hydrocarbon upstream value chain by a RE basis
- utilization of downstream fossil infrastructure
- integrated heating system
- water recycling

Dashed lines represent fluctuating flows
Continuous lines represent steady flows

1 barrel of PtL products (vol%)

H₂

Synthetic Fuels

Naphtha; 15%
Jet fuel/kerosene; 25%
Diesel; 60%
Methodology

- Electricity is transmitted to the coast, where PtX plants are located.

- Hourly basis Model
  - Optimised configuration of PV fixed tilted and single-axis tracking, wind, electrolyser, methanation, electricity transmission line and battery, based on an hourly potential in a 0.45° × 0.45° spatial resolution for the least cost fuel production.

- For Southern Europe, SNG is delivered through the pipelines connecting the Maghreb region to Europe.

- For SNG delivery to Northern Europe, a LNG value chain is applied.

- Liquefaction and Hydrogen-to-Liquids plants always run on base load, due to availability of feedstock storage, cost and process reasons.
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Results
RE-PtG-LNG Value Chain Energy Flow & Mass Balance

Power-to-Gas (2030)

- RE [kWh]
- H2 [kWh]
- Water [kg]
- CO2 [kg]
- HT Heat [kWh]
- O2 [kg]
- LNG [kWh]
- SNG [kWh]
- LT Heat [kWh]
- Seawater [kg]
- Water Loss [kg]
- Heat [kWh]
- Heat Loss [kWh]
- Carbon loss [kg]
- Extra Heat [kWh]

- PtG eff.: 64%
- LNG value chain eff.: 90%
- Overall efficiency: 57%

Oxygen available for potential market

- 87% of energy demand supplied by excess heat
- 78% of water demand supplied by methanation process output

LT Heat: 78 kWh
HT Heat: 118 kWh

Heat Exchanger

CO2 Capture Plant

87% of energy demand supplied by excess heat

Electrolysis

H2: 818 kWh

Heat Loss: 78 kWh
O2: 165 kg
Water Loss: 4 kg

Methanation

SNG: 637 kWh

Heat Loss: 63 kWh
Liquefaction
LNG: 586 kWh
Shipping
LNG: 583 kWh
Regasification
SNG: 574 kWh

*LT: low temperature  *HT: high temperature  *WS: water storage
Results
RE-PtL Value Chain Energy Flow & Mass Balance

Power-to-Liquids (2030)

- RE [kWh]
- Water [kg]
- O2 [kg]
- LT Heat [kWh]
- Sea Water [kg]
- Water Loss [kg]
- Heat [kWh]
- Heat Loss [kWh]
- HT Heat [kWh]
- CO2 [kg]
- H2 [kWh]
- Syngas [kg]
- Syncrude [kg]
- Diesel [kWh]
- Naphtha [kWh]
- Jet fuel [kWh]
- Extra Heat [kWh]
- Carbon loss [kg]
- LFG [kg]

Heat Exchanger

Heat Loss: 25 kWh
Extra Heat: 10 kWh

CO2 Capture Plant

CO2: 146 kg

87% of energy demand supplied by excess heat

Overall efficiency: 51.6%

- PtH2 eff.: 64%
- H2tL eff.: 65%

Oxygen available for potential market

- RE: 33 kWh
- RE: 19 kWh
- RE: 194 kWh
- H2: 796 kWh

60% of water demand supplied by RWGS and FT process output

Heat Loss: 76 kWh
O2: 157 kg
Water Loss: 4 kg

Water: 58 kg

H2

Syncrude: 41 kg
LFG: 2 kg

Jet fuel: 131 kWh
Diesel: 312 kWh

Long-Term Hydrocarbon Trade Options for the Maghreb Region and Europe – RE-based Synfuels
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Results
Hourly Basis Analysis: Full load hours

- solar potential is well distributed, while best sites for wind are limited
- PV single-axis tracking provides 400-500 higher FLh than PV fixed-tilted
- wind FLh are much higher than PV FLh due to 24h harvesting
- Western Sahara and Central Algeria have the highest optimal FLh in the Maghreb region
Results
Levelised Cost of Electricity (LCOE)

- sites of high FLh of PV or Wind plants have the lowest LCOE
- LCOE of PV single-axis tracking is about 4 €/MWh cheaper than LCOE of PV fixed tilted, and even more relevant more FLh (20-30%) on a least cost basis
- top sites in Maghreb reach PV LCOE of close to 20 €/MWh and 16 €/MWh in 2030 and 2040, respectively.
- sharper cost reduction for PV than for wind electricity from 2030 to 2040
Results
LCOE for Cost-optimised PtX Systems

- optimal combination of PV and Wind for hybrid PV-Wind plants to achieve an optimal combination of LCOE and FLh for downstream PtX plants
- PV is the dominating technology in most regions, with an increasing share from 2030 to 2040
- top sites in the Maghreb region may reach hybrid PV-Wind LCOE of 20 - 23 €/MWh in 2030 and 16 – 18 €/MWh in 2040
- top sites in the Maghreb region can deliver electricity to coast at a cost of about 30 €/MWh in 2030 and 24 €/MWh in 2040
- the extra cost is due to power transmission line and batteries cost, efficiency loss and excess electricity curtailments
- electricity generation and transmission for PtG system follows similar pattern, with small differences
- Long distance power lines may be too expensive for harvesting electricity far away from the cost
Results

Sources of Additional LCOE for PtL in 2030 and 2040

- delivered electricity cost as a function of LCOE, excess electricity (including overlap), distance to the shore, and electricity storage options installation (battery and gas turbine)

- excess electricity due to overlap and curtailments (to optimize the capacity of transmission lines and PtX plants)

- distance to coast and consequently electricity transmission cost are determinative factors which can block an exporting case

- In general, from 2030 to 2040, excess electricity increases, as curtailment becomes the cheaper option to balance the system, due to higher cost reduction in electricity production than the cost reduction downstream plants. But for long distances to the coast, such as Southern Algeria, more battery installations, balance the system for a lower electricity transmission cost.
Results
Levelised Cost of Fuel (LCOF)

- LCOF as a function of LCOE and FLh of plants’ components
- regions not so far from the coast are generally a better place due to lower electricity transmission cost
- more regions with attractive production cost in 2040
- Western Sahara, Morocco and Libya produce the cheapest fuels
- in 2030, top sites in the Maghreb region reach LCOF of 90 – 100 €/MWh (0.87 - 0.97 €/l) for diesel and 75 – 85 €/MWh (29.3 - 32.3 USD/MMBtu) for SNG
- in 2040, top sites in the world reach LCOF of 83 – 90 €/MWh (0.80 - 0.87 €/l) for diesel and 66 – 80 €/MWh (25.8 - 31.3 USD/MMBtu) for SNG
- LNG value chain adds about 12-15 €/MWh to delivered SNG cost
Results

Optimised PtG and PtL Production Potential

- maximum 10% of the land allowed to be used for PV and Wind each
- potential of about 27,400 TWh\textsubscript{SNG} or 28,000 TWh\textsubscript{SLF} in 2030 in the Maghreb Region
- 40% and 19% increase in SNG and SLF production potential from 2030 to 2040, respectively
- while Western Sahara, Morocco and Libya can produce the cheapest fuels, Algeria would be the major producer
Optimised PtX Production Potential

- Potential of about 24,000 and 33,000 TWh$_{\text{SLF}}$ for costs less than 140 €/MWh$_{\text{SLF}}$ (0.97 €/l$_{\text{diesel}}$) in 2030 and 2040, respectively
  - From that about 60% diesel and 25% jet fuel

- Based on Greenpeace Energy [r]evolution scenario, European gas demand may decrease from 4,700 TWh (HHV) in 2030 to 3,200 TWh in 2040. This expected SNG demand could be met at costs less than 103 €/MWh$_{\text{SNG}}$ (40.3 USD/MMBtu) in 2030, and 83 €/MWh$_{\text{SNG}}$ (32.5 USD/MMBtu) in 2040, respectively.
Results
Optimised PtX Production Potential by country

- the production potential of each country as a function of production cost, in 2030 and 2040
- Western Sahara and Mauritania can produce the least cost fuel, but for a very limited capacity
Results
Fuel parity in 2030 and 2040

RE-diesel reach the fuel parity sooner than RE-SNG, even with higher production cost.

The first breakeven can be expected for a produced RE-diesel with a WACC of 5% and an O₂ benefit of 20 €/t O₂ and a conventional diesel price with CO₂ emission cost of 50 €/t CO₂ and a crude oil price of 101 USD/bbl in 2030 and 86 USD/bbl in 2040.

For RE-diesel, a realistic breakeven is expected for the crude oil prices between 120-150 USD/bbl in 2030 and 100-140 USD/bbl in 2040.

LNG price in Germany: 102% of Brent crude oil price. (Regasification cost has been added)

Diesel cost in EU: 119% of Brent crude oil price

CO₂ emission cost:
- 0-61 €/t CO₂ in 2030 and 0-75 €/t CO₂ in 2040
- NG CO₂ emission: 56 t CO₂/TJ
- Diesel CO₂ emission: 74 t CO₂/TJ

O₂ profit:
- O₂ market price: up to 80 €/t O₂
- Our most optimistic scenario: 20 €/t O₂
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Summary

- The idea is to use hybrid PV-Wind electricity to produce RE-SNG and RE-diesel in the Maghreb region for export to Europe.
- The role of solar PV and battery increases substantially from 2030 to 2040 due to further declining costs.
- LNG value chain and refinery products downstream value chain can be used.
- RE-SNG and RE-diesel are non-diminishing fossil carbon neutral fuels, which will insure both fuel security and environmental issues.
- In the best scenario, for a Brent crude oil price more than 101 USD/bbl in 2030 and 86 USD/bbl in 2040 and CO₂ emission cost of 61 and 75 €/t CO₂, and O₂ benefit of 20 €/t O₂ RE-diesel is competitive to fossil diesel prices in EU.
- The by-products of the RE-PtX value chain can play a significant role in case of application.
- This would be a business opportunity for the Maghreb region whenever crude oil price is higher than mentioned level, or in case of strict environmental regulations on fossil fuels.
- Europe has already experienced crude oil prices of higher than 100 USD/bbl in the past. This is not a big price to avoid one of the major sources of global warming.

Thank you for your attention!
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## Supplementary Material

### Power sector and feedstock (CO₂ and water) key specification

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<tr>
<th>Device</th>
<th>Unit</th>
<th>2030 / 2040</th>
<th>Device</th>
<th>Unit</th>
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Supplementary Material

Synthetic fuels sector key specification

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<th>Unit</th>
<th>2030/2040</th>
<th>LNG value chain specifications</th>
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