Sectoral integration – long term perspective in the EU energy system

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Consortium E3-Modelling, Ecofys and Tractebel- ENGIE
The pathway towards 2050

- In 2050, 1100 Mt GHG (-80% compared to 1990 levels) are consistent with a 2°C trajectory.

- By 2050, the remaining GHG (in a EU CO scenario) are 58% due to energy, of which:
  - 31% in transport
  - 20% in stationary use
  - Power and heat and energy branch account for 9%

- The challenge is to bring emissions close to zero:
  - Is it possible?
  - How? When? At which cost?
  - Focus on transport: electrification? hydrogen? synthetic fuels?
Structure of the study

Hydrogen roadmap to 2050: Technological and market developments
- Linking the power and mobility sector & Usage of H₂ in transportation
- Linking the power sector and H₂-demanding industry
- Linking the power sector with transport and heating sectors
- Energy storage, integration of RES and sectorial integration
- Analysis by country

Modelling the impact of sectoral integration
- We analyse the following three scenarios:
  - H₂ as a carrier
  - H₂ as feedstock
  - H₂ for power storage
  - and a Balanced realistic scenario
- The new assumptions add to a basic decarbonisation scenario (EUCO)

PRIMES modeling
- Full projections for each EU MS up to 2050
- Impacts on the EU energy system including costs and infrastructure investment
- Modeling market equilibrium with complete integration of demand and supply
- Explicit policy and technological drivers
A process flow diagram

Electric power generated using renewables, nuclear and CCUS, incl. CHP

Capture from Air

Energy CCU

Industry CCU

Water Electrolysts

Water+CO2 Electro-reduction

H2

CO2

Catalytic Methanation

Hydro-genation

Water+CO2 Reverse water gas shift

Fischer Tropsch

CHP

Heat pumps

Electric Boilers

Electric Uses

Electric Processes

Electric Transport Means

End-uses of energy – stationary and mobile

E³M - Lab
November, 2017

3/6/2018
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## Pros and Cons of each stylized scenario

<table>
<thead>
<tr>
<th></th>
<th>Main uncertainties</th>
<th>Main advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H₂ as a carrier</strong></td>
<td>• Distribution and transport network specifically for H₂</td>
<td>• H₂ is an energy carrier valid for the entire system</td>
</tr>
<tr>
<td></td>
<td>• Cost of fuel cells</td>
<td>• High energy efficiency maintained</td>
</tr>
<tr>
<td></td>
<td>• H₂ storage</td>
<td>• No excessive increase in power generation</td>
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<td></td>
<td></td>
<td>• Can accommodate H₂ to fuel processing if technology reached maturity in the future</td>
</tr>
<tr>
<td><strong>H₂ as feedstock</strong></td>
<td>• CO₂ capture from air</td>
<td>• Continued use of existing distribution infra for gas and liquid fuels</td>
</tr>
<tr>
<td></td>
<td>• Poor energy efficiency</td>
<td>• Convenient energy applications, equipment and processes</td>
</tr>
<tr>
<td></td>
<td>• Too high increase in demand for electricity</td>
<td>• No major disturbance of transport system</td>
</tr>
<tr>
<td></td>
<td>• Costs</td>
<td></td>
</tr>
<tr>
<td><strong>H₂ for power storage</strong></td>
<td>• Electric aircrafts, ships and long distance trucks</td>
<td>• High efficiency of electricity in end-uses</td>
</tr>
<tr>
<td></td>
<td>• Electrification of all industrial processes</td>
<td>• Feasible from power system perspective</td>
</tr>
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<td></td>
<td>• Electrification of all residential energy uses</td>
<td>• Power-to-H₂ used mainly for storage purposes can develop without major uncertainties and can achieve low costs</td>
</tr>
</tbody>
</table>
A combined – realistic scenario achieving zero emissions

**Hydrogen uses**

- Mix up to 15% in gas distribution
- Use fuel cells using H2 in vehicles that cannot run in batteries, such as trucks, buses, taxis, duty vehicles. Combine with large-scale H2 refueling stations, which may include electrolysis and H2 storage.
- Use H2 directly in high temperature furnaces in industry combined with local electrolysis and storage
- Produce clean methane in methanation plants using CO2 captured from air, integrated in power utility facilities well interconnected. H2 produced in these locations also serve electricity storage.

**Rest of Options**

- Fully decarbonize power generation using maximum contribution by RES, dispersed and centralized, complemented by nuclear and CCS where possible. Direct storage and chemical storage, as well as interconnections, succeed to balance the RES.
- Exploit to maximum possible potential energy efficiency in buildings and industry
- Electrify car mobility and heating
- Develop advanced sustainable biomass feedstock to produce fungible jet fuels and ship fuel, as well as bio-methane mixed in the gas grid
Uses of hydrogen in the balanced scenario

- Mainly used (3/4 of total) directly in final consumption
  - 15% mixed in gas distribution
  - Directly in high temperature furnaces in industry
  - In transport via fuel cells
- Used directly in power generation as electricity storage (chemical storage)
- As a feedstock (1/4 of total) to produce clean methane (CH4), which is mixed in gas distribution and is used in the power sector as electricity storage
Natural gas (fossil) covers only 54% of a total of 404Mtoe consumption of gaseous fuels in 2050.

Natural gas is roughly the only remaining fossil in the system, being used in the power balancing and mostly in CCGT-CCS plants.

Methanation and bio-energy plants produce 184Mtoe (45% of total gaseous).

Tremendous independence from natural gas imports by 2050.
Emissions and costs in the Balanced Scenario

**PRIMES projections**

- 96% CO₂ emissions reduction in 2050 (relative to 1990)
  - 12 percentage points more than in the basic decarbonisation scenario (-84% CO₂ in 2050)
- The balanced scenario abates CO₂ at an average cost of €88/t CO₂ (cumulatively in the period 2030-2050)
  - Which is less than half of the cost in the basic decarbonisation scenario (€182/tCO₂ abated)
- The performance owes to the multiple roles of hydrogen in sectoral integration, and its particular role in the transport sector

### Remaining CO₂ Emissions in 2050

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy Supply</th>
<th>Transport Sector</th>
<th>Domestic Sector</th>
<th>Industry and Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Decarbonisation</td>
<td>375</td>
<td>99</td>
<td>143</td>
<td>85</td>
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<tr>
<td>Balanced Scenario</td>
<td>85</td>
<td>92</td>
<td>99</td>
<td>375</td>
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### Average unit cost of emissions reduction

<table>
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<th>Basic Decarbonisation</th>
<th>Balanced Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR per tCO₂ abated cumulatively</td>
<td>182</td>
<td>88</td>
</tr>
<tr>
<td>Energy Supply</td>
<td>2031-2050</td>
<td>2021-2030</td>
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<tr>
<td>Transport Sector</td>
<td>132</td>
<td>133</td>
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<tr>
<td>Domestic Sector</td>
<td>59</td>
<td>42</td>
</tr>
<tr>
<td>Industry and Processes</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

132 133 182 88

Basic Decarbonisation Scenario
Balanced Scenario

143 59 42 85

182 132 133 59
Fuel mix in Transport in 2050
PRIMES projections

In the balanced scenario

- Almost no fossil fuels

- Complementary market segments for battery and fuel-cell vehicles
  - Battery-charged cars in cites and short-medium distance trips
  - Fuel cells heavy duty vehicles and cars with high mileage

- Lower total amounts of biofuels than in the basic decarbonisation scenario
  - The fuel cells move biofuels from trucks to aircrafts and ships

- Optimistic learning assumptions, both for batteries and fuel cells, allow for full substitution of fossil fuels in the car market at lower total cost, compared to the basic decarbonisation scenario
Hydrogen further enhances the role of electricity

- Electricity producing hydrogen and clean gas becomes a large sector
- Economic optimality in this sector requires a large scale and a non-interrupted supply of electricity
- Therefore, RES from different origins, with complementary production profiles and nuclear are the optimum input portfolio
- Consequently, large scale interconnections and the full completion of the internal market matter for cost-efficiency
- The power sector thus combines dispersed generation (prosumers) and centralized generation over a mesh grid
- In 2050, RES-power increase by 36%, nuclear by 20% and gas-CCS by 37% in the balanced scenario compared to the basic decarbonisation scenario
Total costs are lower in the balanced scenario, despite higher emissions reduction than in the basic decarbonisation scenario.

A sensitivity analysis scenario involving less optimistic cost assumptions for the hydrogen technologies remains cheaper and achieves 91% emissions reduction in 2050.

The electricity prices remain stable despite the significant increase in total power generation.

The cost reductions owe to the assumptions about availability of the new hydrogen technologies and the string learning effects.

However, the balanced scenario is significantly more demanding in investment funds in the supply system in the period 2030-2050 (48% increase).
Tremendous benefits for import independence

In the balanced scenario by 2050:

- Oil imports are used almost exclusively in petrochemicals, as they are fully substituted in transport.
- Natural gas imports are only slightly lower than in the basic decarbonisation scenario, but they are used in large majority in the power sector.
- Biomass imports do not increase relative to the basic decarbonisation scenario and remain reasonable, as biofuels are used in 2050 only in aircrafts and ships (being advanced and fully fungible).
Concluding remarks

- Sectoral integration enabled by electricity and in the long-term by hydrogen are powerful strategies to decarbonize the energy system in a cost-effective manner.

- The hydrogen technology chain, as an add-on of the EUCO decarbonisation approach, can bring CO₂ emissions down close to a 95% reduction at an affordable cost.

- The H₂ value chain includes clean H₂ from electricity, Power-to-Gas producing clean gas, and direct uses of H₂ in gas grids, high temperature furnaces and in fuel cells for heavy duty and high mileage travelling vehicles.

- All extreme stylized scenarios present serious uncertainties, as for example a full hydrogen, a full electric or a full synthetic-hydrocarbon economy.

- The modelling, based on an enhanced version of PRIMES, illustrated that a balanced scenario towards deep emissions reduction by mid-century is feasible technically and economically.

- However, to achieve the expected cost reductions in the technologies, large-scale investments are necessary and an effective market coordination of different actors, including infrastructure and technology developers.

- As a next step, not addressed in this study, we put emphasis on the assessment of suitable energy policy instruments which could enable emergence and widespread of the technologies.