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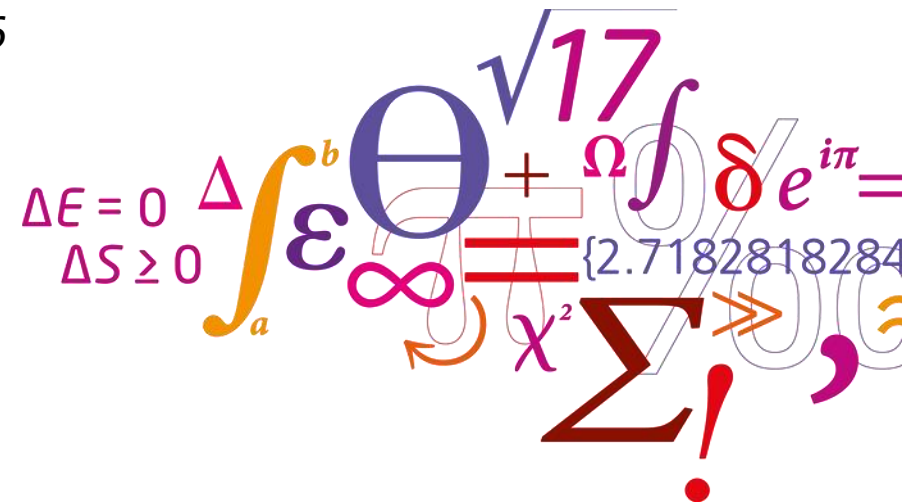
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Modelling transition towards sustainable transportation sector

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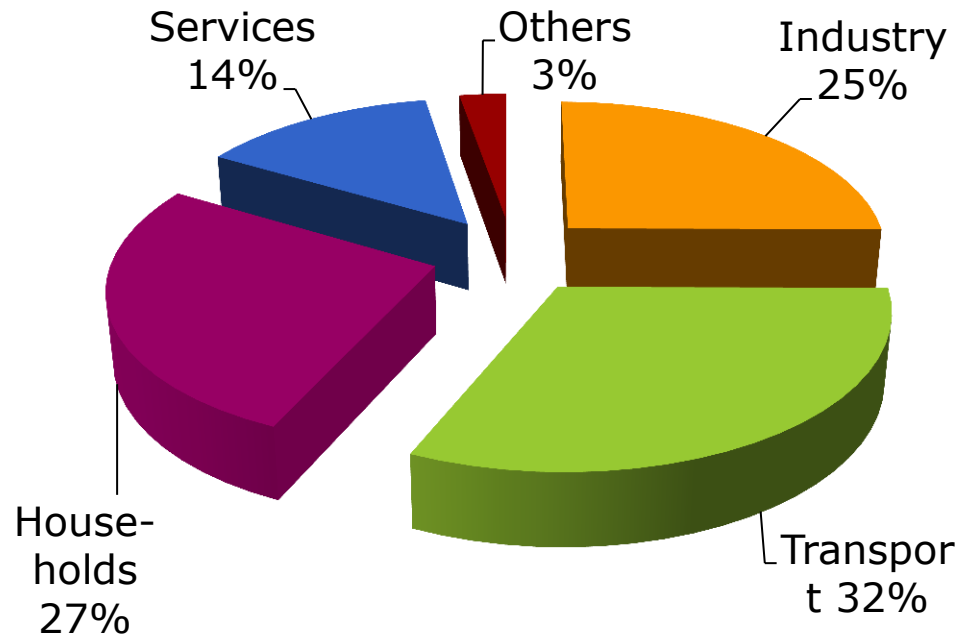


Outline

- Background: energy consumption in the EU per sectors
- Methods
 - Scenario development
- Results
 - Qualitative assessment of the alternatives
 - Infrastructure and economic barriers for the alternatives
- Discussion of results
- Conclusions

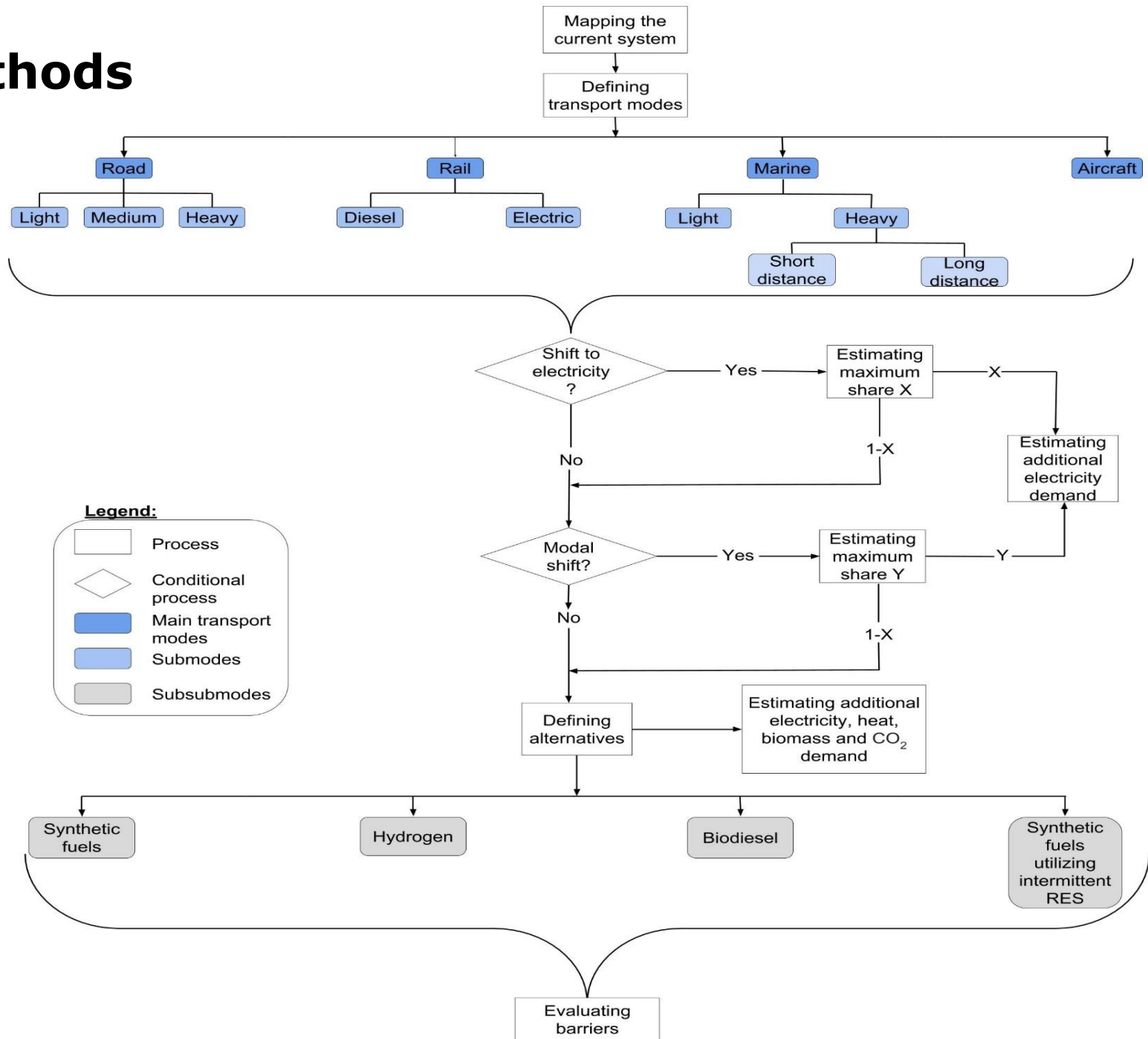
Final energy consumption per sectors

- The European Union
- 2013



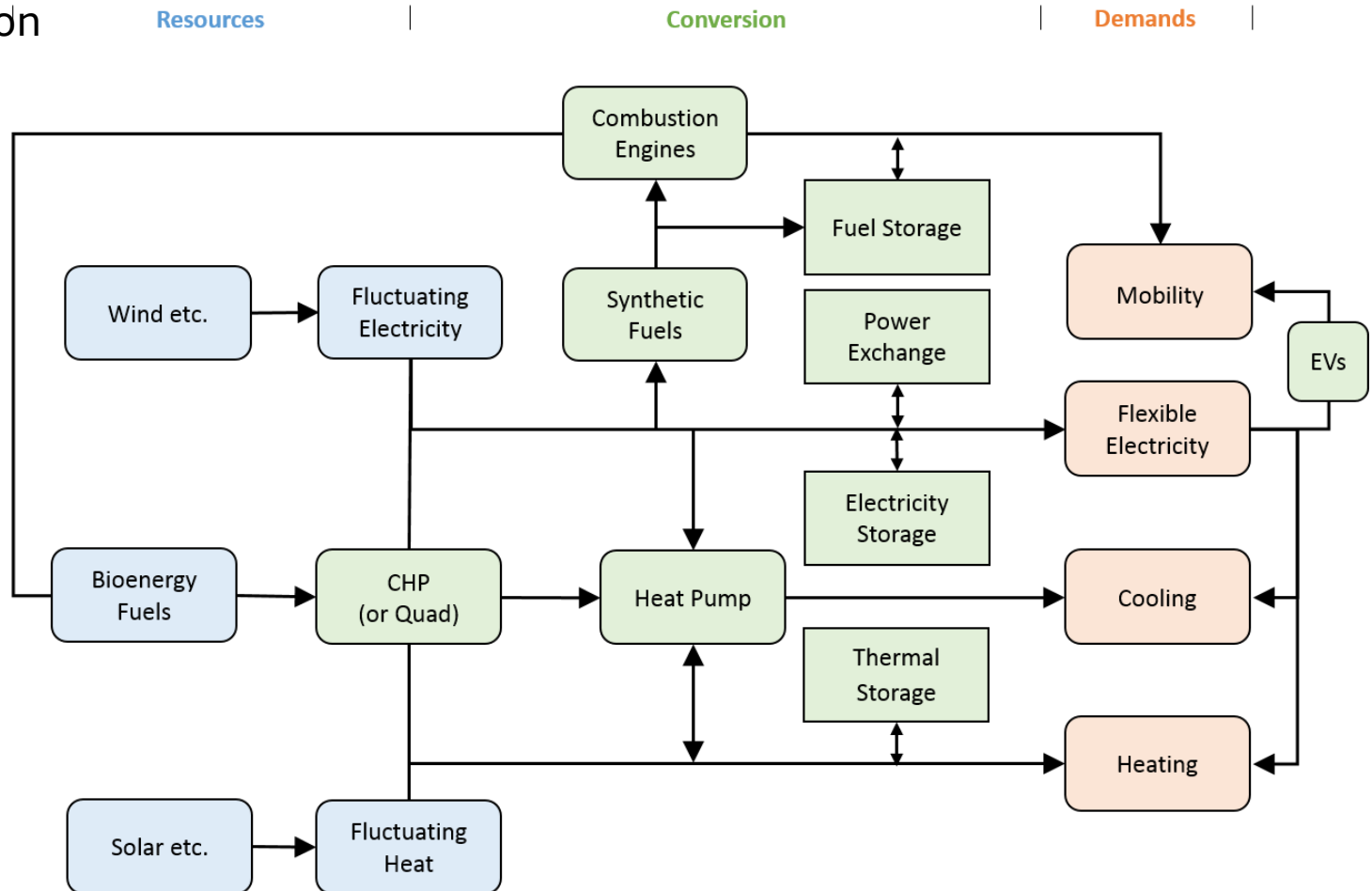
Source: European Environment Agency

Methods



Methods (II) - EnergyPLAN

- Used for modelling of more than ten 100% RES (EU, national and regional)
- Deterministic simulation model
- Input/output model
- Hourly resolution



Three scenarios

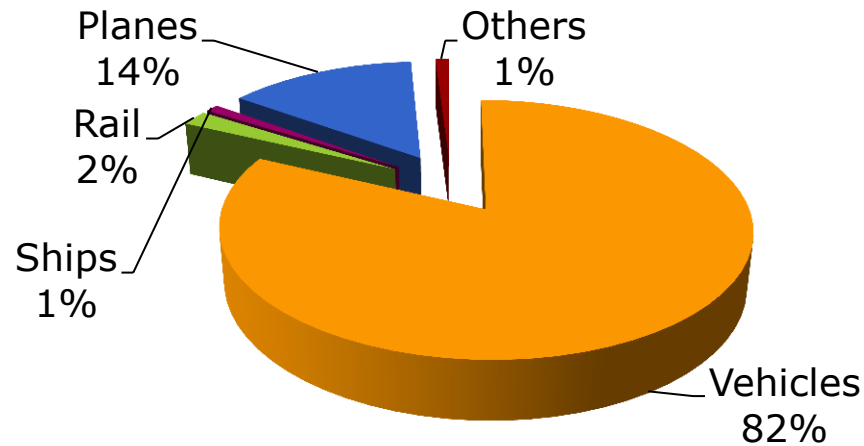
| | |
|--------------|---|
| Scenario I | Replacement by biofuels |
| Scenario II | Replacement by synthetic diesel, methanol and biokerosene |
| Scenario III | Replacement by synthetic fuels only |

| Process | Efficiency |
|--|---------------|
| 2nd gen. bioethanol fermentation | 41% |
| 2nd gen. biodiesel BTL | 39% |
| 2nd gen. biokerosene BTL | 39% |
| Syngas synthesis methanol | 67.3% |
| FT biodiesel&kerosene | 51% |
| SOEC co-electrolysis | 65% |
| SOEC assumed energy input distribution | |
| Heat | 25% |
| Electricity | 75% |
| CO ₂ demand for SOEC | [t/GJ output] |
| CO ₂ | 0.105 |

| Fuel | LHV [GJ/ton] |
|-------------|-----------------|
| Methanol | 19.9 |
| Kerosene | 44 |
| Bio-diesel | 37.8 |
| Bio-ethanol | 29.7 |
| Gasoline | 44.4 |
| Diesel | 43.4 |
| Biokerosene | 44 |

Results – mapping the current energy needs

- Energy end-use of different transportation modes in the EU:



| Transport mode | Transport sub-mode | Share |
|----------------|--------------------|-------|
| Road | Light | 59% |
| | Medium | 23% |
| | Heavy | 18% |
| Rail | Electric | 80% |
| | Diesel | 20% |
| Marine | No sub mode | |
| Aircraft | No sub mode | |

Results – possibilities of direct electrification of transport sector



Measures:

Shift of 87% of passenger cars fuel demand to electricity

Shift of 70% of medium-heavy vehicles fuel demand to electricity

Shift of 90% of heavy vehicles fuel demand to electricity (modal shift to electric rail transport)

Shift of all the remaining diesel railway transportation to electricity

Shift of 20% of light ships and 10% of heavy ships fuel demand to electricity

Modal shift 12.2% of aircraft sector demand to electric rail transport

Results of scenarios – resources needed

| | Scenario I | Scenario II | Scenario III |
|-------------------------------|------------|-------------|--------------|
| Biomass demand [TWh] | 3069.00 | 1279 | 0 |
| Electricity demand [TWh] | 0.00 | 1646 | 2775 |
| Heat demand [TWh] | 0.00 | 549 | 925 |
| CO ₂ demand [Mton] | 0.00 | 539 | 909 |

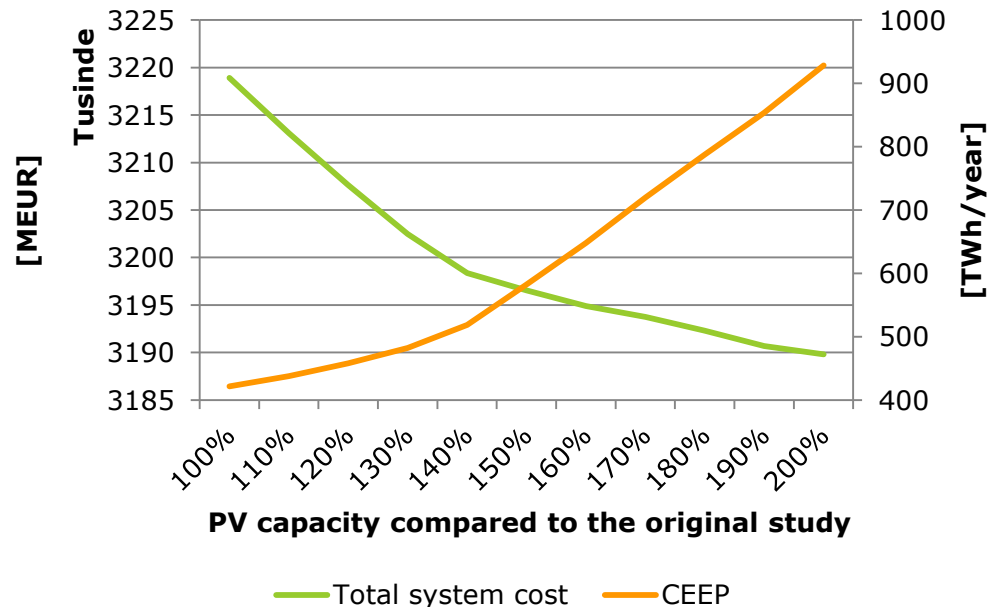
Alternatives

- Synthetic fuels
 - Methane, methanol, FT diesel
 - Still in the R&D phase
- Hydrogen
 - Large market today and growing rapidly
 - Base load production
- Biodiesel
 - 1st generation produced from sugars and vegetable oils
 - 2nd generation produced from various types of biomass
- PV for synthetic fuels
 - Still in R&D phase
 - Highly dependent on electricity price

Barriers detected

| | Economic barriers | | | | Infrastructure barriers | | | |
|------------------------|-------------------------------|-----------------------|---------------------------|------------------------|----------------------------------|-----------------------|--|------------------------|
| | High new infrastructure costs | High production costs | Low production efficiency | Influencing food price | Need new fuelling infrastructure | Need new supply chain | High land demand/ Sustainability problem | Intermittency friendly |
| Hydrogen | Yes | Yes | Yes/No** | No | Yes | Yes | No | Yes* |
| Biodiesel | No | No | No | Yes | No | No | Yes | No |
| Synthetic fuels | No | Yes | Yes | No | No | No | No | Yes* |
| PV for synthetic fuels | No | No | Yes | No | No | No | No | Yes |

PV for synthetic fuels



Discussion – How really big additional demand for resources is?

- Direct electrification of transport sector – threefold benefits (efficiency, flexibility, CO2 emissions reduction)
- 1,125 TWh of fossil fuel demand cannot be directly electrified today
 - Replacing it with biofuels – additional demand for biomass of 3,069 TWh
 - Replacing partly by biofuels and partly by synthetic fuels – additional demand for biomass of 1,279 TWh
 - Current mean EU biomass potential extracted from 70 studies: 1,600 TWh, in 2050: 2,360 TWh
- Synthetic fuels – additional demand for heat and electricity of 925 TWh and 2,775 TWh
 - Electricity demand in the entire EU in 2013: 3,100 TWh
- Demand for electricity for directly electrified part of transport sector: 880 TWh
- Low well to wheel efficiencies for all the alternatives (25% for hydrogen, around 12% for synthetic fuels)

Conclusions

- ✓ All the transport means should be converted to electrified transportation modes if there is a technical possibility for it. Benefits of this transition are threefold: reduced CO₂ emissions, increased energy efficiency and integration of different energy sectors.
- ✓ It is technically possible today to shift 72.3% of the fossil fuel demand in the transportation sector to the electricity. Following this transition, increased efficiency of the electrically driven transportation means could potentially reduce the final energy demand in transportation sector for 50.6% or 2051 TWh.
- ✓ For the remaining part of the fossil fuels several alternatives exist. Due to the lower estimated well to wheel efficiency of the alternatives, a significant additional demand for resources occurs.
- ✓ If the excess capacity for synthetic fuels production would exist in the system, excess electricity for which there is no demand could be utilized at the near-zero price. With the expected technology price drop until the year 2050, the price of producing DME, a potential substitute for diesel fuel, was estimated to be 38 €/GJ of fuel, which would be cost-competitive with the current end user fuel prices.
- ✓ Significant costs of building completely new infrastructure, as well as lower efficiency compared to the electric vehicles, could be too large burden for the wide scale development of the hydrogen driven transportation system.
- ✓ Potential of alternatives such as drones used for delivery, car sharing and similar concepts, increased usage of bicycles and public transportation, induction charging and others should all be seriously taken into consideration and planning of the future transportation sector if additional energy savings are to be achieved.

Thank you for your attention!