Case Study #1

Multi-modal European energy concept for achieving COP 21

EDF, April 11, 2018

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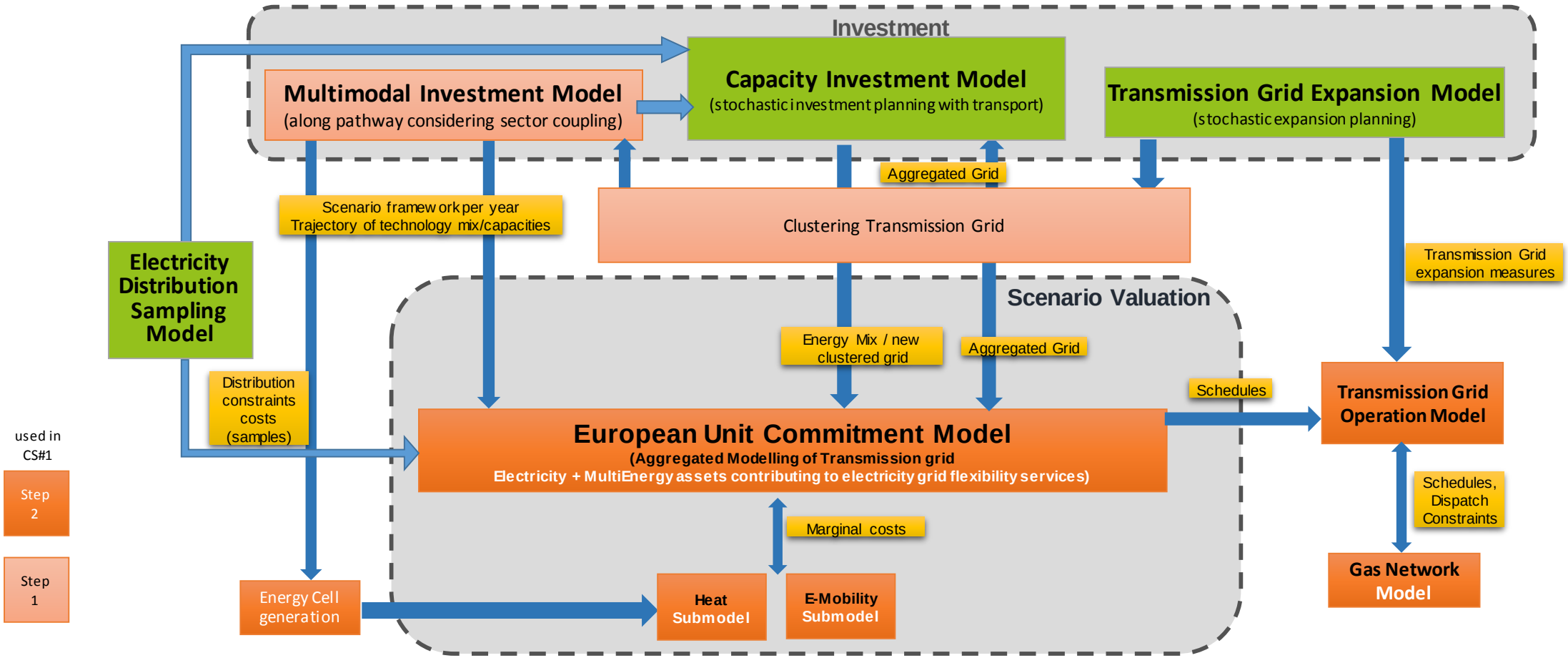
Objectives of Case Study #1

How to meet COP21 targets of Europe
.. and what pathway can/should we take best from now to 2050?

- **In 2040 and 2050, what will the optimal future energy mix look like?**
- **How can we reach that goal with a cost-effective investment pathway?**
- **What impact has sector coupling on the future generation fleet e.g. potential role of Power2Heat, eMobility and Power2Gas?**

plan4res interacting model

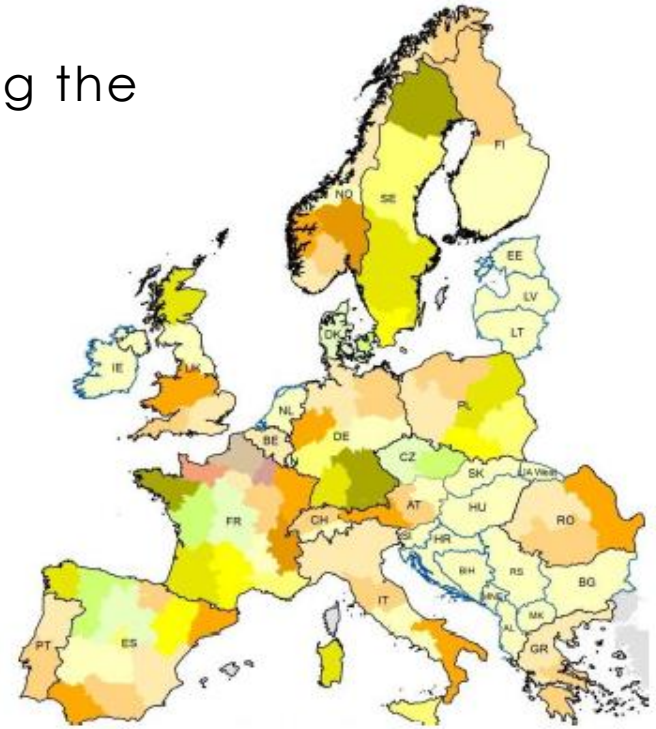


Which questions / problems will be addressed

- **Case study 1 will focus on the modeling of the**

  .. **cost-effective investment trajectory** of the
  .. **future multimodal energy mix** for Europe considering the
  .. **impact of sector coupling**

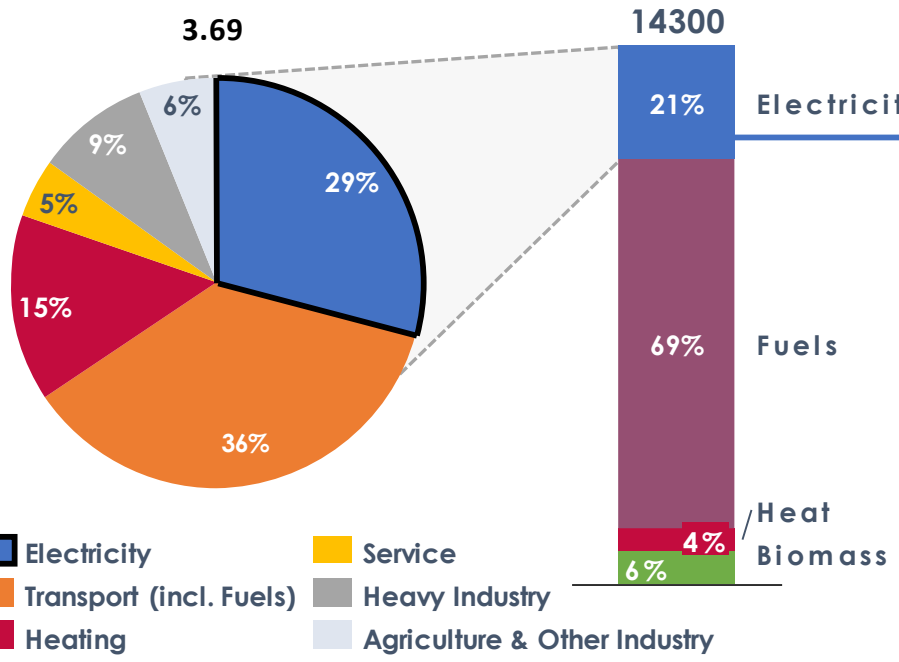
- **The objective of this case study is to assess the plan4res tool's ability to capture :**
  - **The investment trajectory for a cluster of countries**
  - **The impact of a pan-European energy exchange**
  - **The impact of sector coupling on the energy mix**
    - Electrification of transport, heat, cooling
    - Impact, e.g. from Power2Heat, Power2Gas
    - Flexibility by heat storage, eMobility, synthetic fuels



Need for sector coupling ?

- **Reducing CO_2 by using electricity from 100% RES alone is not sufficient to meet COP21**

Europe 2015
Net CO_2 by point of emission (Gt CO_2 p.a.)



Europe 2015
Final consumption - by energy carrier (TWh)

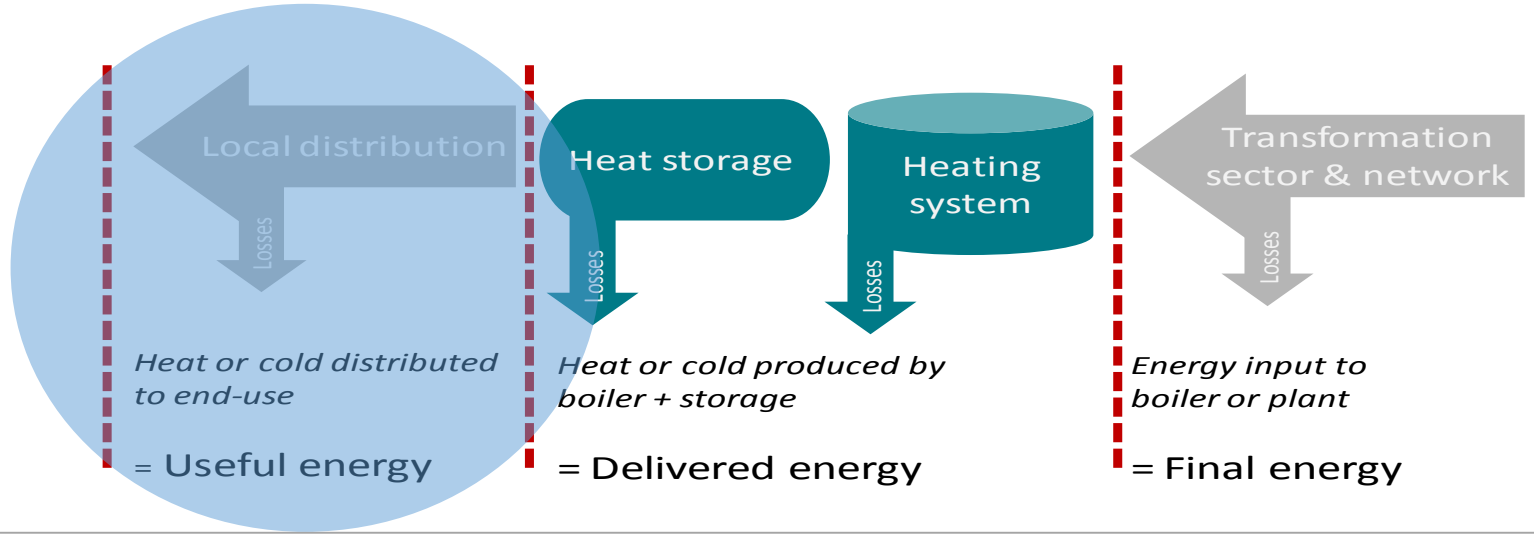
Identified main levers to reduce CO_2 emissions (→ Sector coupling necessary)

Low-carbon electricity (maximize share of RES)	Electrification of heat/cold and transport	Alternative for remaining fossil fuels
Electricity 2015: 42% fossil	Mechanical work (transportation)	Alternative fuels from RES sources (P2Gas, P2Fuels)
	Heat/cold decentral (buildings)	Alternative fuels BioFuel
	Heat/cold central (ind. processes)	

Demand of 'Useful Energy' to determine the future European energy mix

- **'Useful Energy' as starting point to enable competition between a multifold of technologies having different cost structures, efficiencies, availabilities**

Example
Heating of building



Consumption Carrier:	Heat for heating buildings in TWh_thermal	Technologies:	Gas/Coal/Oil Boiler Co-generation PP local CHP District heating Electric heating Heat pump (Air/ Ground) Solar heating	'Fuel' Carrier:	Electricity Natural gas Coal Liquid fuel Solar or ambient heat
					TWh_el MMBTU SKE toe TWh_thermal

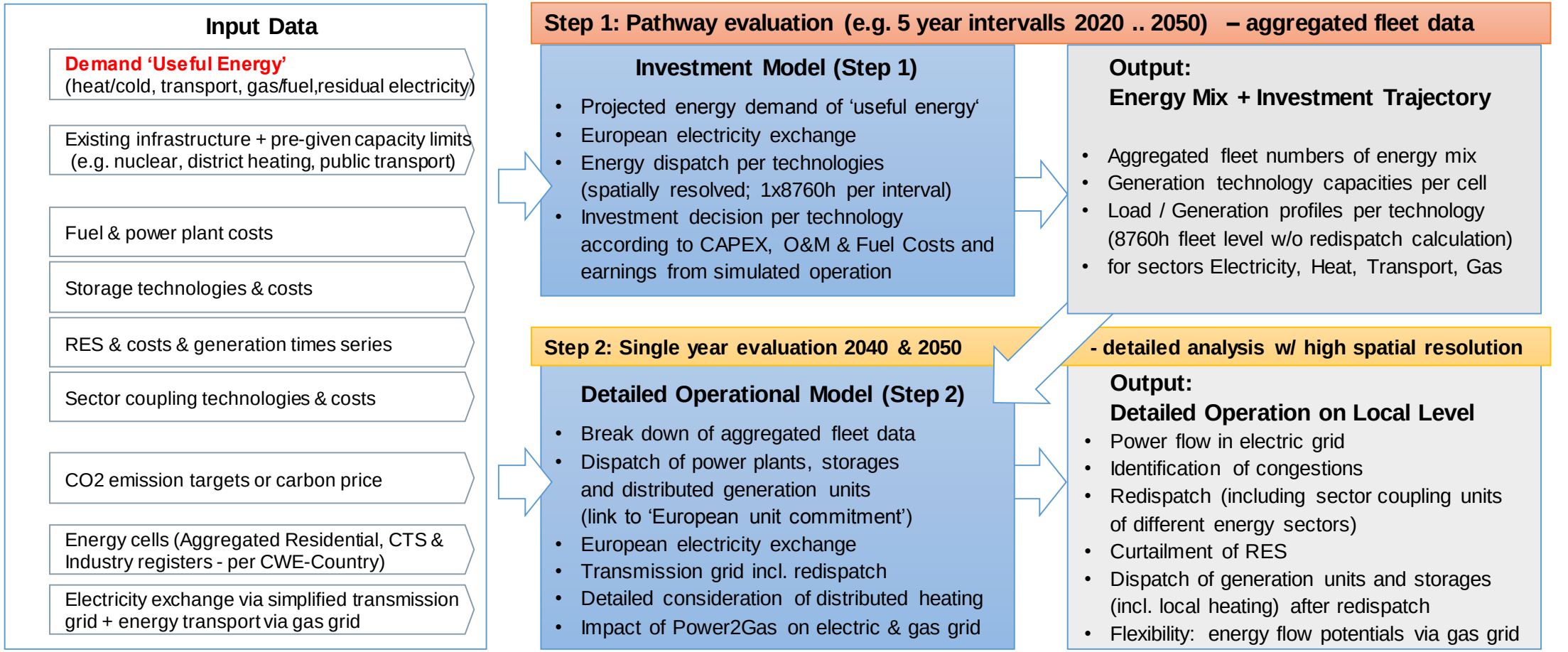
Modeling and Data

- **To model the multimodal pan-European energy system with high spatial resolution along the pathway to 2050 means solving a massive linear problem**
- **Ensure data quality and availability**

→ 2-step Approach

1) **Simulate the optimized future energy mix along the transition pathway (investment trajectory with clustered fleet data per technology)**
2) **Challenge results of 1) with deep dive analysis**
   - **for identifying & clearing congestions in transmission grid using powerflow & redispatch calculation**
   - **for impact of heating, eMobility and energy transport via Power2Gas & gas grids**

Modeling


Input Data
Demand 'Useful Energy'
(heat/cold, transport, gas/fuel,residual electricity)
Existing infrastructure + pre-given capacity limits
(e.g. nuclear, district heating, public transport)
Fuel & power plant costs
Storage technologies & costs
RES & costs & generation times series
Sector coupling technologies & costs
CO2 emission targets or carbon price
Energy cells (Aggregated Residential, CTS & Industry registers - per CWE-Country)
Electricity exchange via simplified transmission grid + energy transport via gas grid
Step 1: Pathway evaluation (e.g. 5 year intervalls 2020 .. 2050) – aggregated fleet data
Investment Model (Step 1)
• Projected energy demand of 'useful energy'
• European electricity exchange
• Energy dispatch per technologies (spatially resolved; 1x8760h per interval)
• Investment decision per technology according to CAPEX, O&M & Fuel Costs and earnings from simulated operation
Output:
Energy Mix + Investment Trajectory
• Aggregated fleet numbers of energy mix
• Generation technology capacities per cell
• Load / Generation profiles per technology (8760h fleet level w/o redispatch calculation)
• for sectors Electricity, Heat, Transport, Gas
Step 2: Single year evaluation 2040 & 2050
- detailed analysis w/ high spatial resolution
Detailed Operational Model (Step 2)
• Break down of aggregated fleet data
• Dispatch of power plants, storages and distributed generation units (link to 'European unit commitment')
• European electricity exchange
• Transmission grid incl. redispatch
• Detailed consideration of distributed heating
• Impact of Power2Gas on electric & gas grid
Output:
Detailed Operation on Local Level
• Power flow in electric grid
• Identification of congestions
• Redispatch (including sector coupling units of different energy sectors)
• Curtailment of RES
• Dispatch of generation units and storages (incl. local heating) after redispatch
• Flexibility: energy flow potentials via gas grid

Cost-optimizing multi-modal model is used to analyze future energy mix plus transition pathway towards it

Fixed Input

- CO_2 emission reduction target
- Demand for useful energy in 2050
- Tech data input
- Regional data input

Investment Model - Optimization

- **Target function:** minimize **OPEX & CAPEX**
- **Multi modal** energy system analysis
- Ensure security of supply on an **hourly basis**
- **Optimization via massive 'Linear Problem'**

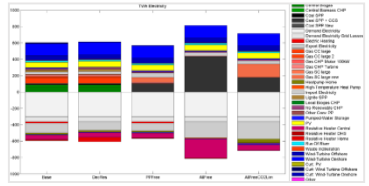
Demand & weather patterns

Technology parameters

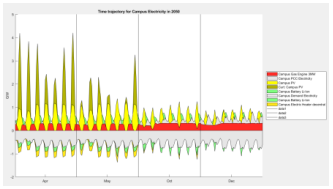
Output

Cost optimized energy system till 2050

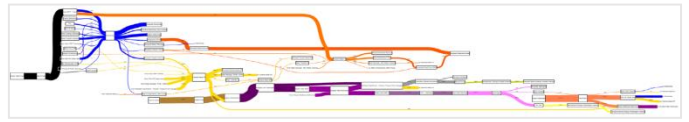
- Capacities for each technology
- Dispatch of generation & storage
- Energy flow
- Marginal costs
- 5-year interval transition pathway (1x 8760h per interval)



Load / generation overview



Energy flow time series



Energy flow diagram

List of Technologies
All Case Studies

Tech data: Installed capacities, specific CAPEX+OPEX, efficiencies, availability, limits & forced fleet (incl. projections from 2015 – 2050)

El. Generation Utility & Industry
- Steam PP Coal/Gas/Oil/Lignite
- GT PP Oil / Gas
- CCGT PP Oil / Gas
- Nuclear PP
- CHP Engine (large)

Renewables
- Run-of-River
- Run-of-River w/ reservoir
- Solar PV (large farms)
- Wind Onshore,
- Wind Offshore
- Geothermal
- Waste
- Biomass / Biogas

Generation - decentral
- Rooftop PV (small)
- Small scale wind
- Micro CHP
- Fuel cells (incl. CHP)

Grids
- Electric (Transmission) Grid

Transport (electricity only)
- E-Mobility (→Charging)
  - eCar, eTruck, eHighway
  - eAircraft, eShip [1)]

Storage (electricity only)
- Pumped Hydro
- Batteries

- Electrolyseur (H_2)

List of Technologies
All Case Studies + Additions for Multimodal Investment Model

Tech data: Installed capacities, specific CAPEX+OPEX, efficiencies, availability, limits & forced fleet (incl. projections from 2015 – 2050)

El. Generation Utility & Industry
- Steam PP Coal/Gas/Oil/Lignite
- GT PP Oil / Gas
- CCGT PP Oil / Gas
- Nuclear PP
- CHP Engine (large)

Renewables
- Run-of-River
- Run-of-River w/ reservoir
- Solar PV (large farms)
- Wind Onshore,
- Wind Offshore
- Geothermal
- Waste
- Biomass / Biogas
- Solar thermal

Generation - decentral
- Rooftop PV (small)
- Small scale wind
- Micro CHP
- Fuel cells (incl. CHP)
- Rooftop Solar Heat

Grids
- Electric (Transmission) Grid
- District Heating
- District Cooling [1)]
- Gas Grid [2)]

Transport (Mobility)
- Classic Mobility (Road/Ship/Air) [1)]
- Fuel Cell Cars / Trucks [1)]
- E-Mobility (→Charging)
  - eCar, eTruck, eHighway
  - eAircraft, eShip [1)]

Transport Demand (short/long distance)
- Passenger
- Freight (large/small)

Heating – temperature levels
- LT <100 °C
- MT 100°C – 150°C
- HT 150°C– 500°C
- VHT >500°C

Heating - decentral
- Small Boiler
- Small Electric
- Micro CHP
- Heat Pumps (Air / Water)

Heating - central
- Large Boiler
- Heating rod (electric) LT / MT
- Heating rod (electric) HT /VHT
- Arc Furnace (electric) VHT
- Furnace VHT
- Heat Pump (LT / MT)

Cooling - central / decentral
- Compression Chiller [1)]
- Compression Chiller HVAC [1)]
- Absorption Chiller (large) [1)]

Storage
- Pumped Hydro
- Batteries
- Air compression (small, large)
- Heat Storage HT (small, large)
- Heat Storage MT (small, large)
- Heat Storage LT (small, large)
- Cold Storage H_2O (small, large) [1)]
- Cold Storage Ice (small, large) [1)]
- Electrolyseur (H_2) [2)]
- Power2Gas (CH4) [2)]
- Power2Synfuel (Liquid Fuel) [2)]
- Hydrogen Storage [2)]
- Gas in Cavern (NG/H_2) [2)]
- Pressurized Vessel (NG/H_2) [2)]
- Pipeline Segment (NG/H_2) [2)]

Industry Demand correlated to P2G [2)]
- Steam Methane Reforming [2)] ??
- Oil refineries H_2 Demand [2)] ??
- Chemical Industry H_2 Demand [2)] ??

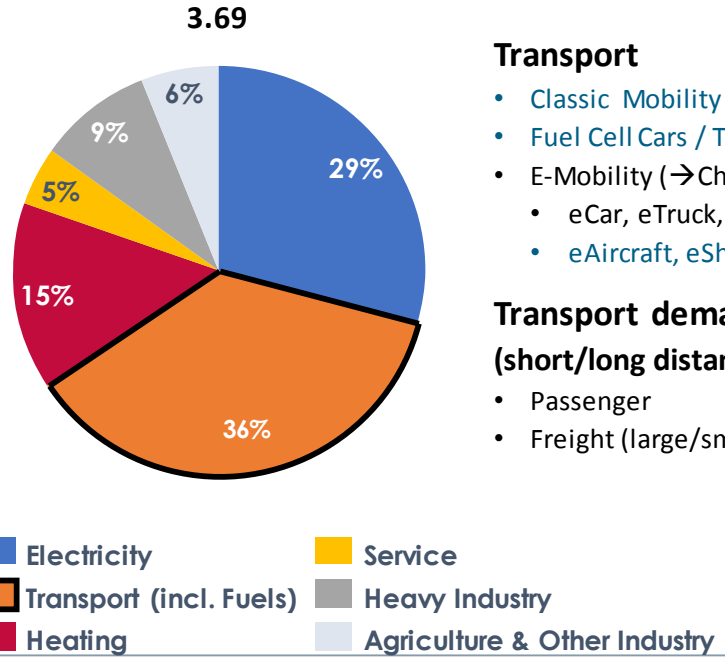
1) CS1:Step 1 not considered in Step 2
2) CS1: Step 1 & Step 2-C, not considered in Step 2 A&B

Identified main levers for CO_2 reduction from sector coupling Sector Mobility

- **Challenge: Which technology mix fits best to meet future demand?**

Europe 2015

Net CO_2 by point of emission (Gt CO_2 p.a.)



Transport

- Classic Mobility (Road/Ship/Air) [1)]
- Fuel Cell Cars / Trucks [1)]
- E-Mobility (→Charging)
  - eCar, eTruck, eHighway
  - eAircraft, eShip [1)]

Transport demand (short/long distance)

- Passenger
- Freight (large/small)

Identified main levers @ mechanical work (Mobility)

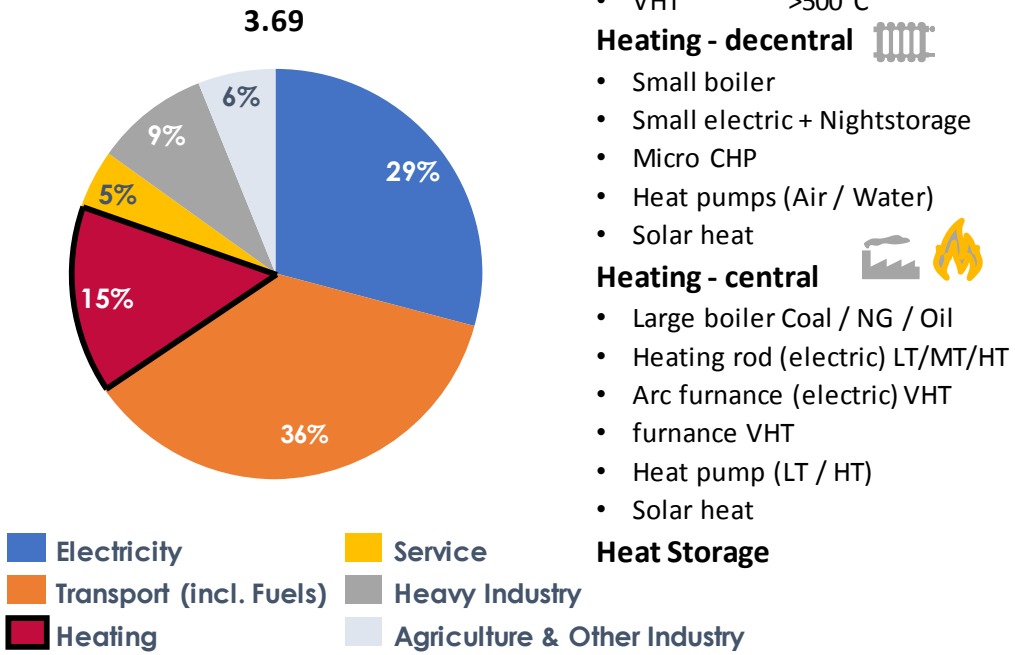
Electrification of Transport	Alternative for remaining fuel demand		Feedback on other sectors
	Gas motor (Car, Truck)	Shift to gas fuels, e.g. CNG, CH_4	
eMobility (eCar, eTruck, eShip, eAircraft)	Mobile fuel cell + Battery (Car, Truck)	Alternative fuels from RES sources (P2Gas, P2Fuels)	(Electricity) Power2Gas Power2Fuel
eMobility @Infrastructure eHighway, Rail	Classic mobility (IC Cars, Trucks Ship , Airplane)	Alternative fuels BioFuel	

Identified main levers for CO_2 reduction from sector coupling Heating

- **Challenge: Which technology mix fits best to meet future demand?**

Europe 2015

Net CO_2 by point of emission (Gt CO_2 p.a.)



Heating temperature levels

- LT <100 °C
- MT 100°C – 150°C
- HT 150°C– 500°C
- VHT >500°C

Heating - decentral

- Small boiler
- Small electric + Nightstorage
- Micro CHP
- Heat pumps (Air / Water)
- Solar heat

Heating - central

- Large boiler Coal / NG / Oil
- Heating rod (electric) LT/MT/HT
- Arc furnance (electric) VHT
- furnance VHT
- Heat pump (LT / HT)
- Solar heat

Heat Storage

Identified main levers @ Heating (central / decentral)

Electrification of Heating /Solar heat		Alternative for remaining fuel demand	Feedback on other sectors
Electric heating [1] Decentral el. Boiler/heater, small heat pump	Classic heating boiler [1], Oven & furnances	Shift to gas fuel, e.g. CNG, CH_4	
Electric heating [1] Central el. boiler/heater, large heat pump, Arc furnance	Heating from CHP [1] Decentral /Central	Alternative fuels from RES sources (P2Gas, P2Fuels)	Power2Gas Power2Fuel (→ electricity)
Solar heating [1] Decentral / Central	District heating [1]	Alternative fuels BioFuel	Heating by co-generation (→ electricity)

1) plus heat storage where applicable – decentral: Nightstorage, H_2O, pit holes; central: steam, H_2O

Challenge: Modeling of the European energy system along the pathway on sub-country resolution

Challenge:

- Massive linear optimization problem → Several European countries are modeled in parallel in sub-country resolution & along the pathway
- Ensure data quality on all spatial resolutions

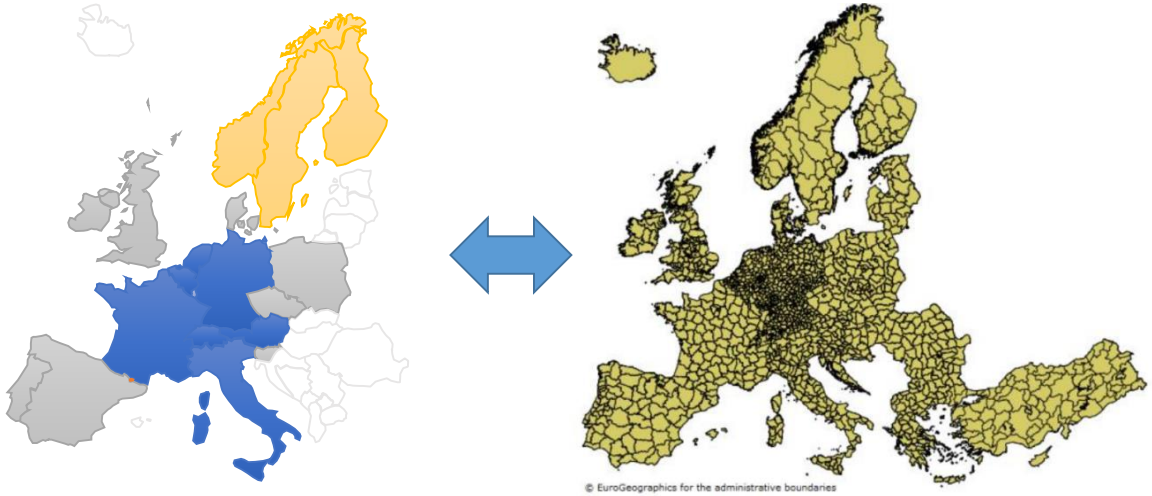
→ Adapt scope and cell sizes level according to available data quality and limiting requirements from modeling & analysis

→ Algorithms to aggregate or break down data and results between cell sizes level

Note: For extended analysis in CS#1 Step 2: Break down of heating technologies & eMobility to postal code level for selected countries (→ CW Europe)

Arguments for usage of NUTS Classification of regions:

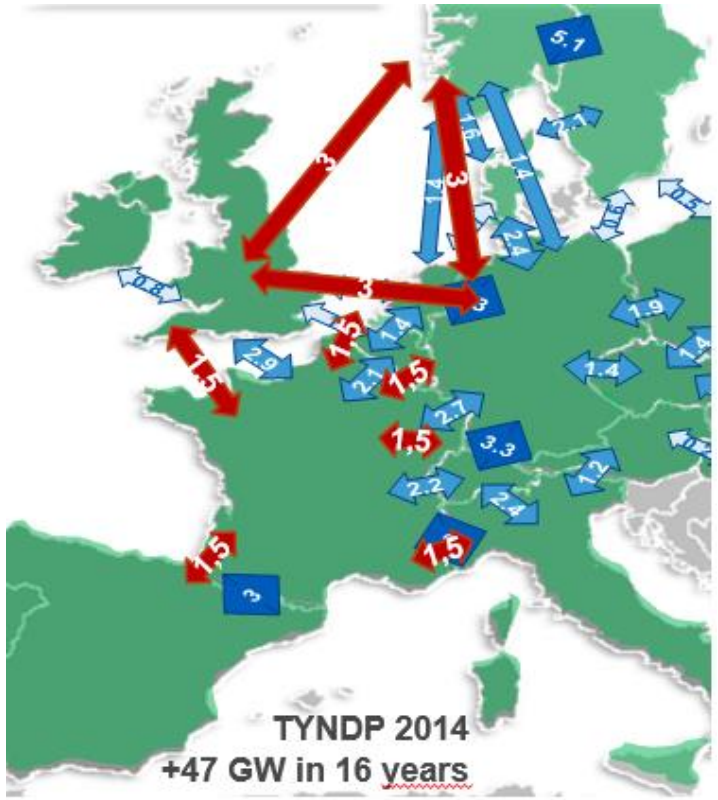
- *cover all the countries that need to be clustered;*
- *boundaries are clearly defined and available for any interested stakeholder;*
- *enable to use European databases defined at this level.*



Country NUTS-3

Simplified cross-cell energy exchange model

- Energy exchange by a simplified transmission grid (Cluster Model)



simplify

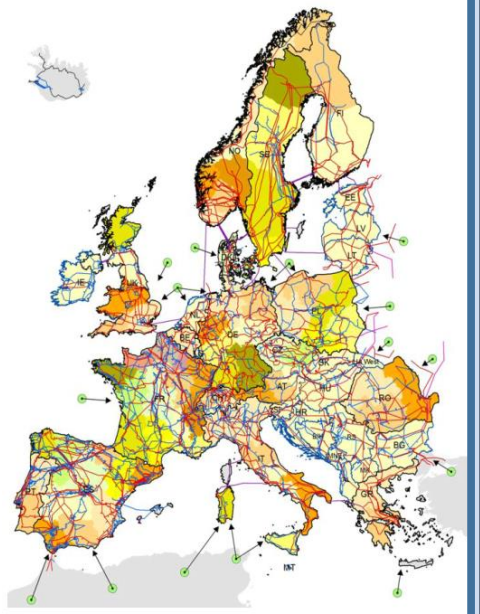


Figure 20: Geographic clustering

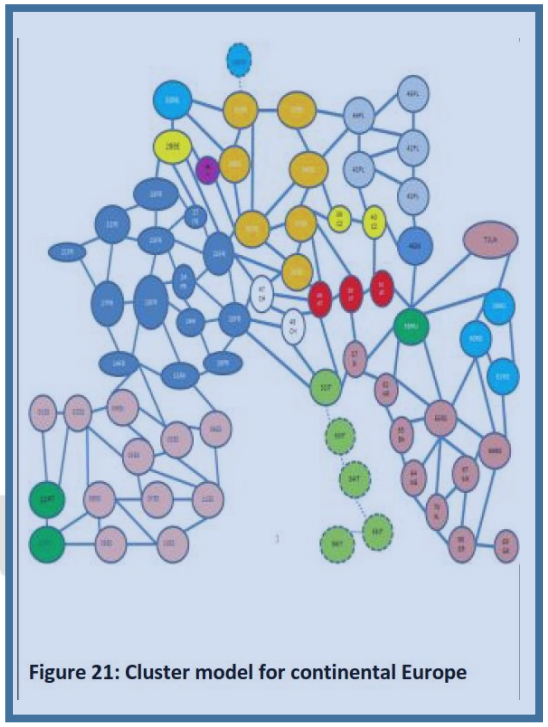


Figure 21: Cluster model for continental Europe

Note:
In Case study #1, no optimization of the transmission grid capacity or detailed consideration is done. Instead we use a simplified model considering a maximum cross-cell energy exchange which reflects the given transport capacity restrictions between cells of the chosen spatial resolution based on the existing and projected transmission grid.

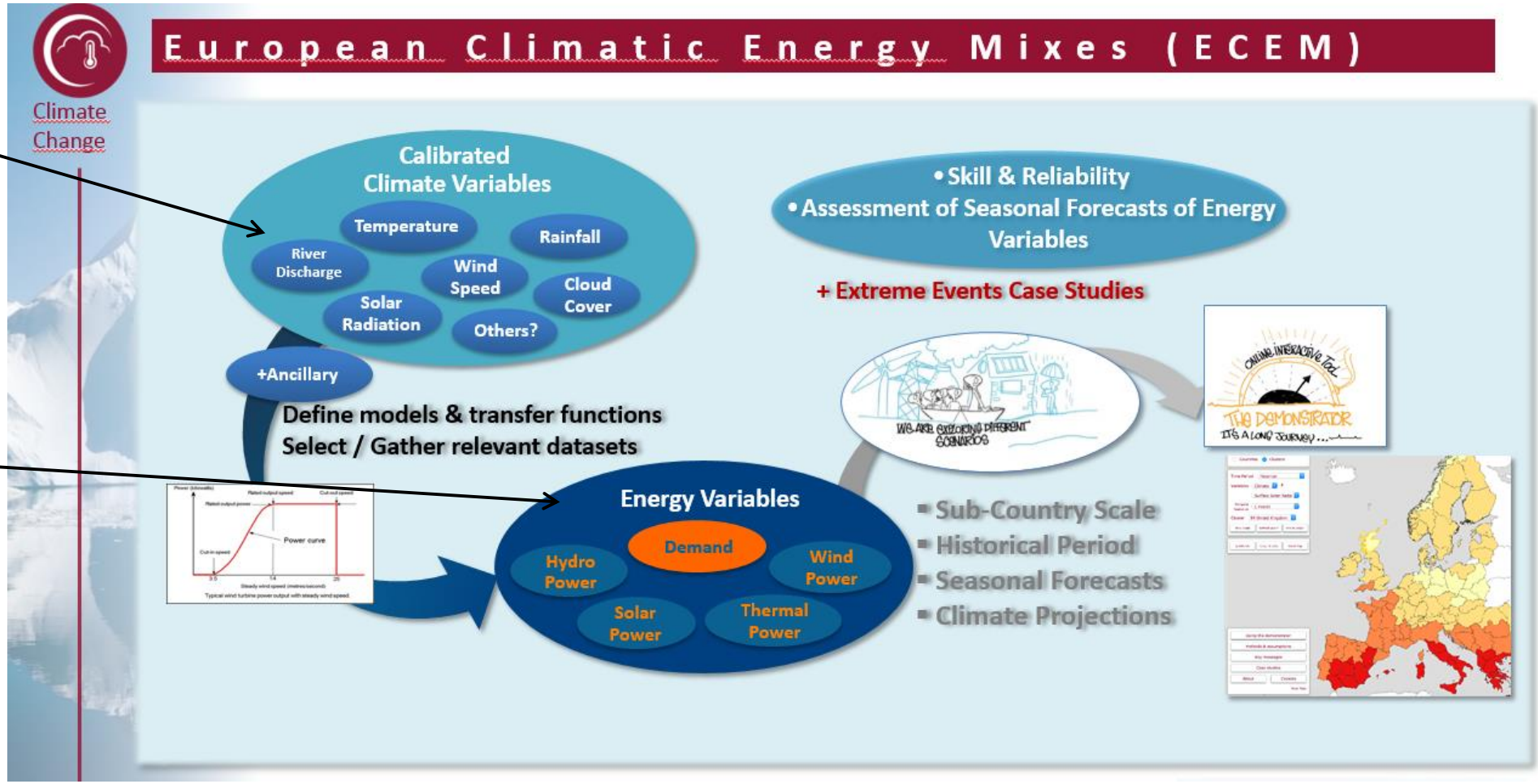
Analog to CS#3

The Impacts of Climate Change

CS#1:

Projected weather data for simulating future demand of cooling and heating

Projected weather data for simulating generation profiles of RES



Data Sources

- **Technology data related to energy types**
  → heating/cooling, transport, electricity, gas/fuel
  - specific CAPEX & O&M
  - efficiency, availability
  - installed fleet (incl. storage)
  - regional limits / forced capacities
- **Simplified cross-border electricity exchange capacities**
- **Demand for 'Useful Energy' per region**
  projection annual demand from 2020 to 2050)
- **Generation profile Wind/PV/Solar per region**
- **Projection of GDP and population per region**
- **Statistical building & sociodemographic data**

Potential External Sources (to be checked for feasibility)

Heating Cooling	→ Heat Roadmap Europe 2050 (HRE4)
Transport	→ EU Reference Scenario 2016
Industry	→ DECHEMA 2017 "Low carbon energy & feedstock for the European chemical industry"
Installed Base PP	→ entso-e
Electric Grid	→ entso-e (TYNDP), eHighway 2050,
Gas Grid	→ entso-g ??
Weather	→ EU ECEM (climate change) or generation profiles: www.renewables.ninja
GDP, Population	→ Projection of EU Reference Scenario 2016
Building data,	→ Digital data service
Socio demographic data	→ Digital data service

Thank you!

Do you have any questions?