# European Power System Long-term development with Flexibility A study on demand projections

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# Outline

**1** EMPIRE (European Model for Power Investments with high shares of Renewable Energy)

2 Uncertainty - Where?

3 Multi-horizon Stochastic Optimization



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# Multi-horizon Scenario Tree



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**Modelling Assumptions** 

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Long-term dynamics (multi-period investments)

**Modelling Assumptions** 

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- Long-term dynamics (multi-period investments)
- Short-term dynamics (multi-period operation)

#### **Modelling Assumptions**



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#### Multi-horizon Stochastic Program

- Long-term dynamics (multi-period investments)
- Short-term dynamics (multi-period operation)
- Short-term and long-term uncertainty

### **Modelling Assumptions**

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Perfect Competition (multi-period investments)

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- Generation capacity aggregated by technology

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#### Multi-horizon Stochastic Program

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- Short-term and long-term uncertainty

- Perfect Competition (multi-period investments)
- Generation capacity aggregated by technology
- Investments are continuous outcomes

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- Perfect Competition (multi-period investments)
- Generation capacity aggregated by technology
- Investments are continuous
- Lines are independent
- Elastic demand (Demand Response)

- Perfect Competition (multi-period investments)
- Generation capacity aggregated by technology
- Investments are continuous
- Lines are independent
- Elastic demand (Demand Response)
- Uncertain foresight of future

# Uncertainty - Where?

- Wind and solar generation
- Fuel prices
- CO2 prices
- Energy policy
- Technology costs
- Energy demand

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Multi-horizon Stoch. Plan.

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# **Electricity Demand Projections**

- PRIMES / EU reference case
- GCAM
- TIMES

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# **PRIMES** Demand Projections



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# Long-term Demand Uncertainty Approaches

- Probabilistic Pathways Sets
- Pathway Uncertainty Estimation
- Stochastic Partial Decomposition Approach

# DR costs

Technology	Investment	Fixed OM	Variable	Efficiency	Fuel
	Cost (€/kW)	$(\mathbf{E}/\mathbf{kW})$ pr. yr.	OM (€/MWh)	Ũ	Cost
HeatingAC	250	7,50	10	0,97	
HVAC-ComInd	10	0,30	5	0,97	
CoolingWater-ComInd	5	0,15	20	$0,\!98$	
ProcessShift-Ind	0	0,00	150	$0,\!99$	
WashingEq-Res	30	0,90	50	$1,\!00$	
StorHeat-ResCom	20	$0,\!60$	10	$0,\!98$	
ProcessShed-Ind	0	0,00	1000	$^{1,00}$	
Battery Storage (Li-ion)	1195			0,88	
Battery Storage (Zn)	588			0,75	
Pumped Storage Hydro	1000			$^{0,80}$	
Gas CCGT	650	30,38	$0,\!45$		42

Source: 2015, H. C. Gils

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# Results

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### Long-term scenarios



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# Europe's Capacity Portfolio Comparison





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# Europe's Capacity Portfolio Comparison





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# Europe's Capacity Portfolio Comparison





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#### Installed capacity solar PV



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