Assessing uncertainties towards an optimal 100% renewable electricity mix in France

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Introduction

- Call for tenders:
  - Ground-mounted PV & Onshore wind : ~ 60 €/MWh
  - Nuclear (*Hinkley Point C*): > 120 €/MWh
  - European wholesale electiricity market: ~ 50 €/MWh
- Storage?
  - Doubts about the profitability of systems with «RES + Storage»
  - Strong cost decrease of Li-Ion batteries and PEM electrolysers
- What does the cost of a 100% renewable system depend on?
  - Power production and storage technologies
  - Capacity constraints
  - Electricity consumption
  - Meteorological conditions

Questions addressed

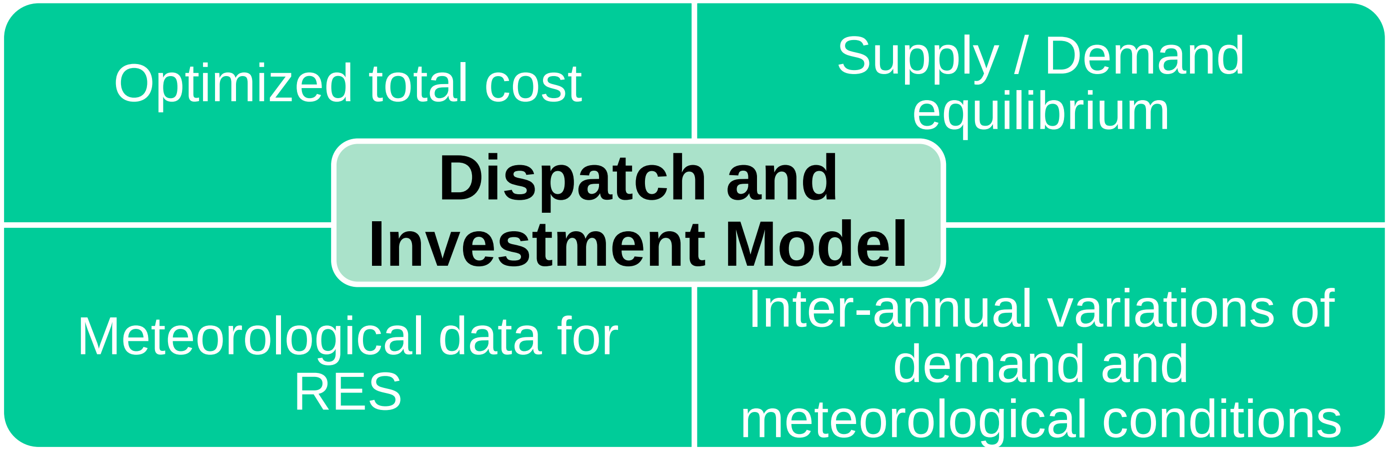
- The optimal installed capacities of power production and storage technologies?
- How much does it cost?
- What do the uncertainties evoke:
  - On the cost
  - On the electricity consumption ?
  - On the meteorological conditions ?

Outlines

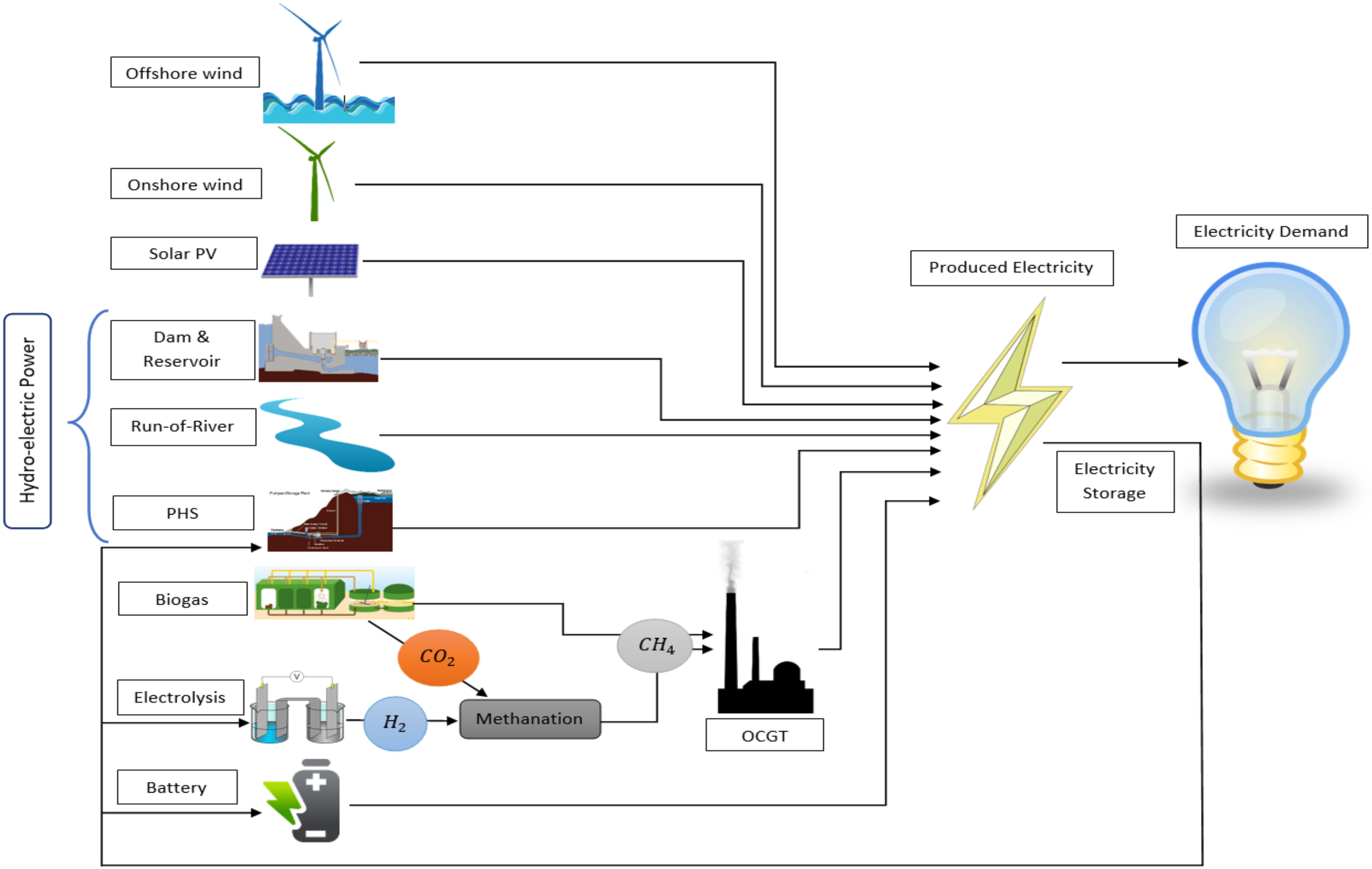
- Model description
- Input data & assumptions
- Results
- Conclusions
- Future work
- Annex

Model description (1/2)

- Dispatch and investment model
- Single node, but with aggregated VRE profiles for all 95 departments of France
- Considering France as an isolated country in a first step.
- Considering only the power sector in a first step.



Model description (2/2)



Input data & assumptions

- Continental France
- Hourly profiles over 18 years
- Electricity consumption
  - RTE (2000-2017) or Ademe central scenario (2050) or scenario négaWatt (2050)
- Offshore and onshore wind and solar PV hourly profiles:
  - Renewables.ninja (from NASA's MERRA-2 data reanalysis)
  - Great correlation with RTE's data – wind 98% and PV 97% (Moraes et al 2018)
  - Offshore wind power: sites in project
  - Onshore wind and solar PV: 1 site in each department, proportional to installed capacity
- Hydro power resources : RTE 2016
- Capacity constraints (Offshore and onshore wind, PV, biogas and hydro-electricity)
  - ADEME Trajectoires d'évolution du mix électrique à horizon 2020-2060 (2018)
  - ADEME visions 2030-2050 (2013)
- Costs and losses
  - JRC 2017 *Cost development of low carbon energy technologies*
  - Fuel cell and hydrogen joint undertaking 2015
  - Schmidt et al (2019): *Projecting the Future Levelized Cost of Electricity Storage Technologies*

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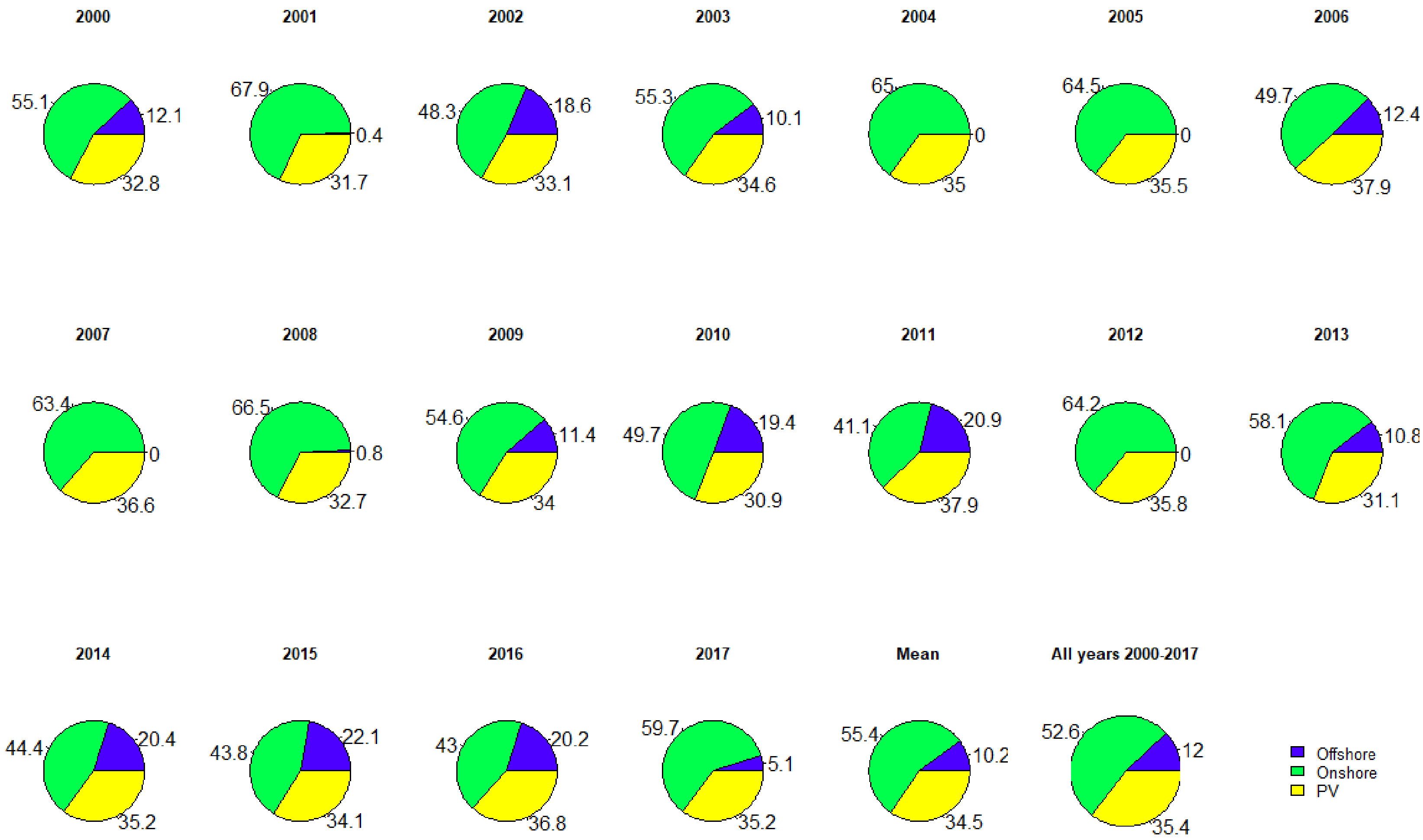
RESULTS

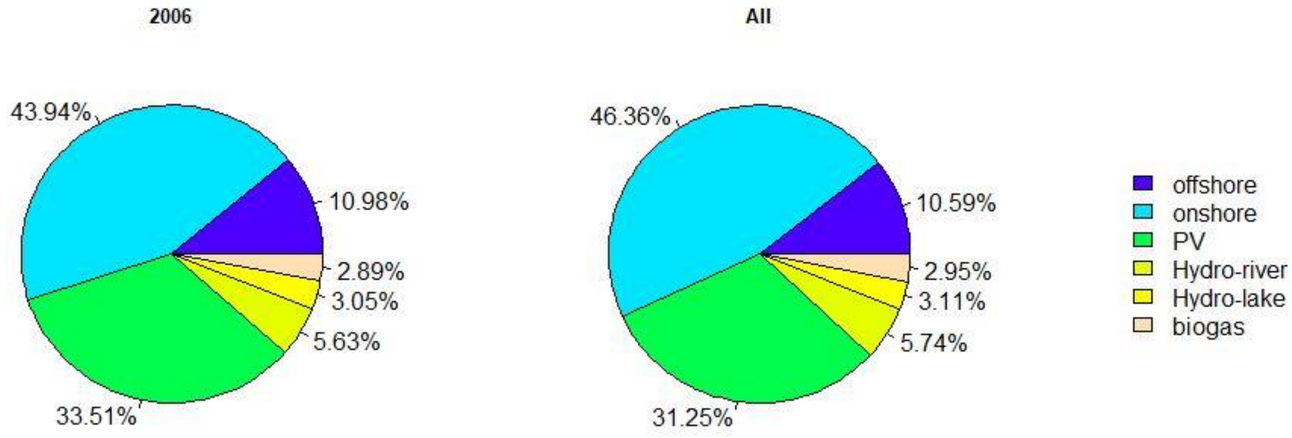
(with ADEME's consumption data)

Energetic mixes



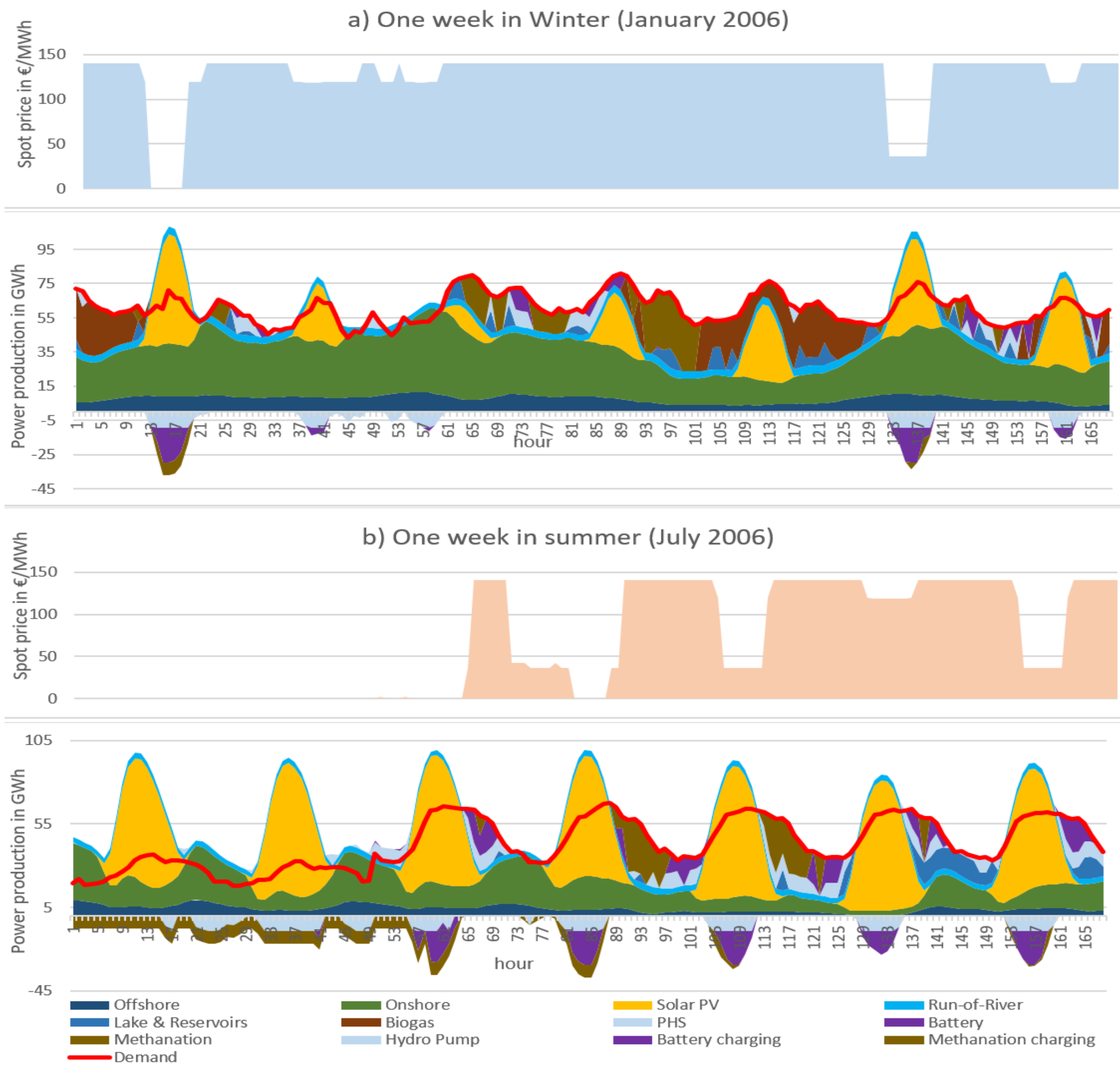
Energetic mixes

Yearly power production



INSTALLED CAPACITIES (GW)	ADEME baseline	néga-Watt	Our results for the whole 2000-2017 period	Our results for 2006
Offshore Wind	10	28	11.77	12.36
Onshore Wind	96.5	49.5	83.30	80.08
Solar PV	63	136	112.21	122.17
Biogas	1	2.5	33.25	32.89
Battery storage	12	-	19.25	20.12
PHS	7	?	9.3	9.3
Hydrogen/methane storage	17	23	33.25	32.89

2 typical weeks



Power production and costs

Production (TWh)	Our results	Ademe	négaWatt (consumption <)
Offshore wind	**57**	42	115
Onshore wind	**236**	261	131
Solar PV	**159**	82	147
Biogas	**15**	8	4
Battery	**11**	?	-
H2+méthanation	**8**	?	16

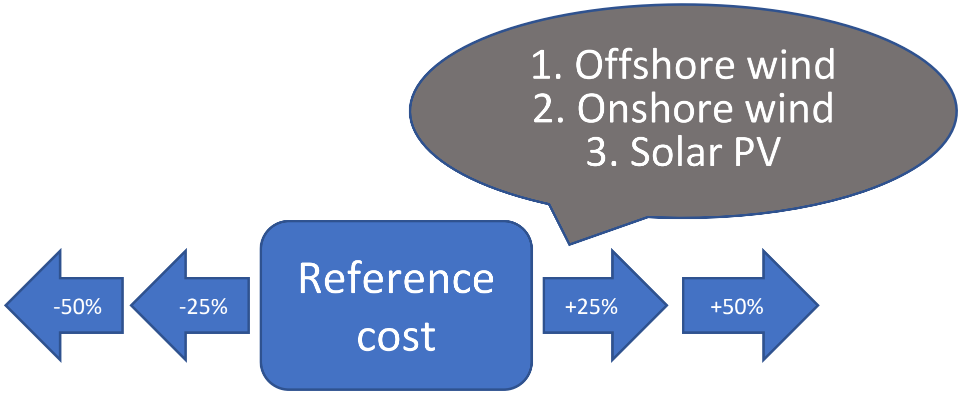
	Our results
Annual cost (b€/year)	**21.33**
LCOE (€/MWh)	**50.5**
LC + storage losses	**17%**

Sensitivity analysis (1/2)

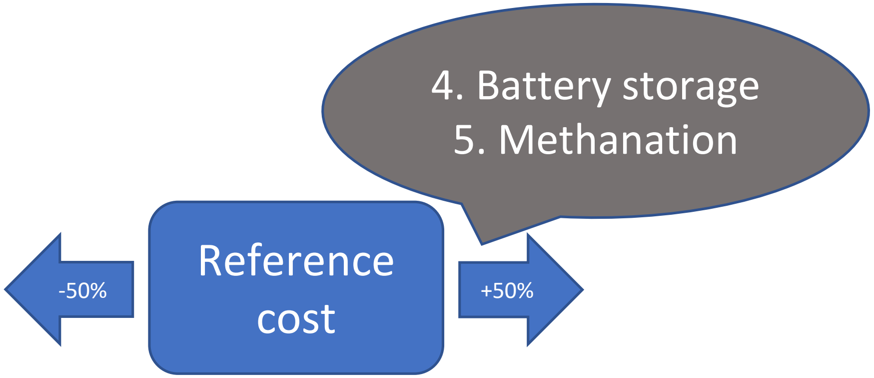
Most economically uncertain technologies:

1. Offshore wind power
2. Onshore wind power
3. Solar PV
4. Short-term storage option (Li-Ion battery)
5. Long-term storage option (Methanation)

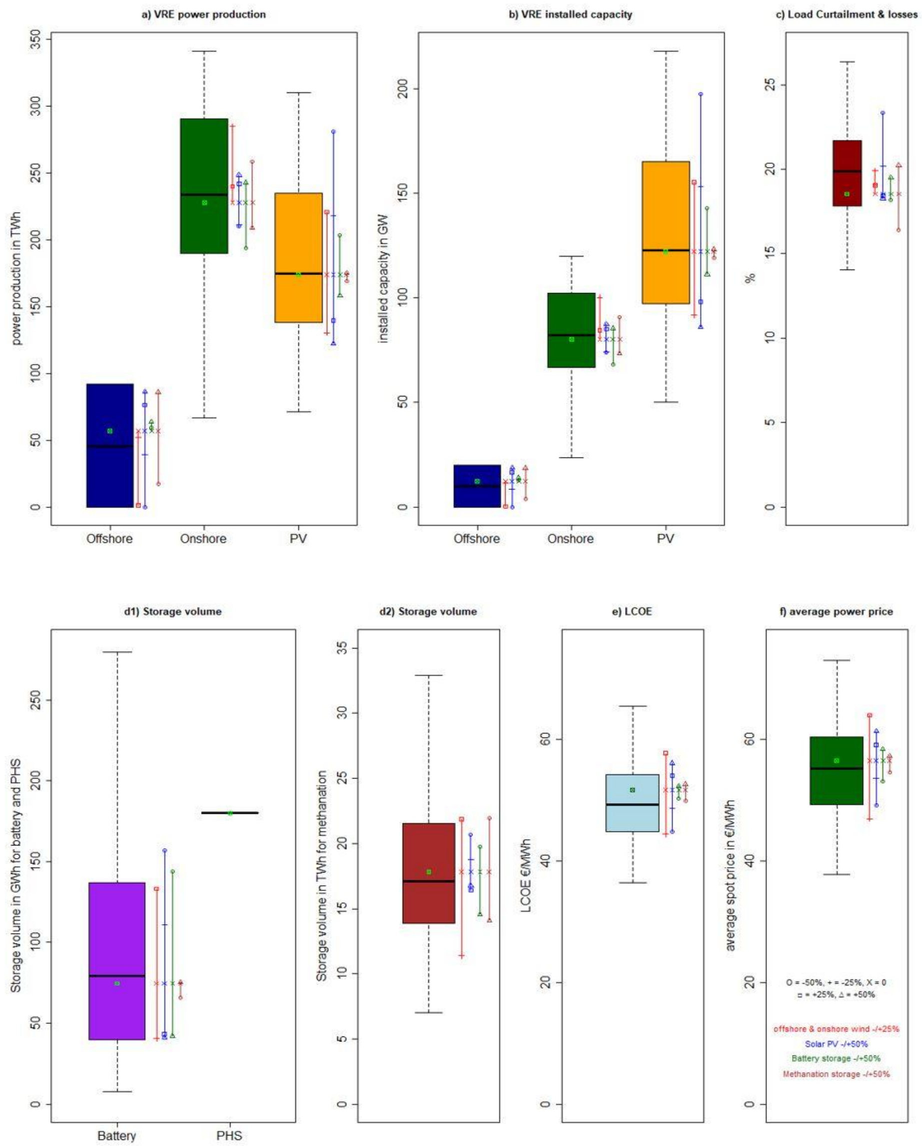
VRE generation technologies



Storage technologies



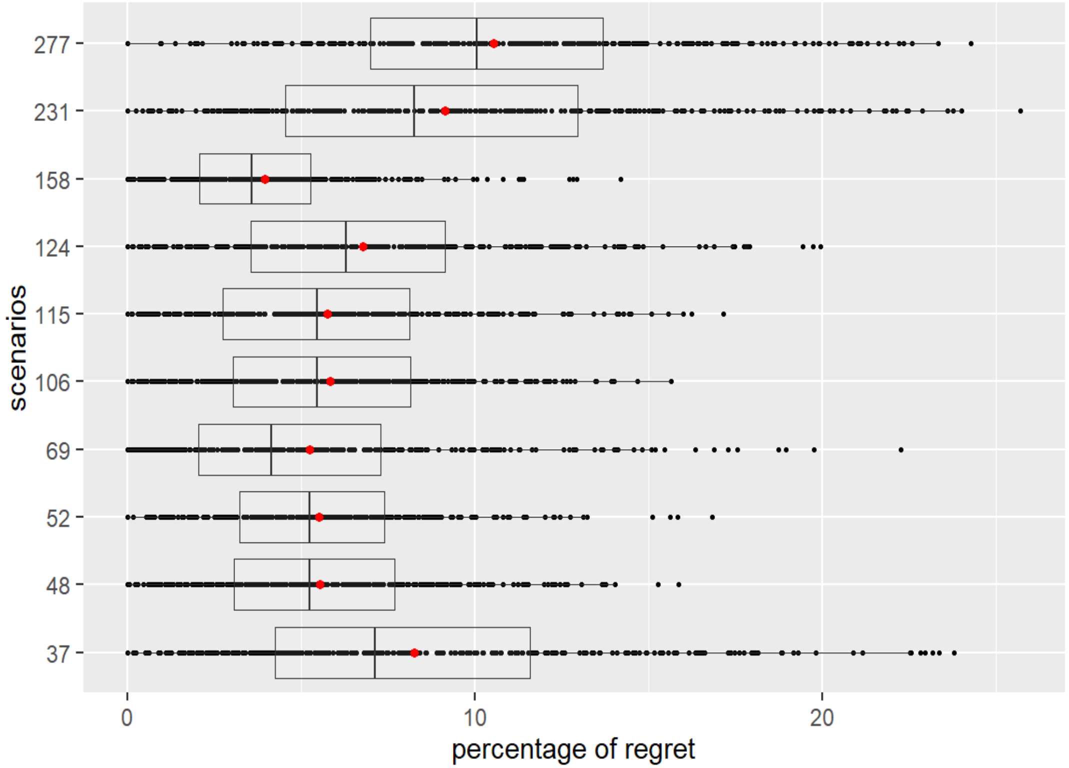
Sensitivity analysis (2/2)



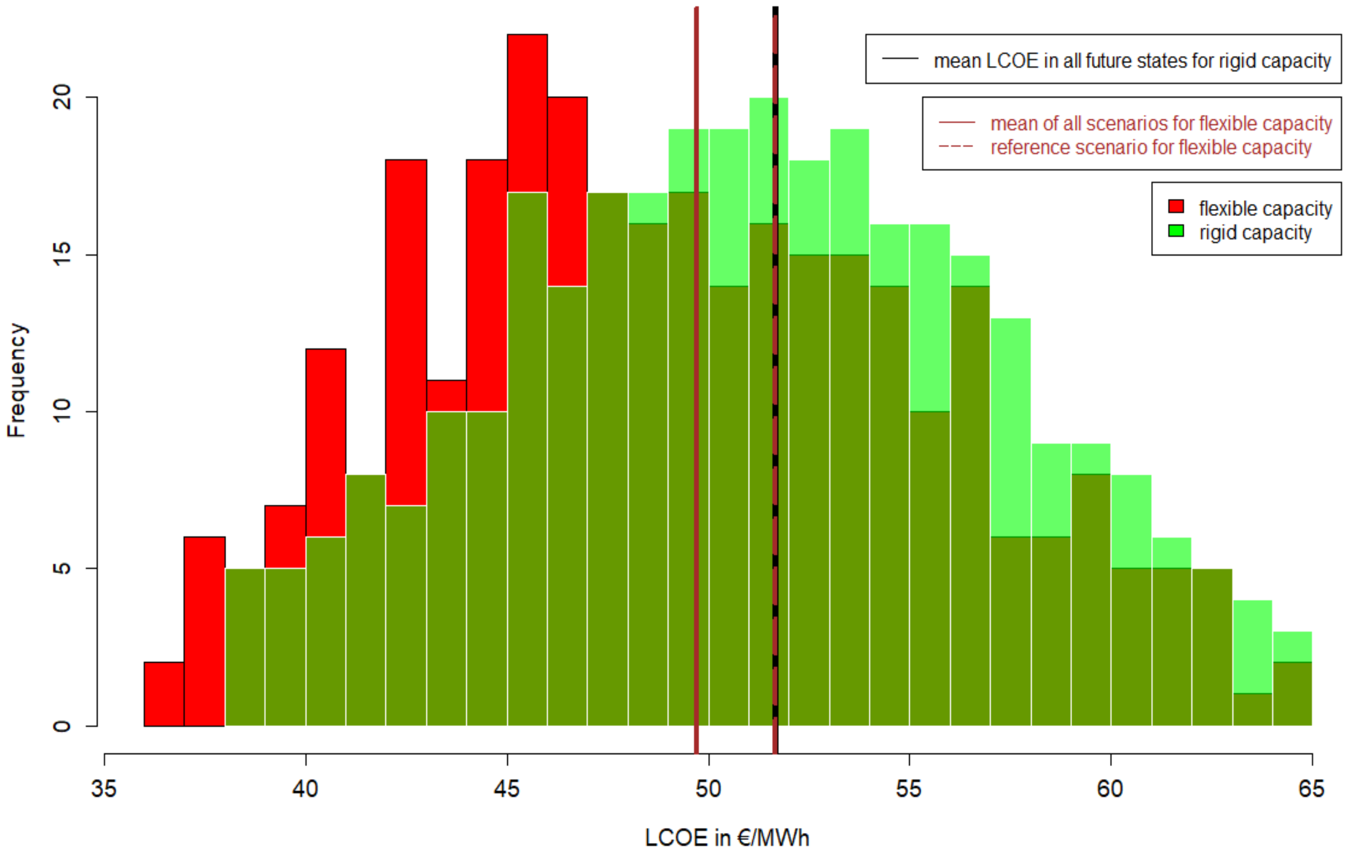
Robustness (1/3)

- RDM framework

$$(s, f) = \max_{s'}\{Performance(s', f)\} - Performance(regrets, f)$$



Robustness (2/3)



Robustness (3/3)

- Flexible energy mix (sensitivity analysis):

1. Mean LCOE 49.7 €/MWh (-3.6% central scenario LCOE)
2. All technologies (Wind*, PV, battery, methanation): + 50%
   - LCOE 51.6 → 65 €/MWh
3. All technologies - 50% & Wind -25%
   - LCOE 51.6 → 36 €/MWh

- Rigid energy mix (Robustness analysis):

1. LCOE 38 → 65 €/MWh
2. Mean LCOE 51.6 €/MWh (central scenario)
3. Mean regret 3.6% → applied to LCOE 53.5 €/MWh

- LCOE estimated: 51.6 ± 3.6%

Conclusion (1/2)

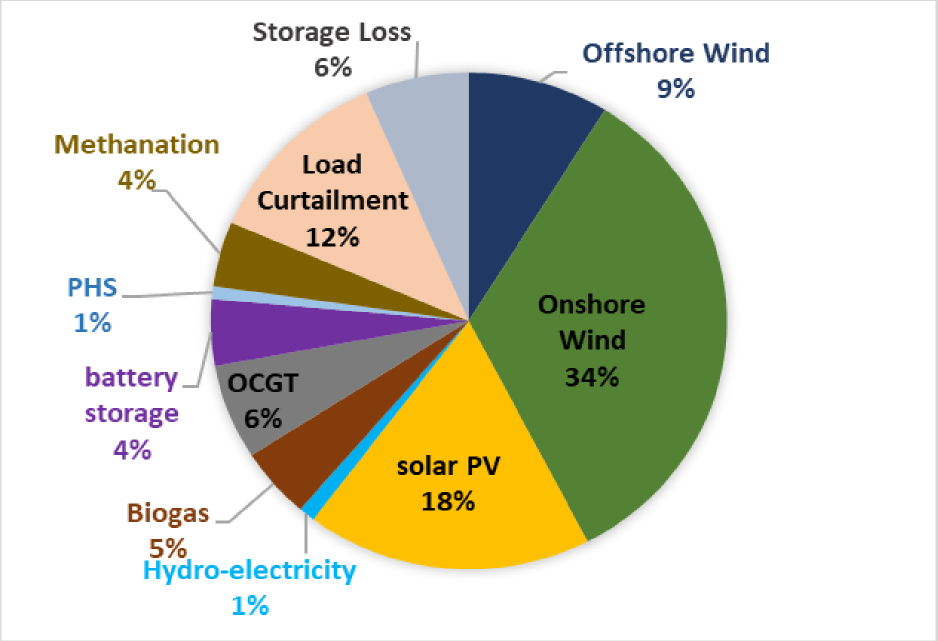
- 100% renewable electricity is not only technically feasible, but also economically affordable and not expensive.
- One-year long modelling can have very different results for each year, the modelling should be made on the basis of longer periods (As also highlighted by *Collins et al*, 2018).
- **#1. The ratio between onshore and offshore wind powers is very sensitive to the choice of the meteorological year; the share of solar PV is also relatively sensitive.**
- **#2. By increasing the optimization period length, we also increase the difficult meteorological conditions to handle; so the needed storage and final total cost also increases respectively, but quantitatively this effect is very weak.**

Conclusion (2/2)

- **#3. Taking into account the uncertainties for a flexible energy mix will decrease the expected cost by 3.6% (because of a complete flexibility in the installed capacity after the reception of future cost information)**

- **#4. Taking into account the uncertainties for a rigid energy mix will increase the expected cost by 3.6% (because of no flexibility in the installed capacity after the reception of future cost information)**

- **#5. Future power system LCOE → 51.6 €/MWh ± 3.6%**



Future work

- What about new nuclear power plants and natural gas with CCS?
  - Nuclear power plant cost hypothesis
  - Natural gas market price hypothesis
  - CO_2 tax and remunération hypothesis
- Multi-vector modelling of the energetic system
  - Heat demand, transport demand and etc.
  - Renewable electricity + renewable gas coupled model
- Interconnection with neighboring countries
- Trajectories → 2050
  - Optimization over 1-2 intermediate points + 2050 ?

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Merci !

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