



# MODELLING AND VALUE OF STORAGE FOR ARBITRAGE AND PEAK CAPACITY IN A HIGH RENEWABLE EUROPEAN POWER SYSTEM

CEEM CONFERENCE – The market architecture for enhancing flexibility  
provision in the EU target model

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# INTRO & MOTIVATIONS

# EDF & STORAGE

## A long story

- For EDF, electricity storage will be one of the essential flexibility levers to succeed the energy transition towards an ever less carbonated energy system
- EDF operates 5GW of Pump-Hydro Storage, nearly 100MW of batteries + 12 millions of domestic water heaters (tanks)
- March 2018: announcement of a storage plan
  - 10GW of new capacities in the World until 2035
  - 8Mds€ investments over 2018-2035
  - Storage R&D budget will double



PHS of Revin (France) ©EDF



Working on some battery development



20MW battery – Mac Henry (USA) ©EDF



Hybrid power plant (kW/kWh for isolated system) (Guyana)



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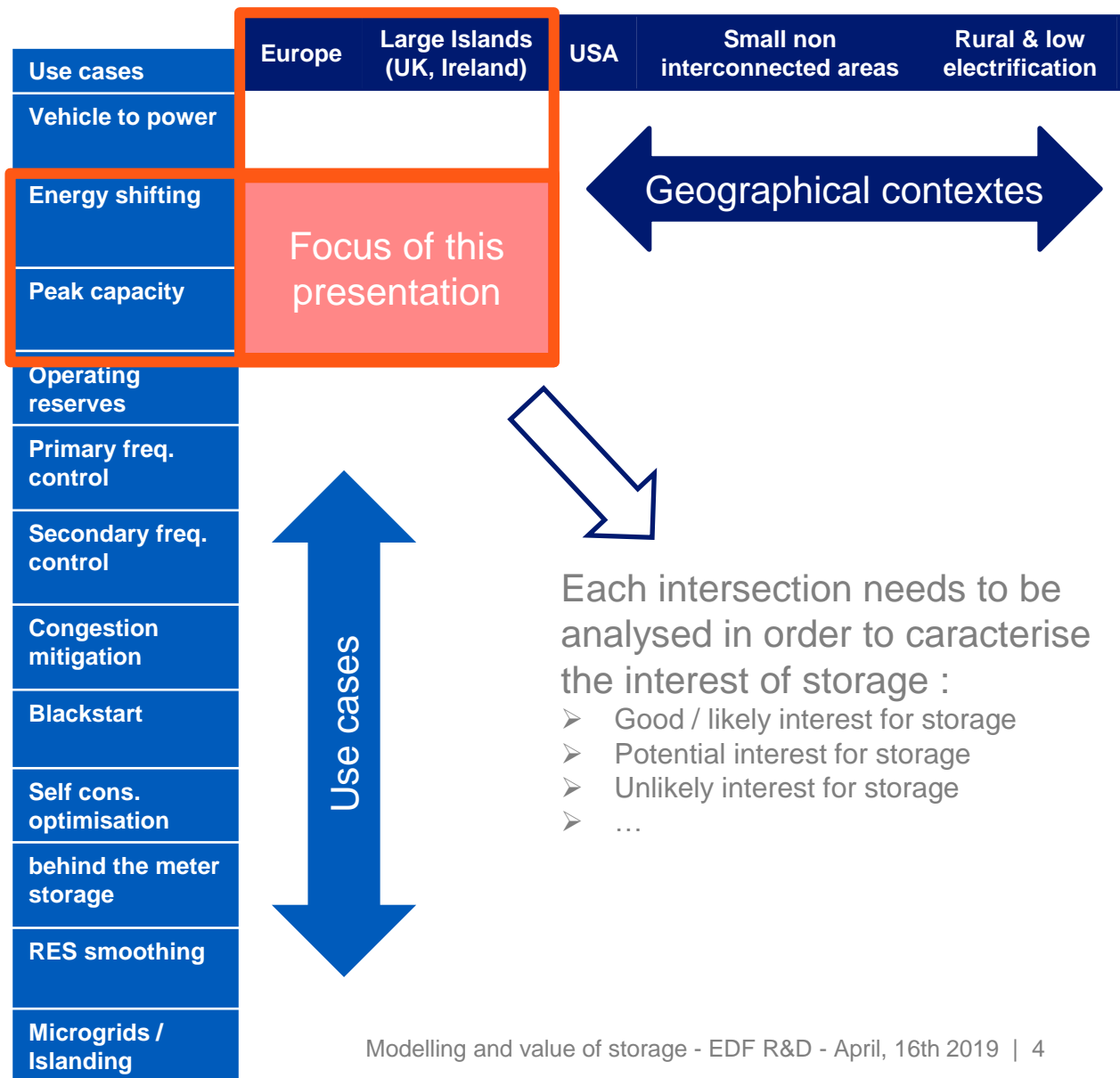
&

Modules

1 MW/0,5 MWh @Concept Grid EDF Lab Les Renardières  
Modelling and value of storage - EDF R&D - April, 16th 2019 | 3

# STORAGE VALUE STREAMS

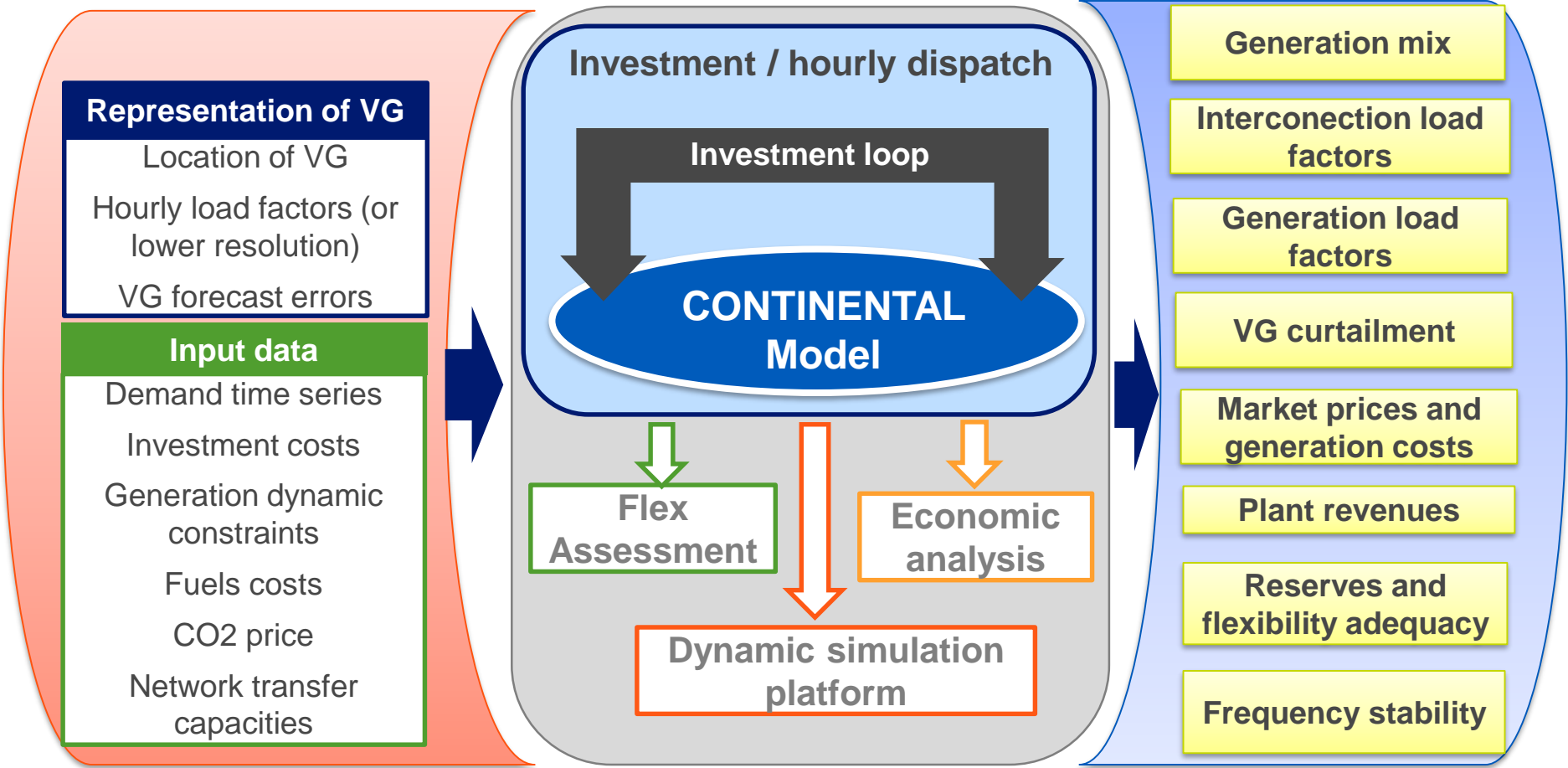
- ES may have different roles according to the context
  - local, regional, national
  - various streams of value to study & quantify
  
- The matrix screens the main electricity storage value streams
  
- In the following presentation, we will focus on arbitrage and capacity values for electricity storage, in Europe
  - The historical business model for storage





# MODELLING

# METHODOLOGY FOR INVESTMENT PLANNING STUDIES AT THE EUROPEAN LEVEL AT EDF R&D



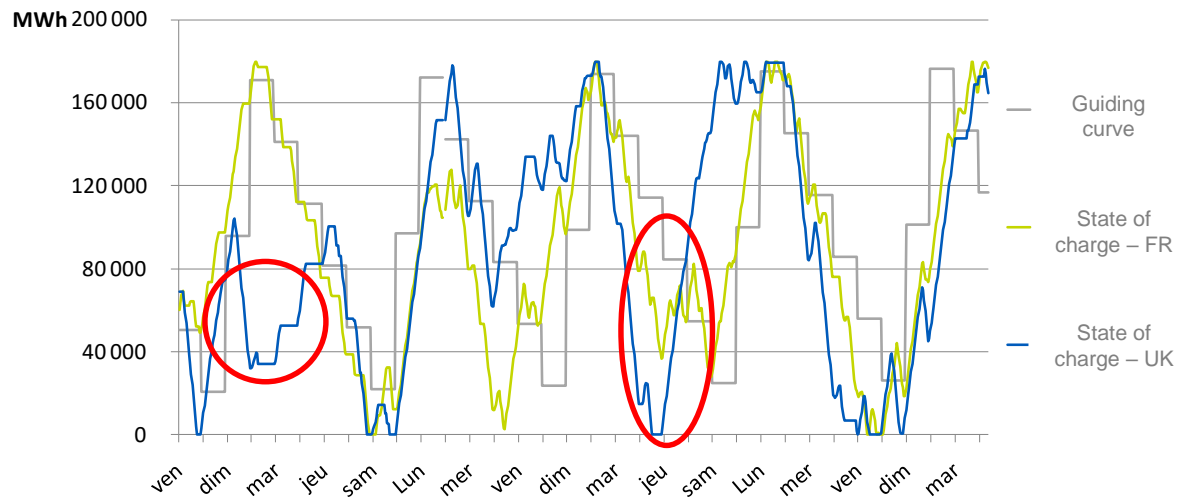
Reference : LOPEZ-BOTET, M. et al. : Methodology for the economic and technical analysis of the European power system with a large share of variable renewable generation, presented at IEEE PES Modelling and Value of Storage - EDF R&D - April, 16th 2019 | 6  
 General Meeting, Washington, USA, 27-31 July, 2014.

# FOCUS ON STORAGE MODELLING

Storage modelling is complex: many parameters & constraints to take into account :

- Capacity, volume, efficiency, CAPEX/OPEX, O&M, technical lifetime...
- Hourly representation
- Searching for an ideal non-deterministic modelling & weekly horizon
- Representation of the hydraulic valleys, dynamic programming, etc.

Storage state of charge over some summer weeks in France and UK



**Storage**  
behaviour can  
be very different  
according to the  
generation mix!

An optimum « complexity vs simplicity » is necessary in order to ensure the understanding of the model i. e. its ability to be checked



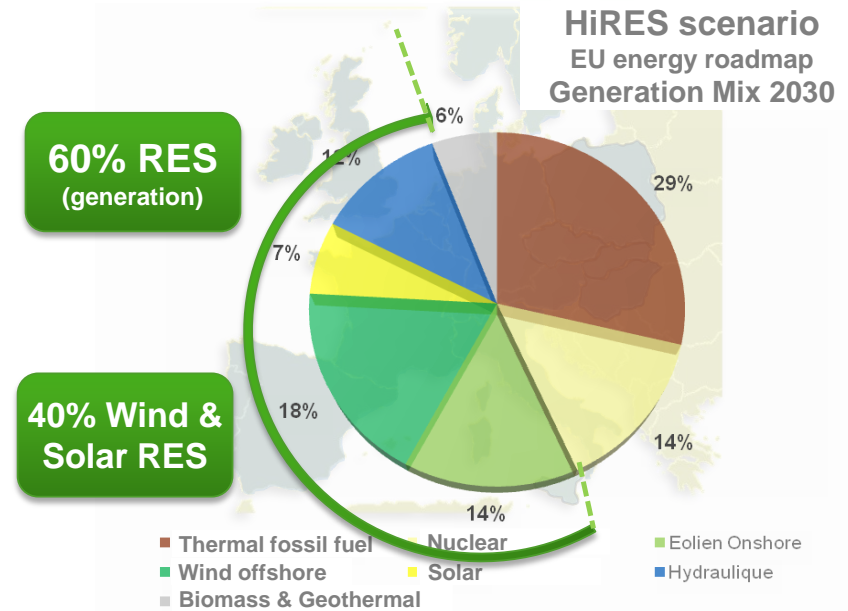


# CONTEXT AND HYPOTHESIS OF THE DATASET



# FRAMEWORK OF THE STUDY

- Analysis of the technical & economic impacts of a high share of renewable energy into the European electricity mix:
  - Characterization of variable RES generation,
  - Need for back up generation and interconnection infrastructure,
  - Impacts on short-term system operation and market profitability
- The chosen reference was the **HIRES scenario of the European Commission (2011) : 60% share of RES in the generation mix in 2030**
  - Some hypothesis may be updated but the mechanisms & main messages remain relevant



High RES 2030	GW	Load factor (h/yr)
Solar (PV)	220	1100
Onshore wind	280	1900
Offshore wind	205	3200
Hydro	120	3800

Fuel	Price
Coal	86 €/t
Gas	10 €/MMBtu
Oil	107 €/baril
CO <sub>2</sub>	35 €/t

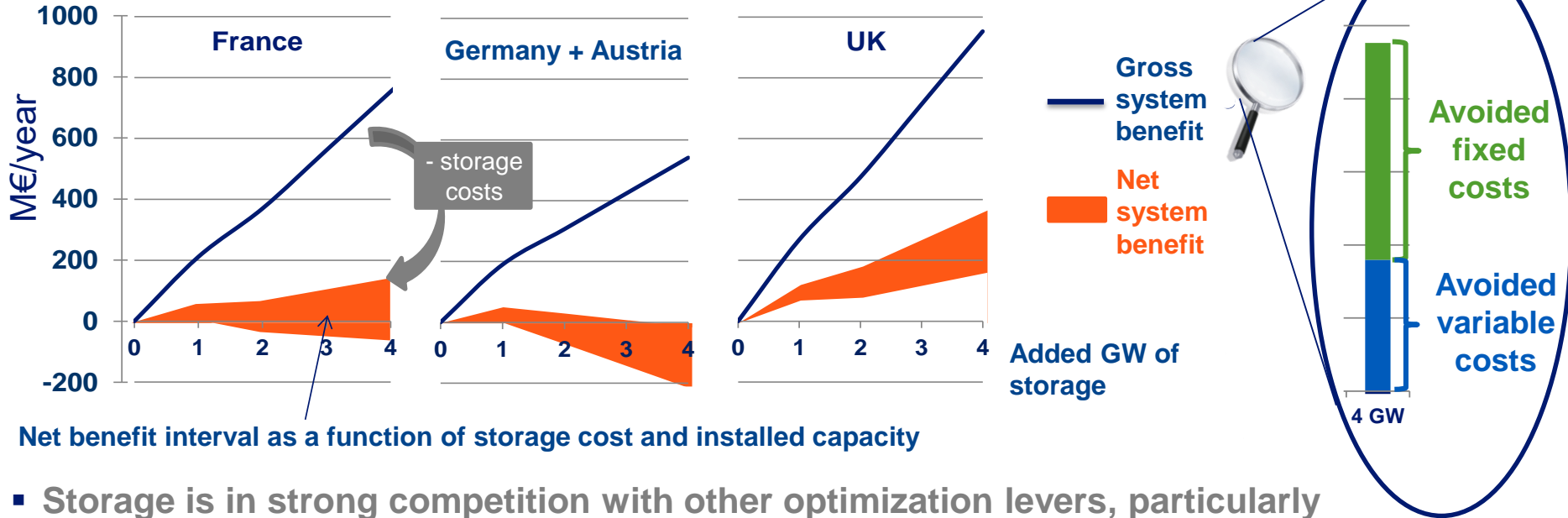


# RESULTS

# INTEREST OF WEEKLY STORAGE IN 3 ZONES

- The need of additional storage capacity depends on the generation mix in each country

Cost-benefit analysis of 40h storage in France, Germany/Austria and in UK



Net benefit interval as a function of storage cost and installed capacity

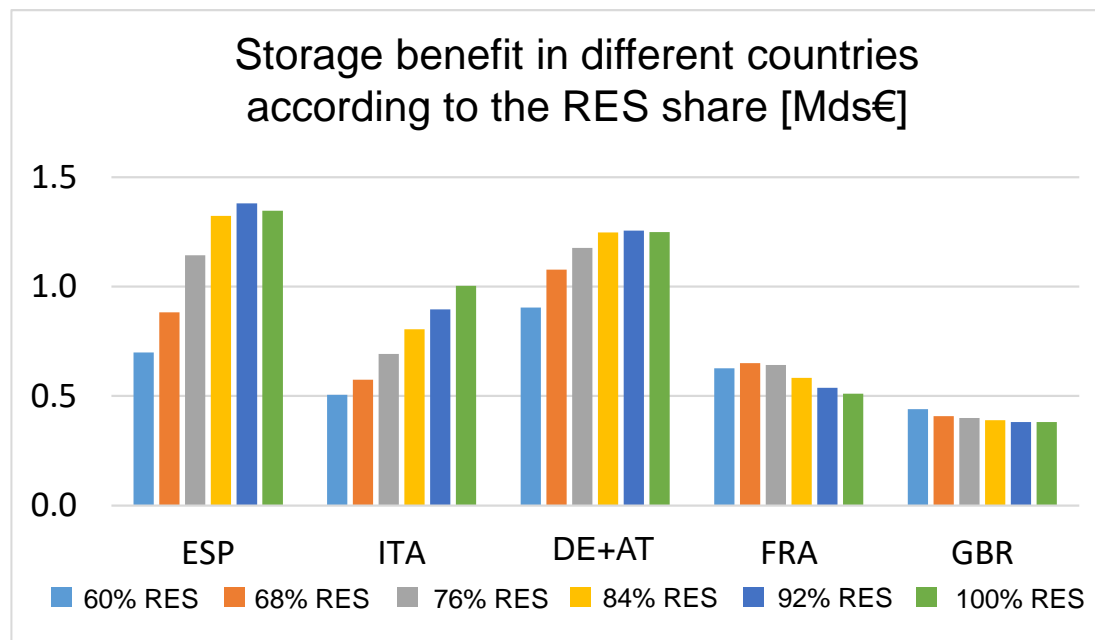
- Storage is in strong competition with other optimization levers, particularly
  - Deploying thermal back up (OCGT) & allowing curtailment
  - Deploying more interconnections

*Grid and conventional back up might face acceptance issues*

➔ The interest of more storage for generation optimization depends on the country, on the other alternatives, on storage costs

# SENSITIVITY OF STORAGE VALUE TO THE WIND & SOLAR PENETRATION

- From the 60% RES, simplified sensitivity analysis on the share of renewables
  - Scaling up the RES production from 60 to 100% of the demand by 8% step
  - **Warning** : resulting shares of wind & PV are probably not realistic, least optimal

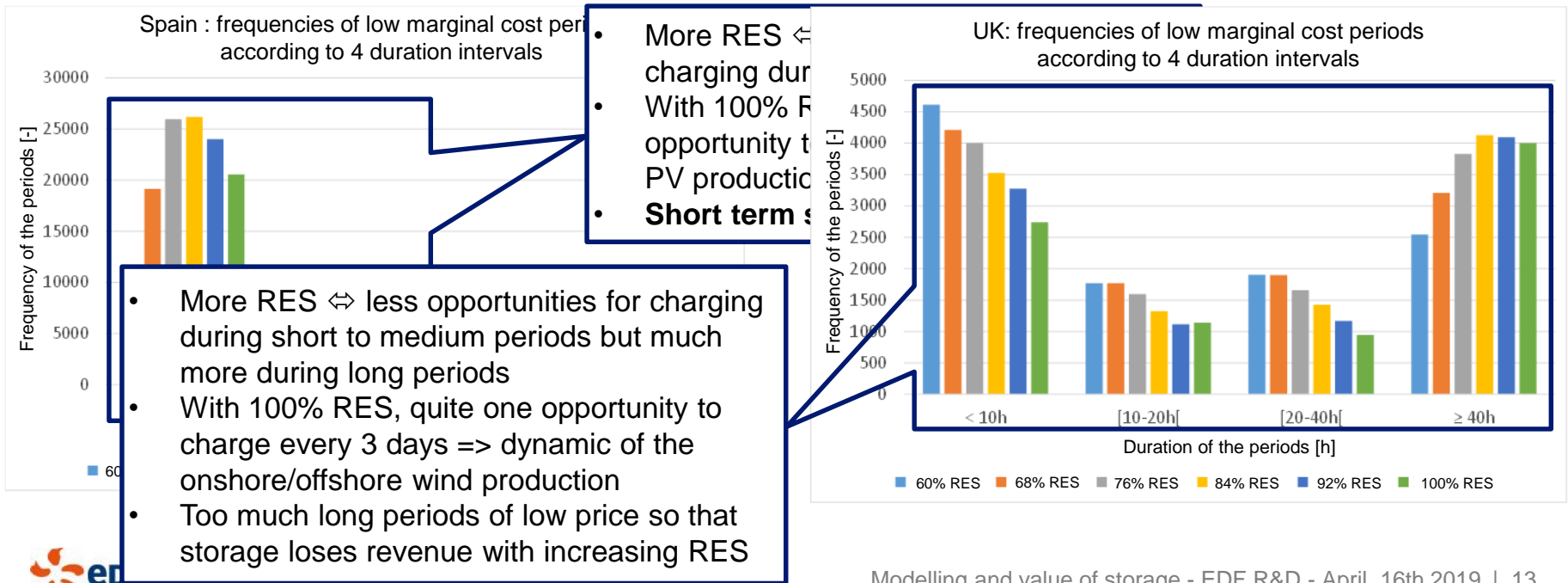


In certain countries, the storage benefit reaches a maximum and even decreases after a certain RES share!

**Storage benefit does not seem to be a systematic growing function of RES share**

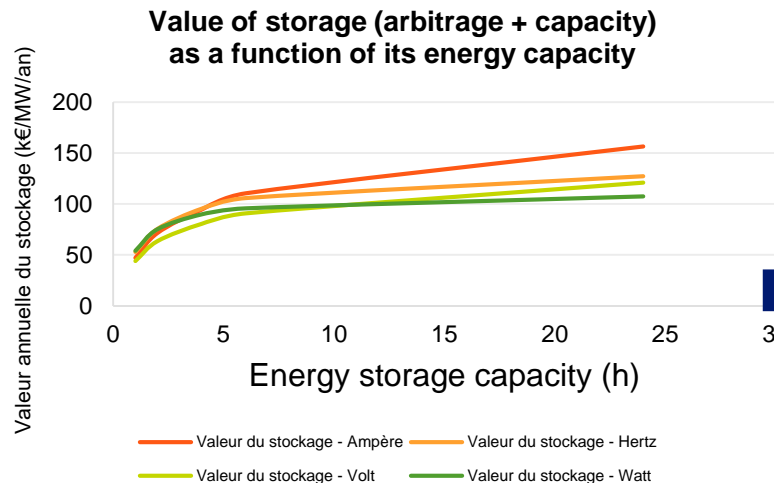
# UNDERSTANDING THE « UNCERTAIN » BENEFIT OF THE STORAGE IN HIGH RES SCENARIOS

- We investigated the economic conditions of charge and discharge of the storage
- We identify periods with continuous (more than 1h)
  - low marginal cost (charge of the storage)
  - high marginal cost (discharge of the storage)
- We analyzed the repartition of low marginal cost periods for Spain and UK (Periods of high marginal cost decrease with an higher share of RES in all cases)



# UNCERTAIN POTENTIAL, SUMMARY OF RECENT STUDY ON SHORT TERM STORAGE POTENTIAL FOR THE FRENCH SYSTEM

Scenarios	Main assumptions				Results		
	Temporal horizon	Share of RES (in energy)	Share of nuclear (in energy)	CO2 price	Space for all the levers of flexibility	Space for storage	Value of a storage of 2h €/kW.y
REI Scenario : « Nouveau Mix » (BP RTE 2014)	2030	39% of which 25% wind and PV	49,2% (France)	95,2 €/t <sub>CO2</sub>	9 GW (France)	3 GW of which 1.3 GW of batteries (with time constant of around 2h)	90 €
	Ampère (2035)	50	46%	108 €/t <sub>CO2</sub>		8.5 GW of which 6 GW of electrochemical storage (with time constant of 2h)	66 €
PEPS-4 (BP RTE 2017)	Hertz (2035)	45	47%	32 €/t <sub>CO2</sub>			71 €
	Watt (2035)	2035	71	11%	108 €/t <sub>CO2</sub>	5-25 GW (France)	71 €
	Volt (2035)	40	56%	32 €/t <sub>CO2</sub>		(without considering competition of other flexibility levers)	58 €



We can confirm 2 trends :

- More RES ⇔ more opportunities for charging during short to medium periods

**Short term storage may be profitable**



# CONCLUSION & APPENDIX

# KEY MESSAGES

- Absolute results of our simulations must be taken carefully as simulations are based on hypothesis which may be updated, intrinsically modelling is a (simplified) representation of the reality...
- Storage as well as RES can provide flexibility & capacity to the power system, however, back-up generation remains necessary!
  - Cost effective, and CO2 emissions of levers must be compared through complete Life Cycle Analysis (and not only marginally)
- Massive penetration of variable RES can lead to new opportunities for storage but these are very dependant on the generation mix in each country
  - There is no unique optimum at the European level regarding the volume & type of storage (hours) to deploy
  - The profitability might not always increase with more RES



# MERCI



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1 LIVRE

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rubrique Environnement.

# SOME PUBLICATIONS OF THE 60% RES STUDY

- **The chosen hypothesis may be updated but the illustrated mechanisms and the main messages remain relevant:**
  - Absolute results must be considered cautiously, as technologies evolve (eg the costs of storage evolve fastly and significantly - in our 2011 study, the range of the storage cost includes the most optimistic cost reduction seen today for 2030– but future breakthrough?)
  - Regulation and new tendencies (e.g. domestic self-consumption) are difficult to foresee - they may have impact on the hypothesis as well as on the results
- **Some publications of the 60% RES study**
  - SILVA, V. and BURTIN, A. : Technical and economic analysis of the European electricity system with 60% RES, EDF R&D, 2015.
  - SILVA, V. and LOPEZ-BOTET ZULUETA, M. and FOURMENT, P. and HINCHLIFFE, T. and BURTIN, A. : Analyse technico-économique d'un système électrique européen avec 60% d'énergies renouvelables, Revue de l'Électricité et de l'Électronique, December 2016
  - PERROT, M. and SILVA, V. and HINCHLIFFE, T. and FOURMENT, P. and LOPEZ-BOTET ZULUETA, M. : Economic and technical analysis of the European system with high RES scenarios, 10th Conference on The Economics of Energy and Climate Change, September 2015, Toulouse
  - WANG, Y. and SILVA, V. and WINKELS, A. : Impact of high penetration of wind and PV generation on frequency dynamics in the continental Europe interconnected system, 13th International Workshop on Large-scale Integration of Wind Power into Power Systems, Berlin, October 2014.
  - WANG, Y. and SILVA, V. and LOPEZ-BOTET ZULUETA, M. : Impact of high penetration of variable renewable generation on frequency dynamics in the continental Europe interconnected system, IET Renewable Power Generation, Volume 10, Issue 1, January 2016, p. 10-16
  - PRIME, G. and SILVA, V. and LOPEZ-BOTET ZULUETA, M. : Integration of flexibility assessment to generation planning of large interconnected systems, IEEE Transactions on Power Systems, and value of storage - EDF R&D - April, 16th 2019 | 18

# LITERATURE REVIEW

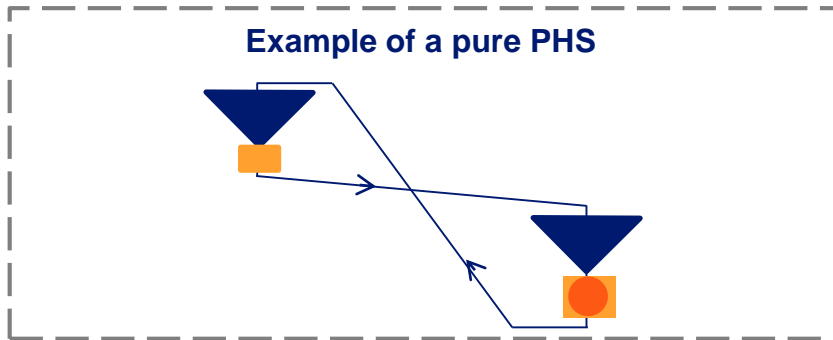
- The literature on Energy Storage (ES) is getting more and more extensive.
- In France over the last ys, several relevant analyses for ES:
  - 2013 : PEPS1
  - 2015 : ADEME 100% EnR, BP RTE, REI 1
  - 2016 : PEPS3
  - 2017 : NFI, IFRI, REI 2
  - 2018 : PEPS4
- **Consensus: reaching profitable business models is generally challenging - storage has strong competitors (thermal back up, DR, interconnectors)**
  - However, battery prices reduce faster than expected
  - Other levers are more & more constrained (thermal back up, grid developement)
- **Analysing storage requires complex modelling, and regularly updated studies as the foreseen scenarios evolve**
  - Investigation with ever higher rates of wind and/or PV
  - Continuous reduction of the storage costs (batteries)
  - Development of new electricity uses (mobility, power to heat, etc.)
  - Cross technical & regulatory evolutions (self consumption, etc.)



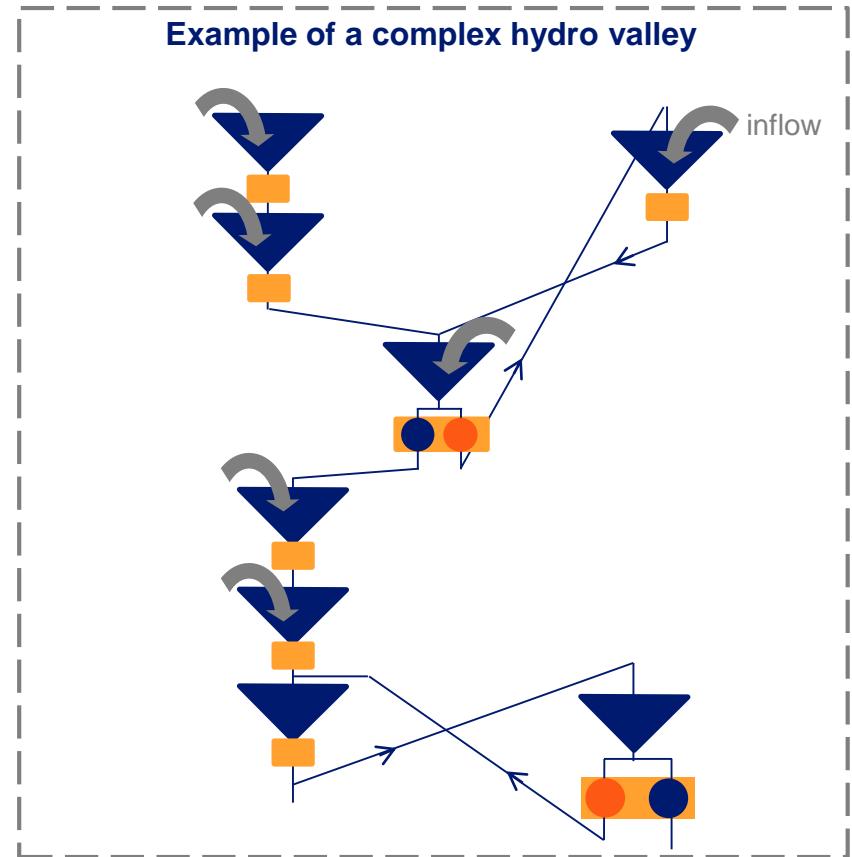
# ILLUSTRATION OF THE MODELLING COMPLEXITY

## Pump-Hydro Storage (PHS) : 2 types of plant

**Pure (or off-stream) PHS :**  
1 upper and 1 lower reservoir with  
a single pump/turbine system



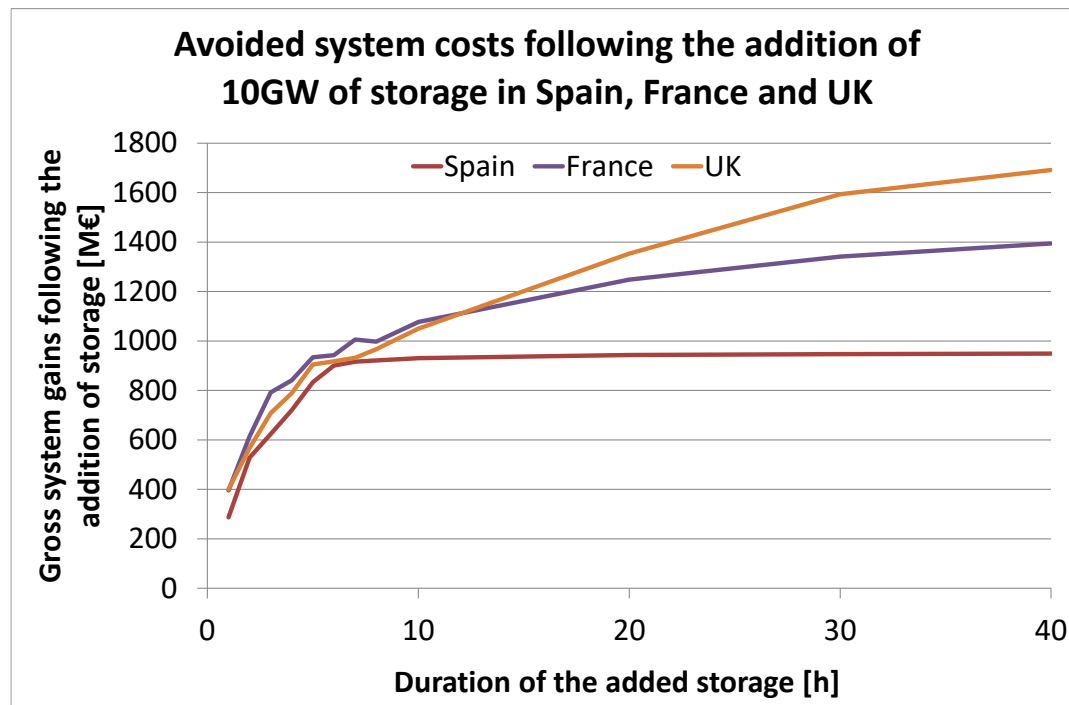
**Combined PHS (pump-back power plants):**  
combination of pumped water and natural  
stream flow to store/release energy (optimised  
within whole hydro valleys)



Availability of input data as well as  
complex valleys modelling in multi-  
zones models at European level are  
both challenges

# SENSITIVITY ON STORAGE DURATION: FROM 0 TO 40H

- With high capacity storage addition :
  - System gains raise consequently between 1 and 10h storage
  - According to the mix, system gains are then saturated (Spain) or may double (UK)



**Storage value is not a linear function of storage duration & the optimal value will depend on the mix (in France & UK, interest 10 h + storage)**