# 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

zinium

Working on some battery developement

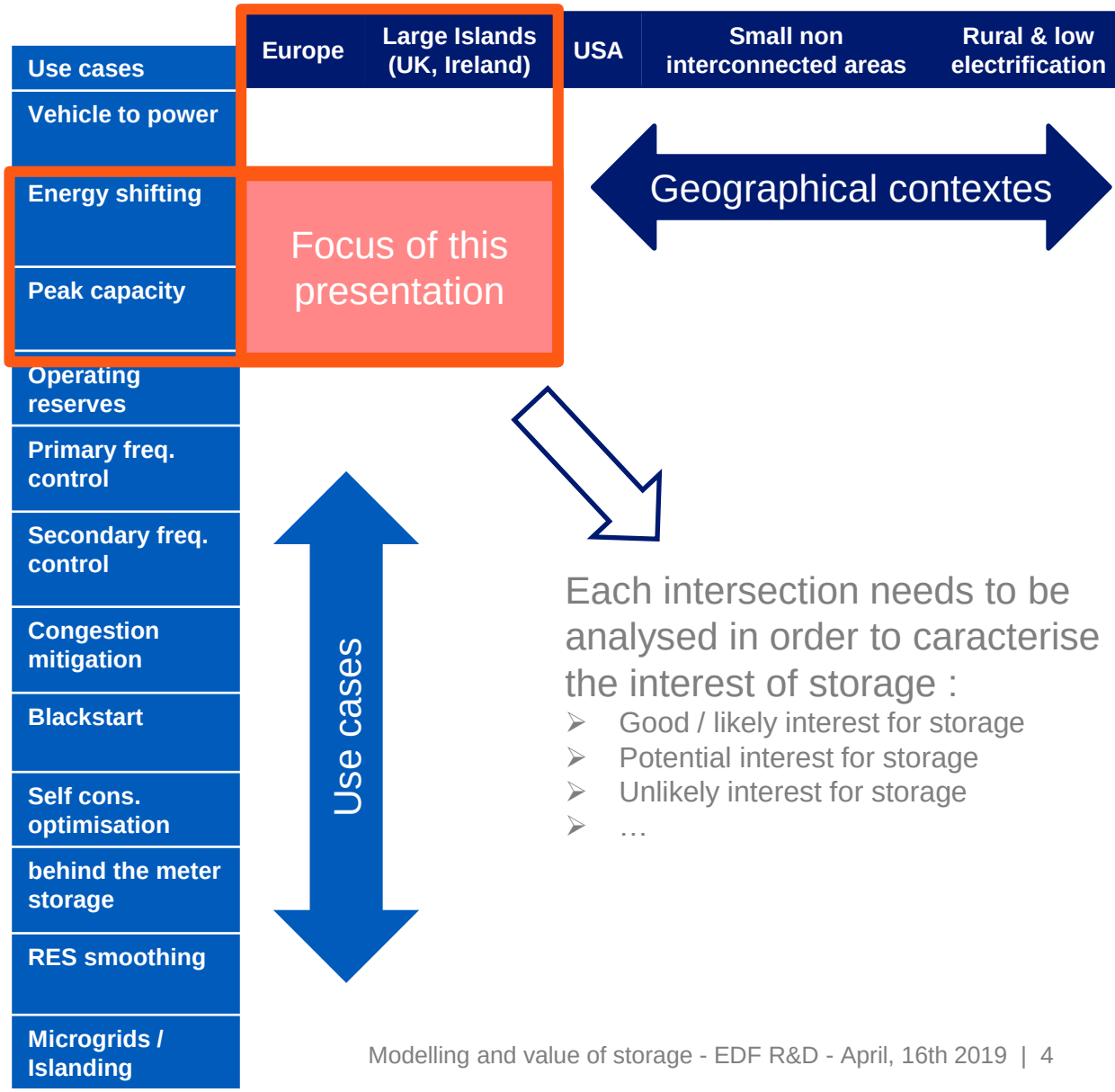
20MW battery – Mac Henry (USA) ©EDF


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


1 MW/0,5 MWh @Concept Grid EDF Lab Les Renardières

# 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

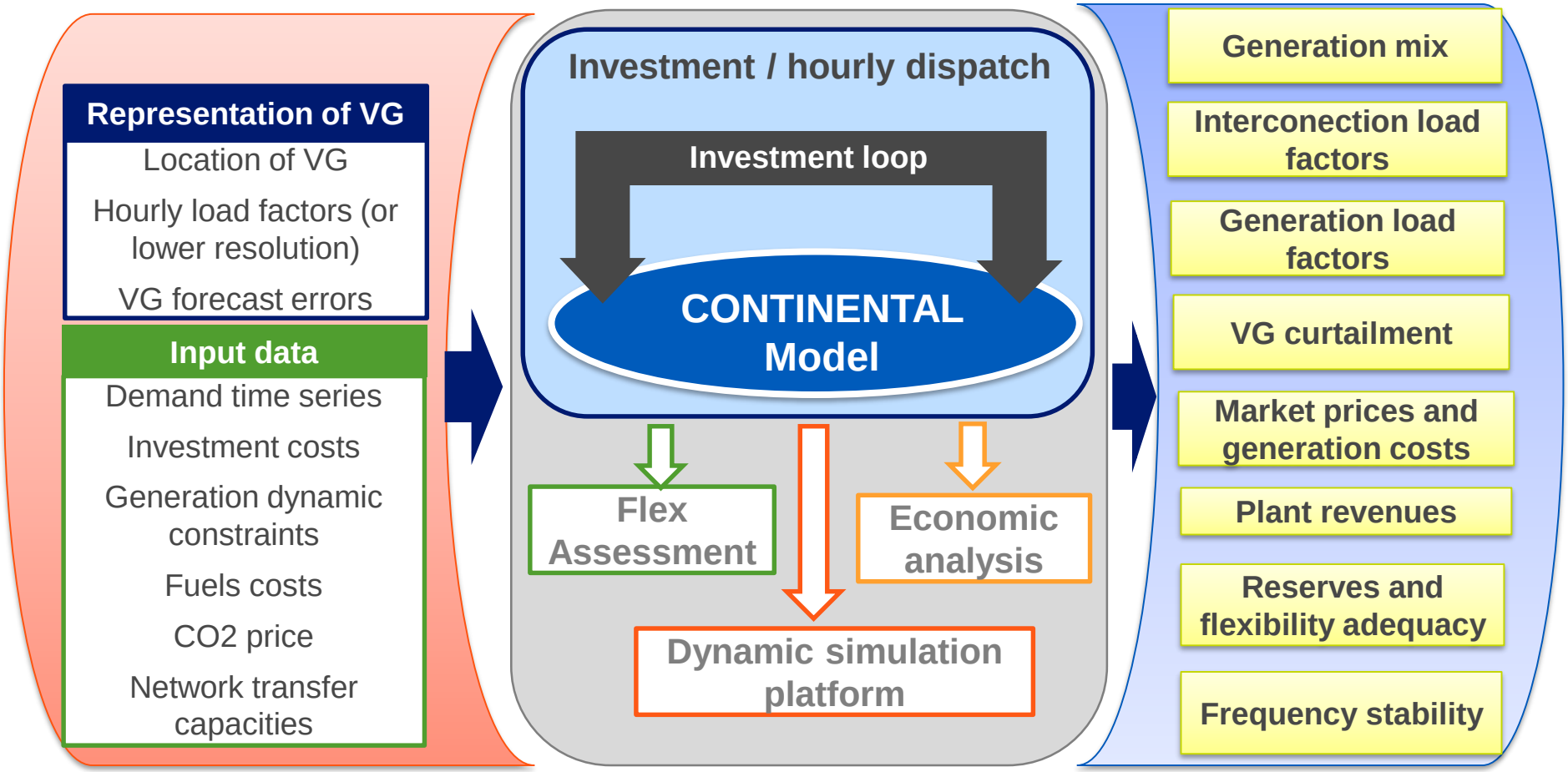



Each intersection needs to be analysed in order to caracterise the interest of storage :

- Good / likely interest for storage
- Potential interest for storage
- Unlikely interest for storage
- …

# MODELLING

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



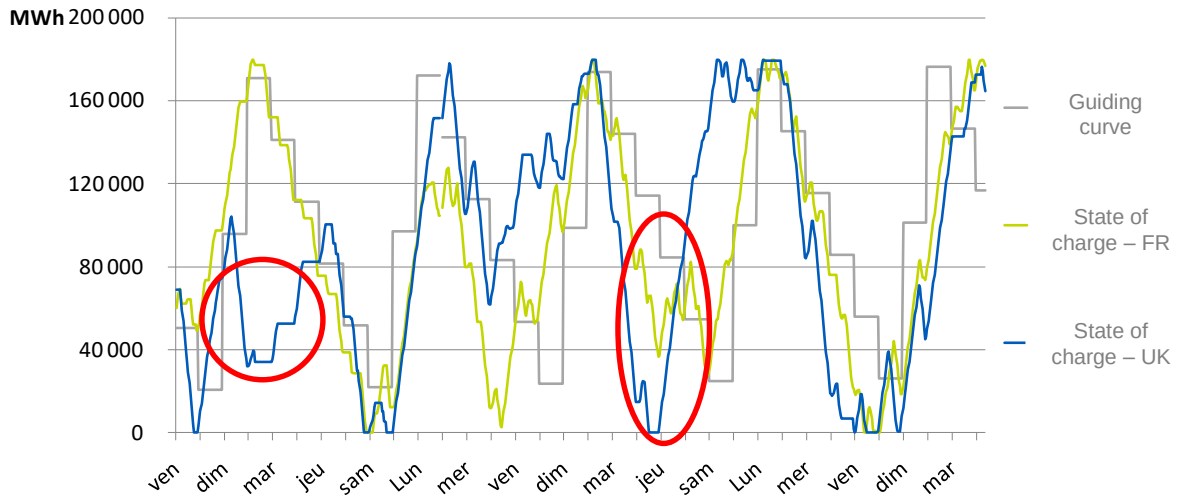

*Reference :* LOPEZ-BOTET, M. et al. : Methodology for the economic and technical analysis of the European power system with a large share of variable renewable generation, presented at IEEE PES General Meeting, Washington, USA, 27-31 July, 2014.

# 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**



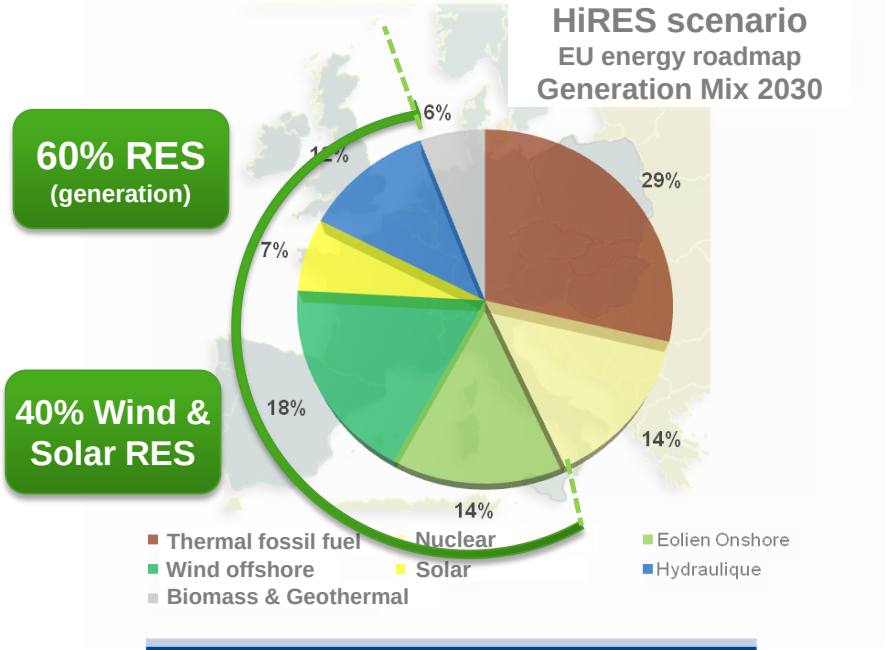

**Storage behaviour can be very different according to the generation mix!**

**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 |

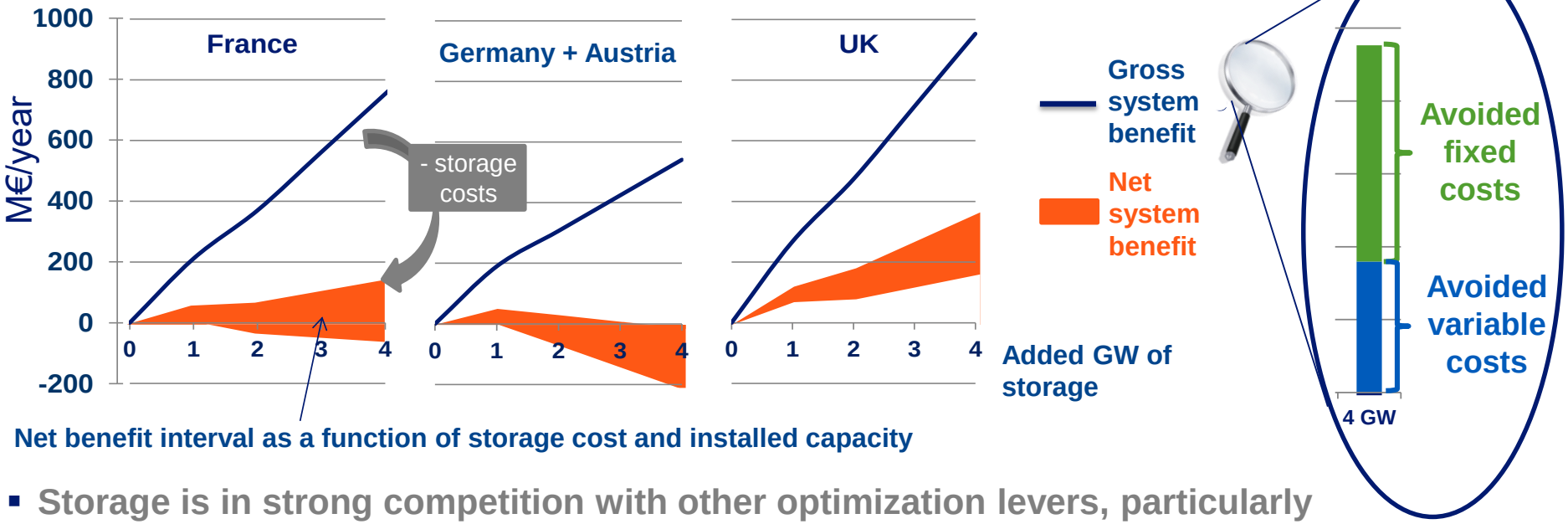
| Fuel | Price |
|---|---|
| **Coal** | 86 €/t |
| **Gas** | 10 €/MMBtu |
| **Oil** | 107 €/baril |
| **$CO_2$** | 35 €/t |

# RESULTS

# INTEREST OF WEEKLY STORAGE IN 3 ZONES

- The need of additionnal 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

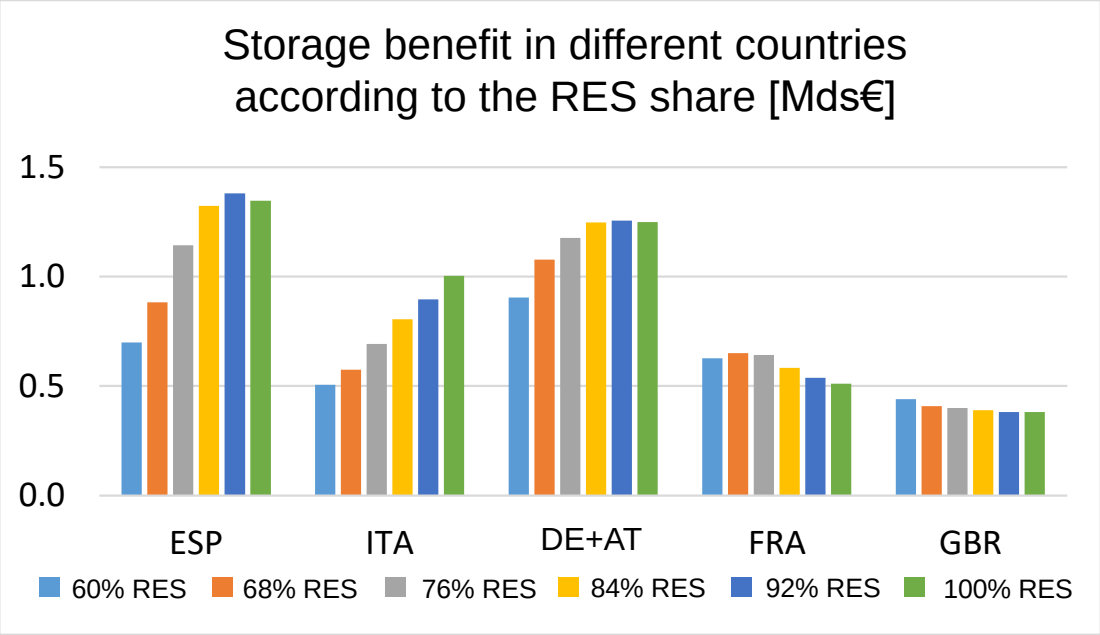
*Grid and conventional back up might face acceptance issues*

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

Our results are in line with the literature – see for example the PEPS study (2013)

# 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

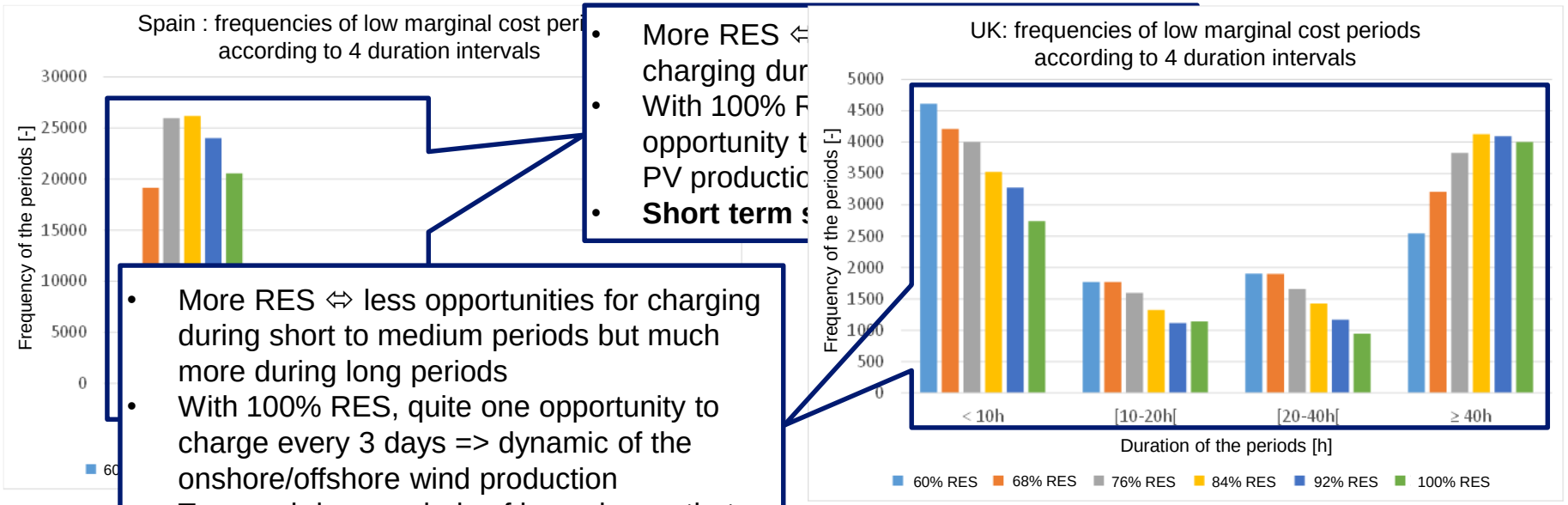



In certain countries, the storage benefit reaches a maximum and even decreases after a certain RES share!

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

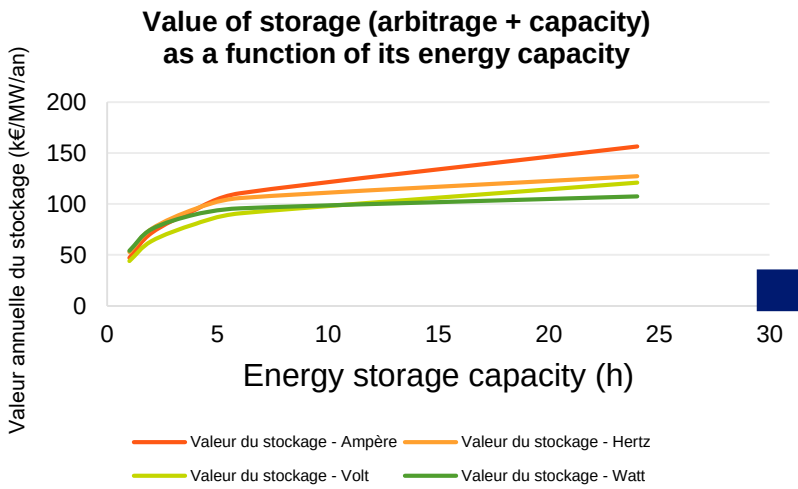
# UNDERSTANDING THE « UNCERTAIN » BENEFIT OF THE STORAGE IN HIGH RES SCENARIOS

- **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 €/$t_{CO2}$ | 9 GW (France) | 3 GW of which 1.3 GW of batteries (with time constant of around 2h) | 90 € |
| PEPS-4 (BP RTE 2017) | Ampère (2035) | 2035 | 50 | 46% | 108 €/$t_{CO2}$ | 5-25 GW (France) | 8.5 GW of which 6 GW of electrochemical storage (with time constant of 2h) (without considering competition of other flexibility levers) | 66 € |
| | Hertz (2035) | | 45 | 47% | 32 €/$t_{CO2}$ | | | 71 € |
| | Watt (2035) | | 71 | 11% | 108 €/$t_{CO2}$ | | | 71 € |
| | Volt (2035) | | 40 | 56% | 32 €/$t_{CO2}$ | | | 58 € |




We can confirm 2 trends :

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

**Short term storage may be profitable**

Source PEPS4

# 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


1 LIVRE

18 CHERCHEURS DE LA R&D D'EDF

18 TECHNOLOGIES DE STOCKAGE DE L'ELECTRICITE

7 SERVICES POUR LE SYSTEME ELECTRIQUE

Achetez le livre sur le site www.lavoisier.fr rubrique Environnement.

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# 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,

# 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.)

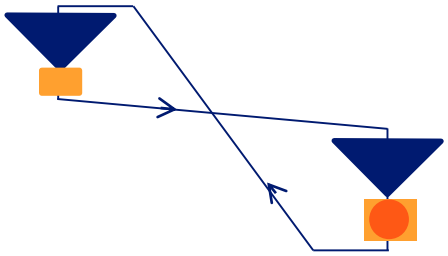
# ILLUSTRATION OF THE MODELLING COMPLEXITY

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

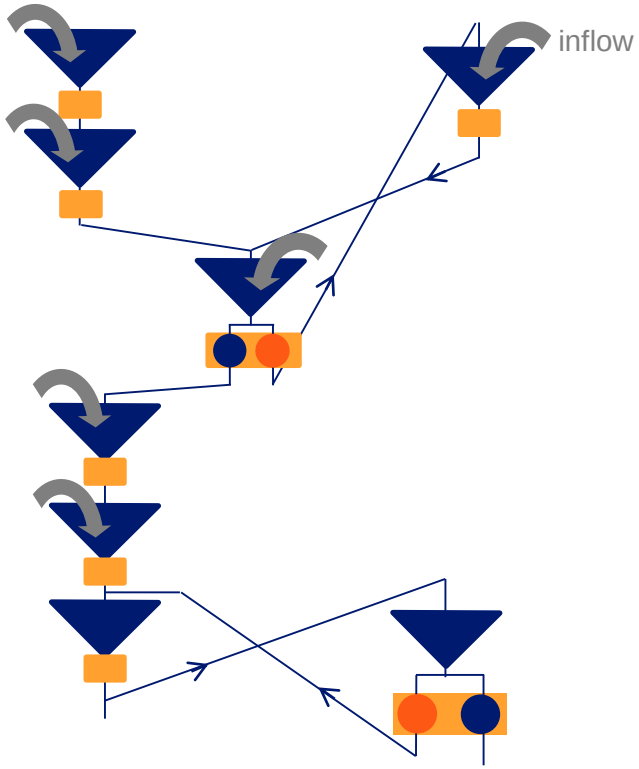
**Pure (or off-stream) PHS :**
1 upper and 1 lower reservoir with a single pump/turbine system

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

**Example of a pure PHS**



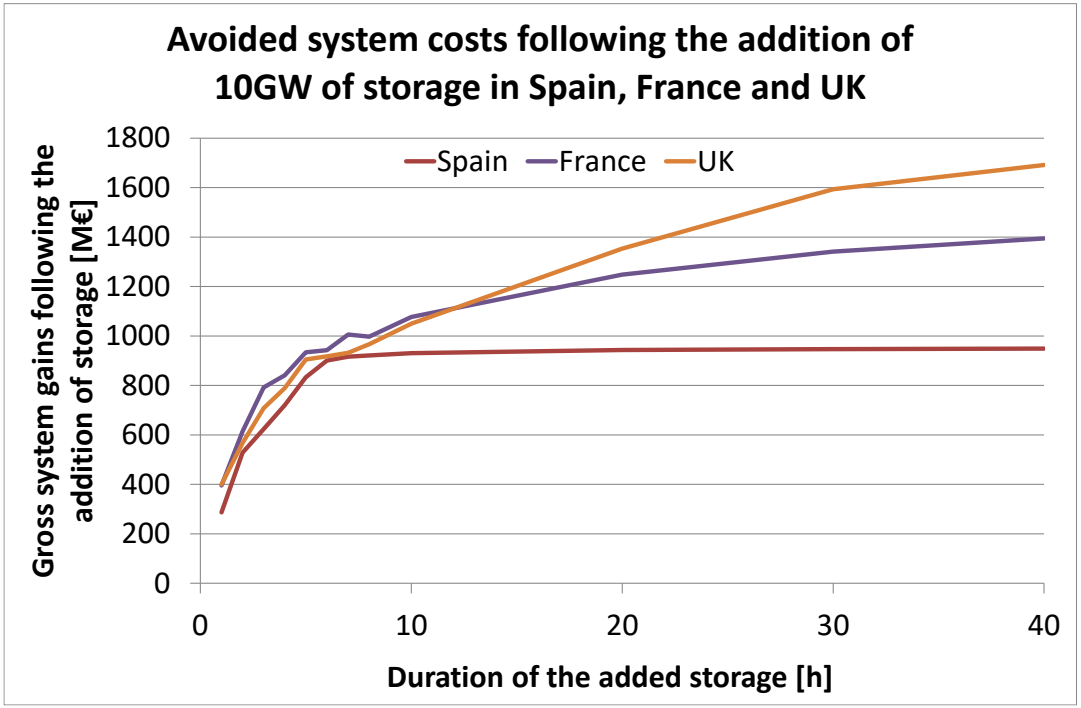
**Example of a complex hydro valley**




**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)**