# Role of Storage in Integrating Wind Energy

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# Outline

- Objective and Assumptions
- Methodology
- Reserve Options
- Case Studies
- Discussion of Results

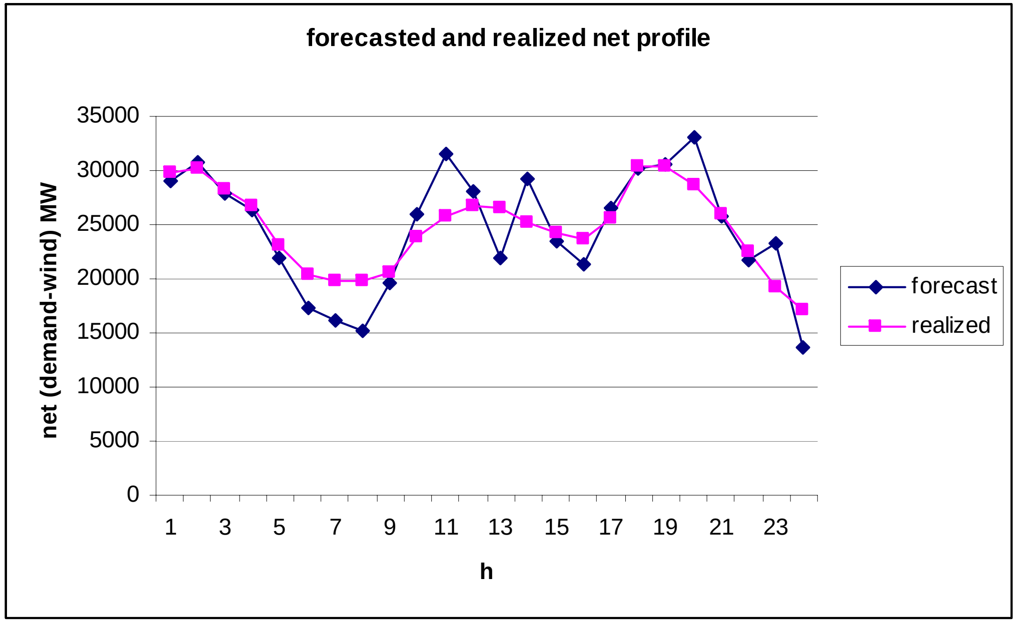
# Objective and Assumptions

- Objective
  - Provide magnitude of order estimates of the value of storage, to the reduction of the additional costs of balancing the system, due to the integration of intermittent wind generation, in the context of the future UK electricity system (2020)
- Assumptions
  - Cost based approach (market arrangements not considered)
  - Balancing task performed at system level not at individual generation / supply company level
  - Arbitrage excluded
  - Management of network constraints not considered
  - Generic, flexible bulk energy storage technology (central or distributed)

# Methodology

- Unit commitment

Mixed Integer Programming (MIP) formulation or, alternatively, a priority ranking method, can be used for committing generating units on a day-ahead basis considering wind and demand forecasts. This is based on the forecast net demand and wind profile.



# Methodology

- Economic dispatch

A Linear Programming (LP) formulation is used for dispatching power among generators, wind, storage and OCGT standing plants in real time with the following objective function:

***Minimise*** *f(x)*

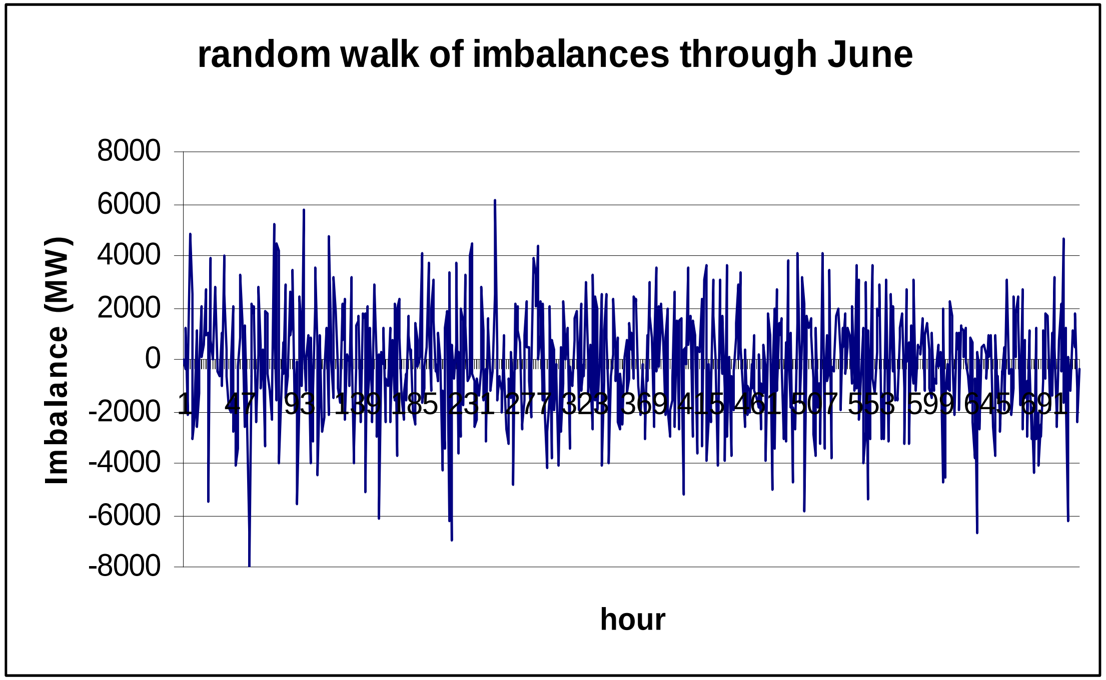
$$f(x) = \left[ \sum_{i=1}^{I} C_i(t) P_i(t) \right] + \alpha Wshed(t) + \beta Sdisch(t) +$$

$$+ \gamma Overslack(t) + OcgtCost * OcgtOut(t) + VOLL * Lshed(t)$$

# Methodology

- Random walk of imbalances

We use the concept of random walk to model the imbalances whereby, at each time period, there is a random displacement step or imbalance from the forecast wind profile. A random number generator generates a uniform distribution of random numbers.



# Methodology

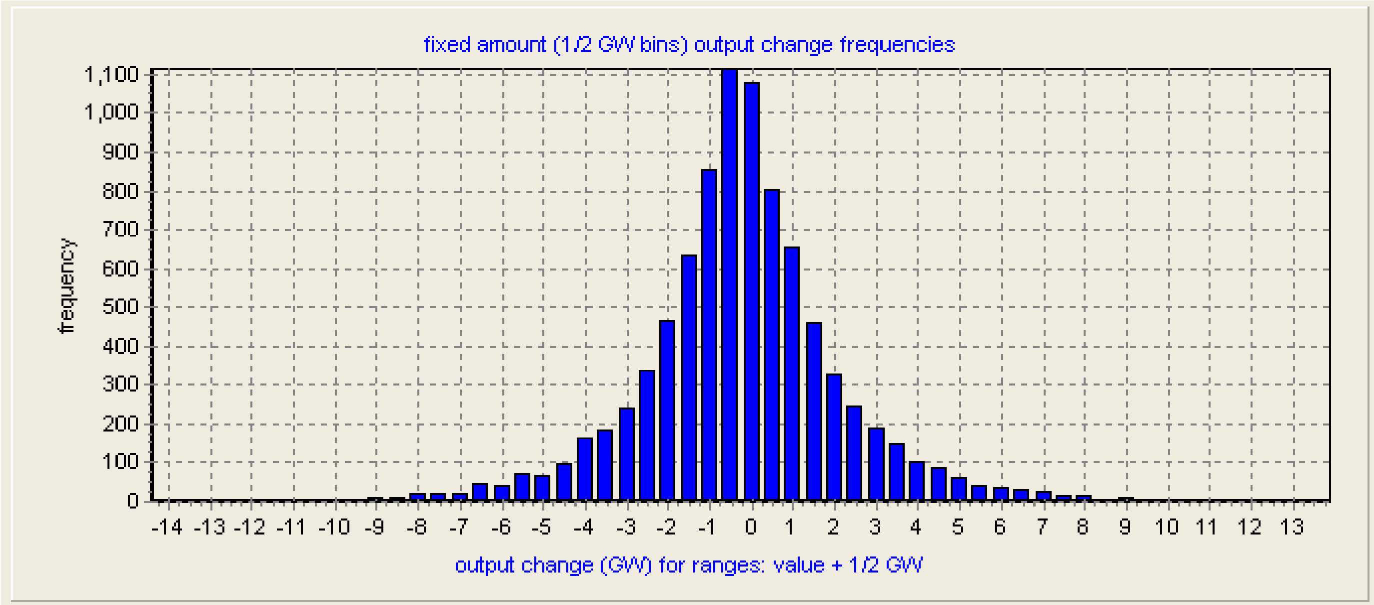
- Statistical Methods

Statistical methods, based on wind time series data analysis and wind forecast error, for determining reserve levels are needed. Persistency based wind forecast techniques are used considering different lead times from one to four hours, considering the last as the typical time to start a new plant.

- The fluctuations of wind power output are described in term of standard deviation of changes of wind output over various time horizons

- Typically using a 4 hour lead time for reserve requirements

# Methodology




| 4 hourly output change (26 GW wind) | Value (GW) |
|---|---|
| Standard Deviation | 2.415 |
| Minimum | -11.716 |
| Maximum | 12.906 |

# Reserve Options

- Spinning Reserve is provided by synchronised plants running part loaded
  - Cost driven by loss in efficiency of part loaded plants
  - Additional plants needed to compensate for running part loaded
- Reserve provided by standing reserve
  - Use fast response plants with higher fuel cost if and when needed
- Optimal mix of spinning and standing reserve
  - Balance between cost of holding spinning reserve and cost of exercise of standing reserve
  - Impact of wind power that can be absorbed

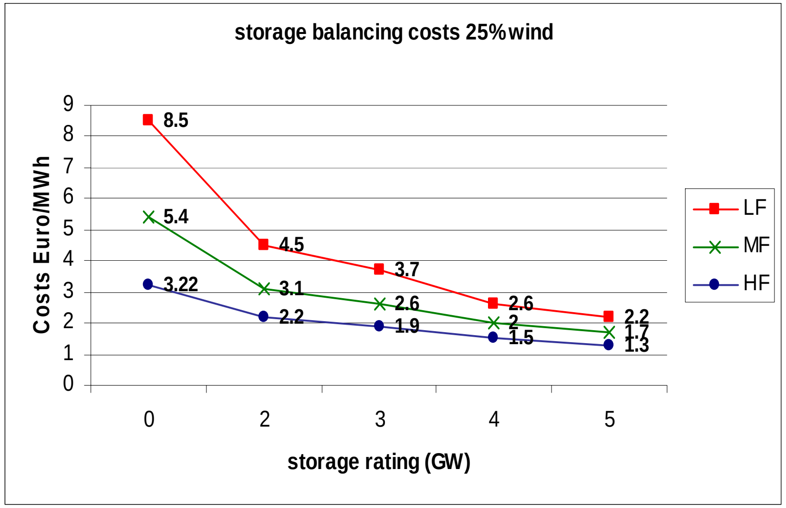
# Case Studies

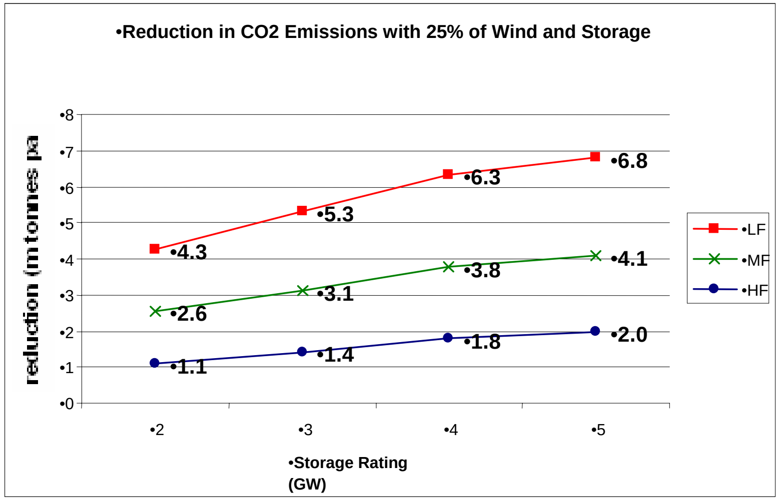
## Generation Systems Studied

| Generation System | Inflexible Generation | Moderately flexible generation | Flexible Generation |
|---|---|---|---|
| ***Low flexibility (LF)*** | 8.4 GW installed, has to run at 100% of max capacity | 26 GW installed, minimum stable generation 77% of max capacity | >25.6 GW installed, minimum stable generation 50% of max capacity |
| ***Medium flexibility (MF)*** | 8.4 GW installed, has to run at 100% of max capacity | 26 GW installed, minimum stable generation 62% of max capacity | >25.6 GW installed, minimum stable generation 50% of max capacity |
| ***High flexibility (HF)*** | None | None | >60 GW installed, minimum stable generation 45% of max capacity |

# Case Studies

## Standing reserve – storage only option



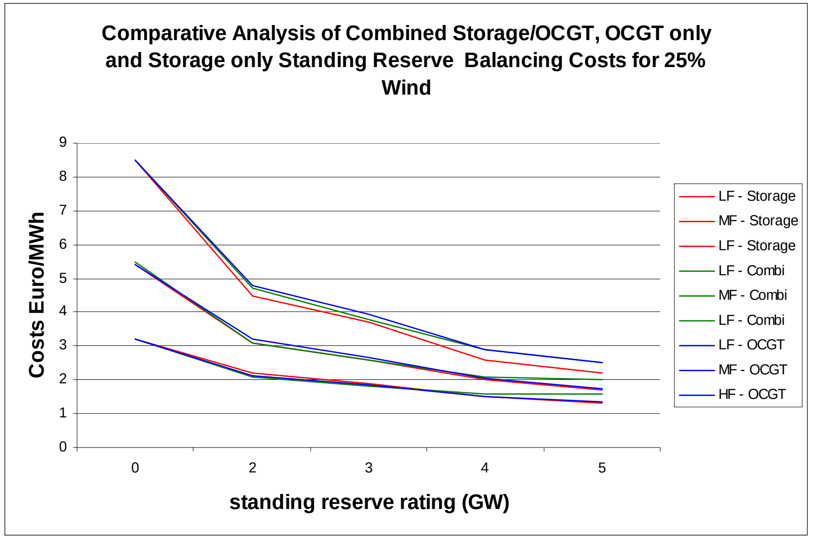



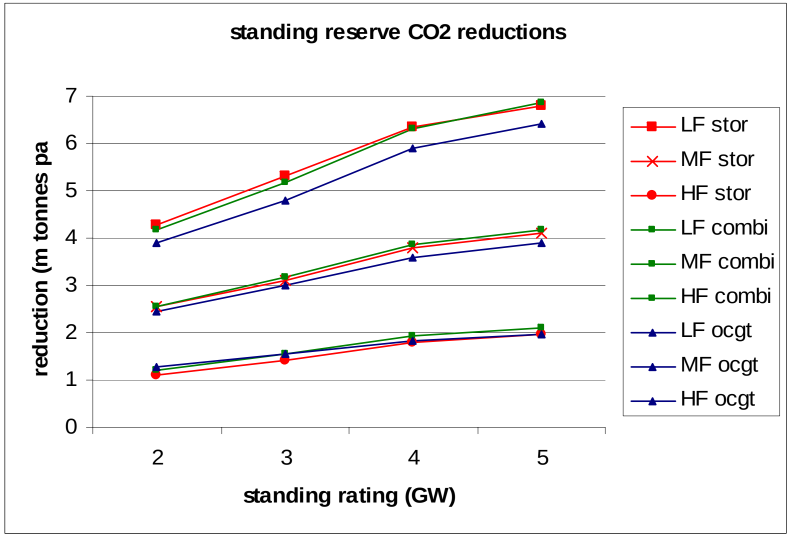

The balancing fuel cost reductions, comparing to the base case, are highest in the LF system so the value of storage increases as the flexibility of the system decreases. The benefit of storage on the reduction of CO2 emissions is higher in the LF system. This is because as the flexibility of the system increases its ability of absorbing wind increases due to the lower values of must run generation.

# Case Studies

## Combined standing reserve option – Storage(1GW)/OCGT

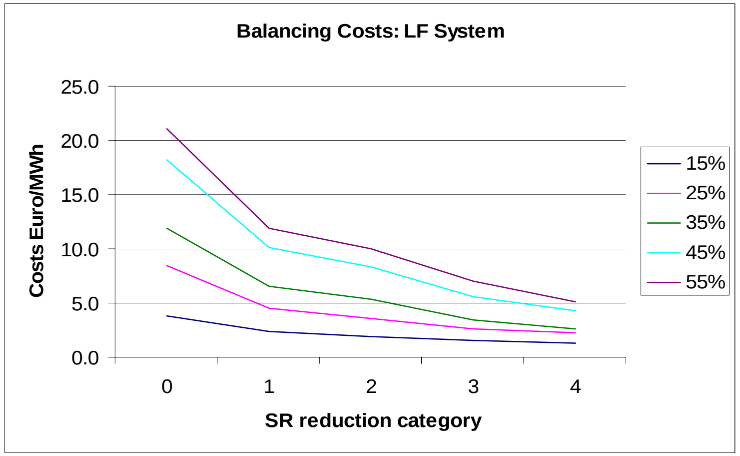
The value of the combined reserve (green line) lies between the value of reserve from OCGT only (blue line) and Storage only (red line). The most efficient technology on the reduction of fuel costs is storage. As the flexibility of the generation system increases this difference becomes less relevant.

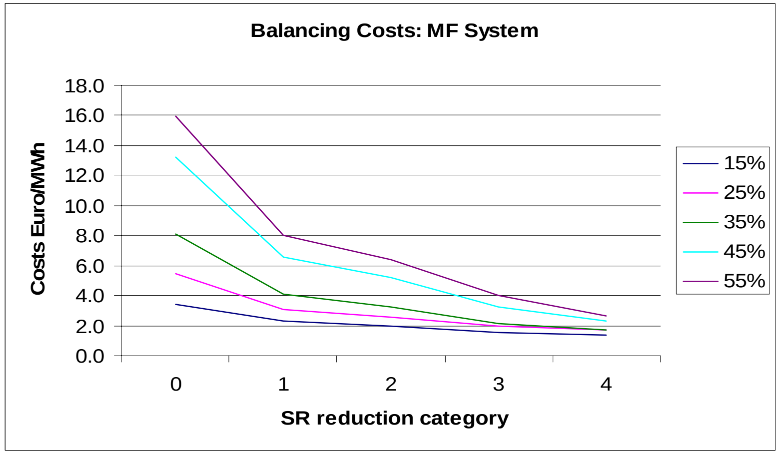


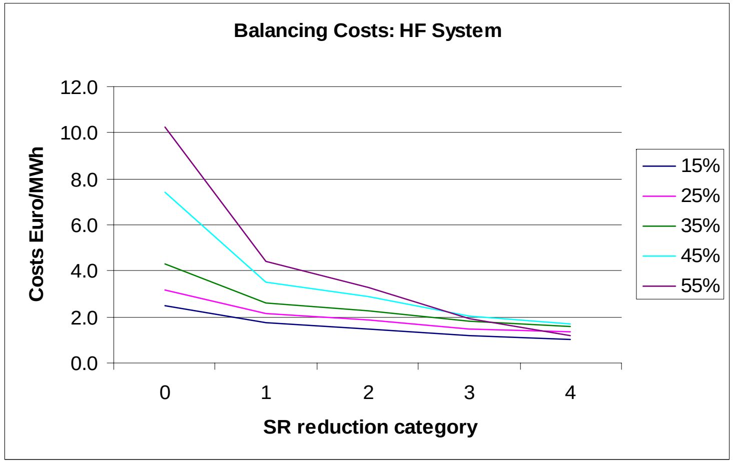



# Case Studies

## Increasing Wind Penetration – Reduction in Balancing Fuel Costs



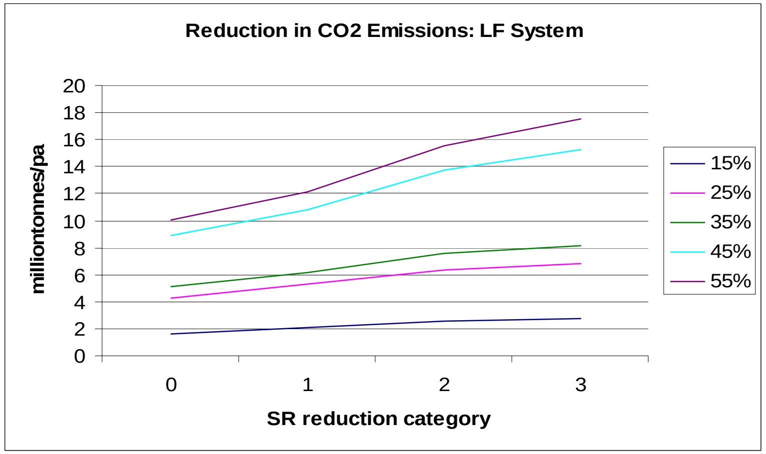

The trend for all cases show an increase in the value of storage with higher wind penetration.

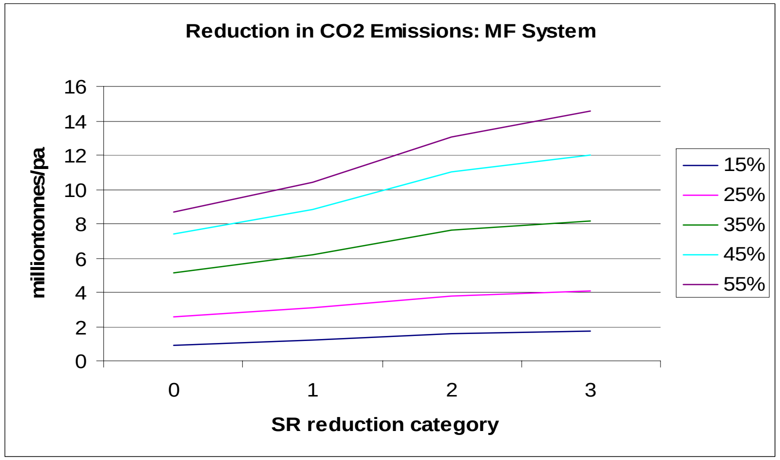
Storage in all cases has its highest value in the low flexibility system.

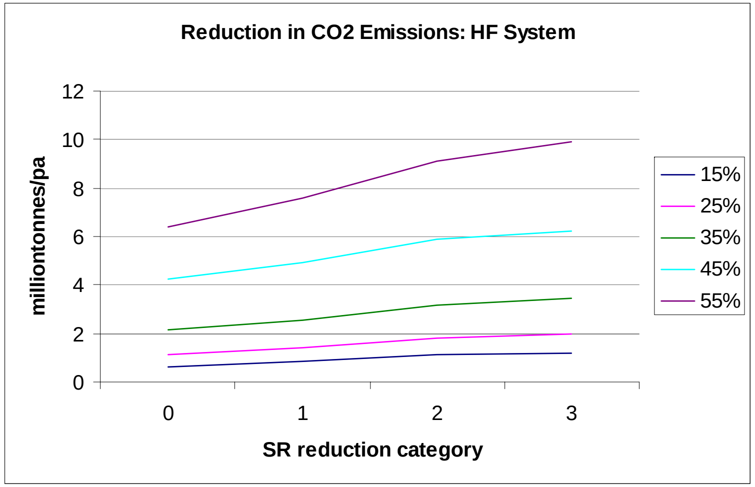
Storage value also increases with reduced spinning reserve.

# Case Studies

## Increasing Wind Penetration – Reduction in CO2 Emissions



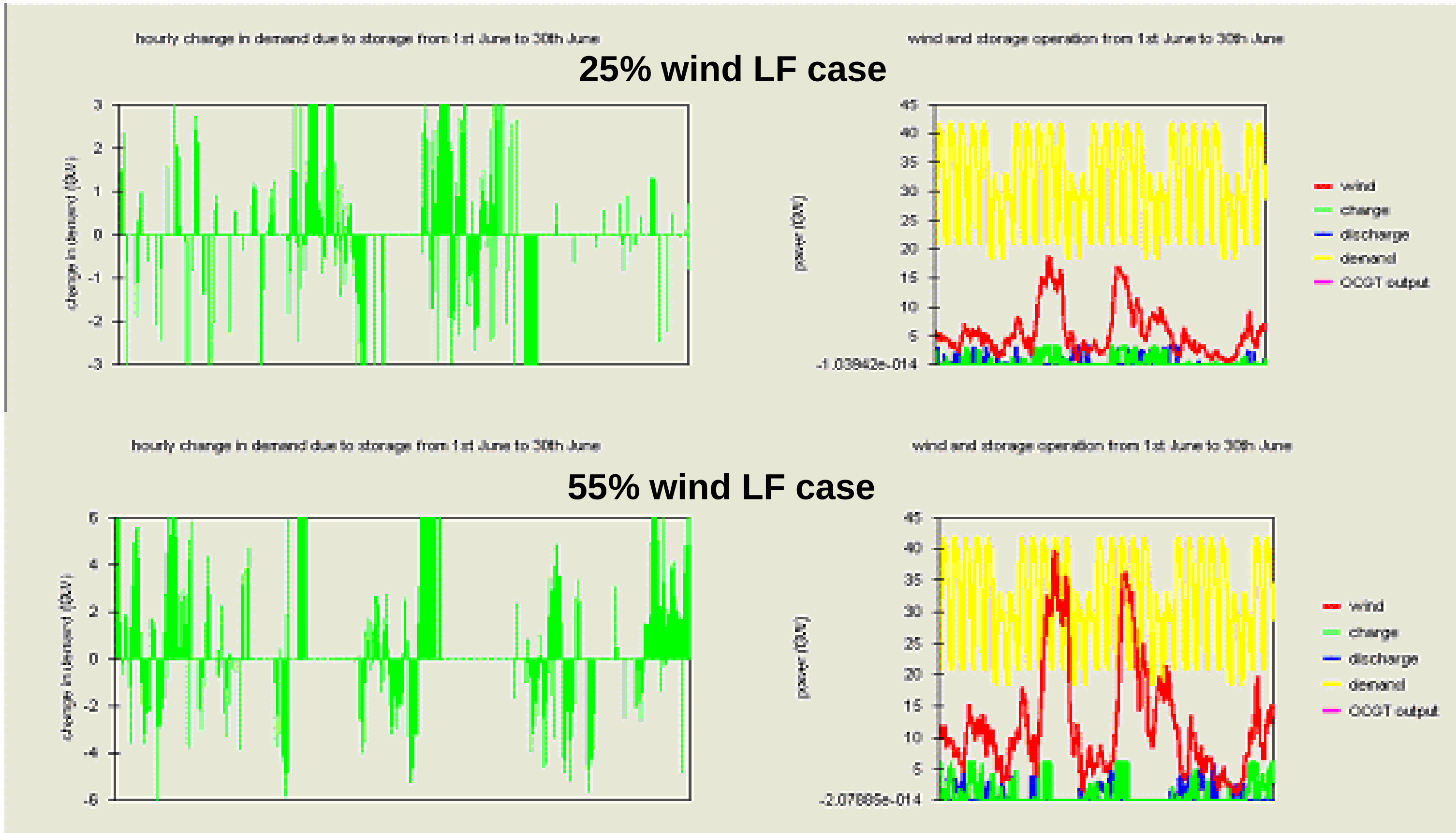

The trend for all cases show an increase in the value of storage on the reduction of CO2 emissions with higher wind penetration.

Storage in all cases has its highest value in the low flexibility system.

Storage value also increases with reduced spinning reserve.

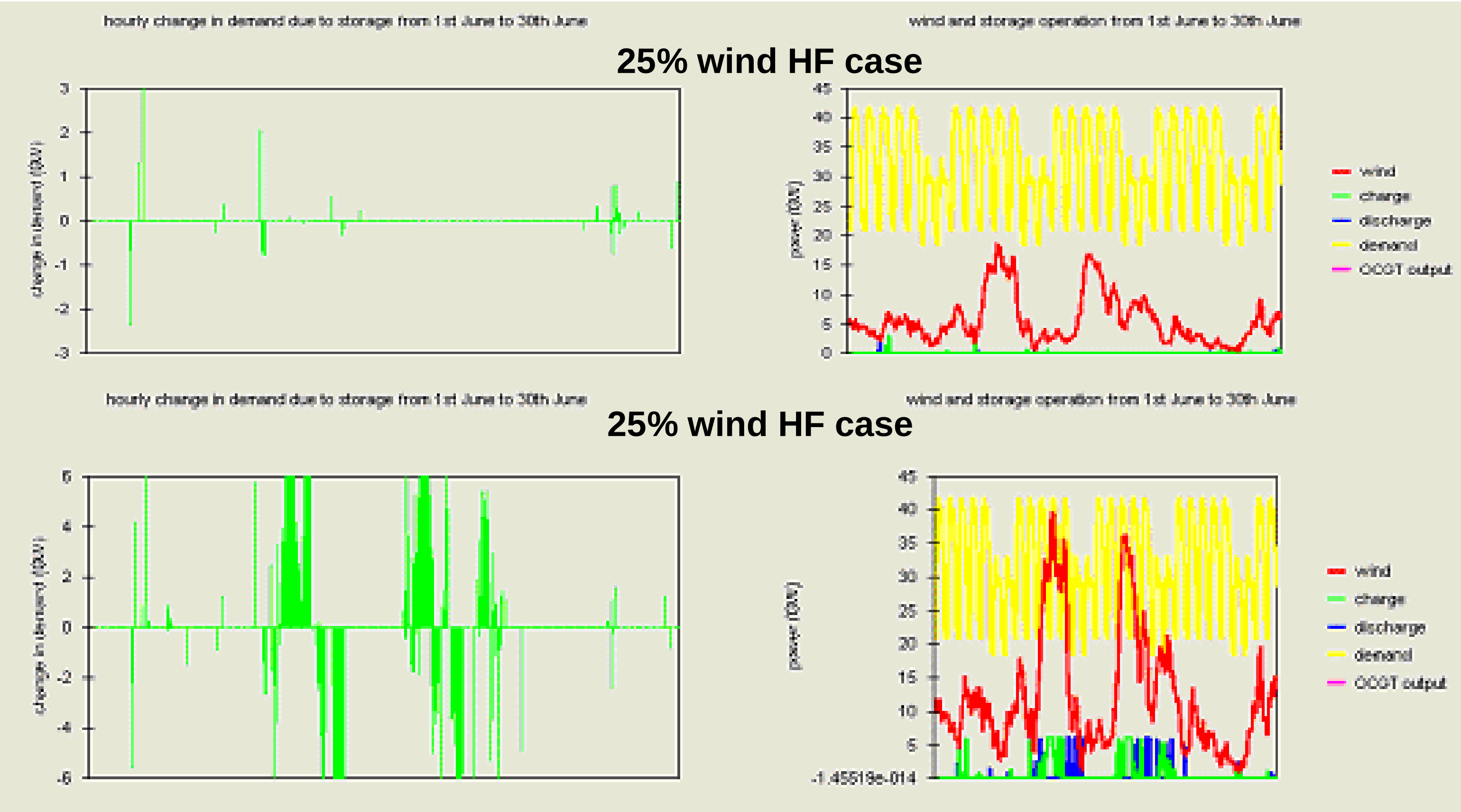
# Case Studies

## Use of Storage in the LF System – Example of June



# Case Studies

## Use of Storage in the HF System – Example of June



# Discussion of Results

## Storage Providing Standing Reserve with 25% Wind Penetration

- storage can play a valuable role in reducing balancing fuel costs and carbon emissions resulting from the additional balancing task associated with the increase on uncertainty introduced by the wind uncertainty
- storage has the unique ability to utilize surplus wind, by charging when wind is high and demand is low and discharging when wind is low and demand high. This leads to a more efficient utilization of wind and helps to deal with the intermittency problem increasing the amount of wind used by the system
- the flexibility of the conventional generation mix is a key factor to the value of storage

# Discussion of Results

## Combined Storage/OCGT Standing Reserve with 25% Wind Penetration

- In reality we will expect standing reserve to be provided by a combination of different technologies. We performed case studies in order to find the value of a small amount of storage combined with OCGT
- we found that just 1 GW of storage makes most of the contribution to the benefit that this solution has over an OCGT only solution
- as standing reserve capacity increases, the weight of the value of the storage part of the solution becomes increasingly important

# Discussion of Results

## Increasing Wind Penetration: 15%, 25%, 35%, 45%, 55%

- from the studies with increasing wind penetration it becomes clear that the value of storage is interacting both with the flexibility of the generation system and the wind penetration level
- high wind penetrations lead to high and frequent surplus wind occurrences. A generating system with low flexibility are particularly vulnerable to these surpluses. Storage does not have the opportunity to discharge so we will not get value on its use
- the flexible system on the other hand, had no surplus wind occasions at lower wind penetrations, and therefore gave storage no advantage in terms of storing the surplus, will get more value for storage with high wind penetration
- the advantage of storage over OCGT increases for the flexible systems with higher wind levels