Enhanced Representative Days and System States Modeling for Energy Storage Investment Analysis

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Outline

- Motivation and Background
- Contributions
- Description of Models
- Case Studies and Results
- Conclusions and Recomendations

Why is energy storage becoming so important?

- Synergies between renewable technologies and energy storage
- Key services for energy storage:
  - Energy Arbitrage
  - Balancing Services
  - Frequency services (e.g. 2nd reserve)
  - Network support
  - Capacity Markets
  - Carbon savings

In order to obtain good policies on energy storage, policymakers need proper energy storage representation in medium and long term planning models

What is needed to properly represent energy storage?

A. The chronological information

Current modeling frameworks that preserve chronology in medium and long term models

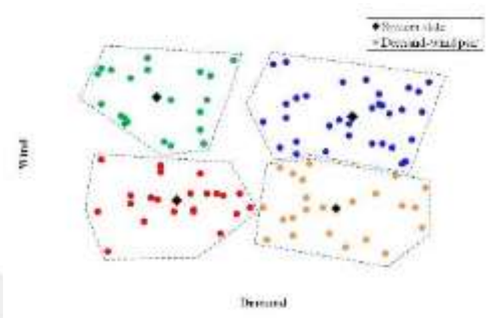
System States

Extended version of time slices, load duration curve, or load blocks

Representative Periods

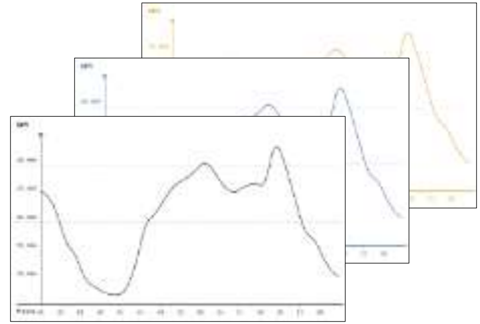
Periods could be days or weeks

System States



- System states are defined by **multiple characteristics** (e.g. wind and demand)
- Values for the states can be obtained via a clustering procedure (**e.g. k-means**)
- Chronology is kept defining a Transition Matrix and a Frequency Matrix, **however**, this increases the total CPU Time.

Representative Periods



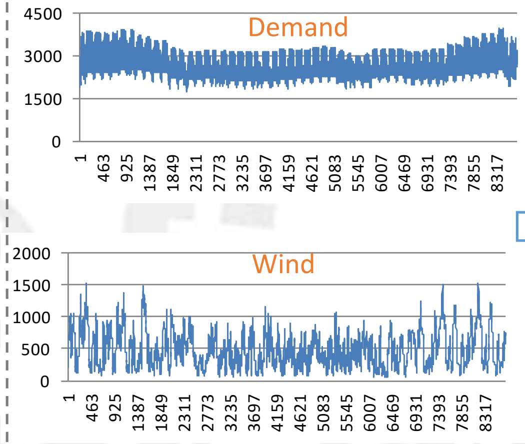
- Representative periods (e.g. days or weeks) are defined by **multiple characteristics** (e.g. wind and demand)
- Representatives can be obtained via a clustering procedure (**e.g. k-medoids**)
- Chronology is kept within hours of representatives, **however**, there is not chronology among the representatives.

What’s new in this research?

The comparison of System States and Representative Periods for Energy Storage investment models using an hourly unit commitment model as a benchmark.

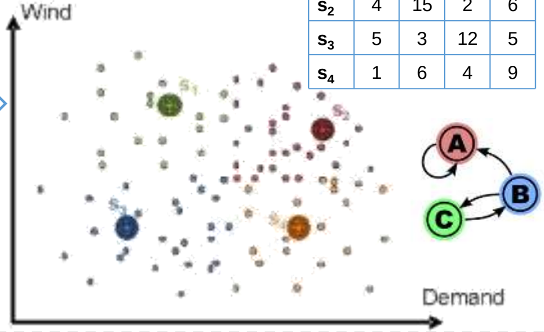
The formulation of an enhanced version of System States and Representative Periods to preserve the chronological information of different kinds of Energy Storage cycles (from hourly to yearly), which improves existing methods in terms of solution quality and CPU time.

Details on System States Model



Transition Matrix $N_{ss'}$

	s_1	s_2	s_3	s_4
s_1	9	5	4	0
s_2	4	15	2	6
s_3	5	3	12	5
s_4	1	6	4	9



Cluster Index: Each hour belongs to only one system state!

- h01→ s1
- h02→ s3
- h03→ s2
- h04→ s2
- h05→ s3
- h06→ s3
- h07→ s2
- h08→ s4
- h09→ s4
- h10→ s4
- ⋮

Frequency Matrix $F_{ss'k}$

$k = \text{h10}$

	s_1	s_2	s_3	s_4
s_1	0	1	0	0
s_2	0	1	1	1
s_3	0	2	1	0
s_4	0	0	0	2

Frequency matrix is used to keep the energy storage within bounds throughout the time horizon. it allows the addition of all changes in storage from the beginning of the time horizon to hour k. However, increasing the number of bounds to limit the short-term/intraday storage leads to a increase of CPU Time

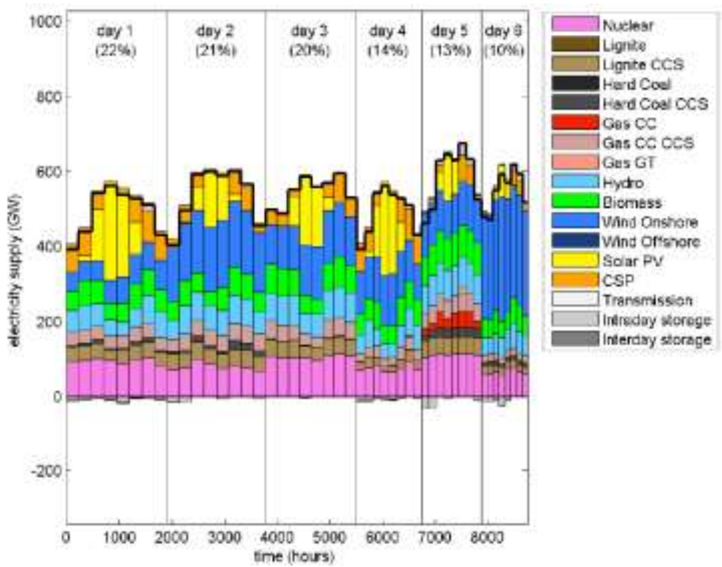
Details of Representative Periods Model

Each day is solved independently and has a weight in the objective function

Short-term/intraday storage is modeled within each representative period

Long-term (e.g. hydro) storage evolution cannot be modeled because there is no relationship among representative periods.

Hydro representation is generally modeled as available production within the representative period.



Source: P. Nahmmacher, E. Schmid, L. Hirth, and B. Knopf, "Carpe diem: A novel approach to select representative days for long-term power system modeling," Energy, vol. 112, pp. 430–442, Oct. 2016.

Energy Storage in Current Models

Model	Short-term / intraday Storage representation	Long-term / hydro storage representation
System States	Fairly Good	Good
Representative Periods	Good	Poor

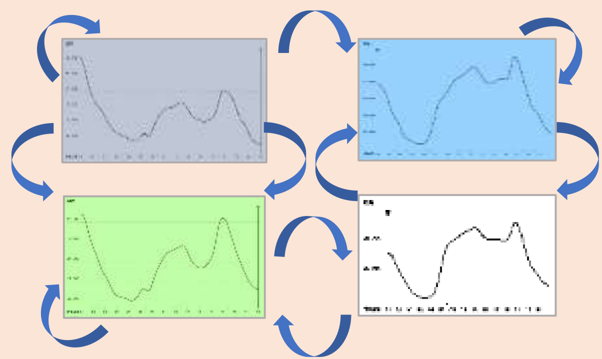
Enhanced Versions

System States with Reduced Frequency Matrix

- Instead of defining a Frequency Matrix beginning from the time horizon, the Reduced Frequency Matrix is defined as a moving window
- This doesn´t improve the actual modeling of short-term storage, but reduces significantly the CPU time needed

Representative Periods with Transition Matrix and Cluster Index

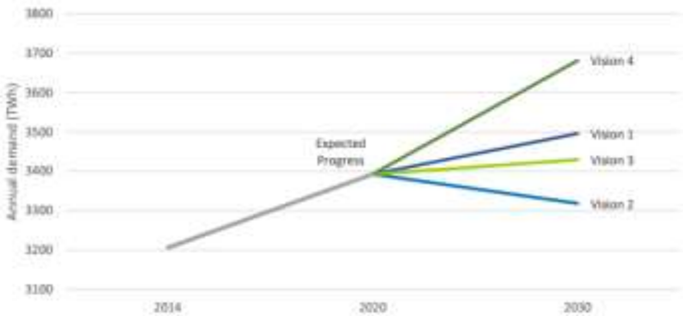
We include the **transition matrix and cluster index** ideas of System States Models into the representative periods, so that it is possible to link chronological information among the representatives such as storage levels or unit commitments



Ten-Year Network Development Plan 2016

We test the proposed models with input data from 4 different EU's policies:

- Vision 1 2030 - IEA "Current Policies"
- Vision 2 2030 - IEA "Current Policies"
- Vision 3 2030 - IEA "450" except coal price IEA "New Policies"
- Vision 4 2030 - IEA "450" except CO2 price (UK FES High)



http://tyndp.entsoe.eu/

Case Study Summary

Target year 2030. Hourly profiles for demand, wind and solar production, and hydro inflows.

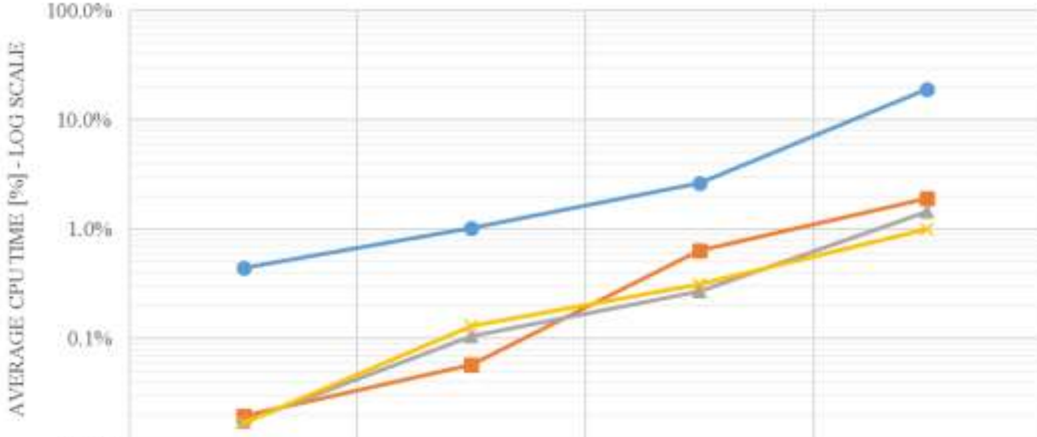
4 visions or policy scenarios taken from ENTSO-E. Analysis for Spain

4 sensitivities to number of clusters

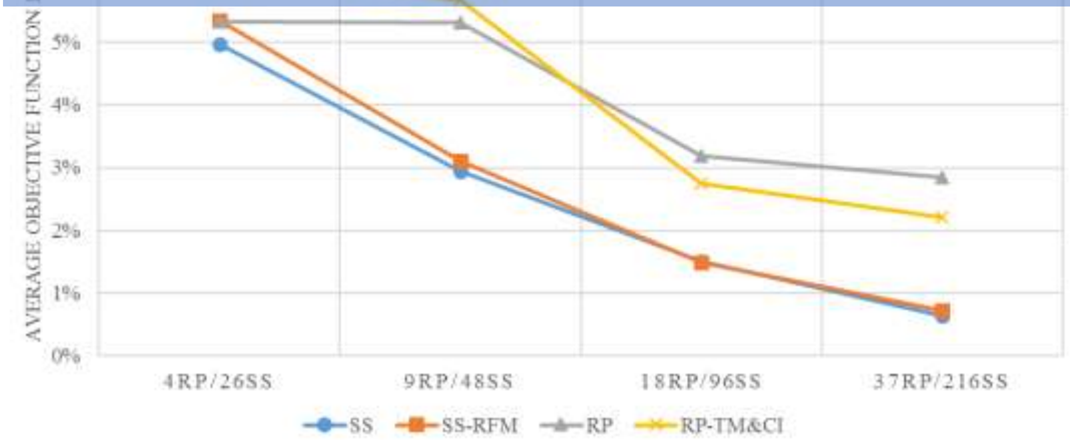
- 26, 48, 96, and 216 System States
- 4, 9, 18, and 37 Representative Days

5 Models:

- Hourly Model **(HM)** which is the benchmark
- System States **(SS)** and System States with Reduced Frequency Matrix **(SS-RFM)**
- Representative days **(RP)** and Representative Periods Model with Transition Matrix and Cluster Indices **(RP-TM&CI)**



If the number of clusters are increased, either system states or representative days, the objective function error decreases, however, the CPU Time increases exponentially.

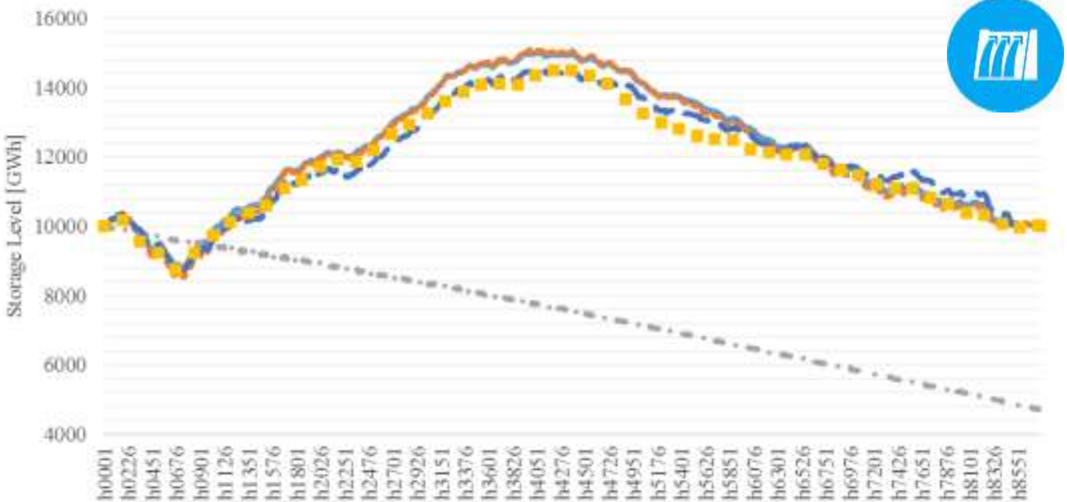


Performance Comparison

Result		SS	SS-RFM	RP	RP-TM&CI
Production	Nuclear	Excellent	Excellent	Good	Excellent
	Coal	Good	Good	Fairly Good	Good
	CCGT	Good	Good	Fairly Good	Good
	Hydro	Excellent	Excellent	Fairly Good	Excellent
	Battery	Fairly Good	Fairly Good	Good	Good
	Renewable	Excellent	Excellent	Excellent	Excellent
Start-up	Coal	Poor	Poor	Poor	Good
	CCGT	Poor	Poor	Poor	Fairly Good
Price	Average	Excellent	Excellent	Fairly Good	Excellent
	Max	Fairly Poor	Fairly Good	Fairly Poor	Good
	Min	Excellent	Excellent	Excellent	Excellent
CPU Time [s]		457	53	44	73

Error compared to hourly model result:

- Excellent: ≤ 1%
- Good: 1% - 5%
- Fairly Good: 5% - 15%
- Fairly Poor: 15%-30%
- Poor: ≥ 30%


16000
14000
12000
10000
8000
6000
4000
Storage Level [GWh]
h0001
h0226
h0451
h0676
h0901
h1126
h1351
h1576
h1801
h2026
h2251
h2476
h2701
h2926
h3151
h3376
h3601
h3826
h4051
h4276
h4501
h4726
h4951
h5176
h5401
h5626
h5851
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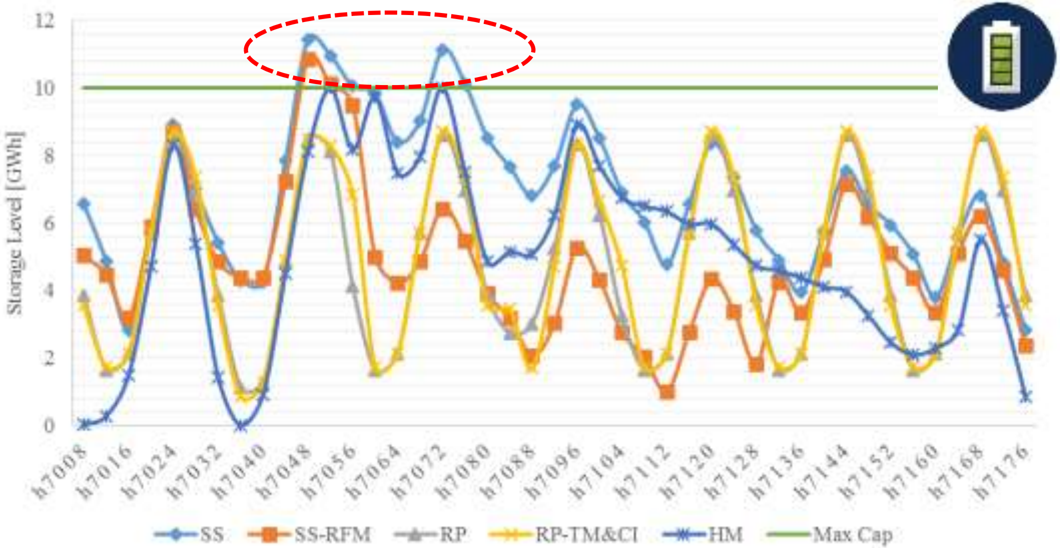
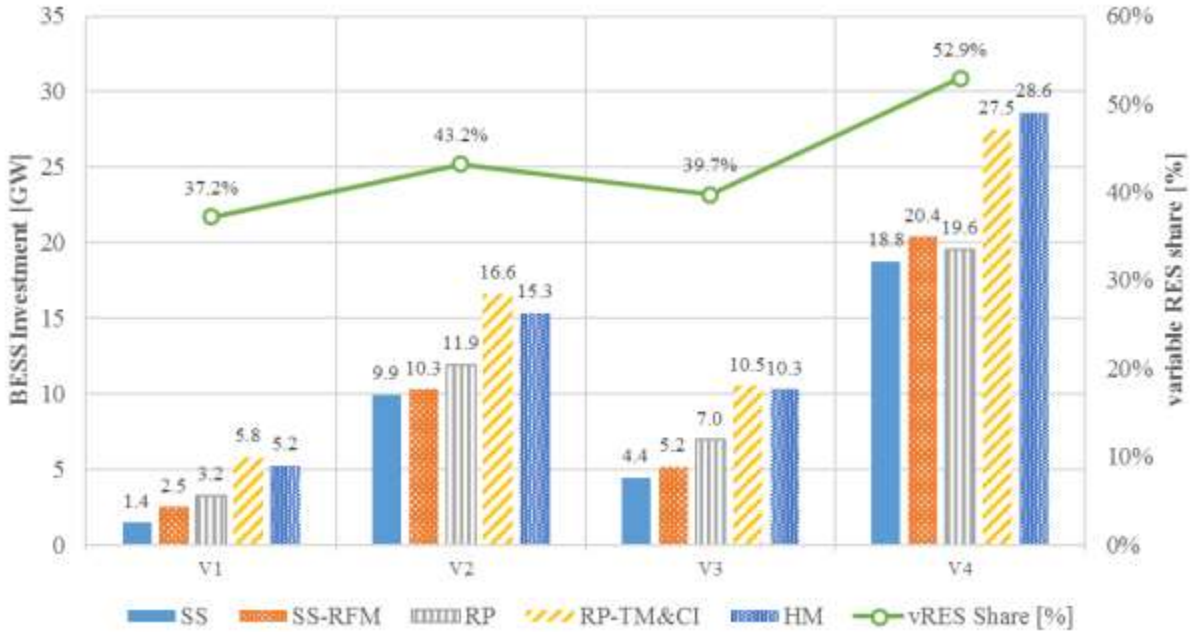
h6751
h6976
h7201
h7426
h7651
h7876
h8101
h8326
h8551


12
10
8
6
4
2
0
Storage Level [GWh]
h7008
h7016
h7024
h7032
h7040
h7048
h7056
h7064
h7072
h7080
h7088
h7096
h7104
h7112
h7120
h7128
h7136
h7144
h7152
h7160
h7168
h7176
SS
SS-RFM
RP
RP-TM&CI
HM
Max Cap

Energy Storage Investment in Spain for each 2030 Vision



- As the variable renewable share increases, more energy storage investment is needed
- Using the Hourly Model (HM) as a benchmark, the enhanced version of Representative Periods (RP-TM&CI) performs better to capture the energy storage investment

Summary...

The RP-TM&CI model combines aspects of the System States and Representative Periods models to account for both short and long-term storage. According to the case study results, it is the most accurate of the four approximate models and does not require a significant increase of CPU time

These results support the idea that including chronological information among representative periods may be an efficient way to include small time scale variations in longer-term planning models that involve storage

This proposed modeling framework could be used to help policymakers setting targets for energy storage in a more accurate way, especially in a high renewable energy penetration context.

Main References

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System States:

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Thank you!

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https://www.iit.comillas.edu/publicacion/mostrar_publicacion_working_paper.php.en?id=314

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