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A system approach for evaluating clean energy goals and the role of flexibility technologies: the case of France

Manuel Villavicencio

Ph.D. candidate

Université Paris-Dauphine, PSL Research University

LEDa – CGEMP

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Chaire European Electricity Markets (CEEM)
Université Paris-Dauphine

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Agenda

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The 2015's French Energy transition Act: How important is the energy policy shock ?

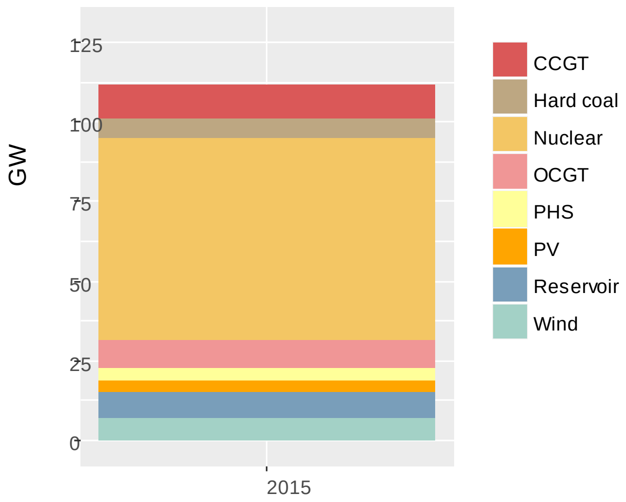
Loi nº 2015-992 of 17 August 2015: "Transition énergétique pour la croissance verte"

Standards		*H2020*	*H2025*	*H2030*
VRE shares	>	27%	-	40%
Nuclear shares	<	-	50%	50%
CO_2 cost [€/ton]	=	20	20	20

The French Power system by 2015:

- *EOM, Reserve markets and CRM*
- *Peak load = 93.63 GW*
- *Total energy =541.4 TWh/year*
- *VoLL = 10 000 €/MWh*
- *Annual Lost load < 3 h/year*
- *CO_2 cost: 6-8 €/ton*

Installed capacity



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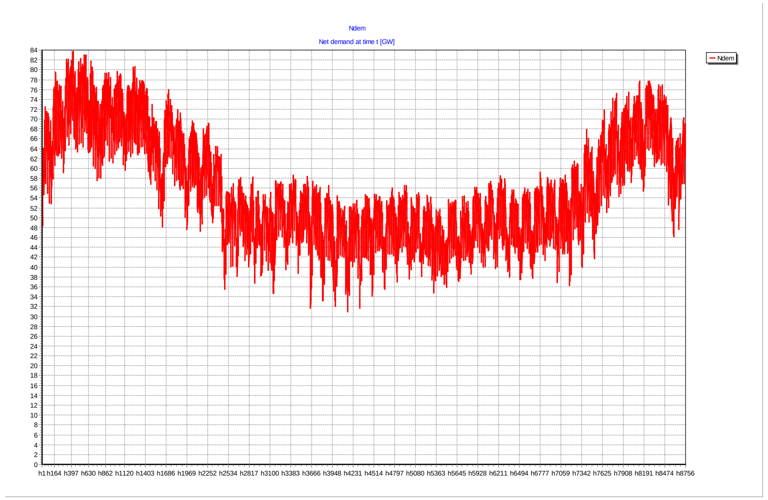
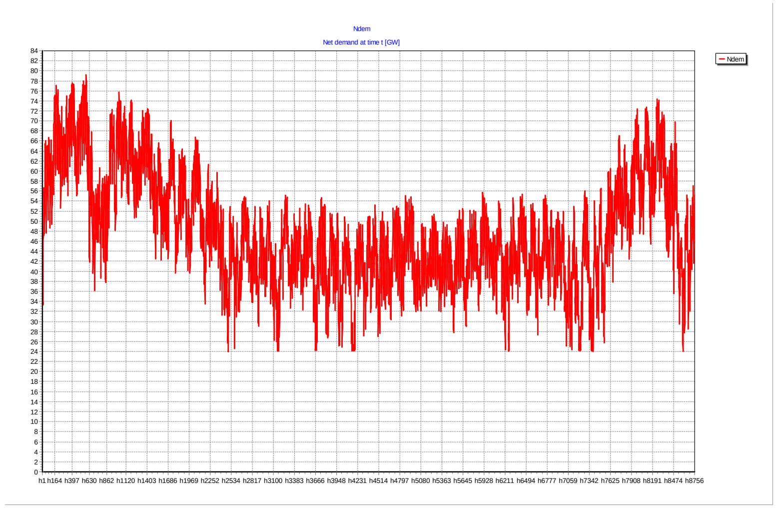
Net demand variability patterns, an interpretation through Scitovsky's externalities (1954):

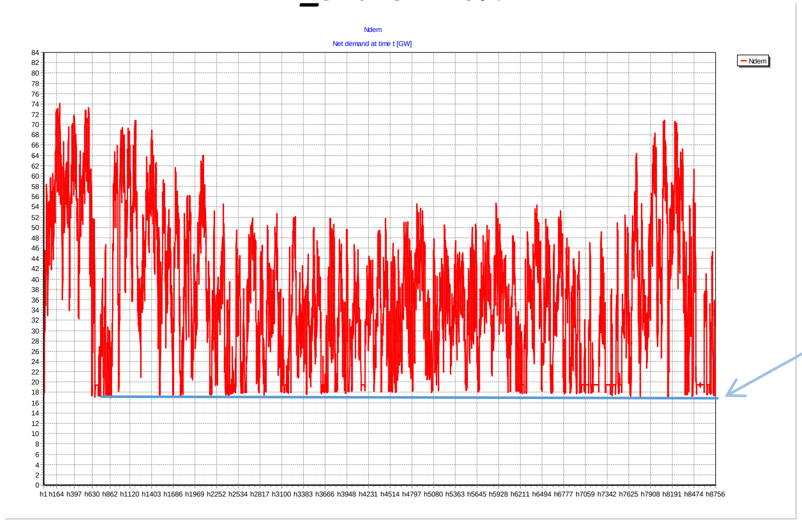
RE_share = 0%



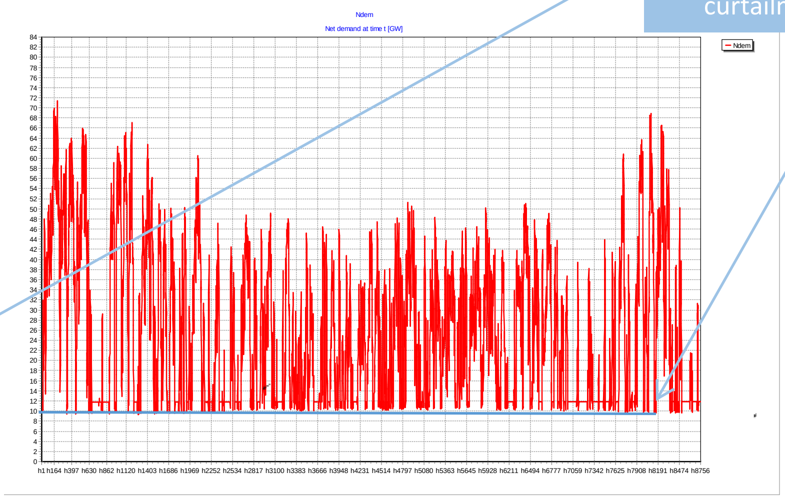
RE_share = 20%



RE_share = 40%



RE_share = 60%



Effect of VRE curtailment

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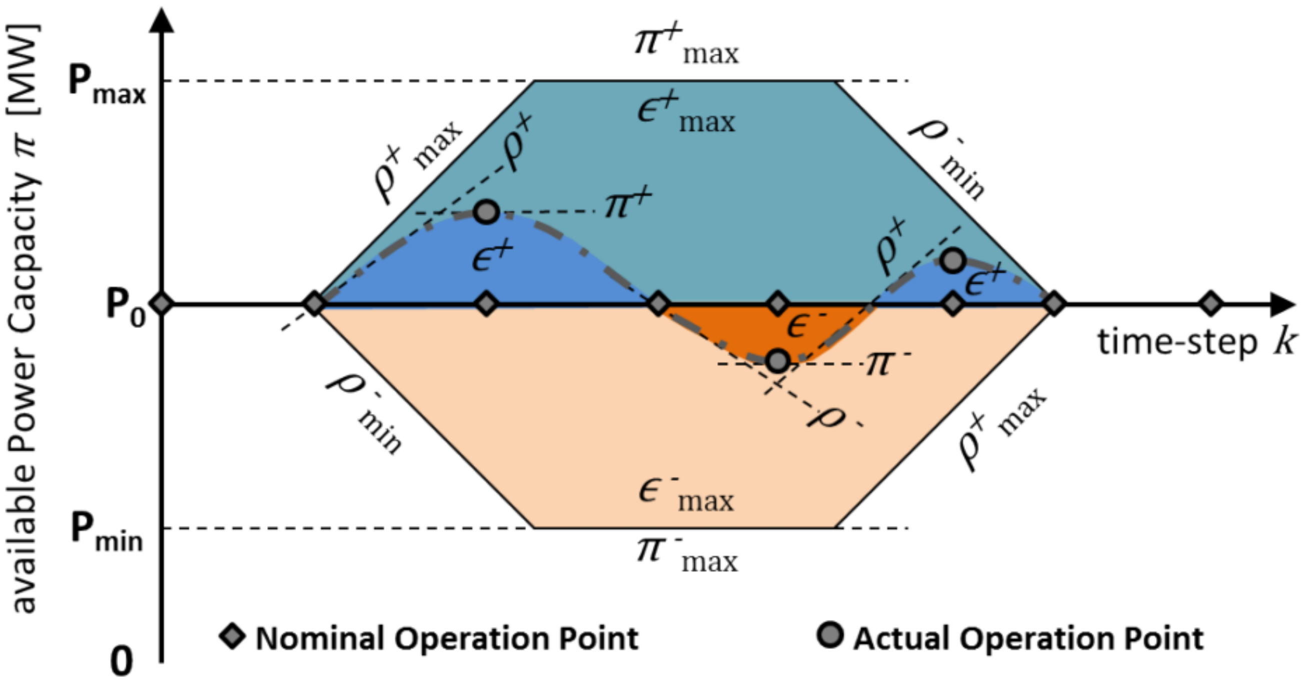
Operational constraints limiting arbitrage produce differences on the marginal value of electricity

Example: Ramping capabilities



Power Ramp-rate ρ, Power π and Energy ε

Flexibility metrics in power system operations. Source: Ulbig and Andersson 2013

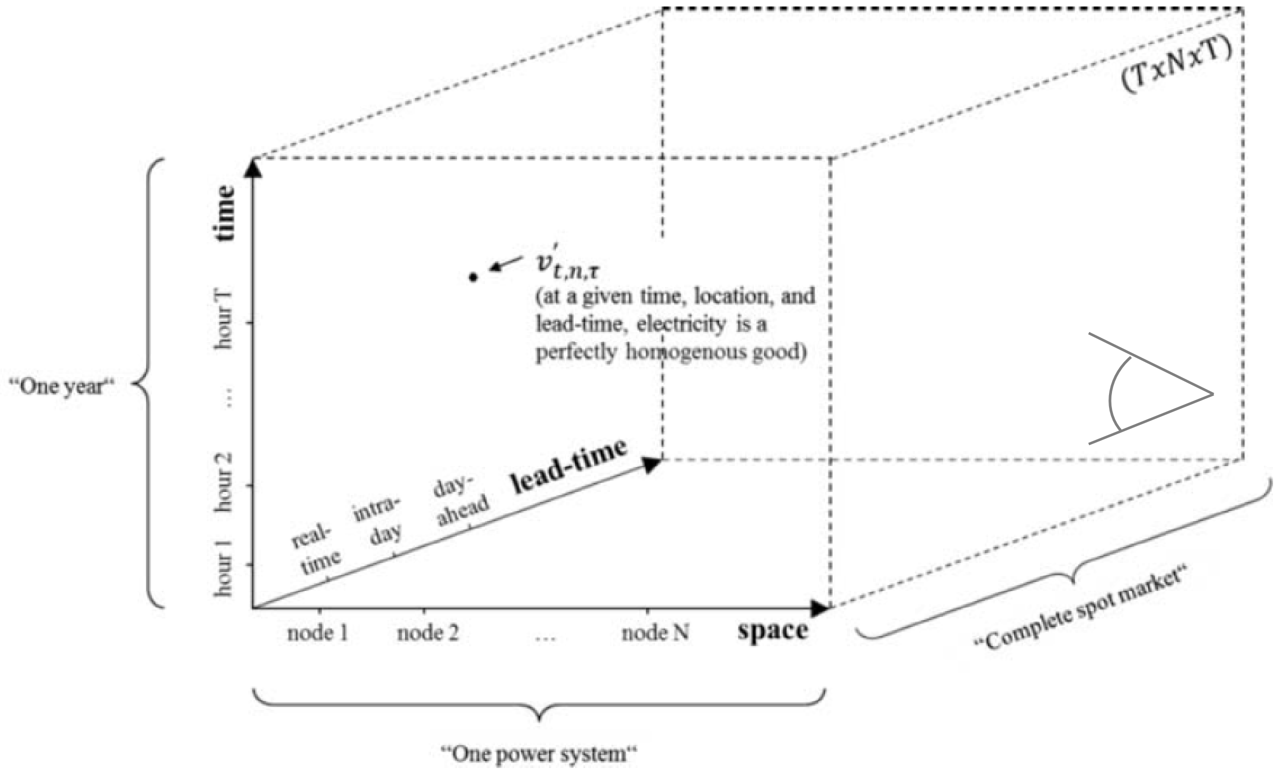
Power plant cycling restrictions:

- Ramping constraints
- Start-up and shut down technical restrictions
- Minimum load
- In load range
- Reserve capabilities
- DSM usage restrictions
- Among others

But also, cycling is costly.. (Kumar et al. 2012), (Hentschel et al. 2016)

Electricity is:

A homogeneous energy vector *(physics)*	≠	***A heterogeneous financial good*** *(economics)*



Marginal value space of electricity (heterogeneity). Source: Hirth 2015

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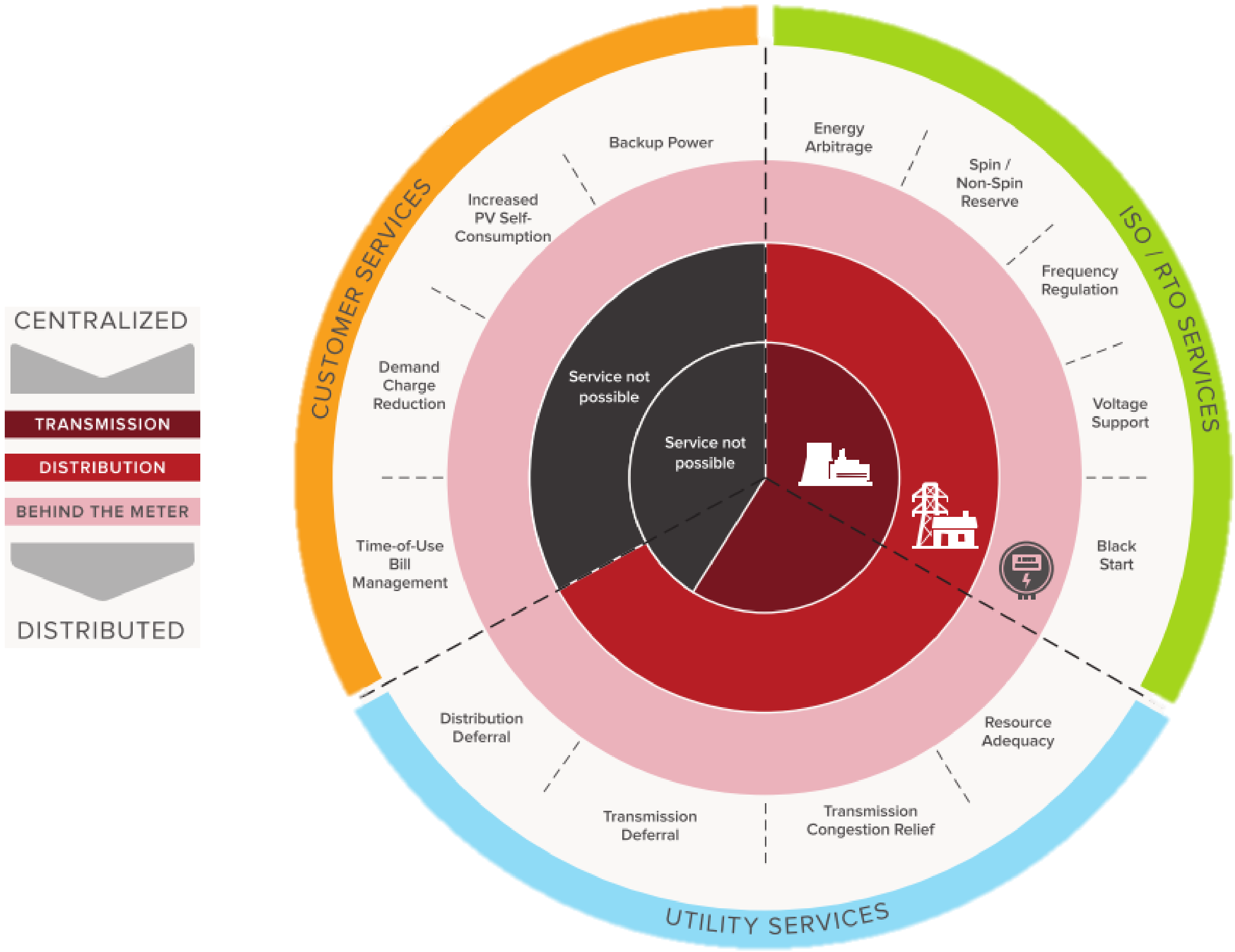
The system benefits of storage capabilities



Services that can be provided by EES technologies. Source: (Fitzgerald et al., 2015)

1. ***Would investments in storage capacity be cost-optimal on these settings?***

Remark 1: *Cost-optimality assumes a system perspective assessment with an unique solution.*

2. ***What is the system value added by storage?***

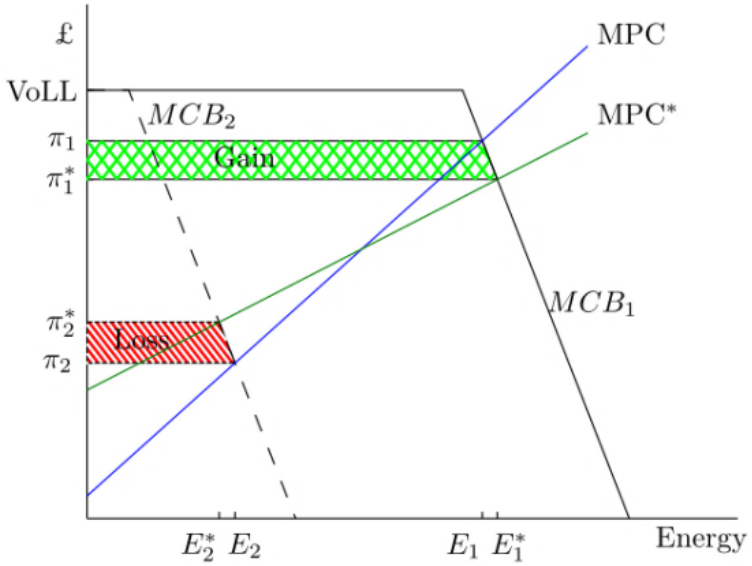
Remark 2: *In such framework the value corresponds to the net social value.*

3. ***What are the distributional effects of such investments?***

Remark 3: *What is in stake is the surplus variations across market players triggered by optimal storage*

Welfare effects of storage:

Short-term:



Welfare effect of storage during peak and off-peak periods. Source: (Grünewald, 2011)

MPC: marginal production cost
MCB: marginal consumer benefit

Mid and long-term (capital stock re-allocations):

Generation and flexibility investments are co-optimized, meaning that the slope and the rotation extent of the MPC curve is adjusted to enhance technologic complementarities, which makes the social welfare gains to be maximized.

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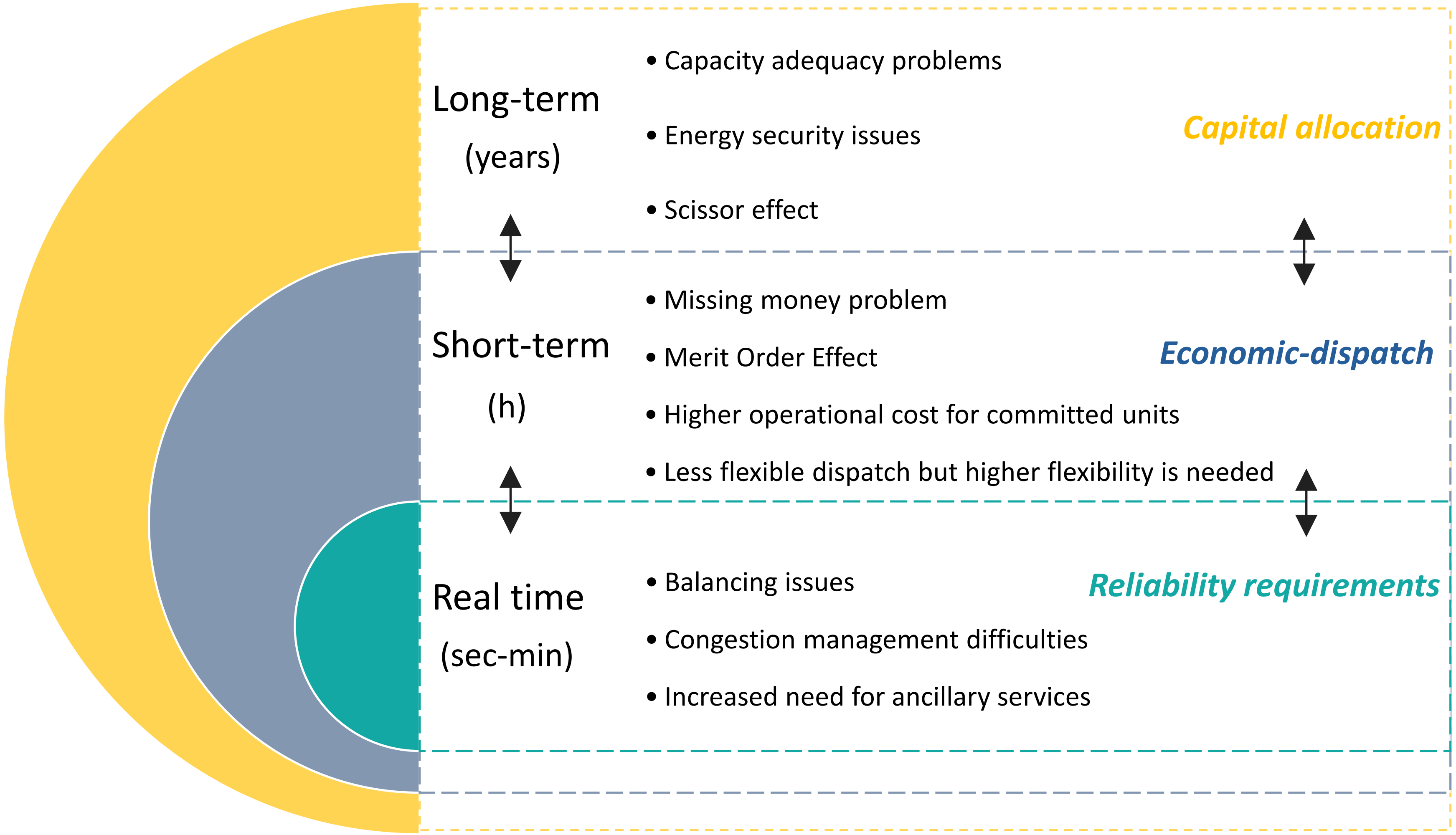
Interrelated and system dependent issues



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System cost represented as:

$$\min Y = \sum_{con}(I_{con} + MB_{con}) + \sum_{con}\sum_{t}(O\&M_{con,t} + F_{con,t} + CO2_{con,t} + \Delta G_{con,t})$$

$$+ \sum_{VRE}(I_{VRE} + MB_{VRE}) + \sum_{VRE}\sum_{t}(O\&M_{VRE,t} + VREC_{VRE,t})$$

$$+ \sum_{ees}(I_{ees} + MB_{ees}) + \sum_{ees}\sum_{t} O\&M_{ees,t}$$

$$+ \sum_{dsm} I_{dsm} + \sum_{lc}\sum_{t} DSM_{lc,t} + \sum_{ls}\sum_{t} DSM_{ls,t}$$

$$+ \sum_{t} LL_t \; VoLL$$ (optional)

LT | ST | RT

***S.T. operational constraints*:**

- *Ramping constraints*
- *Min/max generation level*
- *Part load efficiencies*
- *FRR requirements*
- *DSM and EES operating constraints*
- *Capacity obligation (CRM)*
- *Clean energy policies…*

Set	Element	Description
$\mathbb{T}$	$t, tt \in \mathbb{T}$	Time slice
$\mathbb{I}$	$I \in \mathbb{I}$	Generation technologies
$\mathbb{I} \supseteq \mathrm{CON}$	$con \in \mathbb{I}$	Conventional technologies
$\mathbb{I} \supseteq \mathrm{VRE}$	$vre \in \mathbb{I}$	Renewable energy sources
$\mathbb{I} \supseteq \mathrm{EES}$	$ees \in \mathbb{I}$	Electric energy storage technologies
$\mathrm{DSM} \supseteq \mathrm{LC}$	$lc \in \mathrm{DSM}$	Demand side management for load curtailment
$\mathrm{DSM} \supseteq \mathrm{LS}$	$ls \in \mathrm{DSM}$	Demand side management for load shifting

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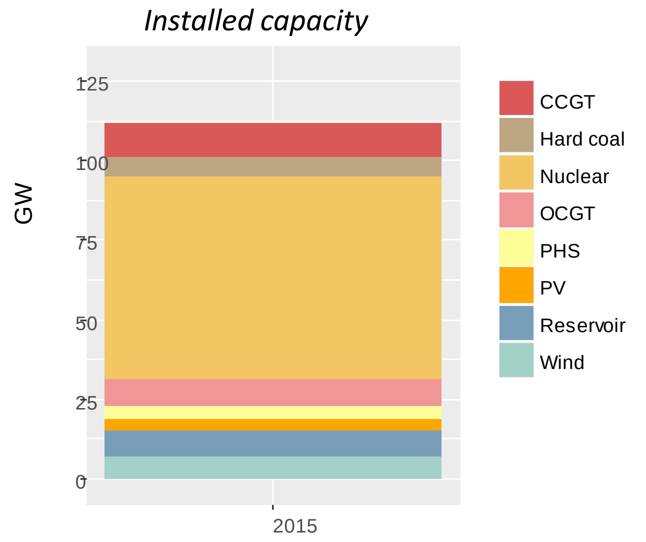
Experimental setup:

Brownfield optimization considering existing capacities on 2015.

- *DIFLEXO formulation: EOM, FRR and CRM and VoLL (perfect foresight)*
- *Peak load = 93.63 GW*
- *Total energy =541.4 TWh/year*
- *VoLL = 10 000* €/MWh
- *Annual Lost load < 3 h/year*



- **Bulk storage technologies (*EES*)** : PHS, DCAES, ACAES, VRFB, NaS, Li-ion
- **DSM**: Load curtailment and load shifting less than 1% and 2% of *load* respectively

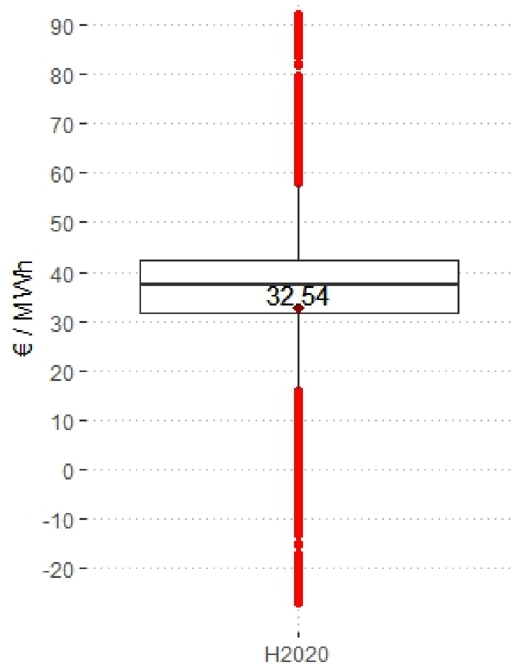
Solved in GAMS under CPLEX 12.5 using the barrier algorithm

		Horizon 2020	Horizon 2030
VRE shares	>	*27%*	*40%*
Nuclear shares	<	*Current levels of 2015*	*50%*
CO_2 cost [€/ton]	=	*20*	*20*
Cost assumptions	appendix	*JRC-ETRI projections for 2020*	*JRC-ETRI projections for 2030*

By 2020:

No EES capacity is cost-optimal => storage adds no value

Technology	*Investments* [GW]	*Retirements* [GW]	*Total capacity H2020* [GW]
Nuclear	-	-	63,13
Hard coal	-	-6,34	-
CCGT	-	-10,46	-
OCOT	15,87	-	15,87
OCGT	-	-	8,78
Reservoir	-	-	8,21
Wind	44,38	-	51,36
PV	-	-	3,43
PHS	-	-	4,30
DSM	4,68	-	4,68



Min. [€/MWh]	*1st Qu.* [€/MWh]	*Median* [€/MWh]	*Mean* [€/MWh]	*3rd Qu.* [€/MWh]	*Max.* [€/MWh]
-27,0	31,7	37,4	32,5	42,2	92,3

3. Findings for the case of France

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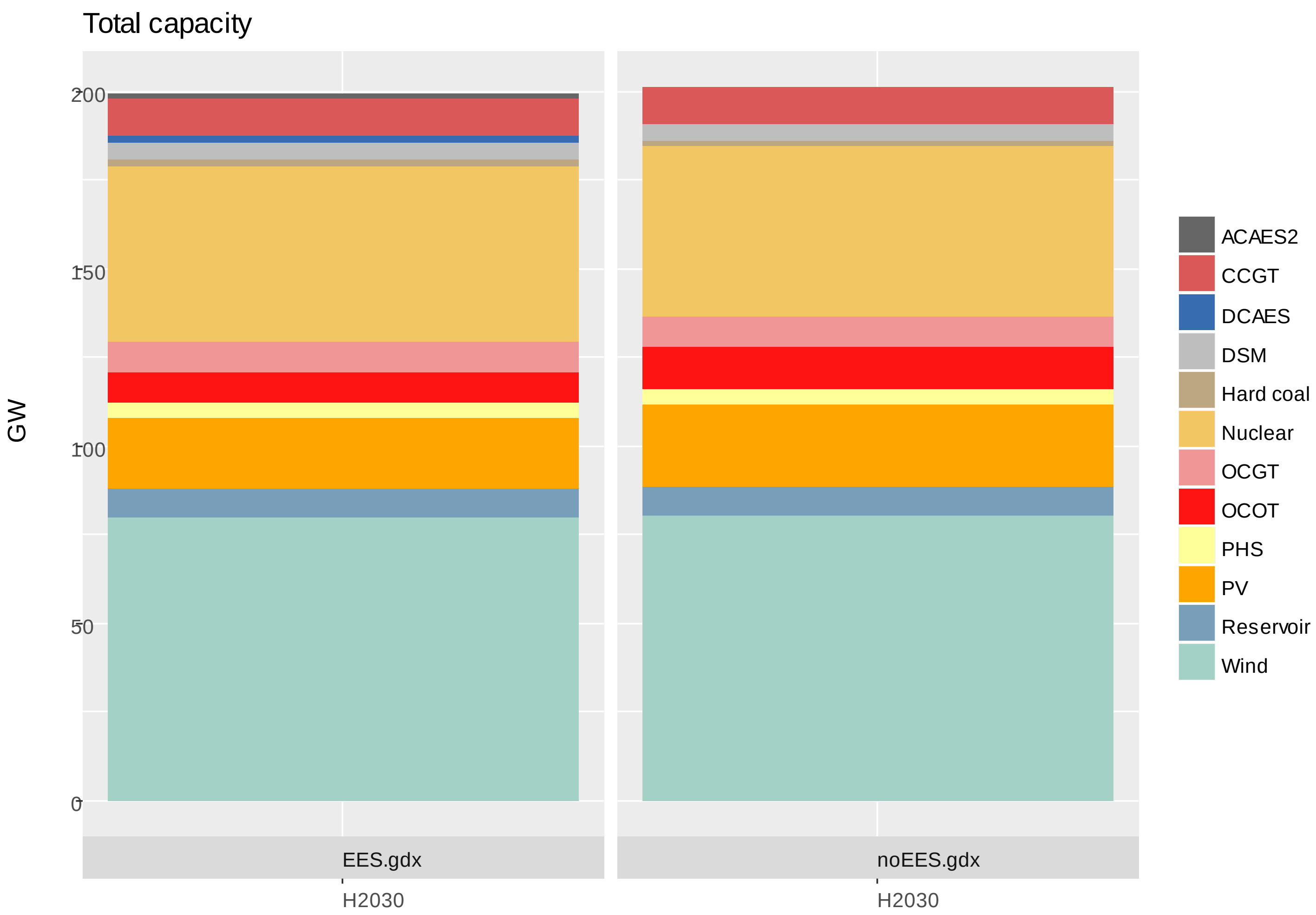
However, by 2030 some EES investments are cost-optimal:

Technology	***Investments*** **[GW]**		***Retirements*** **[GW]**		***Total capacity*** **[GW]**	
	EES	noEES	EES	noEES	EES	noEES
Nuclear	-	-	-14,04	-15,11	49,09	48,02
Hard coal	-	-	-4,06	-4,63	2,28	1,71
CCGT	-	-	-	-	10,46	10,46
OCOT	8,61	11,72	-	-	8,61	11,72
OCGT	-	-	-	-	8,78	8,78
Reservoir	-	-	-	-	8,21	8,21
Wind	72,73	73,28	-	-	79,71	80,26
PV	16,62	19,90	-	-	20,05	23,33
PHS	-	-	-	-	4,30	4,30
DSM	4,68	4,68	-	-	4,68	4,68
DCAES	2,00	-	-	-	2,00	-
ACAES2	1,23	-	-	-	1,23	-

Results: The supply curve changes as well as the dispatch schedules



Click to see the hourly dispatch

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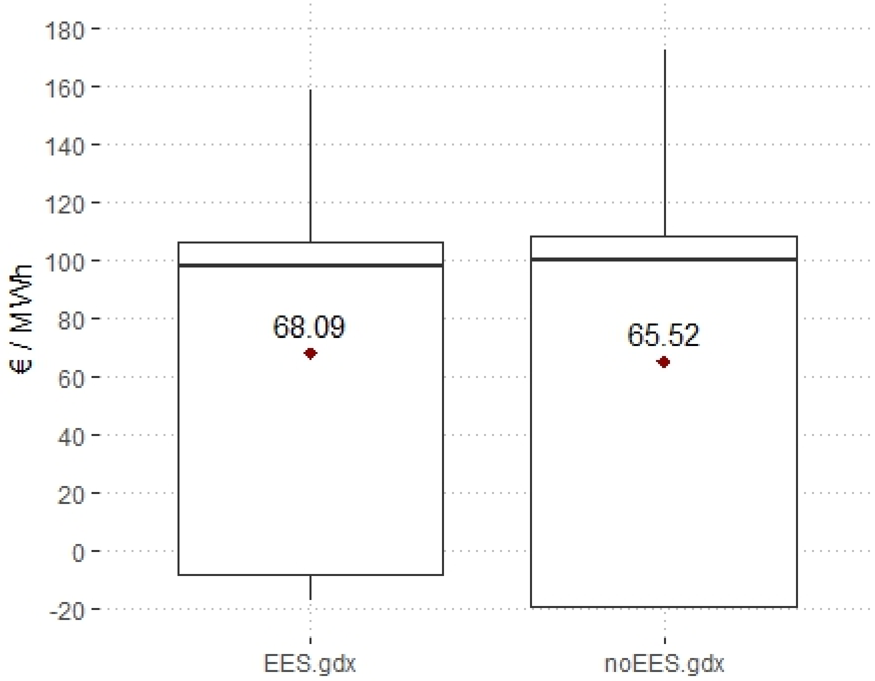
There surplus variations of consumers are due to electricity price variations:

Electricity price statistics

	Min. [€/MWh]	*1st Qu.* [€/MWh]	*Median* [€/MWh]	*Mean* [€/MWh]	*3rd Qu.* [€/MWh]	*Max.* [€/MWh]
EES	-17,3	-8,5	98,1	68,1	106,1	158,7
noEES	-19,4	-19,4	100,1	65,5	108,7	172,4



Other markets (Marginals)

	Price of Capacity obligations [€/MW.year]	*RPS* [€/MWh]	*Nuclear cap* [€/MWh]
EES	29 649	7,46	68,76
noEES	44 962	12,92	65,76

3. Findings for the case of France

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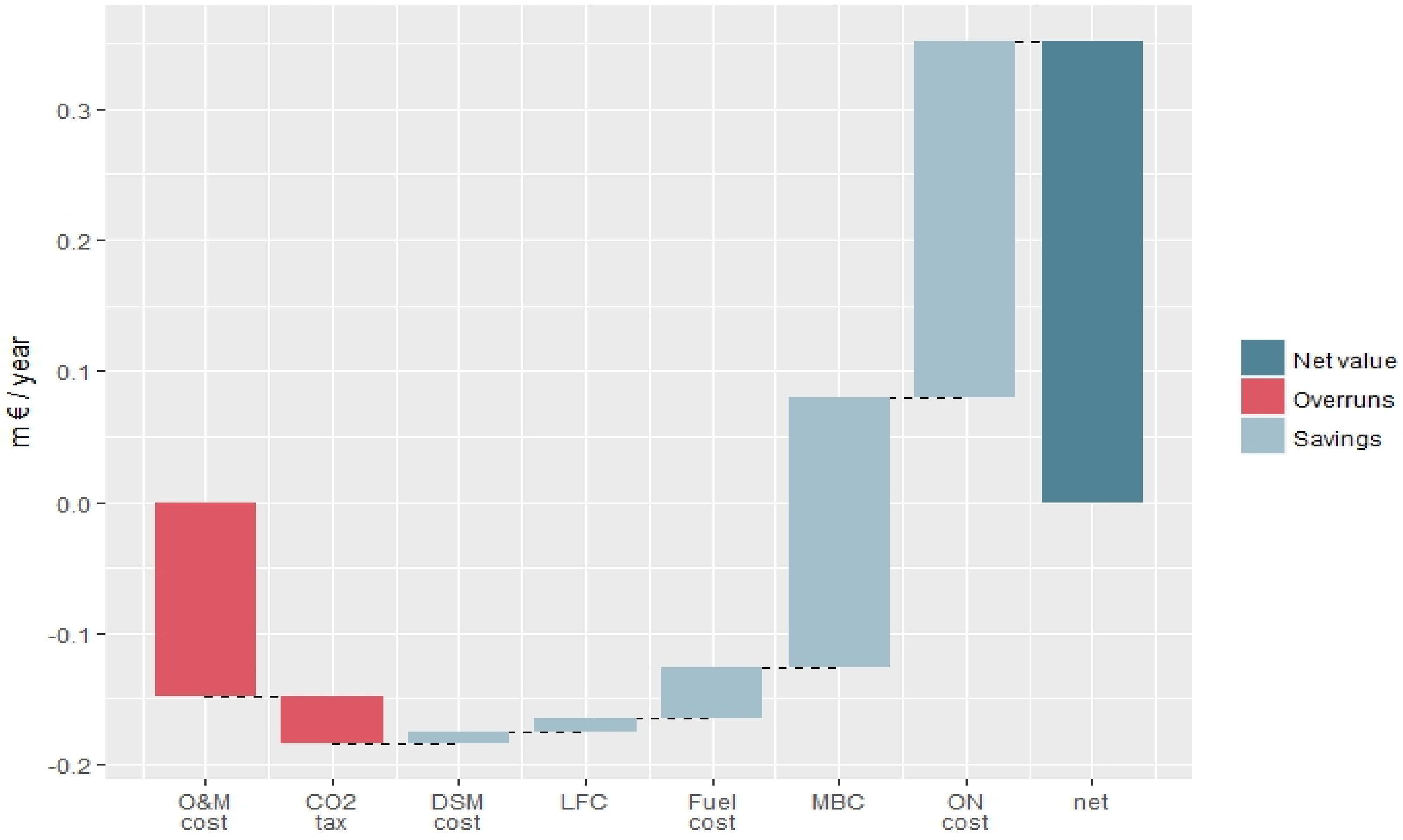
The value of storage by H2030



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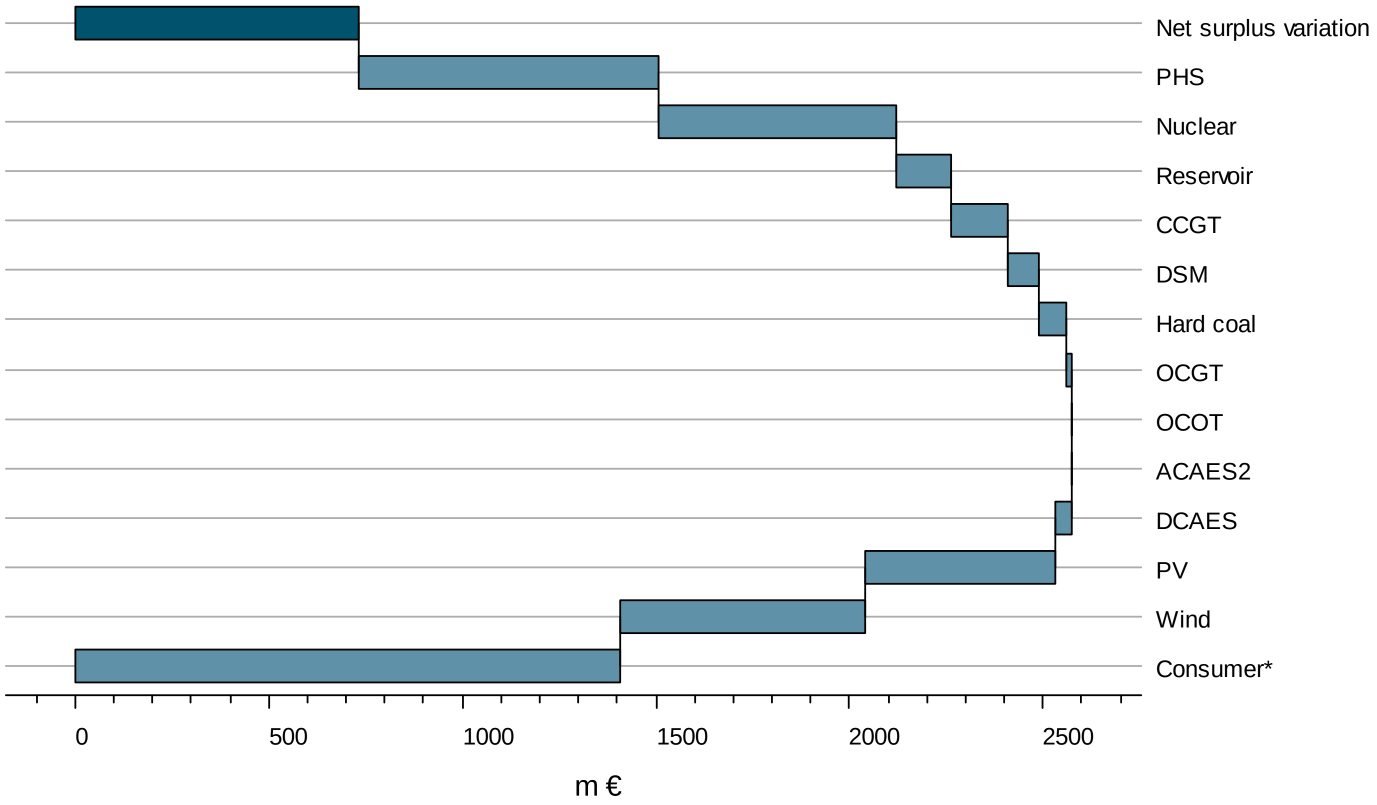
The net surplus variation is 670 M€/year, which is around 2.7% of total system cost

Welfare effects of storage by H2030



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1. A clear definition and a convenient methodology has been applied for assessing the value of new flexibility technologies.
2. An integrated valuation approach based on the DIFLEXO model has been implemented to study the case of France:
   - **H2020**: *even if there is a higher need for flexibility, storage investments are not cost optimal.*
   - **H2030**: *CAES technologies are cost-optimal provided that*:
     - They participate on VRE integration, supply FRR services and participating on capacity adequacy with no regulatory veils.
     - The system value of cost-optimal storage is around 350 m €/year which is 1.3% of total system cost.
     - Important distributional effects appear. This is due to the reduction of revenues coming from the CRM and FRR markets. Nevertheless, VRE producers and consumers are better-off.
3. Effective CO_2 price signals is required for storage to contribute to emission reduction targets: EES shows complementarities with low run marginal cost technologies, enhancing its market shares. In the absence of effectively pricing environmental externalities, EES can increase CO_2 emissions.

REFERENCES

Carlsson, Johan et al. “Energy Technology Reference Indicator Projections for 2010-2050.” Luxembourg, 2014. doi:10.2790/057687.

Fitzgerald, Garrett, James Mandel, Jesse Morris, and Touati Hervé. “The Economics of Battery Energy Storage: How Multi-Use, Customer-Sited Batteries Deliver the Most Services and Value to Customers and the Grid,” 2015.

Grünewald, Philipp. “The Welfare Impact of Demand Elasticity and Storage,” no. September (2011): 1–5.

Hentschel, Julia, Ugljesa Babic, and Hartmut Spliethoff. “A Parametric Approach for the Valuation of Power Plant Flexibility Options.” *Energy Reports* 2 (2016): 40–47. doi:10.1016/j.egyr.2016.03.002.

Hirth, Lion, Falko Ueckerdt, and Ottmar Edenhofer. “Integration Costs Revisited - An Economic Framework for Wind and Solar Variability.” *Renewable Energy* 74 (2015): 925–39. doi:10.1016/j.renene.2014.08.065.

Kumar, N, P Besuner, S Lefton, D Agan, and D Hilleman. “Power Plant Cycling Costs Power Plant Cycling Costs.” 15013 Denver West Parkway Golden, Colorado 80401 303-275-3000, 2012.

Scitovsky, Tibor. “Two Concepts of External Economies.” *The Journal of Political Economy* 62, no. 2 (1954): 143–51. doi:10.1086/257498.

Thank you for your attention.

Any questions?

“What is a cynic? A man who knows the price of everything and the value of nothing”
Oscar Wilde

✉ ***manuel.villavicenio@dauphine.com***

Working paper available at:
http://www.ceem-dauphine.org/working/en/THE-VALUE-OF-ELECTRIC-ENERGY-STORAGE-IN-ELECTRICITY-SYSTEMS-WITH-HIGH-SHARES-OF-WIND-AND-SOLAR-PV

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APPENDIX

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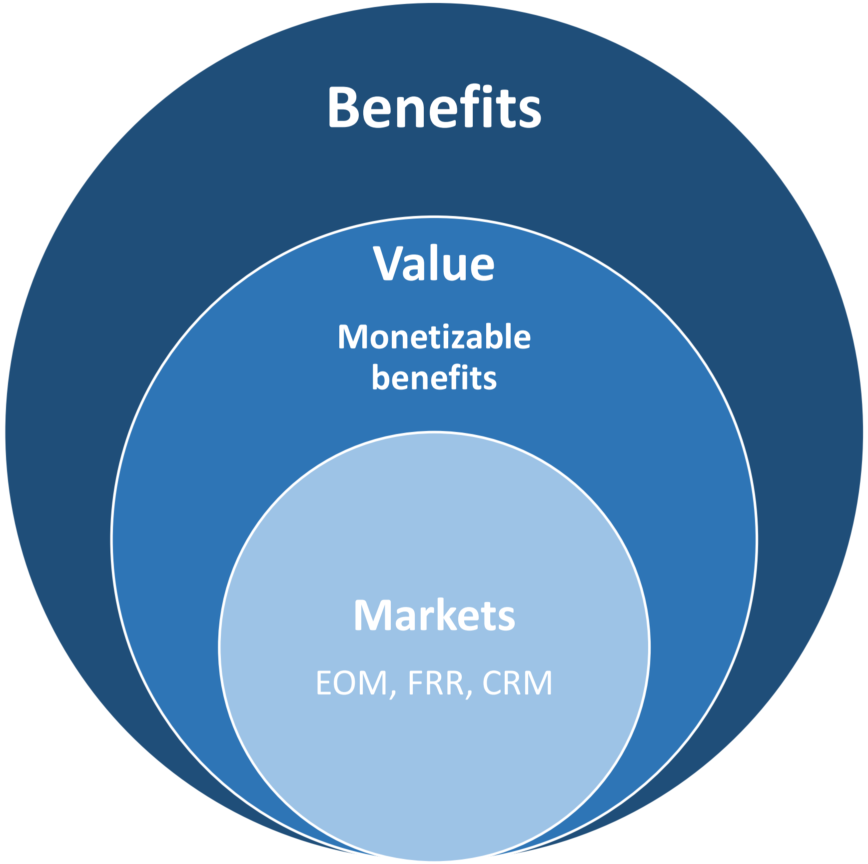
"Cost based analyses" *consider technologies in isolation (e.g., LCOE, LCOS)*

Vs.

"Value based analyses" *consider interactions between technologies (e.g., partial equilibrium setting)*

Defining the meaning of "value":

"The value of storage is defined as the monetizable system benefits generated directly or indirectly by storage, provided a cost-optimized system including capacity allocations, as well as dispatch and inventory decisions."



Experimental Setup using DIFLEXO

- Optimizing the system with and w/o EES technologies
- The value sources correspond to the costs categories considered in the objective function.

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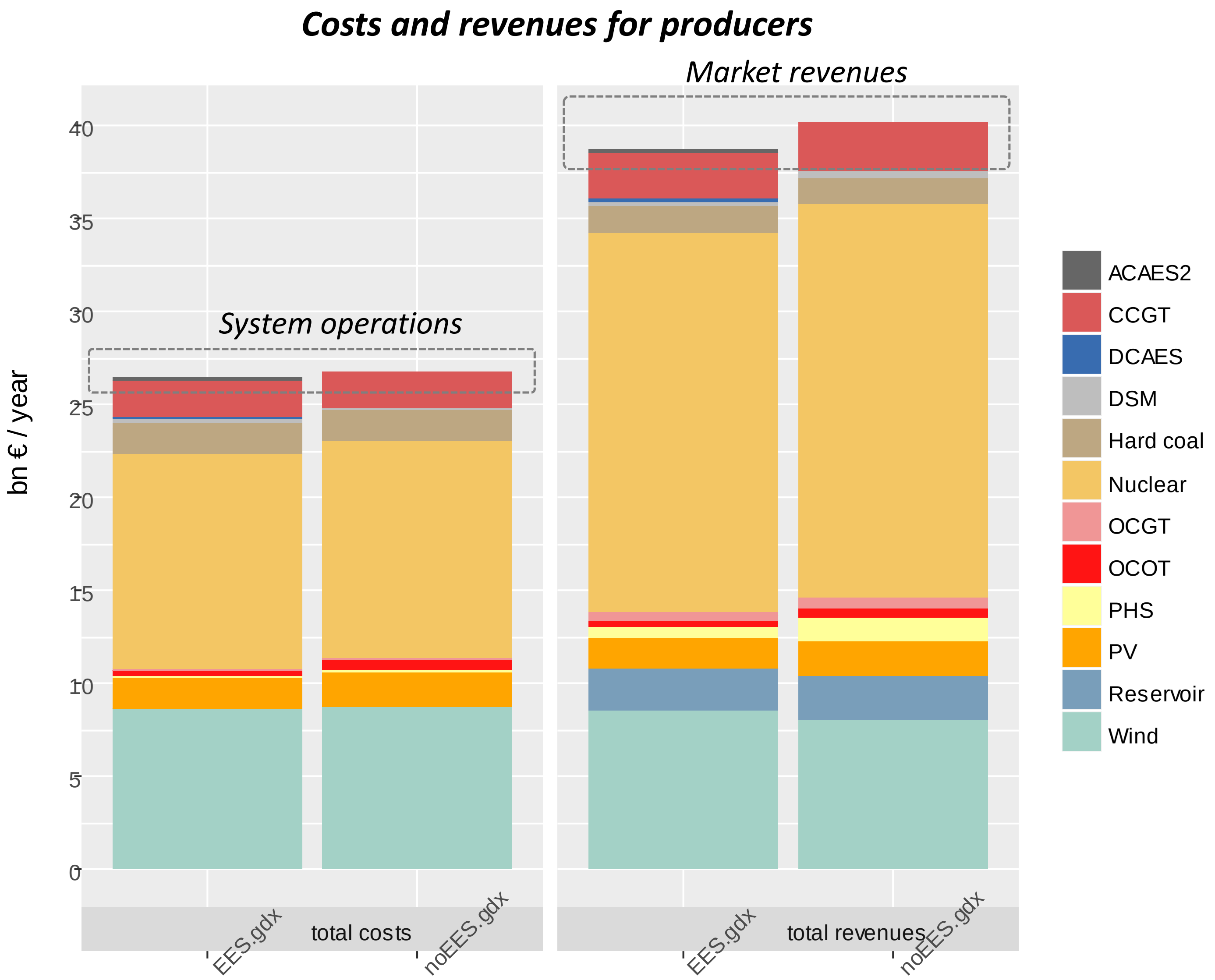
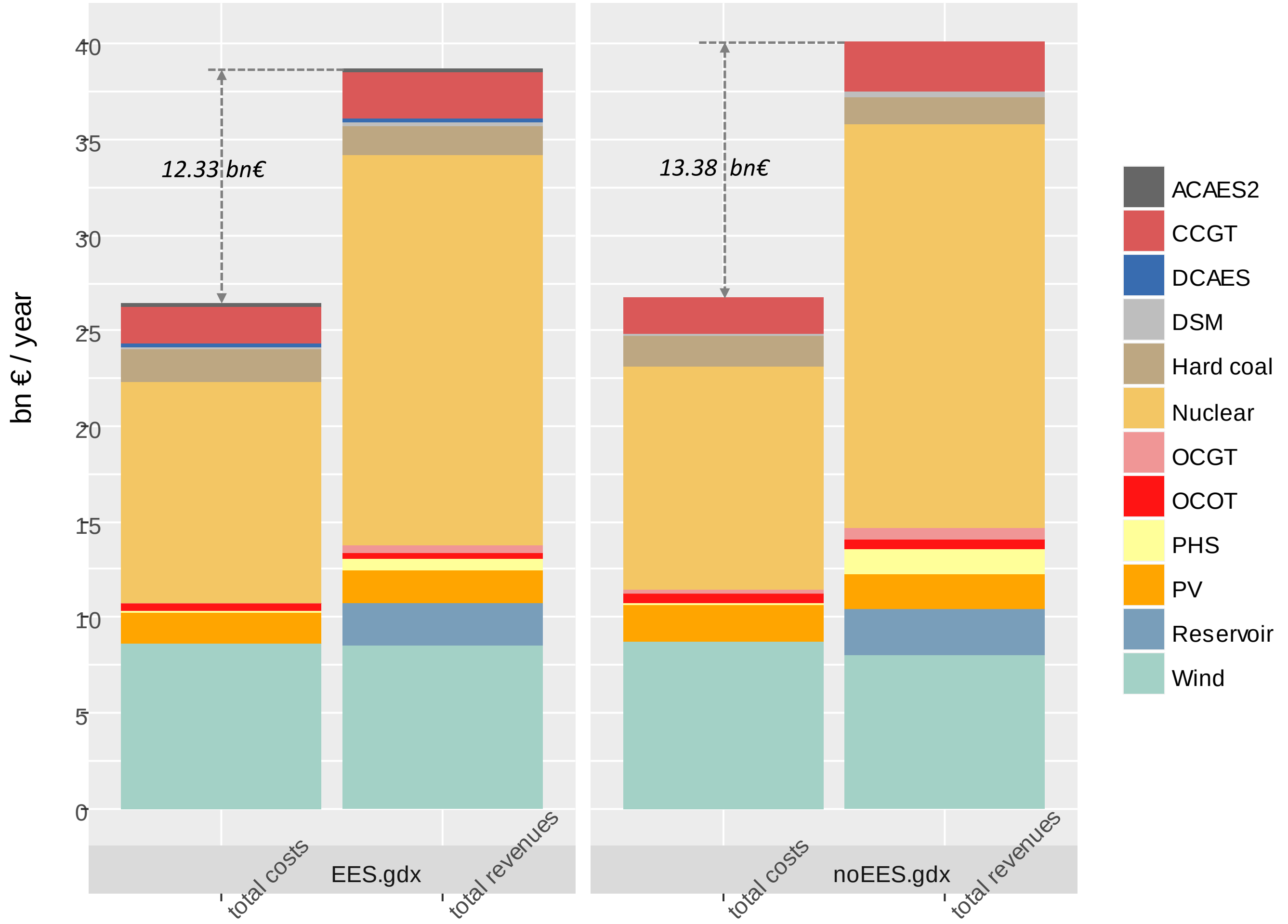
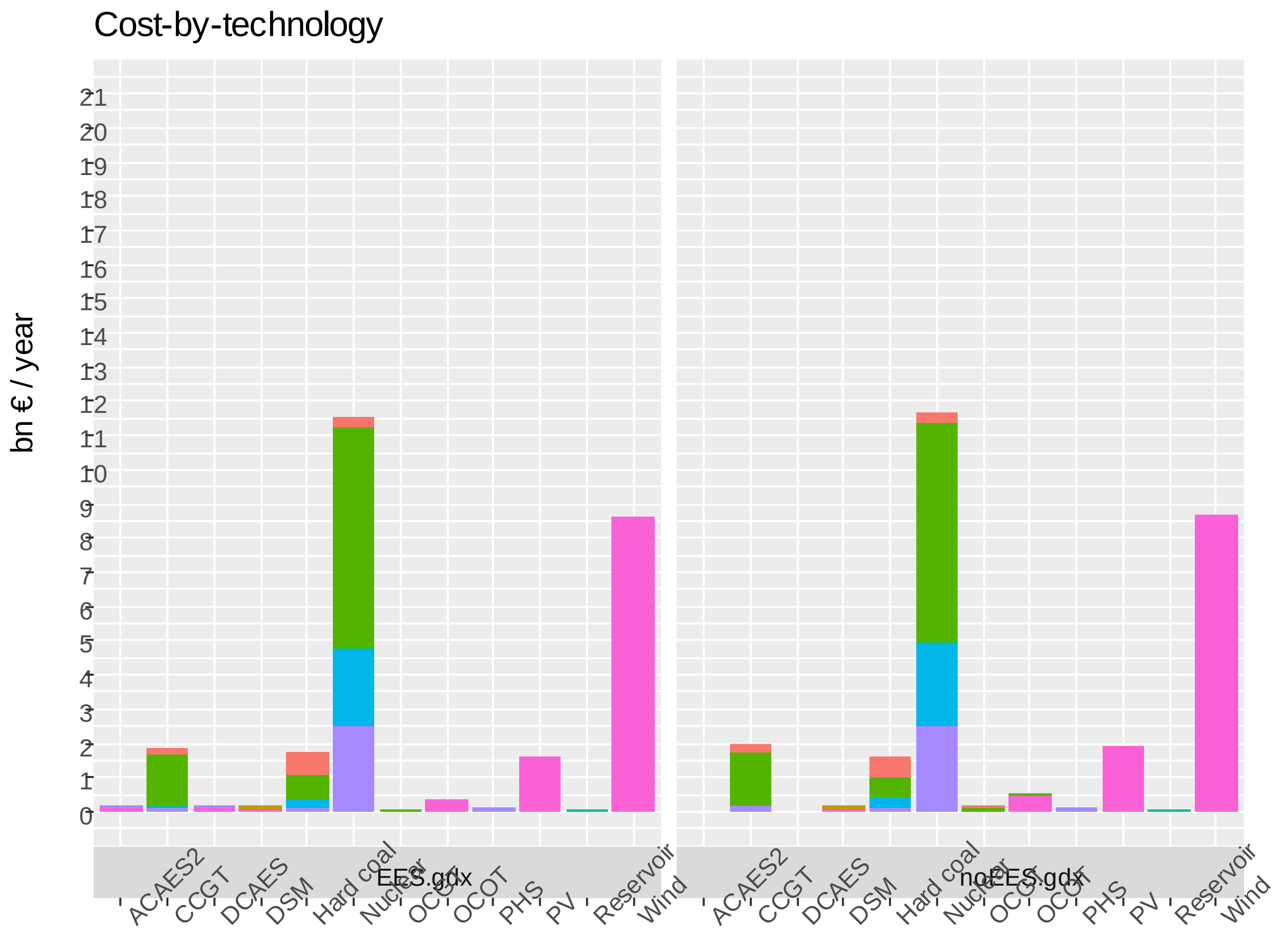
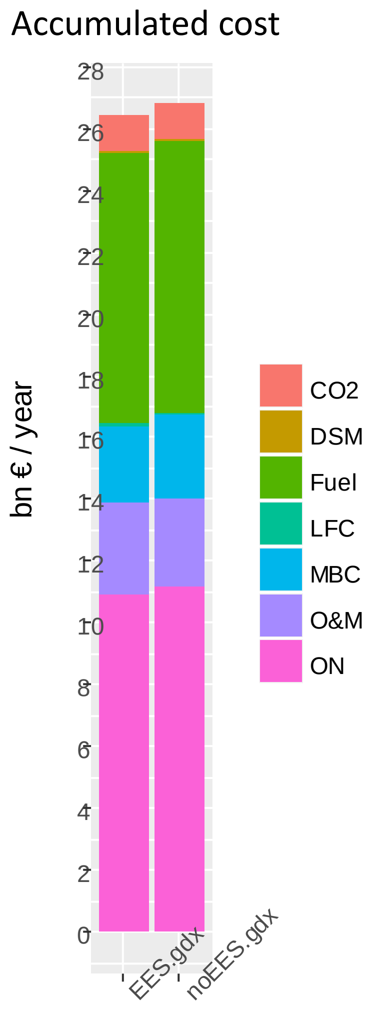


Surplus variations of producers due to market share and price variations. Producers profits are positives in both cases but are higher in the reference case without storage.



Results: Costs variations





3. The public value of electricity storage and its welfare effects