The Participation of Small-scale Variable Distributed Renewable Energy Sources to the Balancing Services Market

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Introduction

- The recent development of a number of small production plants made grid management challenging
  - Increased costs for reserve margin provision
  - Risk of islanding
- The “Clean Energy for all European” package still foster the investments in renewable energy
- The same package also encourages the participation of small agents to the market

=> Designing new markets is a major issue for the functioning of the energy system as a whole

Motivation

- New agents will be included in the market
  - Prosumers
  - Small power plants
  - Aggregators

- The role of existing agents shall be reconsidered (DSOs in particular)

=> It is necessary to study possible ways in which variable distributed energy resources **(V-DER) can participate to markets taking into account the impact that new market frameworks have on the technical management** of the system

Paper contribution

This work wants to provide a first attempt of **interdisciplinary** approach to the design of new electricity markets, considering both economic and technical implications of the possible solutions.

In this paper, we will investigate the impact of different market designs for V-DER provisions of balancing services.

Different market designs are mainly characterized by the role of DSO.

The analysis regards the whole system, i.e. we look at the social cost of the balancing service.

Framework (1/3)

In the paper we analyze the functioning of balancing markets with the participation of V-DER under two different regimes:

1. *Commercial* aggregation

V-DER offers are aggregated to provide balancing services without considering technical feasibility of the offers.

2. *Technical* aggregation

Under the second framework, the DSO is responsible for keeping an agreed exchange path with the TSO, being responsible for local balancing and choosing resources to be called to the market.

Framework (2/3)

The target of the regulation is to choose the market that minimizes the overall cost of balancing.

The balancing process has 3 main actors:

- TSO managing the system through the selection of offers from the market;
- DSO managing the distribution network;
- Aggregator/s of V-DER that offers balancing service on day D exploiting V-DER availability

The model only considers the distribution network. No interplays among agents are considered (small agents).

Framework (3/3)

Model 1 –*commercial*

1. The aggregators collect V-DER and presents a single offer for upward energy and one offer for downward energy
2. The TSO selects and then submits the dispatching order to the DSO for the technical feasibility check
3. The DSO determines viable offers, forcing the disconnection in case of potential violation
4. The TSO buys residual demand from HV resources

Model 2 – *technical*

1. The aggregator collects V-DER availabilities for upward energy and one offer for downward energy, specifying the composition
2. The DSO calculates the optimal power flow with the target of compensating deviations from the pattern agreed with the TSO and using V-DER up to technical limit
3. The TSO buys residual demand from HV resources

Model – balancing process

1) Communication of scheduled profile to the TSO (D-1)

2) The TSO calculates the compensation with HV resources (P0)

3) In day D, the real profile is realized (P(1)) and **the need for balancing services is generated:**

$$\mathbf{P}_{\mathbf{B}}(t) = \mathbf{P}_{\mathbf{ex}}^{(0)}(t) - \mathbf{P}_{\mathbf{ex}}^{(1)}(t)\,, \ \forall t \in (1, 24) \qquad (1)$$

4) Upward and downward offers from V-DER are collected

$$L_A^+ \leq L_i^+$$
$$L_A^- \leq L_i^-$$

5) In case of risk, the DSO can disconnect V-DERs. In this way it generates costs **Z**, curtailement costs (more balancing needed, missing RES used)

6) The TSO buys balancing from the HV:

$$L_{AS}^+ = \sum_{t=1}^{24} \max\left[\mathbf{P}_{\mathbf{B}}(t), 0\right] - L_A^+ \qquad (4)$$

$$L_{AS}^- = \sum_{t=1}^{24} \min\left[\mathbf{P}_{\mathbf{B}}(t), 0\right] - L_A^- \qquad (5)$$

Model – overall cost of balancing

$$C = p_*^+ \cdot E[L_{AS}^+] + p_*^- \cdot E[L_{AS}^-] + p_A^+ \cdot E[L_A^+] + p_A^- \cdot E[L_A^-] \boxed{+ p_Z \cdot E[Z]}$$

- Z can be seen as the consequence of a wrongly incentivized V-DER, as it represents technical constraints

Case study

For the case study, we considered the electrical network described in the picture

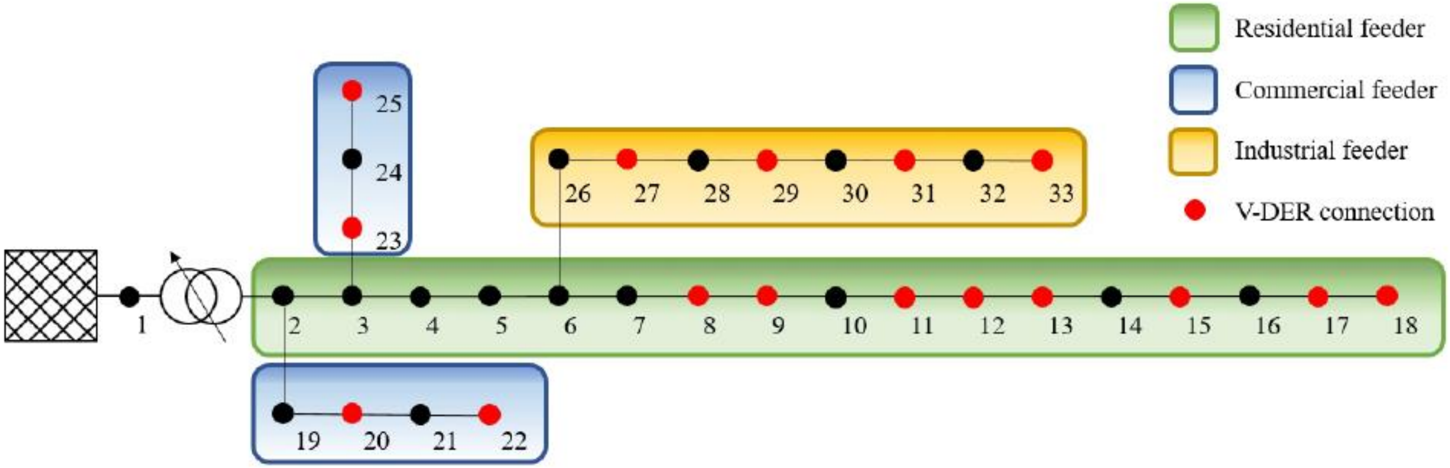
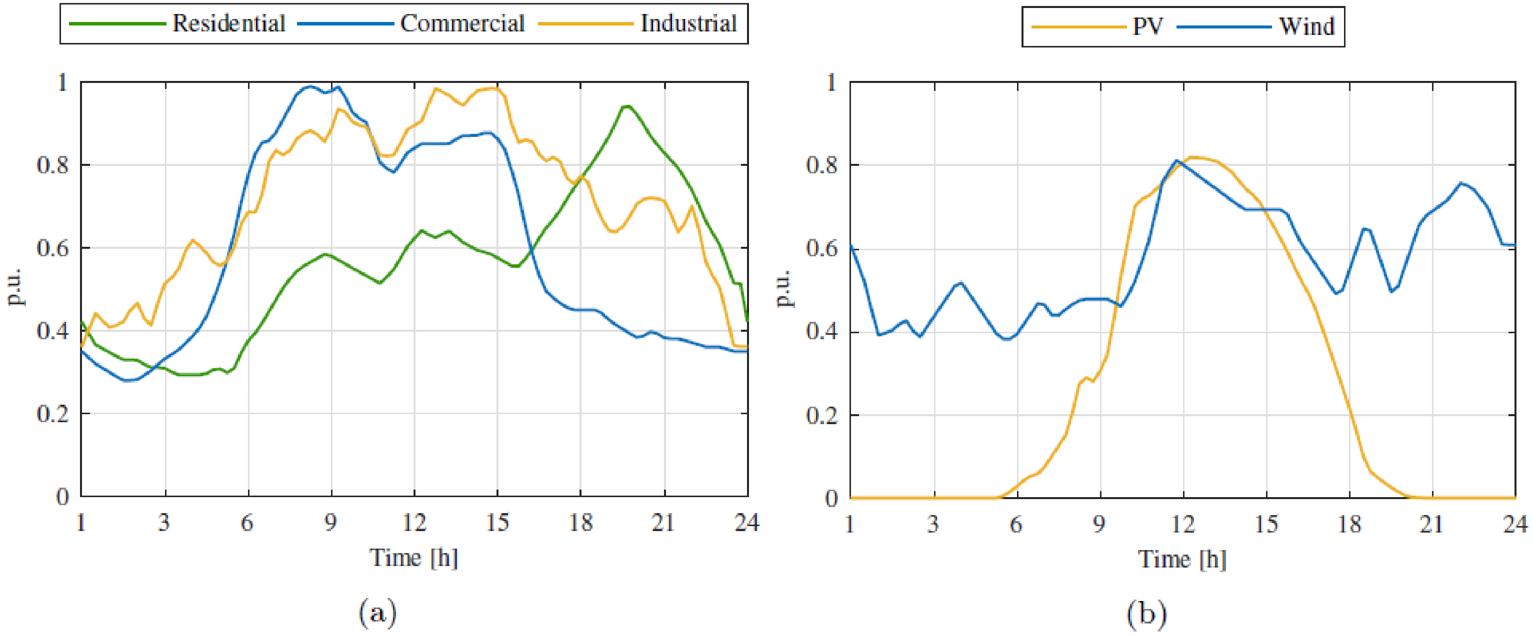


Figure 1: IEEE-33bus reference distribution network.

Simulation parameters

Consumption and production in the network:

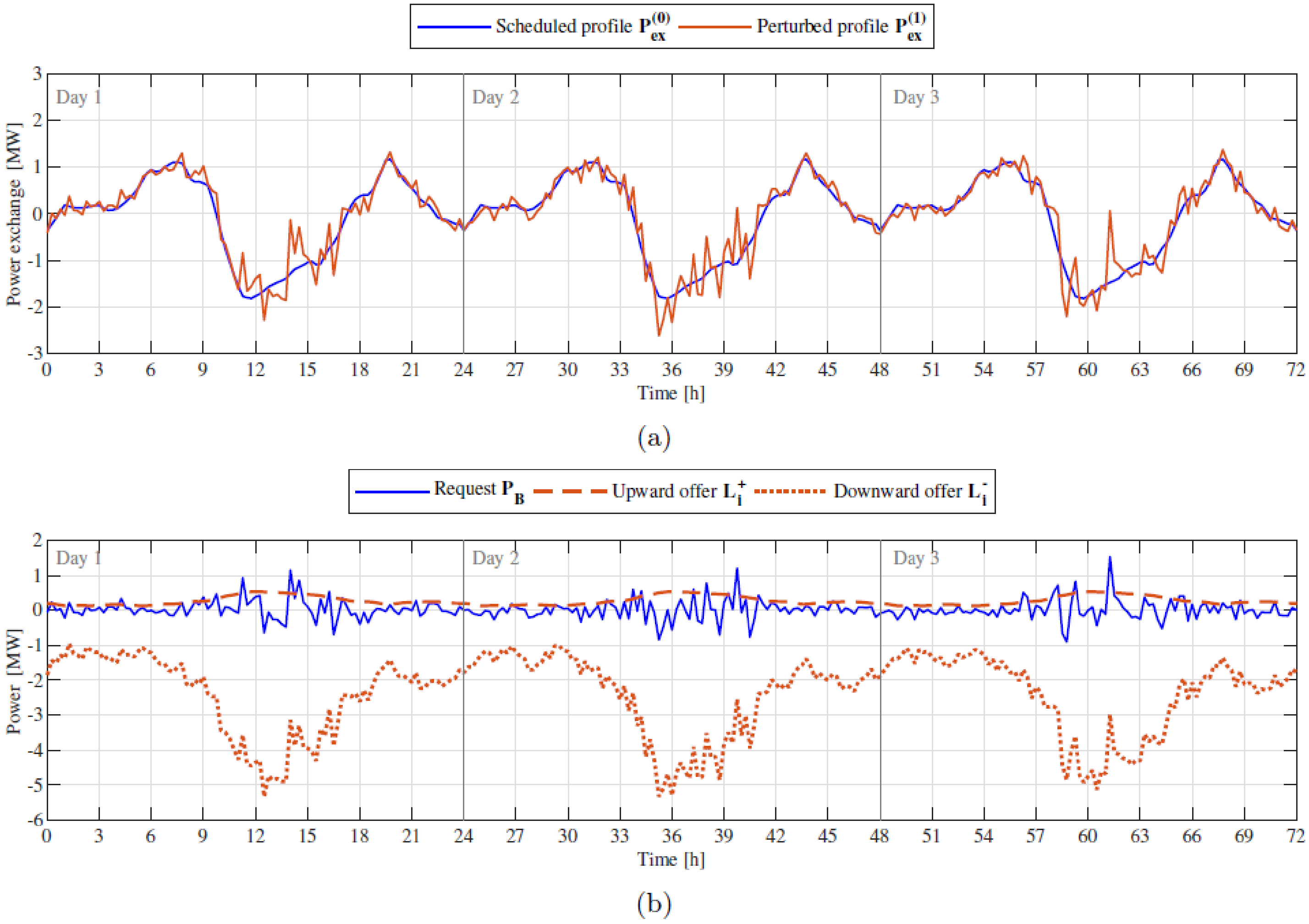


(a)

(b)

Figure 2: Load (a) and generation (b) daily power profiles.

Simulations



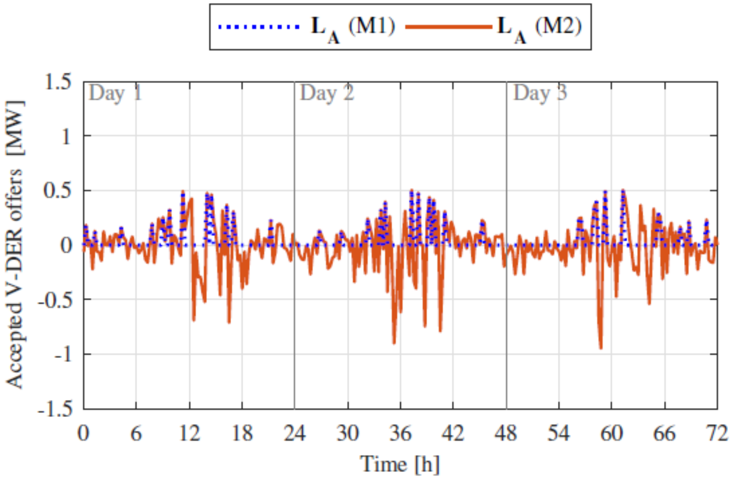
(a)

(b)

Figure 3: a) Scheduled and real exchange profile b) Aggregator offers and balancing request

Simulations

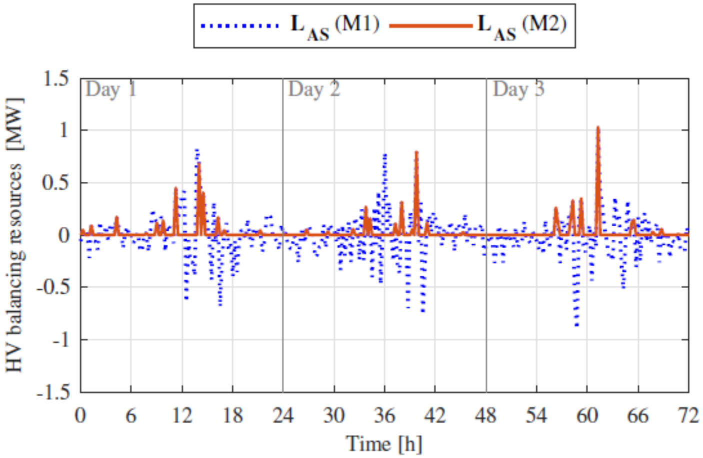
Accepted offers

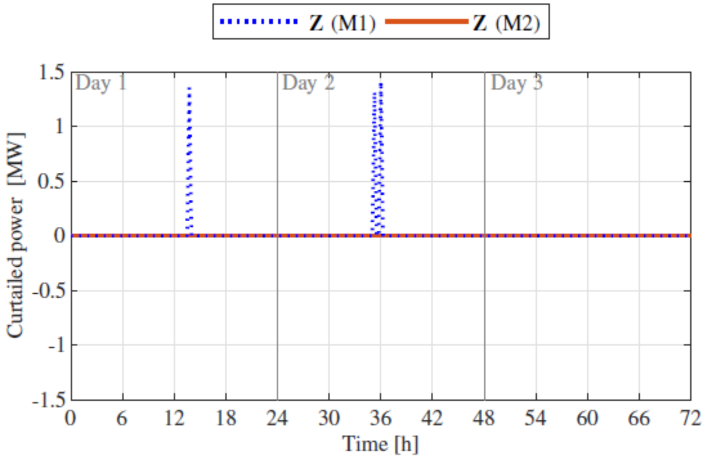


(a)

Residual HV balance

(a)



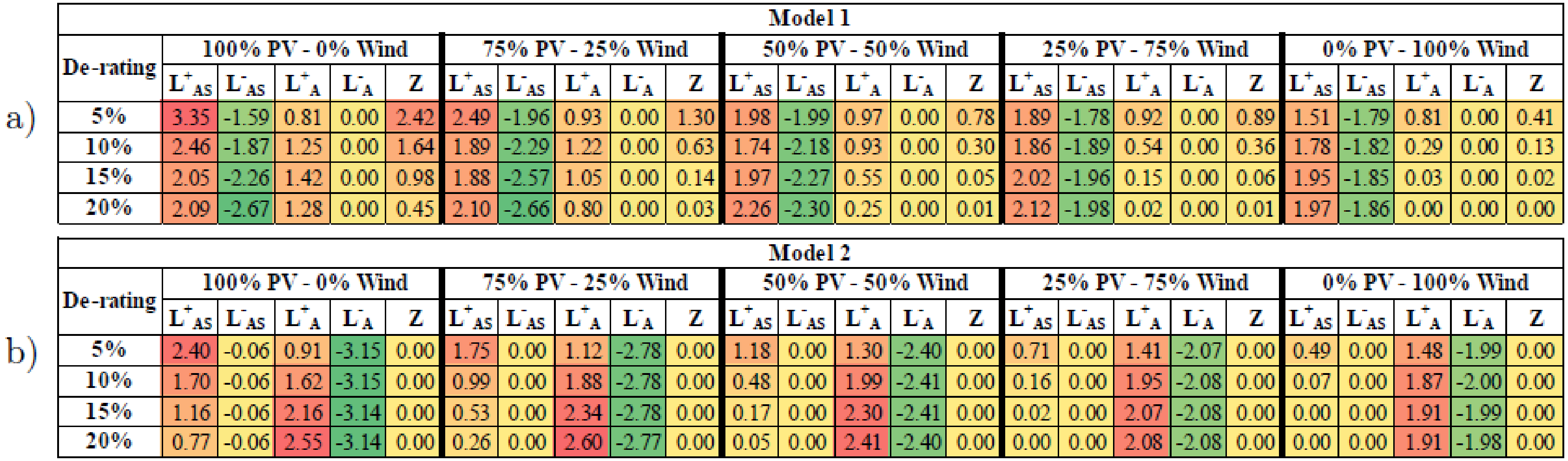


(c)

Curtailed power

Simulation results

Table 1: Parametric analysis results: energy amounts [MWh] in model 1 (a) and model 2 (b).



a)

Model 1																									
De-rating	100% PV - 0% Wind					75% PV - 25% Wind					50% PV - 50% Wind					25% PV - 75% Wind					0% PV - 100% Wind				
	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z
5%	3.35	-1.59	0.81	0.00	2.42	2.49	-1.96	0.93	0.00	1.30	1.98	-1.99	0.97	0.00	0.78	1.89	-1.78	0.92	0.00	0.89	1.51	-1.79	0.81	0.00	0.41
10%	2.46	-1.87	1.25	0.00	1.64	1.89	-2.29	1.22	0.00	0.63	1.74	-2.18	0.93	0.00	0.30	1.86	-1.89	0.54	0.00	0.36	1.78	-1.82	0.29	0.00	0.13
15%	2.05	-2.26	1.42	0.00	0.98	1.88	-2.57	1.05	0.00	0.14	1.97	-2.27	0.55	0.00	0.05	2.02	-1.96	0.15	0.00	0.06	1.95	-1.85	0.03	0.00	0.02
20%	2.09	-2.67	1.28	0.00	0.45	2.10	-2.66	0.80	0.00	0.03	2.26	-2.30	0.25	0.00	0.01	2.12	-1.98	0.02	0.00	0.01	1.97	-1.86	0.00	0.00	0.00

b)

Model 2																									
De-rating	100% PV - 0% Wind					75% PV - 25% Wind					50% PV - 50% Wind					25% PV - 75% Wind					0% PV - 100% Wind				
	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z	L^+_{AS}	L^-_{AS}	L^+_A	L^-_A	Z
5%	2.40	-0.06	0.91	-3.15	0.00	1.75	0.00	1.12	-2.78	0.00	1.18	0.00	1.30	-2.40	0.00	0.71	0.00	1.41	-2.07	0.00	0.49	0.00	1.48	-1.99	0.00
10%	1.70	-0.06	1.62	-3.15	0.00	0.99	0.00	1.88	-2.78	0.00	0.48	0.00	1.99	-2.41	0.00	0.16	0.00	1.95	-2.08	0.00	0.07	0.00	1.87	-2.00	0.00
15%	1.16	-0.06	2.16	-3.14	0.00	0.53	0.00	2.34	-2.78	0.00	0.17	0.00	2.30	-2.41	0.00	0.02	0.00	2.07	-2.08	0.00	0.00	0.00	1.91	-1.99	0.00
20%	0.77	-0.06	2.55	-3.14	0.00	0.26	0.00	2.60	-2.77	0.00	0.05	0.00	2.41	-2.40	0.00	0.00	0.00	2.08	-2.08	0.00	0.00	0.00	1.91	-1.98	0.00

*100 days of simulations

Market model 1 – *commercial* aggregation

- Downward service: increase of derating percentage lead to higher need for balancing downward in all scenarios. The services are bought by HV resources. L^-_a is always 0 in model 1
- Higher the derating, lower the probability of congestion (and lower Z)
- Upward services highly depend on generation mix and deratings

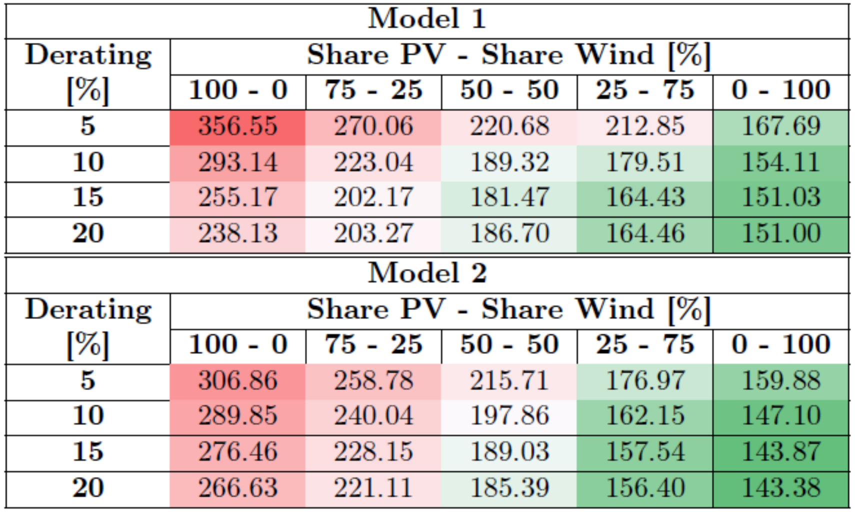
Market model 2 – *technical* aggregation

- Z is always equal to 0
- Downward services: V-DER can decrease the entire production in all intervals to fulfill the demand. In case of 100% PV this is not true during the unproductive interval
- Upward services: a larger amount of offers is selected as the indivisibility constraint is removed

Cost comparison

- P^+_{as} = 100€/MWh
- P^-_{as} = 25€/MWh
- P^+_{as} = 75€/MWh
- P^-_{a} = 0€/MWh
- Pz = 0

Table 2: Social cost C in Model 1 and Model 2 with p_A^+=75 €/MWh and p_Z= 0 €/MWh.



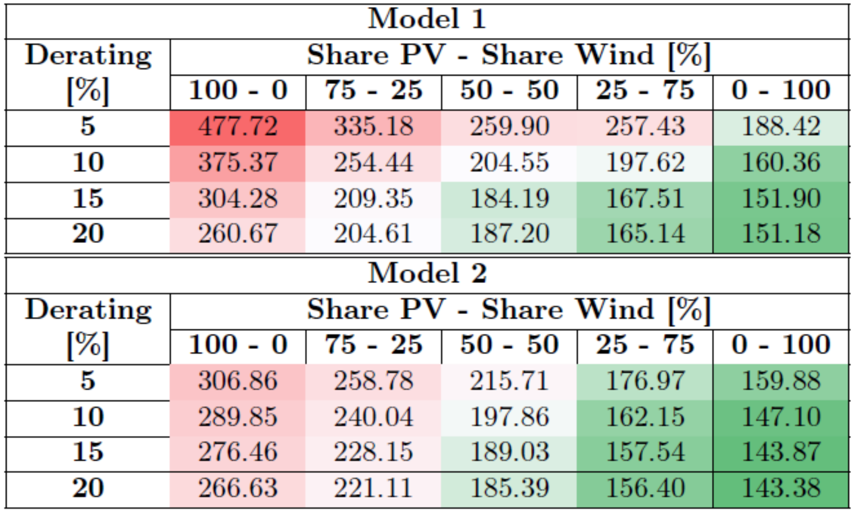
Model 1

Derating [%]	**Share PV - Share Wind [%]**				
	100 - 0	**75 - 25**	**50 - 50**	**25 - 75**	**0 - 100**
5	356.55	270.06	220.68	212.85	167.69
10	293.14	223.04	189.32	179.51	154.11
15	255.17	202.17	181.47	164.43	151.03
20	238.13	203.27	186.70	164.46	151.00

Model 2

Derating [%]	**Share PV - Share Wind [%]**				
	100 - 0	**75 - 25**	**50 - 50**	**25 - 75**	**0 - 100**
5	306.86	258.78	215.71	176.97	159.88
10	289.85	240.04	197.86	162.15	147.10
15	276.46	228.15	189.03	157.54	143.87
20	266.63	221.11	185.39	156.40	143.38

Table 3: Social cost C in Model 1 and Model 2 with p_A^+=75 €/MWh and p_Z=50 €/MWh.



Model 1

Derating [%]	**Share PV - Share Wind [%]**				
	100 - 0	**75 - 25**	**50 - 50**	**25 - 75**	**0 - 100**
5	477.72	335.18	259.90	257.43	188.42
10	375.37	254.44	204.55	197.62	160.36
15	304.28	209.35	184.19	167.51	151.90
20	260.67	204.61	187.20	165.14	151.18

Model 2

Derating [%]	**Share PV - Share Wind [%]**				
	100 - 0	**75 - 25**	**50 - 50**	**25 - 75**	**0 - 100**
5	306.86	258.78	215.71	176.97	159.88
10	289.85	240.04	197.86	162.15	147.10
15	276.46	228.15	189.03	157.54	143.87
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Conclusions (1/2)

- Lot of curtailments in model 1 represent the *missing integration* of V-DER in the system, as technical local constraints force thir interruption
- Model 1 leaves DSOs outside the balancing market
- Model 2, on the contrary, asks the DSO to solve unbalances at distribution network => Z goes to zero

- Model 2, however, is not always preferred to Model 1: downward services, for example, are cheaper outside the distribution network

Conclusions (2/2)

- Overall, *commercial* aggregation is preferable when the penalty price of curtailments is null or low, the PV share is high and V-DER reserve capacity is high too;
- The *technical* aggregation is preferable if the share of wind is higher, lower level of V-DER de-rating capacity or with high explicit penalties for curtailments.

! More models are possible.

⇒ Further research on dynamic interactions among players

⇒ Further studies to implement balancing (and energy) markets reforms

Thank you for your attention!

You can find the working paper in the «Marco Fanno» WP series

https://economia.unipd.it/ricerca/ricerca/marco-fanno-working-papers (n. 263-2020)

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