GALILEO

OFATE DFBEW

Sharing grid access points: Implementation and opportunities for hybrid wind and PV

Presentation at OFATE

15 May 2024, Paris, France

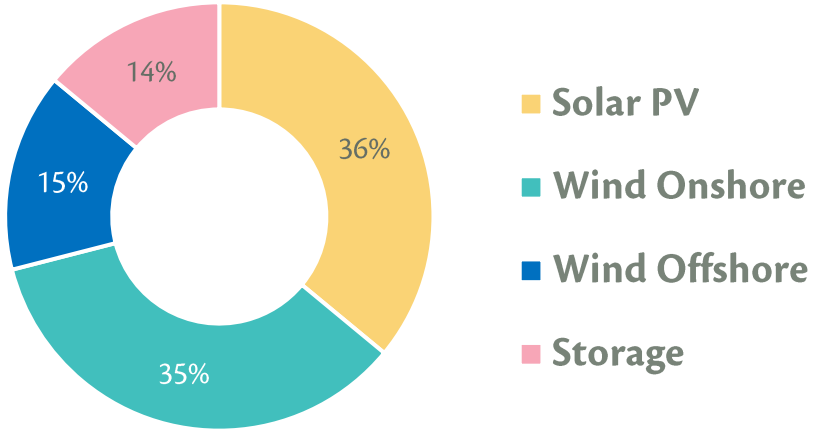
1. Galileo: driving Europe's energy transition

Galileo's mission

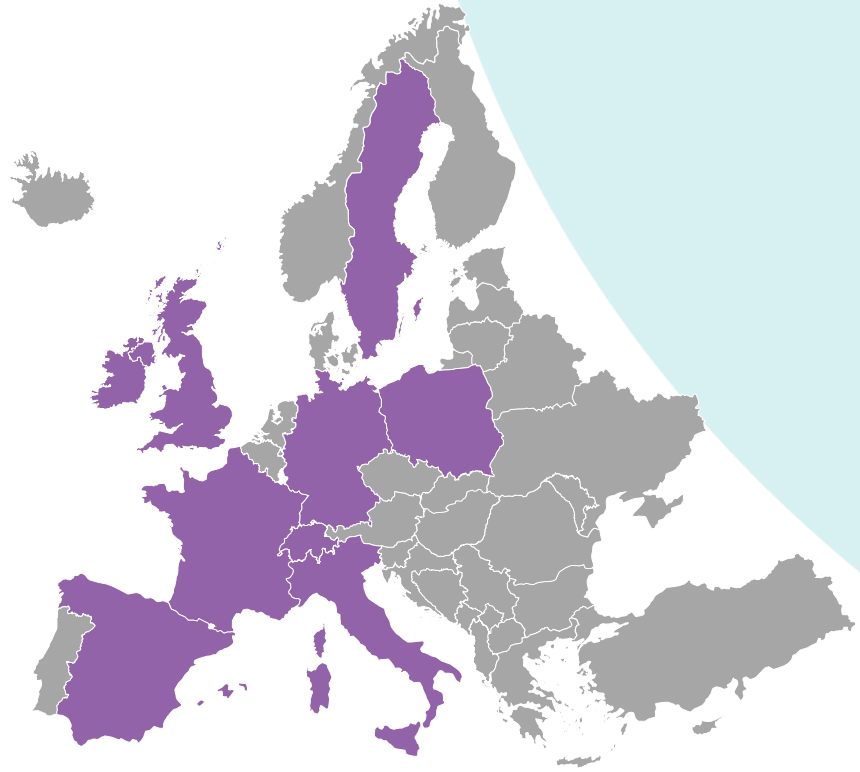
We strive to make a meaningful contribution to the European renewable energy transition

Galileo's pipeline of renewable energy projects

- 12.5 GW across Europe
- 4 technologies
- 10 markets
- 20 development partnerships



Galileo's presence across Europe

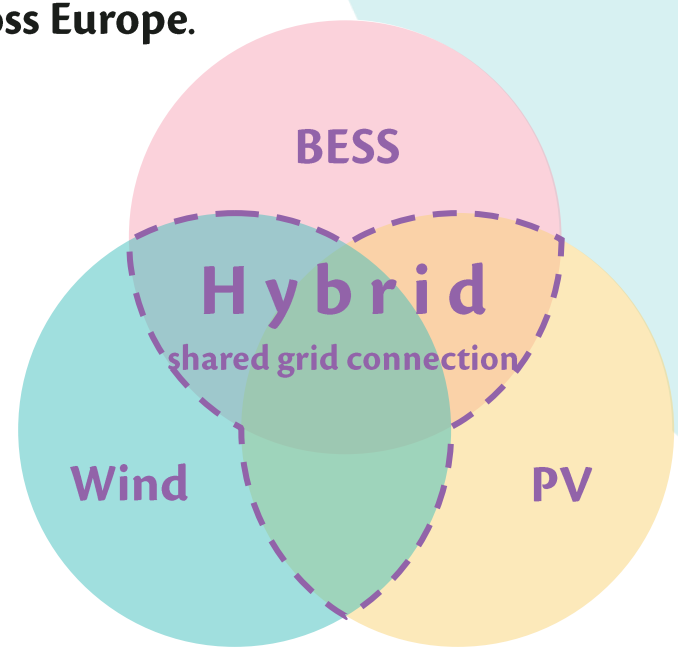


2. Hybrid: the challenges of interconnection

- **Limited capacity for new projects: in many markets, grid connection requests are by far in excess of available grid connection capacity in all major European markets**
- **Substantial grid connections investment: EUR 584 billion needed until 2030 to reach the 2030 RES targets**
- **Long lead times: permitting & construction times reach 5 to 10 years across Europe.**

However, there is still a low-hanging fruit:
make better use of the existing network

= hybridisation !



Sources: European Commission - Networks, the missing link - An EU action plan for networks - 28.11.2023 | EMBER - European Electricity Review 2024

2. Hybrid: opportunities for PV & Wind co-location

For developers:

- **Optimise the use of sites and connections** through co-location
- **Limit the costs and lead times** associated with the development of renewable energy projects
- **Generate renewable** energy production profiles that are **better adapted to consumer needs**
- **Preserve investment returns and competitiveness of electricity costs** thanks to asset optimisations

For grid operators:

- **Minimise generation fluctuations** thanks to the **complementary** nature of solar and wind power profiles
- **Opportunity to further increase flexibility by the addition of batteries**
- **Reduce network constraints** by optimising connections
- **Limit overall system costs**

3. Simulation of a hybrid wind & solar PV power plant

Data supplied by Aurora and analysed by Galileo

Assumptions

Wind turbine capacity: 20 MW (6 wind turbines)

Grid connection: 20 MW

Solar capacity: optimised to allow maximum use of the grid connection while minimising curtailment

Results

Annual average % use of grid connection	Germany North	Germany South	France Northwest	France South
Stand-alone wind (20 MW)	27%	17%	26%	24%
Solar capacity installed (optimised)	46.7 MWp	44.4 MWp	37.51 MWp	35.85 MWp
Stand-alone solar (20 MW Grid connection)	21%	23%	24%	26%
Hybrid (Solar + Wind)	46%	39%	47%	48%
Total annual production	84.23 GWh	74.52 GWh	88.45 GWh	89.15 GWh
Curtailment due to exceeding injection capacity	4.87 GWh (6%)	6.26 GWh (8%)	5.99 GWh (7%)	5.87 GWh (6.60%)

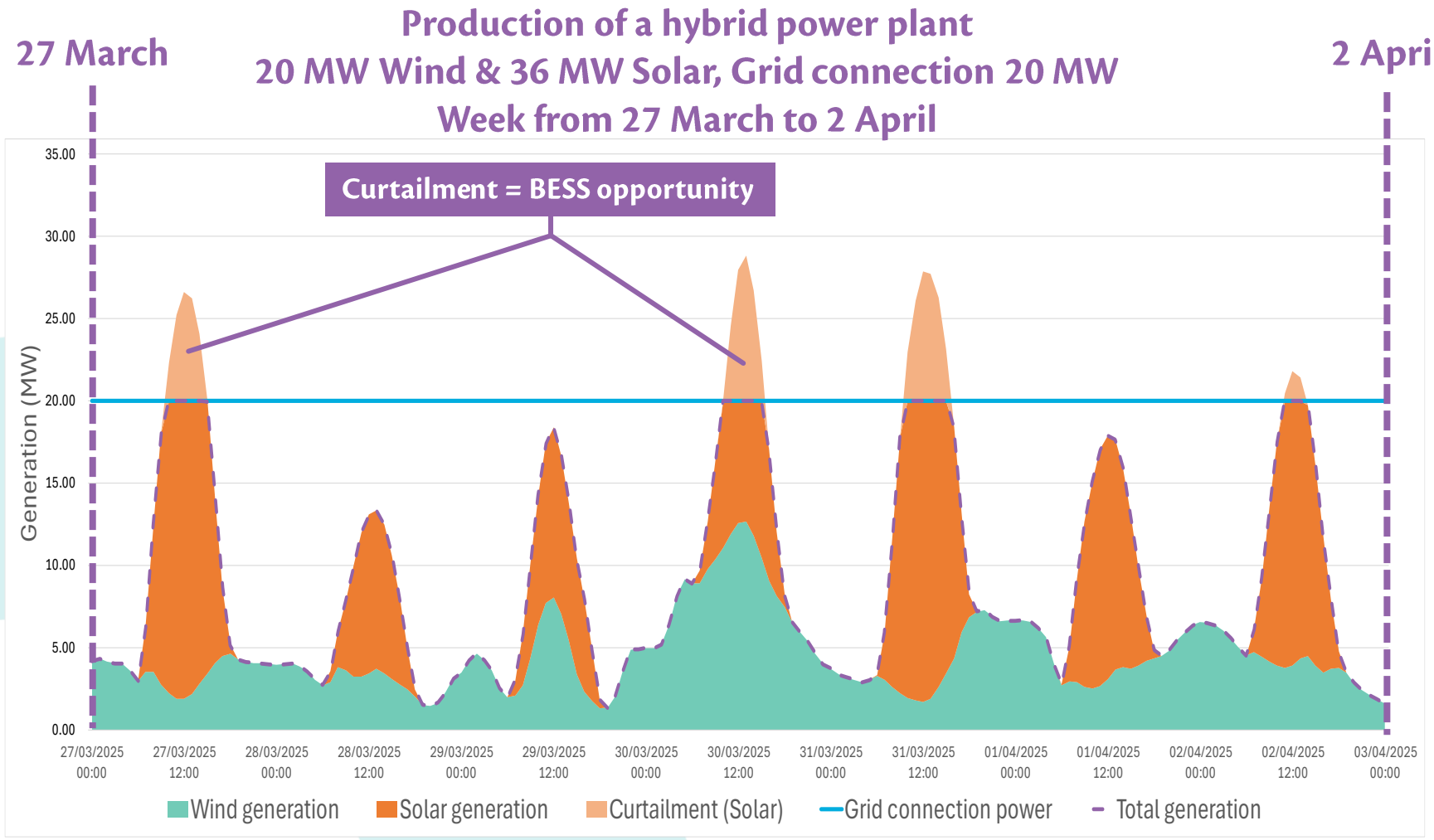
Thanks to the hybrid solution, **usage of the connection capacity increases by the factor 1.5 to 2.3.**

In all cases, curtailment linked to excess capacity are **limited to around 7%** of the energy produced over the year.

The results are very similar across a variety of regions in **France and Germany**.

3. Simulation of a hybrid power plant

Data supplied by Aurora and analysed by Galileo



A hybrid power plant optimises use of the grid throughout the year.

Using the same approach, the assets could also be **sized to fit with specific consumer profiles** and cover an increasing share of local demand.

The need for **buying & selling energy from and to the overlay grid would be reduced.**

3. Simulation of a hybrid site - Use of interconnection capacity

Average rate of use of connection capacity per hour and per month

Data supplied by Aurora and analysed by Galileo

Month

Hours

Wind	1	2	3	4	5	6	7	8	9	10	11	12
00:00	24%	28%	27%	24%	20%	20%	18%	18%	20%	27%	34%	31%
01:00	26%	28%	27%	24%	20%	20%	17%	17%	20%	26%	34%	30%
02:00	26%	28%	27%	24%	20%	20%	16%	16%	20%	26%	34%	29%
03:00	27%	28%	27%	24%	20%	19%	16%	15%	20%	26%	34%	29%
04:00	27%	29%	27%	23%	19%	16%	13%	13%	20%	26%	34%	29%
05:00	27%	29%	27%	20%	18%	16%	11%	10%	18%	26%	34%	29%
06:00	27%	28%	26%	19%	20%	18%	12%	10%	15%	25%	33%	29%
07:00	25%	28%	26%	22%	22%	19%	13%	12%	17%	23%	32%	27%
08:00	24%	29%	28%	23%	22%	20%	13%	12%	18%	25%	33%	24%
09:00	23%	31%	30%	24%	22%	20%	14%	13%	18%	27%	36%	24%
10:00	24%	32%	31%	24%	23%	21%	14%	14%	19%	29%	37%	24%
11:00	24%	32%	32%	25%	25%	22%	14%	15%	20%	30%	38%	25%
12:00	23%	32%	32%	26%	26%	23%	14%	16%	20%	29%	38%	24%
13:00	22%	32%	31%	26%	27%	24%	15%	17%	21%	27%	38%	24%
14:00	21%	31%	30%	26%	27%	24%	15%	17%	20%	25%	36%	26%
15:00	23%	32%	28%	24%	26%	23%	16%	18%	19%	23%	37%	29%
16:00	24%	34%	28%	23%	24%	22%	17%	18%	18%	23%	39%	31%
17:00	25%	35%	29%	23%	23%	21%	18%	20%	20%	25%	39%	32%
18:00	24%	35%	29%	24%	24%	21%	22%	23%	22%	25%	38%	33%
19:00	24%	34%	29%	24%	24%	22%	24%	23%	22%	26%	37%	32%
20:00	23%	32%	28%	24%	23%	22%	23%	22%	22%	27%	36%	32%
21:00	23%	31%	28%	23%	23%	21%	22%	20%	21%	28%	35%	33%
22:00	23%	29%	28%	23%	22%	20%	21%	19%	21%	28%	35%	33%
23:00	23%	28%	28%	24%	21%	20%	19%	18%	20%	27%	35%	32%

Solar	1	2	3	4	5	6	7	8	9	10	11	12
00:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
01:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
02:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
03:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05:00	0%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%
06:00	0%	0%	0%	2%	7%	12%	10%	4%	0%	0%	0%	0%
07:00	0%	1%	5%	17%	26%	33%	31%	26%	13%	2%	0%	0%
08:00	4%	15%	24%	40%	49%	58%	56%	53%	37%	16%	4%	2%
09:00	20%	39%	47%	63%	72%	80%	78%	79%	63%	39%	20%	19%
10:00	38%	60%	68%	79%	86%	92%	92%	95%	83%	60%	37%	40%
11:00	51%	74%	79%	86%	92%	95%	96%	98%	90%	74%	52%	56%
12:00	57%	78%	83%	87%	93%	97%	96%	98%	91%	79%	59%	65%
13:00	56%	77%	81%	85%	92%	96%	95%	98%	90%	76%	58%	64%
14:00	47%	69%	75%	80%	87%	94%	91%	96%	86%	66%	49%	54%
15:00	31%	52%	61%	69%	76%	87%	82%	86%	72%	49%	35%	37%
16:00	12%	29%	40%	51%	58%	68%	63%	65%	50%	29%	16%	13%
17:00	0%	6%	17%	29%	36%	46%	41%	40%	25%	9%	1%	0%
18:00	0%	0%	2%	10%	16%	23%	20%	16%	5%	0%	0%	0%
19:00	0%	0%	0%	0%	3%	6%	5%	1%	0%	0%	0%	0%
20:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
21:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
23:00	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Wind generation's **substantial intraday fluctuations** are **overlooked when averaging** monthly hourly data.
Nevertheless, the **average rate of use of the connection is low**.

Hybrid	1	2	3	4	5	6	7	8	9	10	11	12
00:00	24%	28%	27%	24%	20%	20%	18%	18%	20%	27%	34%	31%
01:00	26%	28%	27%	24%	20%	20%	17%	17%	20%	26%	34%	30%
02:00	26%	28%	27%	24%	20%	20%	16%	16%	20%	26%	34%	29%
03:00	27%	28%	27%	24%	20%	19%	16%	15%	20%	26%	34%	29%
04:00	27%	29%	27%	23%	19%	16%	13%	13%	20%	26%	34%	29%
05:00	27%	29%	27%	20%	18%	17%	11%	10%	18%	26%	34%	29%
06:00	27%	28%	26%	21%	27%	29%	22%	15%	16%	25%	33%	29%
07:00	25%	28%	31%	38%	47%	52%	44%	37%	29%	25%	32%	27%
08:00	27%	45%	52%	63%	72%	77%	70%	66%	55%	41%	37%	26%
09:00	43%	69%	76%	83%	89%	94%	90%	89%	80%	66%	55%	43%
10:00	61%	89%	90%	94%	96%	97%	97%	98%	93%	86%	74%	64%
11:00	74%	96%	94%	97%	98%	99%	99%	99%	97%	94%	85%	80%
12:00	79%	98%	95%	98%	99%	99%	99%	99%	97%	96%	89%	86%
13:00	76%	97%	94%	97%	98%	99%	98%	99%	97%	95%	88%	85%
14:00	68%	93%	91%	95%	97%	99%	96%	99%	94%	88%	82%	79%
15:00	54%	82%	84%	88%	92%	97%	91%	96%	87%	72%	71%	66%
16:00	36%	63%	67%	73%	80%	88%	80%	83%	68%	52%	55%	45%
17:00	25%	42%	46%	53%	59%	67%	60%	60%	46%	33%	39%	32%
18:00	24%	35%	31%	34%	40%	45%	42%	38%	26%	25%	38%	33%
19:00	24%	34%	29%	25%	27%	28%	28%	24%	22%	26%	37%	32%
20:00	23%	32%	28%	24%	23%	22%	23%	22%	22%	27%	36%	32%
21:00	23%	31%	28%	23%	23%	21%	22%	20%	21%	28%	35%	33%
22:00	23%	29%	28%	23%	22%	20%	21%	19%	21%	28%	35%	33%
23:00	23%	28%	28%	24%	21%	20%	19%	18%	20%	27%	35%	32%

In the case of solar generation, as expected we notice a **strong seasonal and hourly correlation**.
This results into a **highly irregular** use of the full connection capacity.

Data provided by Aurora and analysed by Galileo

3. Simulation of a hybrid site - Curtailment analysis

Hourly and monthly totals in MWh of load curtailment due to limited grid connection

Losses	1	2	3	4	5	6	7	8	9	10	11	12	Total
00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
04:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
06:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08:00	0.00	0.00	0.00	1.16	0.13	2.12	0.00	0.00	0.00	0.00	0.00	0.00	3.42
09:00	0.00	0.00	7.90	21.74	32.03	38.64	10.97	15.03	6.57	2.18	0.00	0.00	135.06
10:00	2.30	12.17	59.17	72.77	97.38	121.83	68.69	87.60	54.96	20.23	4.77	0.73	602.59
11:00	8.38	59.40	125.49	121.84	157.90	183.47	119.67	158.67	109.91	58.53	29.80	7.75	1140.81
12:00	14.92	92.23	159.75	139.91	185.02	213.96	140.21	189.69	139.02	78.21	50.12	17.39	1420.43
13:00	11.45	83.35	148.15	125.84	174.85	202.17	131.44	178.56	129.24	57.53	47.57	16.33	1306.48
14:00	3.84	43.07	99.99	88.74	129.07	155.84	96.45	128.77	84.71	15.25	24.43	7.72	877.89
15:00	0.87	11.08	30.15	38.11	63.57	82.17	41.11	51.20	23.72	1.13	4.38	1.13	348.62
16:00	0.00	0.00	2.69	4.18	12.43	16.05	0.11	2.12	0.12	0.00	0.00	0.00	37.70
17:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	41.77	301.31	633.29	614.28	852.38	1016.25	608.65	811.64	548.24	233.05	161.08	51.07	**5873.00**

Number of hours at negative price on the SPOT market per hour and per month

(SPOT)	1	2	3	4	5	6	7	8	9	10	11	12	Total
00:00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	2.00	4.00
01:00	1.00	0.00	0.00	2.00	0.00	0.00	1.00	0.00	2.00	0.00	0.00	3.00	9.00
02:00	2.00	0.00	0.00	1.00	0.00	0.00	2.00	0.00	2.00	0.00	0.00	5.00	12.00
03:00	2.00	0.00	0.00	1.00	0.00	0.00	2.00	0.00	2.00	0.00	0.00	5.00	12.00
04:00	1.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	4.00	7.00
05:00	1.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	2.00	5.00
06:00	1.00	0.00	0.00	1.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	2.00	6.00
07:00	0.00	0.00	0.00	2.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	1.00	5.00
08:00	0.00	0.00	0.00	6.00	3.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	11.00
09:00	0.00	0.00	0.00	7.00	4.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	15.00
10:00	0.00	0.00	1.00	8.00	4.00	2.00	4.00	0.00	1.00	0.00	0.00	0.00	20.00
11:00	0.00	0.00	1.00	9.00	6.00	4.00	4.00	0.00	2.00	1.00	0.00	0.00	27.00
12:00	0.00	0.00	1.00	12.00	7.00	4.00	5.00	0.00	3.00	2.00	0.00	0.00	34.00
13:00	0.00	0.00	1.00	13.00	6.00	3.00	6.00	0.00	1.00	0.00	0.00	0.00	30.00
14:00	0.00	0.00	1.00	13.00	4.00	1.00	6.00	0.00	0.00	0.00	0.00	0.00	25.00
15:00	0.00	0.00	0.00	8.00	2.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	12.00
16:00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00
17:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
20:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
21:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
22:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
23:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	2.00
Total	8.00	0.00	5.00	84.00	36.00	14.00	47.00	0.00	15.00	3.00	0.00	29.00	**241.00**

(Data: 08/05/23 to 07/05/24)

Load curtailment should be viewed in light of the increasing occurrences of negative electricity prices.

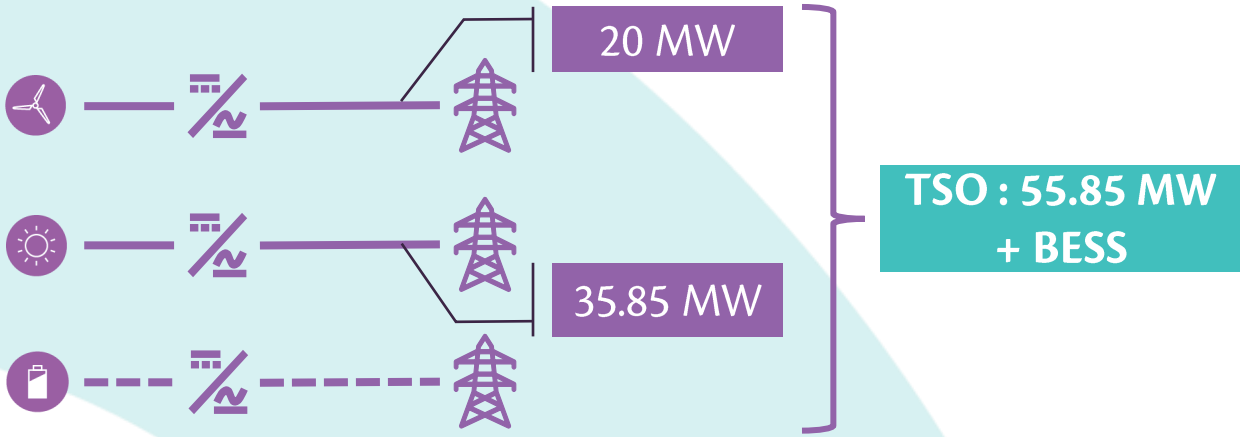
In this simulation:

- **733 MWh** (12% of the curtailed amount) occurs **during periods of negative pricing**.
- **The loss of revenue due to the curtailment in the adjusted load** (excluding negative hours) represents **5.54% of annual revenue**, which is lower than the curtailment percentage (6.6%), as it occurs during periods when prices are low.

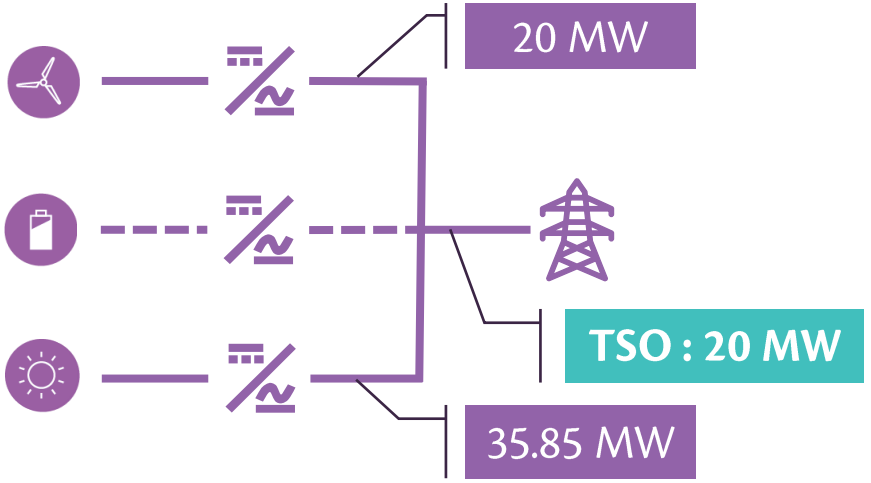
Data supplied by Aurora and analysed by Galileo

4. Implementing connection mutualisation

Standalone model



Hybrid model



The current model of stand-alone projects generates constraints on the grid, in terms of time, cost and use of available capacity.

Wherever possible, projects should be hybrid and the TSO should facilitate and prioritize interconnection applications for such projects.

Conclusion

- **Mutualising the grid connection** of wind and solar generation **significantly improves the utilisation** rate of grid connections, **reducing costs and lead times**, which is crucial for any renewable energy project.

- **Integrating batteries** into hybrid projects takes hybrid to the next level and **makes renewable electricity controllable**, a major opportunity for grid integration and the energy transition.

- **Phase 1** of the energy transition was achieved by **adding new renewable energy capacity** to the grids. **Phase 2** will have to **make hybrid the norm**. To achieve this, the **regulatory environment and the attention paid by TSOs must evolve** if the energy transition is to succeed.

Contact:

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Thank you for your attention