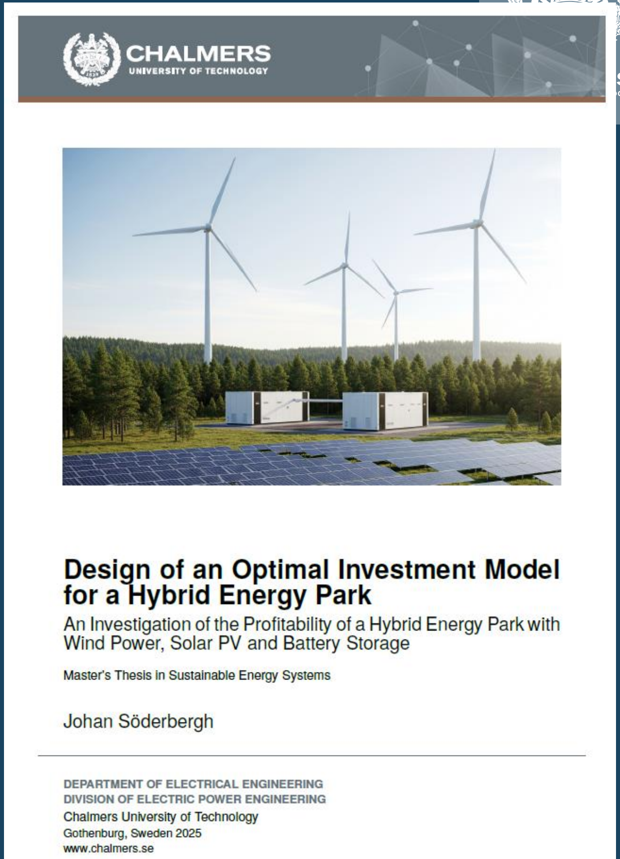
Hybrid energy parks

David Steen, Electric power engineering, Chalmers

Results from Johan Söderbergh’s master thesis conducted at SR energy



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Design of an Optimal Investment Model for a Hybrid Energy Park

An Investigation of the Profitability of a Hybrid Energy Park with Wind Power, Solar PV and Battery Storage

Master's Thesis in Sustainable Energy Systems

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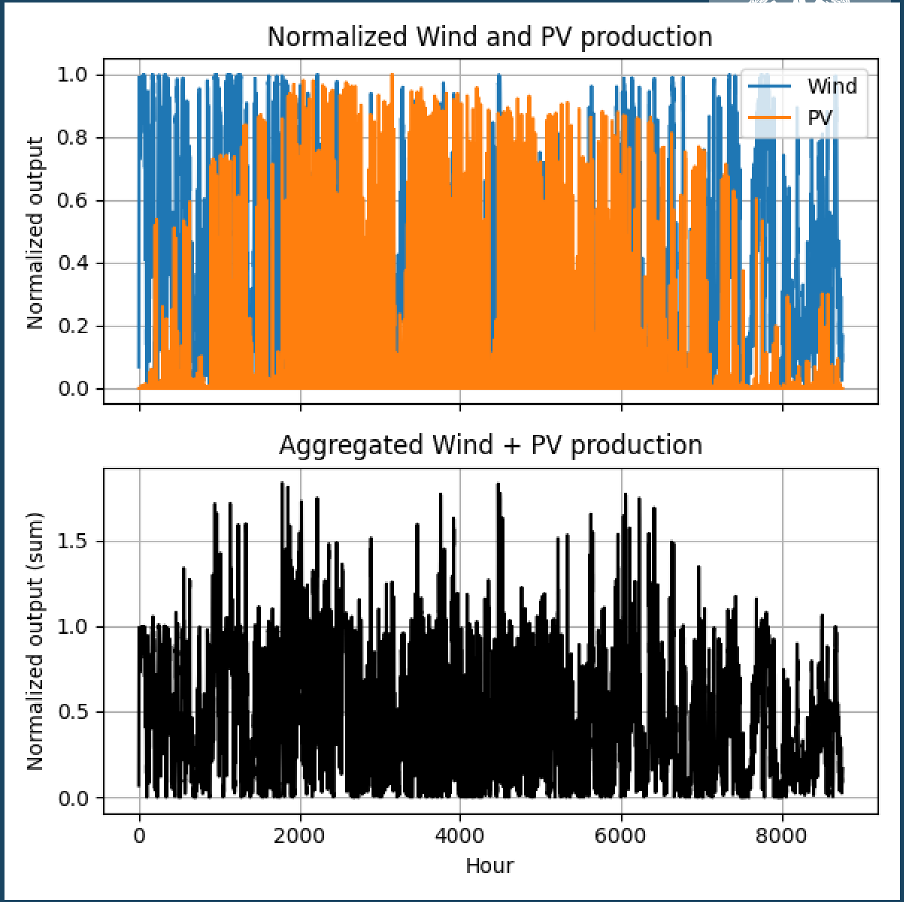
Background

- Combining different production and storage resources could potentially reduce connection cost increasing the grid utilization.
- With the battery one could also provide additional value through arbitrage and ancillary services



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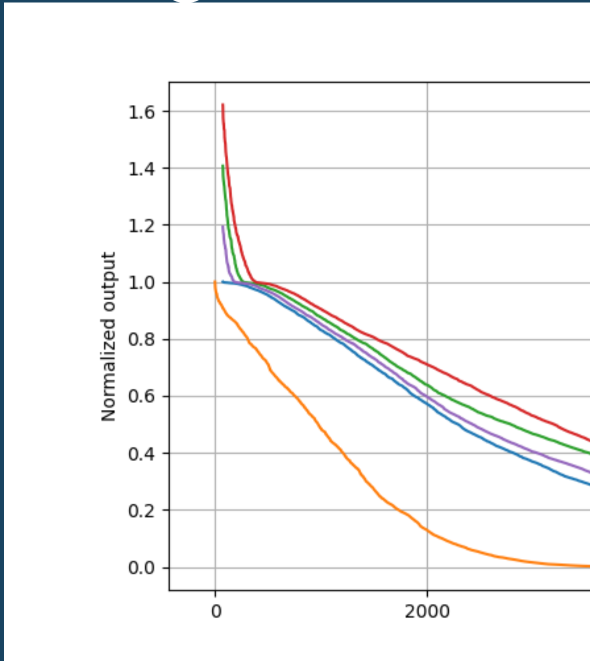
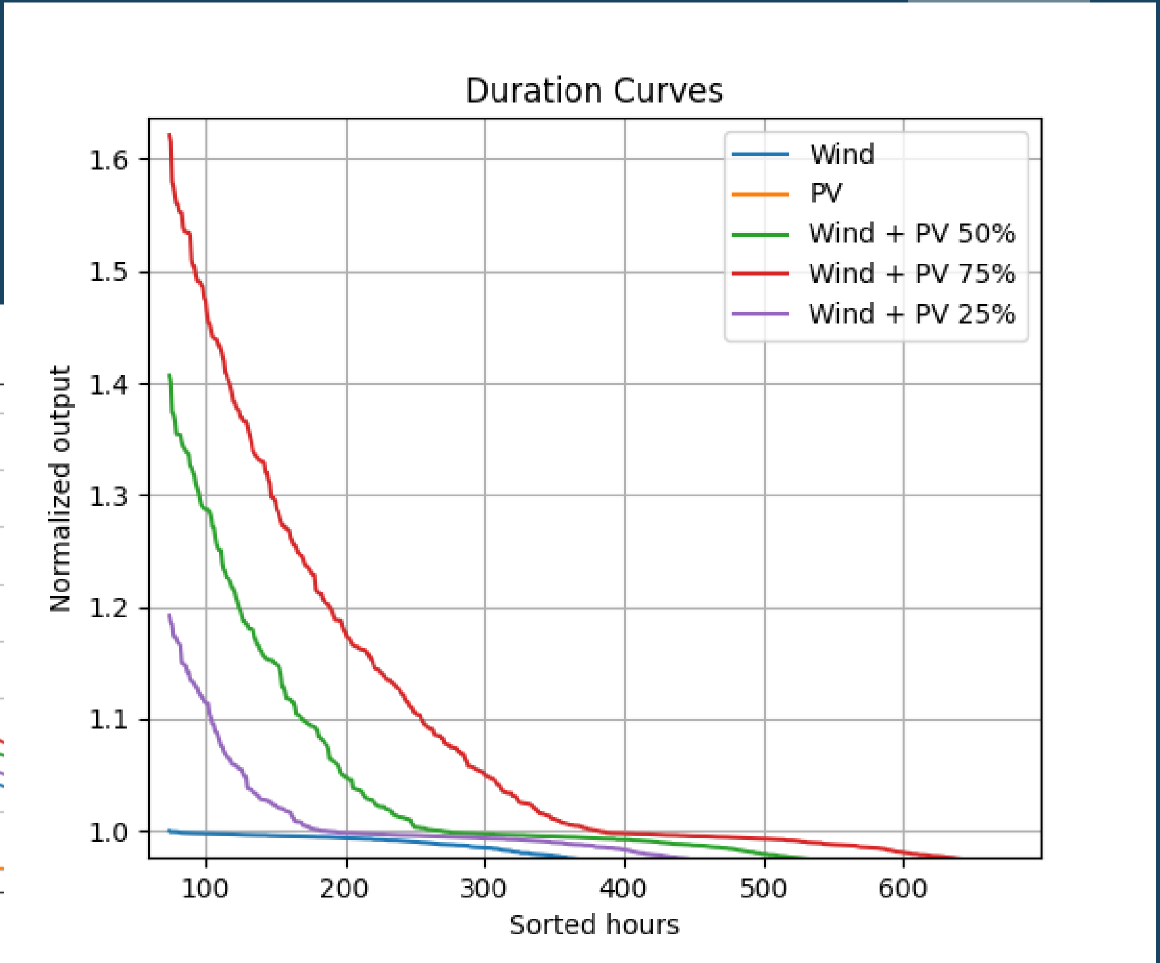


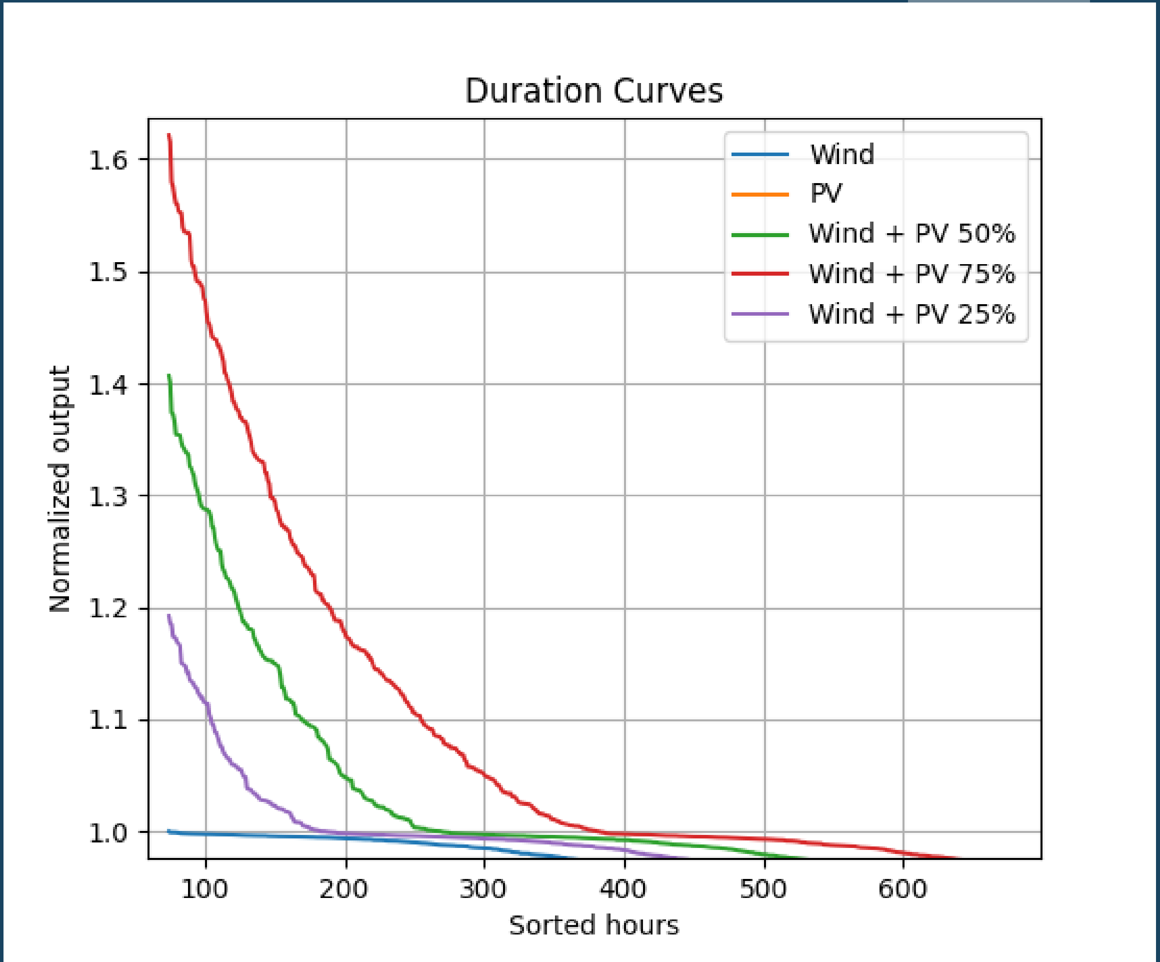
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Normalized output
0
2000



Duration Curves
Wind
PV
Wind + PV 50%
Wind + PV 75%
Wind + PV 25%
Normalized output
1.6
1.5
1.4
1.3
1.2
1.1
1.0
100
200
300
400
500
600
Sorted hours

Background

% PV	Curtalied energy
100%	15,6%
75%	10,4%
50%	6,7%
25%	3,9%

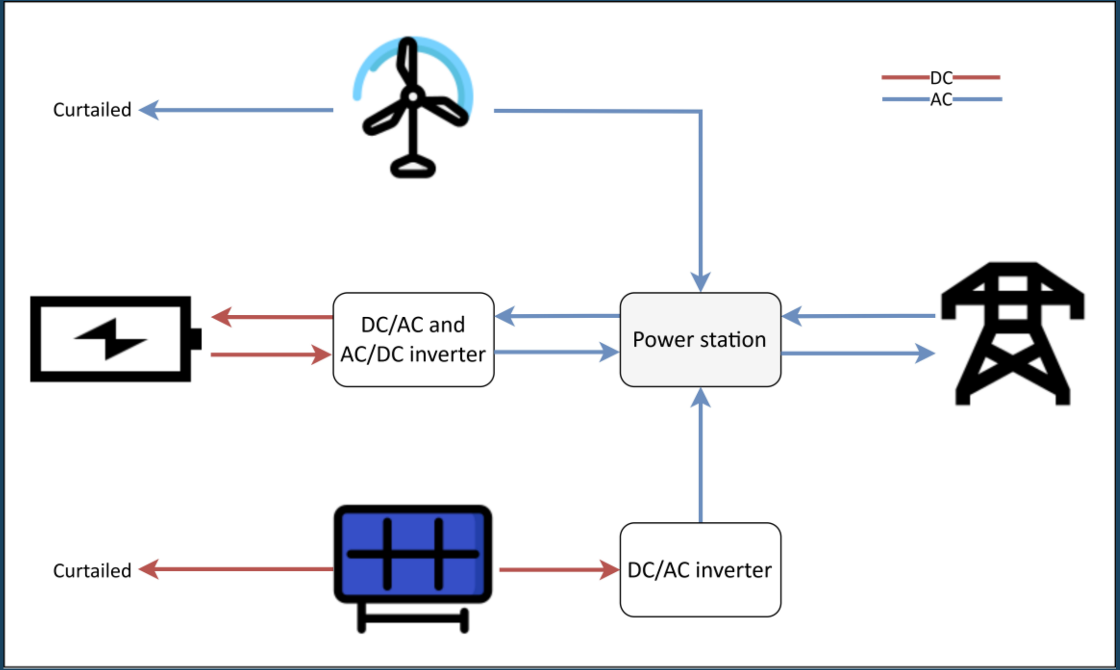


Background – Case study

- Investigate the benefit of installing PVs to an existing wind farm
  - 30 MW
  - Located in SE3
- Investigate the benefit of installing batteries in combination to the site
  - Which size would be best suited
  - How would aging affect the results

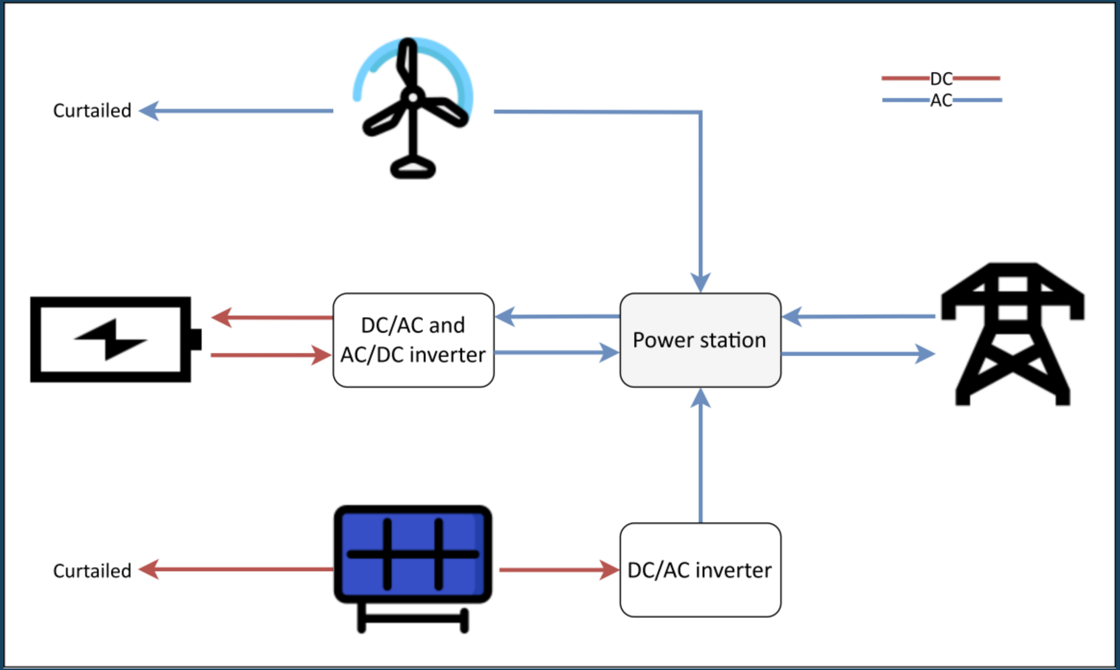
Optimization Model

- Aim to maximize revenue considering:
  - Efficiency
  - Spot prices
  - Battery and PV aging
- Net present value

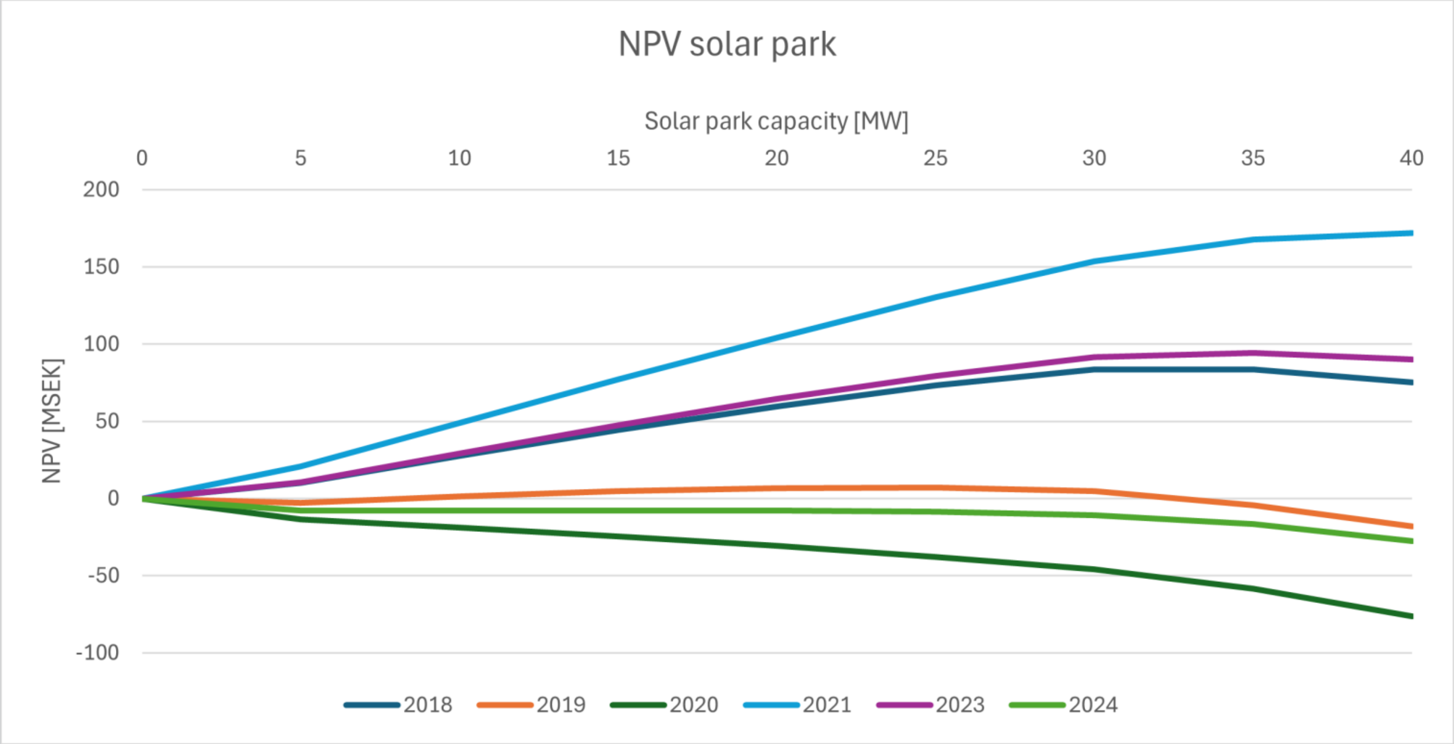


Optimization Model

- Aim to maximize revenue considering:
  - Efficiency
  - Spot prices
  - Battery and PV aging
- Net present value
- PV = 5200 SEK/kW
- BES = 1150 SEK/kWh
- Price data 2018-2024



Results – PV


NPV solar park
Solar park capacity [MW]
0
5
10
15
20
25
30
35
40
200
150
100
50
0
-50
-100
NPV [MSEK]
2018
2019
2020
2021
2023
2024

NPV [MSEK]		Solar park capacity								
2023	MWh MW	0	5	10	15	20	25	30	35	40
Battery capacity	0	0,00	10,54	29,07	47,43	64,64	79,35	91,59	94,47	89,93
	1	-0,18	11,04	29,64	48,02	65,19	79,87	91,82	94,70	90,24
	2	-0,77	10,93	29,68	48,13	65,30	80,08	91,67	96,37	92,68
	3	-1,74	10,09	29,07	47,62	64,81	79,61	91,44	94,55	90,41
	4	-3,33	8,67	27,80	46,50	63,74	78,41	90,24	95,05	91,75
	5	-5,27	6,72	26,02	44,81	62,18	76,99	88,92	92,43	88,44
	6	-7,85	4,05	23,27	42,13	59,54	74,33	86,18	91,13	87,95
	7	-10,73	1,05	20,33	39,17	56,65	71,58	83,65	87,36	83,31
	8	-13,64	-1,87	17,45	36,20	53,81	68,69	80,88	84,63	80,84
	9	-16,81	-5,30	14,02	32,63	50,15	65,21	77,34	82,26	79,25
	10	-20,40	-8,93	10,33	28,82	46,26	61,28	73,36	77,16	73,04

NPV [MSEK]		Solar park capacity								
2024	MWh MW	0	5	10	15	20	25	30	35	40
Battery capacity	0	0,00	-10,27	-12,56	-14,88	-17,30	-20,33	-24,51	-32,22	-44,43
	1	-0,72	-10,77	-13,02	-15,34	-17,77	-20,78	-24,96	-32,69	-44,84
	2	-1,98	-11,88	-14,06	-16,36	-18,78	-21,80	-25,98	-33,20	-45,12
	3	-3,81	-13,76	-15,91	-18,18	-20,59	-23,58	-27,65	-35,19	-47,14
	4	-6,15	-16,15	-18,34	-20,60	-22,95	-25,91	-30,04	-37,16	-48,79
	5	-8,56	-18,59	-20,70	-22,91	-25,25	-28,20	-32,23	-39,71	-51,37
	6	-10,86	-20,90	-22,98	-25,20	-27,59	-30,48	-34,57	-41,71	-53,27
	7	-13,49	-23,40	-25,45	-27,70	-30,22	-32,77	-37,10	-44,30	-55,99
	8	-16,25	-26,28	-28,33	-30,55	-32,93	-35,85	-39,84	-47,30	-58,78
	9	-19,06	-29,06	-31,16	-33,58	-35,93	-38,81	-42,97	-50,18	-61,44
	10	-21,90	-31,77	-33,94	-36,19	-38,60	-41,50	-45,69	-53,24	-64,77

No battery aging cost

NPV [MSEK] 2023 — Solar park capacity (MW) × Battery capacity (MWh)

MWh \ MW	0	5	10	15	20	25	30	35	40
0	0,00	10,54	29,07	47,43	64,64	79,35	91,59	94,47	89,93
1	0,07	11,28	29,87	48,27	65,48	80,23	92,27	95,38	90,97
2	0,16	11,77	30,56	49,01	66,26	80,98	92,67	97,28	93,63
3	0,22	12,05	31,10	49,71	66,95	81,76	93,87	97,09	92,98
4	0,29	12,21	31,52	50,27	67,59	82,27	94,85	98,60	95,39
5	0,33	12,34	31,85	50,76	68,15	82,95	94,87	98,05	94,31
6	0,39	12,43	32,07	51,17	68,71	83,69	95,70	99,87	96,92
7	0,44	12,52	32,24	51,50	69,17	84,28	96,20	99,52	95,95
8	0,49	12,54	32,37	51,77	69,67	84,93	97,14	100,19	96,73
9	0,54	12,57	32,50	51,99	70,02	85,27	97,13	101,73	99,06
10	0,59	12,57	32,58	52,19	70,46	85,67	98,23	101,46	98,23

NPV [MSEK] 2024 — Solar park capacity (MW) × Battery capacity (MWh)

MWh \ MW	0	5	10	15	20	25	30	35	40
0	0,00	-10,27	-12,56	-14,88	-17,30	-20,33	-24,51	-32,22	-44,43
1	-0,45	-10,49	-12,76	-15,07	-17,48	-20,47	-24,59	-32,16	-44,28
2	-0,88	-10,82	-12,99	-15,28	-17,70	-20,71	-24,87	-32,14	-44,00
3	-1,33	-11,22	-13,31	-15,54	-17,92	-20,85	-24,91	-32,34	-44,12
4	-1,77	-11,64	-13,65	-15,82	-18,16	-21,10	-25,17	-32,37	-43,93
5	-2,23	-12,09	-14,08	-16,13	-18,46	-21,32	-25,36	-32,81	-44,35
6	-2,69	-12,56	-14,48	-16,52	-18,76	-21,60	-25,58	-32,68	-43,96
7	-3,13	-13,02	-14,88	-16,97	-19,14	-21,91	-25,80	-33,10	-44,39
8	-3,59	-13,50	-15,31	-17,39	-19,56	-22,24	-26,12	-33,28	-44,44
9	-4,05	-13,98	-15,75	-17,79	-19,92	-22,57	-26,38	-33,22	-44,10
10	-4,51	-14,44	-16,21	-18,18	-20,34	-23,00	-26,74	-33,70	-44,63

Battery revenue x2

NPV [MSEK] 2023	Solar park capacity								
Battery capacity MWh \ MW	0	5	10	15	20	25	30	35	40
0	0,00	10,54	29,07	47,43	64,64	79,35	91,59	94,47	89,93
1	3,78	15,69	34,36	52,77	69,94	84,65	96,59	99,34	95,07
2	5,85	18,75	37,73	56,27	73,46	88,26	99,86	104,36	101,07
3	6,96	20,00	39,41	58,13	75,33	90,27	102,06	105,24	101,59
4	6,36	19,80	39,52	58,53	75,86	90,61	102,51	107,44	104,78
5	5,29	18,66	38,69	57,87	75,50	90,40	102,43	106,26	102,83
6	2,77	15,97	35,81	55,07	72,77	87,73	99,70	105,05	102,58
7	-0,50	12,47	32,49	51,78	69,60	84,75	97,11	101,21	97,79
8	-3,58	9,43	29,49	48,60	66,67	81,79	94,31	98,54	95,65
9	-7,28	5,15	25,29	44,09	61,97	77,47	89,97	95,51	93,45
10	-11,72	0,64	20,69	39,26	56,96	72,40	84,71	89,00	85,38

NPV [MSEK] 2024	Solar park capacity								
Battery capacity MWh \ MW	0	5	10	15	20	25	30	35	40
0	0,00	-10,27	-12,56	-14,88	-17,30	-20,28	-24,30	-31,66	-43,66
1	2,34	-7,38	-9,61	-11,91	-14,33	-17,32	-21,49	-29,17	-41,25
2	3,07	-6,44	-8,49	-10,76	-13,13	-16,06	-20,09	-27,35	-39,01
3	2,10	-7,41	-9,44	-11,64	-14,00	-16,88	-20,82	-28,18	-39,85
4	0,19	-9,47	-11,55	-13,68	-15,98	-18,88	-22,74	-29,71	-40,90
5	-2,04	-11,70	-13,69	-15,74	-17,99	-20,82	-24,68	-31,97	-42,93
6	-3,92	-13,61	-15,60	-17,77	-20,12	-22,78	-26,58	-33,56	-44,52
7	-6,43	-16,11	-17,84	-19,98	-22,29	-24,92	-28,69	-35,89	-46,90
8	-9,13	-18,98	-20,67	-22,82	-25,13	-27,91	-31,72	-38,74	-49,61
9	-11,98	-21,73	-23,65	-25,84	-28,19	-31,08	-35,25	-42,05	-52,77
10	-14,54	-24,34	-26,28	-28,42	-30,83	-33,67	-37,83	-44,94	-55,64

Summary

- Hybrid parks can increase utilization of grid connection
  - Economically it depends on future electricity prices
- Batteries can improve the value further
  - Increases further if additional services can be provided
- Further studies needed to see how the BES utilization is limited in a hybrid park compared to a sole BES installation

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