

Photovoltaic and Battery Bank Optimization for District Scale Systems

Jared Landsman



INTEGRAL | ELEMENTA

OVERVIEW

01 Background

02 Demand Forecasting

03 Understanding the Grid

04 Energy Storage Implementation

05 Life Cycle Costs

06 Looking into the Future

07 Questions

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Background

Demand Forecasting for District Scale Projects

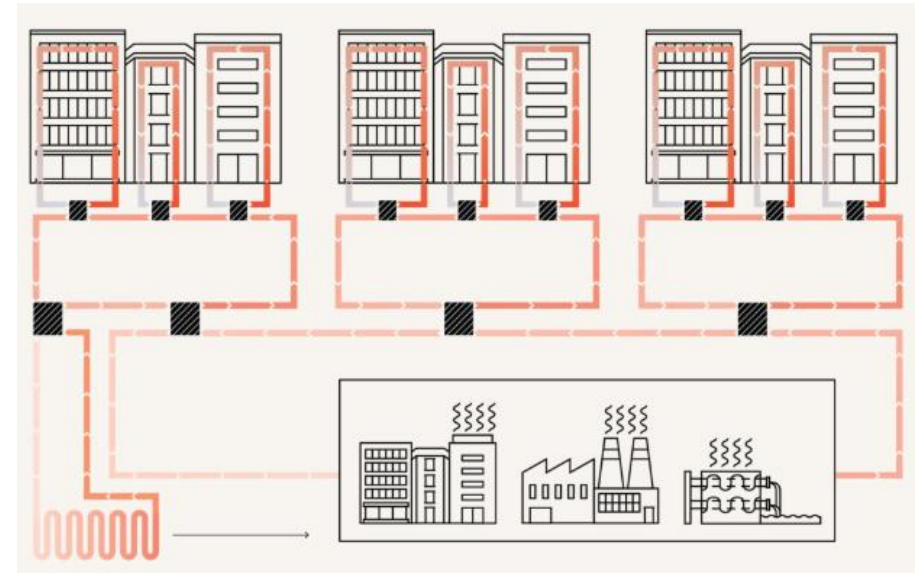
Uncertainty in building composition and construction staging

ZNE Market Growth

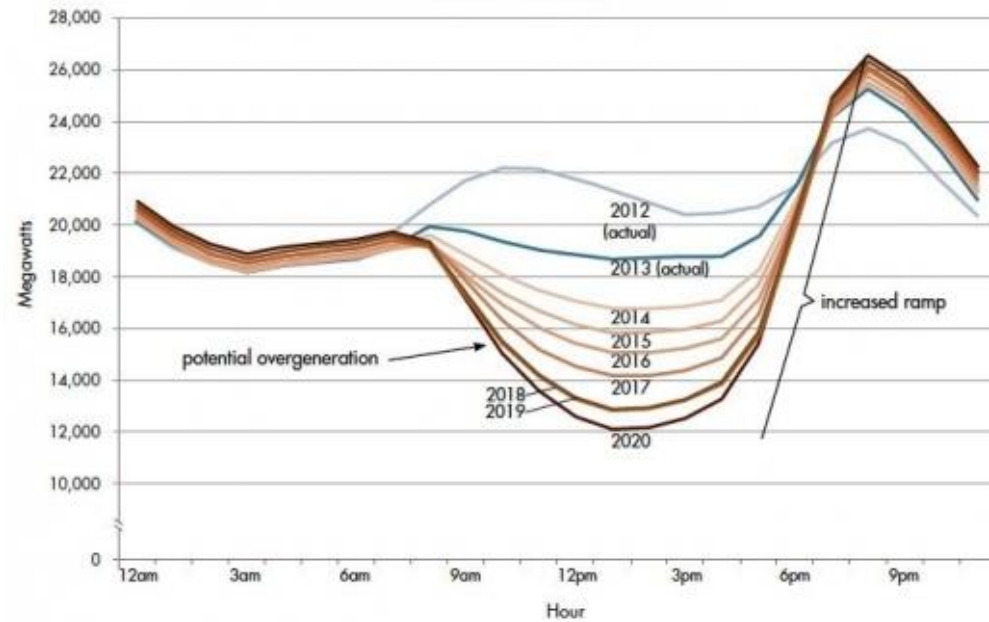
Renewables and energy storage market follows

Electrification & Grid Interaction

Huge implications for grid operation



Net load - March 31



OVERVIEW

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03 Understanding the Grid

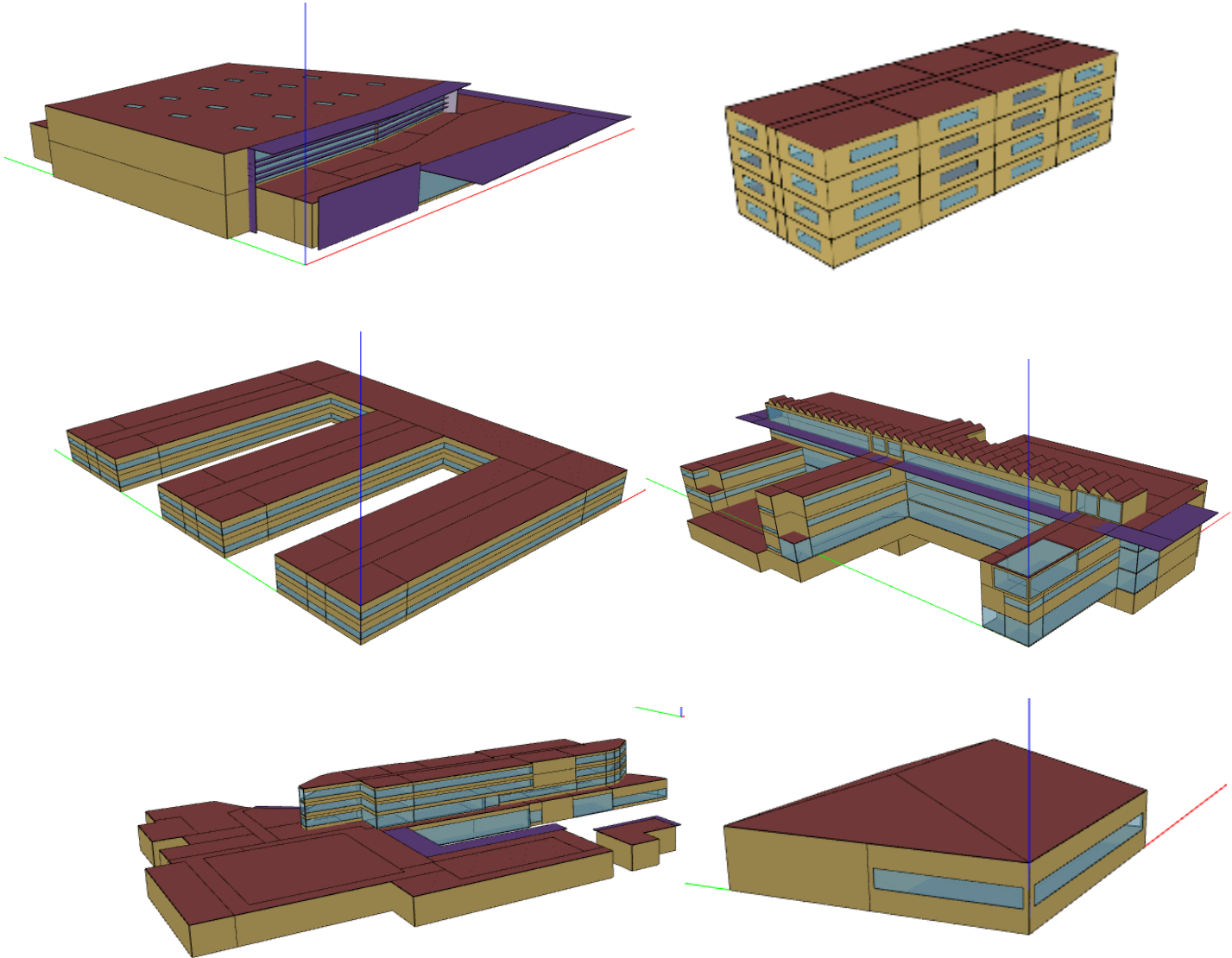
04 Energy Storage Implementation

05 Life Cycle Costs

06 Looking into the Future

07 Questions

Prototypical Shoebox Modeling



Hourly Outputs

Hourly Outputs

sum	74,190,735	62,747,364	19,953,970	1,777,331	1,777,331	8,983,292	7,416,016	3,153,758	2,694,416	10,760,623	9,193,347	1,510,354	41,779	8,401,521	4,096,007	4,520,267	715,264	31,053	2,607,543	2,440,480	105,953	8,896,938	42,793,394
max	20,429	18,013	9,835	828	828	8,751	8,801	2,653	2,600	9,052	8,872	1,898	348	6,621	6,009	1,282	1,154	7	716	3,936	24	2,443	8,185
99%	17,484	15,650	8,342	784	784	7,580	5,177	2,331	1,534	7,955	5,232	1,418	137	5,441	3,182	1,270	1,154	7	716	3,936	24	2,443	7,907

Electrical

Time	Month	Day	Hour	Outdoor Air Drybulb Temperature [F]	Total District Electrical Load [kBtu]	Total Bldg Electrical Load [kBtu]	Total Bldg Thermal Load [kBtu]	Simul Cooling Load [kBtu]	Simul Heating Load [kBtu]	Non-Simul Cooling Load [kBtu]	Non-Simul Heating Load [kBtu]	Total Cooling Load [kWh]	Total Heating Load [kWh]	Total Cooling Load [kBtu]	Total Heating Load [kBtu]	Ventilation Cooling Load [kBtu]	Ventilation Heating Load [kBtu]	Space Cooling Load [kBtu]	Space Heating Load [kBtu]	DHW Load [kBtu]	Snow Melt [kWh]	Park Lighting [kWh]	EV Charging [kWh]	Snow Melt [kBtu]	Park Lighting [kBtu]	EV Charging [kBtu]	Electricity:Facility [kBtu]
1/1/02 1:00 AM	1	1	1	7.43	8,013.80	7,884.45	5,424.55	5.24	5.24	0.00	5,414.07	1.54	1,588.31	5.24	5,419.31	0.18	92.62	7.85	4,201.10	45.57	0.00	7.12	30.79	0.00	24.29	105.07	2,460
1/1/02 2:00 AM	1	1	2	8.06	7,804.67	7,754.12	5,409.99	1.99	1.99	0.00	5,406.01	0.58	1,584.99	1.99	5,408.00	0.25	99.14	2.81	4,192.84	35.89	0.00	7.12	7.70	0.00	24.29	26.27	2,344
1/1/02 3:00 AM	1	1	3	4.27	8,173.46	8,122.90	5,809.22	0.58	0.58	0.00	5,808.07	0.17	1,702.42	0.58	5,808.64	0.00	139.65	0.89	4,471.80	35.89	0.00	7.12	7.70	0.00	24.29	26.27	2,314
1/1/02 4:00 AM	1	1	4	1.37	8,578.64	8,396.76	6,095.54	0.09	0.09	0.00	6,095.36	0.03	1,786.47	0.09	6,095.45	0.00	170.57	0.14	4,699.03	6.83	0.00	7.12	46.19	0.00	24.29	157.60	2,301
1/1/02 5:00 AM	1	1	5	-0.63	9,430.18	8,880.56	6,398.28	0.01	0.01	0.00	6,398.25	0.00	1,875.22	0.01	6,398.26	0.00	191.46	0.02	4,805.10	122.06	0.00	7.12	153.96	0.00	24.29	525.33	2,482
1/1/02 6:00 AM	1	1	6	-2.03	10,375.58	9,326.90	6,402.79	1.26	1.26	0.00	6,400.27	0.37	1,876.18	1.26	6,401.53	0.00	207.54	1.93	4,788.45	126.16	0.00	7.12	300.23	0.00	24.29	1,024.39	2,924
1/1/02 7:00 AM	1	1	7	-1.62	12,133.27	11,110.86	7,550.84	42.91	42.91	0.00	7,465.02	12.58	2,200.45	42.91	7,507.93	0.00	198.40	65.80	4,702.03	1,137.38	0.00	7.12	292.53	0.00	24.29	998.12	3,560
1/1/02 8:00 AM	1	1	8	-0.41	12,056.63	11,248.40	7,335.07	72.34	72.34	0.00	7,190.38	21.20	2,128.58	72.34	7,262.72	0.00	198.76	110.92	4,656.49	1,007.97	0.00	5.93	230.95	0.00	20.24	787.99	3,913
1/1/02 9:00 AM	1	1	9	-0.56	11,169.35	10,538.96	6,883.97	76.15	76.15	0.00	6,731.66	22.32	1,995.26	76.15	6,807.82	0.00	203.74	116.77	4,395.91	902.45	0.00	0.00	184.76	0.00	0.00	630.39	3,655
1/1/02 10:00 AM	1	1	10	-0.94	9,186.98	8,530.32	5,176.62	51.63	51.63	0.00	5,073.36	15.13	1,502.05	51.63	5,124.99	0.00	195.85	79.16	3,534.10	407.90	0.00	0.00	192.46	0.00	0.00	656.66	3,354
1/1/02 11:00 AM	1	1	11	-0.41	9,169.55	8,407.83	4,566.33	75.20	75.20	0.00	4,415.93	22.04	1,316.27	75.20	4,491.13	0.00	195.97	115.31	3,052.51	399.58	0.00	0.00	223.25	0.00	0.00	761.72	3,841
1/1/02 12:00 PM	1	1	12	0.59	9,193.12	8,378.86	4,511.98	78.64	78.64	0.00	4,354.71	23.05	1,299.34	78.64	4,433.35	0.00	186.33	120.58	2,997.83	420.19	0.00	0.00	238.65	0.00	0.00	814.26	3,867
1/1/02 1:00 PM	1	1	13	-0.11	9,490.46	8,544.87	4,521.97	79.34	79.34	0.00	4,363.28	23.25	1,302.06	79.34	4,442.63	0.00	204.63	121.66	2,983.49	424.17	0.00	0.00	277.14	0.00	0.00	945.59	4,023
1/1/02 2:00 PM	1	1	14	4.31	9,021.17	7,885.45	4,114.35	55.65	55.65	0.00	4,003.05	16.31	1,189.54	55.65	4,058.70	0.99	130.82	84.34	2,746.57	410.38	0.00	0.00	338.72	0.00	0.00	1,155.72	3,751
1/1/02 3:00 PM	1	1	15	9.22	9,244.82	7,668.83	3,945.20	63.53	63.53	0.00	3,818.14	18.62	1,137.65	63.53	3,881.67	11.12	79.06	86.29	2,540.20	532.66	0.00	0.00	461.89	0.00	0.00	1,575.98	3,724
1/1/02 4:00 PM	1	1	16	12.35	10,075.59	8,000.55	4,088.44	56.18	56.18	0.00	3,976.08	16.46	1,181.79	56.18	4,032.26	0.65	14.57	85.48	2,721.14	531.30	0.00	0.00	608.16	0.00	0.00	2,075.04	3,912
1/1/02 5:00 PM	1	1	17	12.85	11,898.91	9,448.04	4,751.12	76.79	76.79	0.00	4,597.54	22.51	1,369.97	76.79	4,674.33	0.84	15.50	116.91	2,836.48	943.79	0.00	2.37	715.94	0.00	8.10	2,442.77	4,697
1/1/02 6:00 PM	1	1	18	10.87	12,794.84	10,354.05	5,185.75	82.01	82.01	0.00	5,021.72	24.04	1,495.82	82.01	5,103.73	3.32	28.21	122.44	2,935.26	1,179.67	0.00	0.00	712.04	0.00	24.29	2,416.50	5,168
1/1/02 7:00 PM	1	1	19	8.26	12,760.27	10,634.67	5,312.48	88.22	88.22	0.00	5,136.05	25.85	1,531.14	88.22	5,224.26	8.93	94.30	126.34	3,098.66	1,051.14	0.00	7.12	615.86	0.00	24.29	2,101.31	5,322
1/1/02 8:00 PM	1	1	20	5.83	12,228.13	10,522.80	5,441.72	62.06	62.06	0.00	5,317.59	18.19	1,576.69	62.06	5,379.65	0.27	113.32	94.90	3,325.66	910.26	0.00	7.12	492.69	0.00	24.29	1,681.05	5,081
1/1/02 9:00 PM	1	1	21	5.00	12,075.90	10,633.23	5,600.88	61.01	61.01	0.00	5,478.87	17.88	1,623.64	61.01	5,539.87	4.86	119.07	88.68	3,463.95	893.62	0.00	7.12	415.70	0.00	24.29	1,418.38	5,032
1/1/02 10:00 PM	1	1	22	5.00	10,971.60	9,844.13	5,351.82	56.25	56.25	0.00	5,239.32	16.49	1,552.04	56.25	5,295.57	0.00	121.46	86.25	3,616.35	539.89	0.00	7.12	323.33	0.00	24.29	1,103.19	4,492
1/1/02 11:00 PM	1	1	23	4.37	9,734.83	9,080.15	5,298.84	54.60	54.60	0.00	5,189.64	16.00	1,537.00	54.60	5,244.24	0.00	133.23	83.72	3,923.01	179.19	0.00	7.12	184.76	0.00	24.29	630.39	3,781
1/2/02 12:00 AM	1	2	0	3.40	9,214.07	8,874.59	5,658.20	52.88	52.88	0.00	5,552.44	15.50	1,642.83	52.88	5,605.32	0.00	147.54	81.08	4,235.05	140.45	0.00	7.12	92.38	0.00	24.29	315.20	3,216
1/2/02 1:00 AM	1	2	1	2.39	8,499.14	8,369.79	5,800.98	4.62	4.62	0.00	5,791.73	1.36	1,698.81	4.62	5,796.36	0.00	154.76	7.09	4,440.14	45.57	0.00	7.12	30.79	0.00	24.29	105.07	2,569
1/2/02 2:00 AM	1	2	2	1.94	8,426.64	8,376.09	5,919.49	1.01	1.01	0.00	5,917.48	0.30	1,734.61	1.01	5,918.49	0.00	161.03	1.54	4,538.61	35.89	0.00	7.12	7.70	0.00	24.29	26.27	2,457
1/2/02 3:00 AM	1	2	3	1.94	8,454.89	8,404.33	5,983.28	0.12	0.12	0.00	5,983.04	0.04	1,753.57	0.12	5,983.16	0.00	161.53	0.19	4,589.21	35.89	0.00	7.12	7.70	0.00	24.29	26.27	2,421
1/2/02 4:00 AM	1	2	4	4.88	8,343.29	8,161.40	5,762.06	0.00	0.00	0.00	5,762.06	0.00	1,688.76	0.00	5,762.06	0.00	129.44	0.00	4,473.38	6.83	0.00	7.12	46.19	0.00	24.29	157.60	2,399
1/2/02 5:00 AM	1	2	5	8.14	8,707.89	8,158.27	5,586.53	0.00	0.00	0.00	5,586.53	0.00	1,637.32	0.00	5,586.53	0.00	98.70	0.00	4,248.46	122.06	0.00	7.12	153.96	0.00	24.29	525.33	2,572
1/2/02 6:00 AM	1	2	6	10.12	9,366.25	8,317.57	5,226.53	2.59	2.59	0.00	5,221.36	0.76	1,531.05	2.59	5,223.94	0.05	52.95	3.91	4,001.94	126.16	0.00	7.12	300.23	0.00	24.29	1,024.39	3,091
1/2/02 7:00 AM	1	2	7	11.57	13,828.24	12,805.83	8,942.68	70.68	70.68	0.00	8,801.32	20.72	2,600.23	70.68	8,872.00	0.27	3.18	108.11	6,008.87	1,137.38	0.00	7.12	292.53	0.00	24.29	998.12	3,863
1/2/02 8:00 AM	1	2	8	12.02	13,202.20	12,393.97	7,747.74	112.44	112.44	0.00	7,522.85	32.96	2,237.78	112.44	7,635.29	0.48	0.00	171.93	5,182.72	1,007.97	0.00	5.93	230.95	0.00	20.24	787.99	4,646
1/2/02 9:00 AM	1	2	9	12.55	13,001.77	12,371.38	6,392.01	109.60	109.60	0.00	6,172.82	32.12	1,841.27	109.60	6,282.42	0.61	0.00	167.43	4,203.86	902.45	0.00	0.00	184.76	0.00	0.00	630.39	5,979
1/2/02 10:00 AM	1	2	10	12.92	11,742.41	11,085.75	5,087.94	73.42	73.42	0.00	4,941.11	21.52	1,469.67	73.42	5,014.52	1.07	0.00	111.50	3,657.56	407.90	0.00	0.00	192.46	0.00	0.00	656.66	5,998
1/2/02 11:00 AM	1	2	11	13.55	11,395.39	10,633.66	4,411.35	96.73	96.73	0.00	4,217.90	28.35	1,264.54	96.73	4,314.63	0.77	0.00	147.54	3,123.05	399.58	0.00	0.00	223.25	0.00	0.00	761.72	6,222
1/2/02 12:00 PM	1	2	12	14.00	10,823.78	10,009.52	3,759.80	117.66	117.66	0.00	3,524.47	34.49	1,067.45	117.66	3,642.14	0.71	0.00	179.71	2,579.80	420.19	0.00	0.00	238.65	0.00	0.00	814.26	6,250
1/2/02 1:00 PM	1	2	13	14.63	10,478.85	9,533.26	3,398.44	165.89	165.89	0.00	3,066.66	48.62	947.41	165.89	3,232.55	1.66	0.00	252.70									

Plug & Play Building Parameters

Building Area Allocation

Residential vs commercial dominated districts

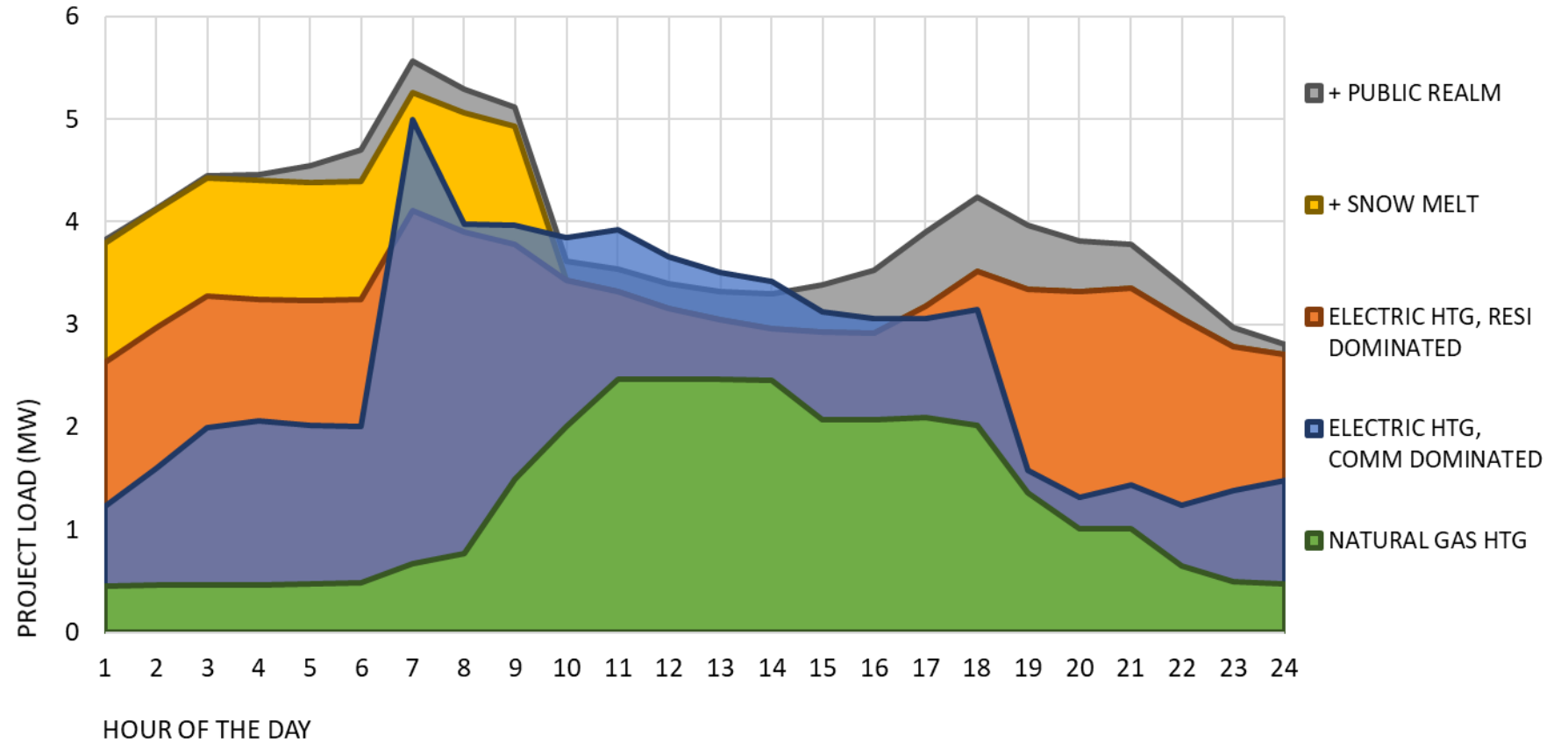
Public Realm Loads

EV charging, street lighting, snow melt

HVAC & Envelope

Heating fuel and new vs existing construction

TYPICAL WINTER DAY ELECTRICAL LOAD PROFILE



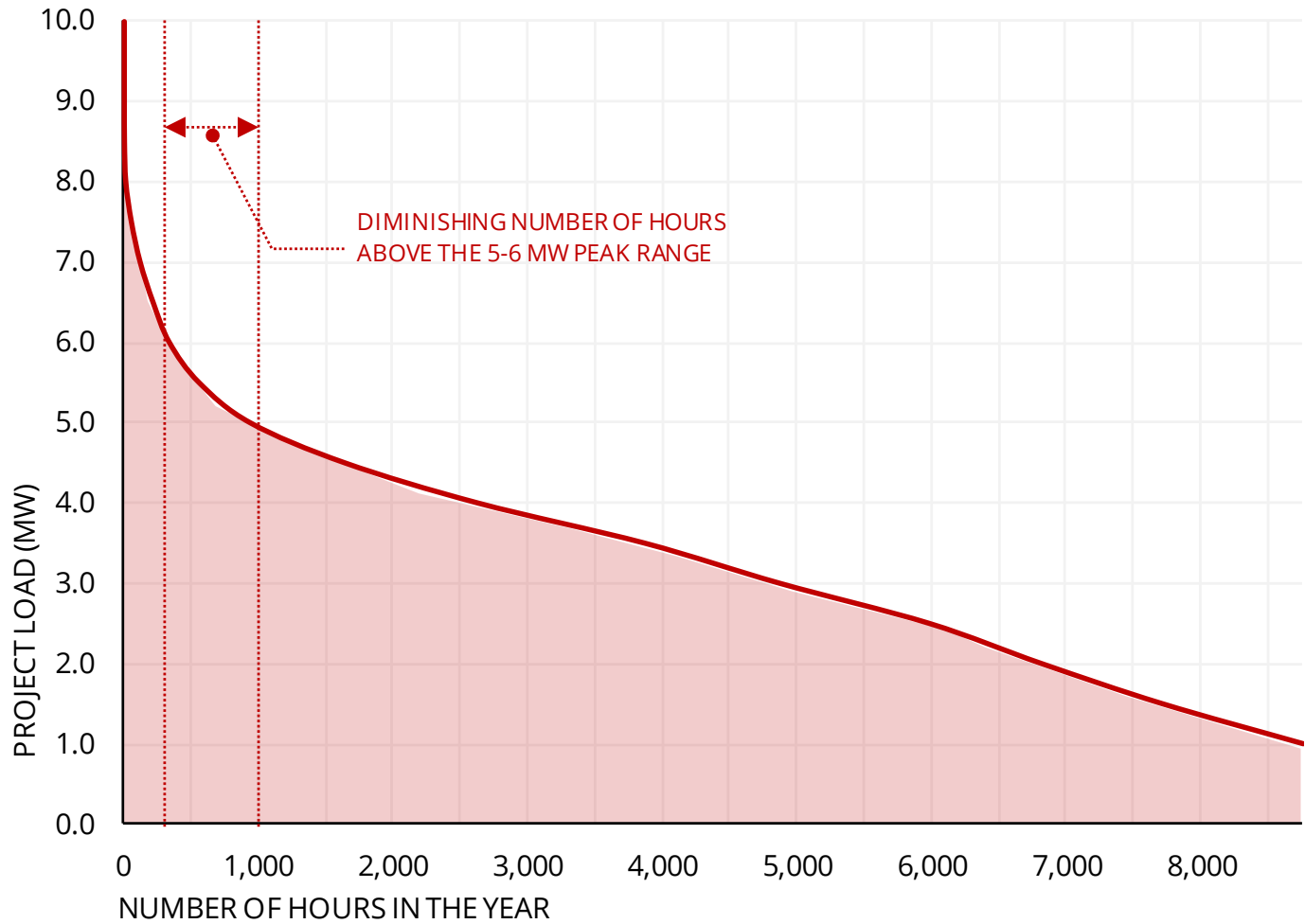
Electrical Load Profiles

What is the district peak?

Captures worst case scenario, but probably not realistic for energy storage

What is the point of diminishing returns?

50% smaller than peak, but will cover almost entire year



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GHG Emissions

Grid Generation Makeup

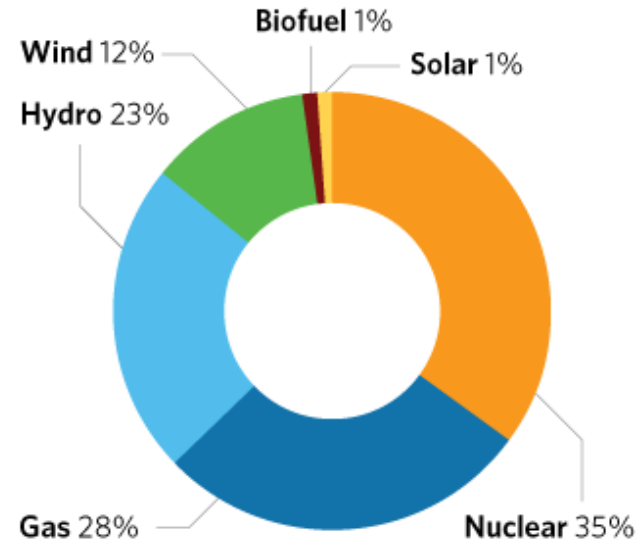
GHG emissions correlated to non-renewable fuel usage

Average Emission Factors

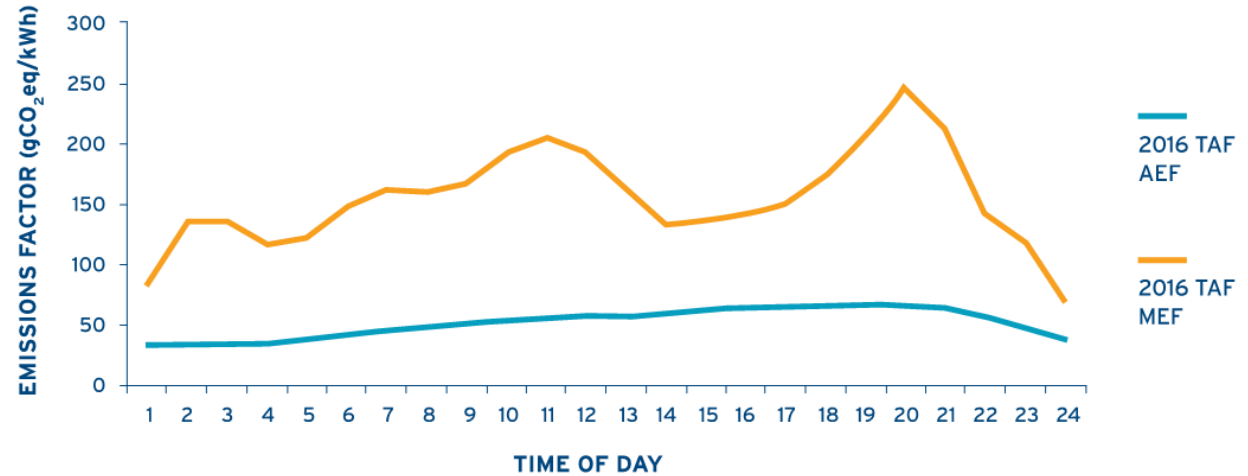
Captures baseline GHG emissions

Marginal Emission Factors

Captures avoided GHG emissions



Nuclear	13,009 MW or 35%
Gas/Oil	10,277 MW or 28%
Hydro	8,499 MW or 23%
Wind	4,486 MW or 12%
Biofuel	295 MW or 1%
Solar	424 MW or 1%



Time of Use Energy Rates

Time of Day

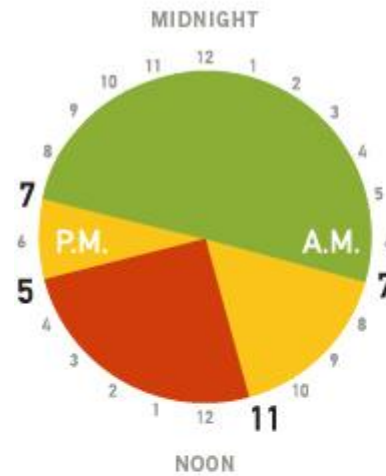
Morning vs afternoon vs evening vs night

Day of Week

Weekday vs weekend

Season

Summer vs Winter



Summer
(May 1 – October 31)
Weekdays



**Weekends and
Statutory Holidays**



Winter
(November 1 – April 30)
Weekdays



Peak Demand Charges

Transmission & Distribution Charges

Many different complicated rate riders

Global Adjustment Costs

Based on your contribution to top 5 peak hours over an entire year

Transmission Charges		
Network	2.8295	\$ per Peak kW per 30 days
Connection	2.2769	\$ per Peak kW per 30 days
Distribution Charges		
Distribution Volumetric Rate	6.5820	\$ per kVA per 30 days
Rate Rider for Disposition of LRAM Variance Account	0.2763	\$ per kVA per 30 days
Rate Rider for Disposition of Post Employment Benefit – Tax Savings	-0.0675	\$ per kVA per 30 days
Rate Rider for Application of Operations Center Consolidation Plan Sharing	-0.2084	\$ per kVA per 30 days
Rate Rider for Recovery of the Gain on the Sale of Named Properties	0.0044	\$ per kVA per 30 days
Rate Rider for Recovery of Hydro One Capital Contributions Variance	0.0039	\$ per kVA per 30 days
Rate Rider for Application of IFRS – 2014 Derecognition	0.0648	\$ per kVA per 30 days
Rate Rider for Recovery of 2015 Foregone Revenue	0.1382	\$ per kVA per 30 days
Rate Rider for Recovery of 2016 Foregone Revenue	0.0406	\$ per kVA per 30 days
Rate Rider for Disposition of Deferral/Variance Account	-0.8782	\$ per kVA per 30 days
Rate Rider for Disposition of Deferral/Variance Account for Non-Wholesale Market Participant Customers	-0.5945	\$ per kVA per 30 days
Rate Rider for Disposition of Capacity Based Recovery Variance Sub-Account	0.0032	\$ per kVA per 30 days
Transformer Allowance for Ownership (if Applicable)	-0.6200	\$ per kVA per 30 days

Transmission & Distribution Charges

Rank	Date	Hour Ending (EST)	Ontario Demand (MW)
1	July 29, 2019	17	21,791
2	July 05, 2019	17	21,716
3	July 20, 2019	18	21,646
4	July 19, 2019	12	21,545
5	July 04, 2019	18	21,423
6	August 21, 2019	17	21,354
7	July 30, 2019	17	21,269
8	August 20, 2019	17	21,145
9	July 10, 2019	18	21,083
10	August 07, 2019	18	21,033

Top Ten Ontario Demand Peaks to Date

How It All Fits Together

When am I getting free energy?

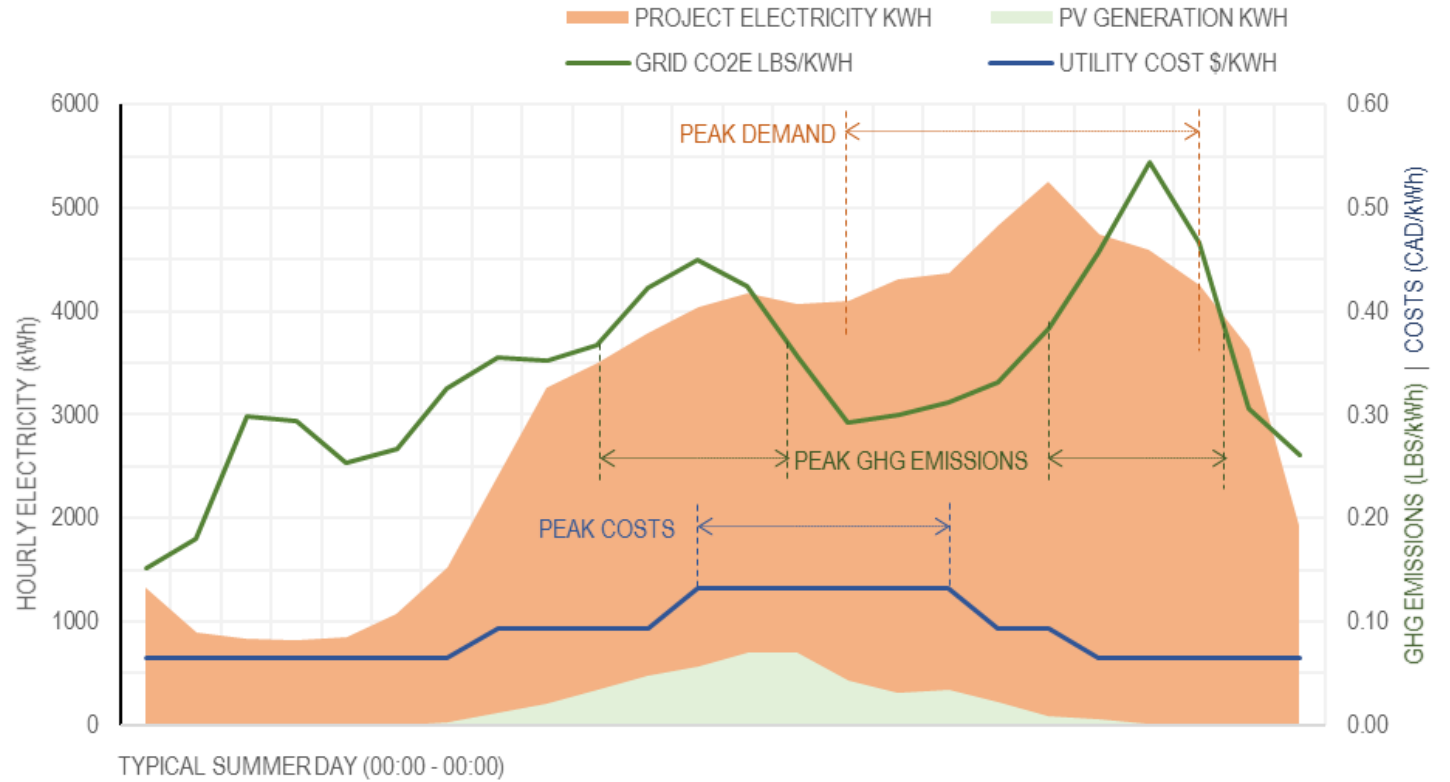
Project demand vs solar generation

How does my project demand align with grid demand?

Project demand vs GHG emissions vs utility costs

What should be optimized for battery bank deployment?

Finding the balance between cost and GHG emission reduction



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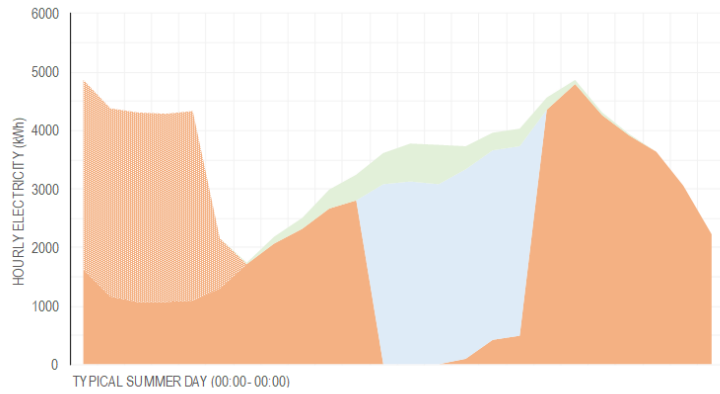
05 Life Cycle Costs

06 Looking into the Future

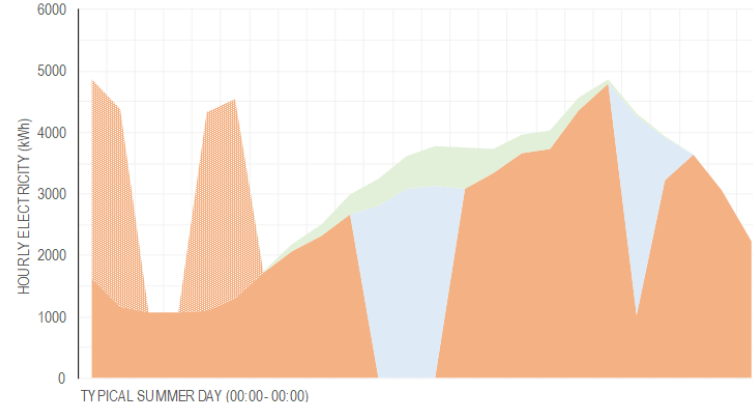
07 Questions

Battery Charging

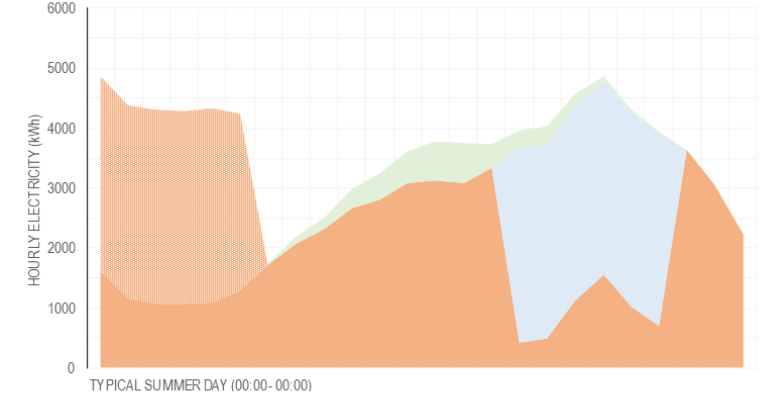
- GRID TO PROJECT KWH
- BATTERY TO PROJECT KWH
- GRID TO BATTERY KWH
- PV TO PROJECT KWH



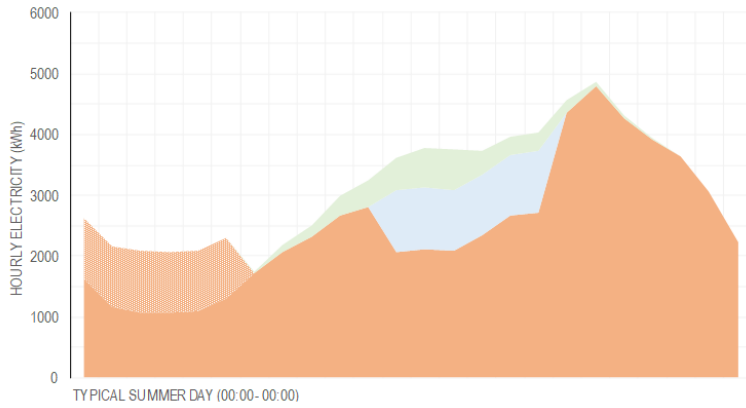
SCENARIO 1: 849 kW_p PV, 9.7 MW Battery | Control Sequence tracks Utility Costs



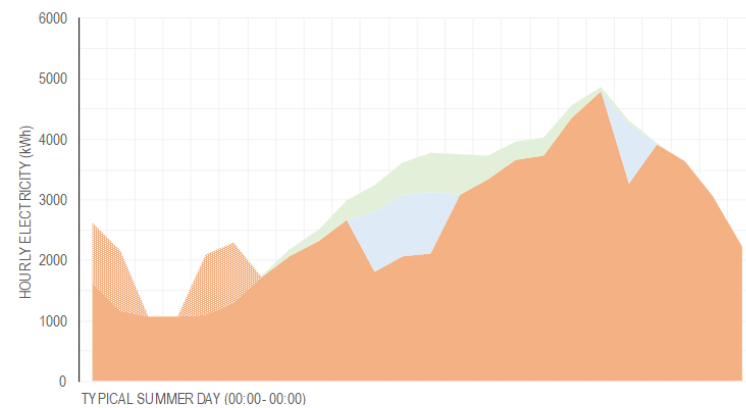
SCENARIO 2: 849 kW_p PV, 9.7 MW Battery | Control Sequence tracks Grid Emissions



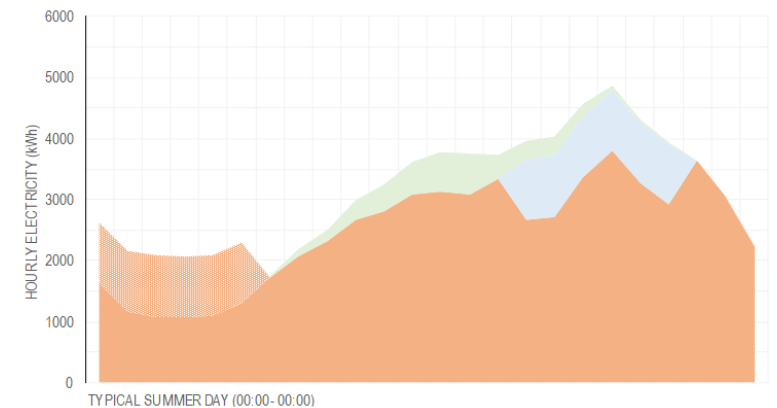
SCENARIO 3: 849 kW_p PV, 9.7 MW Battery | Control Sequence tracks Project Demand



SCENARIO 4: 849 kW_p PV, 3.0 MW Battery | Control Sequence tracks Utility Costs

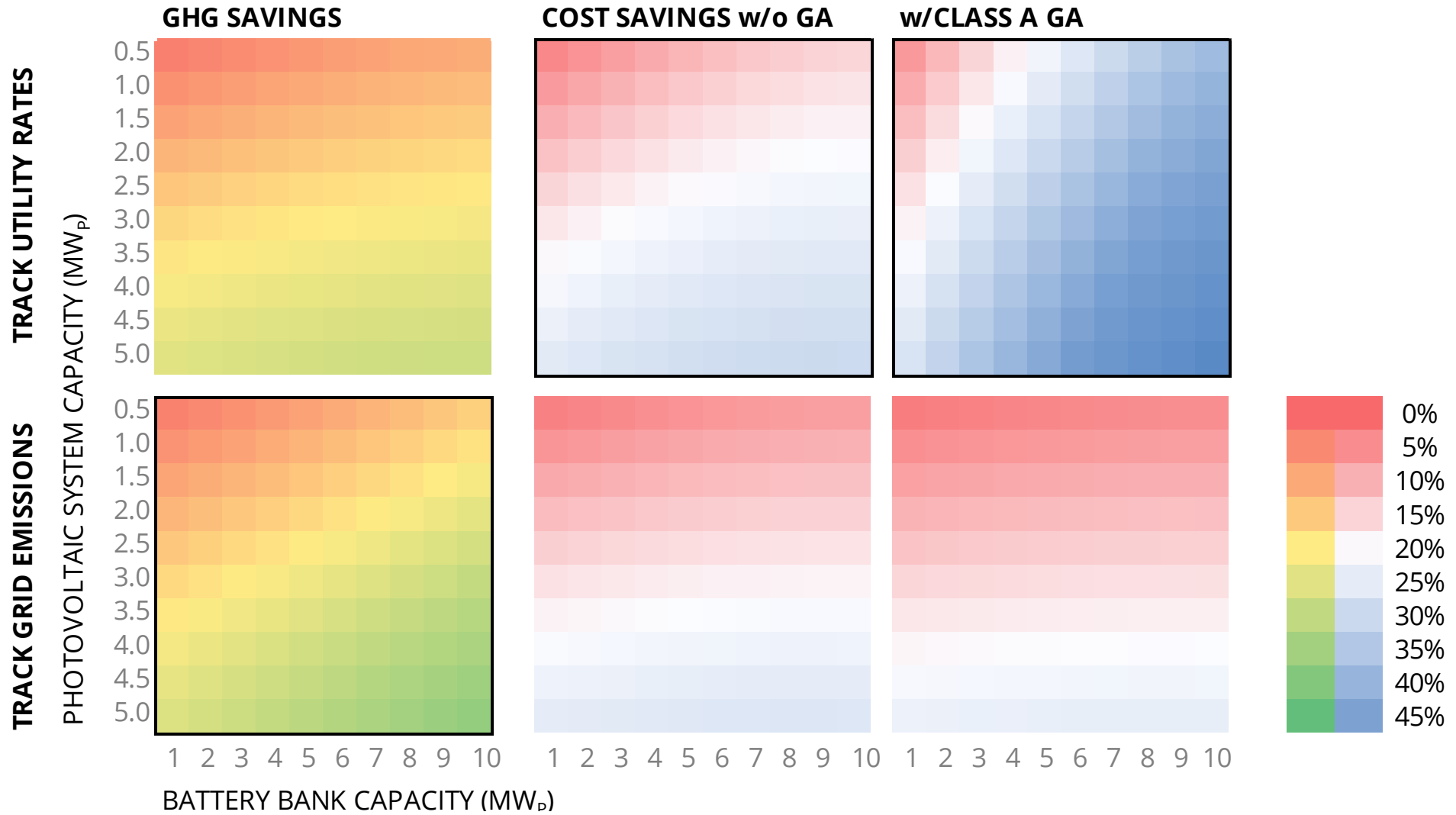


SCENARIO 5: 849 kW_p PV, 3.0 MW Battery | Control Sequence tracks Grid Emissions

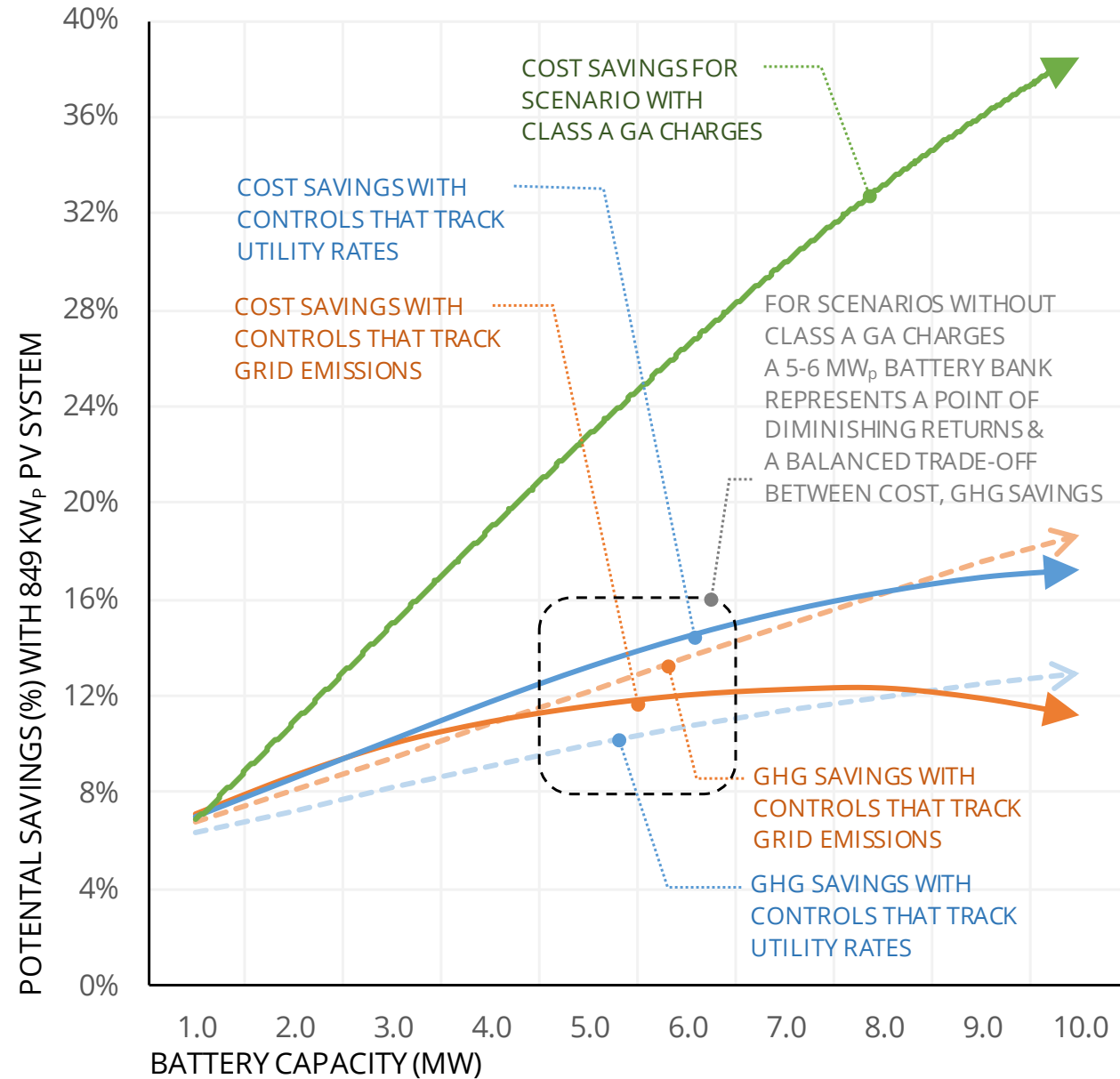


SCENARIO 6: 849 kW_p PV, 3.0 MW Battery | Control Sequence tracks Project Demand

Battery and PV Sizing



Optimizing Savings



OVERVIEW

01 Background

02 Demand Forecasting

03 Understanding the Grid

04 Energy Storage Implementation

05 Life Cycle Costs

06 Looking into the Future

07 Questions

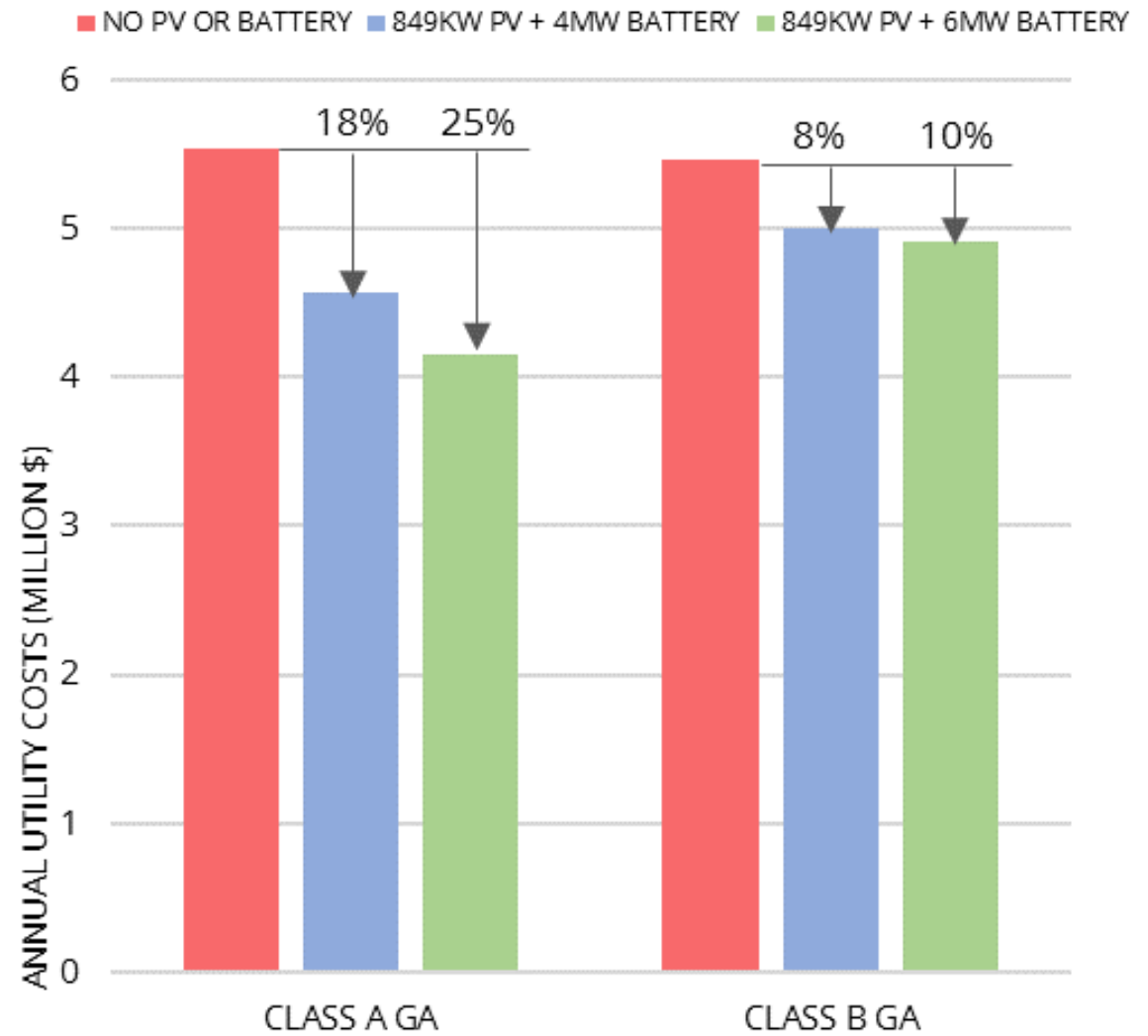
Annual Cost Savings

Annual savings of up to \$1.5 million

Energy storage extremely valuable for district scale systems

Savings contingent on many optimized variables

Sizing, controls implementation, rate structure



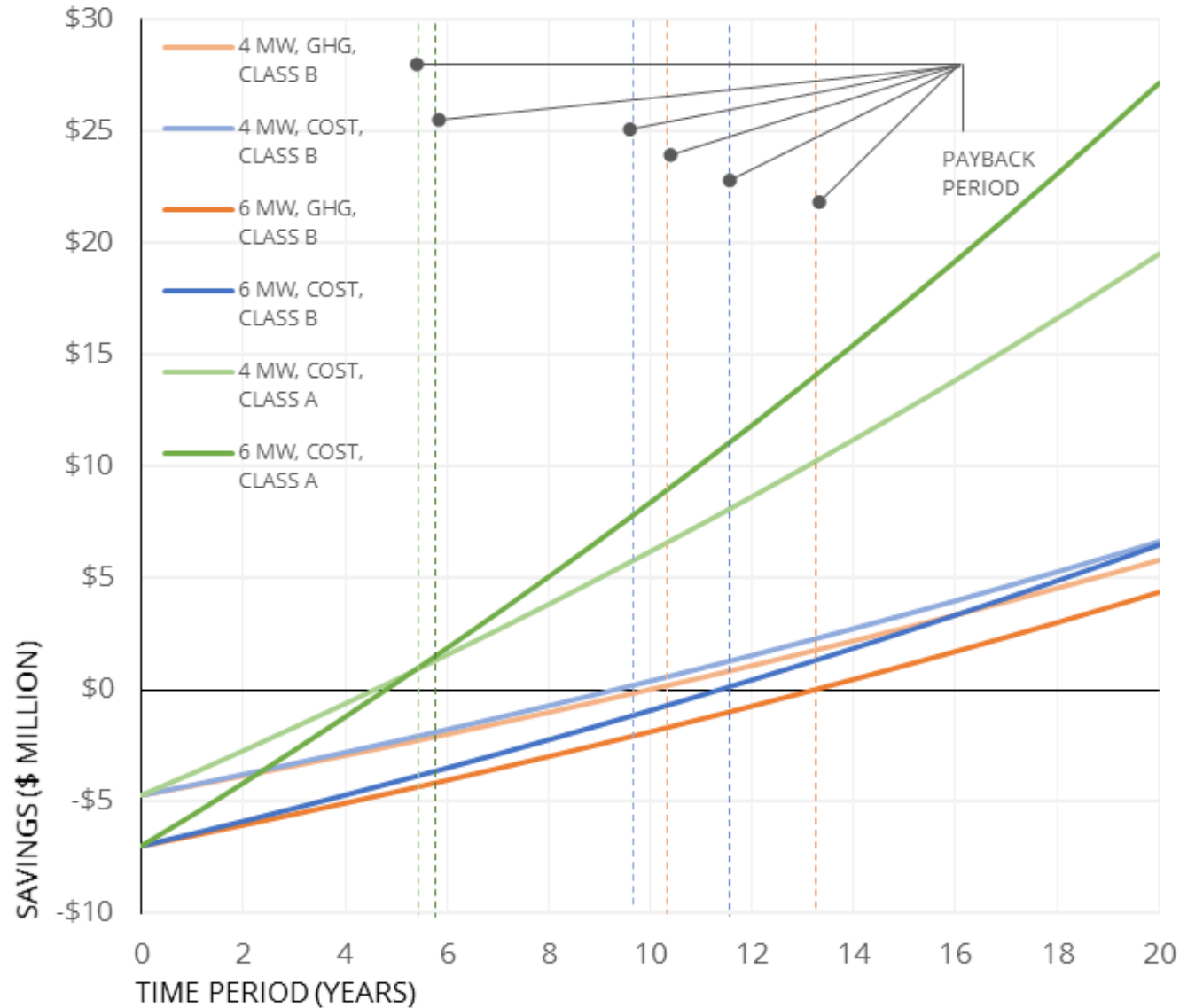
Payback

Payback as early as 5 years

Feasible timelines for district scale projects

Class A development obtains best break-even scenario

Larger battery bank breaks even <1 year later than smaller battery bank



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01 Background

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03 Understanding the Grid

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06 Looking into the Future

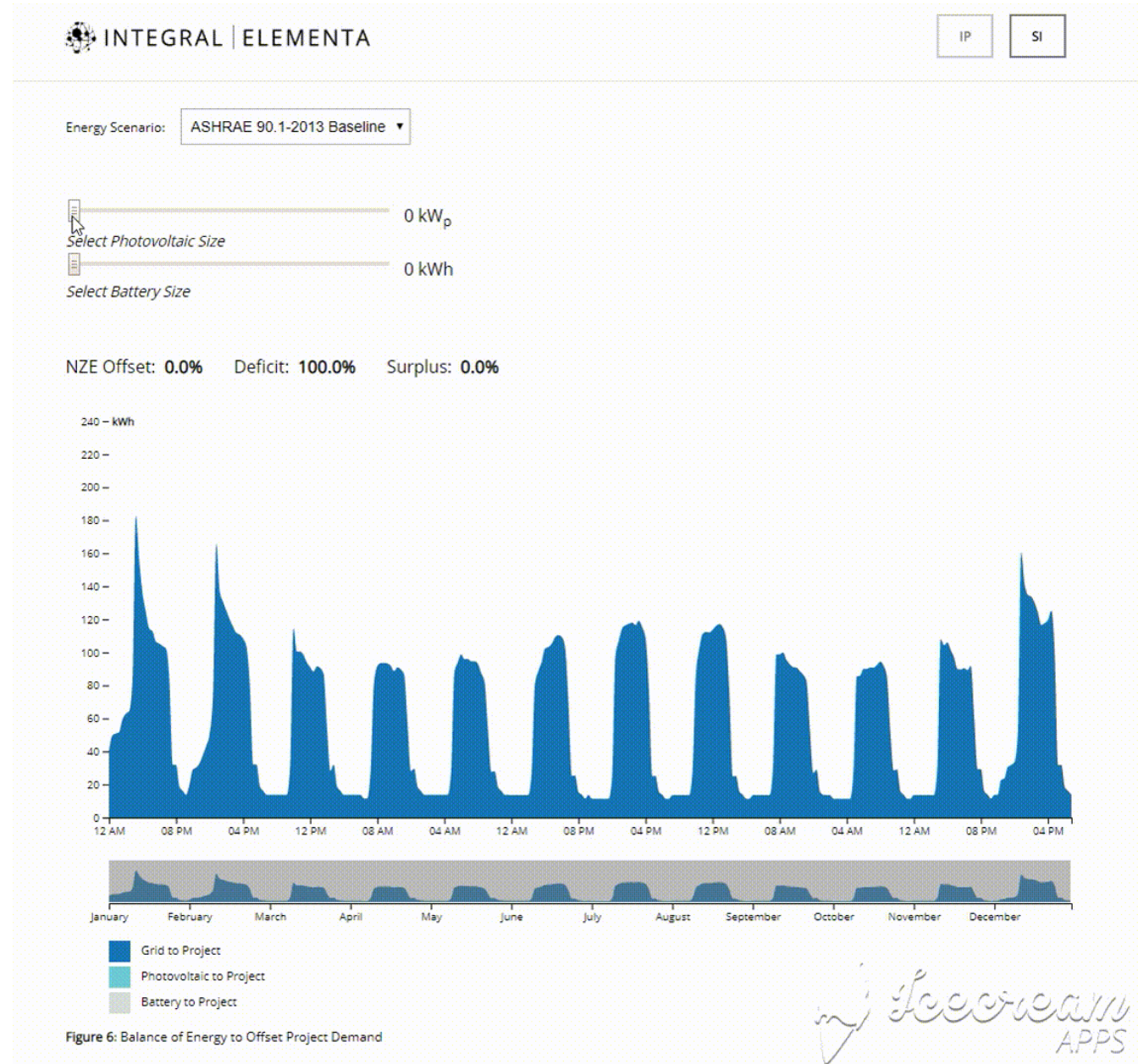
07 Questions

Looking into the Future

Realistic load profiles are a necessity

The grid will continue to change

**More tools are being developed to assist
in design decision making**



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Photovoltaic and Battery Bank Optimization for District Scale Systems

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