Hawaiian Electric

IGP Stakeholder Technical Working Group Energy Reserve Margin Criteria Analyses

October 13, 2021

Agenda

- AEG – Update on Supply Curves
- Overview of ERM Criteria
- Review of ERM Testing Analyses
- HNEI Presentation – Review of ERM

Energy Reserve Margin (ERM)

- Energy Reserve Margin (ERM) is a planning criteria to satisfy load and plan for a reasonable reserve that can be called upon for a range of contingencies. It is the percentage of system load by which the system capacity must exceed the system load in each hour.
- It is intended to be a planning reserve rather than an operating reserve

Hourly Available Energy | Hourly Demand with Energy Reserve Margin

Firm Capability
- Maintenance
+ Hourly Dependable Capacity
+ Shifted Load
+ Interruptible Load

≥

Load Demand X (1+ Energy Reserve Margin%)

Firm Capacity (Capability): Capacity that is 100% available at any time under Company dispatch, except during periods of outage and deration; independent of source energy resource availability.
Maintenance: Planned scheduled maintenance of thermal generating units
Hourly Dependable Capacity: Minimum expected capacity from variable generation resources based on empirical data
Shifted Load: Energy charged and discharged by energy storage systems in each hour
Interruptible Load: Customer loads that can be reduced to support system capacity needs e.g. demand response

Energy Reserve Margin Concept

- The ERM criteria is composed of two key assumptions:
  - Target percent reserves to cover various contingencies
  - Hourly dependable capacity to account for the impact of weather variability on renewable generation output
- Cases were constructed to assess the reliability impacts of changing these two key assumptions along with other planning assumptions

Incorporating Feedback from Ulupono

- The Company will test lower Energy Reserve Margin target percentages in RESOLVE and evaluate the impact on the resulting resource plans in PLEXOS.
- A sensitivity will be performed to remove the Hourly Dependable Capacity assumption for variable renewables and instead consider the full production profiles.
- HNEI is independently testing the reliability of the various resource plans generated from RESOLVE at different ERM levels using their stochastic resource adequacy methodology.

Additional Comments From Ulupono

- It would probably be helpful to include N-1 outage criteria in RESOLVE itself, so the model can optimize the selection of large vs. small power plants.
  - RESOLVE is a linear optimization model that does not differentiate between large and small plants. If a resource representing a larger plant is built at a reduced capacity that is less than its block size, a similar unit will be substituted in its place e.g. if a 50 MW 2x1 combined cycle plant is built by RESOLVE on O‘ahu, it will be substituted for a simple cycle combustion turbine sized at 57 MW.
- The September 7, 2021 proposal uses 10% steps in the ERM. Once the modeling is underway, it would be useful to evaluate finer steps between the maximum inadequate ERM and the minimum adequate ERM, to more closely identify the correct level.
  - Finer percentage steps can be evaluated in future IGP cycles. Because ERM is a new concept, the 10% steps were used in the testing analyses to narrow down the ERM target percentages to an appropriate starting point.
- Hawaiian Electric reported in the September 7, 2021, meeting that they do not plan to include demand response in the ERM calculation. We recommend that demand response (and all other resources) be included in the ERM calculation in the same way that they are included in the day-to-day load balancing (more on this below).
  - Demand response resources are now being modeled on the supply side and are accounted for as part of the ERM calculation

TAP Recommendation based on their ERM Review

- Technical Advisory Panel recommends that a) a more complete description of the determination of the current ERM values be developed and made available for review as soon as possible and b) analysis be conducted to determine the relationship between ERM and detailed resource adequacy analysis.

ERM Testing Process

- RESOLVE and PLEXOS models were updated to the August 2021 Inputs and Assumptions in the IGP docket[1]
- RESOLVE was run to solve for various changes in ERM target percentage and HDCs to examine its effect on the resulting resource build in year 2030
- PLEXOS was run to assess the ERM and related metrics of the resource build developed in RESOLVE for year 2030
- The 2030 plan includes planned Stage 1 and 2, demand response, and existing renewables. For the purposes of ERM testing, HNEI suggested taking out future resources selected by RESOLVE for economic reasons (and not for capacity) e.g. wind or solar. In further testing by the Company, the firm thermal capacity built by RESOLVE was unchanged when variable renewables were not allowed to be built.
- As a starting point, all generating unit removal assumptions by 2030 proposed in August 2021 Inputs and Assumptions were included
- Feedback from Ulupono was incorporated in the case construction

1 See Inputs and Assumptions, https://www.hawaiianelectric.com/clean-energy-hawaii/integrated-grid-planning/stakeholder-engagement/key-stakeholder-documents

ERM Target Percentage Analysis

- For each island, the ERM target percentage was incremented at regular intervals to assess the incremental impact to the resource build
  - Oʻahu, Hawaiʻi Island, Maui: 0%, 10%, 20%, 30%, 40%
  - Molokaʻi, Lānaʻi: 0%, 20%, 40%, 60%
- RESOLVE was able to build PV, onshore & offshore wind, BESS, PV+BESS, internal combustion engines (ICE), combustion turbines (CT), combined cycle (CC), biomass, and geothermal (Hawaiʻi Island) as replacement capacity

HDC and Resource Candidate Analysis

- Using the 30% ERM target for O‘ahu, Hawaii Island, Maui and 60% ERM target for Lāna‘i, Moloka‘i, further cases were developed to test:
  - Use of the regular production profile instead of the HDCs
  - Use of HDCs for PV defined as mean minus 1 sigma, instead of minus 2 sigma
  - Removal of all thermal units (ICE, CT, CC, biomass, geothermal) as a candidate option for RESOLVE to select. Only wind, solar, and storage were allowed to be built to meet capacity needs.

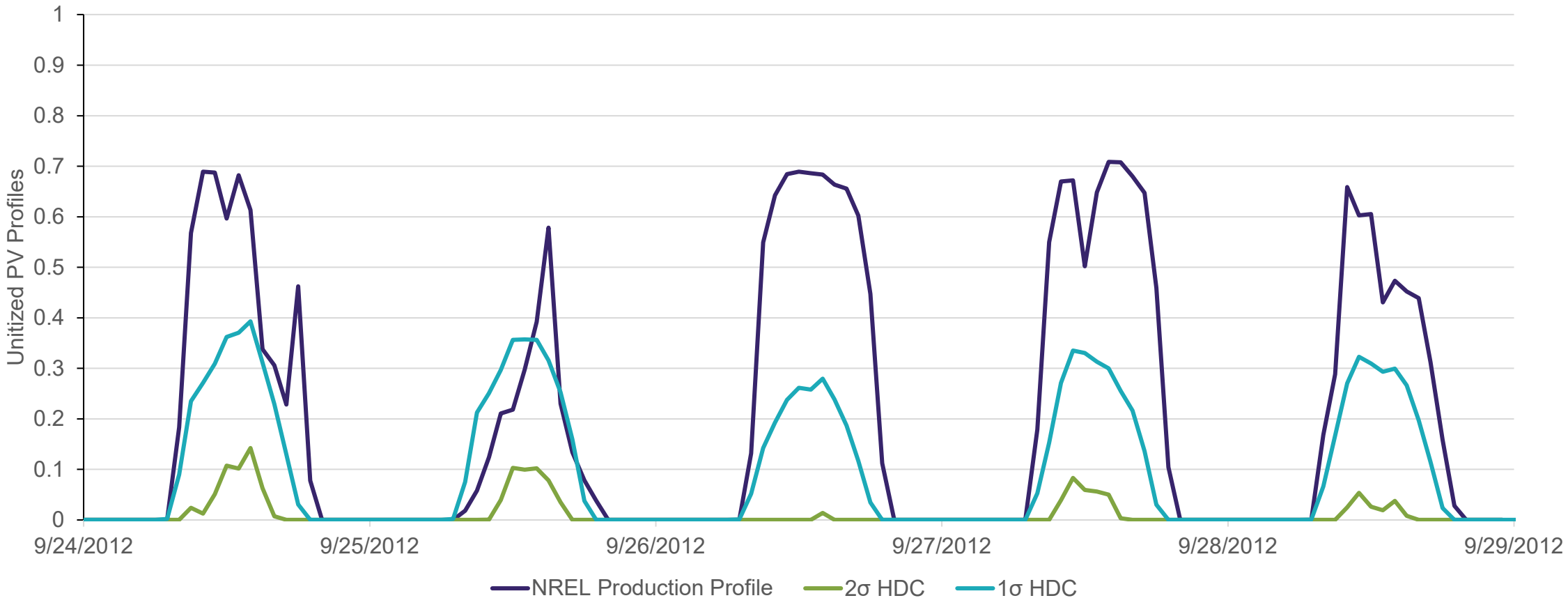
Summary of Cases (Oahu)

Cases	RESOLVE Capacity Expansion		PLEXOS Resource Adequacy	
	ERM	HDC	ERM Evaluation (21 cases)	Economic Production Simulation (7 cases)
1	0%	PV: 2σ, Wind: 1σ	1σ, 2σ, Production Profiles	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
2	10%	PV: 2σ, Wind: 1σ	1σ, 2σ, Production Profiles	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
3	20%	PV: 2σ, Wind: 1σ	1σ, 2σ, Production Profiles	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
4	30%	PV: 2σ, Wind: 1σ	1σ, 2σ, Production Profiles	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
5	40%	PV: 2σ, Wind: 1σ	1σ, 2σ, Production Profiles	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
6	30%	None, Production Profiles Used	1σ, 2σ, Production Profiles	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
7	30%; No Thermal Candidate Resources	PV: 2σ, Wind: 1σ	1σ, 2σ, Production Profiles	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops

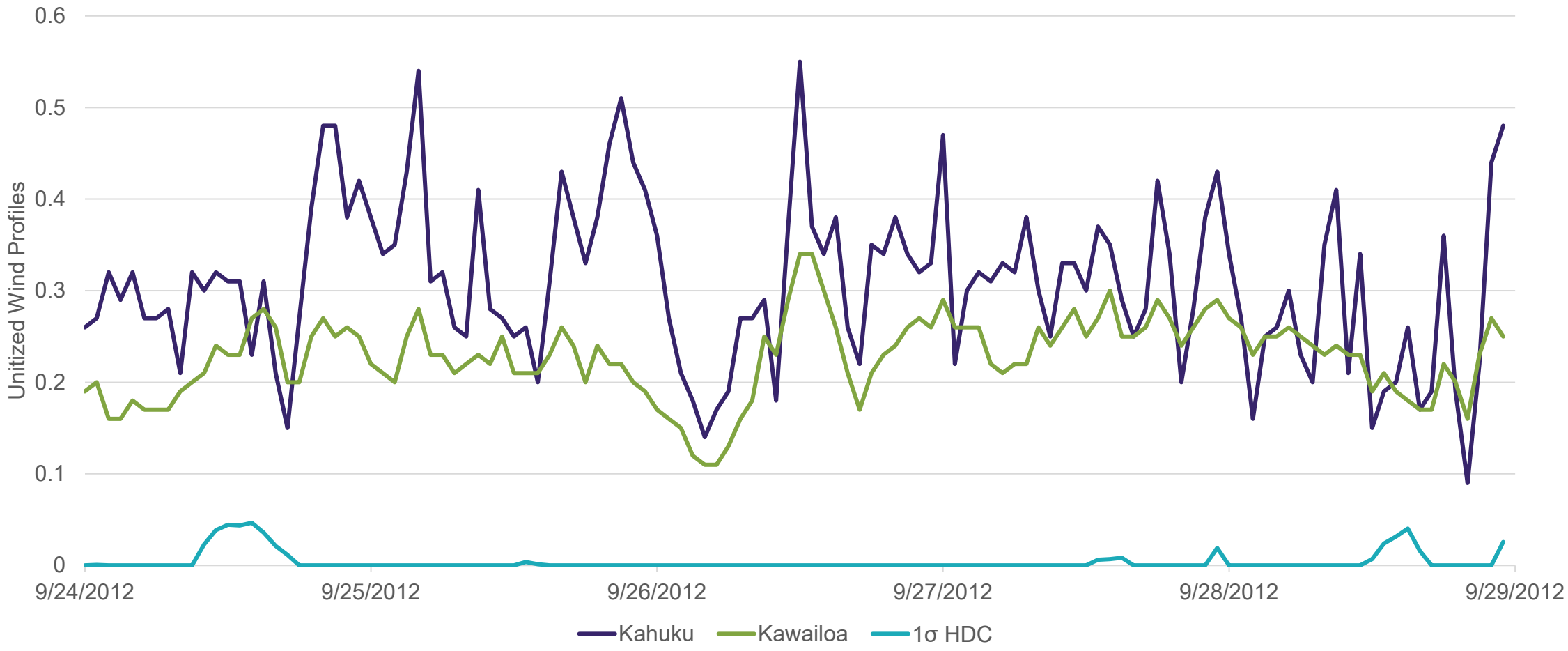
Summary of Cases (Hawaii and Maui)

Cases	RESOLVE Capacity Expansion		PLEXOS Resource Adequacy	
	ERM Hawaii Maui [Molokai/Lanai]	HDC	ERM Evaluation (8 cases)	Economic Production Simulation (7 cases)
1	0%	PV: 2σ, Wind: 1σ	2σ PV, 1σ Hydro, Wind	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
2	10% [20%]	PV: 2σ, Wind: 1σ	2σ PV, 1σ Hydro, Wind	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
3	20% [40%]	PV: 2σ, Wind: 1σ	2σ PV, 1σ Hydro, Wind	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
4	30% [60%]	PV: 2σ, Wind: 1σ	2σ PV, 1σ Hydro, Wind 1σ PV, Hydro, Wind	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
5	40%	PV: 2σ, Wind: 1σ	2σ PV, 1σ Hydro, Wind	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
6	30% [60%]	None, Production Profiles Used	Production Profiles	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops
7	30% [60%]; No Thermal Candidate Resources	PV: 2σ, Wind: 1σ	2σ PV, 1σ Hydro, Wind	Production Simulation with 15 Monte Carlo Generating Unit Outage Loops

Comparison of PV Production and HDC Profiles



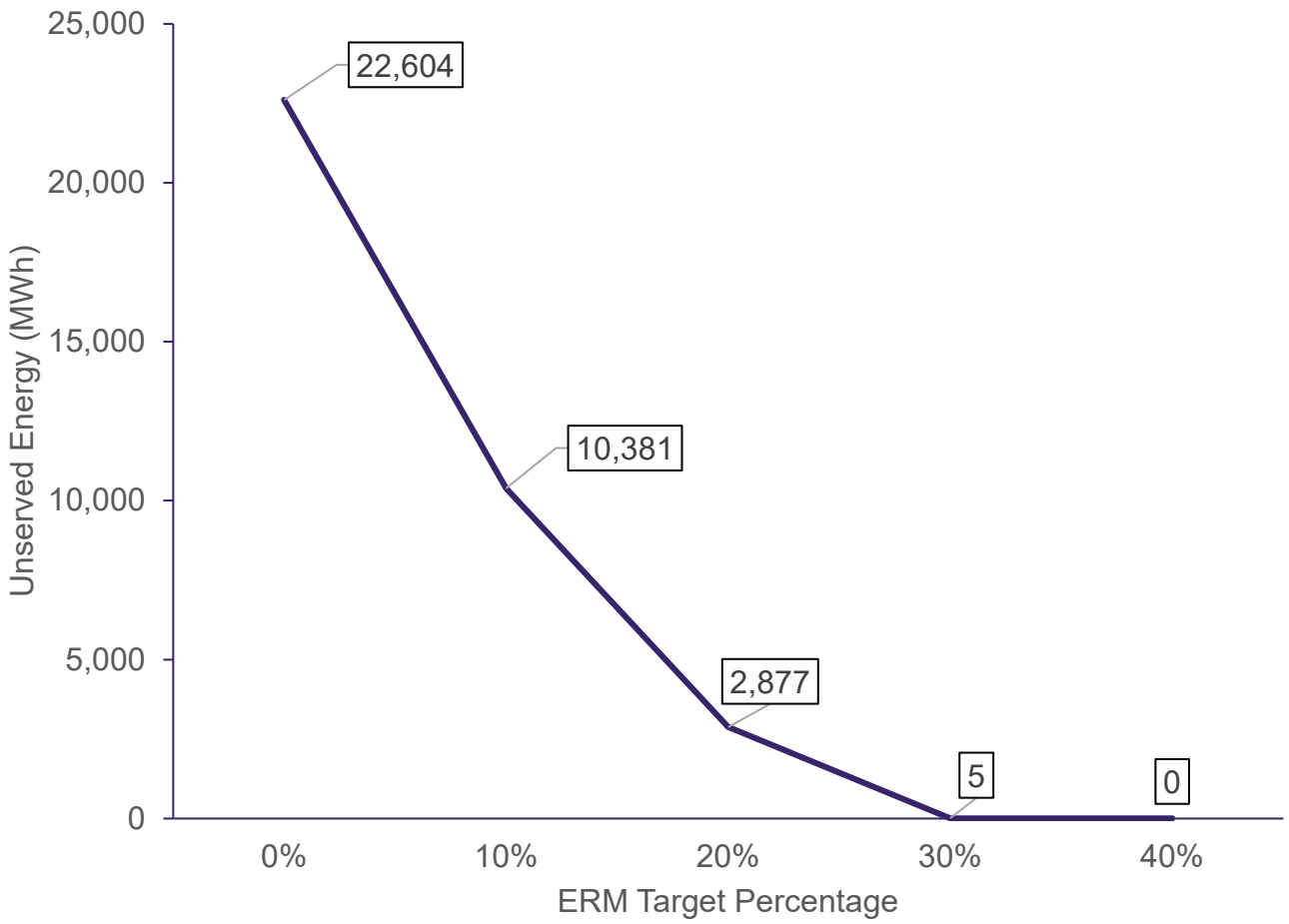
Comparison of Wind Production and HDC Profiles



Key Results

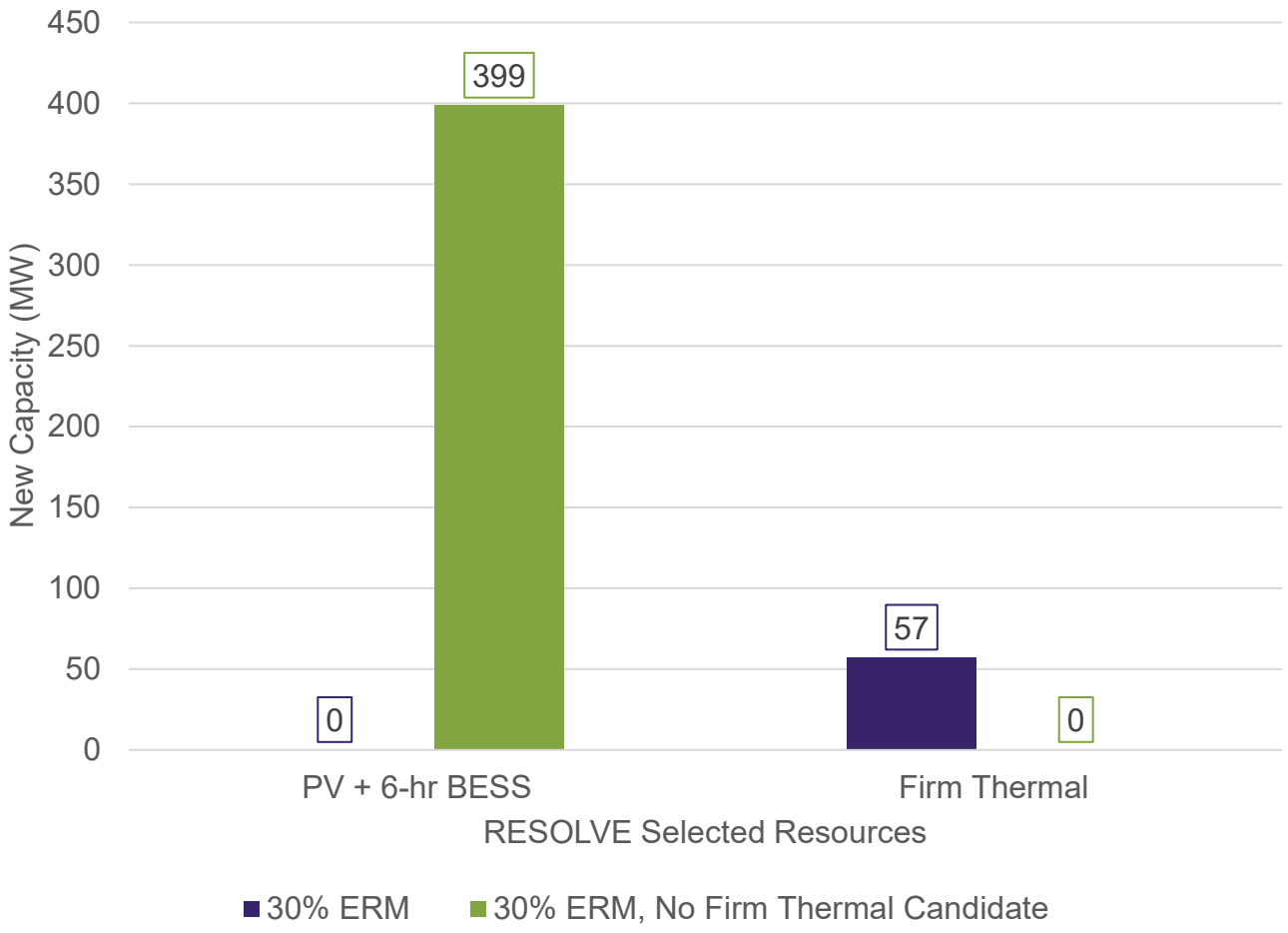
- Variable renewables reduce the amount of replacement thermal capacity that is needed to meet ERM targets
- Higher ERM targets require additional firm thermal capacity than lower ERM targets
- Comparing the 30% ERM target case to the no thermal candidate case, a firm generator is approximately equivalent to nearly 7x the capacity of PV+ 6-hr BESS on O‘ahu. This relationship may change as longer planning horizons are examined in the resource plan development.
- In a PLEXOS economic production simulation where no margin is modeled, significant unserved energy is observed at ERM targets less than 30% on O‘ahu

O‘ahu Unserved Energy by ERM Percentage



- The capacity expansion cases, constructed at each ERM target, were run as an economic production simulation
- In the economic production simulations, which account for unit maintenance and forced outages that are not considered in RESOLVE, unserved energy (i.e. load that is not served by available generating resources) is nearly zero at 30%

O‘ahu Firm Thermal Value



- The 30% ERM capacity expansion case selected 57 MW of firm thermal resource.
- Using the same ERM target, the capacity expansion selected 399 MW of PV + 6-hr BESS when firm thermal resources were not allowed to be selected.

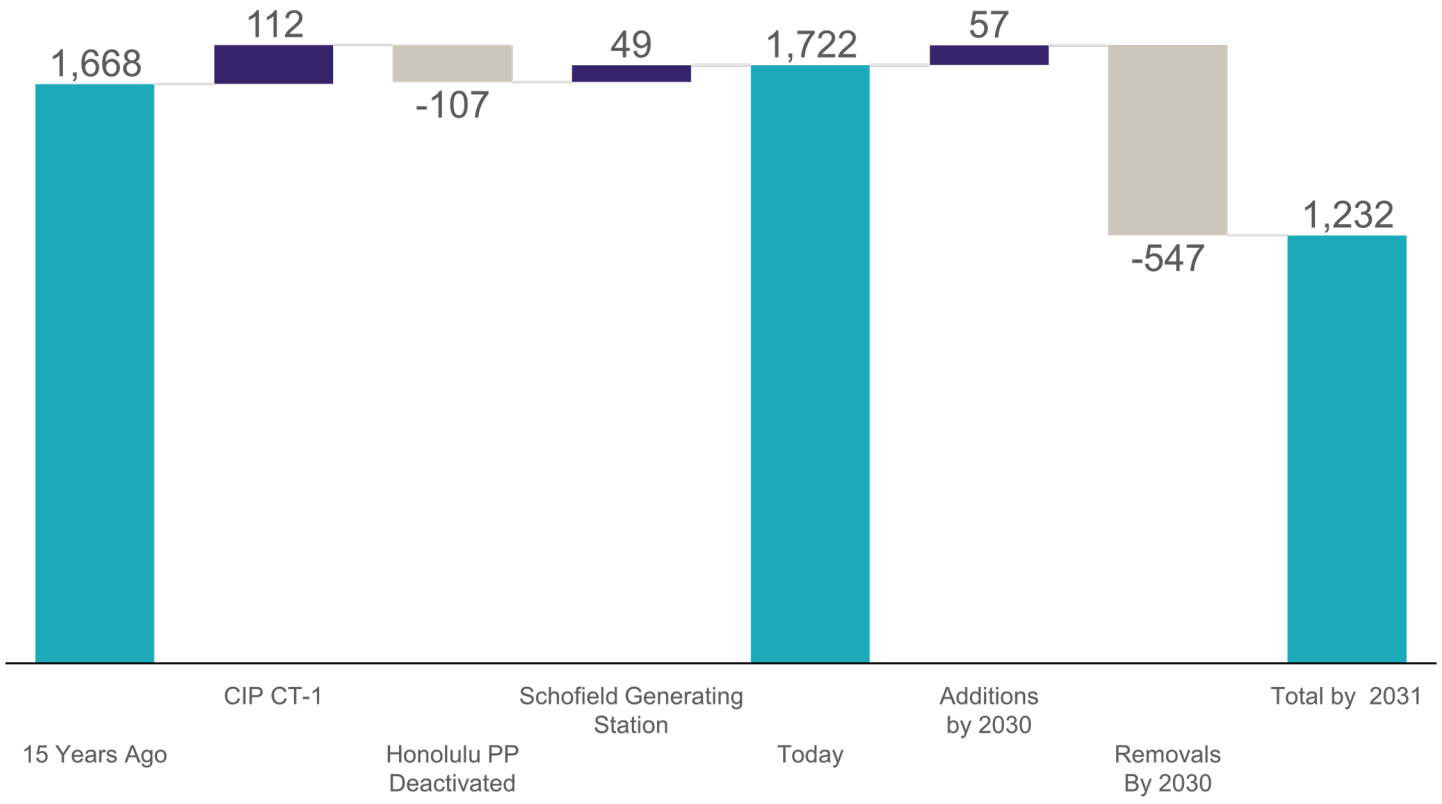
O‘ahu Results – Capacity Expansion

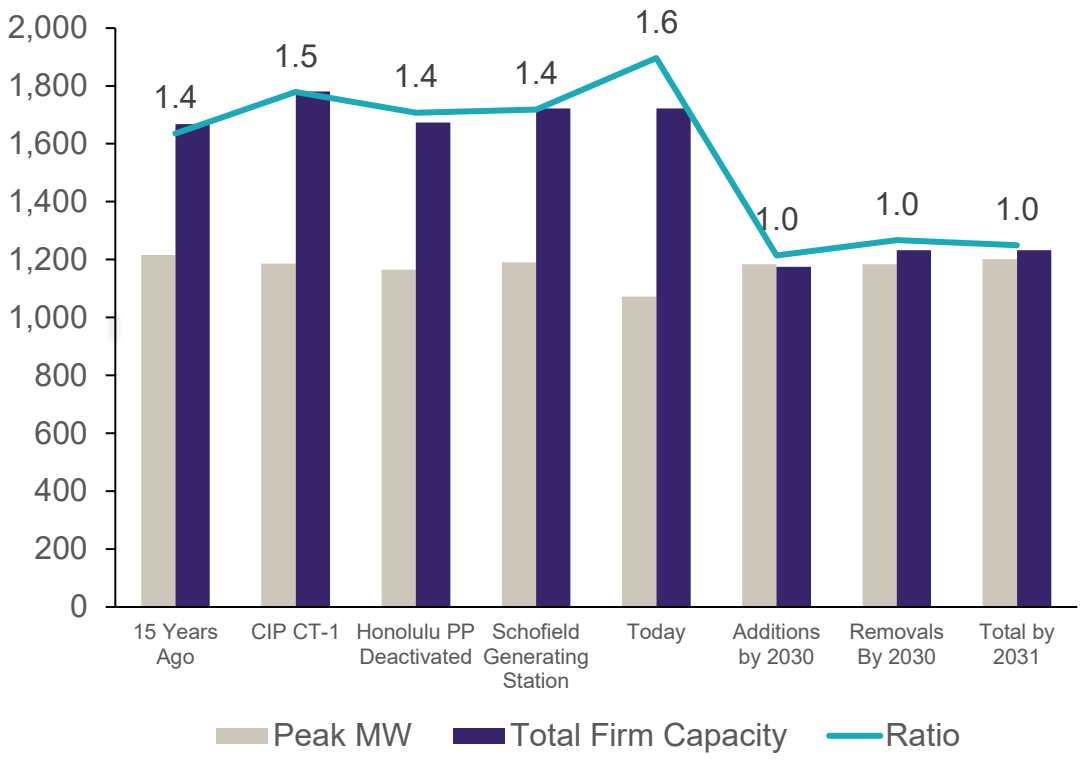
Island (MW)	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Existing Thermal Capacity	1,542	1,542	1,542	1,542	1,542	1,542	1,542
Thermal Capacity Removed (-)	-636	-536	-450	-367	-367	-367	-367
Remaining Thermal Capacity	906	1,006	1,092	1,175	1,175	1,175	1,175
Planned DR Capacity	88	88	88	88	88	88	88
Planned PV Capacity	398	398	398	398	398	398	398
Planned Wind Capacity	123	123	123	123	123	123	123
Planned PV+BESS Capacity	372	372	372	372	372	372	372
Planned BESS Capacity	185	185	185	185	185	185	185
New Thermal Capacity (+)	0	0	0	57	171	0	0
New BESS Capacity (+)	316 MW 594 MWh	316 MW 594 MWh	316 MW 594 MWh	308 MW 579 MWh	283 MW 532 MWh	316 MW 594 MWh	344 MW 667 MWh
New PV+BESS Capacity (+)							399 MW 6-hr PV+BESS
New Variable Renewables (+)	771	771	771	760	732	771	648

- RESOLVE installed capacity rounded to LM6000 block size, 57 MW;
- The 180 MW AES Coal Plant is not included in Thermal Capacity Removed;
- Further testing indicated variable renewables could be removed with minimal impact to the resource plan

- Base Assumption Consistent with Total Removals by 2030 from August I&A Update
- Additional Firm Fossil Fuel Units Retired to Create 0%-20% ERM Cases

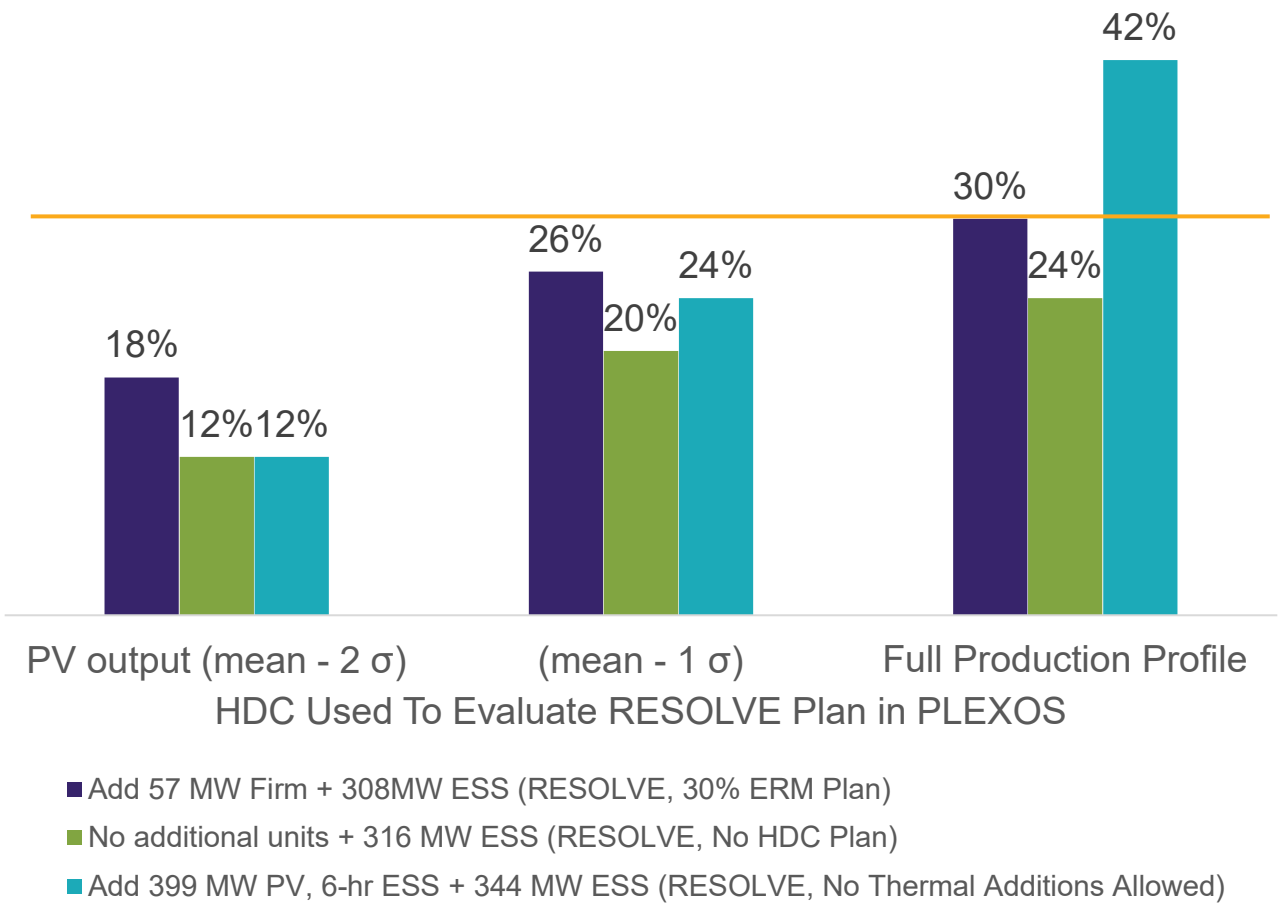
O‘ahu 30% ERM Additions/Removals





Variable renewables reduce the amount of replacement thermal capacity that is needed to meet ERM targets

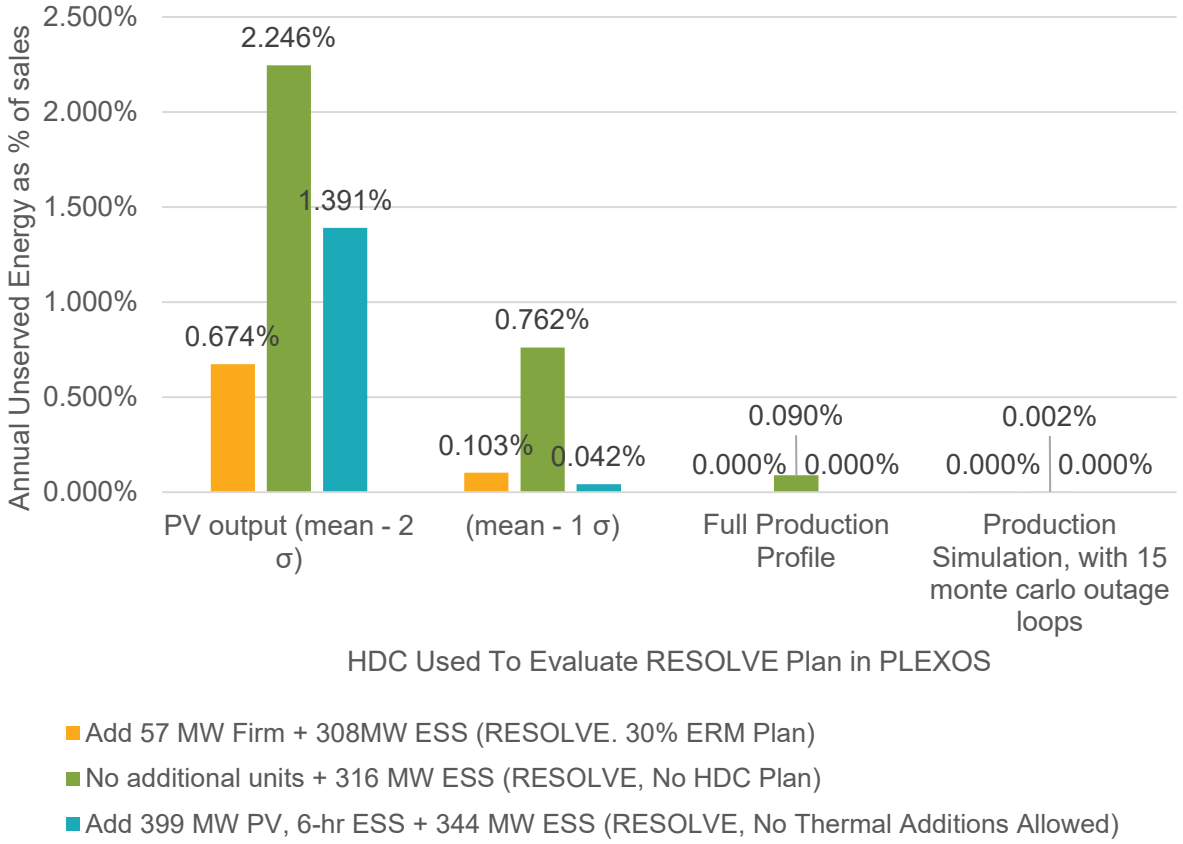
O‘ahu HDC Analysis on 30% ERM cases



- RESOLVE built three different plans at 30% ERM
  - Using standard HDC, Production Profile instead of HDC, and standard HDC but disallow Firm Gen to be built
- RESOLVE plans built without HDC results in a shortfall of ERM (24%) when evaluated in PLEXOS using full production profiles
- Full production profiles more easily meet ERM target; however, may not account for energy needs on poor weather days, weeks, months
  - Increased risk of shortfalls on poor weather days. 1 or 2 σ can help mitigate this risk

RESOLVE plans built using HDCs perform more reliably over a range of PV outputs

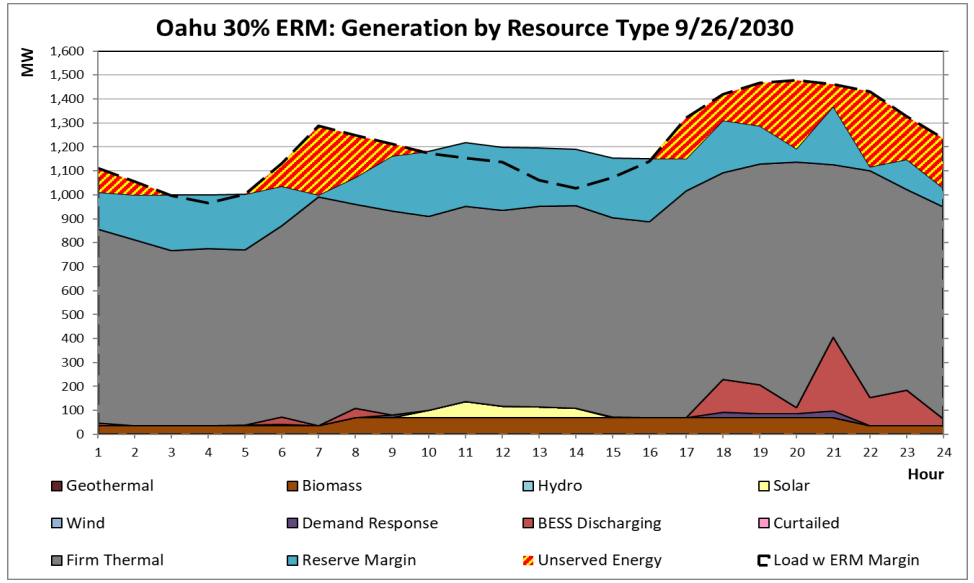
Unserved Energy Under Different HDCs

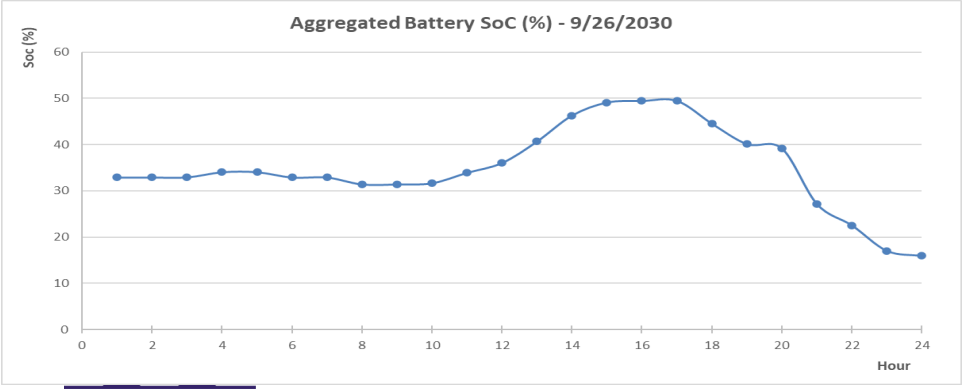


- Production simulation accounts for planned and forced outages.
- Generation must meet demand profile + 30% ERM (i.e., abnormal operating conditions)
- As expected, unserved energy decreases from 2σ to full production profiles
- Little to no unserved energy found in the production simulation with 15 Monte Carlo outage patterns suggests 30% ERM may sufficiently mitigate risk of forced outages causing unserved energy
  - Combined with mitigating weather risk through HDCs, 30% ERM + HDC provides a reasonable reliability planning criteria

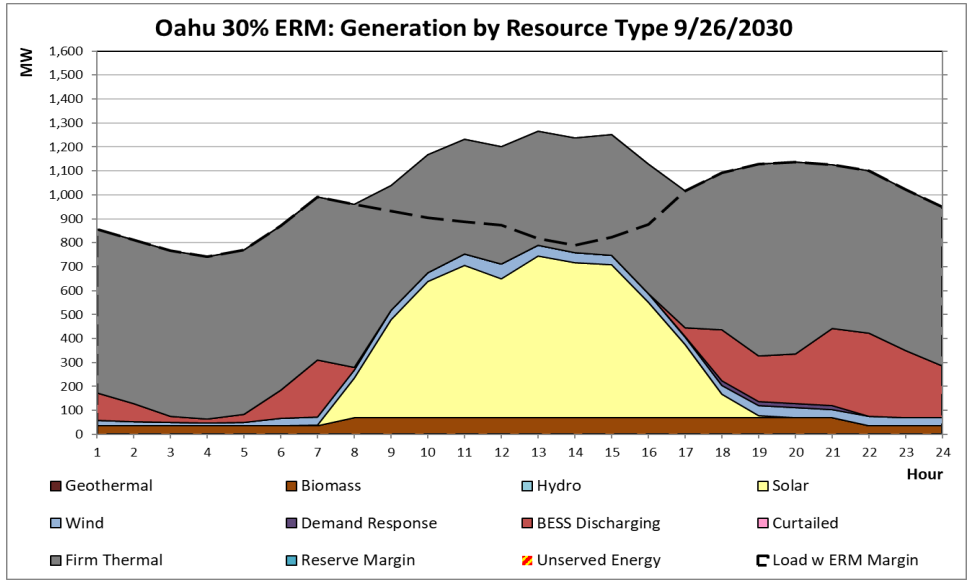
O‘ahu Representative Day

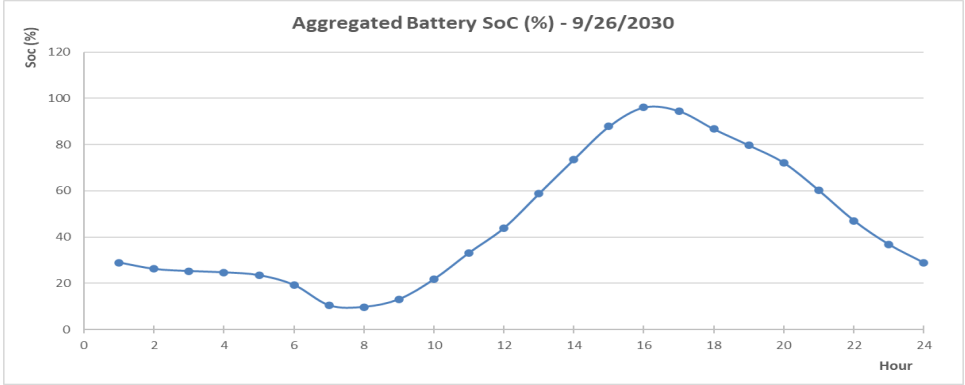
30% ERM Test





Production Simulation



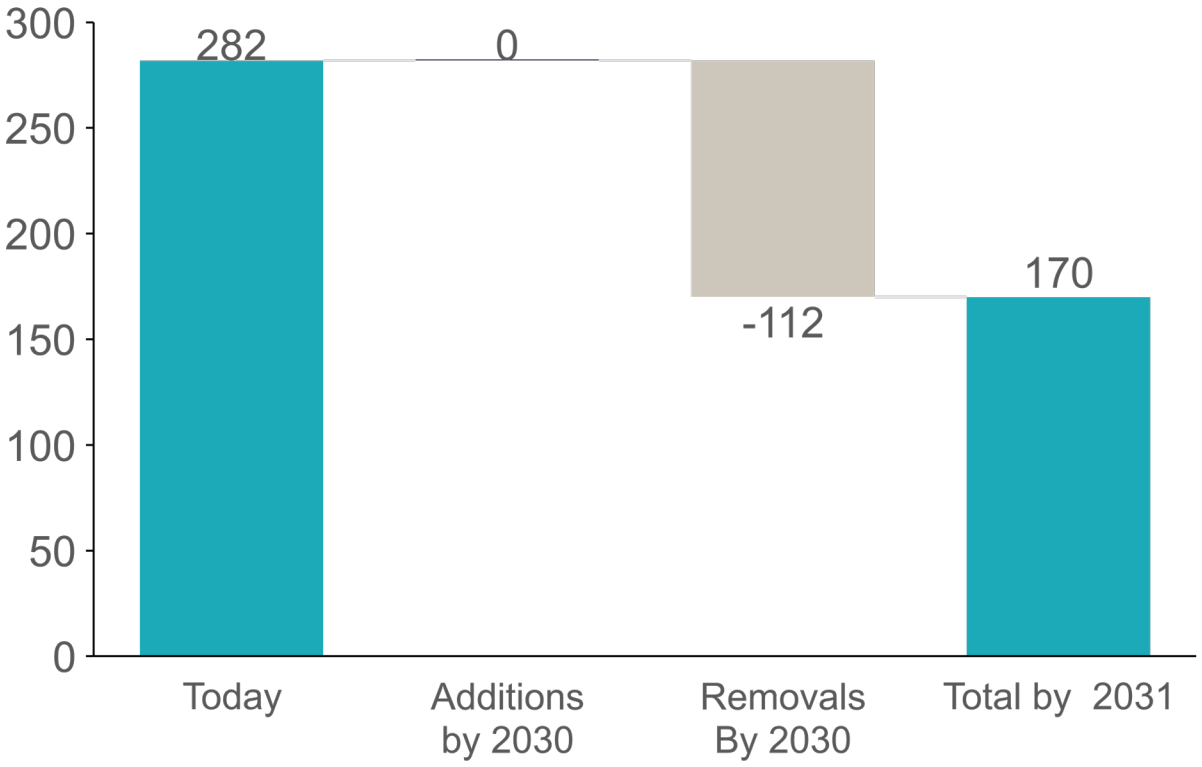


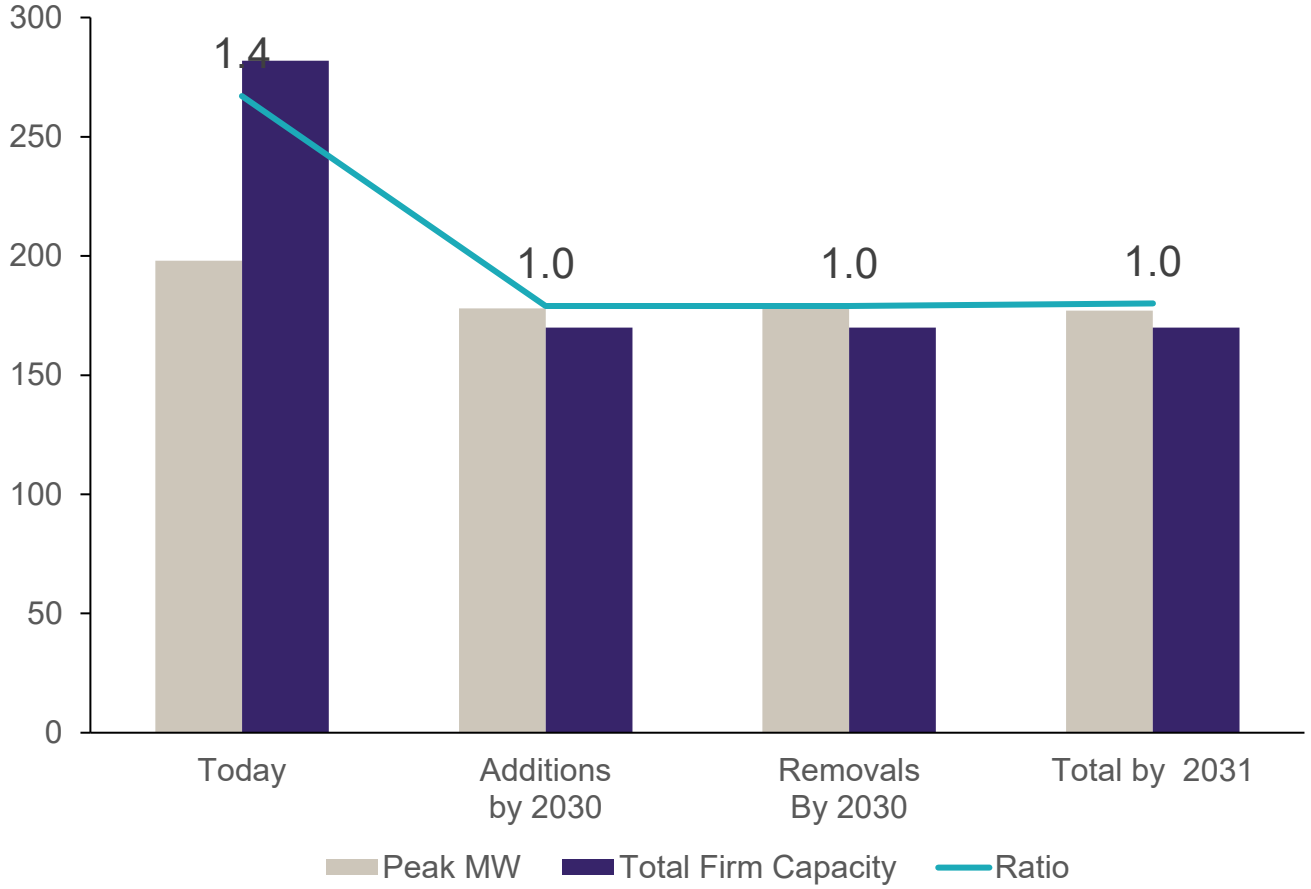
- In the ERM cases, unserved energy is caused in part by insufficient energy available to charge the BESS resources.
- In the economic production simulations, this unserved energy is largely avoided due to the greater availability of variable renewables using their production profiles.
- If periods of prolonged poor weather occur with unexpected outages, the energy reserve margin is expected to provide additional generating capability to avoid unserved energy.

Hawai‘i Island Results – Capacity Expansion

Island (MW)	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Existing Thermal Capacity	282	282	282	282	282	282	282
Thermal Capacity Removed (-)	-155	-141	-127	-112	-112	-127	-112
Remaining Thermal Capacity	127	141	155	170	170	155	170
Planned DR Capacity	0	0	0	0	0	0	0
Planned PV Capacity	9	9	9	9	9	9	9
Planned Wind Capacity	0	0	0	0	0	0	0
Planned PV+BESS Capacity	145	145	145	145	145	145	145
New Thermal Capacity (+)	0	0	0	0	16	0	0
New BESS Capacity (+)	14 MW 26 MWh	14 MW 26 MWh	14 MW 26 MWh	14 MW 26 MWh	14 MW 26 MWh	14 MW 26 MWh	14MW 28 MWh
New PV+BESS Capacity (+)	0	0	0	0	0	0	95 MW
New Variable Renewables (+)	0	0	0	0	0	0	0

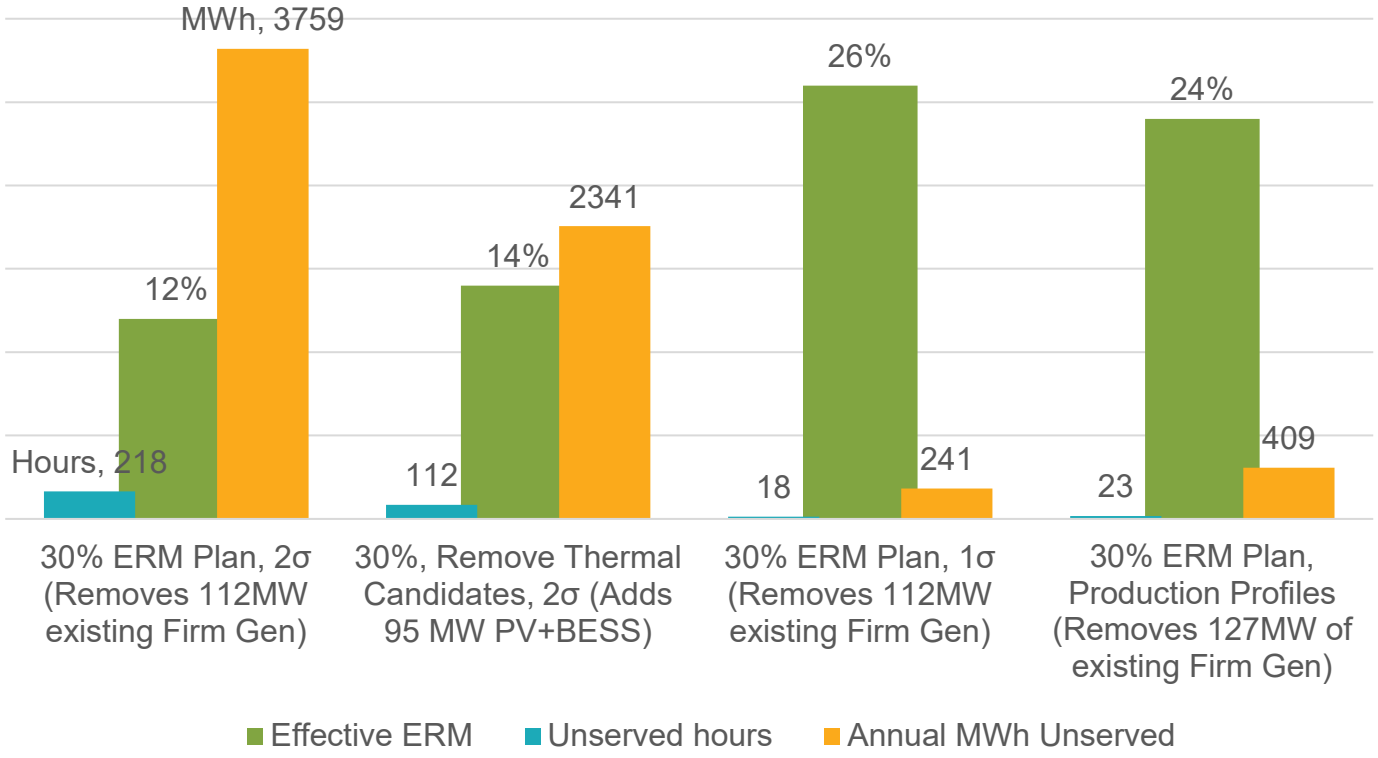
Hawai‘i Island 30% ERM Additions/Removals





Potential 40% reduction in fossil fuel generation over the next decade

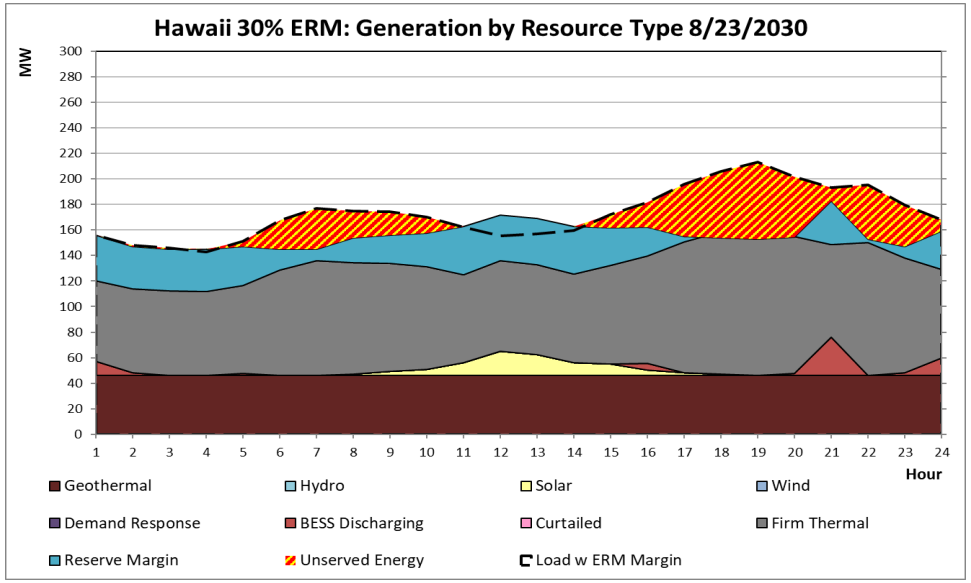
Hawai‘i Island HDC Analysis on 30% ERM cases

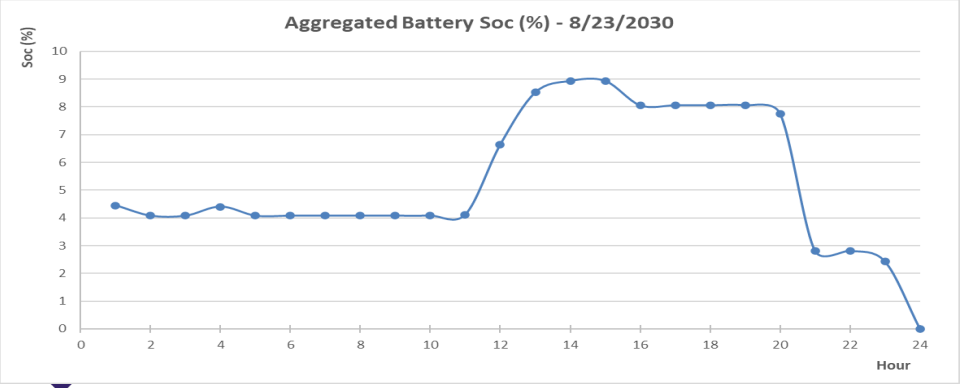


- Resource plans perform better (closer to 30% target, less unserved energy, and hours) when applying PV at 1σ or production profiles
- Under a PV at 2σ evaluation, more resources may need to be added to achieve ERM closer to target

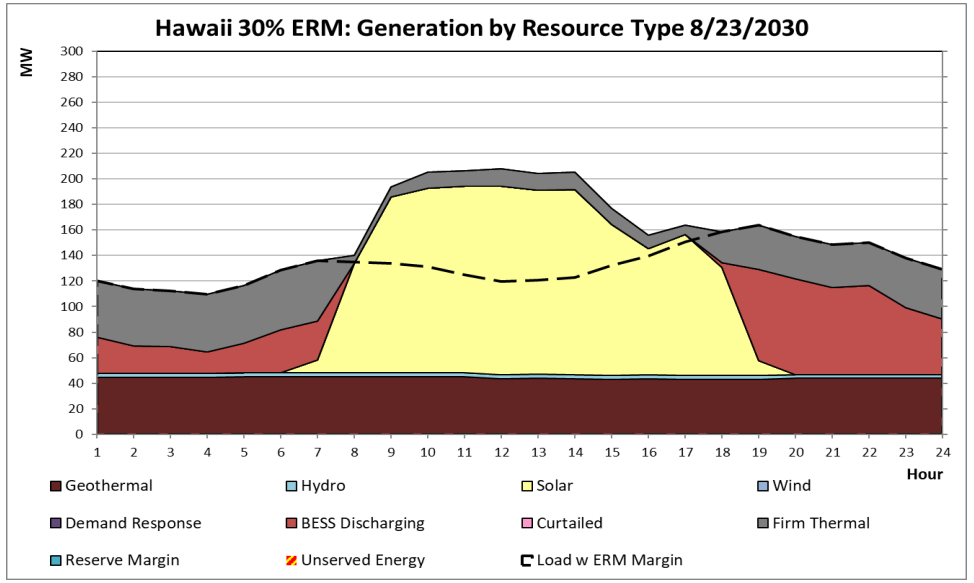
Hawai‘i Representative Day

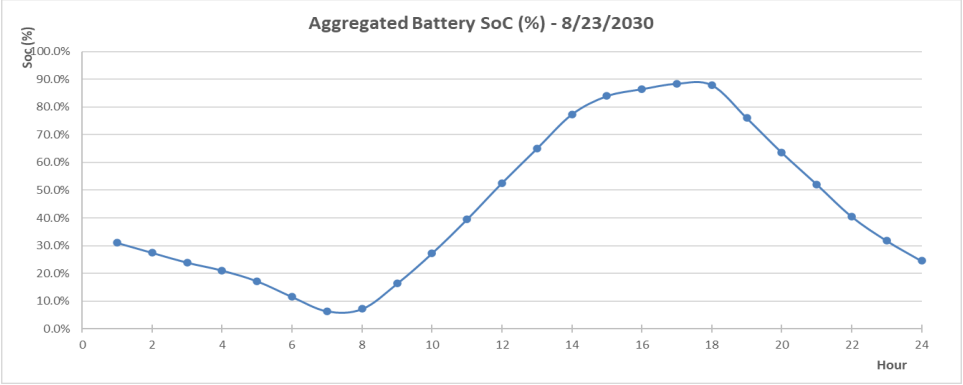
30% ERM Test





Production Simulation



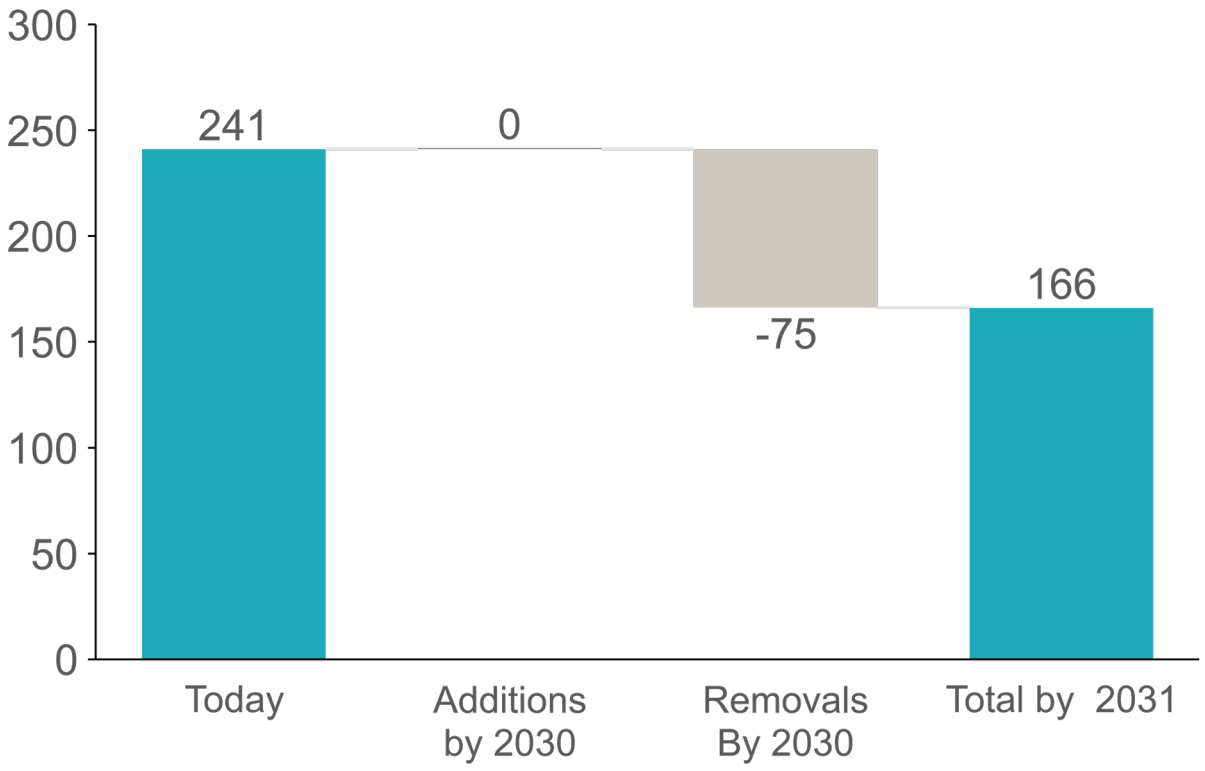


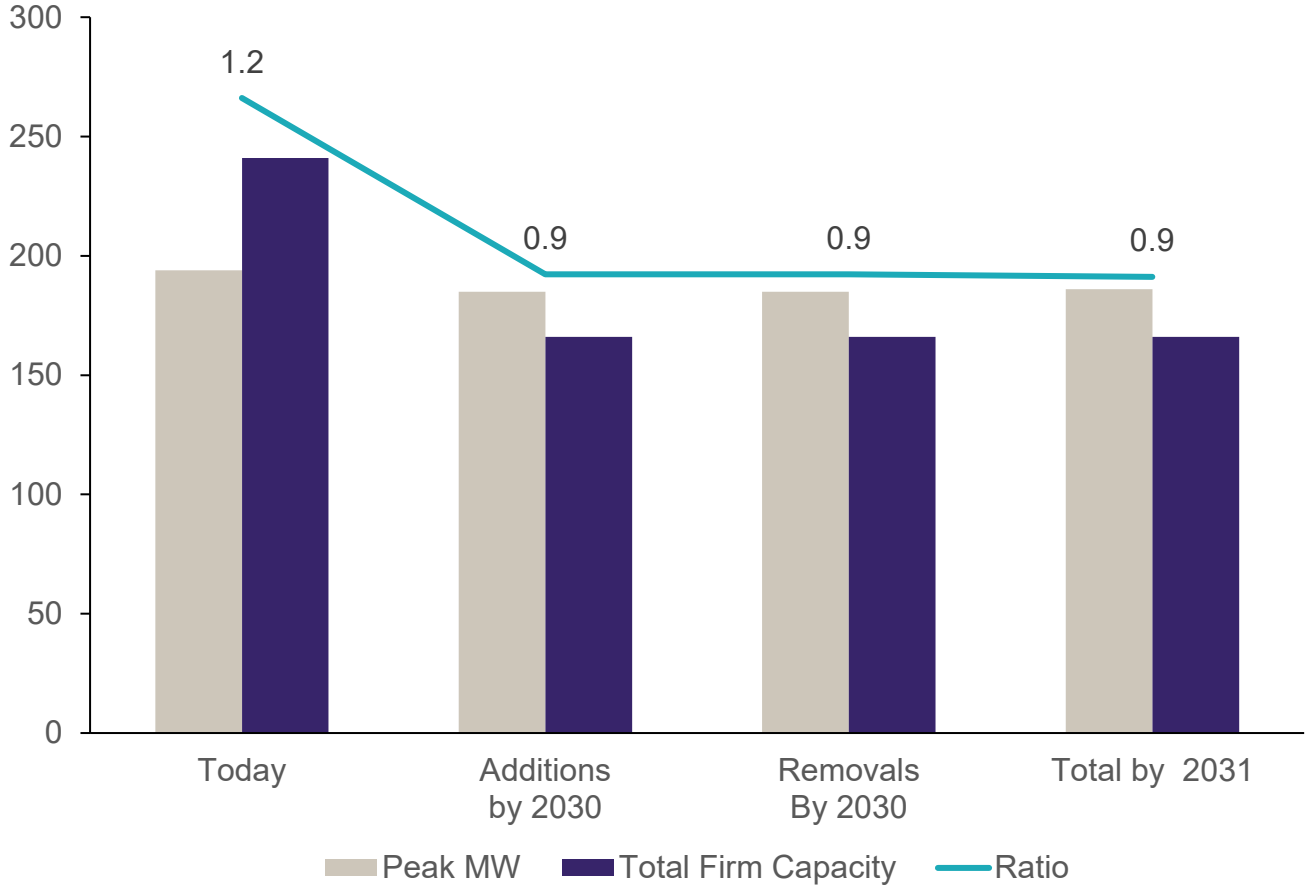
Assumed No IPP wind and hydro due to end of contract term prior to 2030

Maui Results – Capacity Expansion

Island (MW)	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Existing Thermal Capacity	241	241	241	241	241	241	241
Thermal Capacity Removed (-)	-117	-102	-90	-75	-65	-127	-65
Remaining Thermal Capacity	124	138	151	165	175	114	175
Planned DR Capacity	5	5	5	5	5	5	5
Planned PV Capacity	21	21	21	21	21	21	21
Planned Wind Capacity	42	42	42	42	42	42	42
Planned PV+BESS Capacity	200	200	200	200	200	200	200
Planned BESS Capacity	40	40	40	40	40	40	40
New Thermal Capacity (+)	0	0	0	0	0	0	0
New BESS Capacity (+)	0	0	0	0	0	0	0
New PV+BESS Capacity (+)	0	0	0	0	0	0	42 MW, 4hr 9 MW, 6hr
New Wind Capacity (+)	0	0	0	0	0	0	0

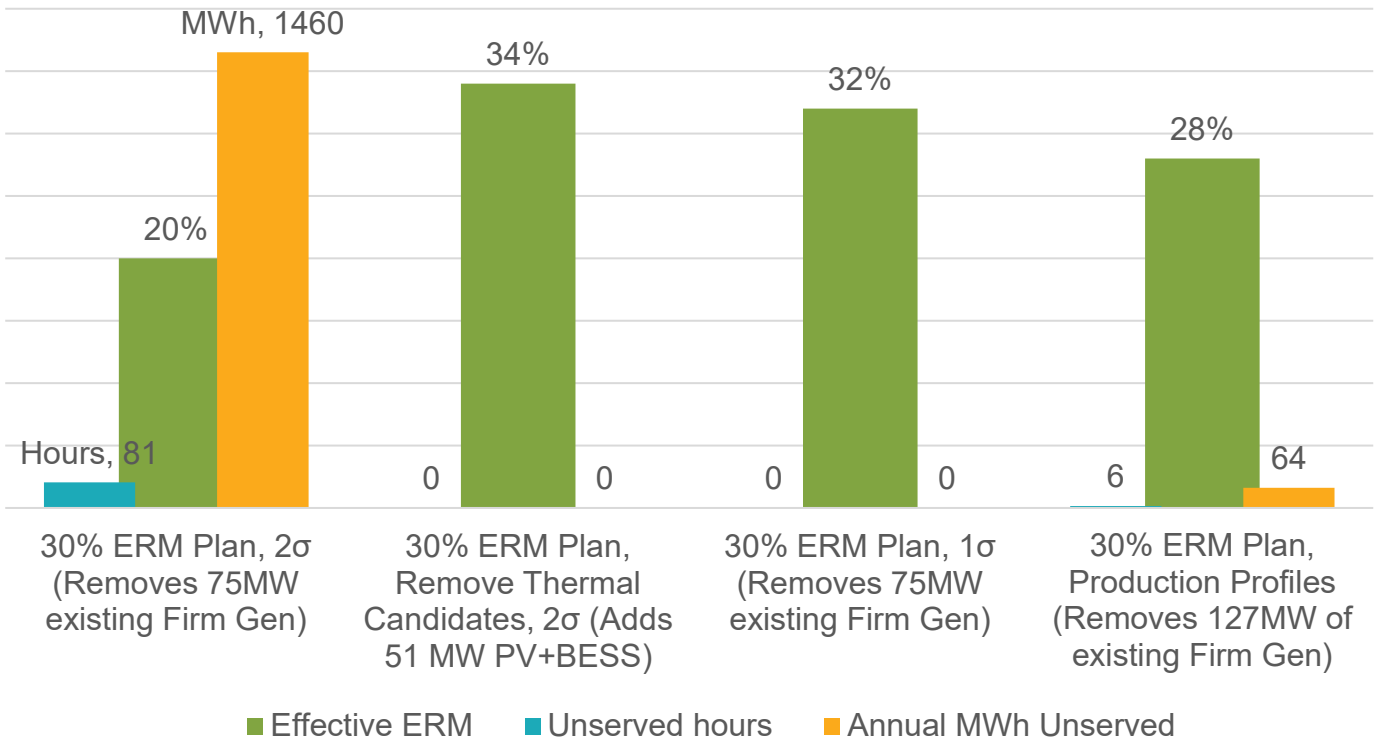
Maui 30% ERM Additions/Removals





Potential 31% reduction in fossil fuel generation over the next decade

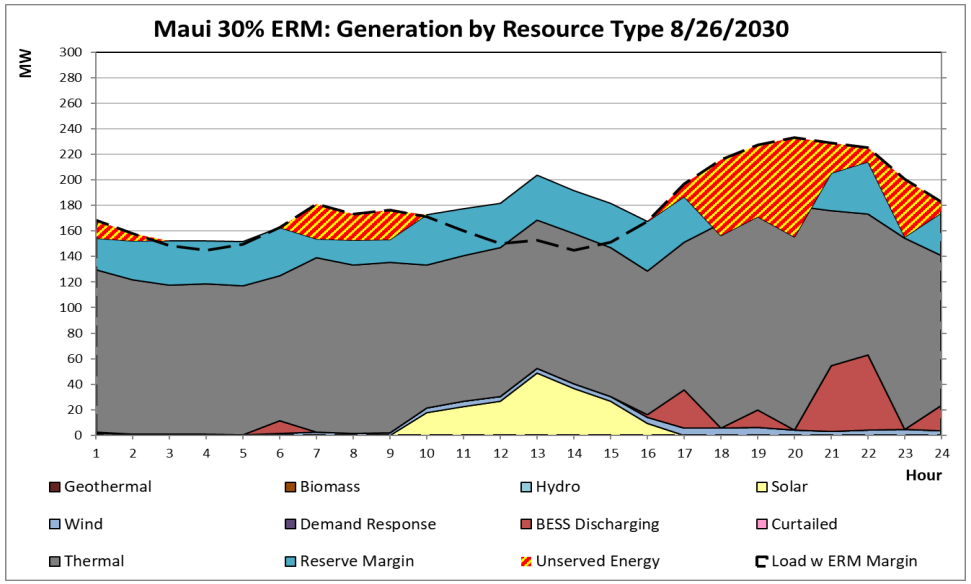
Maui HDC Analysis on 30% ERM cases

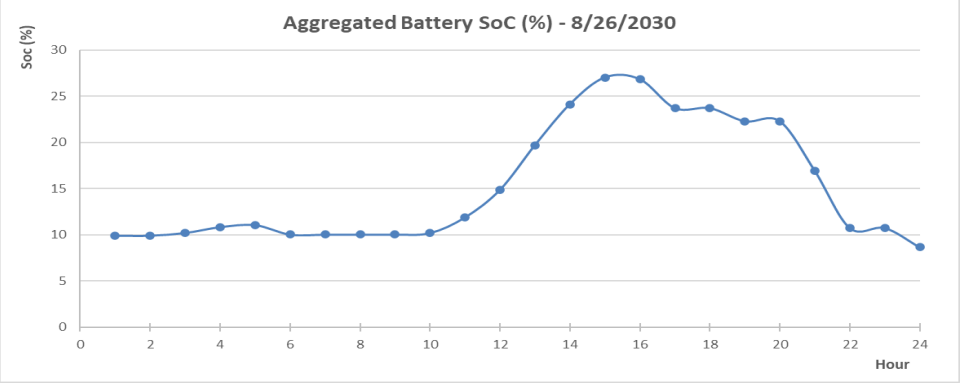


- Resource plans perform better (closer to 30% target, less unserved energy, and hours) when applying PV at 1σ or production profiles
- Under PV at 2σ evaluation, more resources may need to be added to achieve ERM closer to target

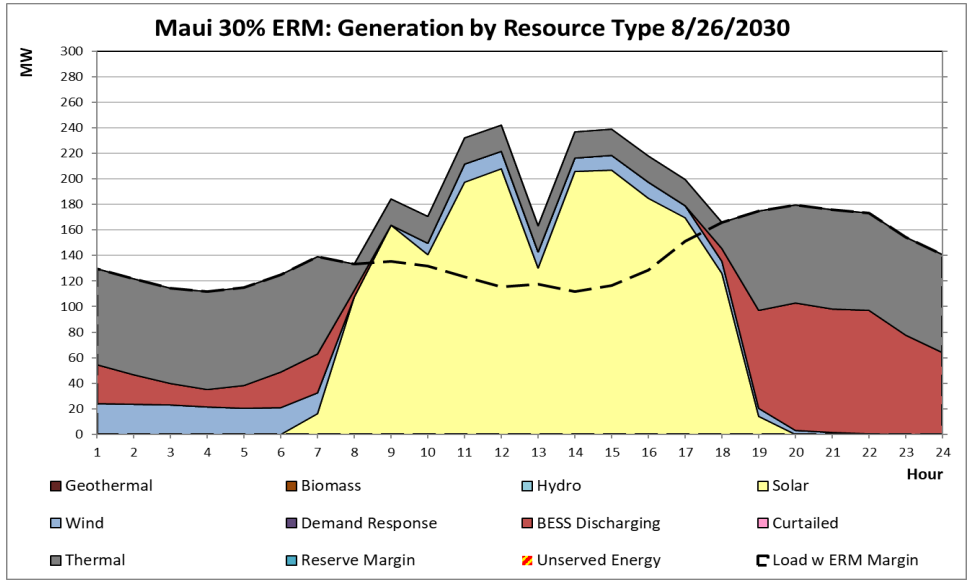
Maui Representative Day

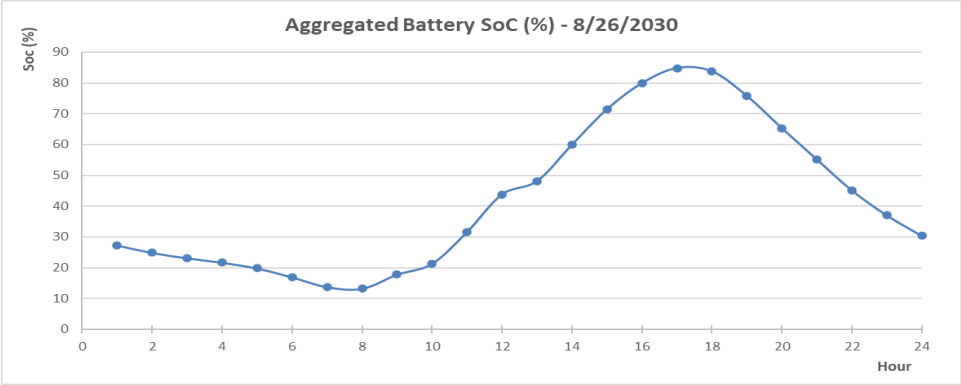
30% ERM Test





Production Simulation



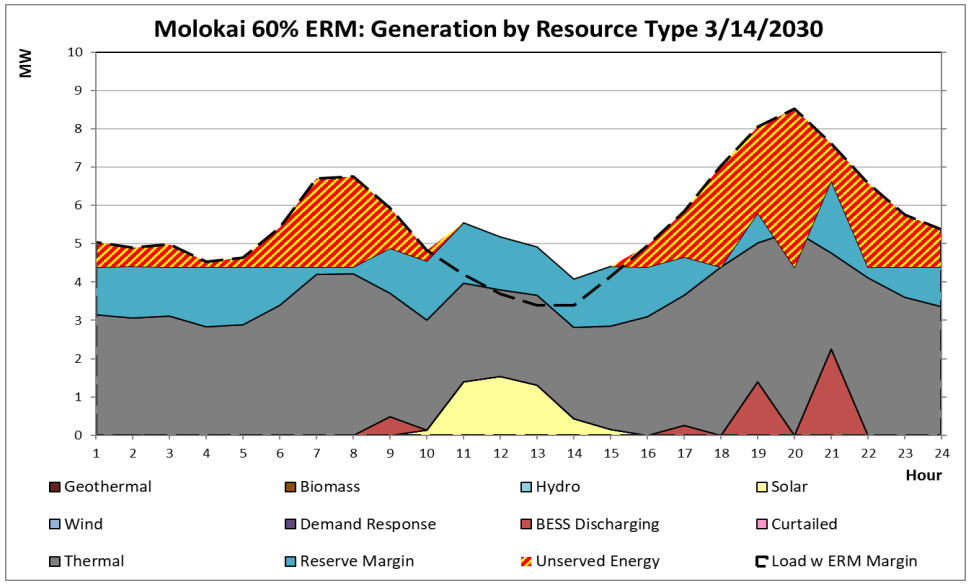


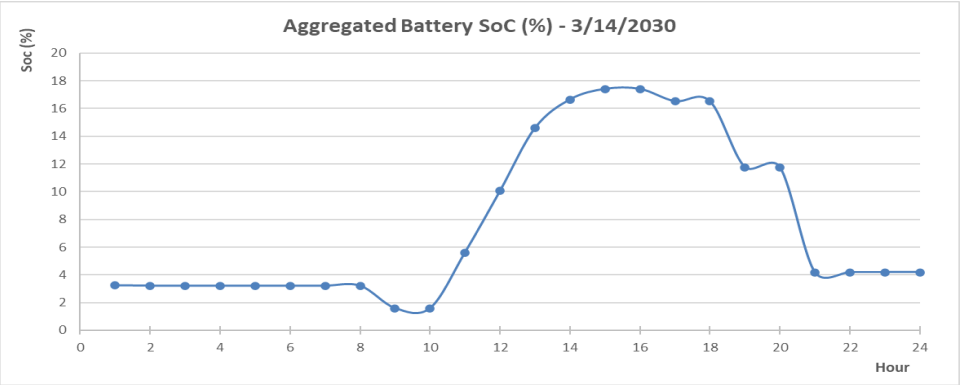
Moloka‘i Results – Capacity Expansion

Island (MW)	60% ERM	40% ERM	20% ERM	0% ERM	Production Profile (60% ERM)	Remove Thermal Candidates (60% ERM)
Existing Thermal Capacity	15.2	15.2	15.2	15.2	15.2	15.2
Thermal Capacity Removed (-)	15.2	15.2	15.2	15.2	15.2	15.2
Remaining Thermal Capacity	0.0	0.0	0.0	0.0	0.0	0.0
Planned DR Capacity	0.0	0.0	0.0	0.0	0.0	0.0
Planned PV Capacity	0.3	0.3	0.3	0.3	0.3	0.3
Planned Wind Capacity	0.0	0.0	0.0	0.0	0.0	0.0
Planned PV+BESS Capacity	7.2	7.2	7.2	7.2	7.2	7.2
New Thermal Capacity (+)*	6.6	4.4	4.4	4.4	4.4	0.0
New BESS Capacity (+)	0.3	0.3	0.3	0.5	0.3	0.7
New PV+BESS Capacity (+)	1.0 MW, 2hr	1.0 MW, 2hr	1.0 MW, 2hr	0.8 MW, 2hr	0.9 MW, 4hr 1.6 MW, 6hr	1 MW, 6hr 136 MW, 8hr
New Wind Capacity (+)	0.0	0.0	0.0	0.0	0.2	0.0

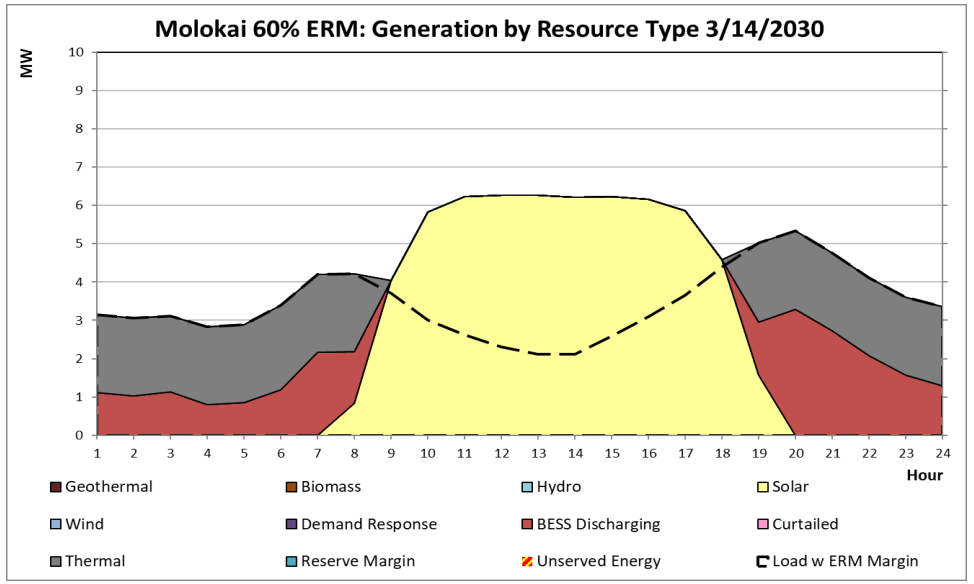
Moloka‘i Representative Day

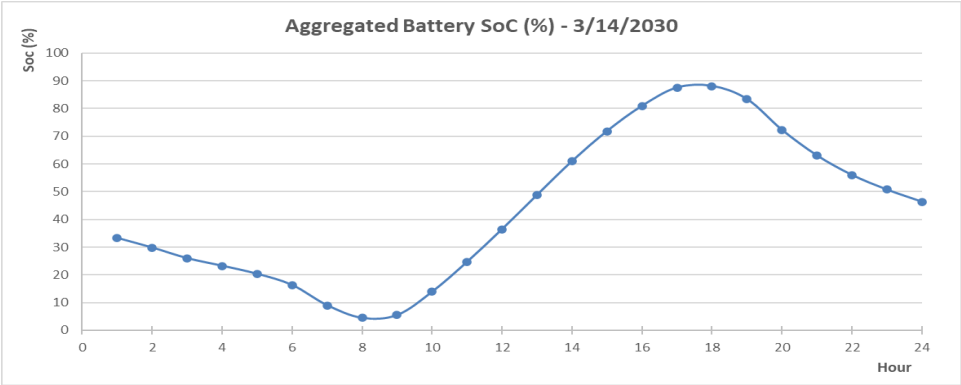
60% ERM Test



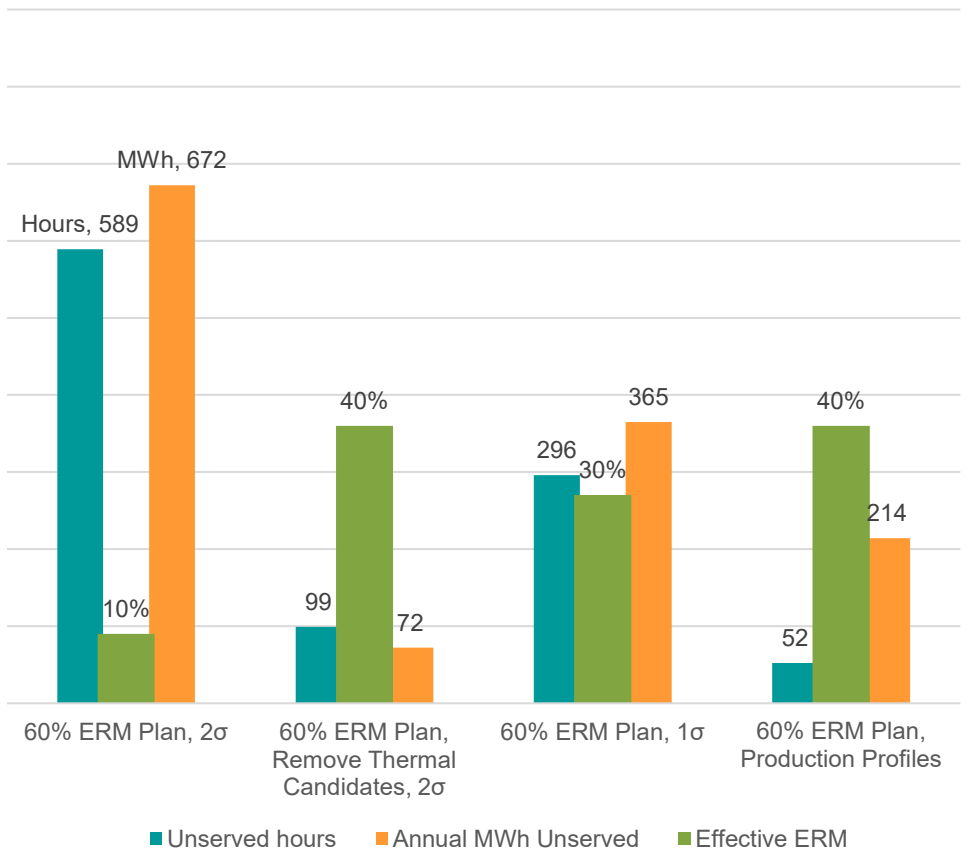


Production Simulation





Moloka‘i HDC Analysis on 60% ERM cases



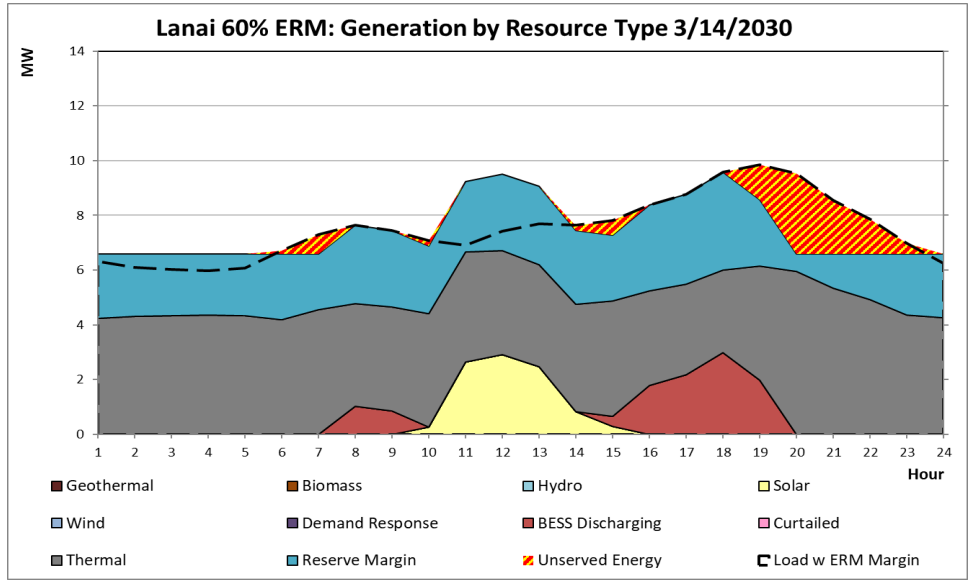
- In all cases, the estimated ERM fell short of the 60% target when evaluated in PLEXOS.
- Block sizes for replacement thermal generation will play a key role in meeting the 60% ERM, especially on smaller systems, due to the amount of capacity removed in forced outages and maintenance

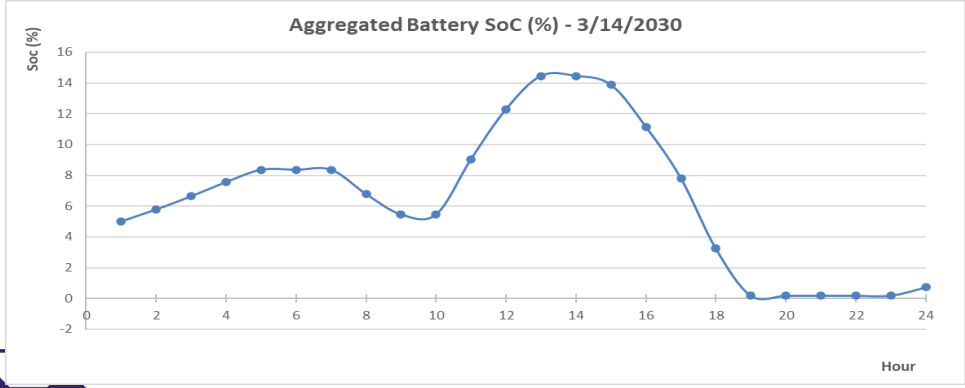
Lānaʻi Results – Capacity Expansion

Island (MW)	60% ERM	40% ERM	20% ERM	0% ERM	Production Profile (60% ERM)	Remove Thermal Candidates (60% ERM)
Existing Thermal Capacity	10.4	10.4	10.4	10.4	10.4	10.4
Thermal Capacity Removed (-)	10.4	10.4	10.4	10.4	10.4	10.4
Remaining Thermal Capacity	0	0	0	0	0	0
Planned DR Capacity	0	0	0	0	0	0
Planned PV Capacity	0	0	0	0	0	0
Planned Wind Capacity	0	0	0	0	0	0
Planned PV+BESS Capacity	15.8	15.8	15.8	15.8	15.8	15.8
New Thermal Capacity (+)	8.8	6.6	6.6	4.4	6.6	0
New BESS Capacity (+)	0	0	0	0	0	0
New PV+BESS Capacity (+)	0.5 MW, 2hr	0.5 MW, 2hr	0.5 MW, 2hr	0.5 MW, 2hr	0.5 MW, 2hr	87 MW, 6hr 89 MW, 8hr
New Wind Capacity (+)	0	0	0	0	0	0

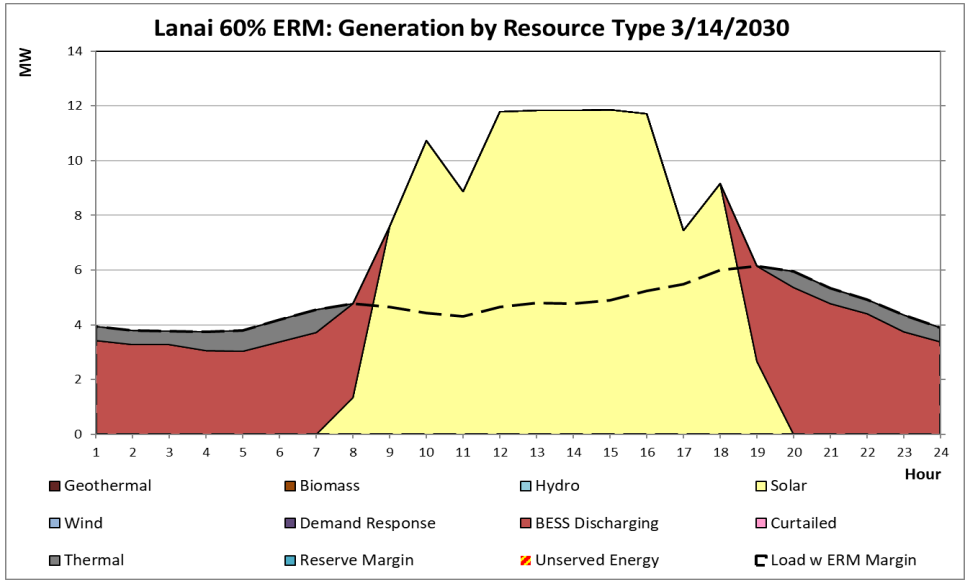
Lānaʻi Representative Day

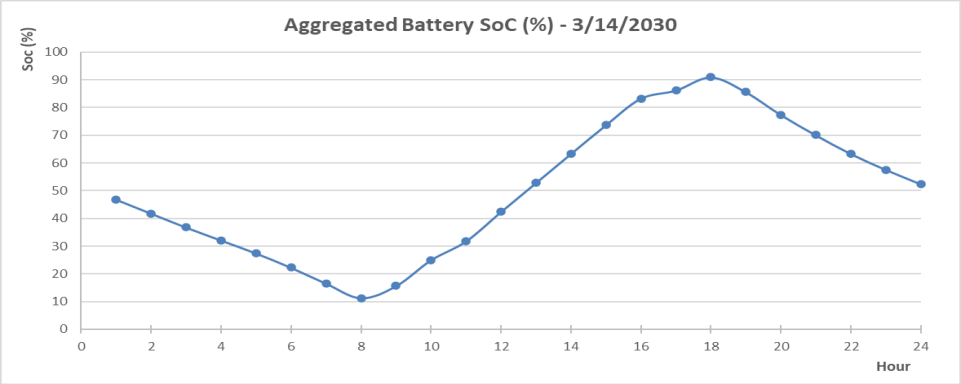
60% ERM Test



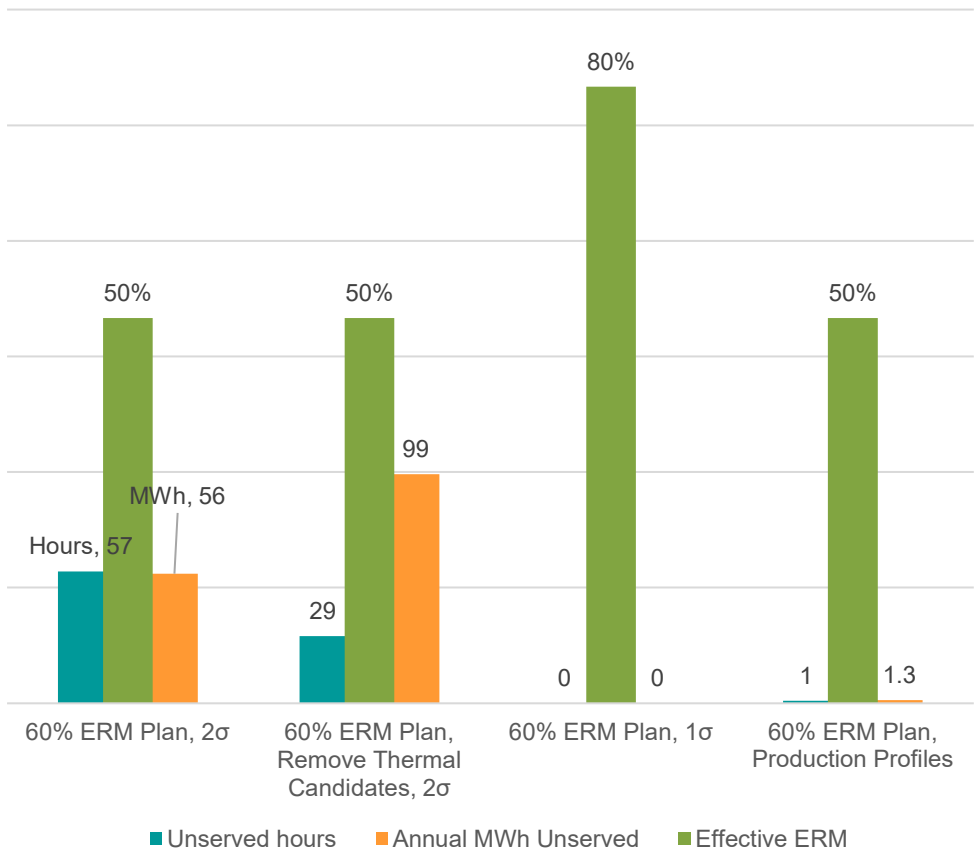


Production Simulation





Lānaʻi HDC Analysis on 60% ERM cases



- Resource plans perform better (less unserved energy and hours) when applying PV at 1σ or production profiles
- Compared to Molokaʻi, this may be due in part to the Lānaʻi RFP placeholder that was assumed in service (15.8 MW PV+BESS)
- Block sizes for replacement thermal generation will play a key role in meeting the 60% ERM, especially on smaller systems, due to the amount of capacity removed in forced outages and maintenance

Key Conclusions

- 30% ERM and HDC is a reasonable long term metric based on ERM analysis conducted
  - ERM of 40% may be reasonable if added reliability and resilience is desired
- 30% ERM is rooted in historical planning for the loss of largest generator and intended to cover a range of abnormal events such as forced outages, unplanned maintenance, atypical weather, battery energy storage failures, forecast uncertainty
- HDC is a reasonable approach to mitigate potential impacts of low solar and wind output and their ability to charge BESS
- ERM and HDC help to provide a balanced portfolio of resources that can mitigate risks of reliance on a single technology
- A firm generator is approximately equivalent to nearly 7x the capacity of PV+ 6-hr BESS on O‘ahu.
- Firm capacity assets plays a critical role during periods of low wind and solar availability
- A fuller analysis of reliability will be completed in the Grid Needs Assessment Resource Adequacy Step.
- Further refinement of reliability planning criteria may be warranted in the future once the Company gains operational data and experience operating novel (solar + BESS) technologies

Reference

O‘ahu Results – Resource Adequacy

2 Std Dev PV HDC	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Pass / Fail	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
Estimated ERM Level (%)	-16%	-6%	4%	18%	30%	12%	12%
Annual Unserved Energy (MWh)	97,478	103,441	129,827	44,712	21,136	148,968	92,235
Annual Unserved Hours (Hrs)	847	964	1118	493	260	1206	737

1 Std Dev PV HDC	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Pass / Fail	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
Estimated ERM Level (%)	-10%	0%	10%	26%	38%	20%	24%
Annual Unserved Energy (MWh)	27,476	29,313	43,759	6,839	1,386	50,542	2,797
Annual Unserved Hours (Hrs)	314	332	476	124	31	515	43

O‘ahu Results – Resource Adequacy

No HDC	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Pass / Fail	FAIL	FAIL	FAIL	PASS	PASS	FAIL	PASS
Estimated ERM Level (%)	-4%	8%	14%	30%	42%	24%	42%
Annual Unserved Energy (MWh)	753	583	4,441	0	0	5,974	0
Annual Unserved Hours (Hrs)	28	25	105	0	0	144	0

Production Simulation with 15 Outage Loops	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Annual Unserved Energy (MWh)	22,604	10,381	2,877	4.8	0	153.8	0
Annual Unserved Hours (Hrs)	191.7	84.9	21.9	0.1333	0	2.1333	0

Hawai‘i Island Results – Resource Adequacy

ERM Cases	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM
Pass / Fail	FAIL	FAIL	FAIL	FAIL	FAIL
Estimated ERM Level (%)	<-15%	-10%	2%	12%	26%
Annual Unserved Energy (MWh)	6,773	5,423	3,920	3,759	1,982
Annual Unserved Hours (Hrs)	324	274	215	218	115

ERM Cases	1 Std Dev PV HDC (30% ERM)	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Pass / Fail	FAIL	FAIL	FAIL
Estimated ERM Level (%)	26%	24%	14%
Annual Unserved Energy (MWh)	241	409	2,341
Annual Unserved Hours (Hrs)	18	23	112

Hawai‘i Island Results – Resource Adequacy

Production Simulation with 15 Outage Loops	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Annual Unserved Energy (MWh)	0	0	0	0	0	0	0
Annual Unserved Hours (Hrs)	0	0	0	0	0	0	0

Maui Results – Resource Adequacy

ERM Cases	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM
Pass / Fail	FAIL	FAIL	FAIL	FAIL	FAIL
Estimated ERM Level (%)	-8%	4%	14%	20%	26%
Annual Unserved Energy (MWh)	1,766	678	1,008	1,460	2,448
Annual Unserved Hours (Hrs)	118	12	66	81	3,411

ERM Cases	1 Std Dev PV HDC	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Pass / Fail	PASS	FAIL	PASS
Estimated ERM Level (%)	32%	28%	34%
Annual Unserved Energy (MWh)	0	64	0
Annual Unserved Hours (Hrs)	0	6	0

Maui Results – Resource Adequacy

Production Simulation with 15 Outage Loops	0% ERM	10% ERM	20% ERM	30% ERM	40% ERM
Annual Unserved Energy (MWh)	0	0	0	0	0
Annual Unserved Hours (Hrs)	0	0	0	0	0

Production Simulation with 15 Outage Loops	1 Std Dev PV HDC	Production Profile (30% ERM)	Remove Thermal Candidates (30% ERM)
Annual Unserved Energy (MWh)	0	0	0
Annual Unserved Hours (Hrs)	0	0	0

Moloka‘i Results – Resource Adequacy

ERM Cases	0% ERM	20% ERM	40% ERM	60% ERM
Pass / Fail	FAIL	FAIL	FAIL	FAIL
Estimated ERM Level (%)	-40%	-40%	-40%	10%
Annual Unserved Energy (MWh)	772	1,726	4,322	672
Annual Unserved Hours (Hrs)	643	1277	3,107	589

ERM Cases	1 Std Dev PV HDC (60% ERM)	Production Profile (60% ERM)	Remove Thermal Candidates (60% ERM)
Pass / Fail	FAIL	FAIL	FAIL
Estimated ERM Level (%)	30%	40%	40%
Annual Unserved Energy (MWh)	365	214	72
Annual Unserved Hours (Hrs)	296	52	99

Moloka‘i Results – Resource Adequacy

Production Simulation with 15 Outage Loops	0% ERM	20% ERM	40% ERM	60% ERM
Annual Unserved Energy (MWh)	86	83	83	0
Annual Unserved Hours (Hrs)	40.3	38.3	38.3	0

Production Simulation with 15 Outage Loops	1 Std Dev PV HDC	Production Profile	Remove Thermal Candidates
Annual Unserved Energy (MWh)	0	35	0
Annual Unserved Hours (Hrs)	0	25.1	0

Lānaʻi Results – Resource Adequacy

ERM Cases	0% ERM	20% ERM	40% ERM	60% ERM
Pass / Fail	FAIL	FAIL	FAIL	FAIL
Estimated ERM Level (%)	-50%	0%	0%	50%
Annual Unserved Energy (MWh)	83	223	1163	56
Annual Unserved Hours (Hrs)	994	239	831	57

ERM Cases	1 Std Dev PV HDC (60% ERM)	Production Profile (60% ERM)	Remove Thermal Candidates (60% ERM)
Pass / Fail	PASS	FAIL	FAIL
Estimated ERM Level (%)	80%	50%	50%
Annual Unserved Energy (MWh)	0	1.3	99
Annual Unserved Hours (Hrs)	0	1	29

Lāna‘i Results – Resource Adequacy

Production Simulation with 15 Outage Loops	0% ERM	20% ERM	40% ERM	60% ERM
Annual Unserved Energy (MWh)	6.6	0	0	0
Annual Unserved Hours (Hrs)	3.7	0	0	0

Production Simulation with 15 Outage Loops	1 Std Dev PV HDC	Production Profile	Remove Thermal Candidates
Annual Unserved Energy (MWh)	0	0	0
Annual Unserved Hours (Hrs)	0	0	0