

ELECTRICITY GENERATION SCENARIOS SUMMARY for EPC-19-060

(Deliverable for Subtask 3.4)

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Executive Summary

This Electricity Generation Technology Summary gives an overview of how we will model the electricity generation using RESOLVE. The inputs for SWITCH are summarized elsewhere. This document includes a summary of the inputs for

- the baseline scenario
- sensitivity analysis to test effects of the generation profiles on the value of long-duration energy storage.

California is blessed with abundant solar resource that is widely estimated to be adequate to supply all of California's energy needs. California also has access to hydropower, wind energy, geothermal, and biomass as valuable, but less abundant, generation resources that will complement solar to provide reduced need for storage.

The Preferred System Portfolio (PSP)¹ has been defined using substantial public input, so we have chosen to use it as the starting point. Historically, it has been used for 37 representative days. To implement our 365-day modeling technique, we need generation profiles for every hour of the year. To address this need, we have calculated 365-day solar resource generation profiles as described herein. Additionally, the 365-day modeling technique we have developed does not easily allow us to fully optimize dispatch of the hydropower. We have selected historical hydropower dispatch data from 2019, 2020, and 2021.

For more extensive analyses of the value of long-duration energy storage we will also consider:

- Inclusion of solar resources with south-facing tilt, both fixed and tracked
- Inclusion of winter-dominant on-shore wind resources
- Biomass converter that uses oxycombustion to provide negative carbon emissions

We anticipate that the seasonal dispatch of some of these generators may help to reduce the need for seasonal storage.

¹ <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/2019-20-irp-events-and-materials>

1. Introduction

This “Electricity Generation Scenarios Summary” (deliverable 3.4) leverages the “Electricity generation technology summary” (deliverable 3.3). That summary and related studies that we have published, concluded that the choice of the generation technology will affect how storage will be used by a zero-carbon emissions grid.

Modeling grid operation to fully understand the potential value of long-duration storage is built on an understanding of the generation profiles. The sun shines during the day, though some days are cloudy. The wind blows more at night, but not every day. The storage that is needed to fill the gaps will be intimately dependent on the details of the generation. Though the generation profiles will be unpredictable in some ways (we don’t know when the wind will stop blowing), the profiles are very predictable in other ways (the sun sets every night leaving us without solar electricity each night).

Prices for solar and wind plants have dropped impressively. The prices for geothermal, biomass, and others could also drop in the coming years. The best values to assume for modeling have significant uncertainty. We choose to leverage the PSP because it reflects a lot of thought and is familiar to the CEC.

2. Generation Resources Available in California

For consistency with the ongoing planning process, we will use the preferred system plan (PSP) documentation of “38MMT_20211005_PSP_LSEplan_2020IEPR_2020IEPRHighEV”² as a starting point for our documentation of the generation resources we will use in RESOLVE. Some additions will be made from the PSP as indicated. The generation profiles, costs, and potential for the generators are presented in Section 3.

2.1 Solar Resources

Solar resources included in the PSP are tabulated in Tables 2.1 and 2.2.

Table 2. 1 Solar Resources

Resource name	Zone	Curtailement_cost_per_MWh	RPS eligible	Can build
Arizona_Solar	CAISO	-	TRUE	TRUE
BANC_Solar_for_Other	BANC	30	FALSE	FALSE
CAISO_Solar_for_CAISO	CAISO	-	TRUE	FALSE
CAISO_Solar_for_Other	CAISO	-	FALSE	FALSE
Customer_PV	CAISO	-	FALSE	FALSE
Distributed_Solar	CAISO	-	TRUE	TRUE
Greater_Kramer_Solar	CAISO	-	TRUE	TRUE
Greater_LA_Solar	CAISO	-	TRUE	TRUE
IID_Solar_for_CAISO	IID	-	TRUE	FALSE
IID_Solar_for_Other	IID	30	FALSE	FALSE
Imperial_Solar	CAISO	-	TRUE	TRUE
LDWP_Solar_for_Other	LDWP	30	FALSE	FALSE
Northern_California_Solar	CAISO	-	TRUE	TRUE
NW_Solar_for_Other	NW	30	FALSE	FALSE
Riverside_Solar	CAISO	-	TRUE	TRUE
Southern_NV_Eldorado_Solar	CAISO	-	TRUE	TRUE
Southern_PGAE_Solar	CAISO	-	TRUE	TRUE
SW_Solar_for_CAISO	SW	-	TRUE	FALSE
SW_Solar_for_Other	SW	30-	FALSE	FALSE
Tehachapi_Solar	CAISO	-	TRUE	TRUE

Table 2. 2 Planned Installed (Minimum) Capacities for Solar Resources

Resource name	2030	2035	2040	2045
Arizona_Solar	NA	NA	NA	NA
BANC_Solar_for_Other	3747	3747	3747	3747
CAISO_Solar_for_CAISO	16405	16405	16405	16405
CAISO_Solar_for_Other	12	12	12	12
Customer_PV *	21706	26928	32151	37374
Distributed_Solar	125.2	125.2	125.2	125.2
Greater_Kramer_Solar	850.3	850.3	850.3	850.3
Greater_LA_Solar	NA	NA	NA	NA
IID_Solar_for_CAISO	49.9	49.9	49.9	49.9

² <https://files.cpuc.ca.gov/energy/modeling/2021%20PSP%20RESOLVE%20Package.zip>

IID_Solar_for_Other	115.7	115.7	115.7	115.7
Imperial_Solar	NA	NA	NA	NA
LDWP_Solar_for_Other	3459	3459	3459	3459
Northern_California_Solar	NA	NA	NA	NA
NW_Solar_for_Other	2601	2601	2600	2600
RiverSide_Solar	4001.3	4001.3	4001.3	4001.3
Southern_NV_Eldorado_Solar	785.7	785.7	785.7	785.7
Southern_PGAE_Solar	1238.0	1238.0	1238.0	1238.0
SW_Solar_for_CAISO	65	65	65	65
SW_Solar_for_Other	1831	1652	1647	1637
Tehachapi_Solar	2969.5	2969.5	2969.5	2969.5

* These are set to zero and the load (when using the 2021 IEPR – UCM scenario tag to use the 2021 IEPR net load) is reduced by the comparable amount.

2.2 Wind Resources

Similarly, the wind resources for the PSP are summarized in Tables 2.3 and 2.4.

Table 2. 3 Wind Resources

Resource name	Zone	Curtailement_cost_per_MWh	RPS eligible	Can build
Arizona_Wind	CAISO	-	TRUE	FALSE
Baja_California_Wind	CAISO	-	TRUE	TRUE
BANC_Wind_for_Other	BANC	30	FALSE	FALSE
CAISO_Wind_for_CAISO	CAISO	-	TRUE	FALSE
CAISO_Wind_for_Other	CAISO	-	FALSE	FALSE
Carizzo_Wind	CAISO	-	TRUE	TRUE
Central_Valley_North_Los_Banos_Wind	CAISO	-	TRUE	TRUE
Humboldt_Bay_Offshore_Wind	CAISO	-	TRUE	TRUE
Humboldt_Wind	CAISO	-	TRUE	TRUE
Idaho_Wind	CAISO	-	TRUE	FALSE
IID_Wind_for_Other	IID	30	FALSE	FALSE
Kern_Greater_Carrizo_Wind	CAISO	-	TRUE	TRUE
LDWP_Wind_for_CAISO	LDWP	-	TRUE	FALSE
LDWP_Wind_for_Other	LDWP	30	FALSE	FALSE
Morro_Bay_Offshore_Wind	CAISO	-	TRUE	TRUE
New_Mexico_Wind	CAISO	-	TRUE	TRUE
Northern_California_Wind	CAISO	-	TRUE	TRUE
NW_Ext_Tx_Wind	CAISO	-	TRUE	TRUE
NW_Wind_for_CAISO	NW	-	TRUE	FALSE
NW_Wind_for_Other	NW	30	FALSE	FALSE
Pacific_Northwest_Wind	CAISO	-	TRUE	TRUE
Riverside_Palm_Springs_Wind	CAISO	-	TRUE	FALSE
Solano_Wind	CAISO	-	TRUE	TRUE
Southern_Nevada_Wind	CAISO	-	TRUE	TRUE
SW_Ext_Tx_Wind	CAISO	-	TRUE	TRUE
SW_Wind_for_CAISO	SW	-	TRUE	FALSE
SW_Wind_for_Other	SW	30	FALSE	FALSE
Tehachapi_Wind	CAISO	-	TRUE	TRUE
Utah_Wind	CAISO	-	TRUE	FALSE
Wyoming_Wind	CAISO	-	TRUE	TRUE

Table 2. 4 Planned Installed Capacities (MW) for Wind Resources

Resource name	2030	2035	2040	2045
Arizona_Wind*	0	0	0	0
Baja_California_Wind	0	0	0	0
BANC_Wind_for_Other	0	0	0	0
CAISO_Wind_for_CAISO	6690	6690	6690	6690
CAISO_Wind_for_Other	280	280	280	280
Carizzo_Wind	181	181	181	181
Central_Valley_North_Los_Banos_Wind	46	46	46	46
Humboldt_Bay_Offshore_Wind	0	0	0	0
Humboldt_Wind	31	31	31	31
Idaho_Wind*	0	0	0	0
IID_Wind_for_Other	0	0	0	0
Kern_Greater_Carrizo_Wind	15	15	15	15
LDWP_Wind_for_CAISO	5	5	5	5
LDWP_Wind_for_Other	705	705	705	705
Morro_Bay_Offshore_Wind	75	75	75	75
New_Mexico_Wind	0	0	0	0
Northern_California_Wind	25	25	25	25
NW_Ext_Tx_Wind	0	0	0	0
NW_Wind_for_CAISO	1417	1417	1417	1417
NW_Wind_for_Other	10989	10989	10989	10989
Pacific_Northwest_Wind*	0	0	0	0
Riverside_Palm_Springs_Wind*	NA	NA	NA	NA
Solano_Wind	25	25	25	25
Southern_Nevada_Wind	177	177	177	177
SW_Ext_Tx_Wind	265	265	265	265
SW_Wind_for_CAISO	50	50	50	50
SW_Wind_for_Other	1877	1877	1877	1877
Tehachapi_Wind	275	275	275	275
Utah_Wind*	0	0	0	0
Wyoming_Wind	0	0	0	0

* These are effectively “turned off,” but they may be offered in the model if desired.

2.3 Small and Large Hydro Resources

Similarly, the hydro resources for the PSP are summarized in Table 2.5. None of these are offered to the model for new builds.

Table 2. 5 Hydro Resources

Resource name	Zone	RPS eligible	Available capacity fraction	Planned capacity (MW)
BANC_Small_Hydro_for_CAISO	BANC	1	0.5	0
BANC_Small_Hydro_for_Other	BANC	0	1	41.2
CAISO_Small_Hydro_for_CAISO	CAISO	1	0.5	944.5
CAISO_Small_Hydro_for_Other	CAISO	0	1	13.8
IID_Small_Hydro_for_Other	IID	0	1	0
LDWP_Small_Hydro_for_Other	LDWP	0	1	56
NW_Small_Hydro_for_CAISO	NW	1	0.5	6.9
NW_Small_Hydro_for_Other	NW	0	1	41
SW_Small_Hydro_for_Other	SW	0	1	0
BANC_Hydro	BANC	0	Hourly profile	2724

CAISO_Hydro	CAISO	0	Hourly profile	7073
IID_Hydro	IID	0	Hourly profile	83.5
LDWP_Hydro	LDWP	0	Hourly profile	1108
NW_Hydro	NW	0	Hourly profile	31295 (31288)
NW_Hydro_for_CAISO	CAISO_NW_Hydro	0	Hourly profile	2852
SW_Hydro	SW	0	Hourly profile	2532

2.4 Geothermal and Biomass Resources

Similarly, geothermal and biomass resources for the PSP are summarized in Tables 2.6 and 2.7.

Table 2. 6 Geothermal and Biomass Resources

Resource name	Zone	Variable_cost_per_MWh	RPS eligible	Can build	Provide power potential
BANC_Biomass_for_Other	BANC	1.68	FALSE	FALSE	1
BANC_Geothermal_for_Other	BANC	1.18	FALSE	FALSE	1
CAISO_Biomass_for_CAISO	CAISO	1.68	TRUE	FALSE	0.58
CAISO_Biomass_for_Other	CAISO	1.68	FALSE	FALSE	1
CAISO_Geothermal_for_CAISO	CAISO	1.18	TRUE	FALSE	0.62
CAISO_Geothermal_for_Other	CAISO	1.18	FALSE	FALSE	1
Greater_Imperial_Geothermal	CAISO	1.18	TRUE	TRUE	0.88
IID_Biomass_for_Other	IID	1.68	FALSE	FALSE	1
IID_Geothermal_for_CAISO	IID	1.18	TRUE	FALSE	0.62
IID_Geothermal_for_Other	IID	1.18	FALSE	FALSE	1
Instate_Biomass	CAISO	1.68	TRUE	TRUE	0.85
Inyokern_North_Kramer_Geothermal	CAISO	1.18	TRUE	TRUE	0.8
LDWP_Biomass_for_Other	LDWP	1.68	FALSE	FALSE	1
LDWP_Geothermal_for_Other	LDWP	1.18	FALSE	FALSE	1
Northern_California_Geothermal	CAISO	1.18	TRUE	TRUE	0.81
NW_Biomass_for_CAISO	NW	1.68	TRUE	FALSE	0.58
NW_Biomass_for_Other	NW	1.68	FALSE	FALSE	1
NW_Geothermal_for_CAISO	NW	1.18	TRUE	FALSE	0.62
NW_Geothermal_for_Other	NW	1.18	FALSE	FALSE	1
Pacific_Northwest_Geothermal	CAISO	1.18	TRUE	TRUE	0.84
Riverside_Palm_Springs_Geothermal	CAISO	1.18	TRUE	TRUE	0.8
Solano_Geothermal	CAISO	1.18	TRUE	TRUE	0.9
Southern_Nevada_Geothermal	CAISO	1.18	TRUE	TRUE	0.84
SW_Biomass_for_Other	SW	1.68	FALSE	FALSE	1
SW_Geothermal_for_Other	SW	1.18	FALSE	FALSE	1

Table 2. 7 Planned Installed Capacities (MW) for Geothermal and Biomass Resources

Resource name	2030	2035	2040	2045
BANC_Biomass_for_Other	17.5	17.5	17.5	17.5
BANC_Geothermal_for_Other	31	31	31	31
CAISO_Biomass_for_Other	11.7	11.7	11.7	11.7
CAISO_Geothermal_for_Other	8.7	8.7	8.7	8.7
IID_Biomass_for_Other	77	77	77	77
IID_Geothermal_for_Other	401	401	401	401
Instate biomass	0	0	0	0

LDWP_Biomass_for_Other	0	0	0	0
LDWP_Geothermal_for_Other	0	0	0	0
NW_Biomass_for_Other	544	544	544	544
NW_Geothermal_for_Other	154	154	154	154
SW_Biomass_for_Other	107.5	107.5	107.5	107.5
SW_Geothermal_for_Other	778	778	778	778
CAISO_Biomass_for_CAISO	796	796	796	796
CAISO_Geothermal_for_CAISO	1578.8	1578.8	1578.8	1578.8
IID_Geothermal_for_CAISO	83	83	83	83
NW_Biomass_for_CAISO	46	46	46	46
NW_Geothermal_for_CAISO	0	0	0	0
Greater_Imperial_Geothermal	102.3	102.3	102.3	102.3

2.5 Fossil-fuel and Nuclear Resources

Similarly, the fossil-fuel and nuclear resources for the PSP are summarized in Tables 2.8 and 2.9.

Table 2. 8 Fossil-fuel and Nuclear Resources

Resource name	Zone	Variable_cost_per_MWh	GHG emissions /MMBTU	Fuel use slope MMBTU/MWh	Fuel use intercept MMBTU/h	Can Build
BANC_CCGT	BANC	0.26	0.053	6.68	134.13	FALSE
BANC_Peaker	BANC	1.73	0.053	7.54	92.96	FALSE
CAISO_Advanced_CCGT	CAISO	0.28	0.053	6	500	TRUE
CAISO_Aero_CT	CAISO	0.28	0.053	6.12	345.46	TRUE
CAISO_CCGT1	CAISO	0.28	0.053	6.54	272.2	FALSE
CAISO_CCGT2	CAISO	0.45	0.053	7.84	112.07	FALSE
CAISO_CHP	CAISO	1.61	0.053	7.61	0	FALSE
CAISO_Coal	CAISO	2.69	0.094	9.16	840.48	FALSE
CAISO_Nuclear	CAISO	1.95	0	11.36	695.45	FALSE
CAISO_Peaker1	CAISO	1.45	0.053	8.09	74.57	FALSE
CAISO_Peaker2	CAISO	1.53	0.053	9.48	110.97	FALSE
CAISO_Reciprocating_Engine	CAISO	1.12	0.053	8.59	1.21	TRUE
IID_CCGT	IID	0.26	0.053	6.77	142.33	FALSE
IID_Peaker	IID	1.22	0.053	8.91	88.47	FALSE
LDWP_CCGT	LDWP	0.30	0.053	6.51	202.85	FALSE
LDWP_Coal	LDWP	2.69	0.094	9.16	840.48	FALSE
LDWP_Nuclear	LDWP	1.95	0	10.54	0	FALSE
LDWP_Peaker	LDWP	1.06	0.053	7.05	127.34	FALSE
LDWP_ST	LDWP	0.33	0.053	9.31	84.37	FALSE
NW_CCGT	NW	0.27	0.053	6.57	233.32	FALSE
NW_Coal	NW	2.69	0.094	10.2	182.29	FALSE
NW_Nuclear	NW	1.95	0	10.91	0	FALSE
NW_Peaker	NW	1.52	0.053	8.71	51.42	FALSE
SW_CCGT	SW	0.28	0.053	6.68	257.63	FALSE
SW_Coal	SW	2.69	0.094	9.81	207.23	FALSE
SW_Nuclear	SW	1.95	0	10.54	0	FALSE
SW_Peaker	SW	1.63	0.053	8.34	100.76	FALSE
SW_ST	SW	0.33	0.053	9.99	133.78	FALSE

Table 2. 9 Planned Installed Capacities (MW) for Fossil-fuel and Nuclear Resources

Resource name	2030	2035	2040	2045
BANC_CCGT	1797.5	1797.5	1797.5	1797.5
BANC_Peaker	867	867	867	867
CAISO_CCGT1	13449	13449	13449	13449
CAISO_CCGT2	2921	2921	2921	2921
CAISO_CHP	1892	946	0	0
CAISO_Coal	0	0	0	0
CAISO_Nuclear	635	635	635	635
CAISO_Peaker1	4941	4941	4941	4941
CAISO_Peaker2	1309	1309	1309	1309
CAISO_Reciprocating_Engine	255.3	255.3	255.3	255.3
IID_CCGT	255.3	255.3	255.3	255.3
IID_Peaker	327	327	327	327
LDWP_CCGT	2754.7	2754.7	2754.7	2754.7
LDWP_Coal	0	0	0	0
LDWP_Nuclear	407	407	407	407
LDWP_Peaker	1647	1647	1647	1647
LDWP_ST	197	197	197	197
NW_CCGT	9573.4	9573.4	9573.4	9573.4
NW_Coal	7363.8	7363.8	7363.8	7363.8
NW_Nuclear	1756.6	1756.6	1756.6	1756.6
NW_Peaker	2993	2993	2737.5	2587.5
SW_CCGT	19741.1	19152.6	18498.1	16156.7
SW_Coal	6140.6	6140.6	6140.6	6140.6
SW_Nuclear	2998	2998	2998	2998
SW_Peaker	6301.9	6237.9	5481.9	5481.9
SW_ST	966.5	824.5	824.5	824.5

3. Candidate Resources Costs, Potential, and Profiles

Section 2 described the generators used in the simulations, including both the existing and candidate generators. The minimum or planned installed capacities were tabulated and those included in the Renewable Portfolio Standard were identified. In Section 3, we tabulate the data needed by the model to identify which new generators will be selected, including the costs, the generation profiles, and the maximum capacity that that generator could provide. These data supplement the information provided in Section 2.

3.1 Candidate Solar Generators

Tables 3.1 – 3.3 tabulate descriptions of candidate solar resources offered to the model for new builds. A solar thermal option is included based on NREL Annual Technology Baseline cost numbers with 30-year lifetime. This asset is not selected by the model, but we include it for completeness and in anticipation of it becoming cost-effective in the future.

Table 3. 1 Candidate Solar Resources Zones and Potential

Resource name	Zone	RPS eligible	Fix O&M \$/kW-yr	Potential (MW)
Arizona_Solar	CAISO	1	18.79	77080
Distributed_Solar	CAISO	1	22.08	78294
Greater_Kramer_Solar	CAISO	1	19.4	30410
Greater_LA_Solar	CAISO	1	19.4	3000
Imperial_Solar	CAISO	1	19.4	35868
New Solar Thermal - CSP	CAISO	1	52	50000
Northern_California_Solar	CAISO	1	19.4	79975
Riverside_Solar	CAISO	1	19.4	106392
Southern_NV_Eldorado_Solar	CAISO	1	18.86	148848
Southern_PGAE_Solar	CAISO	1	19.4	91663
Tehachapi_Solar	CAISO	1	19.4	6289

Table 3. 2 Annualized Capital & O&M Costs (\$/kW) for Candidate Solar Resources by Installed Year

Resource name	2030	2035	2040	2045
Arizona_Solar	62.55	60.30	58.05	55.80
Distributed_Solar	92.02	87.75	83.48	79.22
Greater_Kramer_Solar	64.22	61.90	59.57	57.25
Greater_LA_Solar	64.22	61.90	59.57	57.25
Imperial_Solar	64.22	61.90	59.57	57.25
New Solar Thermal - CSP	320	290	273	265
Northern_California_Solar	64.22	61.90	59.57	57.25
Riverside_Solar	64.22	61.90	59.57	57.25
Southern_NV_Eldorado_Solar	52.9	51.08	49.25	47.43
Southern_PGAE_Solar	64.22	61.90	59.57	57.25
Tehachapi_Solar	64.22	61.90	59.57	57.25

Table 3.3 Annual O&M Costs (\$/kW-yr) for Candidate Solar Resources by Installed Year

Resource name	2030	2035	2040	2045
Arizona_Solar	9.81	9.37	8.94	8.51
Distributed_Solar	9.12	8.6	8.06	7.53
Greater_Kramer_Solar	10.13	9.68	9.23	8.79
Greater_LA_Solar	10.13	9.68	9.23	8.79
Imperial_Solar	10.13	9.68	9.23	8.79
New Solar Thermal - CSP	52	52	52	52
Northern_California_Solar	10.13	9.68	9.23	8.79
Riverside_Solar	10.13	9.68	9.23	8.79
Southern_NV_Eldorado_Solar	9.84	9.41	8.97	8.54
Southern_PGAE_Solar	10.13	9.68	9.23	8.79
Tehachapi_Solar	10.13	9.68	9.23	8.79

As part of our sensitivity study, we will explore the change in the use of long-duration energy storage for resources with generation profiles that provide more electricity in winter. When changing the generation profile for a different mounting configuration, the investment costs should also be changed to reflect the difference in cost. The cost differential for mounting solar in tilted configurations is difficult to nail down because the difference in cost between the mounting configurations is comparable to the differences in cost from project to project for other reasons. Also, new innovations enable costs to be reduced, so the cost differential is anticipated to vary in the coming years. Thus, we plan to vary our assumptions. As a starting point (baseline assumption), after Jones, et al³ we use the relative costs shown in Table 3.4. The application of these costs is documented in Tables 3.5 and 3.6 for each individual resource.

Table 3.4 Relative Costs for Tilted Solar

Mounting configuration	Relative annualized cost (capex + O&M)	Scenario tag
One-axis-tracked, no tilt	1	1axis_notilt
One-axis-tracked, latitude tilt	1.05	1axis_tilt
Fixed, latitude tilt	0.93	fixed_tilt

Table 3.5 Annualized Capital & O&M Costs (\$/kW) for “1axis_tilt” Candidate Solar Resources

Resource name	2030	2035	2040	2045
Arizona_Solar	65.68	63.32	60.95	58.59
Distributed_Solar	96.62	92.14	87.65	83.18
Greater_Kramer_Solar	67.43	65.00	62.55	60.11
Greater_LA_Solar	67.43	65.00	62.55	60.11
Imperial_Solar	67.43	65.00	62.55	60.11
Northern_California_Solar	67.43	65.00	62.55	60.11
Riverside_Solar	67.43	65.00	62.55	60.11
Southern_NV_Eldorado_Solar	55.55	53.63	51.71	49.80
Southern_PGAE_Solar	67.43	65.00	62.55	60.11
Tehachapi_Solar	67.43	65.00	62.55	60.11

³ Russell K. Jones and Sarah Kurtz, “Optimizing the Configuration of Photovoltaic Plants to Minimize the Need for Storage” IEEE Journal of Photovoltaics, 2022.

Table 3. 6 Annualized Capital & O&M Costs (\$/kW) for “fixed_tilt” Candidate Solar Resources

Resource name	2030	2035	2040	2045
Arizona_Solar	58.17	56.08	53.99	51.89
Distributed_Solar	85.58	81.61	77.64	73.67
Greater_Kramer_Solar	59.72	57.57	55.40	53.24
Greater_LA_Solar	59.72	57.57	55.40	53.24
Imperial_Solar	59.72	57.57	55.40	53.24
Northern_California_Solar	59.72	57.57	55.40	53.24
Riverside_Solar	59.72	57.57	55.40	53.24
Southern_NV_Eldorado_Solar	59.72	57.57	55.40	53.24
Southern_PGAE_Solar	49.20	47.50	45.80	44.11
Tehachapi_Solar	59.72	57.57	55.40	53.24

Profiles have been calculated for each of the three mounting configurations for each candidate resource. The new profiles are named using the Scenario tag from Table 3.4. An example is shown for the tag “1axis_notilt” in Table 3.7.

Table 3. 7 Solar Profile File Names

component	instance	filename
Resource	Arizona_Solar	Arizona_1axis_notilt_Solar
Resource	Greater_Kramer_Solar	Greater_Kramer_1axis_notilt_solar
Resource	Greater_LA_Solar	Greater_LA_1axis_notilt_solar
Resource	Imperial_Solar	Greater_Imperial_1axis_notilt_solar
Resource	Northern_California_Solar	Northern_California_1axis_notilt_solar
Resource	Riverside_Solar	Riverside_1axis_notilt_solar
Resource	Southern_NV_Eldorado_Solar	Southern_NV_Eldorado_1axis_notilt_Solar
Resource	Southern_PGAE_Solar	Central_Valley_North_Los_Banos_1axis_notilt_solar
Resource	Tehachapi_Solar	Tehachapi_1axis_notilt_solar

The profiles are calculated using historical weather data from the National Solar Radiation Database (NSRDB). The NSRDB provides a grid of data; the nearest grid point is selected for each location. Data were compiled for the years 2007-2009, aligning with the load data that E3 has assembled for RESOLVE. Example inputs for the automated profile calculations are shown in Table 3.8 for one latitude-longitude combination. The values for the latitude and longitude are taken from Table 3.9. Multiple profiles are calculated for each resource, with the final profile representing the average of the individual profiles calculated using the latitude and longitude combinations listed in Table 3.8. The 30-min interval data were calculated, but to be consistent with the hourly datasets for RESOLVE, only the data points “on” the hour were recorded. Our understanding is that all data reflect the data as a snapshot of the top of the hour.

Table 3. 8 Inputs for Calculation of Solar Profiles

Description	Parameter	Value
System-level efficiency losses	Losses	14.0757 %
Ratio of solar panel ratings to inverter rating (inverter loading ratio)	Dc_ac_ratio	1.3
Inverter efficiency	Inv_eff	96%

System capacity (final output scaled to this value)	System_capacity	1 kW
Ground coverage ratio	Gcr	0.4
Tilt	Tilt	0°
Azimuth	Azimuth	180°
Latitude	Lat	37.77°
Longitude	lon	-121.06°
Year	year	2007
Interval for calculation's step size	Interval	30 min
Model to use for calculation	model	Pvwatts7
Type of module 0, 1, 2 for standard, premium, thin film	Module_type	0
Constant loss adjustment	Adjust:constant	0
Mounting configuration: 0 For fixed tilt, 2 for 1-axis and 4 for 2-axis	Array_type	2
Elevation	Elev	19.72 m
Time zone	tz	-8.0

Table 3. 9 Details for Solar Profile Calculations (2007-2009)

Resource name	project name	latitude	longitude	DC-AC ratio
GREATER KRAMER	BV_CA_555	35.0750974	-118.17628	1.3
	BV_CA_556	35.0750974	-118.17628	1.3
	BV_CA_574	34.5382277	-115.9394	1.3
	BV_CA_580	34.6169883	-117.13046	1.3
	BV_CA_578	34.3739902	-116.53412	1.3
	BV_CA_552	36.192008	-116.33578	1.3
	BV_CA_572	34.5382277	-115.9394	1.3
	BV_CA_571	34.7982356	-116.50992	1.3
	BV_CA_99	34.9144	-116.6883	1.3
	BV_CA_98	34.8688	-116.654	1.3
	BV_CA_100	34.9622	-116.751	1.3
	BV_CA_125	34.2247	-116.5173	1.3
	BV_CA_102	34.9166	-116.9521	1.3
	BV_CA_104	34.7021	-116.8525	1.3
	BV_CA_103	34.8217	-116.9277	1.3
	BV_CA_111	34.6561	-117.0543	1.3
	BV_CA_112	34.6811	-117.2531	1.3
	BV_CA_107	34.7182	-116.9251	1.3
	BV_CA_106	34.818	-117.1139	1.3
	BV_CA_108	34.7075	-116.9766	1.3
BV_CA_109	34.7699	-117.1702	1.3	
BV_CA_101	34.928	-116.8736	1.3	
BV_CA_110	34.66	-117.1195	1.3	
BV_CA_105	34.7867	-116.983	1.3	
TEHACHAPI	BV_CA_557	35.0763763	-118.1883	1.3
	BV_CA_561	34.6357016	-118.35784	1.3
	BV_CA_593	34.2984325	-118.79783	1.3
	BV_CA_94	35.4469	-118.1011	1.3
	BV_CA_97	35.1121	-118.4128	1.3
	BV_CA_95	35.3184	-118.2456	1.3
	BV_CA_123	34.8835	-118.5819	1.3
	BV_CA_117	34.9665	-118.2495	1.3
	BV_CA_118	34.8554	-118.3955	1.3
	BV_CA_122	34.331	-118.7316	1.3
BV_CA_96	35.425	-118.181	1.3	
RIVERSIDE	BV_CA_550	33.1310392	-115.24512	1.3
	BV_CA_566	33.7774	-116.17455	1.3
	BV_CA_567	33.6839279	-114.95678	1.3
	BV_CA_127	33.8701	-116.36	1.3
	BV_CA_132	33.6847	-115.9891	1.3

	BV_CA_155	33.4188	-114.9881	1.3
	BV_CA_131	33.3949	-115.2227	1.3
	BV_CA_130	33.3511	-114.951	1.3
	BV_CA_129	33.5173	-115.0704	1.3
GREATER_LA	BV_CA_555	35.0750974	-118.17628	1.3
	BV_CA_556	35.0750974	-118.17628	1.3
	BV_CA_574	34.5382277	-115.9394	1.3
	BV_CA_580	34.6169883	-117.13046	1.3
	BV_CA_578	34.3739902	-116.53412	1.3
	BV_CA_557	35.0763763	-118.1883	1.3
	BV_CA_572	34.5382277	-115.9394	1.3
	BV_CA_561	34.6357016	-118.35784	1.3
	BV_CA_571	34.7982356	-116.50992	1.3
	BV_CA_579	34.5929461	-115.43368	1.3
	BV_CA_577	34.5382277	-115.9394	1.3
	BV_CA_575	34.5382277	-115.9394	1.3
	BV_CA_576	34.5382277	-115.9394	1.3
	BV_CA_573	34.5382277	-115.9394	1.3
	BV_CA_554	35.0750974	-118.17628	1.3
	BV_CA_558	35.0750974	-118.17628	1.3
	BV_CA_99	34.9144	-116.6883	1.3
	BV_CA_98	34.8688	-116.654	1.3
	BV_CA_100	34.9622	-116.751	1.3
	BV_CA_125	34.2247	-116.5173	1.3
	BV_CA_94	35.4469	-118.1011	1.3
	BV_CA_97	35.1121	-118.4128	1.3
	BV_CA_95	35.3184	-118.2456	1.3
	BV_CA_123	34.8835	-118.5819	1.3
	BV_CA_117	34.9665	-118.2495	1.3
	BV_CA_118	34.8554	-118.3955	1.3
	BV_CA_96	35.425	-118.181	1.3
	BV_CA_128	34.0026	-115.7412	1.3
	BV_CA_126	34.2226	-116.2	1.3
	BV_CA_102	34.9166	-116.9521	1.3
	BV_CA_104	34.7021	-116.8525	1.3
	BV_CA_103	34.8217	-116.9277	1.3
	BV_CA_111	34.6561	-117.0543	1.3
	BV_CA_112	34.6811	-117.2531	1.3
	BV_CA_107	34.7182	-116.9251	1.3
	BV_CA_106	34.818	-117.1139	1.3
	BV_CA_108	34.7075	-116.9766	1.3
	BV_CA_109	34.7699	-117.1702	1.3
	BV_CA_101	34.928	-116.8736	1.3
	BV_CA_110	34.66	-117.1195	1.3
	BV_CA_105	34.7867	-116.983	1.3
ARIZONA_SOLAR	AZ_NE_0	34.36512	-109.5833	1.3
	AZ_NE_1	34.69122	-110.84166	1.3
	AZ_NE_3	34.55458	-110.39669	1.3
	AZ_NE_4	34.5979	-109.93407	1.3
	AZ_NE_7	34.19884	-109.44836	1.3
	AZ_WE_0	33.77904	-113.8158	1.3
	AZ_WE_1	33.33516	-112.85795	1.3
	AZ_WE_2	32.91217	-113.48219	1.3
	AZ_WE_5	34.04666	-113.53874	1.3
	AZ_WE_6	32.9033	-113.07185	1.3
	AZ_WE_7	33.82832	-113.56733	1.3
	AZ_WE_10	33.67385	-114.2039	1.3
	AZ_WE_16	34.28072	-113.23688	1.3
	AZ_NE_7_1	36.1463	-111.79218	1.3
	AZ_NE_1_7	36.07757	-111.68674	1.3
	AZ_WE_18_13	34.29111	-113.48639	1.3
	AZ_WE_1_14	33.83229	-112.39537	1.3

SOUTHERN_NV_ELDORADO_SOLAR	NV_EA_0	37.89252	-115.79568	1.3
	NV_EA_1	37.57186	-115.57279	1.3
	NV_EA_5	38.4761	-115.06788	1.3
	NV_EA_6	37.9747	-114.71439	1.3
	NV_EA_15	38.40434	-116.23463	1.3
	NV_SW_0	36.02663	-115.89843	1.3
	NV_SW_1	36.29179	-116.36163	1.3
	NV_SW_2	36.48092	-115.5157	1.3
	NV_SW_8	36.80007	-116.61182	1.3
	NV_WE_0	38.21113	-116.62717	1.3
	NV_WE_1	37.45742	-117.37971	1.3
	NV_WE_2	38.40853	-117.71148	1.3
	NV_WE_16	36.93483	-116.80631	1.3
	NV_EA_15_1	38.78984	-115.90975	1.3
	NV_SW_0_1	36.18058	-116.43691	1.3
	NV_WE_7_1	37.87572	-118.03068	1.3
	NV_WE_9_1	38.29281	-118.86042	1.3
	NV_WE_19_1	37.57699	-118.02983	1.3
	NV_WE_20_3	38.29367	-118.88289	1.3
SOUTHERN_PGAE_SOLAR	BV_CA_591	37.762	-120.8463	1.3
	BV_CA_563	37.0829	-121.0431	1.3
	BV_CA_85	37.0829	-121.0431	1.3
IMPERIAL_SOLAR	BV_CA_551	32.8252021	-115.80262	1.3
	BV_CA_568	33.7805561	-115.09199	1.3
	BV_CA_582	32.7483769	-116.35095	1.3
	BV_CA_547	32.858521	-114.93628	1.3
	BV_CA_548	32.9965332	-115.25449	1.3
	BV_CA_549	32.9965332	-115.25449	1.3
	BV_CA_581	33.2383	-116.63513	1.3
	BV_CA_156	32.887	-114.7154	1.3
	BV_CA_137	32.9002	-114.6466	1.3
	BV_CA_135	33.0957	-116.626	1.3
	BV_CA_134	33.224	-116.6312	1.3
	BV_CA_133	33.3952	-116.6482	1.3
	BV_CA_154	32.69	-116.2915	1.3
	BV_CA_138	32.6292	-116.2762	1.3
	BV_CA_153	32.6548	-116.1292	1.3
	BV_CA_139	32.6589	-116.4214	1.3
NORTHERN_CALIFORNIA_SOLAR	BV_CA_560	40.9069143	-120.51681	1.3
	BV_CA_564	41.6217	-120.32535	1.3
	BV_CA_614	38.934675	-122.5517	1.3
	BV_CA_588	40.8586	-121.85165	1.3
	BV_CA_612	39.6314571	-122.11339	1.3
	BV_CA_589	41.465026	-121.95546	1.3
	BV_CA_632	39.9704714	-122.26589	1.3
	BV_CA_609	39.09435	-122.05005	1.3
	BV_CA_607	39.5546857	-121.84367	1.3
	BV_CA_619	38.2894	-122.1696	1.3
	BV_CA_635	38.8315625	-121.94088	1.3
	BV_CA_631	38.952575	-121.67655	1.3
	BV_CA_2000	39.31228	-122.05336	1.3
	BV_CA_5	41.1083	-120.5721	1.3
	BV_CA_15	40.7684	-120.6185	1.3
	BV_CA_14	40.7568	-120.4895	1.3
	BV_CA_145	40.6811	-120.1686	1.3
	BV_CA_9	41.0201	-120.3143	1.3
	BV_CA_11	40.8605	-120.0698	1.3
	BV_CA_144	41.0399	-120.6064	1.3
	BV_CA_10	40.9916	-120.17	1.3
	BV_CA_7	40.9333	-120.5139	1.3
	BV_CA_6	40.9755	-120.693	1.3
	BV_CA_16	40.6531	-120.5766	1.3

	BV_CA_8	40.9909	-120.3906	1.3
	BV_CA_31	41.1304	-121.2569	1.3
	BV_CA_13	40.7869	-120.7952	1.3
	BV_CA_1	41.9746	-120.0587	1.3
	BV_CA_4	41.2688	-120.592	1.3
	BV_CA_33	40.7998	-121.8433	1.3
	BV_CA_32	40.9174	-121.86	1.3
	BV_CA_45	38.8639	-122.4339	1.3
	BV_CA_25	39.8512	-122.1237	1.3
	BV_CA_29	39.9455	-122.2056	1.3
	BV_CA_30	40.0239	-122.2065	1.3
	BV_CA_51	38.9123	-122.0859	1.3
	BV_CA_48	38.8005	-122.0665	1.3
	BV_CA_49	38.7768	-121.9794	1.3
	BV_CA_47	38.9154	-122.1697	1.3
	BV_CA_50	38.8002	-121.9117	1.3
	BV_CA_58	38.7915	-121.7061	1.3
	BV_CA_52	38.8864	-121.9889	1.3
	BV_CA_27	39.8621	-122.263	1.3
	BV_CA_26	39.8012	-122.262	1.3
	BV_CA_17	40.059	-122.3217	1.3
	BV_CA_53	38.9975	-122.1102	1.3
	BV_CA_57	38.8876	-121.8689	1.3
	BV_CA_23	39.6872	-122.0282	1.3
	BV_CA_35	39.8518	-121.9943	1.3
	BV_CA_28	39.9016	-122.3344	1.3
	BV_CA_46	39.0183	-121.8199	1.3
	BV_CA_38	39.5746	-121.8577	1.3
	BV_CA_59	38.8171	-121.5875	1.3
	BV_CA_36	39.662	-121.9307	1.3
	BV_CA_148	38.7941	-121.8358	1.3
	BV_CA_56	38.9418	-121.7582	1.3
	BV_CA_39	39.5325	-121.7762	1.3
	BV_CA_41	39.3671	-121.7617	1.3
	BV_CA_147	39.6109	-122.1614	1.3
	BV_CA_22	39.6016	-122.0849	1.3
	BV_CA_54	39.0117	-121.9685	1.3
	BV_CA_37	39.4927	-121.9353	1.3
	BV_CA_44	38.9925	-122.3977	1.3
	BV_CA_40	39.4465	-121.8286	1.3
	BV_CA_24	39.7023	-122.2531	1.3
	BV_CA_60	38.8649	-121.5033	1.3
	BV_CA_18	40.15	-122.4063	1.3
	BV_CA_146	39.4483	-121.7565	1.3
	BV_CA_20	39.3792	-122.0519	1.3
	BV_CA_75	38.8759	-122.7583	1.3
	BV_CA_42	39.1865	-121.8572	1.3
	BV_CA_43	39.1665	-122.4679	1.3
	BV_CA_55	38.9808	-121.9127	1.3
	BV_CA_21	39.5243	-122.0688	1.3
	BV_CA_74	39.0064	-122.6169	1.3
	BV_CA_19	39.2885	-121.9834	1.3

Examples of the profiles for the three mounting configurations are compared in Figs. 3.1 - 3.3. The 1-axis, no tilt data show the highest output during the summer, which is the highest priority for today's grid. As winter becomes a greater problem for high penetration renewable electricity, the solar arrays facing south with a latitude tilt may reduce the need for seasonal storage. The tracked solar arrays provide more consistent output during the day, reducing the need for diurnal storage compared with the fixed-tilt configuration.

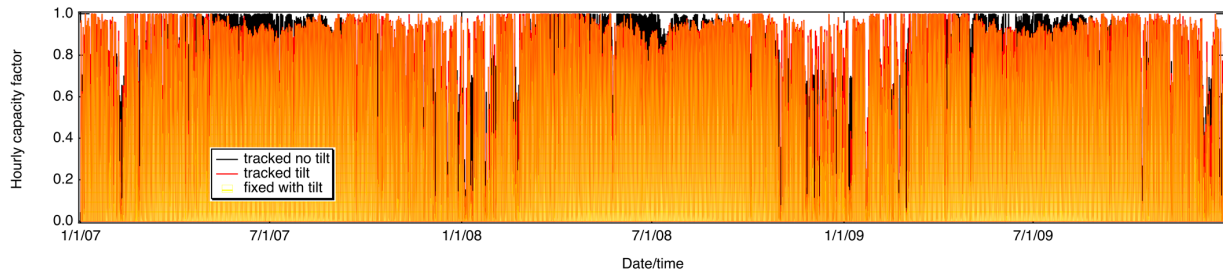


Fig. 3. 1 Profiles for Tehachapi Solar for Three Mounting Configurations over 3 years

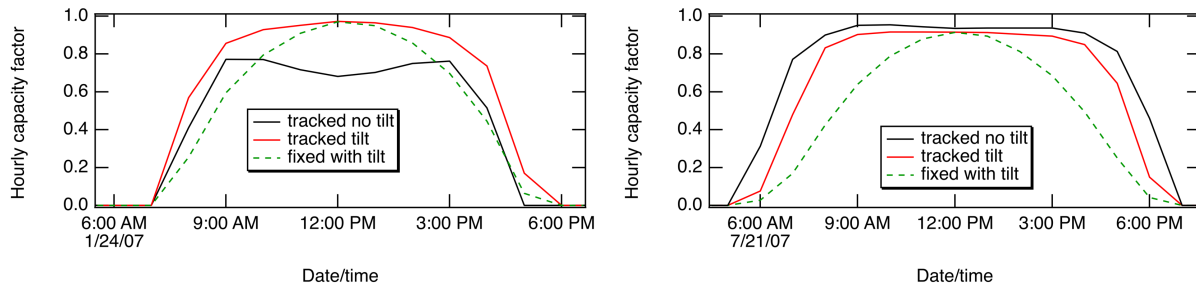


Fig. 3. 2 Profiles for Tehachapi Solar for Three Mounting Configurations on 2 Days

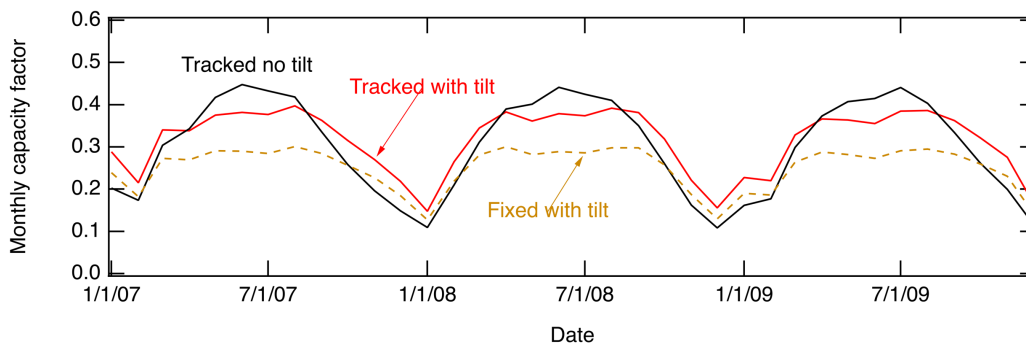


Fig. 3. 3 Monthly capacity factors for solar profiles

3.2 Candidate Wind Generators

Wind resources included as candidate resources are tabulated in Tables 3.10 - 3.12. The resources in blue are offshore wind resources that don't appear in the E3 documentation, but that we will add, especially as the state is discussing plans for 20 GW of offshore wind. Two new winter-dominant wind resources are also identified.

Table 3. 10 Candidate Wind Resources with O&M Costs for Planned Capacity

Resource name	Zone	Offshore	RPS eligible	Fixed O&M \$/kW-yr
Baja_California_Wind	CAISO	-	1	44.26
Cape_Mendocino_Offshore_Wind	CAISO	X	1	128.55
Carrizo_Wind	CAISO	-	1	45.73
Central_Valley_North_Los_Banos_Wind	CAISO	-	1	45.73
Del_Norte_Offshore_Wind	CAISO	X	1	129.74
Diablo_Canyon_Offshore_Wind	CAISO	X	1	127.52
Humboldt_Bay_Offshore_Wind	CAISO	X	1	124.44
Humboldt_Wind	CAISO	-	1	45.73

Kern_Greater_Carrizo_Wind	CAISO	-	1	45.73
Morro_Bay_Offshore_Wind	CAISO	X	1	129.74
New onshore sites	CAISO	-	1	45.73
New_Mexico_Wind	CAISO	-	1	44.39
Northern_California_Wind	CAISO	-	1	45.73
NW_Ext_Tx_Wind	CAISO	-	1	45.79
Solano_Wind	CAISO	-	1	45.73
Southern_Nevada_Wind	CAISO	-	1	44.84
SW_Ext_Tx_Wind	CAISO	-	1	44.39
Tehachapi_Wind	CAISO	-	1	45.73
Utah_Wind	CAISO	-	1	44.54
Wyoming_Wind	CAISO	-	1	44.76

Table 3. 11 Capacity Limits (MW) for Candidate Wind Resources

Resource name	2030	2035	2040	2045
Baja_California_Wind	600	600	600	600
Cape_Mendocino_Offshore_Wind	0	0	0	0
Carrizo_Wind	287	287	287	287
Central_Valley_North_Los_Banos_Wind	173	173	173	173
Del_Norte_Offshore_Wind	0	0	0	0
Diablo_Canyon_Offshore_Wind	0	0	0	0
Humboldt_Bay_Offshore_Wind	1607	1607	1607	1607
Humboldt_Wind	34	34	34	34
Kern_Greater_Carrizo_Wind	60	60	60	60
Morro_Bay_Offshore_Wind	3220	3100	3100	3100
New Winter Dominant California site North (41.38, -122.20)	5000	5000	5000	5000
New Winter Dominant California site South (36.5, -118.51)	5000	5000	5000	5000
New_Mexico_Wind	1500	34580	34580	34580
Northern_California_Wind	866	866	866	866
NW_Ext_Tx_Wind	1500	1500	1500	1500
Solano_Wind	560	560	560	560
Southern_Nevada_Wind	442	442	442	442
SW_Ext_Tx_Wind	500	500	500	500
Tehachapi_Wind	275	275	275	275
Wyoming_Wind	1500	33862	33862	33862

Table 3. 12 Annualized Capital + O&M Costs (\$/kW-y) for Candidate Wind Resources by Installed Year

Resource name	2030	2035	2040	2045
Baja_California_Wind	147.2	140.2	133.1	125.8
Cape_Mendocino_Offshore_Wind	185.7	169.2	228.6	215.5
Carrizo_Wind	164.65	156.14	147.41	138.45
Central_Valley_North_Los_Banos_Wind	163.72	155.21	146.47	137.52
Del_Norte_Offshore_Wind	191.87	175.00	234.70	221.28
Diablo_Canyon_Offshore_Wind	194.85	177.86	237.91	224.40
Humboldt_Bay_Offshore_Wind	188.88	172.47	232.21	219.06
Humboldt_Wind	148.46	141.34	134.07	126.67
Kern_Greater_Carrizo_Wind	165.25	156.74	148.01	139.05
Morro_Bay_Offshore_Wind	193.20	176.23	237.20	223.57

New onshore candidates	123.42	116.46	109.27	101.86
New_Mexico_Wind	227.15	222.02	216.83	211.59
Northern_California_Wind	167.13	158.67	159.99	141.10
NW_Ext_Tx_Wind	212.00	203.48	194.73	185.77
Solano_Wind	163.33	154.98	146.41	137.63
Southern_Nevada_Wind	166.83	158.49	149.93	141.15
SW_Ext_Tx_Wind	229.20	222.28	215.23	208.04
Tehachapi_Wind	145.01	137.77	130.37	122.82
Wyoming_Wind	240.33	235.03	229.69	224.30

The winter-summer difference for wind generators is calculated from the capacity factors (CF) according to

$$\text{Winter-summer difference} = (\text{winter CF} - \text{summer CF}) / (\text{annual CF}).$$

In some cases, the difference is more than 100% as in the case of the Carrizo Wind which shows a difference in capacity factor of 43% which is greater than the annual capacity factor of 31%. The methodology for calculating this metric has been published.⁴ This metric has been used to characterize the RESOLVE wind resources in Table 3.13 using the weighted 37 days and using the full year of data for 2007, 2008, and 2009. The weighted 37 days were selected to match the expected annual capacity factor and histogram of wind resource, not the seasonal distribution, so it is not surprising that the full-year analysis differs significantly from the weighted-37-days analysis.

Two new sites were selected based on existing locations of wind turbines exhibiting more generation in winter than in summer. The potential wind resource at these sites has not been evaluated. The potential wind resource is set to 5 GW for both the southern and northern areas, which represents about half of the potential identified previously without economic considerations.⁵ This large number has been adopted so that the impact of using such resources can be evaluated. If we find the use of winter-dominant onshore California wind to influence the needed storage, we suggest that further evaluation of the true potential for such wind resource would be valuable.

Table 3. 13 Seasonal Capacity Factors for Candidate Wind Resources

Resource name	Weighted 37 days				2007	2008	2009
	Annual	Winter (D-J-F)	Summer (J-J-A)	W-S differ.	W-S difference		
Arizona_Wind	29.90%	24.20%	31.30%	-24%	+16%	+23%	+23%
Baja_California_Wind	36.20%	42.80%	37.20%	+15%	+57%	+44%	+41%
Carrizo_Wind	31.10%	11.30%	54.30%	-138%	+7%	+18%	+10%
Central_Valley_North_Los_Banos_Wind	31.10%	11.30%	54.30%	-138%	-83%	-76%	-94%
Humboldt_Wind	29.20%	21.40%	29.40%	-27%	+48%	+49%	+67%
Idaho_Wind	31.80%	33.40%	29.30%	+13%	+43%	+52%	+46%

⁴ “Geographical variability of summer- and winter-dominant onshore wind” Journal of Renewable and Sustainable Energy 14, 023303 (2022); <https://doi.org/10.1063/5.0070430>.

⁵ Z. Mahmud, K. Shiraishi, M. Abido, D. Millstein, P. Sanchez, and S. Kurtz, “Geographical variability of summer- and winter-dominant onshore wind” Journal of Renewable and Sustainable Energy, Volume 14, 023303, 2022.

Kern_Greater_Carrizo_Wind	31.10%	11.30%	54.30%	-138%	+7%	+18%	+10%
New_Mexico_Wind	44.00%	61.30%	28.10%	+75%	+77%	+76%	+60%
Northern_California_Wind	29.20%	21.40%	29.40%	-27%	+24%	+19%	+21%
NW_Ext_Tx_Wind	30.40%	26.70%	30.70%	-13%	+47%	+48%	+42%
Pacific_Northwest_Wind	32.10%	28.60%	32.50%	-12%	+35%	+37%	+17%
Riverside_Palm_Springs_Wind	33.90%	40.70%	35.00%	+17%	-5%	-22%	-17%
Solano_Wind	30.40%	2.80%	59.10%	-185%	-85%	-83%	-114%
Southern_Nevada_Wind	28.10%	19.10%	32.90%	-49%	+21%	+24%	+21%
SW_Ext_Tx_Wind	36.20%	55.90%	18.50%	+103%	+105%	+98%	+82%
Tehachapi_Wind	34.30%	27.10%	44.00%	-49%	-19%	-14%	-27%
Utah_Wind	30.80%	17.50%	35.00%	-57%	-9%	+13%	-2%
Wyoming_Wind	44.20%	52.00%	22.10%	+68%	+80%	+83%	+98%
Diablo_Canyon_Offshore_Wind					-20%	+18%	+17%
Humboldt_Bay_Offshore_Wind					-22%	-35%	-22%
Morro_Bay_Offshore_Wind					-64%	-49%	-60%
Cape_Mendocino_Offshore_Wind					-35%	-43%	-25%
Del_Norte_Offshore_Wind					-4%	-8%	-2%
New Winter Dominant California site North (41.38, -122.20)					+125%	+104%	+104%
New Winter Dominant California site South (36.5, -118.51)					+110%	+84%	+86%

The monthly capacity factors for the Central Valley North Los Banos Wind and the New Winter Dominant California site in the North are compared in Fig. 3.4

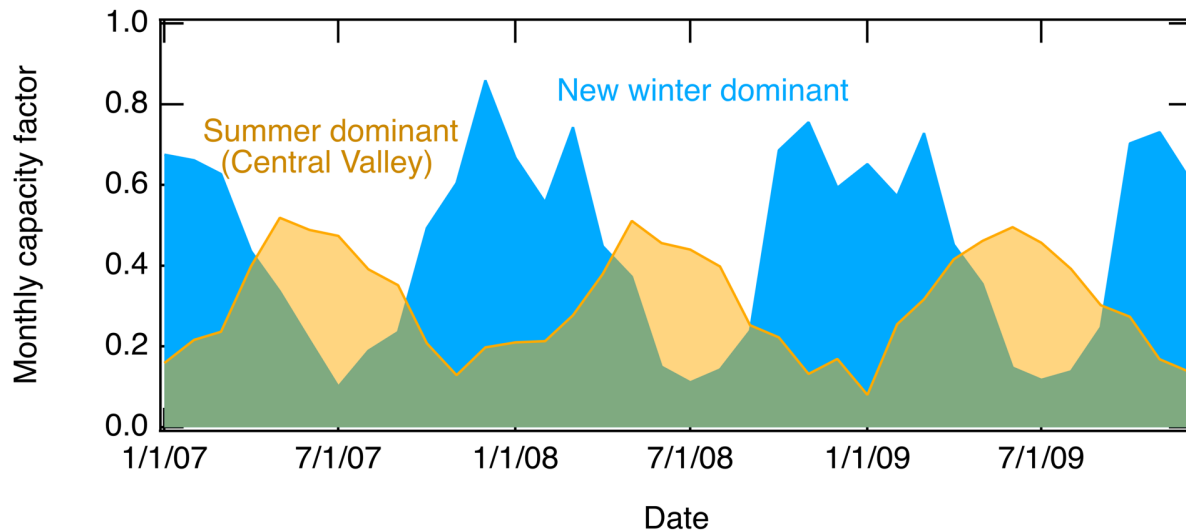


Fig. 3. 4 Monthly capacity factors comparing wind profiles

3.3 Hydropower Generators

No candidate hydropower generators are offered, though we recognize that there are plans to upgrade some of the existing hydropower plants. Some pumped hydro generators are under development, but these will be treated as storage rather than as generators. In this section, we discuss the generation profiles we use for the existing hydropower generators. The profiles used for the existing generators are selected to represent a dry year, as that is a year when storage will be most valuable.

The primary uncertainty with hydropower is the availability of water to drive the turbines. The variability of electricity from hydropower is commonly greater than a factor of two from year to year. An electrical grid will be most challenged to provide the needed storage in a dry year, so we choose to study primarily the dry years. We note that studying only dry years misses a key assessment for a company that is looking for a return on investment over many years, some of which will be wet and some of which will be dry.

The method we developed for tracking energy storage throughout an entire year is incompatible with the method that the new-modeling-toolkit uses for defining the seasonal variations in hydropower usage. Instead of addressing this by modifying the code, we have chosen to use the historical dispatch of hydropower to define the hydropower generation profiles instead of asking the model to optimize the dispatch with the assumption that the generation profiles for hydropower will not be significantly different in future years. This misses the opportunity to use hydropower as a primary tool for reducing needed storage, which would be useful in a location that can be confident of the hydropower resource in every year. Given the ongoing severe drought in California, we feel that exploring the need for storage in the absence of significant hydropower dispatchability is useful.

Hydro profiles were constructed as summarized in Table 3.14. Data were downloaded for 2019, 2020, and 2021 from the EIA and CAISO data bases as indicated in Table 3.45 footnote. The data were normalized to the power indicated in Table 3.14 for each resource to provide the generation profile in a data set that does not exceed unity. For data points that would have exceeded unity, the data were capped at 1.0. The EIA’s data set for LDWP hydropower generation was inconsistent with EIA’s 860 data for the capacity of the generator. The capacity of the generator was set to 1108 MW to better align with the maximum generation reported for the LDWP hydropower generation.

For each balancing area, the wettest year of the three is used for the “wet” scenario and the driest year of the 3 taken for the “dry” scenario, as indicated in Table 3.15. The resource file for each hydropower resource was then modified to identify the profile taken from 2019, 2020, or 2021, depending on the scenario tag (indicating dry, medium, or wet) used for the run.

Table 3. 14 Source of hydropower generation profiles

Profile/Resource	Source of data	Details
BANC Hydro	EIA*	
NW Hydro	EIA*	
SW Hydro	EIA*	
LDWP Hydro	EIA*	
IID Hydro	EIA*	
CAISO Hydro	CAISO**	5-minute data averaged to create hourly data
NW CAISO for Hydro	EIA	Duplicated BANC hydro

* https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48

** <http://www.caiso.com/informed/Pages/ManagingOversupply.aspx>

Table 3. 15 Generation from hydropower used for dry, medium, and wet scenarios.

Resource	Year	Net Generation (GWh)	Scenario
BANC_Hydro	2021	2910	DRY
	2020	4258	MEDIUM
	2019	6492	WET
CAISO_Hydro	2021	9022	DRY
	2020	13294	MEDIUM
	2019	25945	WET
IID_Hydro	2021	228646	WET
	2020	205834	DRY
	2019	213445	MEDIUM
LDWP_Hydro	2021	596	DRY
	2020	651	MEDIUM
	2019	1401	WET
NW_Hydro	2021	122106	DRY
	2020	137393	WET
	2019	126339	MEDIUM
NW_Hydro_for_CAISO	2021	3129	DRY
	2020	4705	MEDIUM
	2019	7725	WET
SW_Hydro	2021	5299290	WET
	2020	5173506	MEDIUM
	2019	4973559	DRY

3.4 Candidate Geothermal and Biomass Generators

Candidate geothermal and biomass generators are summarized in Tables 3.16-3.19. The “New – Biomass using oxycombustion” candidate resource is proposed to use biogas. This biogas could be used in the Allam cycle – an oxycombustion cycle that simplifies the capture of carbon dioxide from the waste stream and avoids emission of NO_x and other criteria pollutants. Any cost evaluation of this approach has high uncertainty because the technology is not yet mature. Here, we have used the same assumptions as are used for the InState Biomass with the exception that we add the sequestration of the captured carbon dioxide, resulting in possible negative emissions (-0.053/MMBTU) associated with operation of these plants. We will compare build out found as a function of the assumed emissions and cost scenarios. The potential scale-up is estimated in Table 3.17 based on the existence of a 50-MW oxycombustion plant (by NetPower) in Texas and plans for multiple 250 MW plants to come online in 4 years. Use of these new plants with biomass will, of course, be also limited by the availability of biomass fuel.

Table 3. 16 Candidate Geothermal and Biomass Resources

Resource name	Zone	Geothermal?	RPS eligible	Variable cost \$/MWh	Available capacity fraction
InState_Biomass	CAISO	-	1	1.55	85%
Greater_Imperial_Geothermal	CAISO	X	1	1.09	88%
Inyokern_North_Kramer_Geothermal	CAISO	X	1	1.09	80%
Northern_California_Geothermal	CAISO	X	1	1.09	81%

Riverside_Palm_Springs_Geothermal	CAISO	X	1	1.09	84.3%
Solano_Geothermal	CAISO	X	1	1.09	90%
Southern_Nevada_Geothermal	CAISO	X	1	1.09	84.3%
New – Biomass using oxycombustion	CAISO	-	1	1.55	85%

Table 3. 17 Capacity Limits (MW) for Candidate Geothermal and Biomass Resources

Resource name	2030	2035	2040	2045
InState_Biomass	1146.9	1146.9	1146.9	1146.9
Greater_Imperial_Geothermal	1352.1	1352.1	1352.1	1352.1
Inyokern_North_Kramer_Geothermal	24	24	24	24
Northern_California_Geothermal	469	469	469	469
Riverside_Palm_Springs_Geothermal	32	32	32	32
Solano_Geothermal	135	135	135	135
Southern_Nevada_Geothermal	320	320	320	320
New – Biomass using oxycombustion	500	1000	2000	4000

Table 3. 18 Annualized Capital Costs (\$/kW-y) for Candidate Geothermal and Biomass Resources by Installed Year

Resource name	2030	2035	2040	2045
InState_Biomass	618.91	610.71	601.65	593.68
Greater_Imperial_Geothermal	366.63	357.83	349.26	340.90
Inyokern_North_Kramer_Geothermal	405.28	396.48	387.91	379.55
Northern_California_Geothermal	379.47	370.67	362.10	353.74
Riverside_Palm_Springs_Geothermal	359.17	350.38	341.80	333.45
Solano_Geothermal	357.19	348.40	339.82	331.47
Southern_Nevada_Geothermal	356.68	348.15	339.83	331.72
New – Biomass using oxycombustion	618.91	610.71	601.65	593.68

Table 3. 19 Annual O&M Costs (\$/kW) for Candidate Geothermal and Biomass Resources by Installed Year

Resource name	2030	2035	2040	2045
InState_Biomass	135.1	135.1	135.1	135.1
Greater_Imperial_Geothermal	135.2	135.2	135.2	135.2
Inyokern_North_Kramer_Geothermal	135.2	135.2	135.2	135.2
Northern_California_Geothermal	135.2	135.2	135.2	135.2
Riverside_Palm_Springs_Geothermal	135.2	135.2	135.2	135.2
Solano_Geothermal	135.2	135.2	135.2	135.2
Southern_Nevada_Geothermal	131.2	131.2	131.2	131.2
New – Biomass using oxycombustion	135.1	135.1	135.1	135.1

3.5 Candidate Fossil Fuel and Other Dispatchable Generators

Candidate fossil fuel and other generators are summarized in Tables 3.20-3.24.

Table 3. 20 Candidate Fossil-fuel Resources

Resource name	Zone	Variable cost \$/MWh	GHG emissions /MMBTU	Fuel use slope MMBTU/MWh	Fuel use intercept MMBTU/MWh	Start Fuel use
CAISO_Advanced_CCGT	CAISO	0.28	0.053	6.00	500.00	2742.4
CAISO_Aero_CT	CAISO	0.28	0.053	6.12	345.46	457.1
CAISO_Reciprocating_Engine	CAISO	1.03	0.053	8.59	1.21	8.3
New Clean Source Optimistic	CAISO	0.25	0	6.00	345	
New Clean Source Conservative	CAISO	1.80	0	11.36	695.45	

Table 3. 21 Candidate Fossil-fuel Resources

Resource name	Unit size (MW)	Min. down time (h)	Min. stable level	Min. up time (h)	Ramp rate (/h)	Start/stop cost
CAISO_Advanced_CCGT	600	1	0.2	2	1	16236.5
CAISO_Aero_CT	100	1	0.3	1	1	541.2
CAISO_Reciprocating_Engine	10.35	1	0.15	2	8.98	80.7
New Clean Source Optimistic		1	0.15	1	1	
New Clean Source Conservative		1	0.3	2	1	

Table 3. 22 Capacity Limits (MW) for Candidate Fossil-fuel Resources

Resource name	2030	2035	2040	2045
CAISO_Advanced_CCGT	99999	99999	99999	99999
CAISO_Aero_CT	99999	99999	99999	99999
CAISO_Reciprocating_Engine	99999	99999	99999	99999
New Clean Source Optimistic	500	1000	2000	4000
New Clean Source Conservative	500	1000	2000	4000

Table 3. 23 Annualized Capital Costs (\$/kW-y) for Candidate Fossil-fuel Resources by Installed Year

Resource name	2030	2035	2040	2045
CAISO_Advanced_CCGT	109.2	107.6	106.1	105.0
CAISO_Aero_CT	128.9	126.7	125.1	123.7
CAISO_Reciprocating_Engine	115.4	113.2	111.6	110.2
New Clean Source Optimistic	94.9	93.2	91.8	90.7
New Clean Source Conservative	618.91	610.71	601.65	593.68

Table 3. 24 Annual O&M Costs (\$/kW) for Candidate Geothermal and Biomass Resources by Installed Year

Resource name	2030	2035	2040	2045
CAISO_Advanced_CCGT	14.3	14.3	14.3	14.3
CAISO_Aero_CT	13.5	13.5	13.5	13.5
CAISO_Reciprocating_Engine	13.5	13.5	13.5	13.5
New Clean Source Optimistic	13.5	13.5	13.5	13.5
New Clean Source Conservative	135.1	135.1	135.1	135.1

The “New Clean Source Optimistic” and “New Clean Source Conservative” are constructed to reflect the least cost of today’s dispatchable generations and the highest cost, respectively, but with zero carbon dioxide emissions. These could represent enhanced geothermal, oxycombustion using the Allam cycle, small-scale nuclear, or another new technology. We assume that these are not ready to be built in 2025, but they could be built at 500 MW scale in 2030 and double in installed capacity every 5 years after that. Each of these will be introduced separately to identify how much each affects the use of storage.