NorthernGrid

Economic Study Request
Pumped Storage Hydro in Oregon

Request

In March of 2023, Rye Development submitted to the NorthernGrid planning region a request for Economic Study Request (ESR) of a pumped storage project. The high-level details are listed below.

1. 500 MW dispatchable pumping capability; 10-hour duration at the proposed 500 kV Wendson substation
2. 500 MW dispatchable generating capability, 10-hour duration at the proposed 500 kV Fairview substation
3. Planned in-service date of December, 2032

From the request: "The projects could be used to integrate offshore wind in the Brookings and Coos Bay Call, provide shaping and firming of Oregon offshore wind to meet regional generation capacity needs, relieve congestion on transmission across the Coast Range and potentially relieve congestion on Cross Cascades transmission paths."

Analysis

The analysis will build upon the 2022 Offshore Wind Economic Study Request.

Study Scope

The analysis for the Rye Development pumped storage project will build upon the analysis used for the 2022 ESR regarding the installation of 3,000 MW of offshore wind.

The 2022 ESR analysis performed modeled the installation of 1.8 GW of offshore wind from the Brookings wind pocket concurrent with 1.2 GW of offshore wind from the Coos Bay wind pocket. The 230 kV system to which these points of interconnection were originally proposed was insufficient to handle a penetration of 3 GW of offshore wind. The solution was to create a "500 kV loop" which would connect to the existing 500 kV system east of the Coast Range through new lines from Fairview and Wendson; this "500 kV loop" allows for the interconnection of the offshore wind units at 500 kV instead of 230 kV. With the "500 kV loop", the offshore wind farms were allowed their maximum output and no new violations in the underlying transmission system were introduced.

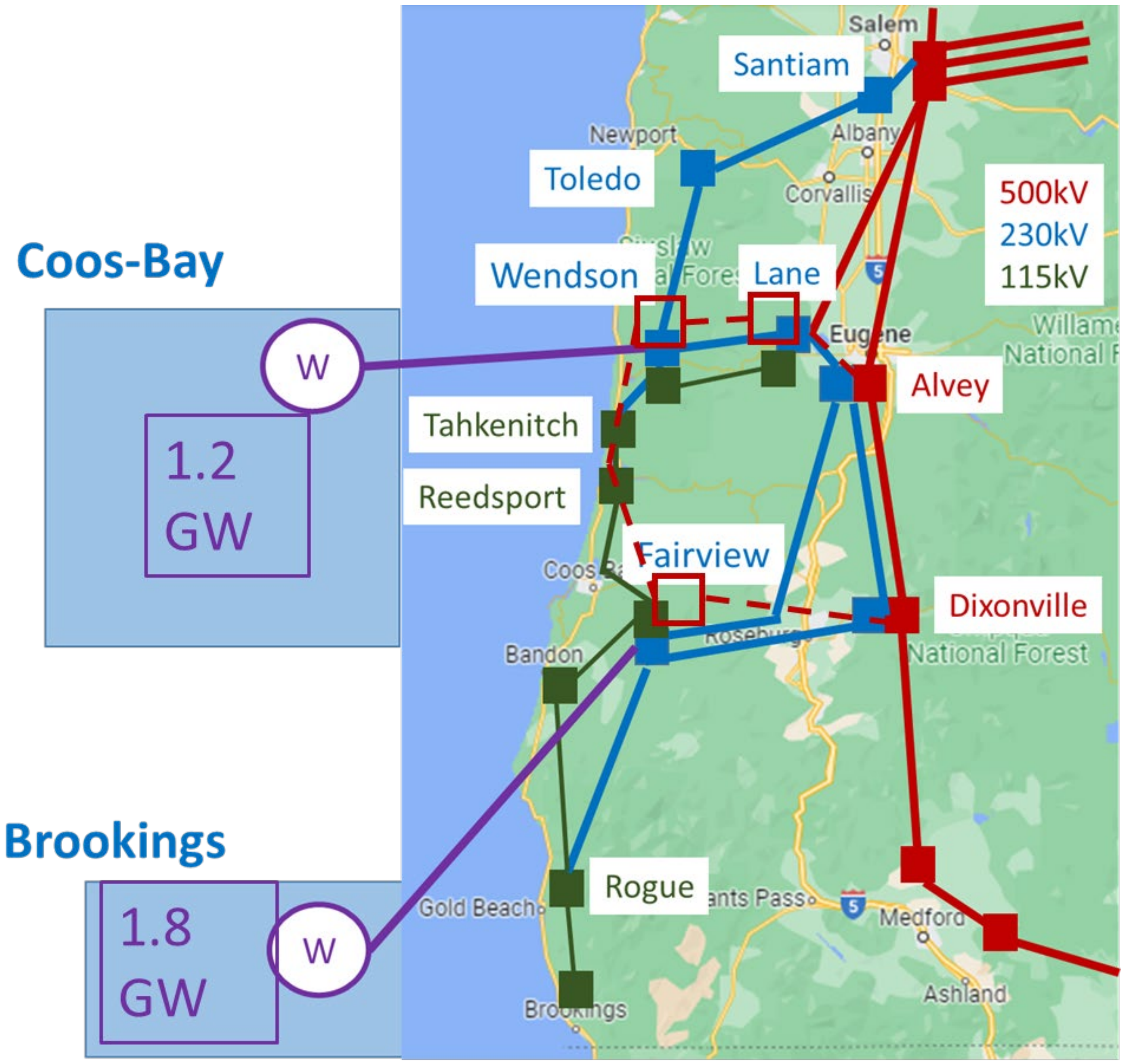


Figure 1: 2022 Offshore Wind Request with "500 kV loop"

This pumped storage hydro request builds upon the results from the 2022 offshore wind analysis. The study assumes the presence of the "500 kV loop" as well as the installation of 3,000 MW of offshore wind. The pumped storage units, two 500 MW units for a total installation of 1,000 MW, will be modeled at the Fairview and Wendson 500 kV buses and production cost modeling analysis performed.

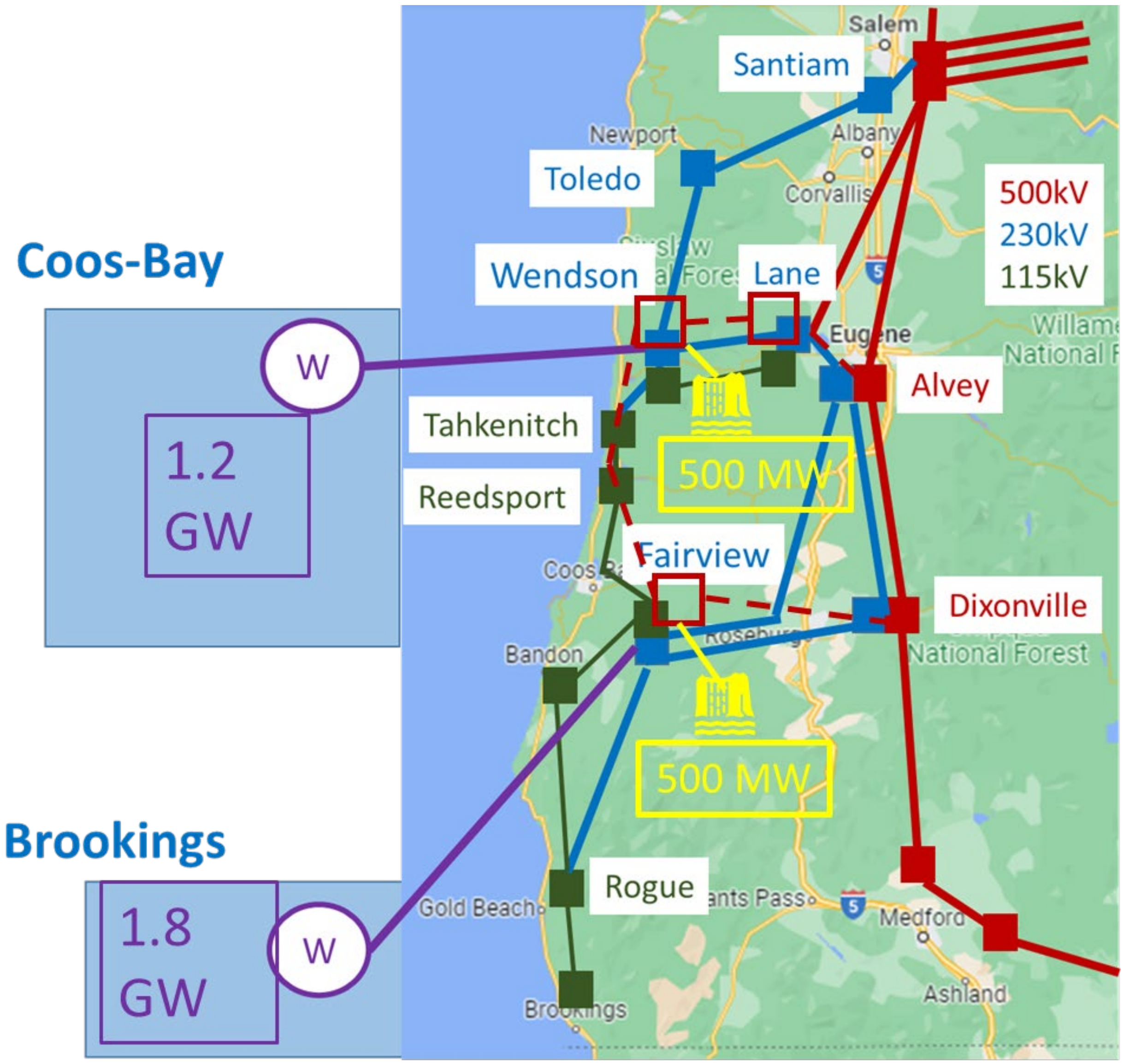


Figure 2: 2023 Pumped Storage Request, total of 1,000 MW

Analysis

All findings in this report are informative in nature and conclusions from this analysis should be limited to the assumptions built into the base cases used for the analysis. These findings do not represent a definitive future and additional analysis would be required to firm up the results of the study. The findings help to illustrate the possible transmission system need on a regional level in a potential ten-year future and do not address the myriad of impacts to the local transmission system. Nothing in this report should be interpreted as a construction plan or a replacement for any local transmission planning process.

The base case developed for the 2022 offshore wind analysis was used for this pumped storage analysis. The enhancements included in the 2032 Anchor Data Set case and identified from the 2022 ESR, are as follows:

Upgrades to the underlying 230 kV system in Oregon

"500 kV loop", with 500 kV substations at Wendson, Fairview, and Lane.

1.2 GW of offshore wind modeled at the Wendson 500 kV substation

1.8 GW of offshore wind modeled at the Fairview 500 kV substation

The 1,000 MW of Rye Development pumped storage hydro was modeled at two points of interconnection: 500 MW at the 500 kV Wendson bus and 500 MW at the 500 kV Fairview bus.

Production cost modeling was performed using Hitachi GridView version 10.3.62. The pumped storage simulation option used was that of, "Daily Scheduling on Price". While GridView dispatches the system on an hourly basis given the fuel costs and transmission constraints of the transmission system, the results of GridView analyses should in no way be construed as operational instruction. Using the Multi-Integer-Optimization (MIO) and the "Daily Scheduling based on Price" option, the GridView Pumped Hydro Storage (PHS) algorithm commits PHS in consideration of other system resources based on PHS pumping efficiency/plant volume/ramping rates to optimize and schedule the generation/pumping dispatch 24-hour forward. This option does not require iterating to determine a pre-price forecast. GridView allows the user to schedule PHS with the given storage target looking at weekly, daily or monthly schedules with consideration of load pattern, wind and solar patterns (these are fixed energy patterns). It supports modeling for high wind events for the chosen period by emptying storage or to prepare for rain days (or low solar generation for the period) by filling up storage over weekly or even longer period of time. The 2032 ADS has negative pricing for wind (onshore and offshore) and solar (-$25), reflecting either an investment tax credit (ITC) or a production tax credit (PTC). Significant addition of utility-scale solar and behind-the-meter solar installations has changed the net load shape; in some areas, the net daily minimum load now occurs mid-day. Accordingly, Hydro generation is responding to the price signals, and had shifted its operation from "Peak" to "Load – Solar – Wind". The daily ending storage targets from longer duration storage scheduling will guide how to best utilize storage plants in the daily optimization. The charge and discharge prices optimize over 24 hours with given initial storage and ending storage targets.

Due to the location of the cumulative installation of 4,000 MW of new generation in Oregon, a handful of cut planes and lines were identified to monitor along with the traditional Western Electricity Coordinating Council (WECC)-defined interfaces.

Altogether, a total of four base cases were developed to analyze this Rye Development project. They are as follows:

01, Anchor Data Set (ADS): the 2032 ADS with no modifications

02, 230 kV upgrade: 2032 ADS with the 230 kV upgrades specified in the 2022 OSW ESR, no additional generation

03, Offshore wind: 230 kV upgrade case with the "500 kV loop" and 3,000 MW of offshore wind

04, OSW PSH: Offshore wind case with the two 500 kV Rye Development pumped storage hydro projects

Results

Results demonstrating the output of the two PSH units are shown in Figure below. Positive values indicate the pumped storage unit is generating and negative values indicate the pumped storage unit is charging. Pumped Storage Unit Output

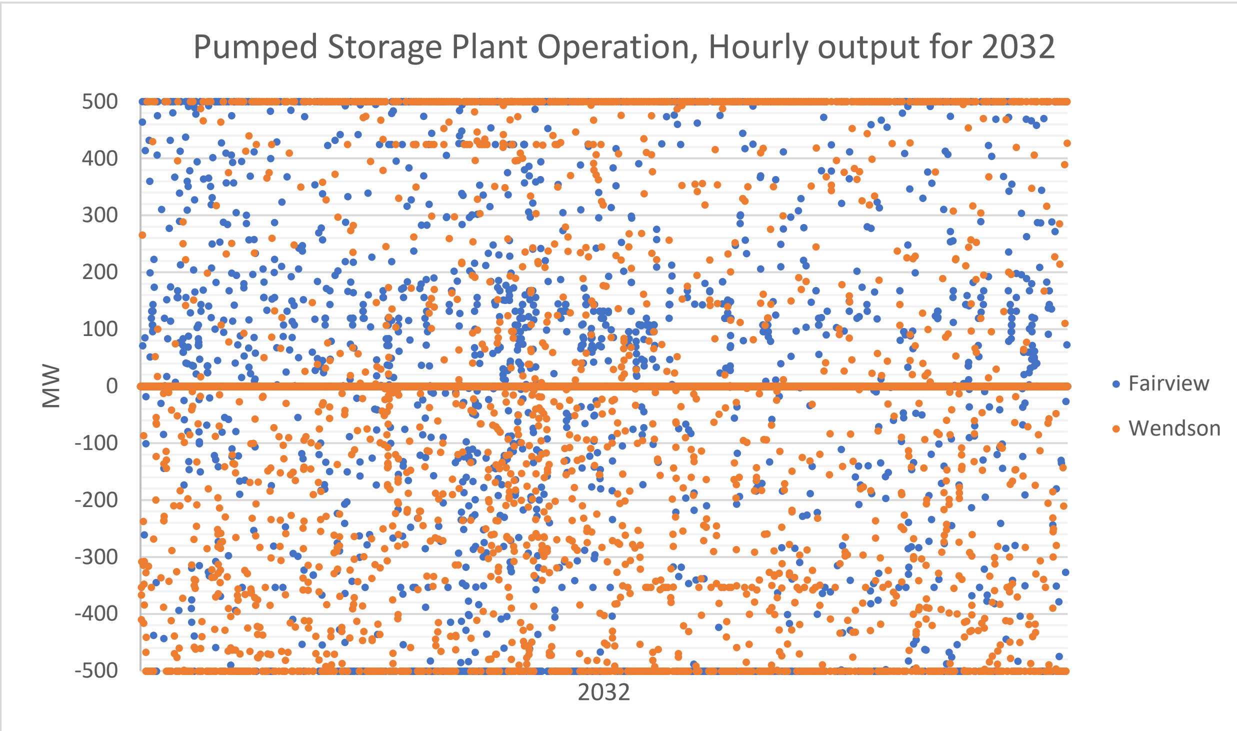


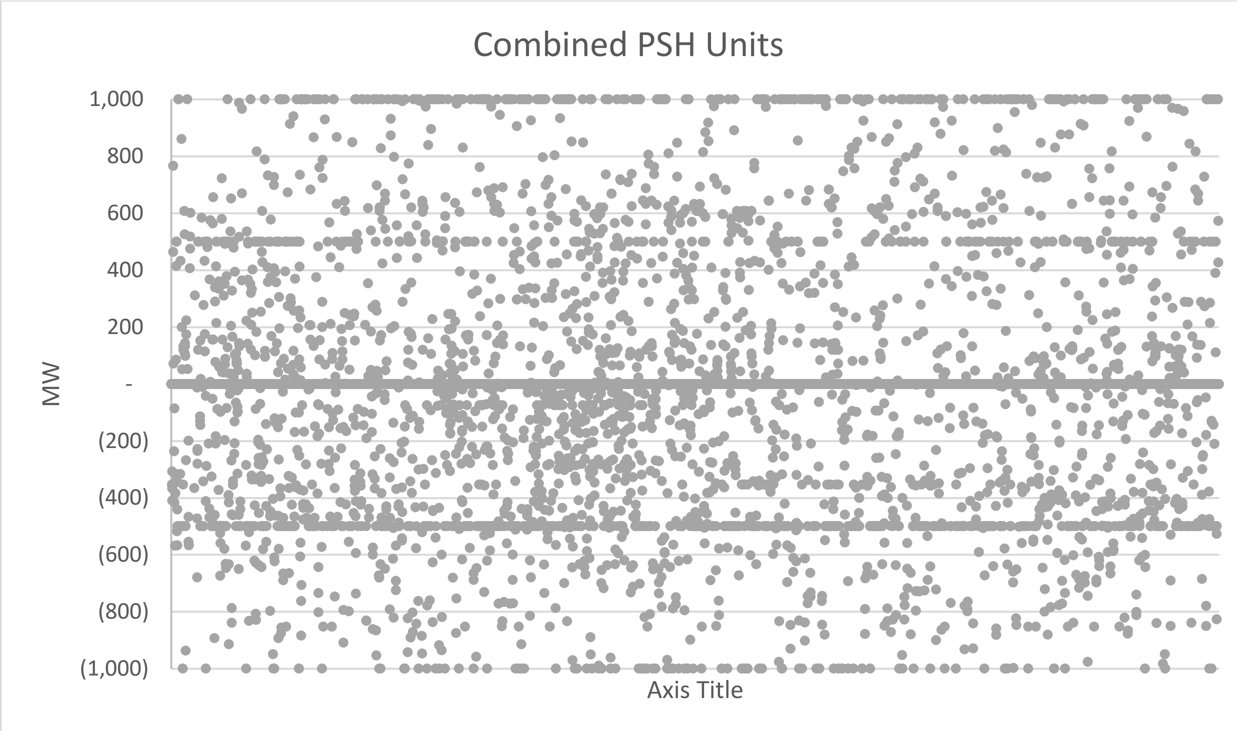
Figure 3: Raw output for the Rye Development pumped storage units

Figure 3: Raw output for the Rye Development pumped storage units allows for visual examination of the output of the Rye Development pumped storage units interconnected at the 500 kV level. Each of the 500 MW units was able to achieve full charge and full discharge.

Table 1: Percent utilization of the Rye Development pumped storage units

Fairview Discharge	Fairview Charge	Wendson Discharge	Wendson Charge	Conflict
15%	10%	11%	18%	2%

The Fairview unit was either charging or discharging 25% of the time, with the Wendson unit at 29%. Only 2%, or 176 hours out of 8784 were in “Conflict” in that one unit was charging while the other was discharging.



Offshore Wind Farm Output

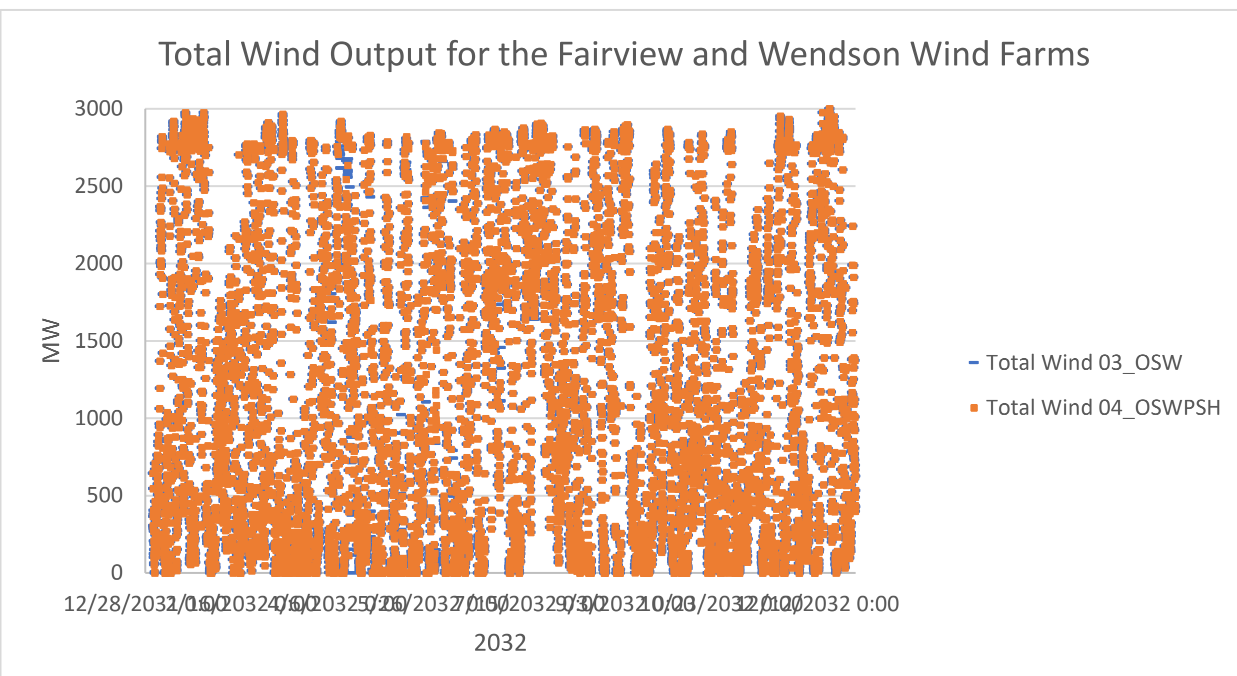


Figure 4: Offshore wind output

Figure 4: Offshore wind output demonstrates that the offshore wind farms were able to achieve their total maximum output. The pumped storage project seems to have negligible impact on the offshore wind projects themselves.

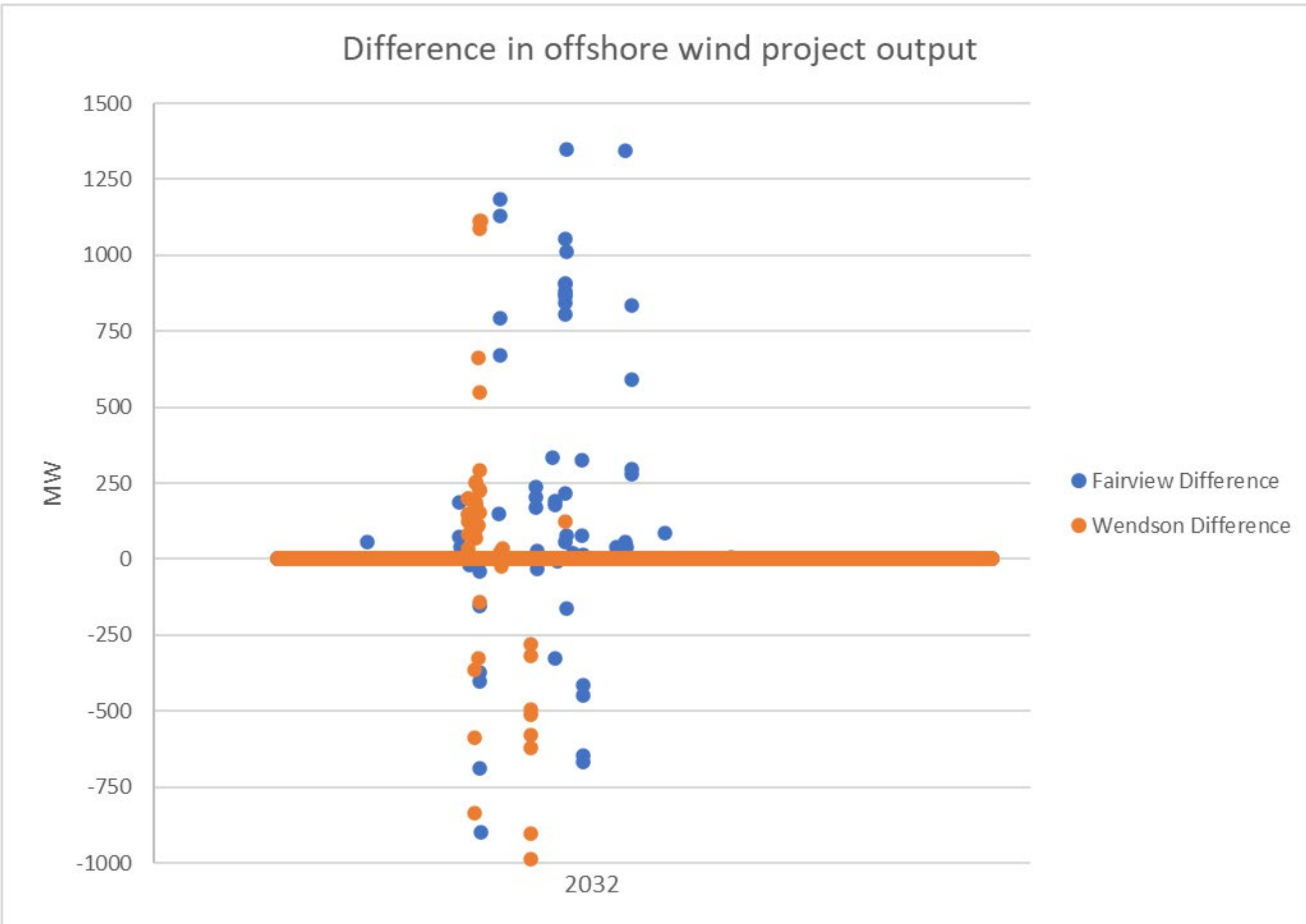


Figure 5: Differences in offshore wind output

The main differences in the output of the offshore wind farms appears to be in the late spring/early summer timeframe.

Lines Results

The monitored lines in the underlying Wendson and Fairview transmission system were monitored to help ascertain if the introduction of a cumulative 4,000 MW in the coastal region would negatively impact the functional operation of the lines.

Table 2: Yearly average real power flow through the monitored lines

Line	ADS	230 kV Upgrade	Offshore Wind	Offshore wind with Pumped Storage Hydro
Hilltop-Hilltop	(70)	(70)	(64)	(28)
John Day-John Day	(513)	(513)	(513)	(513)
Reston-Dixonville	(43)	14	29	29
Vantage-Vantage N	(156)	(157)	(151)	(152)
Rock Creek-Lund Hill	(135)	(135)	(135)	(135)
Burns-Summer Lake	503	508	445	498
Delta-Cascade	60	60	61	62
DR W TP-Dalreed	44	48	61	60
Weed JPS-Weed Junction	(61)	(61)	(61)	(62)
Box PS-Box Canyon	51	51	15	49
Big LWCYN-John Day	309	309	308	308
Big LWCYN-Golden Hill	(177)	(176)	(177)	(177)
Bonanza-Mona	(74)	(78)	(63)	(61)
Bonanza-Craig	226	230	250	260
Bridger-Bridger	(2)	(4)	(22)	(19)
Dave John-LarRiver	64	66	78	82
Rangely-Calamaro	49	50	54	56
Sheridan-Yellowtail	35	35	39	41

Table 2: Yearly average real power flow through the monitored lines suggests that the introduction of 4,000 MW in the coastal region on the “500 kV loop” does not negatively impact the underlying system.

Line	ADS (MW)	230 kV Upgrade (MW)	Offshore Wind (MW)	Offshore wind with Pumped Storage Hydro (MW)
Hilltop-Hilltop	92	102	286	108
John Day-John Day	10,585	10,571	9,948	9,919
Reston-Dixonville	-	-	-	-
Vantage-Vantage N	203	209	94	113
Rock Creek-Lund Hill	2,927	2,920	2,810	2,805
Burns-Summer Lake	10	4	2	3
Delta-Cascade	202	195	310	374
DR W TP-Dalreed	582	694	890	894
Weed JPS-Weed Junction	485	484	648	670
Box PS-Box Canyon	118	127	124	132
Big LWCYN-John Day	643	642	606	595
Big LWCYN-Golden Hill	11	11	8	13
Bonanza-Mona	0	-	25	-
Bonanza-Craig	24	24	71	29
Bridger-Bridger	8	12	15	28
Dave John-LarRiver	754	743	1,109	748
Rangely-Calamaro	913	911	1,188	1,197
Sheridan-Yellowtail	88	92	43	84

The impacts on the above monitored transmission lines is inconclusive. In some instances, the offshore wind introduces transmission loading that is further exacerbated by the pumped storage hydro. In other instances, the offshore wind introduces transmission loading that is relieved by the pumped storage hydro. The presence of offshore wind in conjunction with pumped storage hydro may unload transmission under certain circumstances.

Cut Planes

Cut planes are collections of lines for which a reliable limit has been established. Cut planes may be formally defined through the WECC Path Rating Process; these cut planes are often referred to as "WECC Paths". Cut planes may be defined at the utility level to monitor a set of lines that may be of particular interest to a study outcome. For this pumped storage hydro analysis, the following cut planes were analyzed.

Table 3: Description of the Cut Planes either created for this study or from the WECC Path Rating Catalog

Cut Plane	In WECC Path Rating Catalog	General Area
Fairview 500 kV	No	Lines coming out of Fairview 500 kV bus
Wendson 500 kV	No	Lines coming out of Wendson 500 kV bus
Cut Plane 1	No	Dixonville
Cut Plane 2	No	Sams Valley
Cut Plane 3	No	Meridian-Klamath Falls
Cut Plane 4	No	Snow Goose
WECC Path 5, West of Cascades South	Yes	Lines crossing the southern region of the Cascades mountain range; generally westbound into the Portland area
WECC Path 14, Idaho to Northwest	Yes	Lines connecting Idaho with Washington, typically westbound
WECC Path 66, California-Oregon Intertie	Yes	Lines connecting California and Oregon, historically southbound
WECC Path 71, South of Allston	Yes	Lines feeding directly into the Portland area, typically southbound

Table 4: Average yearly real power flow through the identified Cut Planes (MW)

Cut Plane	ADS (MW)	230 kV Upgrade (MW)	Offshore Wind (MW)	Offshore wind with Pumped Storage Hydro (MW)
Fairview 500 kV	-	-	760	770
Wendson 500 kV	-	-	202	203
Cut Plane 1	235	327	679	689
Cut Plane 2	(30)	82	721	737
Cut Plane 3	(53)	(19)	186	187
Cut Plane 4	(277)	(270)	(228)	(228)
WECC Path 5, West of Cascades South	4,070	4,124	3,504	3,541
WECC Path 14, Idaho to Northwest	632	659	511	655
WECC Path 66, California-Oregon Intertie	2,687	2,696	2,942	2,971
WECC Path 71, South of Allston	587	591	425	407

The average yearly real power flow through the cut planes suggests the following:

1. The Fairview and Wendson cut planes yearly average increases with the presence of the pumped storage hydro. This finding is notable because charging for the pumped storage units is represented as negative generation.
2. The introduction of the 4,000 MW of cumulative generation on the "500 kV loop" increases the flows through Cut Planes 1-4, in some instances, changing direction.
3. WECC Path 5 and WECC Path 14, and Path 71, all of which are defined in the east-to-west/north-to-south/Portland-bound directions demonstrated decreased flows with just the offshore wind alone, but then increased a bit with the introduction of the pumped storage hydro. This change, concurrent with the negligible change in offshore wind output between the case with and without the pumped storage hydro projects, suggests that the system is charging the pumped storage projects, not the offshore wind specifically.
4. The generally southbound California-Oregon Intertie demonstrated increased southbound flows for the introduction of the offshore wind project and again further increased southbound flows with the introduction of the pumped storage projects.

Table 5: Average yearly congestion costs through the identified Cut Planes ($/MWh)

Cut Plane	ADS	230 kV Upgrade	Offshore Wind	Offshore wind with Pumped Storage Hydro
Fairview 500 kV			-	$110
Wendson 500 kV			-	-
Cut Plane 1	-	-	-	-
Cut Plane 2	-	-	-	-
Cut Plane 3	-	-	-	-
Cut Plane 4	-	-	-	-
WECC Path 5, West of Cascades South	-	$0	-	-
WECC Path 14, Idaho to Northwest	$73	$77	$47	$45
WECC Path 66, California-Oregon Intertie	$3,635	$4,014	$8,052	$8,694
WECC Path 71, South of Allston	-	-	$113	$116

The table above suggests the following:

1. The Fairview point of interconnection is the only non-WECC path to experience any increase in transmission loading due to the introduction of the 4,000 MW of new generation; the loading is only present in the case with the pumped storage hydro.
2. The transmission loading on WECC Path 14, Idaho to Northwest is reduced with the installation of the 4,000 MW of new generation.
3. WECC Path 66, the California-Oregon Intertie (COI) experienced significantly increased flows that increased starting with the supporting 230 kV upgrades. This suggests that the flows that are predominantly southbound have an easier time getting to the COI which is causing the additional loading on the COI.
4. WECC Path 71 generally serves the Portland area. Increased transmission loading was not seen on this path until the new resources were added; suggests significant interplay with the output of the new generation and WECC Path 71.

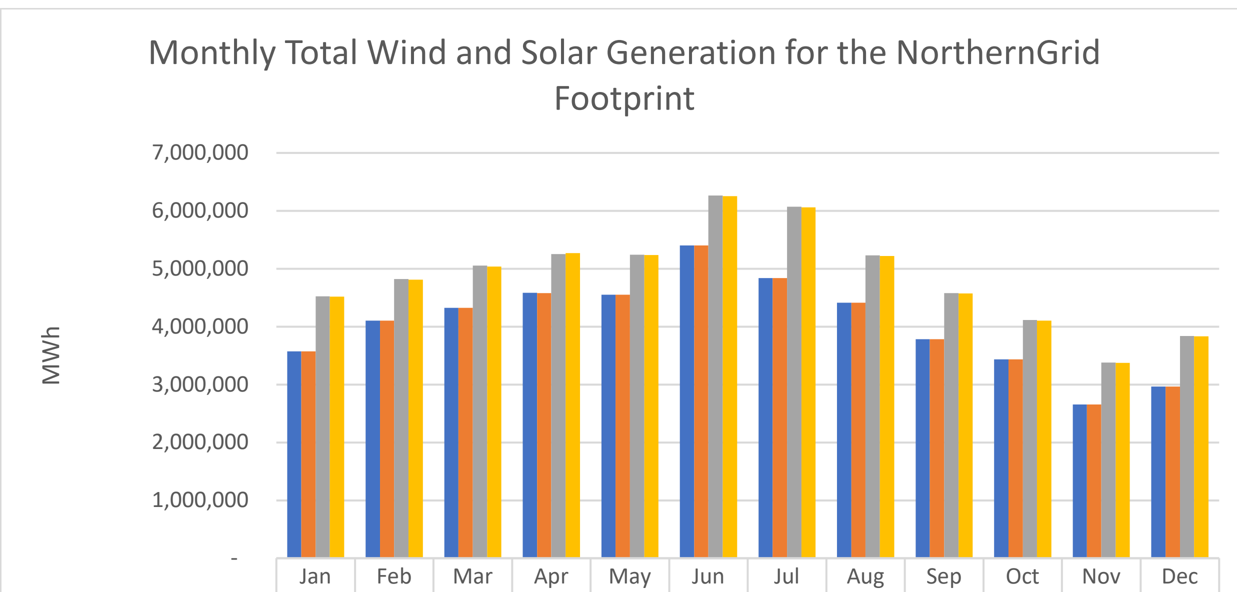
NorthernGrid footprint output

Table 6: Yearly cumulative characteristics for the NorthernGrid footprint

NG Area Characteristics, Yearly Cumulative Total	01_ADS	02_ADS230Upgrade	03_OSW	04_OSWPSH
Generation (MWh)	268,514,427	268,224,448	272,967,096	273,330,765
Load (MWh)	227,050,889	227,051,415	227,072,750	227,039,312
Losses (MWh)	5,287,753	5,291,296	5,285,663	5,312,541
Spillage (MW)	1,412,243	1,413,869	1,679,051	1,638,073
Average LMP ($)	4,982,949	4,981,269	4,912,745	4,919,841

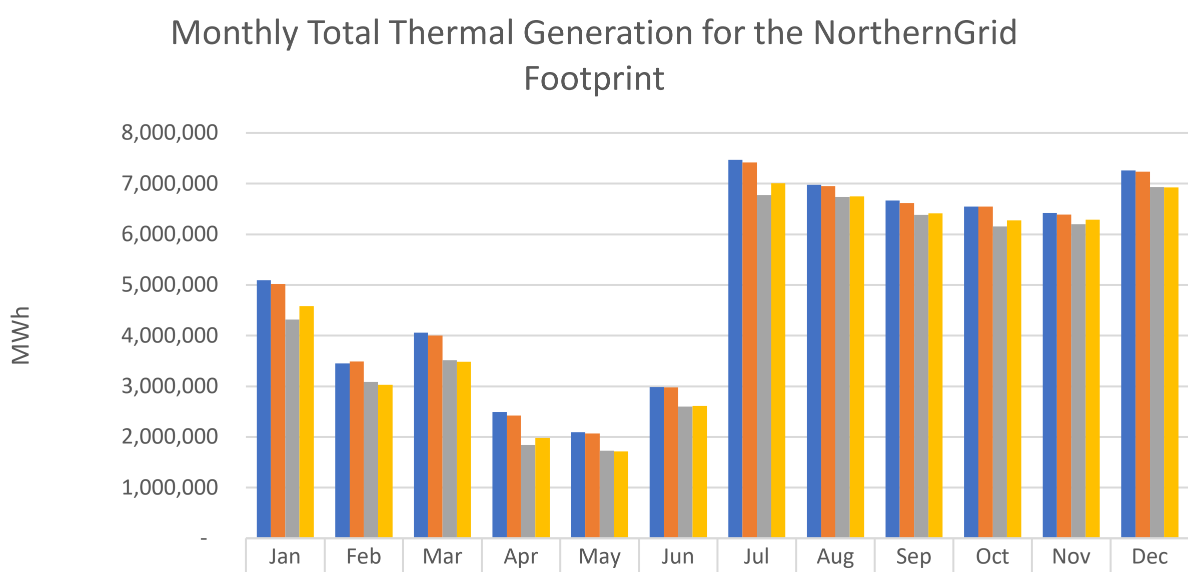
Overall, for the cumulative yearly NorthernGrid region:

1. There is increased NorthernGrid generation when offshore wind is introduced and again further increased with the pumped storage hydro project
2. The load decreases with the introduction of the pumped storage hydro.
3. The losses decrease with the offshore wind, and further decrease with the pumped storage hydro project
4. Spillage increases with the introduction of the offshore wind projects, but then decreases when the pumped storage is added
5. The Average LMP decreases when offshore wind is added and increases when the pumped storage project is added.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01_ADS	3,572	4,104	4,325	4,583	4,549	5,402	4,841	4,413	3,780	3,434	2,656	2,966
02_ADS230Upgrade	3,572	4,106	4,327	4,580	4,549	5,402	4,841	4,413	3,780	3,433	2,656	2,966
03_OSW	4,525	4,821	5,051	5,254	5,244	6,263	6,071	5,232	4,580	4,114	3,382	3,841
04_OSWPSH	4,517	4,812	5,039	5,268	5,234	6,256	6,059	5,222	4,570	4,105	3,372	3,831

Figure 6: Total monthly NorthernGrid footprint renewable generation



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01_ADS	5,095	3,454	4,059	2,490	2,095	2,987	7,468	6,973	6,665	6,545	6,419	7,261
02_ADS230Upgrade	5,019	3,489	3,998	2,420	2,067	2,975	7,421	6,948	6,614	6,546	6,387	7,234
03_OSW	4,314	3,087	3,515	1,843	1,727	2,599	6,774	6,734	6,384	6,154	6,200	6,931
04_OSWPSH	4,585	3,027	3,482	1,981	1,712	2,612	7,008	6,751	6,411	6,276	6,290	6,928

Figure 7: Total monthly NorthernGrid footprint carbon-based generation

Figures 6 and 7 together indicate that the presence of the offshore wind farms and pumped storage units both allow for increased renewable generation and decreased thermal generation in the NorthernGrid.

The following figures help further demonstrate the behavior of the pumped storage units and their collective impact on the NorthernGrid Region.

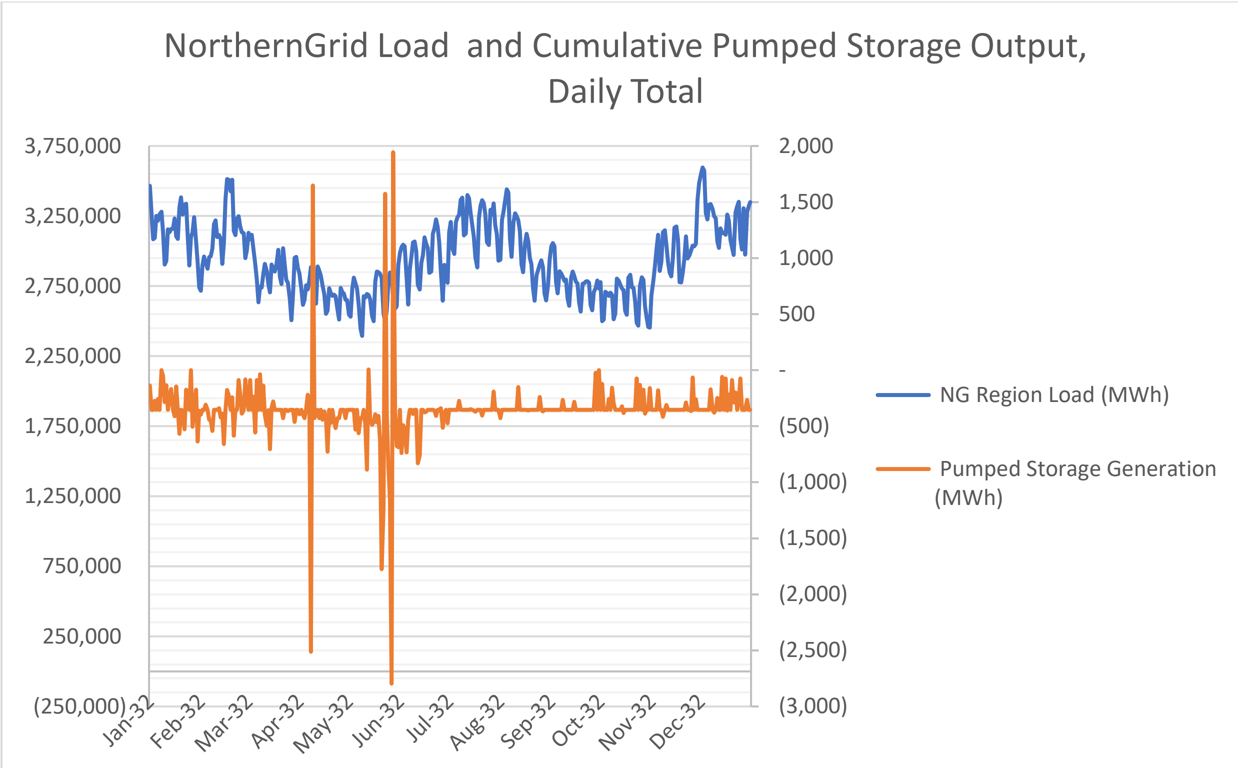


Figure 8: NorthernGrid Regional Load and the Cumulative Pumped Storage Output, 2032 full-year

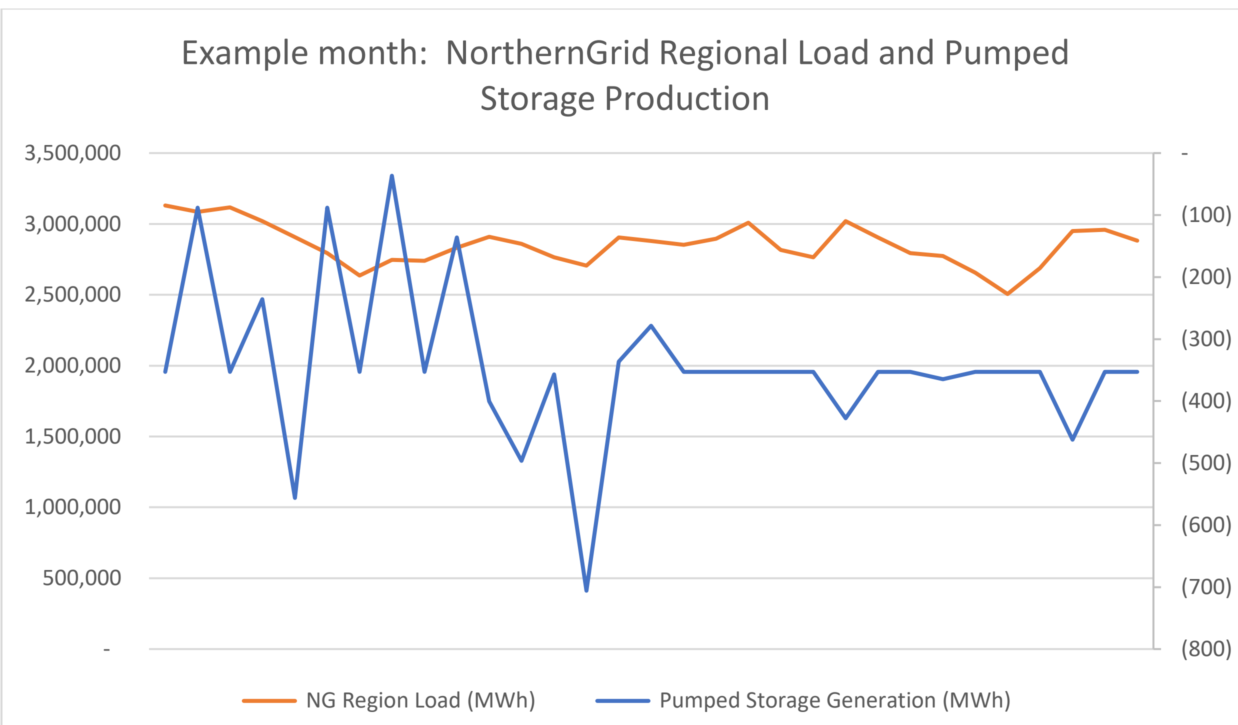
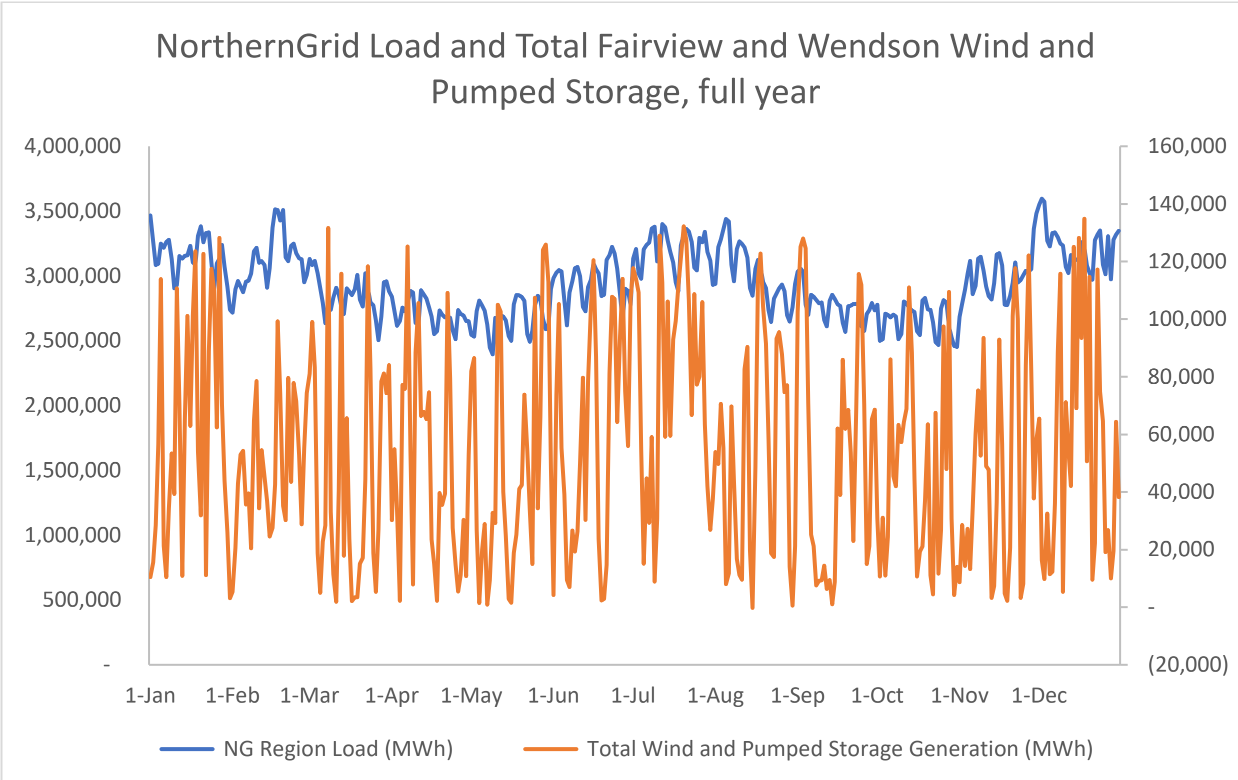


Figure 9: NorthernGrid Regional Load and the Cumulative Pumped Storage Output, 2032 March


NorthernGrid Load and Total Fairview and Wendson Wind and Pumped Storage, full year
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
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160,000
140,000
120,000
100,000
80,000
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40,000
20,000
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(20,000)
1-Jan
1-Feb
1-Mar
1-Apr
1-May
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1-Sep
1-Oct
1-Nov
1-Dec
NG Region Load (MWh)
Total Wind and Pumped Storage Generation (MWh)

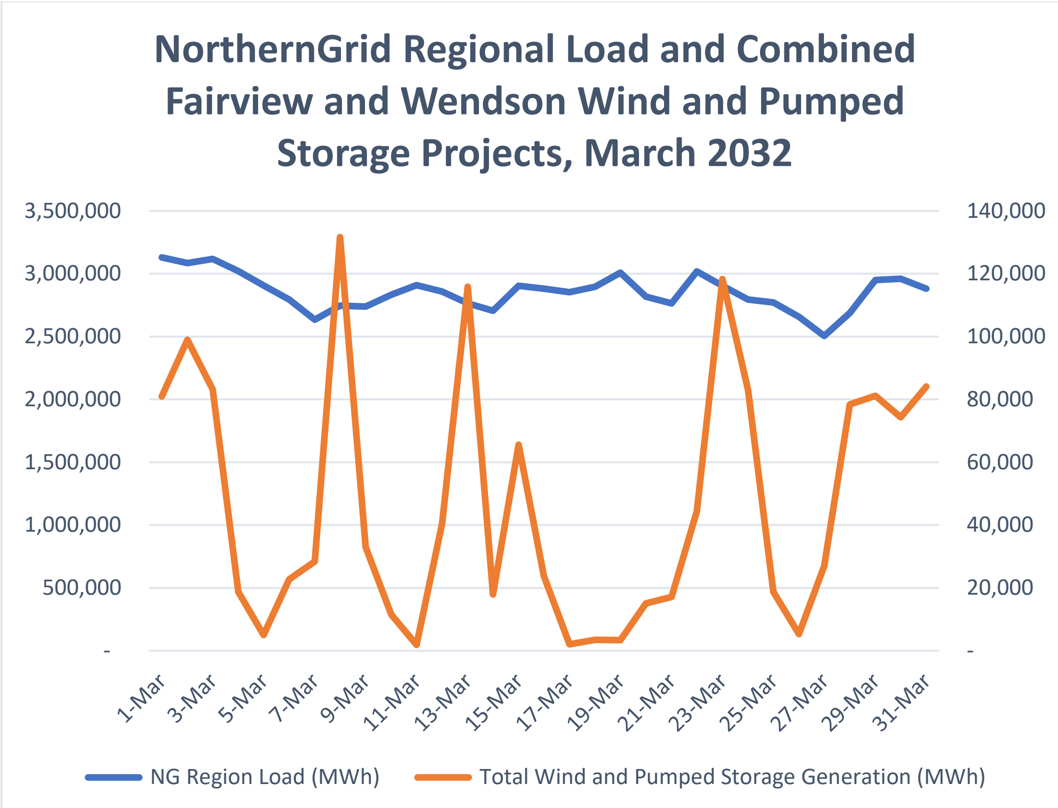


Figure 10: Month of March, NorthernGrid regional load with combined project output

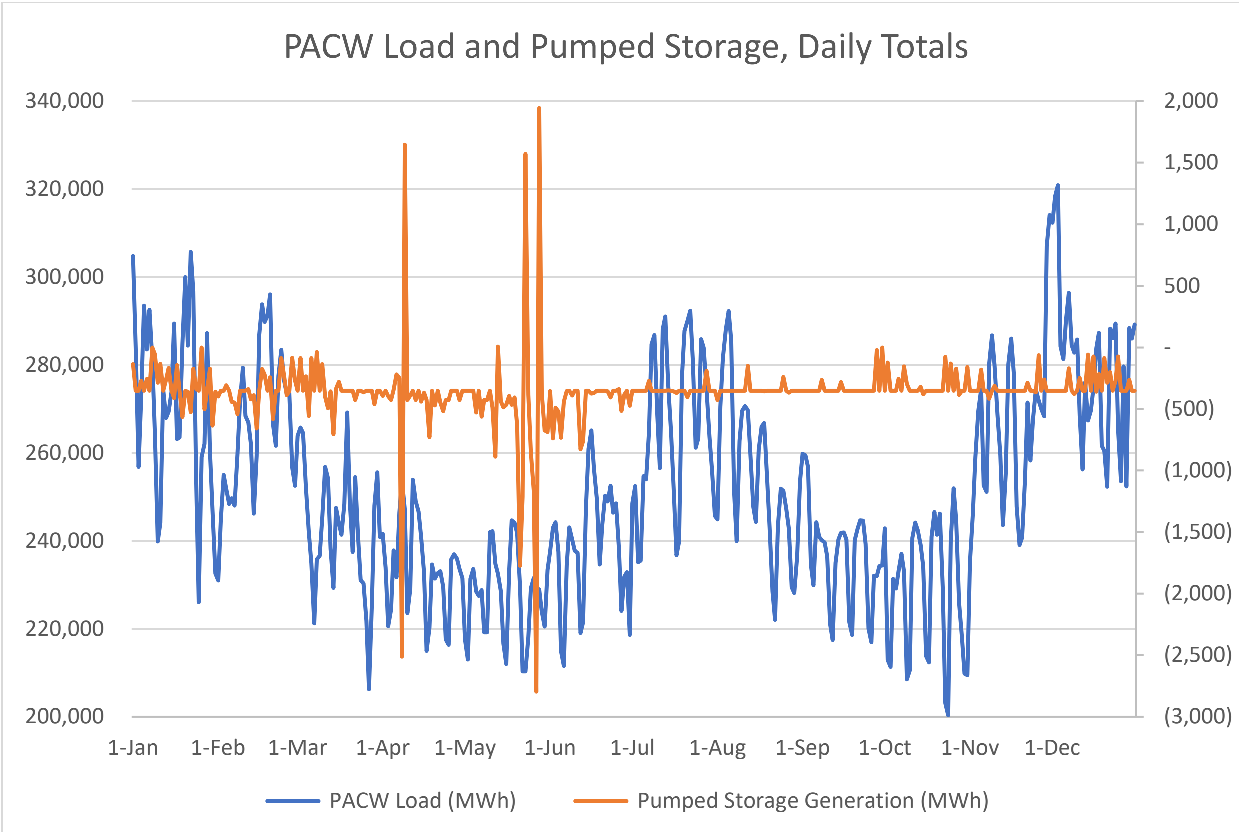


Figure 11: Interaction of the Pumped Storage units with the PACW load

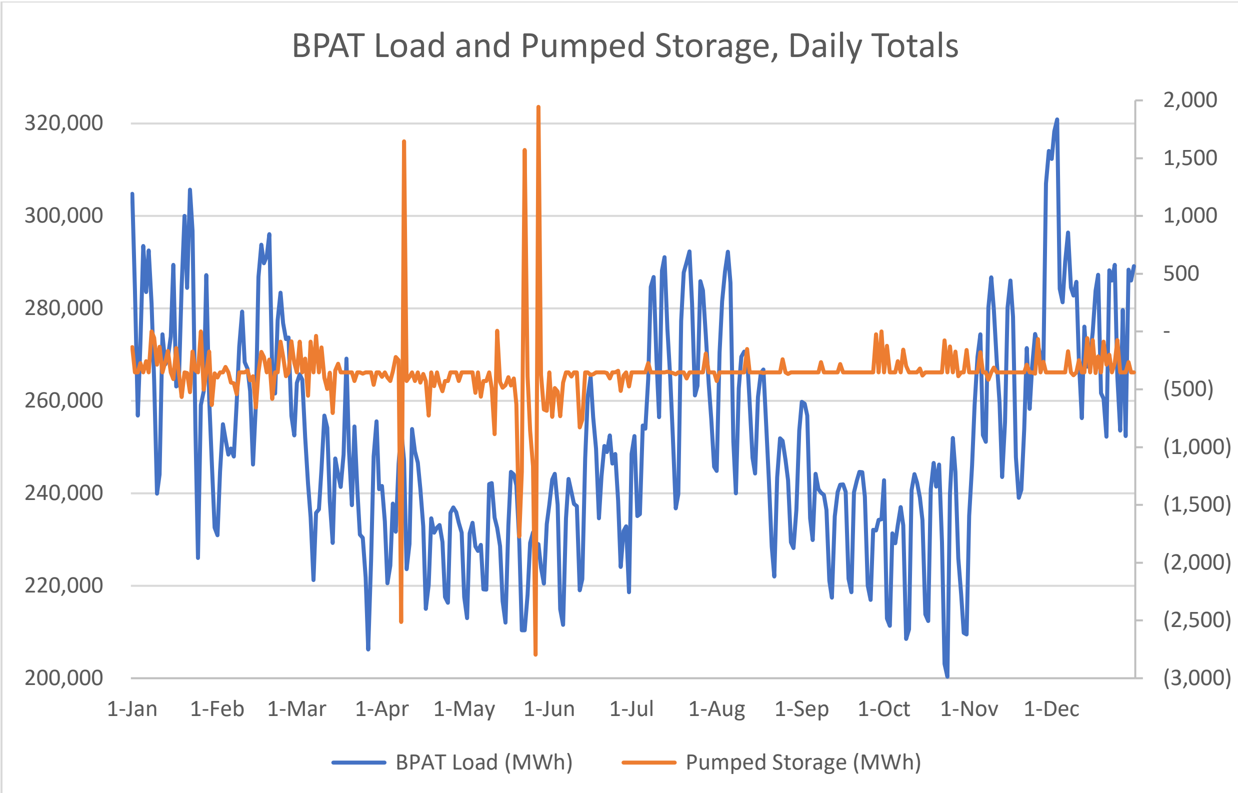
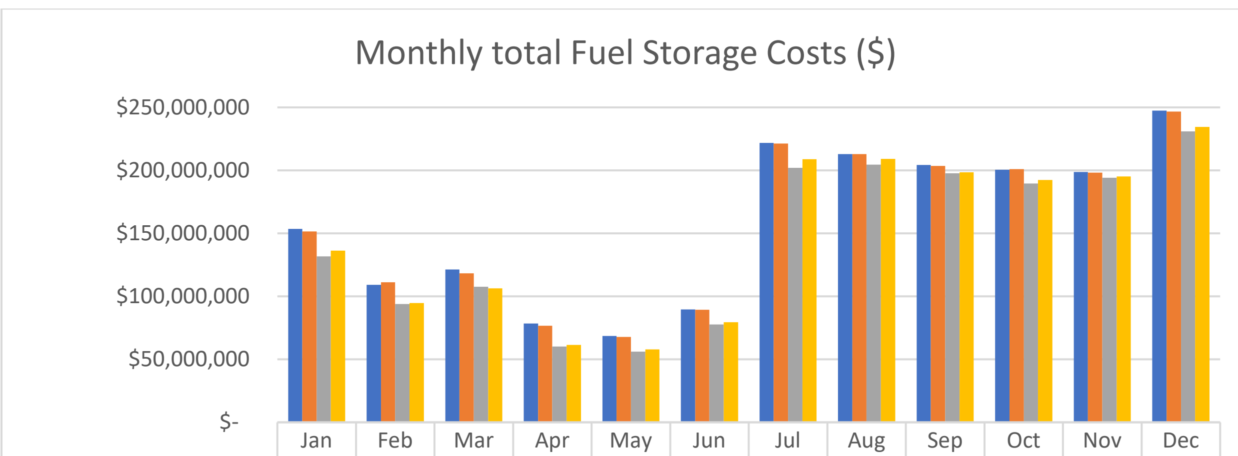
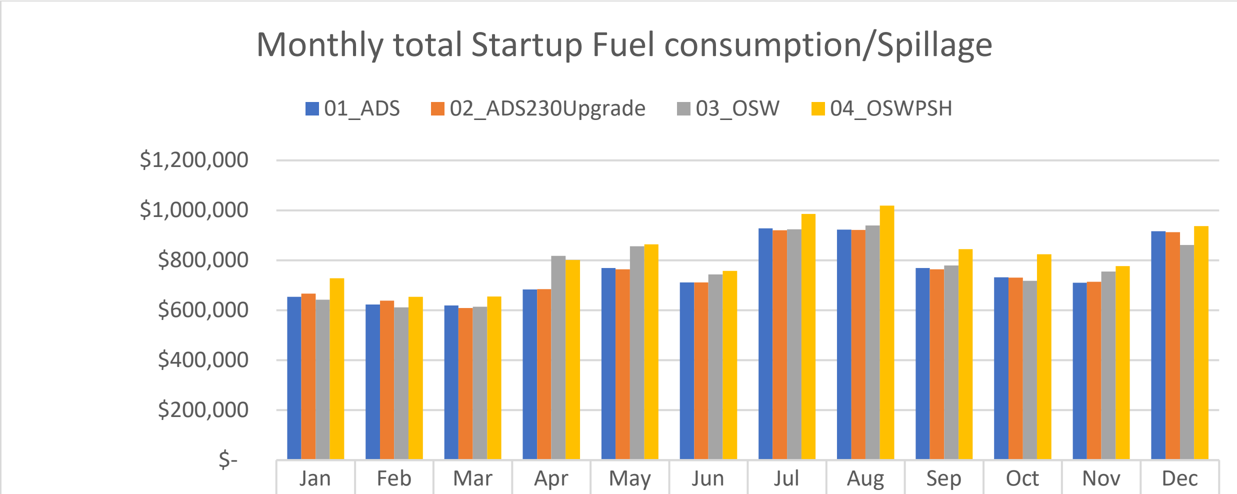


Figure 12: Interaction of the Pumped Storage units with the BPAT load



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01_ADS	$153,6	$109,2	$121,2	$78,40	$68,66	$89,56	$221,8	$212,9	$204,2	$200,4	$198,7	$247,5
02_ADS230Upgrade	$151,4	$111,1	$118,2	$76,65	$67,72	$89,39	$221,4	$212,8	$203,6	$201,0	$198,2	$246,7
03_OSW	$131,8	$93,82	$107,7	$60,05	$56,07	$77,58	$201,9	$204,4	$197,6	$189,4	$194,1	$230,8
04_OSWPSH	$136,2	$94,73	$106,3	$61,42	$57,88	$79,46	$208,9	$209,1	$198,3	$192,4	$195,1	$234,3

Figure 13: NorthernGrid total monthly storage costs



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01_ADS	$653,6	$623,2	$619,5	$682,8	$768,7	$711,7	$928,1	$922,4	$769,4	$731,7	$710,4	$916,2
02_ADS230Upgrade	$666,9	$638,2	$609,1	$684,5	$764,2	$712,0	$919,8	$921,8	$764,3	$730,3	$713,6	$912,4
03_OSW	$642,4	$611,9	$614,1	$818,4	$856,3	$743,0	$923,7	$938,9	$779,4	$718,1	$755,6	$861,8
04_OSWPSH	$728,5	$653,7	$655,1	$801,7	$864,5	$757,9	$985,0	$1,019	$844,5	$823,7	$776,5	$937,3

Figure 14: NorthernGrid total monthly Startup and Spillage costs

Conclusions

The introduction of pumped storage hydro onto the proposed “500 kV loop” in conjunction with the offshore wind impacts both the local and regional transmission systems. In some instances the impact is negative: increased transmission loading or LMP. In other instances, the impacts are positive: reduced imports to the NorthernGrid region and increased opportunity for renewable generation. Additional analysis needs to be completed with the assumption of operating the pumped storage hydro project in conjunction with the offshore wind project which was not done for this study due to time constraints to modify the tool for implementing this functionality. This study does not represent the benefits that may be present with more intentional operation.