AN ABSTRACT OF THE THESIS OF

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Interest in renewable energy is on the rise, in both grid-connected operations and research projects. Major types of renewable energy include: wind, solar, wave, tidal, biomass, and geothermal. The majority are variable, non-dispatchable sources, which can have a negative impact on reserve requirements. This study focused on determining the optimal combination of renewable sources with a total penetration of 30% to minimize the impact on the reserve requirements. The current state of renewable energy in the grid leans very strongly to wind, but as a greater diversity is incorporated into the grid, the reserve requirements decrease. The optimum combination was determined to be 5% each of wind, solar, wave, tidal, biomass, and geothermal. A diverse mix of renewable energy helps counteract the impact of individual variable, non-dispatchable renewable energy sources, and reduces the impact of variability and uncertainty in meeting the power demand.

Key Words: renewable energy, reserve requirements

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Analysis of Penetration and Reserve Requirements

when Incorporating Renewable Energy Power Generation

in the Bonneville Power Administration Balancing Authority Area

by

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Section 1) Introduction

Renewable energy is becoming more efficient and more feasible to replace traditional, non-renewable energy sources, and the use of renewable energy has been on the rise in recent years. While on the whole this is a very good thing, careful study is needed to make sure this level of renewable energy interfaces with the power grid well. “Reserve Requirement Impacts of Large-Scale Integration of Wind, Solar, and Ocean Wave Power Generation”, a study by Douglas A. Halamay, Ted K. A. Brekken, Asher Simmons, and Shaun McArthur [1], explores the needed reserve requirements when a renewable energy penetration of 15% is used. However, given the recent increases in the amount and diversity of renewable energy, an extension of the study is needed. To account for the increasing diversity of viable renewable energy sources, three new sources are included in the study; to account for the increasing capacity of renewable energy, the penetration level is brought to 30%. Finally, data from 2011 will be used when available.

Prior to discussing and characterizing the types of renewable energy and their impact in the Pacific Northwest (PNW), some characteristics need to be defined and reviewed. The first of these is “variable.” “Variable” describes the short term nature of energy generation. While minute-to-minute variations in generation are generally low, a variable source can see its energy production go from full output to none (or none to full output) in even a few hours. Another characteristic typically used in describing renewable energy is “non-dispatchable.” “Non-dispatchable” versus “dispatchable” refers to the operator’s ability to control how much energy is being produced. For example, a coal plant is dispatchable, while a wind farm is non-dispatchable. The final characteristic is an energy source’s contribution to the “power requirements" and "energy requirements" of the grid. Non-dispatchable resources, such as wind or solar, don't contribute much to the power requirements of the grid (as they cannot be depended upon to generate their nameplate capacity on demand), while dispatchable resources do. However, both dispatchable and non-dispatchable resources do contribute to the energy requirements of the grid, as every Joule generated by renewable means is one less Joule generated by non-renewable means [1].

This study focuses on the reserve requirements needed for various renewable energy situations viable for the PNW. "Reserve requirements" are a measure of how much non-renewable energy must be kept in reserve to counteract a shortage in renewable energy, greater load than predicted, or a combination of the two. Reserve requirements are calculated from three timescales used in industry: regulation, following, and imbalance. The "regulation" timescale is the difference between the minute-average of the net load and the ten-minute-average of the net load. This study does not use the regulation timescale as it is negligible compared to the remaining two. The "following" timescale is the difference between the ten-minute-average and the hour-average of the net load, while "imbalance" is the difference between the hour-average and the predicted hour-average. Following and imbalance can also be thought of as the variability and uncertainty, respectively. For all three timescales, a negative number indicates that there was less renewable energy generation than expected, greater load than expected, or a combination of the two. Similarly, a positive number indicates the opposite: more renewable energy generation than expected, less load than expected, or a combination of the two [1].

Section 1.1) Overview of Renewable Generation Technologies

Some background information that is needed for fully understanding this study is an overview of the six renewable energy types examined, which include: wind, solar (photovoltaic and concentrating thermal), ocean wave, ocean tidal, geothermal, and biomass. The technology of each, how it is characterized, and the advantages and disadvantages will be discussed first.

Section 1.1.1) Wind Energy

Wind energy works on the basis of taking the kinetic energy in the wind and turning it into electricity. This is done by using a wind turbine. There are different designs of wind turbines, but all operate using three main components. The wind turns the rotor, which causes a shaft to spin, which is in turn connected to a generator that makes electricity from the spinning shaft. Wind turbines are quite often mounted on towers to provide some extra elevation [2]. Single homes are quite often capable of getting most of the electricity they need from a single, small wind turbine (< 10 kW [3]), but larger turbines (up to 3500 kW [2]) are generally grouped together in one location to make a wind farm [4]. Wind energy can be characterized as a variable, non-dispatchable renewable energy source [1].

Wind energy has several advantages. The most obvious is that it's an extremely available resource. No matter how much wind energy is used to power customers today, there will be more wind tomorrow. A related benefit is that once a wind turbine is constructed, there is no need to purchase fuel for it, unlike non-renewable sources such as coal. Since it doesn't burn any fuel, it doesn't release any harmful gases or pollutants into the environment [4]. However, there are a few disadvantages as well. The first is that the wind isn't always blowing at a wind turbine, and if the wind isn't blowing, the electricity isn't being generated. It's not possible to store the wind itself, and though energy storage technologies such as batteries can be used to store electricity, this requires AC to DC (and vice versa) conversion, which introduces efficiency losses. Also, though wind power can eventually cost less in the long run, the upfront costs are high compared to traditional non-renewable energy sources [2]. Finally, the best sites for wind farms tend to be very remote from customers living in urban areas [4].

Section 1.1.2) Solar Energy

There are two different types of solar energy used in this study: photovoltaic solar, and concentrating thermal solar. Photovoltaic solar energy utilizes semi-conductors to directly turn sunlight into electricity. Certain materials, such as silicon, can be doped with other elements, such as boron and phosphorous, to create P-N junctions in the material. The sunlight will excite electrons from the valence band to the conduction band causing them to travel through the electrical circuit [5]. Concentrating thermal solar power, on the other hand, does not directly convert sunlight to electricity. Instead, it starts by focusing large amounts of sunlight into a small area using mirrors. This concentrated sunlight heats a fluid, producing steam, which drives a turbine [6]. Solar energy, whether photovoltaic or concentrating solar, is classified as a variable, non-dispatchable renewable energy source [1].

Though solar energy is fundamentally quite different from wind, some of its characteristics are very similar in practice. Sunlight can be harvested to generate electricity, but no matter how much sunlight is used, there will still be an ample supply tomorrow. Once again similar to wind, once a solar panel is built, there is no need to purchase fuel for it. The fluid used in concentrating thermal solar power might occasionally need to be replaced, but compared to purchasing coal, it is a miniscule cost. Neither type of solar energy releases pollutants into the atmosphere. Still similar to wind energy, the major disadvantage of solar energy is that it is entirely dependent on the sun shining, and if there is no sunlight, no electricity is being produced. Also, sunlight itself can't be stored for the future, and unless large batteries are used, a significant amount of electricity can't be stored either. Very different from wind energy, however, is that photovoltaic panels are more aesthetically pleasing and can easily be included in urban and suburban areas [7]. Large solar farms are not possible in those areas, but many small distributed panels can still make a significant contribution to the energy requirements of the grid [1].

Section 1.1.3) Ocean Wave Energy

Ocean wave energy is a relatively new form of energy, with significant research effort being put into it. There is currently no one agreed-upon best method, but all the methods use some form of the wave's energy to power a generator. The energy utilized can either be the vertical or horizontal motion of the wave (or both), or of the wave cresting over the device and excess water falling through it powering a turbine [8]. Much like solar and wind energy, ocean wave energy is a variable, non-dispatchable renewable energy source [1].

Wave energy has several benefits, with the largest being that, like all renewable energy sources, we can harvest as much wave energy as we need today and the waves will still be there tomorrow. The power output from wave energy farms still depends on the weather, like wind and solar, but can be predicted a day or two ahead, which means other, easier to control forms of energy can be scheduled as needed, leading to smaller reserve requirements. Wave energy farms are also capable of producing energy all day and night, unlike solar which cannot operate at night [9]. There are disadvantages to wave energy, though. Even though the waves are always present, they can be exceptionally weak in very calm weather, so very little electricity will be produced. The ecological impact of installing wave farms is currently unknown, but these farms may have the potential to affect ecosystems. If smaller, lower profile wave energy generators are used, boats can accidentally run into them and damage/destroy them. Another major limiting factor is that ocean wave energy can only be gathered at the coast, making transmission of this power to distant inland customers difficult [10].

Section 1.1.4) Ocean Tidal Energy

Another type of energy that can be harvested from the ocean is tidal energy. While wave energy captures the motion of the waves for electricity, tidal energy uses the flow of the tides. There are different designs, but "the leading designs have a horizontal axis; that is, the axis of rotation is along the same principle axis as the fluid flow" [11]. Many design considerations have been borrowed from the wind energy industry, but the largest constraint is the size of the turbine blades. While wind turbine blades can easily be 100m or more in diameter in offshore applications, tidal turbine blades tend to max out at 20m due to the higher density of water exerting more force on the blades. The maximum speed at which the blades are allowed to spin is also capped to prevent damage from cavitation. The spinning blades are connected to a generator which converts the rotation to electrical energy. An electrical cable connects the generator to an onshore facility [11]. Using the above definitions, tidal energy is also defined as a variable, non-dispatchable renewable energy source.

As with all the energy sources covered so far, tidal energy generates no harmful emissions or pollutants, and no matter how much energy we harvest from the tides today, they will still be there tomorrow. Another benefit is that, depending on which of the available technologies are used, tidal plants can be invisible to people (aside from the onshore facility), making it one of the more aesthetically pleasing options covered in this study. Tidal currents, while varying, are predictable, and thus fewer reserve requirements are needed. However, much like wave energy, tidal energy can also potentially have some major disadvantages. Again, depending on the technology, it can interfere with maritime business, and the environmental impacts are still not fully understood. Also, given that the technology is still in its infancy, tidal plants have a very high initial cost which is significant enough to prevent much construction until the cost is reduced [12].

Section 1.1.5) Geothermal Energy

Geothermal energy, unlike the other renewable energy sources explored in this study, is a relatively mature form of energy. There are two different types of geothermal energy, but only one was used in this study. (Not used is geothermal heating/cooling, which works by drawing heat up from the earth's crust in the winter-time into buildings, while in the summer shunts the heat in the building into a cool layer of the earth's crust.) The form of geothermal energy used in this study generates electricity from the heat stored in the earth. There are three different forms of geothermal electrical plants: dry steam, flash steam, and binary cycle. Dry steam power plants draw steam directly from underground reservoirs to turn a turbine. However, there are only two locations in the U.S. that have these underground reservoirs, The Geysers in northern California and Yellowstone National Park in Wyoming. No development is allowed in Yellowstone, so the only dry steam plants are located in The Geysers. Flash steam geothermal power plants are the most common type of geothermal power plant. They tap into a reservoir of hot water above 182°C. Due to the pressure difference, water travels up the pipes of its own accord, and at a certain point the pressure decreases enough that most of the water turns to steam. This steam continues flowing up the pipes and turns a turbine. After turning the turbine, the steam and any excess water are pumped back into the reservoir. Lastly are binary cycle geothermal power plants. Binary cycle plants tap into reservoirs of water between 107°C and

182°C. Instead of using the water/steam to directly power a turbine, a working fluid is heated from the water, and the steam of the working fluid turns the turbine. The water and working fluid never come in direct contact, keeping the fluid flow a closed system [13]. Unlike the other renewable energy sources covered so far, geothermal energy is actually a non-variable, dispatchable renewable energy source.

As with all forms of renewable energy, geothermal energy's biggest advantage is that it does not require a constant fuel source to be purchased to keep the turbines running. Geothermal plants also do not emit harmful pollutants into the environment [14]. However, the potential disadvantages of geothermal energy are large. Though geothermal energy is a renewable source, if too much heat is harvested to create more energy, it is possible to overuse the reservoir and cause it to turn cold. To prevent this from happening and get an idea of the limits of the reservoir, extensive research is required prior to building a plant. Geothermal energy is also a location-specific energy source, as it requires hot rocks close to the surface and the ability to generate steam over long periods of time [15].

Section 1.1.6) Biomass

The last type of renewable energy explored in this study is biomass. Biomass energy operates much on the same basis as coal energy, but instead of burning a non-renewable resource, excess bio-waste is processed and used to heat water into steam to turn turbines. It is also possible to burn biomass in conjunction with another fuel, like coal, in a process called co-firing [16].

Biomass, despite being a renewable energy, is not a renewable source where as much as needed can be harvested all at once. If too much biomass is harvested, it will damage the ecosystem. However, staying below that threshold will keep biomass fuel available as needed.

Also, while some carbon dioxide is released into the environment, it is a very small amount compared to non-renewable sources [16]. Similar to geothermal energy, biomass can be classified as a non-variable, dispatchable renewable energy source.

Section 1.2) Current Renewable Energy Situation

In Oregon, the current state of renewable energy has been driven by the Renewable Portfolio Standard (RPS), put into law in June 2007. The RPS states that Oregon's major electric utilities must provide 25% of their electricity from renewable sources by 2025. While hydropower is classified as a renewable source, only a small portion of the 25% is allowed to come from hydro.

In response to the restriction on hydropower for the RPS, other renewable sources are being developed. The most developed resource in the PNW currently is wind energy. For example, at the end of 1998, there was only a total nameplate capacity of 25 MW in the Bonneville Power Administration (BPA) Balancing Authority Area (BAA). However, as of mid 2012, there is a nameplate capacity of 4711 MW [17]. Over the course of about 12 years, wind energy in the BPA BAA has grown by nearly 18,850%. The same cannot be said of the remaining renewable resources.

Section 1.3) Need For This Study

While any increase in renewable energy is very good, it also comes with its own share of problems, the foremost being the impact on reserve requirements. As mentioned above, the previous study [1] conducted reserve requirement research at a renewable energy penetration level of 15%. Between the RPS and the resultant growth of renewable energy (including a nameplate capacity for wind energy rising to half of the load [17]), an extension of the previous study was needed. With the goal of 25% renewable energy by 2025, this study was conducted at a penetration level of 30% to give validity to planning beyond the minimum standards set. In addition, additional resources are being developed and researched, so more sources and more combinations are included in this study. The goal was to find the optimal penetration level of solar, wind, ocean wave, ocean tidal, biomass, and geothermal energy sources to minimize the reserve requirements needed. The combinations were carefully chosen to represent feasible combinations for the PNW.

Section 2) Methods

There were two main portions to analyzing the data for this study. The first portion involved collecting and, as needed, generating the data.

Section 2.1) Data Collection/Generation

Load data for 2010 and 2011 and wind power generation data for 2011 were downloaded from the BPA website [17]. Solar and wave power data generated in the previous study were used in this study.

The solar power generation data was developed from irradiance data downloaded from the University of Oregon Solar Radiation Monitoring Laboratory [18]. Ten locations in the PNW were used: Aberdeen, Ashland, Bend, Burns, Dillon, Eugene, Hermiston, Portland, Salem, and Twin Falls. Solar power generation was assumed to be 50% PV and 50% thermal concentrating. To develop the PV portion of the solar power generation data, the downloaded solar irradiance data was used directly. PV power generation is directly proportional to total irradiance, and since the solar power generation will be scaled as needed to different penetration levels, efficiency losses in the PV panel itself will be lost upon scaling.

However, for the concentrating thermal portion of the solar power generation, some modifications must be applied to the irradiance data. A six hour time constant was assumed, so a single-pole low-pass filter with a time constant of six hours was applied to the data to account for the delays in heating/cooling. For each location, the PV and concentrating thermal data were added together to get the total solar power generation data for that location. Lastly, the ten locations were added together equally to provide the total solar power generation data used in the data analysis [1].

As stated above, the wave power generation data developed in the previous study was used in this study. The paper detailing the complete process is [19], and a summary from [1] is given here:

> In short, the spectral significant wave height, dominant period, and dominant direction is collected from three different measurement buoys in the Pacific Northwest for 2008. Using the data from the measurement buoys, time-series water surface elevation data at a 0.5 second sample time for a 5 by 80 grid with 100 meter spacing is reconstructed. Each of the 400 locations in the grid is occupied by a 250 kW generic wave-following point-absorber wave energy converter. The converter power output is assumed to be proportional to the vertical water surface velocity squared. If the instantaneous power production exceeds 250 kW, it is clipped at that level. The proportionality is set such that the combined output of the wave energy converters produces a capacity factor of 50% for an average winter day (e.g., a day in January). The power from each of the three parks is then averaged over 10 minute intervals to generate the power time-series (52704 points). The power from the three locations is added together to produce the total wave power generation data. This total is then scaled as necessary to achieve the desired penetration rate for a given scenario.

Of the three new types of renewable energy power generation added in this study, no year-long data sets were available. Data to develop the biomass power generation data was retrieved from the U.S. Energy Information Administration Monthly Energy Review (2011 monthly data was used) [20]. Geothermal data was retrieved from the U.S. Energy Information Administration (EIA) 2011 Annual Energy Review [21]. The data used to develop the ocean tidal power generation data was downloaded from the Northwest National Marine Renewable Energy Center University of Washington Tidal Energy Site [22].

The directly downloaded data for the biomass set was a monthly summary of generation in BTU. The first step was to convert the data to MWH. From the MWH generated per month, the data was converted to MW at ten minute intervals. The last step came in introducing a small random factor to simulate the output of a real power plant. Biomass power generation, given a steady supply of fuel, generates a steady output, but since the output won’t be exactly the same from one ten-minute interval to the next, a plus/minus one percent random factor was applied.

The geothermal data set was generated in much the same way as the biomass data set, except that monthly generation totals were not available, so a single year-long generation total value was used. This value was originally in BTUs, so it was first converted into MWH, then to MW at ten-minute intervals. Finally, the plus/minus one percent random factor was overlaid on the data.

A plus/minus one percent factor was chosen by investigating the generation curve of non-renewable thermal plants (e.g. coal, natural gas, etc.), as both biomass and geothermal share a dispatchable nature with them. The maximum thermal generation for 2011 was approximately 5000 MW, and on the ten-minute time scale, the variability of the combined plants was approximately 50 MW. At a ten-minute time scale, this variability is largely due to small fluctuations in the power output of the plants themselves, rather than operators ramping the output to balance generation and load. This does not affect the steady, dispatchable nature of biomass, but does add in the small variability factor needed to more realistically represent power plants.

To create the tidal data set, five separate data sets were downloaded from the University of Washington Northwest National Marine Renewable Energy Center. These data sets contained velocity information of the tides in one minute increments at 1m above the sea bed. However, there were gaps between the data sets which had to be filled in. To fill in these gaps a search was first conducted to evaluate any possible weather phenomena that would have an effect on the tidal velocity measurements. No significant results were found. Given this information, each gap was filled with the “n” closest data points in time to the gap of the preceding set, with “n” being the number of data points needed to completely fill the gap. Once all gaps were filled, a continuous data set of tidal velocities for 2011 could be used to achieve power generation. The following equation was used to determine the power available from the tides:

$$Power = \frac{1}{2} * Density * Speed^3$$

Much like solar power, efficiency losses did not need to be accounted for, as scaling the data overrides it.

Section 2.2) Data Analysis

Once all the power generation data sets were developed, the same general method of data analysis was used for all data test runs. A complete list of the data test runs is included in Appendix A. The following methodology is based off that of the previous study, coded in Matlab, and modified as needed for both more types of renewable energy and personal coding preferences. An example file (that of 5% equally of all sources) is included in Appendix B.

First, all of the data sets were loaded into variables. Next, the renewable power generation sets were scaled to the needed penetration levels (e.g., for the 25% wind and 5% solar test, the peak wind generation was scaled to 25% of the peak load, and the peak solar generation was scaled to 5% of the peak load, for a total of 30% renewable energy penetration). Then, the load and renewable energy schedules were generated using a function developed by Dr. Brekken [1]. This function utilizes the one-hour persistence method, which is an approximation of BPA's wind forecasting method.

The one-hour persistence method states that the power output for the next hour will be the same as when the prediction is made. Predictions are made at the 40-minute mark of the hour, and the prediction will be good for the 10-minute through the 50-minute mark of the next hour. 20 minutes are allowed to ramp between predictions [1]. As an example, if a wind farm was generating 150 MW at 4:40 pm, the prediction would be that between 5:10 pm and 5:50 pm the farm will be outputting 150 MW. At 5:40 pm, if the farm is actually producing 125 MW, the prediction for the 6:00 hour (6:10 pm to 6:50 pm) will be 125 MW, and the 20 minutes from 5:50 pm to 6:10 pm will ramp down from 150 MW to 125 MW.

Once the schedules for load and renewable energy sources were created, the renewable energy schedules were subtracted from the load schedule to create a net load schedule. Using the definitions of following and imbalance, these values were determined for the entire year at each ten minute interval. The maximum and minimum were then determined and stored for the final output of the data test run. Afterward, the top and bottom 0.25% (for 0.5% total) of the following and imbalance arrays were discarded as per industry-standard practice [1]. This allows for utilities to meet the North American Electric Reliability Corporation (NERC) and Western Electricity Coordinating Council (WECC) reliability standards while eliminating events beyond three standard deviations of the following and imbalance mean [1]. After the data trimming, the new following and imbalance maximum and minimum were stored. Finally, the four stored values, and other statistical measurements (mean, variance, skew, kurtosis, mean absolute error, root mean square error) of the following and imbalance arrays are outputted to the screen.

Section 3) Results

The following and imbalance results for the data analysis are listed in Table 1. Both untrimmed and trimmed data is included, but only the trimmed data is used for analysis, as this is industry-standard practice when determining reserve requirements. According to BPA, keeping the middle 99.5% of data allows for accurate planning while ignoring statistically insignificant outliers [1]. A summary of selected trimmed data, with decreasing wind penetration levels and representing varying degrees of reserve requirements, can be found in Table 2. The column in each table labeled "Control Load" represents the control case: the total load of the PNW excluding any renewable energy generation. Figures 1 and 2 visualize the summarized results of Table 2, displaying the following and imbalance results, respectively (the absolute value of the reserve requirement is used). The minimum is referred to as an "incremental" reserve requirement as the operator is required to increase the non-renewable energy generation to compensate for a greater net load than expected. Similarly, the "decremental" reserve requirement corresponds to the maximum, and the operator is required to decrease the non-renewable energy generation.

Penetration Level		Wind	Control Load	30	25	25	25	25
		Solar			5			
		Geo				5		
		Bio					5	
		Wave						5
		Tidal						
Untrimmed	Following	Min	-0.18089	-0.18057	-0.18024	-0.18059	-0.181	-0.18065
		Max	0.16971	0.17242	0.17196	0.17207	0.17184	0.17356
		Mean	4.35E-06	1.14E-05	1.06E-05	1.03E-05	1.02E-05	9.87E-06
		Var	4.90E-05	7.55E-05	6.80E-05	6.72E-05	6.72E-05	6.80E-05
		Skew	-0.18122	0.07271	0.00185	-0.00527	-0.00717	-0.00217
		Kurtosis	27.2095	15.32224	17.03128	17.28644	17.31225	17.11001
		MAE	0.0048	0.00607	0.00578	0.00574	0.00574	0.00578
		RMSE	0.007	0.00869	0.00824	0.0082	0.0082	0.00824
	Imbalance	Min	-0.07335	-0.1088	-0.08841	-0.08809	-0.08806	-0.08745
		Max	0.06432	0.12749	0.10582	0.10612	0.10566	0.10653
		Mean	2.17E-04	2.40E-04	2.29E-04	2.36E-04	2.35E-04	2.66E-04
		Var	1.40E-04	3.15E-04	2.64E-04	2.60E-04	2.60E-04	2.61E-04
		Skew	-0.19007	0.07664	0.03187	0.00076	0.00275	0.01042
		Kurtosis	6.61347	5.42374	5.0509	5.0749	5.07215	5.02481
		MAE	0.00826	0.013	0.01199	0.01187	0.01186	0.01192
		RMSE	0.01183	0.01774	0.01624	0.01611	0.01611	0.01615
Trimmed	Following	Min	-0.03089	-0.03495	-0.03377	-0.03367	-0.03338	-0.03331
		Max	0.02271	0.0328	0.02933	0.02895	0.029	0.02894
		Mean	1.82E-05	-2.16E-06	4.47E-06	3.99E-06	3.99E-06	3.79E-06
		Var	4.21E-05	6.52E-05	5.88E-05	5.82E-05	5.82E-05	5.89E-05
		Skew	-0.36042	-0.1928	-0.23755	-0.24439	-0.24393	-0.23751
		Kurtosis	5.26611	4.7725	4.73553	4.7659	4.76256	4.73877
		MAE	0.00466	0.00588	0.00561	0.00557	0.00557	0.00561
		RMSE	0.00649	0.00807	0.00767	0.00763	0.00763	0.00767
	Imbalance	Min	-0.05084	-0.06351	-0.05863	-0.05776	-0.05776	-0.05798
		Max	0.04467	0.06211	0.05734	0.05599	0.05608	0.05573
		Mean	2.42E-04	2.28E-04	2.26E-04	2.36E-04	2.34E-04	2.65E-04
		Var	1.26E-04	2.86E-04	2.41E-04	2.38E-04	2.38E-04	2.39E-04
		Skew	-0.06459	0.03964	0.0232	-0.00552	-0.00445	0.00398
		Kurtosis	5.2542	3.97327	3.95561	3.97358	3.97726	3.95114
		MAE	0.00803	0.01268	0.01171	0.01159	0.01159	0.01164
		RMSE	0.01122	0.0169	0.01554	0.01542	0.01542	0.01546

Table 1 – Full Data

Penetration Level		Wind	25	20	20	20	20	20
		Solar		10				
		Geo			10			
		Bio				10		
		Wave					10	
		Tidal	5					10
Untrimmed	Following	Min	-0.18062	-0.17991	-0.18061	-0.18144	-0.18073	-0.18062
		Max	0.17197	0.17149	0.17173	0.17127	0.17469	0.17197
		Mean	1.02E-05	9.93E-06	9.15E-06	9.09E-06	8.38E-06	1.02E-05
		Var	6.72E-05	6.33E-05	6.07E-05	6.06E-05	6.34E-05	6.72E-05
		Skew	-0.00577	-0.05549	-0.07786	-0.08253	-0.06125	-0.00577
		Kurtosis	17.30951	18.34293	19.63223	19.70998	18.59297	17.30951
		MAE	0.00574	0.0056	0.00546	0.00545	0.00561	0.00574
		RMSE	0.0082	0.00796	0.00779	0.00779	0.00796	0.0082
	Imbalance	Min	-0.08769	-0.08245	-0.08269	-0.08115	-0.08266	-0.08769
		Max	0.10596	0.08416	0.08474	0.08382	0.08557	0.10596
		Mean	2.36E-04	2.17E-04	2.32E-04	2.29E-04	2.92E-04	2.36E-04
		Var	2.59E-04	2.34E-04	2.15E-04	2.15E-04	2.20E-04	2.59E-04
		Skew	0.00245	0.03393	-0.08081	-0.07646	-0.05156	0.00245
		Kurtosis	5.07027	4.67627	4.93884	4.93358	4.76783	5.07027
		MAE	0.01186	0.01142	0.01082	0.01082	0.01102	0.01186
		RMSE	0.01611	0.01529	0.01467	0.01467	0.01485	0.01611
Trimmed	Following	Min	-0.03349	-0.03274	-0.03244	-0.03219	-0.03273	-0.03349
		Max	0.02896	0.02658	0.02638	0.0264	0.02717	0.02896
		Mean	3.91E-06	1.13E-05	1.06E-05	1.05E-05	1.01E-05	3.91E-06
		Var	5.81E-05	5.50E-05	5.26E-05	5.25E-05	5.52E-05	5.81E-05
		Skew	-0.24464	-0.25878	-0.28731	-0.28725	-0.25588	-0.24464
		Kurtosis	4.7698	4.6735	4.80784	4.80755	4.70283	4.7698
		MAE	0.00556	0.00544	0.0053	0.00529	0.00545	0.00556
		RMSE	0.00762	0.00742	0.00725	0.00725	0.00743	0.00762
	Imbalance	Min	-0.05757	-0.05521	-0.05512	-0.05453	-0.05348	-0.05757
		Max	0.05593	0.05287	0.04926	0.04958	0.05034	0.05593
		Mean	2.36E-04	2.21E-04	2.43E-04	2.40E-04	3.01E-04	2.36E-04
		Var	2.38E-04	2.16E-04	1.98E-04	1.98E-04	2.04E-04	2.38E-04
		Skew	-0.0047	0.05274	-0.04974	-0.04611	-0.0263	-0.0047
		Kurtosis	3.97627	3.86612	4.06147	4.06357	3.95723	3.97627
		MAE	0.01158	0.01117	0.01058	0.01057	0.01078	0.01158
		RMSE	0.01541	0.01469	0.01407	0.01408	0.01427	0.01541

Table 1 (cont.) – Full Data

Penetration Level		Wind	20	20	20	20	20	20
		Solar	5	5	5	5		
		Geo	5				7.5	5
		Bio		5			2.5	5
		Wave			5			
		Tidal				5		
Untrimmed	Following	Min	-0.18026	-0.18068	-0.18032	-0.1803	-0.18081	-0.18102
		Max	0.17161	0.17138	0.17309	0.1715	0.17161	0.1715
		Mean	9.54E-06	9.51E-06	9.16E-06	9.48E-06	9.14E-06	9.12E-06
		Var	6.13E-05	6.13E-05	6.20E-05	6.12E-05	6.06E-05	6.05E-05
		Skew	-0.0697	-0.07217	-0.06491	-0.07047	-0.07922	-0.08046
		Kurtosis	19.32728	19.35978	19.12064	19.35784	19.70554	19.7431
		MAE	0.00549	0.00549	0.00553	0.00548	0.00545	0.00545
		RMSE	0.00783	0.00783	0.00787	0.00783	0.00778	0.00778
	Imbalance	Min	-0.08257	-0.0818	-0.08255	-0.08235	-0.0823	-0.08192
		Max	0.08445	0.08399	0.08486	0.0843	0.08451	0.08428
		Mean	2.24E-04	2.23E-04	2.54E-04	2.25E-04	2.31E-04	2.30E-04
		Var	2.19E-04	2.19E-04	2.21E-04	2.19E-04	2.15E-04	2.15E-04
		Skew	-0.02871	-0.02658	-0.01656	-0.02693	-0.07976	-0.07869
		Kurtosis	4.89062	4.88887	4.82996	4.88863	4.93962	4.939
		MAE	0.01097	0.01096	0.01101	0.01096	0.01082	0.01081
		RMSE	0.01481	0.01481	0.01486	0.01481	0.01466	0.01466
Trimmed	Following	Min	-0.0325	-0.03244	-0.0327	-0.03262	-0.03244	-0.03244
		Max	0.02663	0.02646	0.02676	0.02656	0.02652	0.02644
		Mean	1.11E-05	1.10E-05	1.07E-05	1.10E-05	1.06E-05	1.06E-05
		Var	5.31E-05	5.31E-05	5.38E-05	5.30E-05	5.24E-05	5.24E-05
		Skew	-0.27955	-0.27981	-0.2724	-0.28004	-0.28815	-0.28841
		Kurtosis	4.77986	4.77913	4.75901	4.78549	4.81593	4.81847
		MAE	0.00533	0.00533	0.00537	0.00532	0.00529	0.00529
		RMSE	0.00729	0.00729	0.00733	0.00728	0.00724	0.00724
	Imbalance	Min	-0.05533	-0.05487	-0.05356	-0.05517	-0.0549	-0.0548
		Max	0.05142	0.05119	0.0513	0.05133	0.04952	0.04961
		Mean	2.32E-04	2.31E-04	2.61E-04	2.32E-04	2.43E-04	2.42E-04
		Var	2.02E-04	2.02E-04	2.03E-04	2.02E-04	1.98E-04	1.98E-04
		Skew	-0.00369	-0.00172	0.00617	-0.00196	-0.04877	-0.04783
		Kurtosis	4.01776	4.02088	3.98336	4.0194	4.06372	4.06492
		MAE	0.01072	0.01071	0.01077	0.01071	0.01057	0.01057
		RMSE	0.01421	0.01422	0.01426	0.01421	0.01407	0.01407

Table 1 (cont.) – Full Data

Penetration Level		Wind	20	20	20	15	15	15
		Solar				15		
		Geo	5	5	2.5		15	
		Bio			7.5			15
		Wave	5					
		Tidal		5				
Untrimmed	Following	Min	-0.18067	-0.18064	-0.18123	-0.17958	-0.18062	-0.18187
		Max	0.17321	0.17162	0.17138	0.17103	0.17138	0.17069
		Mean	8.77E-06	9.09E-06	9.10E-06	9.21E-06	8.05E-06	7.95E-06
		Var	6.13E-05	6.05E-05	6.05E-05	6.16E-05	5.59E-05	5.57E-05
		Skew	-0.0728	-0.07877	-0.08157	-0.08725	-0.1362	-0.14454
		Kurtosis	19.49023	19.7415	19.74457	18.7404	22.06868	22.23273
		MAE	0.00549	0.00544	0.00545	0.00556	0.00523	0.00522
		RMSE	0.00783	0.00778	0.00778	0.00785	0.00747	0.00747
	Imbalance	Min	-0.08267	-0.08247	-0.08154	-0.07755	-0.07791	-0.07561
		Max	0.08516	0.08459	0.08405	0.06888	0.06336	0.06199
		Mean	2.62E-04	2.32E-04	2.30E-04	2.06E-04	2.27E-04	2.23E-04
		Var	2.16E-04	2.15E-04	2.15E-04	2.25E-04	1.81E-04	1.81E-04
		Skew	-0.0672	-0.07916	-0.07758	0.0942	-0.15656	-0.14981
		Kurtosis	4.87863	4.93787	4.93699	4.37505	5.13458	5.12736
		MAE	0.01087	0.01081	0.01081	0.01132	0.00988	0.00987
		RMSE	0.0147	0.01466	0.01466	0.015	0.01346	0.01346
Trimmed	Following	Min	-0.0326	-0.03237	-0.03235	-0.03239	-0.03189	-0.03178
		Max	0.0267	0.02644	0.02639	0.02507	0.02458	0.02458
		Mean	1.03E-05	1.05E-05	1.06E-05	1.60E-05	1.60E-05	1.59E-05
		Var	5.31E-05	5.23E-05	5.24E-05	5.38E-05	4.83E-05	4.82E-05
		Skew	-0.28124	-0.2889	-0.28811	-0.25938	-0.3235	-0.32435
		Kurtosis	4.7938	4.82492	4.81579	4.57478	4.89295	4.89862
		MAE	0.00533	0.00528	0.00529	0.0054	0.00508	0.00507
		RMSE	0.00729	0.00724	0.00724	0.00733	0.00695	0.00694
	Imbalance	Min	-0.05356	-0.05461	-0.05477	-0.05158	-0.05078	-0.0508
		Max	0.05008	0.04942	0.04969	0.05115	0.04654	0.04659
		Mean	2.72E-04	2.44E-04	2.41E-04	2.11E-04	2.48E-04	2.44E-04
		Var	1.99E-04	1.98E-04	1.98E-04	2.09E-04	1.66E-04	1.67E-04
		Skew	-0.03885	-0.04821	-0.04697	0.12721	-0.08795	-0.08135
		Kurtosis	4.02524	4.06325	4.06477	3.69524	4.24239	4.24346
		MAE	0.01063	0.01057	0.01057	0.01108	0.00965	0.00964
		RMSE	0.01412	0.01406	0.01407	0.01445	0.01291	0.01291

Table 1 (cont.) – Full Data

Penetration Level		Wind	15	15	15	15	15	15
		Solar			10	10	10	10
		Geo			5			
		Bio				5		
		Wave	15				5	
		Tidal		15				5
Untrimmed	Following	Min	-0.18081	-0.18073	-0.17993	-0.18035	-0.17999	-0.17997
		Max	0.17583	0.17106	0.17115	0.17092	0.17263	0.17104
		Mean	6.89E-06	7.85E-06	8.83E-06	8.79E-06	8.44E-06	8.76E-06
		Var	6.19E-05	5.52E-05	5.83E-05	5.83E-05	5.89E-05	5.82E-05
		Skew	-0.08616	-0.14004	-0.11179	-0.11471	-0.10582	-0.11275
		Kurtosis	19.24109	22.48833	20.53412	20.57103	20.32099	20.57032
		MAE	0.00556	0.00518	0.00537	0.00537	0.00541	0.00536
		RMSE	0.00787	0.00743	0.00763	0.00763	0.00768	0.00763
	Imbalance	Min	-0.07786	-0.07726	-0.07767	-0.0769	-0.07765	-0.07745
		Max	0.06461	0.06291	0.06396	0.06427	0.06366	0.06425
		Mean	3.18E-04	2.29E-04	2.13E-04	2.12E-04	2.43E-04	2.13E-04
		Var	1.93E-04	1.80E-04	2.00E-04	2.00E-04	2.01E-04	2.00E-04
		Skew	-0.08973	-0.15189	0.00928	0.01122	0.02217	0.01094
		Kurtosis	4.73556	5.13758	4.74871	4.7482	4.68445	4.7495
		MAE	0.01035	0.00984	0.01055	0.01055	0.0106	0.01055
		RMSE	0.01391	0.01343	0.01415	0.01415	0.0142	0.01415
Trimmed	Following	Min	-0.03262	-0.03168	-0.03224	-0.03208	-0.03219	-0.03211
		Max	0.02613	0.02458	0.02454	0.02461	0.0249	0.02462
		Mean	1.41E-05	1.58E-05	1.66E-05	1.66E-05	1.63E-05	1.66E-05
		Var	5.40E-05	4.77E-05	5.06E-05	5.06E-05	5.13E-05	5.05E-05
		Skew	-0.24594	-0.32902	-0.2931	-0.2936	-0.28535	-0.29362
		Kurtosis	4.65725	4.95088	4.74464	4.74412	4.72689	4.75009
		MAE	0.00541	0.00503	0.00522	0.00521	0.00525	0.00521
		RMSE	0.00735	0.00691	0.00711	0.00711	0.00716	0.00711
	Imbalance	Min	-0.05086	-0.05099	-0.0508	-0.05103	-0.05094	-0.05104
		Max	0.04756	0.04616	0.04882	0.04888	0.04935	0.04883
		Mean	3.31E-04	2.49E-04	2.24E-04	2.22E-04	2.52E-04	2.24E-04
		Var	1.79E-04	1.66E-04	1.85E-04	1.85E-04	1.86E-04	1.85E-04
		Skew	-0.04364	-0.08273	0.05616	0.05797	0.06442	0.05801
		Kurtosis	3.97791	4.24751	3.95217	3.95357	3.91058	3.95334
		MAE	0.01012	0.00962	0.01032	0.01032	0.01037	0.01032
		RMSE	0.01338	0.01288	0.0136	0.0136	0.01365	0.0136

Table 1 (cont.) – Full Data

Penetration Level		Wind	15	15	15	15	15	15
		Solar				5	5	5
		Geo	10	10	10			
		Bio	5			5	5	
		Wave		5		5		5
		Tidal			5		5	5
Untrimmed	Following	Min	-0.18104	-0.18069	-0.18066	-0.18076	-0.18073	-0.18038
		Max	0.17115	0.17287	0.17128	0.17252	0.17093	0.17264
		Mean	8.02E-06	7.66E-06	7.98E-06	8.02E-06	8.34E-06	7.99E-06
		Var	5.56E-05	5.63E-05	5.55E-05	5.69E-05	5.61E-05	5.68E-05
		Skew	-0.13996	-0.12958	-0.13796	-0.12441	-0.13236	-0.12232
		Kurtosis	22.30332	21.99495	22.30414	21.61125	21.90544	21.61266
		MAE	0.00521	0.00525	0.0052	0.00528	0.00524	0.00528
		RMSE	0.00745	0.0075	0.00745	0.00754	0.00749	0.00754
	Imbalance	Min	-0.07714	-0.07789	-0.07769	-0.07701	-0.07681	-0.07756
		Max	0.0629	0.06378	0.06321	0.06303	0.06246	0.06333
		Mean	2.26E-04	2.57E-04	2.28E-04	2.49E-04	2.19E-04	2.51E-04
		Var	1.81E-04	1.82E-04	1.81E-04	1.87E-04	1.85E-04	1.87E-04
		Skew	-0.15464	-0.13824	-0.15526	-0.05992	-0.07483	-0.06062
		Kurtosis	5.13948	5.05773	5.1393	4.96726	5.04436	4.96761
		MAE	0.00986	0.00993	0.00986	0.01009	0.01003	0.01009
		RMSE	0.01345	0.01349	0.01344	0.01367	0.01362	0.01366
Trimmed	Following	Min	-0.03186	-0.03205	-0.03179	-0.03183	-0.03171	-0.03202
		Max	0.02445	0.02466	0.02455	0.02467	0.02454	0.02455
		Mean	1.60E-05	1.57E-05	1.60E-05	1.62E-05	1.65E-05	1.61E-05
		Var	4.80E-05	4.87E-05	4.80E-05	4.93E-05	4.86E-05	4.92E-05
		Skew	-0.32624	-0.3177	-0.32657	-0.30836	-0.31743	-0.30872
		Kurtosis	4.91941	4.88803	4.92511	4.85383	4.88479	4.86096
		MAE	0.00505	0.0051	0.00505	0.00513	0.00508	0.00513
		RMSE	0.00693	0.00698	0.00693	0.00702	0.00697	0.00702
	Imbalance	Min	-0.05014	-0.0505	-0.05056	-0.05034	-0.05091	-0.05076
		Max	0.04643	0.04699	0.04623	0.04709	0.04727	0.04743
		Mean	2.46E-04	2.76E-04	2.48E-04	2.63E-04	2.35E-04	2.65E-04
		Var	1.66E-04	1.67E-04	1.66E-04	1.72E-04	1.71E-04	1.72E-04
		Skew	-0.08594	-0.0751	-0.0864	-0.00579	-0.01544	-0.00636
		Kurtosis	4.24887	4.19459	4.24736	4.11917	4.17207	4.11856
		MAE	0.00964	0.0097	0.00964	0.00986	0.0098	0.00986
		RMSE	0.01289	0.01294	0.01289	0.01312	0.01306	0.01311

Table 1 (cont.) – Full Data

Penetration Level		Wind	15	15	15	15	10	10
		Solar	5				20	5
		Geo	2.5	5	5	5		5
		Bio	2.5	5	5			5
		Wave	2.5	5		5		2.5
		Tidal	2.5		5	5		2.5
Untrimmed	Following	Min	-0.18053	-0.1811	-0.18108	-0.18072	-0.17925	-0.18076
		Max	0.17184	0.17263	0.17105	0.17276	0.17057	0.17138
		Mean	8.20E-06	7.63E-06	7.95E-06	7.60E-06	8.50E-06	7.08E-06
		Var	5.63E-05	5.61E-05	5.53E-05	5.61E-05	6.28E-05	5.28E-05
		Skew	-0.128	-0.1328	-0.14125	-0.13071	-0.08948	-0.16768
		Kurtosis	21.87355	22.12824	22.44403	22.13009	17.95976	24.1608
		MAE	0.00525	0.00524	0.00519	0.00523	0.00564	0.00506
		RMSE	0.0075	0.00749	0.00744	0.00749	0.00792	0.00727
	Imbalance	Min	-0.07729	-0.07713	-0.07693	-0.07768	-0.07367	-0.07347
		Max	0.06297	0.06332	0.06275	0.06363	0.07086	0.0609
		Mean	2.35E-04	2.56E-04	2.26E-04	2.58E-04	1.94E-04	2.30E-04
		Var	1.86E-04	1.82E-04	1.81E-04	1.82E-04	2.37E-04	1.62E-04
		Skew	-0.06878	-0.13597	-0.15311	-0.13682	0.18108	-0.09177
		Kurtosis	5.01532	5.05973	5.14036	5.05903	4.13161	5.47334
		MAE	0.01005	0.00991	0.00985	0.00991	0.01168	0.00928
		RMSE	0.01363	0.01349	0.01344	0.01348	0.0154	0.01274
Trimmed	Following	Min	-0.03197	-0.03185	-0.03174	-0.03182	-0.03226	-0.03171
		Max	0.02466	0.02466	0.02445	0.02467	0.025	0.02315
		Mean	1.63E-05	1.56E-05	1.59E-05	1.56E-05	1.62E-05	1.90E-05
		Var	4.87E-05	4.86E-05	4.78E-05	4.85E-05	5.51E-05	4.56E-05
		Skew	-0.3159	-0.31918	-0.32828	-0.31946	-0.24559	-0.34736
		Kurtosis	4.88472	4.9008	4.93882	4.90808	4.45058	5.01006
		MAE	0.00509	0.00509	0.00504	0.00508	0.00549	0.00491
		RMSE	0.00698	0.00697	0.00692	0.00697	0.00742	0.00675
	Imbalance	Min	-0.05055	-0.05041	-0.05055	-0.05053	-0.05094	-0.04971
		Max	0.04747	0.04688	0.04633	0.04685	0.05242	0.04621
		Mean	2.50E-04	2.75E-04	2.47E-04	2.77E-04	1.94E-04	2.48E-04
		Var	1.71E-04	1.67E-04	1.66E-04	1.67E-04	2.21E-04	1.48E-04
		Skew	-0.01172	-0.07296	-0.08414	-0.0737	0.20547	-0.00819
		Kurtosis	4.15184	4.19874	4.25049	4.19708	3.51053	4.43944
		MAE	0.00982	0.00969	0.00963	0.00969	0.01145	0.00905
		RMSE	0.01307	0.01294	0.01288	0.01293	0.01487	0.01217

Table 1 (cont.) – Full Data

Penetration Level		Wind	10	10	5	5	0
		Solar	5		25	5	30
		Geo		5		5	
		Bio	5	5		5	
		Wave	5	5		5	
		Tidal	5	5		5	
Untrimmed	Following	Min	-0.18081	-0.18116	-0.17893	-0.18083	-0.1786
		Max	0.17206	0.17218	0.1701	0.17172	0.16964
		Mean	6.85E-06	6.46E-06	7.78E-06	5.75E-06	7.07E-06
		Var	5.33E-05	5.25E-05	6.69E-05	5.13E-05	7.39E-05
		Skew	-0.16217	-0.17003	-0.06918	-0.17504	-0.03938
		Kurtosis	23.90111	24.5719	16.20407	25.40766	14.00037
		MAE	0.00509	0.00504	0.00584	0.00497	0.00616
		RMSE	0.0073	0.00724	0.00818	0.00716	0.0086
	Imbalance	Min	-0.07228	-0.0728	-0.07364	-0.07277	-0.07361
		Max	0.06056	0.06053	0.07698	0.06168	0.0831
		Mean	2.45E-04	2.52E-04	1.83E-04	2.41E-04	1.71E-04
		Var	1.63E-04	1.58E-04	2.70E-04	1.50E-04	3.25E-04
		Skew	-0.08014	-0.18217	0.24444	-0.0718	0.26145
		Kurtosis	5.41162	5.57458	3.89706	5.92904	3.68119
		MAE	0.00932	0.0091	0.01248	0.00879	0.01364
		RMSE	0.01278	0.01257	0.01644	0.01226	0.01802
Trimmed	Following	Min	-0.03183	-0.03157	-0.03231	-0.03165	-0.03245
		Max	0.0235	0.02349	0.02644	0.02302	0.02855
		Mean	1.88E-05	1.84E-05	1.23E-05	1.94E-05	6.76E-06
		Var	4.60E-05	4.53E-05	5.90E-05	4.42E-05	6.57E-05
		Skew	-0.33927	-0.35034	-0.22078	-0.35155	-0.18796
		Kurtosis	4.98719	5.05071	4.32878	5.0896	4.23779
		MAE	0.00494	0.00489	0.00569	0.00482	0.006
		RMSE	0.00679	0.00673	0.00768	0.00665	0.0081
	Imbalance	Min	-0.0491	-0.04989	-0.05135	-0.0495	-0.05273
		Max	0.04632	0.04553	0.05557	0.04555	0.05934
		Mean	2.63E-04	2.74E-04	1.74E-04	2.60E-04	1.56E-04
		Var	1.49E-04	1.44E-04	2.54E-04	1.36E-04	3.07E-04
		Skew	0.00027	-0.09337	0.25191	0.02788	0.25679
		Kurtosis	4.40126	4.53602	3.39064	4.78518	3.28851
		MAE	0.0091	0.00888	0.01225	0.00857	0.01339
		RMSE	0.01221	0.01201	0.01593	0.01168	0.01751

Table 1 (cont.) – Full Data

Penetration Level		Wind	Control Load	30	25	20	15	10	5
		Solar				5	5	5	5
		Geo					2.5	5	5
		Bio			5	5	2.5	5	5
		Wave					2.5	2.5	5
		Tidal					2.5	2.5	5
Trimmed	Following	Min	-0.03089	-0.03495	-0.03338	-0.03244	-0.03197	-0.03171	-0.03165
		Max	0.02271	0.0328	0.029	0.02646	0.02466	0.02315	0.02302
		Mean	1.82E-05	-2.16E-06	3.99E-06	1.10E-05	1.63E-05	1.90E-05	1.94E-05
		Var	4.21E-05	6.52E-05	5.82E-05	5.31E-05	4.87E-05	4.56E-05	4.42E-05
		Skew	-0.36042	-0.1928	-0.24393	-0.27981	-0.3159	-0.34736	-0.35155
		Kurtosis	5.26611	4.7725	4.76256	4.77913	4.88472	5.01006	5.0896
		MAE	0.00466	0.00588	0.00557	0.00533	0.00509	0.00491	0.00482
		RMSE	0.00649	0.00807	0.00763	0.00729	0.00698	0.00675	0.00665
	Imbalance	Min	-0.05084	-0.06351	-0.05776	-0.05487	-0.05055	-0.04971	-0.0495
		Max	0.04467	0.06211	0.05608	0.05119	0.04747	0.04621	0.04555
		Mean	2.42E-04	2.28E-04	2.34E-04	2.31E-04	2.50E-04	2.48E-04	2.60E-04
		Var	1.26E-04	2.86E-04	2.38E-04	2.02E-04	1.71E-04	1.48E-04	1.36E-04
		Skew	-0.06459	0.03964	-0.00445	-0.00172	-0.01172	-0.00819	0.02788
		Kurtosis	5.2542	3.97327	3.97726	4.02088	4.15184	4.43944	4.78518
		MAE	0.00803	0.01268	0.01159	0.01071	0.00982	0.00905	0.00857
		RMSE	0.01122	0.0169	0.01542	0.01422	0.01307	0.01217	0.01168

Table 2 – Summarized Comparison of Results

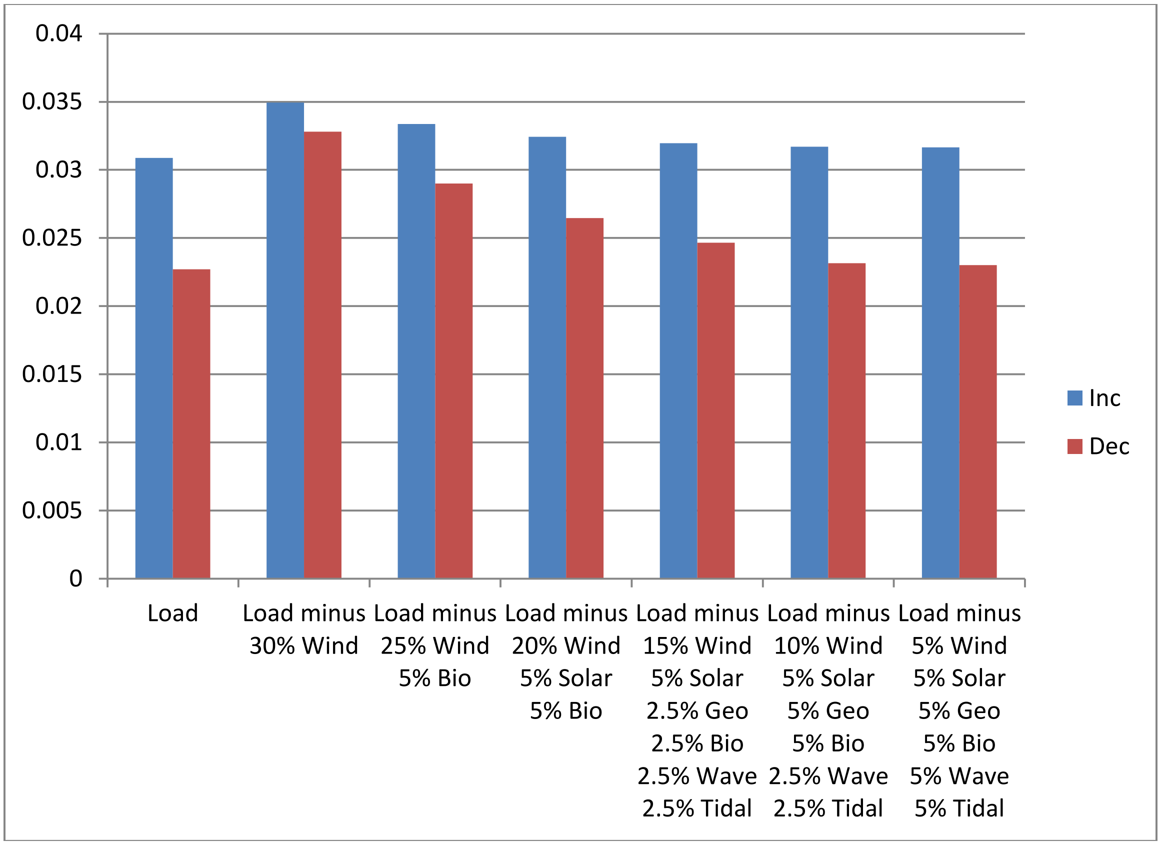

Figure 1 – Comparison of Incremental and Decremental Following Reserve Requirements of Options with Varying Levels of Wind Penetration listed in Table 2

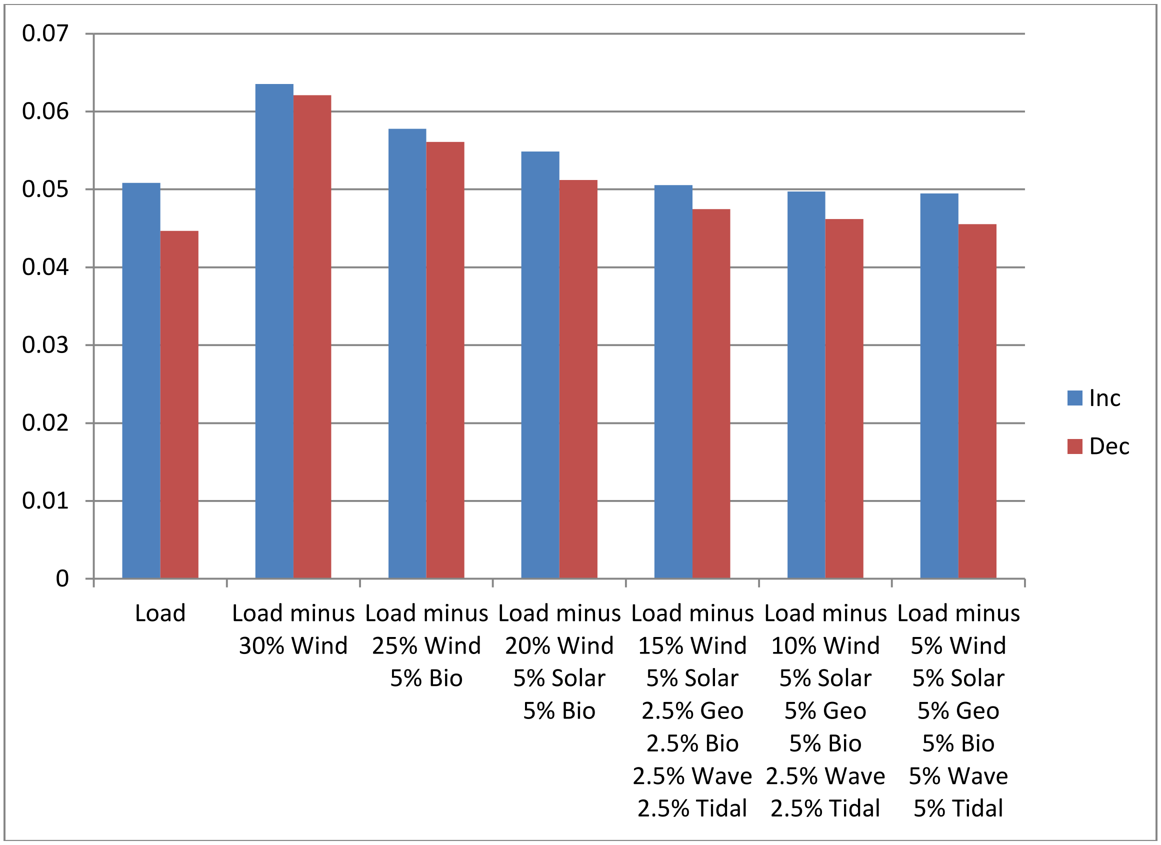

Figure 2 – Comparison of Incremental and Decremental Imbalance Reserve Requirements of Options with Varying Levels of Wind Penetration listed in Table 2

Of the statistical analyses used, the two most important measurements are the minimum and maximum, which represent the largest following and imbalance measurements over the course of the year. The minimum represents those times when either the load was greater than expected, the renewable energy generation was less than expected, or a combination of the two. The balancing operator must increase the non-renewable energy generation to deal with these shortages. On the other hand, the maximum represent the times when either the load was less than expected, the renewable energy generation was greater than expected, or a combination of the two. In this case, the balancing operator must decrease the generation of non-renewable energy.

As stated above, the control case analyzes on the total load. Since there are fewer factors affecting the prediction than the other tests, it follows that the following and imbalance are relatively low, and thus are theoretically better than runs with renewable energy. The minimum and maximum of the following are -0.03089 pu and 0.02271 pu (-301.5 MW and 221.7 MW) respectively. The imbalance has a minimum and maximum of -0.05084 pu and 0.04467 pu (-496.2 MW and 435.0 MW) respectively.

Once a renewable penetration of 30% wind is introduced, the minimum and maximum of both the following and imbalance take a significant jump. The following minimum and maximum jump to: -0.03495 pu and 0.0328 pu (-341.1 MW and 320.1 MW) respectively. The imbalance sees an even more drastic jump: -0.06351 pu and 0.06211 pu (-619.9 MW and 606.2 MW) respectively. Both of these increases show a need for a larger reserve requirement. In addition to these increases in reserve requirements, both the Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE) increase. Larger errors get weighted more heavily in the RMSE, which implies an increase in occurrences where greater reserve requirements are needed.

Following the minimum and maximum rows across Tables 1 and 2, the general trend is that as wind energy penetration decreases, the number of renewable sources increases, and the penetration percentages equalize, the reserve requirements for the grid decrease. The trial using 5% penetration from each source has the best combination of following and imbalance characteristics. The following minimum and maximum are -0.03165 pu and 0.02302 pu (-308.9 MW and 224.7 MW) respectively. The imbalance minimum and maximum are -0.0495 pu and 0.04555 pu (-483.1 MW and 444.6 MW) respectively. When compared to the control values, it can be seen that the minimum of the imbalance is actually closer to zero than the control. This shows that as the diversity of renewable resources increases, there are still low reserve requirements for the times when less renewable energy is produced than expected. In fact, even up to 15% penetration of wind, if all six renewable sources are used, the imbalance minimum is still better than that of the control.

In addition to the summary table (Table 2), two other tables were created to compare certain portions of the results. Table 3 holds a constant wind energy penetration of 20% and exchanges geothermal and biomass in 2.5% intervals while keeping the sum total at 10%. This survey was conducted to determine which source better meets the power requirements of the grid, as both have similar characteristics. Table 4 shows an exchange of solar and wind energy in 5% increments, while keeping the sum total of the two at 30%. Figures 3 and 4 visualize the results of Table 4 much like Figures 1 and 2 do for Table 2. Both wind and solar energy are similar in that they are the most unpredictable of the sources studied, hence determining a good ratio between these two can help guide grid-connected renewable energy operations.

Penetration Level		Wind	20	20	20	20	20
		Solar					
		Geothermal	10	7.5	5	2.5	
		Biomass		2.5	5	7.5	10
		Wave					
		Tidal					
Trimmed	Following	Min	-0.03244	-0.03244	-0.03244	-0.03235	-0.03219
		Max	0.02638	0.02652	0.02644	0.02639	0.0264
		Mean	1.06E-05	1.06E-05	1.06E-05	1.06E-05	1.05E-05
		Var	5.26E-05	5.24E-05	5.24E-05	5.24E-05	5.25E-05
		Skew	-0.28731	-0.28815	-0.28841	-0.28811	-0.28725
		Kurtosis	4.80784	4.81593	4.81847	4.81579	4.80755
		MAE	0.0053	0.00529	0.00529	0.00529	0.00529
		RMSE	0.00725	0.00724	0.00724	0.00724	0.00725
	Imbalance	Min	-0.05512	-0.0549	-0.0548	-0.05477	-0.05453
		Max	0.04926	0.04952	0.04961	0.04969	0.04958
		Mean	2.43E-04	2.43E-04	2.42E-04	2.41E-04	2.40E-04
		Var	1.98E-04	1.98E-04	1.98E-04	1.98E-04	1.98E-04
		Skew	-0.04974	-0.04877	-0.04783	-0.04697	-0.04611
		Kurtosis	4.06147	4.06372	4.06492	4.06477	4.06357
		MAE	0.01058	0.01057	0.01057	0.01057	0.01057
		RMSE	0.01407	0.01407	0.01407	0.01407	0.01408

Table 3 – Comparison of Geothermal and Biomass at Constant Wind Penetration

Penetration Level		Wind	30	25	20	15	10	5	0
		Solar		5	10	15	20	25	30
		Geo							
		Bio							
		Wave							
		Tidal							
Trimmed	Following	Min	-0.03495	-0.03377	-0.03274	-0.03239	-0.03226	-0.03231	-0.03245
		Max	0.0328	0.02933	0.02658	0.02507	0.025	0.02644	0.02855
		Mean	-2.16E-06	4.47E-06	1.13E-05	1.60E-05	1.62E-05	1.23E-05	6.76E-06
		Var	6.52E-05	5.88E-05	5.50E-05	5.38E-05	5.51E-05	5.90E-05	6.57E-05
		Skew	-0.1928	-0.23755	-0.25878	-0.25938	-0.24559	-0.22078	-0.18796
		Kurtosis	4.7725	4.73553	4.6735	4.57478	4.45058	4.32878	4.23779
		MAE	0.00588	0.00561	0.00544	0.0054	0.00549	0.00569	0.006
		RMSE	0.00807	0.00767	0.00742	0.00733	0.00742	0.00768	0.0081
	Imbalance	Min	-0.06351	-0.05863	-0.05521	-0.05158	-0.05094	-0.05135	-0.05273
		Max	0.06211	0.05734	0.05287	0.05115	0.05242	0.05557	0.05934
		Mean	2.28E-04	2.26E-04	2.21E-04	2.11E-04	1.94E-04	1.74E-04	1.56E-04
		Var	2.86E-04	2.41E-04	2.16E-04	2.09E-04	2.21E-04	2.54E-04	3.07E-04
		Skew	0.03964	0.0232	0.05274	0.12721	0.20547	0.25191	0.25679
		Kurtosis	3.97327	3.95561	3.86612	3.69524	3.51053	3.39064	3.28851
		MAE	0.01268	0.01171	0.01117	0.01108	0.01145	0.01225	0.01339
		RMSE	0.0169	0.01554	0.01469	0.01445	0.01487	0.01593	0.01751

Table 4 – Wind vs. Solar Tradeoff at Constant Penetration

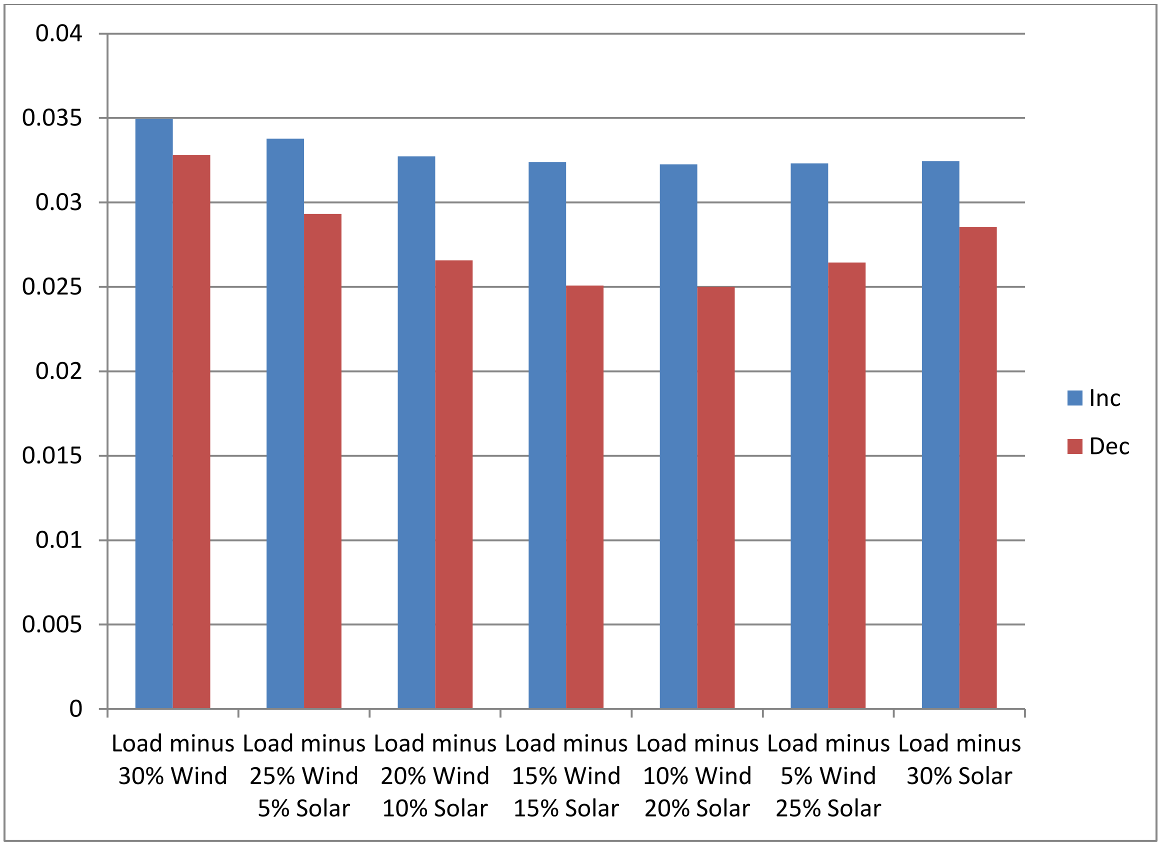

Figure 3 – Comparison of Incremental and Decremental Following Reserve Requirements of Wind vs. Solar Tradeoff at Constant Penetration (Table 4)

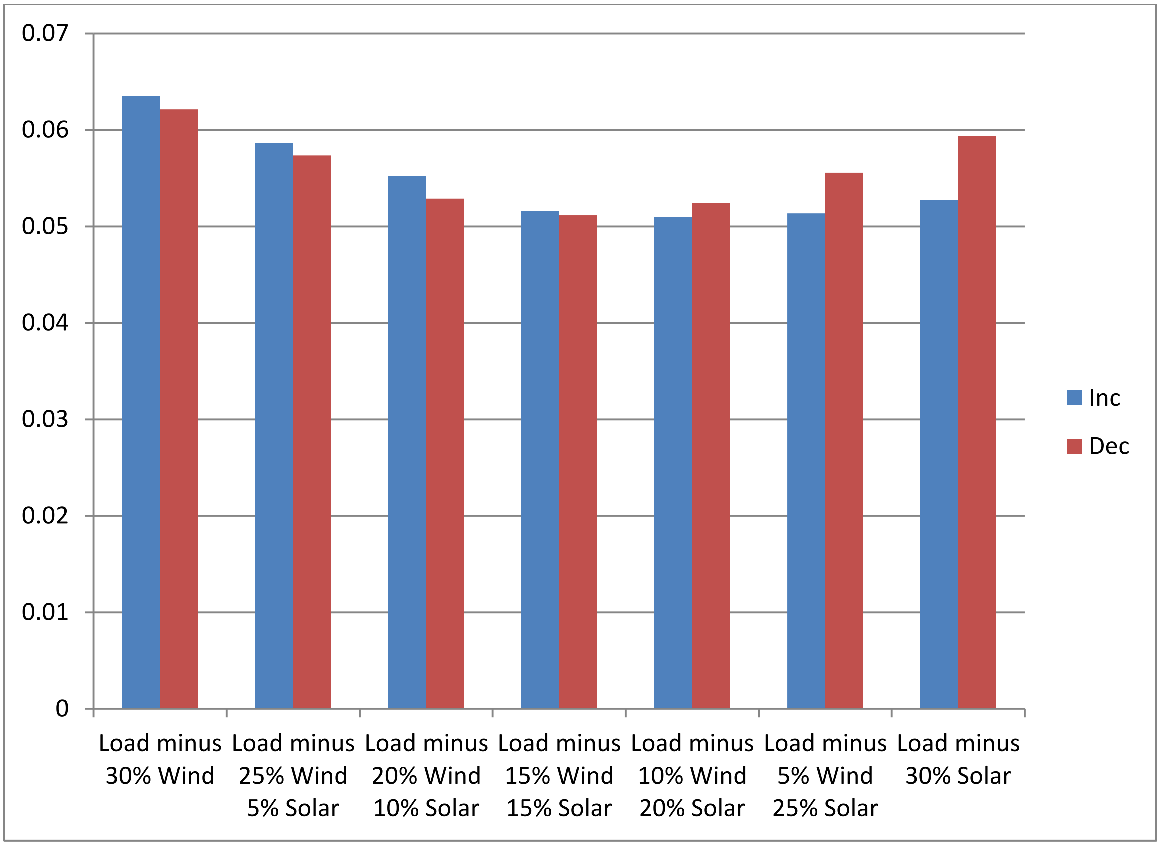

Figure 4 – Comparison of Incremental and Decremental Imbalance Reserve Requirements of Wind vs. Solar Tradeoff at Constant Penetration (Table 4)

As the minimum and maximum of the following and imbalance are followed across the rows of Table 3 (direction of decreasing geothermal production and increasing biomass production), an pattern emerges: that the reserve requirements stay largely the same. The means of the following minimum and maximum are -0.03237 pu and 0.026426 pu (-315.9 MW and 257.9 MW), while the imbalance minimum and maximum means are -0.05482 pu and 0.049532 pu (-535.0 MW and 483.4 MW). All data points are within three standard deviations of the mean, hence there are no large outliers to skew the average. Given these results, it can be seen that both biomass and geothermal have approximately the same level of impact on reserve requirements, which is expected due to both energy sources being dispatchable.

Table 4, as stated above, directly compares exchanged wind and solar energy at 30% penetration. The first two cases to compare are the 30% wind and 30% solar cases. The 30% wind following results are -0.03495 pu and 0.03280 pu (-341.1 MW and 320 MW), while the imbalance results are -0.06351 pu and 0.06211 pu (-619.9 MW and 606.2 MW). The 30% solar case gives following results of -0.03245 pu and 0.02855 pu (-316.7 MW and 278.6 MW) and imbalance results of -0.05273 pu and 0.05934 pu (-514.6 MW and 579 MW). Inspecting these two cases, it is clear that 30% solar has much better reserve requirements than 30% wind. This result becomes especially clear when looking at the imbalance minimum, in which there is a difference of over 100 MW.

Two other cases from Table 4 to inspect closer are the 15% wind, 15% solar and 10% wind, 20% solar cases. While the following and imbalance results for the two are slightly similar, each case has certain advantages and disadvantages. The optimum following results occur in the 10% wind, 20% solar case, with the values being -0.03226 pu and 0.02500 pu (-324.9 MW and 244.0 MW). While slightly larger, the following results of the 15% wind, 15% solar case are within 0.00015 pu (less than 1.5 MW) of the optimum. However, the imbalance results of the two cases present a slight dilemma. The results for the 15% wind, 15% solar case are -0.05158 pu and 0.05115 pu (-503.4 MW and 499.2 MW), while the 10% wind, 20% solar case gives -0.05094 pu and 0.05242 pu (-497.2 MW and 511.6 MW). The 15% wind, 15% solar case provides better reserve requirements when judged by the difference between the minimum and maximum values, but the individual values of the minimum and maximum must also be taken into account. The 10% wind, 20% solar case has a minimum closer to 0, which indicates that there is less of a deficit when renewable energy generation is less than predicted. Using this line of reasoning, it appears there is a tradeoff between a tighter range of reserve requirements or reserve requirements that tend to be more positive. Once the mean is added into the analysis, however, the best result becomes clear. The 15% wind, 15% solar case has a higher mean (2.11E-04 pu, or 2.06 MW), indicating the imbalance is positive more often than the 10% wind, 20% solar case. The variance, MAE, and RMSE are also all smaller in the 15% wind, 15% solar case, leading to more accurate predictions. Using the above results and analysis, an equal split of wind and solar is ideal, even with slightly larger reserve requirements.

Section 4) Conclusions

This study shows the impact of renewable energy at high penetration levels on reserve requirements. As a greater diversity is incorporated into the grid, and as more renewable sources are equally included in energy generation, the reserve requirements decrease and come close to matching, and sometimes beating, that of the control case. However, the current state of renewable energy in the grid leans very strongly to wind. Significant investments will be needed to increase the diversity of renewable energy in the PNW. A diverse mix of renewable energy helps counteract the impact of individual variable, non-dispatchable renewable energy sources, and reduces the impact of variability and uncertainty in meeting the power demand.

Section 5) References

[1] Halamay, D.A.; Brekken, T.K.A.; Simmons, A.; McArthur, S.; , "Reserve Requirement Impacts of Large-Scale Integration of Wind, Solar, and Ocean Wave Power Generation," *Sustainable Energy, IEEE Transactions on* , vol.2, no.3, pp.321-328, July 2011 doi: 10.1109/TSTE.2011.2114902

[2] Herbert, G. M. J., Iniyan, S., Sreevalsan, E., & Rajapandian, S. (2007). A review of wind energy technologies. Renewable and Sustainable Energy Reviews, 11(6), 1117-1145. doi: 10.1016/j.rser.2005.08.004

[3] *Domestic scale wind turbines, 1 - 6 kw*. (2013). Retrieved from http://www.greenspec.co.uk/small-wind-turbines.php

[4] *Wind energy basics*. (2008). Retrieved from http://windeis.anl.gov/guide/basics/index.cfm

[5] Toothman, J., & Aldous, S. (2010). *How solar cells work: How silicon makes a solar cell*. Retrieved from http://science.howstuffworks.com/environmental/energy/solar-cell2.htm

[6] (2012). Concentraing solar power. *Renewable Energy Technologies: Cost Analysis Series*, *1*(2), Retrieved from http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-CSP.pdf

[7] Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy*, *33*(3), 289-296. doi: 10.1016/S0301-4215(03)00241-6

[8] *Devices*. (2103). Retrieved from http://nnmrec.oregonstate.edu/devices

[9] Pelc, R., & Fujita, R. M. (2002). Renewable energy from the ocean. *Marine Policy*, *26*(6), 471-479. doi: 10.1016/S0308-597X(02)00045-3

[10]Zimesnick, M. (2010, Jan 28). *Advantages and disadvantages of wave power*. Retrieved from http://renewableenergyindex.com/hydro/advantages-disadvantages-wave-power

[11]*Fundamentals of tidal energy*. (2011, Nov 19). Retrieved from http://depts.washington.edu/nnmrec/overview.html

[12]Wong, J. (2006). *Tidal energy*. Retrieved from http://www.odec.ca/projects/2006/wong6j2/tidal.html

[13]*Geothermal electricity production*. (2013). Retrieved from http://www.renewableenergyworld.com/rea/tech/geoelectricity

[14]*Advantages of geothermal energy*. (2013). Retrieved from http://www.conserve-energy-future.com/Advantages_GeothermalEnergy.php

[15]*Disadvantages of geothermal energy*. (2013). Retrieved from http://www.conserve-energy-future.com/Disadvantages_GeothermalEnergy.php

[16]*How biomass energy works*. (2010, Oct 29). Retrieved from http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-biomass-energy-works.html

[17]*Wind generation & total load in the bpa balancing authority*. (2013). Retrieved from http://transmission.bpa.gov/Business/Operations/Wind/default.aspx

[18]*Solar data*. (2004, Mar 9). Retrieved from http://solardat.uoregon.edu/SolarData.html

[19]S. McArthur, T.K.A. Brekken, "Ocean Wave Power Data Generation for Grid Integration Studies," Power and Energy Society General Meeting, 2010.

[20]*Monthly energy review*. (2012, Dec 21). Retrieved from http://www.eia.gov/totalenergy/data/monthly/index.cfm

[21]U.S. Energy Information Administration, (2012). *Annual energy review 2011*. Retrieved from website: http://oregonstate.qualtrics.com/WRQualtricsSurveyEngine/?Q_SS=4JfBH8NUxgCen6l_8of3AaqvmhEkVH7&_=1

[22]*Task overview*. (2012, Oct 1). Retrieved from http://depts.washington.edu/nnmrec/project_meas.html

APPENDICES

Appendix A) Data Test Runs

Penetration Level	Wind	0	30	25	25	25	25	25	20	20	20	20	20	20	20	20	20	20
	Solar	0		5					10					5	5	5	5	
	Geothermal	0			5					10				5				7.5
	Biomass	0				5					10				5			2.5
	Wave	0					5					10				5		
	Tidal	0						5					10				5	
Penetration Level	Wind	20	20	20	20	15	15	15	15	15	15	15	15	15	15	15	15	15
	Solar					15					10	10	10	10				5
	Geothermal	5	5	5	2.5		15				5				10	10	10	
	Biomass	5			7.5			15				5			5			5
	Wave		5						15				5			5		5
	Tidal			5						15				5			5	
Penetration Level	Wind	15	15	15	15	15	15	10	10	10	10	5	5	0				
	Solar	5	5	5				20	5	5		25	5	30				
	Geothermal			2.5	5	5	5		5		5		5					
	Biomass	5		2.5	5	5			5	5	5		5					
	Wave		5	2.5	5		5		2.5	5	5		5					
	Tidal	5	5	2.5		5	5		2.5	5	5		5					

Appendix B) Code (example):
5% Wind, 5% Solar, 5% Geothermal, 5% Biomass, 5% Wave, 5% Tidal

```
% File: DataAnalysisWind5Solar5Geo5Wave5Bio5Tidal5.m
% Based off DataAnalysis2.m by Doug Halamay
% Author: Scott Harpool

%% Data Loading
clc;
clear all;
close all;

% Load 2010 load data
load2010 = load('10LoadData.mat');

% Load 2011 load data
load2011 = load('11LoadData.mat');

% Load 2011 wind data
wind2011 = load('11WindData.mat');

% Load 2008 solar data
solar2008 = load('08SolarData.mat');

% Load 2008 wave data
wave2008 = load('08WaveData.mat');

% Load 2011 biomass data
bio2011 = load('11BioData.mat');

% Load 2011 tidal data
tidal2011 = load('11TidalData.mat');

% Load 2008 geothermal data
geo2011 = load('11ThermData.mat');

%% Initialization

dataLength = length(load2011.data);

% Get maximums for 2010 and 2011 data
load2010max = max(load2010.data);
load2011max = max(load2011.data);
wind2011max = max(wind2011.data);
tidal2011max = max(tidal2011.TidalData10min);
bio2011max = max(bio2011.BiomassMW);
geo2011max = max(geo2011.data);
```

```
% Create new arrays to normalize load data into
load10 = zeros(dataLength, 1);
load11 = zeros(dataLength, 1);
wind11 = zeros(dataLength, 1);
solar08 = zeros(dataLength, 1);
wave08 = zeros(dataLength, 1);
bio11 = zeros(dataLength, 1);
tidal11 = zeros(dataLength, 1);
geo11 = zeros(dataLength, 1);

% Create new arrays for hour averages
load11HourAve = zeros(dataLength, 1);
load11NetHourAve = zeros(dataLength, 1);
load10HourAve = zeros(dataLength, 1);
wind11HourAve = zeros(dataLength, 1);
solar08HourAve = zeros(dataLength, 1);
wave08HourAve = zeros(dataLength, 1);
bio11HourAve = zeros(dataLength, 1);
tidal11HourAve = zeros(dataLength, 1);
geo11HourAve = zeros(dataLength, 1);

load11Net = zeros(dataLength, 1);

% Normalize 2010 load data
for n = 1:dataLength
   load10(n, 1) = load2010.data(n, 1) / load2011max;
end

% Normalize 2011 load data
for n = 1:dataLength
   load11(n, 1) = load2011.data(n, 1) / load2011max;
end

% Normalize 2011 wind data to 2011 load data max
for n = 1:dataLength
   wind11(n, 1) = wind2011.data(n, 1) / load2011max;
end

% Normalize 2008 solar data to 2011 load data max
% Get data into array
for n = 1:dataLength
   solar08(n, 1) = solar2008.solar10(1, n);
end
% Data must be converted to MW
solar08 = solar08./1e6;
solar2008max = max(solar08);
% Data normalized
solar08 = solar08./load2011max;
```

```
% Normalize 2008 wave data to 2011 load data max
% Get data into array
for n = 1:dataLength
   wave08(n, 1) = wave2008.wave10(1, n);
end
% Data must be converted to MW
wave08 = wave08./1e6;
wave2008max = max(wave08);
% Data normalized
wave08 = wave08./load2011max;

% Normalize 2011 biomass data to 2011 load data max
% Get data into array
for n = 1:dataLength
   bio11(n, 1) = bio2011.BiomassMW(n, 1) / load2011max;
end

% Normalize 2011 tidal data to 2011 load data max
% Get data into array
for n = 1:dataLength
   tidal11(n, 1) = tidal2011.TidalData10min(n, 1);
end
% Data normalized
tidal11 = tidal11./load2011max;

% Normalize 2011 geothermal data to 2011 load data max
% Get data into array
for n = 1:dataLength
   geo11(n, 1) = geo2011.data(n, 1) / load2011max;
end

% Scale 2011 wind data to 20%
wind11 = wind11.*(.05/(wind2011max/load2011max));

% Scale 2008 solar data to 5%
solar08 = solar08.*(.05/(solar2008max/load2011max));

% Scale 2008 wave data to 5%
wave08 = wave08.*(.05/(wave2008max/load2011max));

% Scale 2011 biomass data to 5%
bio11 = bio11.*(.05/(bio2011max/load2011max));

% Scale 2011 tidal data to 5%
tidal11 = tidal11.*(.05/(tidal2011max/load2011max));

% Scale 2011 geothermal data to 5%
```

```
geo11 = geo11.*(.05/(geo2011max/load2011max));

% Calculate net load
load11Net = load11 - wind11 - solar08 - geo11 - wave08 - bio11 - tidal11;

%% Initialize following and imbalance matrices
% These will come in handy later when we calculate stats on all of the
% collected data.

follow = zeros(dataLength, 1);
imbalance = zeros(dataLength, 1);

%% Perform load analysis

% Calculate load hour averages
% These are calculated at the 0:50 point, including the previous six data
% points (including the 0:50 point).
load11HourAve(1) = load11(1);
for i=6:6:length(load11)
   load11HourAve(i-4:i) = mean(load11(i-5:i));
   if(i>6)
      load11HourAve(i-5) = (load11HourAve(i-4) + load11HourAve(i-6))/2;
   end
end

% Initialize the load schedule vector
loadSchedule = NaN(size(load11));

% Calculate previous year load hour averages (introduces month-to-month
% transition discontinuities)
load10HourAve(1) = load10(1);
for i=6:6:length(load10)
   load10HourAve(i-4:i) = mean(load10(i-5:i));
   if(i>6)
      load10HourAve(i-5) = (load10HourAve(i-4) + load10HourAve(i-6))/2;
   end
end

% Calculate hour average load differences between 2007 and 2008
loadDiff = load11HourAve - load10HourAve;

% Initialize loadSchedule with the first hour
loadSchedule(1:7) = load11HourAve(1:7);

% Calculate the scheduled load using the previous year's data and some
% logic functions
for i = 6:6:length(load11)-3
   for k = 2:6
```

```
        loadSchedule(i+k) = load10HourAve(i+k) + mean(loadDiff(i-5:i));
    end

    % Deal with discontinuity issues caused by month-to-month transitions
    if (mean(diff(load11(i-4:i))) < 0 && (loadSchedule(i+2) > loadSchedule(i))) ||
(mean(diff(load11(i-4:i))) > 0 && (loadSchedule(i+2) < loadSchedule(i)))
        % Go with 1-hour persistence in these cases
        loadSchedule(i+2:i+6) = load11(i);
    end

    % Fix the transition point
    loadSchedule(i+1) = (loadSchedule(i) + loadSchedule(i+2))/2;
end

% Fix the NaNs (for the very last hour)
loadScheduleNaNs = find(isnan(loadSchedule));
loadSchedule(loadScheduleNaNs) = load11(loadScheduleNaNs);

%% Perform 5% wind analysis

% Calculate wind hour averages
% These are calculated at the 0:50 point, including the previous six data
% points (including the 0:50 point).
wind11HourAve(1) = wind11(1);
for i=6:6:length(wind11)
    wind11HourAve(i-4:i) = mean(wind11(i-5:i));
    if(i>6)
        wind11HourAve(i-5) = (wind11HourAve(i-4) + wind11HourAve(i-6))/2;
    end
end

% Calculate the scheduled power (1-hour persistence)
% Utilize Dr. Brekken's powerforecast function
windSchedule = powerforecastfixed(wind11,0,0,1,2);

% Fix the NaNs (for the very first hour)
windScheduleNaNs = find(isnan(windSchedule));
windSchedule(windScheduleNaNs) = wind11HourAve(windScheduleNaNs);

%% Perform 5% solar analysis

% Calculate solar hour averages
% These are calculated at the 0:50 point, including the previous six data
% points (including the 0:50 point).
solar08HourAve(1) = solar08(1);
for i=6:6:length(solar08)
    solar08HourAve(i-4:i) = mean(solar08(i-5:i));
    if(i>6)
```

```
    solar08HourAve(i-5) = (solar08HourAve(i-4) + solar08HourAve(i-6))/2;
  end
end

% Calculate the scheduled power (1-hour persistence)
% Utilize Dr. Brekken's powerforecast function
solarSchedule = powerforecastfixed(solar08,0,0,1,2);

% Fix the NaNs (for the very first hour)
solarScheduleNaNs = find(isnan(solarSchedule));
solarSchedule(solarScheduleNaNs) = solar08HourAve(solarScheduleNaNs);

%% Perform 5% wave analysis

% Calculate solar hour averages
% These are calculated at the 0:50 point, including the previous six data
% points (including the 0:50 point).
wave08HourAve(1) = wave08(1);
for i=6:6:length(wave08)
  wave08HourAve(i-4:i) = mean(wave08(i-5:i));
  if(i>6)
    wave08HourAve(i-5) = (wave08HourAve(i-4) + wave08HourAve(i-6))/2;
  end
end

% Calculate the scheduled power (1-hour persistence)
% Utilize Dr. Brekken's powerforecast function
waveSchedule = powerforecastfixed(wave08,0,0,1,2);

% Fix the NaNs (for the very first hour)
waveScheduleNaNs = find(isnan(waveSchedule));
waveSchedule(waveScheduleNaNs) = wave08HourAve(waveScheduleNaNs);

%% Perform 5% biomass analysis

% Calculate geothermal hour averages
% These are calculated at the 0:50 point, including the previous six data
% points (including the 0:50 point).
bio11HourAve(1) = bio11(1);
for i=6:6:length(bio11)
  bio11HourAve(i-4:i) = mean(bio11(i-5:i));
  if(i>6)
    bio11HourAve(i-5) = (bio11HourAve(i-4) + bio11HourAve(i-6))/2;
  end
end

% Calculate the scheduled power (1-hour persistence)
% Utilize Dr. Brekken's powerforecast function
```

```
bioSchedule = powerforecastfixed(bio11,0,0,1,2);

% Fix the NaNs (for the very first hour)
bioScheduleNaNs = find(isnan(bioSchedule));
bioSchedule(bioScheduleNaNs) = bio11HourAve(bioScheduleNaNs);

%% Perform 5% tidal analysis

% Calculate tidal hour averages
% These are calculated at the 0:50 point, including the previous six data
% points (including the 0:50 point).
tidal11HourAve(1) = tidal11(1);
for i=6:6:length(tidal11)
   tidal11HourAve(i-4:i) = mean(tidal11(i-5:i));
   if(i>6)
      tidal11HourAve(i-5) = (tidal11HourAve(i-4) + tidal11HourAve(i-6))/2;
   end
end

% Calculate the scheduled power (1-hour persistence)
% Utilize Dr. Brekken's powerforecast function
tidalSchedule = powerforecastfixed(tidal11,0,0,1,2);

% Fix the NaNs (for the very first hour)
tidalScheduleNaNs = find(isnan(tidalSchedule));
tidalSchedule(tidalScheduleNaNs) = tidal11HourAve(tidalScheduleNaNs);

%% Perform 5% geothermal analysis

% Calculate geothermal hour averages
% These are calculated at the 0:50 point, including the previous six data
% points (including the 0:50 point).
geo11HourAve(1) = geo11(1);
for i=6:6:length(geo11)
   geo11HourAve(i-4:i) = mean(geo11(i-5:i));
   if(i>6)
      geo11HourAve(i-5) = (geo11HourAve(i-4) + geo11HourAve(i-6))/2;
   end
end

% Calculate the scheduled power (1-hour persistence)
% Utilize Dr. Brekken's powerforecast function
geoSchedule = powerforecastfixed(geo11,0,0,1,2);

% Fix the NaNs (for the very first hour)
geoScheduleNaNs = find(isnan(geoSchedule));
geoSchedule(geoScheduleNaNs) = geo11HourAve(geoScheduleNaNs);
```

```
%% Perform load net 5% wind and 5% solar and 5% geo and 5% tidal and 5% biomass and 5%
wave analysis

% Calculate load net wind hour averages
% These are calculated at the 0:50 point, including the previous six data
% points (including the 0:50 point).
load11NetHourAve(1) = load11Net(1);
for i=6:6:length(load11Net)
  load11NetHourAve(i-4:i) = mean(load11Net(i-5:i));
  if(i>6)
    load11NetHourAve(i-5) = (load11NetHourAve(i-4) + load11NetHourAve(i-6))/2;
  end
end

% Calculate following difference
follow(:,1) = load11NetHourAve - load11Net;

% Fix the NaN's in the follow array
followNaNs = find(isnan(follow));
n = length(followNaNs);
for k = 1:n
  follow(followNaNs(k)) = follow(followNaNs(k) - 1);
end

% Calculate the scheduled power (1-hour persistence)
% Utilize Dr. Brekken's powerforecast function for the wind schedule and
% the custom load schedule algorithm above
loadnetSchedule = loadSchedule - windSchedule - geoSchedule - tidalSchedule - solarSchedule -
waveSchedule - bioSchedule;

% Fix the NaNs (for the very first hour)
loadnetScheduleNaNs = find(isnan(loadnetSchedule));
loadnetSchedule(loadnetScheduleNaNs) = load11Net(loadnetScheduleNaNs);

% Calculate the imbalance difference
imbalance(:,1) = loadnetSchedule - load11NetHourAve;

% Fix the NaN's in the imbalance array
imbalanceNaNs = find(isnan(imbalance));
n = length(imbalanceNaNs);
for k = 1:n
  imbalance(imbalanceNaNs(k)) = imbalance(imbalanceNaNs(k) - 1);
end

%% Outlier removal

% Throw out the top and bottom 0.25% of the following and imbalance
% matrices by using a temp matrix to sort into and then trimming
```

```
followTempSort = zeros(dataLength, 1);
imbalanceTempSort = zeros(dataLength, 1);

% Sort the data
%for k=1:7
followTempSort(:, 1) = sort(follow(:, 1));
imbalanceTempSort(:, 1) = sort(imbalance(:, 1));
%end

% Create new (shorter) matrices to contain the trimmed data
newDataLength = ceil(dataLength*.995);
followSort = zeros(newDataLength, 1);
imbalanceSort = zeros(newDataLength, 1);

% Cut off the bottom and top 0.25% of the data and save in the new matrices
m = 1;
start = ceil((dataLength - newDataLength)/2);
stop = ceil(dataLength - (dataLength - newDataLength)/2);
for k = start:stop
  followSort(m, 1) = followTempSort(k, 1);
  imbalanceSort(m, 1) = imbalanceTempSort(k, 1);
  m = m + 1;
end

%% Display results in a table

results1 = zeros(8,1);
results2 = zeros(8,1);
results3 = zeros(8,1);
results4 = zeros(8,1);

% Create a cell array to store the labels for easy access
labels = cell(8,1);
labels{1} = 'Min     ';
labels{2} = 'Max     ';
labels{3} = 'Mean    ';
labels{4} = 'Var     ';
labels{5} = 'Skew    ';
labels{6} = 'Kurtosis';
labels{7} = 'MAE     ';
labels{8} = 'RMSE    ';

% Calculate stats

% Following
results1(1,1) = min(follow(:,1));
results1(2,1) = max(follow(:,1));
results1(3,1) = mean(follow(:, 1));
```

```
results1(4,1) = var(follow(:,1));
results1(5,1) = skewness(follow(:,1));
results1(6,1) = kurtosis(follow(:,1));
% MAE
results1(7,1) = (1/length(follow(:,1)))*sum(abs(follow(:,1)));
% RMSE
results1(8,1) = sqrt((1/length(follow(:,1)))*sum((follow(:,1)).^2));

% Imbalance
results2(1,1) = min(imbalance(:,1));
results2(2,1) = max(imbalance(:,1));
results2(3,1) = mean(imbalance(:,1));
results2(4,1) = var(imbalance(:,1));
results2(5,1) = skewness(imbalance(:,1));
results2(6,1) = kurtosis(imbalance(:,1));
% MAE
results2(7,1) = (1/length(imbalance(:,1)))*sum(abs(imbalance(:,1)));
% RMSE
results2(8,1) = sqrt((1/length(imbalance(:,1)))*sum((imbalance(:,1)).^2));

% Following (99.5% Data)
results3(1,1) = min(followSort(:,1));
results3(2,1) = max(followSort(:,1));
results3(3,1) = mean(followSort(:,1));
results3(4,1) = var(followSort(:,1));
results3(5,1) = skewness(followSort(:,1));
results3(6,1) = kurtosis(followSort(:,1));
% MAE
results3(7,1) = (1/length(followSort(:,1)))*sum(abs(followSort(:,1)));
% RMSE
results3(8,1) = sqrt((1/length(followSort(:,1)))*sum((followSort(:,1)).^2));

% Imbalance (99.5% Data)
results4(1,1) = min(imbalanceSort(:,1));
results4(2,1) = max(imbalanceSort(:,1));
results4(3,1) = mean(imbalanceSort(:,1));
results4(4,1) = var(imbalanceSort(:,1));
results4(5,1) = skewness(imbalanceSort(:,1));
results4(6,1) = kurtosis(imbalanceSort(:,1));
% MAE
results4(7,1) = (1/length(imbalanceSort(:,1)))*sum(abs(imbalanceSort(:,1)));
% RMSE
results4(8,1) = sqrt((1/length(imbalanceSort(:,1)))*sum((imbalanceSort(:,1)).^2));

disp('Following:')
disp('            ____(pu)_____')
disp('Statistic    Wind5Solar5Geo5Wave5Bio5Tidal5       ')
for k = 1:8
```

```
  if (k == 3 || k==4)
    disp([labels{k},'    ',sprintf('% 0.4e',results1(k,1)),]);
  else
    disp([labels{k},'      ',sprintf('%9.5f',results1(k,1)),]);
  end
end

disp(' ');
disp('Imbalance:')
disp('             ____(pu)_____')
disp('Statistic    Wind5Solar5Geo5Wave5Bio5Tidal5     ')
for k = 1:8
  if (k == 3 || k==4)
    disp([labels{k},'    ',sprintf('% 0.4e',results2(k,1)),]);
  else
    disp([labels{k},'      ',sprintf('%9.5f',results2(k,1)),]);
  end
end

disp(' ');
disp(' ');
disp('With Outliers Removed (kept middle 99.5% of data):');
disp('Following:')
disp('             ____(pu)_____')
disp('Statistic    Wind5Solar5Geo5Wave5Bio5Tidal5     ')
for k = 1:8
  if (k == 3 || k==4)
    disp([labels{k},'    ',sprintf('% 0.4e',results3(k,1)),]);
  else
    disp([labels{k},'      ',sprintf('%9.5f',results3(k,1)),]);
  end
end

disp(' ');
disp('Imbalance:')
disp('             ____(pu)_____')
disp('Statistic    Wind5Solar5Geo5Wave5Bio5Tidal5     ')
for k = 1:8
  if (k == 3 || k==4)
    disp([labels{k},'    ',sprintf('% 0.4e',results4(k,1)),]);
  else
    disp([labels{k},'      ',sprintf('%9.5f',results4(k,1)),]);
  end
end
```