College of Engineering

Civil and Environmental Engineering

CEE 5910: Master of Engineering Management Project Fall 2013

Combining Renewable Energy Options in the Pacific Northwest

Advisor: Professor Francis M. Vanek

Team Members

Shaheen Mashraqui (leader)	Zeyu Bai	Francisco Saravia
Jeff Alfano	Julio Gerlein	Vaibhav Gupta
Mark Howe	Cheuk Hui	Anuj Gautam
Vani Rikhy	Harim Choi	Mengying Shi
Ingrid Tu	Maria Vissas	Mahina Wang
Nandkishore Sathiamoorthy		

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1. Project Advisor's Preface

The following report is one of a series of technical reports produced by teams of engineering graduate students from the M.Eng in Engineering Management program at Cornell University, going back to the year 2004 (see www.lightlink.com/francis/). Student members of each team join after choosing from among several project team topics offered by our M.Eng program, and organized structure that would execute the research. Thus the concept and initial outline for the project is chosen by me, the advisor, but once launched, the student team is in charge of its management.

The topic, namely renewable energy in the Pacific Northwest, originally came to my attention thanks to news of the closing of the Transalta coal-fired thermal power station in Centralia, WA. Given the large potential for wind, solar, and biomass power generation in the region, the possibility of both reducing CO_2 emissions and generating new jobs by replacing fossil-generated electricity with renewables appeared interesting. I reached out to the Renewable Northwest Project office in Portland, OR, and developed collaboration with Michael O'Brien of RNP. I would like to thank him for his valuable time and input. Although in the project we chose to focus on the states of Oregon and Washington for reasons of time and resource limits, a more complete study of the region would ideally also include the states of Idaho and Montana, and this could provide a fruitful extension in the future.

From my perspective as advisor, some of the highlights of the project and report include information obtained about Geographic availability of wind, solar, and renewable resources in different parts of two-state region. The presentation about the diurnal (i.e., 24-hour) and seasonal variability of solar and wind is also important, as is the comparison to daily and seasonal variation in electricity demand. Readers of Chap.13 on the optimal mix of wind/solar/biomass to meet demand under varying solar/wind availability and electricity demand will notice quite high average values of levelized cost per kWh. These values should be interpreted carefully, since they are a function of tight constraints on production and demand, that in a more complete study would be relaxed to allow for more economically realistic values. As an indication, in a scenario where wind, solar, and biomass can respectively produce electricity at 8, 15, and 21 cents per kWh (typical values) under ideal conditions, an allocation that meets the demand for 5.01 billion kWh of electricity with the respective proportions of 45%/35%/25% for the three sources would have a levelized cost of $0.131/kWh. Although this value is a theoretical limit, further research might reveal a value closer to this lower bound.

In closing I wish to thank the students for their efforts, both in the research and the management of the project, and to Renewable Northwest Project for their collaboration. Wind, solar, and biomass are all already present in the region, and prospects for their growth appear promising.

Respectfully submitted,

Francis M Vanek, Advisor

2. Executive Summary

The Pacific Northwest region of the United States, which includes Oregon and Washington, currently obtains most of their electricity from hydropower, coal, and gas. Similarly, only about 5% of Oregon's electricity is from sources such as solar, wind or biomass. However, Washington and Oregon have unexplored potential in these sources due to respectively, appropriate insolation, high average wind speeds, and sufficient forest resources. Thus, the two goals for this project will be to evaluate capacity, cost, and ecological benefits of solar, wind, and biomass and to assess economic renewal benefits of rebuilding the energy sector with these new considerations.

Our partner organization is the Renewable Northwest Project (RNP), which promotes the development of renewable energy resources in the Pacific Northwest. They will provide feedback throughout the project, review the final report, and propose new project topics concerning this region.

Key technical aspects of the project include conducting a background and literature review, analyzing project data such as energy resource and cost data for different technologies, using spreadsheet modeling to create various energy production scenarios to determine the optimal scenario, and evaluating greenhouse gas reductions due to shift of energy mix. Key management aspects of the project include establishing an efficient team structure for sixteen team members, and delivering a final oral presentation and written final report. Other project management dimensions of the project include developing a proposal for the scope of work and ensuring that the project is finished on time, accomplishes the two goals above, and has an economically feasible recommendation.

Through several scenario analysis, we identified that wind energy was the cheapest source of energy in the distribution and was followed by solar and biomass energy respectively. The model attempts at addressing the uncertainties associated with the seasonal variations by randomizing values of the energy demand and capacity factors of the energy sources. The model focuses on identifying a reasonably diverse and economically feasible solution; a recommended mix is with wind, solar and biomass in the ratios of 60:30:10. In the process of spreadsheet modeling, several calculations were performed to understand the effect of tax incentives and CO_2 mitigation and the report touches on these aspects briefly. A list of recommended further research will also be compiled throughout the semester as possible areas of interest for future teams.

3. Acknowledgement and Disclaimer

The project team would like to express its sincere gratitude to Dr. Francis Vanek who provided invaluable support, supervision, encouragement and constructive critiques as an advisor throughout the semester.

The project team would also like to thank member of Renewable Northwest Project: Michael O'Brien and Cornell CEE PhD students: Sue Nee Tan and Jonathan Lamontagne for their inputs and support for this project.

While their contribution is gratefully acknowledged, the contents of this report do not reflect the official position of RNP, or of Cornell University, and responsibility for any and all errors rests with the authors.

Part I: Project Scope of Work and Background

4. Motivation

The basic motivation of this project lies in the need to promote sustainable development. The ever increasing size of the world's population and the increasing demand of energy have led to a potential exhaustion of the nonrenewable sources of energy in the near future. In the light of these advances, we need to consider all efforts to confront the exhaustion of nonrenewable energy resources and curb the rate of negative environmental impact.

The project aims to approach the problem of environmental sustainability by way of economic analysis of technologies and systems aimed at reducing their negative impact on the environment. This is one of the big engineering challenges of our time and requires us to meet the present needs without compromising on the ability of future generations to meet their needs.

The environmental, technological, social and economic aspects are key factors that shall be analyzed in the course of the project. In our efforts, Northwest Renewables Project is supporting the team as the team goals align well with their constant efforts to promote environmental sustainability.

5. Project Goals

1. Find the existing potential of the different renewable energy sources in Washington/Oregon region-

   This includes study of how much capacity in terms of energy demand or annual electricity production could be developed if these sources were developed on a large scale.
2. Determine how much of the demand can be satisfied by each of the sources-

   The total energy demand required from 2014-2034 will be identified and the percentage that each energy source can satisfy will be determined based on economic and technological feasibility.
3. Analyze existing technologies that can be used and explore new available technologies that can be implemented-

   This includes understanding various energy technologies and analyzing the best type to be implemented for the model.
4. Assess possible locations for setting up energy producing units-

   This includes the study of the feasible sites where the energy plants can be set up in the states of Oregon and Washington.
5. Calculate the energy efficiency of each source-

This includes studying the efficiency of each source and thus calculating the required installation capacity.

6. Determine the levelized cost for each source and the entire system for 2014-2034.
7. Assess the social impact of each energy unit-
   This point covers social aspects of the implementation of such a model for the future in the states of Oregon and Washington such as effect on the masses and job creation.

6. Team Introduction

The team is divided into three subteams that look at individual energy technologies and a fourth that integrates the three energy subteams work and provides managerial guidance and coordination. For efficient organization and coordination across the teams, each subteam nominated a leader to coordinate with the integration team and other team leaders. The integration team focuses on the communication between the teams, and spearheads the work on preparation of the spreadsheet model for the three technologies. The team also has two presentation leaders, who are responsible for overseeing the final presentation that needs to be delivered alongside the spreadsheet model. Lastly, the team has two liaisons to coordinate with a contact from Renewables Northwest Project to gather their feedback and inputs throughout the duration of the project.

NW Pacific Team Advisor: Dr. Francis Vanek	**Solar**	Vaibhav Gupta (Sub-team leader)
		Mark Howe (NW Pacific liaison)
		Ingrid Tu
		Francisco Saravia
	Wind	Maria Vissas (Sub-team leader)
		Mengying Shi
		Anuj Gautam
		Julio Gerlein (NW Pacific liaison)
	Biomass	Jeff Alfano (Presentation co-leader)
		Cheuk Hui (Sub-team leader)
		Zeyu Bai
		Vani Rikhy
	Integration	Mahina Wang (Presentation co-leader)
		Harim Choi
		Shaheen Mashraqui (Sub-team leader)
		Nandkishore Sathiamoorthy

Team Members Background

SOLAR:

1. **Mark Howe** P.E received a B.S in Mechanical Engineering from Binghamton University in 1999. He will be graduating in May 2015 with his M.Eng. in Engineering Management from Cornell University. He works for Cornell University Energy and Sustainability department as a Senior Engineer. His current project is the Cornell University Energy Conservation Initiative, a five year program that will decrease utility costs on Cornell's Ithaca campus by over $3.1 million per year. Mark is from Ithaca and enjoys hiking and sailing with his wife and 5 year old daughter.

2. **Ingrid Tu** received a B.S. in Mechanical Engineering from Cornell University in May 2013. She will be graduating in December 2013 with her Masters of Engineering in Engineering Management. Ingrid had internship experiences with product and equipment design. She worked for Giant Bicycles on a female mountain bike prototype and for Corning Incorporated for various equipment. She is interested in design-thinking, applying human-centred approach to engineering and technology. She is originally from Taipei, Taiwan, but came to the United States eight years ago at a boarding school in California. She enjoys playing taiko, playing basketball, biking, exploring, travelling, making scrapbooks, cooking, and collecting postcards from all over the world.

3. **Francisco Saravia** received a B.S. in Electrical Engineering from Rochester Institute of Technology in May of 2013. He will graduate in May 2014 with his M.Eng. in Engineering Management from Cornell University. Francisco has worked for Readix inc, a research and development firm where he participated in developing various products. Most of the products he worked were embedded systems with FPGAs and microcontrollers. Francisco has also worked for LAN Cargo, an airline operating cargo flights in South America, North America and Asia. He spent his time at LAN developing user interfaces for data analysis for the Revenue Management department. Some of his professional interests are data analysis and electronics. He enjoys playing the drums and going to the beach.

4. **Vaibhav Gupta** received B.S. in Mechanical Engineering from Cornell University in May 2013 and will be graduating in December 2013 which a Master in Engineering in Engineering Management. Vaibhav has interned in a variety of industries covering banking, consulting and food manufacturing in companies such as Deloitte and Royal Bank of Scotland. He plans to enter the consulting industry after graduation. He is originally from New Delhi, India and his interests range from cricket and hiking to travelling, singing and listening to good music.

WIND:

5. **Mengying Shi** received B.S. in Electrical and Computer Engineering (Power System) from Harbin University of Science and Technology and will graduate from her M.Eng. in Engineering Management in Jan 2014 from Cornell University. She worked as a engineer in a construction company and China Power. Her professional interests include power systems and structures management. She comes from Beijing and enjoys sleeping, travelling, basketball, playing piano, skiing, and game theory. She loves pets and raised a bichon frise dog and 50 fish.

6. **Anuj Gautam** received B.Tech in Mechanical Engineering from Punjabi University, Patiala, India in May 2010. He will be graduating in May 2014 with Master of Engineering in Engineering Management. Anuj has worked for Infosys Technologies, an IT services and consulting firm, for three years where he was involved in software integration and deployment and software architecture management. He is from India and his personal interests include travelling, reading and sports.

7. **Maria Vissas** received a B.S. In Civil Engineering from Cornell University in January 2013 and will be graduating in January 2014 with her Masters of Engineering in Engineering Management. Maria has gained work experience in construction management by working for Turner Construction and Tishman Construction. She is originally from Scarsdale, NY and plans to work for a construction management company in New York City. Her personal interests include Greek culture, historical buildings, travelling, Muay Thai and Cross fit.

8. **Julio Gerlein** received a B.S In Civil Engineering from Cornell University in May 2013 and will be graduating in May 2014 with a Masters of Engineering in Engineering Management. Julio has had internship experience in the construction and project management industry in Colombia, for the last two summers. He is originally from Barranquilla, Colombia and plans to work for a construction management company after graduation. His personal interests include soccer, tennis, traveling, and listening to music.

BIOMASS:

9. **Cheuk Hang Hui** graduated from Cornell University in May 2013 with a B.S. in Environmental Engineering in the Civil and Environmental Engineering Department. He is pursuing a M.Eng. degree in Engineering Management in hopes of learning more about project management and group dynamics. Cheuk has had an internship in Coastal Marine Lab in Hong Kong doing water consulting and research in *E. coli* survivability in sea sedimentation. Asides from his coursework, he enjoys playing table tennis for Cornell in regional and national competitions, as well as traveling around the beautiful Cayuga Lake region.

10. **Jeffrey Alfano** graduated from Cornell University in May of 2013 with a B.S. in Civil Engineering. He will graduate in May of 2014 with his Master of Engineering in Engineering Management. Jeff has had internship experience in the construction and project management industry. His professional interest is in structures and construction management. He is from Berkeley Heights, New Jersey and his hobbies include golfing, bowling, and listening to music.

11. **Zeyu Bai** graduated from Shanghai Jiao Tong University in June of 2013 with a B.S. in Mechanical Engineering. He will graduate in May of 2014 with his Master of Engineering in Engineering Management. Zeyu has had internship experience with Daikin Industries. His professional interest include energy calculations and marketing management. He is from Shanghai, China. His hobbies include photography, listening to music and playing Chinese chess.

12. **Vani Rikhy** received her B.E in Instrumentation and Control Engineering from Manipal University, India in May 2011. She will be graduating with an M.Eng in Engineering Management from Cornell University in May 2014. Prior to joining Cornell, she worked as a Maintenance Manager in the Petrochemical Sector of Reliance Industries Limited in India. Vani is from Mumbai, India and enjoys swimming and playing the piano.

INTEGRATION:

13. **Mahina Wang** received her B.S. in Chemical Engineering from Cornell and is graduating from her M.Eng. in Engineering Management in December 2013. After graduation, she will work as a Risk Manager in the financial services industry. Her professional interests include data analytics and project management. Personally, she enjoys playing volleyball and tennis, eating, and traveling.

14. **Harim Choi** graduated from Cornell University in May 2013 with a Bachelor's degree in Operations Research & Information Engineering, and will be graduating in May 2014 with a Master of Engineering degree in Engineering Management. His work experience includes data analytics and front-end software development. Currently he is looking for a full-time opportunity in quantitative analytics at a financial firm upon graduation. Outside of school he has a strong passion for music and is a part time DJ at a venue in collegetown.

15. **Shaheen Mashraqui** received her B.E degree in Mechanical Engineering from Mumbai University and is graduating with a M.Eng. in Engineering Management in May 2014. After graduation, she aims to propel her career in technology consulting and is particularly interested in project management and business development. Prior to joining Cornell, she worked for two years at Aker Solutions - an oil and gas design consulting services. Cooking and dancing are her stress busters and she enjoys playing basketball.

16. **Nandkishore Sathiamoorthy (Nandu)** received his B.E in Instrumentation Engineering from Mumbai University in May 2012 is graduating with a M.Eng. in Engineering Management in May 2014. After graduation, he plans to pursue a career in the consulting industry with special focus in project management and energy consulting. Prior to joining Cornell, he worked for a year at Uhde India- a leader in process technology consulting services. He is currently representing the Cornell Cricket team and is very passionate about Cricket, travelling and novels.

7. Scope of Work Statements and Caveats

The scope of this project, assumptions and caveats are as follows:

- Development of specific hardware designs is outside the scope of the project. The type of project is a systems-level feasibility study, so it is not the intent to design changes to the technology to address some problem or other. Many times, the systems design is built out of existing, off-the-shelf component designs.
- Basic assumptions about the characteristics of components under development shall be made so that we can incorporate them in future scenarios.
- All stakeholders studied by the team are assumed to acting in good faith and to be truthfully stating cost or performance characteristics of any system in which they have an interest.
- The project shall also include brief analysis of the non-cost issues, such as employment opportunities and the social impact of development.
- It is not the responsibility of the team to overcome political or social barriers, as the primary focus of the study is technical and economic. The team shall state that such barriers exist where they are identified. Thereafter they shall be left off further discussion, or optionally probe these political/social barriers for possible solutions.
- The exploration of greenhouse gas (GHG) emissions is limited to CO_2 at the end use stage of the life cycle. Thus other life cycle stages (manufacturing, installation, and dismantling and resource recovery) are outside of the scope.
- The geography of the project is limited to Washington and Oregon regions. Although, in real-world scenario, electricity distribution takes place across the boundary towards the south like California, this has not been considered in this project for the sake of simplicity.
- The units of measure for the purpose of this project shall be Metric (SI) units.
- Natural gas will be a logical replacement for coal considering the fact that there are hardly any operational coal plants in the Northwest Region and the last few remaining are proposed to be shut down soon. In addition, natural gas is relatively cheap making it a competitor to the renewable mix, but is outside the scope of the project so that effort could be focused on the renewables.
- Fluctuations in electricity pricing and changes to electric grid are outside of the scope.

- In case, the renewable mix is not able to meet the specified demand at any point of time, hydroelectricity will be used as a cushion. The use of hydroelectricity as cushion is an assumption and the modeling of hydroelectricity to meet demand is outside of the scope.
- The model has been designed for endogenous capacity, i.e. the demand determines the capacity of wind, solar and biomass required.
- The wind assessment is constraint to all wind energy harnessing systems on land.
- The team shall assess current wind/solar farms and study the possibility of expansion of capacity of existing farms in addition to exploring new wind/solar farm locations.
- Assumptions are made looking at large scale generation and not distributed generation such as small solar PV systems for households or small businesses.
- Manufacturing and setup considerations for the facilities are outside the scope of this project.
- Electricity storage is an option but is outside the scope of this project.
- Electricity transmission will be ignored in calculations.
- Comparing coal demand with natural gas and seeing its impact in the scenario is an option but is outside the scope of this project.
- Although the geographic boundary considered is WA-OR, much of the wind power is shipped south to CA.
- Government rebate/ assistance in reducing financial load is outside of the scope.
- We shall consider that solar and wind no do not emit any CO_2 directly or indirectly and are clean sources of energy.
- The hydroelectric demand does not necessarily follow the demand trend line and hence its output has been assumed as constant.
- Carbon credits have not been analyzed as a part of this project.
- For the purpose of the project, we assume that the time required for infrastructure built up would be between 2014 - 2023, and by the onset of 2024, we would have all essential resources in place to facilitate project initiation. These resources include and are not limited to technology, equipment, capital, labor, material, land and technical expertise.

Part II: Literature Review

8. Existing Demand

a. Current Energy Distribution

The Energy Information Administration of the United States Department of Energy (EIA) energy distribution data from 2012, the most recent year, for Oregon and Washington are show below in Figure 1 for comparison. These distribution values represent the in-state energy production and exclude the amount of out-of-state import that is also contributing to meeting the energy demand of the two states.

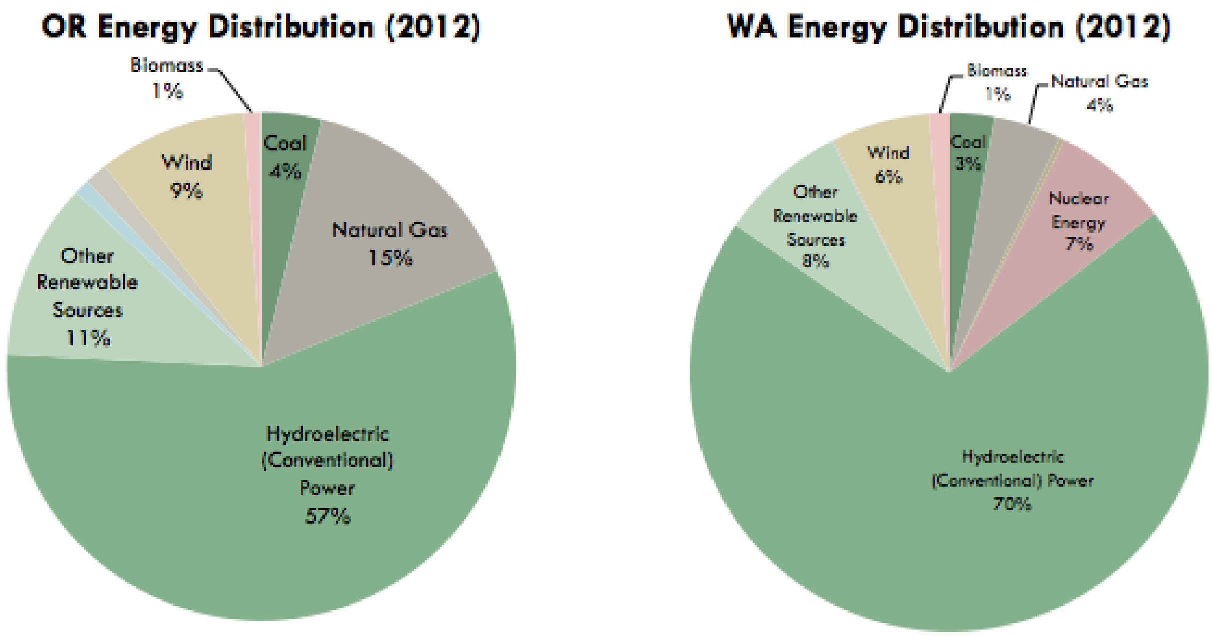

Figure 1. OR and WA Energy Distribution in 2012

In 2012, total Oregon electricity demand was 59.8 million MW hours and total Washington electricity demand was 116.7 million MW hours. Hydroelectric power accounts for the majority of each state's energy distribution. In Oregon, it supplied about 57% while in Washington, it supplied about 70%. Because the project goal is to replace fossil fuel electricity sources with renewable options, the demand focus was on total demand excluding hydropower.

In addition to a commitment to a low carbon future, the motivation behind the decision to design for total demand excluding hydropower was the potential future exhaustion of nonrenewables, especially coal in the Pacific Northwest. In 2011, a deal was struck in Washington stating that TransAlta's Centralia coal-fired plant would be completely shut down by 2025. Coal is the most CO_2-intensive source of electricity generation in Washington and shutting down the TransAlta

Centralia plant essentially ends coal-fired power in Washington. Renewables may be a feasible option to replace fossil fuel electricity sources such as coal.

In Oregon and Washington, significant amounts of electricity consumed are imported from other states. When this distribution for Oregon and Washington includes out of state production, electricity from coal is much larger, as shown in Figure 2. Oregon electricity mix including imports, 2010 and Figure 3 respectively.[1]

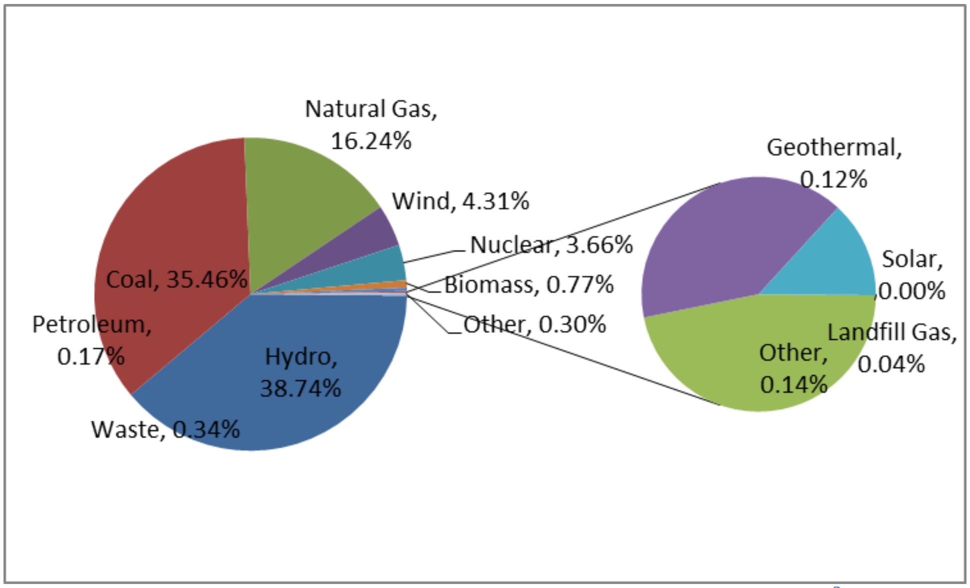

Figure 2. Oregon electricity mix including imports, 2010[2]

[1] Note that these were the most recent mix figures that were available according to our research. Coal share has been declining since 2009 and 2010, so current values may be smaller than the 17% and 35% figures shown.

[2] Oregon electricity mix including imports, 2010. Source: Oregon Dept. of Energy

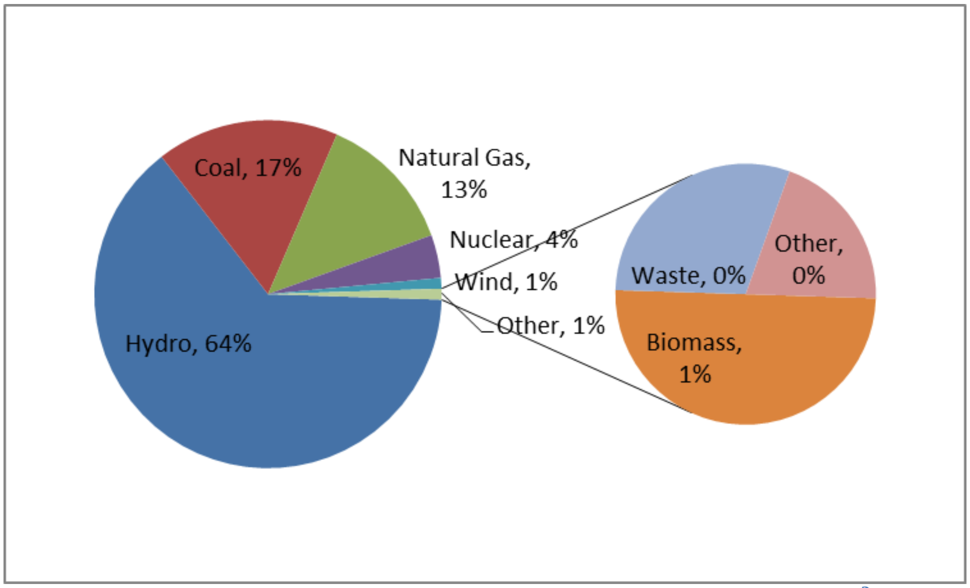

Figure 3. Washington electricity mix including imports, 2009[3]

b. Annual Demand Variation

EIA's historical data was used to represent demand data for the United States from 1949 to 2011. USDOE's Wind 2030 report projected the United States demand to reach 5.8 trillion kWh by 2030. Assuming a linear trend from 2011 and 2030, demand is estimated in this range. Linear extrapolation is used to project demand from 2031 to 2034. Historically reported demand and project demand up to 2034 are shown in Figure 4. Annual demand in 2034 peaks at about 6.2 trillion kWh.

[3] Washington electricity mix including imports, 2009. Source: Washington State Dept of Ecology

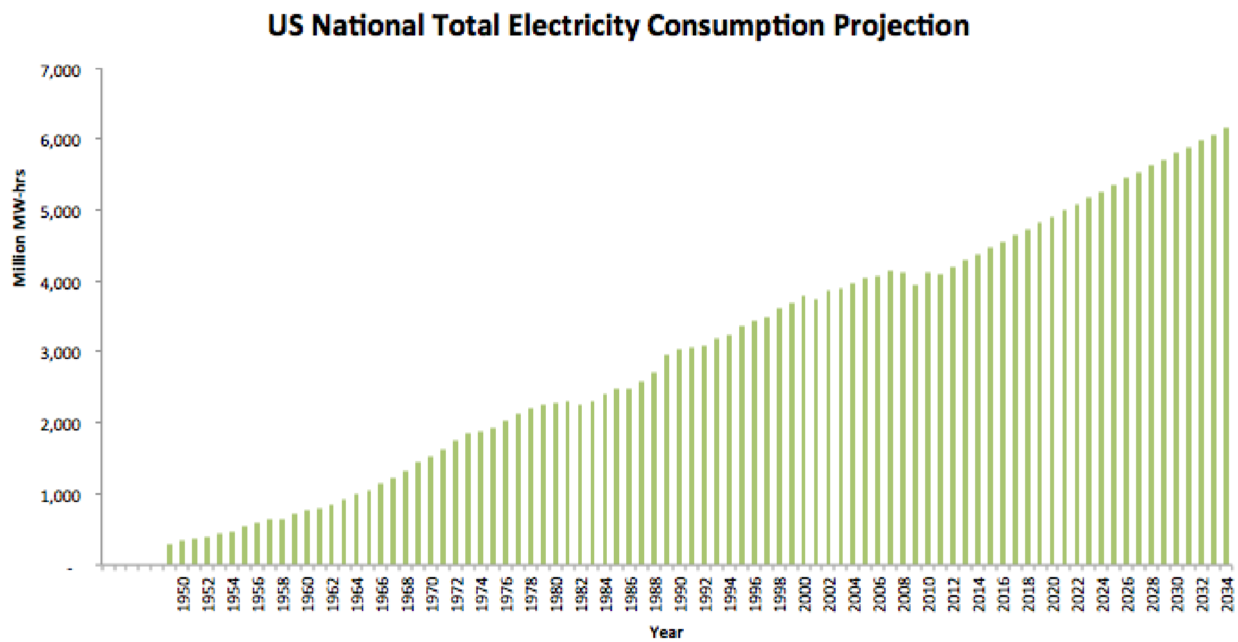

Figure 4. US National Total Electricity Consumption Projection up to 2034

Assuming that the states of Washington and Oregon follow a similar trend to the entire nation, demand for Washington and Oregon from 2014-2034 is estimated by taking 2012, a year with known demand as a base and assuming an equal proportion of demand up to 2034. Because hydropower will be a constant source and the goal of the project is to replace mainly fossil fuel electricity sources such as coal and natural gas, subteams designed for the two state's total demand excluding hydropower. Demand projections excluding hydropower for Oregon and Washington from 2012-2034 are shown in Figure 5 and Figure 6 respectively. Subteams designed for the two state's 2012 energy demand, which is about 20 million kWh in Oregon and 32 million kWh in Washington.

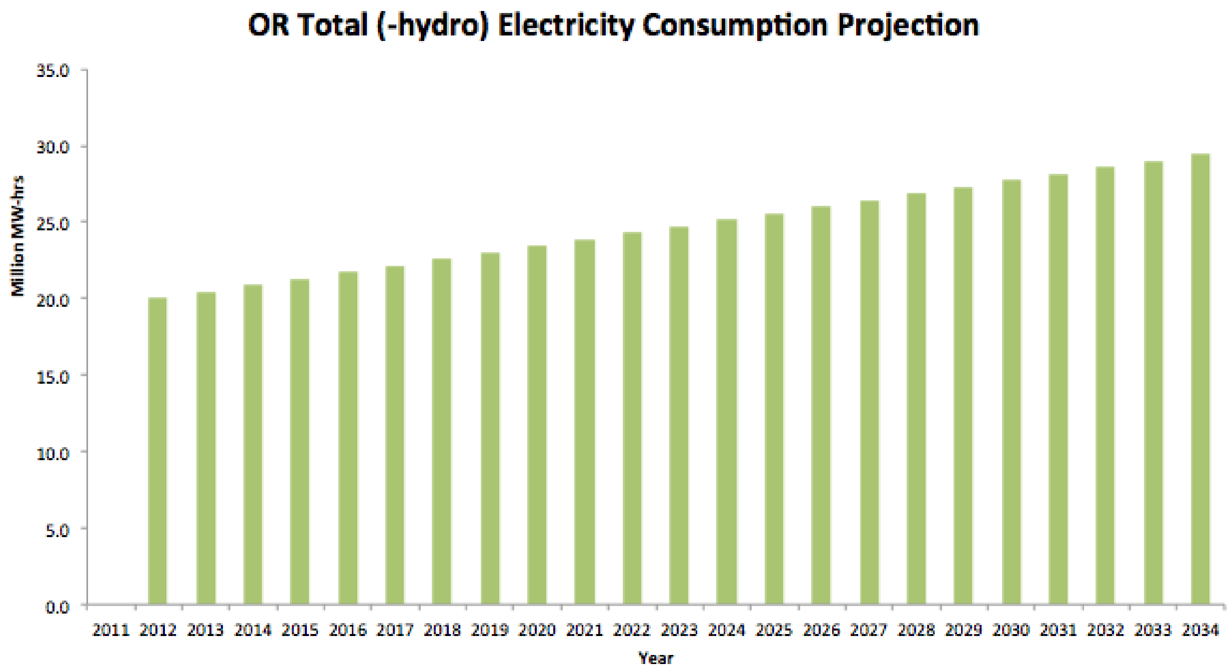

Figure 5. OR Total (-hydro) Electricity Consumption Projection up to 2034

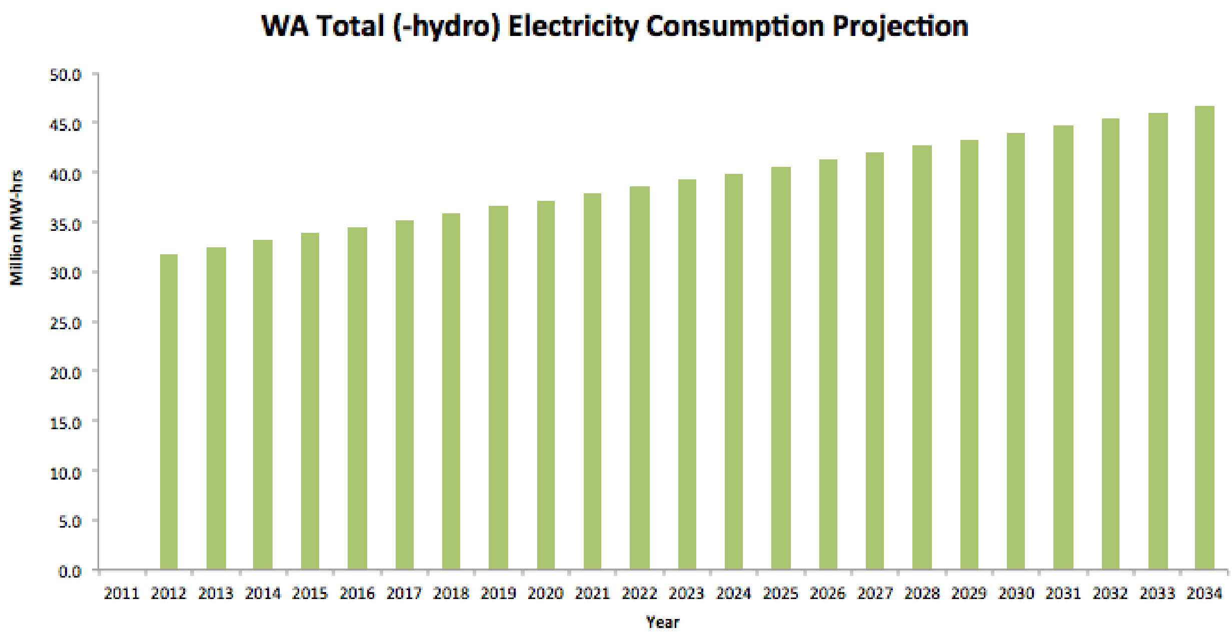

Figure 6. WA Total (-hydro) Electricity Consumption Projection up to 2034

c. Monthly Demand Variation

The optimized model projects the future demand for energy in the states of Oregon and Washington for the next 20 years based on data from EIA website for the years 2008-2012. The EIA data for each state's energy demand was used, wherein demand per source of energy production was listed. This data was then used to calculate the (total-hydro) demand value, which is the basis for all demand calculations. The (total-hydro) demand value was calculated for each month of the years 2010- 2013. Each month's demand was averaged over the four year period and summed to get a total average year demand value. Finally, each month's contribution to a particular year was calculated based on this average yearly demand data. The contribution of each month over the next 20 years, has been assumed constant for both Oregon and Washington. A snapshot of the energy demand for the months January- May of the years 2010-2013 is shown in Figure 7.

Total Energy Generation - Hydro Electric Generation Data From EIA										
1000 MW-h (Total)	Jan '10	2255	Feb '10	2058	Mar '10	2432	Apr '10	2306	May '10	1091
	Jan '11	1638	Feb '11	1216	Mar '11	1008	Apr '11	1053	May '11	701
	Jan '12	2411	Feb '12	1754	Mar '12	2504	Apr '12	1908	May '12	1276
	Jan '13	2414	Feb '13	2113	Mar '13	1768	Apr '13	992	May '13	878
Total		8718		7141		7712		6259		3946
Monthly Average		2179.5		1785.25		1928		1564.75		986.5
Percentage		10.45%		8.56%		9.25%		7.50%		4.73%

Figure 7. Monthly demand percentage estimate Jan-May (2010-2013)

The percentage data calculated for each month was then used to project the values for both the states for the next 20 years. Figure 8 shows the projected demand values for the state of Oregon in 2014.

Oregon		
Annual Demand (Total - Hydro)		20,881.56
1000 MWh	**Percentage**	**2014**
January	10.45%	2,182.39
February	8.56%	1,787.62
March	9.25%	1,930.56
April	7.50%	1,566.82
May	4.73%	987.81
June	4.95%	1,034.37
July	5.46%	1,140.76
August	9.18%	1,916.29
September	9.38%	1,957.84
October	10.36%	2,163.20
November	10.02%	2,092.77
December	10.16%	2,121.14

Figure 8. Projected Energy demand for Oregon (2014)

Figure 9 shows the projected demand for the state of Washington in 2014.

Washington		
Annual Demand (Total - Hydro)		33,180.10
1000 MWh	**Percentage**	**2014**
January	10.45%	3,467.74
February	8.56%	2,840.46
March	9.25%	3,067.59
April	7.50%	2,489.63
May	4.73%	1,569.59
June	4.95%	1,643.58
July	5.46%	1,812.63
August	9.18%	3,044.92
September	9.38%	3,110.95
October	10.36%	3,437.25
November	10.02%	3,325.34
December	10.16%	3,370.42

Figure 9. Projected Energy demand for Washington (2014)

d. Hourly Demand Variation

The hourly energy demand displayed the demand pattern throughout the 24 hours of an average day of a given month. Sue Nee Tan, PhD student of Civil Engineering, provided applicable data to calculate hourly demand projections. Sue Nee had collected hourly demand figures of the Bonneville Power Authority (BPA) balancing area from May 2008 to December 2012. The following figure shows the map of the BPA balancing area.

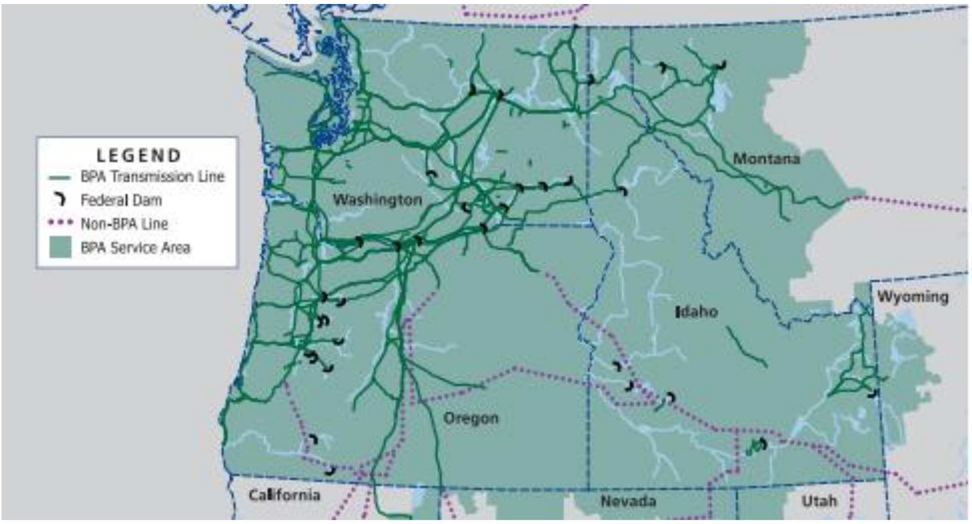

Figure 10. BPA Balancing Area

For each date, each hourly demand figure was converted to a percentage of the total daily demand load. For example, the following figure shows the percent total daily load of the month January.

January Percent Total Daily Load

Hour	1	2	3	4	5	6	7	8	9	10	11	12
1/1/2012	3.04%	2.80%	2.74%	2.67%	3.00%	3.37%	3.70%	3.80%	4.13%	4.40%	4.65%	4.88%
1/2/2012	2.60%	2.31%	2.20%	2.40%	2.60%	3.38%	4.02%	4.69%	4.81%	4.85%	4.99%	4.95%
1/3/2012	3.02%	2.85%	2.73%	2.71%	2.75%	3.50%	3.91%	4.03%	4.32%	4.54%	4.62%	4.45%
1/4/2012	3.47%	3.28%	3.14%	3.19%	3.11%	3.33%	3.64%	3.77%	4.14%	4.20%	4.26%	4.45%
1/5/2012	2.49%	2.25%	2.48%	2.56%	2.68%	3.29%	4.21%	4.75%	5.10%	5.08%	4.92%	4.80%
1/6/2012	2.67%	2.44%	2.51%	2.47%	2.80%	3.50%	4.31%	4.96%	5.30%	5.19%	5.04%	4.99%
1/7/2012	2.49%	2.56%	2.59%	2.52%	2.85%	3.63%	4.52%	5.10%	5.20%	5.07%	4.86%	4.69%
1/8/2012	2.60%	2.51%	2.45%	2.47%	2.64%	3.37%	4.31%	4.92%	5.29%	5.17%	5.30%	5.09%
1/9/2012	2.63%	2.67%	2.63%	2.69%	2.93%	3.50%	4.47%	5.32%	5.43%	5.18%	5.02%	4.87%
1/10/2012	3.06%	2.94%	2.92%	2.92%	3.17%	3.46%	4.08%	4.37%	4.53%	4.53%	4.56%	4.58%
1/11/2012	3.23%	3.06%	3.06%	3.13%	3.25%	3.37%	3.81%	4.17%	4.24%	4.35%	4.49%	4.55%
1/12/2012	2.86%	2.64%	2.39%	2.52%	2.83%	3.47%	4.31%	4.91%	5.16%	4.98%	4.86%	4.94%
1/13/2012	2.45%	2.46%	2.43%	2.45%	2.64%	3.09%	4.41%	4.67%	4.79%	5.00%	5.01%	4.98%
1/14/2012	2.66%	2.43%	2.44%	2.67%	2.82%	3.51%	4.40%	4.77%	4.72%	4.79%	4.75%	4.72%
1/15/2012	2.88%	2.76%	2.67%	2.78%	3.31%	3.76%	4.82%	5.18%	5.17%	5.11%	4.76%	4.54%
1/16/2012	2.64%	2.56%	2.46%	2.57%	2.87%	3.54%	5.09%	5.19%	5.13%	5.08%	4.97%	4.77%
1/17/2012	3.00%	2.94%	2.90%	2.90%	3.00%	3.52%	4.37%	4.48%	4.68%	5.01%	4.93%	4.80%

Figure 11. January Percent Total Daily Load

For example, on January 1, 2012, 3.04% of total energy generated on that day was between midnight and 1 AM. Then, using the collection of data over the three and a half years, the average percent total daily load for each month was calculated.

Average Percent Total Daily Load

Hour	1	2	3	4	5	6	7	8	9	10	11	12
January	2.78%	2.64%	2.57%	2.62%	2.87%	3.45%	4.37%	4.73%	4.87%	4.87%	4.75%	4.63%
February	3.08%	2.92%	2.88%	2.92%	3.14%	3.79%	4.48%	4.79%	4.90%	4.81%	4.66%	4.50%
March	3.39%	3.26%	3.20%	3.21%	3.37%	3.81%	4.28%	4.52%	4.64%	4.64%	4.59%	4.49%
April	3.71%	3.59%	3.52%	3.51%	3.59%	3.83%	4.08%	4.26%	4.39%	4.48%	4.51%	4.47%
May	3.52%	3.37%	3.29%	3.29%	3.39%	3.62%	3.97%	4.22%	4.37%	4.44%	4.55%	4.60%
June	3.76%	3.64%	3.55%	3.51%	3.57%	3.70%	3.88%	4.06%	4.20%	4.29%	4.39%	4.42%
July	3.51%	3.36%	3.29%	3.22%	3.25%	3.34%	3.58%	3.84%	4.05%	4.24%	4.41%	4.52%
August	3.33%	3.18%	3.09%	3.03%	3.06%	3.23%	3.33%	3.58%	3.83%	4.10%	4.34%	4.54%
September	2.98%	2.86%	2.77%	2.74%	2.78%	3.04%	3.48%	3.82%	4.10%	4.30%	4.48%	4.64%
October	2.92%	2.82%	2.77%	2.76%	2.89%	3.31%	4.11%	4.67%	4.87%	4.89%	4.86%	4.80%
November	2.93%	2.81%	2.75%	2.77%	2.94%	3.40%	4.19%	4.66%	4.82%	4.81%	4.77%	4.66%
December	2.94%	2.80%	2.74%	2.77%	2.99%	3.49%	4.28%	4.65%	4.77%	4.73%	4.68%	4.53%

Figure 12. Average Percent Total Daily Load

The daily demand figures that were calculated from monthly demand figures were multiplied with the given hourly percentages to provide hourly demand figures.

Oregon - 2024

	January	February	March	April	May	June	July	August	September	October	November	December
Hour/Daily Demand	77.36	73.54	73.12	69.09	64.55	69.11	65.01	62.60	67.60	61.92	66.91	73.68
1	2.15	2.26	2.48	2.56	2.27	2.60	2.28	2.09	2.01	1.81	1.96	2.17
2	2.05	2.15	2.38	2.48	2.18	2.51	2.19	1.99	1.93	1.75	1.88	2.06
3	1.99	2.12	2.34	2.43	2.12	2.45	2.14	1.93	1.88	1.71	1.84	2.02
4	2.03	2.14	2.35	2.42	2.12	2.43	2.09	1.90	1.85	1.71	1.85	2.04
5	2.22	2.31	2.46	2.48	2.19	2.47	2.11	1.92	1.88	1.79	1.97	2.20
6	2.67	2.78	2.78	2.64	2.34	2.56	2.17	2.02	2.06	2.05	2.28	2.57
7	3.38	3.29	3.13	2.82	2.56	2.68	2.32	2.09	2.35	2.54	2.81	3.15
8	3.66	3.52	3.31	2.94	2.72	2.81	2.50	2.24	2.58	2.89	3.12	3.43
9	3.77	3.60	3.40	3.04	2.82	2.90	2.63	2.40	2.77	3.01	3.22	3.52
10	3.77	3.54	3.40	3.10	2.87	2.97	2.76	2.57	2.91	3.03	3.22	3.49
11	3.67	3.43	3.35	3.12	2.94	3.03	2.86	2.72	3.03	3.01	3.19	3.45
12	3.58	3.31	3.28	3.09	2.97	3.05	2.94	2.84	3.13	2.97	3.12	3.34
13	3.48	3.19	3.20	3.05	2.95	3.07	3.01	3.02	3.33	2.94	3.05	3.23
14	3.40	3.08	3.13	3.02	2.94	3.09	3.09	3.16	3.48	2.88	2.98	3.13
15	3.34	3.01	3.09	3.01	2.91	3.11	3.15	3.25	3.57	2.84	2.93	3.08
16	3.38	3.02	3.08	2.99	2.91	3.13	3.20	3.30	3.63	2.82	2.96	3.17
17	3.79	3.22	3.19	3.00	2.91	3.14	3.21	3.32	3.65	2.84	3.19	3.66
18	4.32	3.72	3.42	2.97	2.89	3.13	3.21	3.29	3.60	2.94	3.46	4.12
19	4.36	3.95	3.56	3.02	2.89	3.13	3.16	3.19	3.56	3.19	3.58	4.10
20	4.14	3.86	3.60	3.19	2.98	3.10	3.10	3.09	3.53	3.25	3.51	3.87
21	3.79	3.59	3.48	3.20	3.06	3.11	3.02	2.91	3.33	3.08	3.29	3.57
22	3.38	3.21	3.21	3.06	2.96	3.04	2.85	2.69	2.98	2.75	2.96	3.24
23	2.71	2.79	2.88	2.83	2.63	2.89	2.60	2.46	2.43	2.18	2.41	2.71
24	2.36	2.46	2.62	2.65	2.41	2.72	2.41	2.23	2.12	1.93	2.12	2.37
Total	**77.360**	**73.543**	**73.124**	**69.087**	**64.549**	**69.115**	**65.010**	**62.598**	**67.597**	**61.922**	**66.907**	**73.677**

Figure 13. Hourly Demand Table

9. Literature Review

a. Wind

i. General Introduction

Wind power captures the natural wind in our atmosphere and converts it into mechanical energy then electricity, as defined by the American Wind Energy Association (AWEA). When wind blows past a turbine, the blades begin to turn and capture the energy. The turning of the blades causes an internal shaft to spin, which is connected to a gearbox that increases the speed of the rotations. The gearbox is connected to a generator that is responsible for producing electricity for the previously mentioned rotation.

In wind farms, the turbines are all connected so that the wind energy they generate can then be transferred to a power grid, which delivers the energy to a large network of transmission lines so that the electricity can travel to the locations where it will ultimately be delivered. Each wind turbine operates independently and turns itself on when conditions are right, and turns itself off when speeds are either too slow (below 7 to 10 mph depending on the turbine model), or too high (above 50 mph). The larger the turbine and the windier the spot, the more power it will generate. Most wind turbines are made up of three large blades that sit on top of a steel tower. Turbines can range from 20 feet (enough to power a single family home) to 260 feet (utility-scale turbines that can power hundreds of homes)[4].

[4] "AWEA Website." *Advocacy*. American Wind Energy Association, n.d. Web. 25 Sept. 2013.

Every state in the United States has either an operational wind energy project or a wind-related manufacturing facility, or both. Nearly 900 utility-scale wind projects, producing over 60,000 megawatts, are installed across 39 U.S. states and Puerto Rico. In addition there are over 550 wind manufacturing facilities spread across 44 states[20]. As of now, wind power has the potential to provide 20% of all electricity for the nation by 2030. By the end of 2013, 16% of the 300,000 MW had to be installed to achieve 20% by 2030.

Wind energy has grown 30% on average in the past five years. The planning of a wind farm considers wildlife, public lands, property values, sounds and worker safety and health on the job. To encourage the building of wind farms, the federal government instituted the Production Tax Credit (PTC). This resulted in the United States installing enough wind power to power over 15 million homes, grow the wind energy workforce to 80,000 and drive down the cost of wind energy by over 90%[19].

In 2012 when the production tax credit was due to expire, in conjunction with a drop in wind power prices, the wind farm industry saw a building boom. As a result, the United States installed 13.2 gigawatts worth of wind energy making the total number of gigawatts of wind energy in the United States sixty. Due to this influx, wind energy now represents 6% of the nation's total generating capacity. In 2011, wind electricity production reached 3% of the total U.S. demand, according to the U.S. Energy Information Administration[5]. In some areas of the U.S., such as Texas, wind energy is now a competitive energy source with natural gas-fired power plants.[3] The PTC was so influential in the wind farm industry that wind advocates urged Congress to extend it. Congress agreed to extend the PTC to 2013, but the wind industry is pushing for something similar that will be longer lasting[19].

The PTC played a role in New England when the biggest utilities providers there signed long-term contracts for wind energy, buying energy from six wind farms to power approximately 170,000 homes. According to a diagram by the US Department of Energy, the price of these mass wind power contracts (on average less than $0.08/kWh) would be cheaper than hydro, conventional coal, nuclear and solar per kWh. If contracts are approved then customers could save between $0.75 and $1.00 a month[6].

In addition to the PTC, the federal government has mandated that utilities providers get 15% of their power from renewable sources by 2020 in states like Massachusetts. With the help of the

[5] www.eia.gov
[6] Ailworth, Erin. "Wind Power Now Competitive with Conventional Sources." *BostonGlobe.com*. Boston Globe, 23 Sept. 2013. Web. 25 Sept. 2013.

federal government and a continuing decrease in wind energy prices the United States is seeing a growth in wind energy.

ii. Existing Wind Technology in NW Region

WIND ENERGY IN THE NORTHWEST	Potential	Installed Capacity*
Oregon	7,991 aMW	886 MW
Washington	7,078 aMW	1165 MW
Idaho	5,594 aMW	75 MW
Montana	116,438 aMW	164 MW
Resource type	Variable, predictable	
Capacity factor		28-36%
Real levelized cost (2006$)		4-7 ¢/kWh
Construction lead time		1-3 years

**Installed capacity as of February 2008.*
MW= Megawatts (capacity),
aMW = average MW;
Sources: see endnote 1.

Table 1. Wind Energy in the Northwest

As is evident from Table 1. Wind Energy in the Northwest, wind energy capacity currently installed in the Northwest is 2,290 MW and has a potential of producing 13,700 MW with advances of technology. This would satisfy four times the electricity demand of the Northwest region.

Currently, the wind power capacity from Northwest wind farms is nearly 2,300 MW yet this number could triple in the next several years as projects currently under development are completed[7]. Recent data validates that the savings, from adding wind energy to the grid affecting emissions and fuel use, are even greater than perceived. In addition to producing power, wind farms help in reducing emissions by replacing the energy demand met by otherwise polluting and inflexible power plants. Today, a typical wind turbine installed in the Pacific Northwest produces enough electricity to meet the annual needs of approximately 500 homes[8].

iii. Available Wind Technology

There are two kinds of land turbines used to capture wind energy; horizontal axis turbine and the vertical axis turbine. The horizontal axis turbine consists of a tall tower with a fan like rotor, a

[7] US Department of energy- Wind Program accomplishments

[8] Wind works Northwest

generator, controller, and 2 or 3 blades attached to it[19]. Vertical axis turbines are less commonly used and there are two types: Savonius and Darrieus. Darrieus consists of vertical blades that rotate into and out of the wind, using aerodynamic lift that enables them to capture more energy than common drag devices[9]. The other kind, the Savonius, has an S shaped form when viewed from above. This shape is efficient for pumping water, yet not so much when generating electricity.

Another less commonly used turbine is an offshore (or floating) wind turbine, which is a recently developed technology primarily used in Europe[10]. These turbines are proving to be more efficient because wind is generally more consistent and robust above the sea. In addition, they provide benefits such as reducing visual pollution and better accommodating for fishing and shipping lanes. The average capacity of each turbine is about 3MW, and they are expected to increase to 5 MW in the future.

A disadvantage of this technology is that it costs a lot more than the land turbine technology; therefore it is common for these projects to be infeasible on a limited budget. In addition, the location of offshore turbines creates more problems with accessibility, which adds to the cost of maintenance. The Vestas V 164 offshore model, which is currently being developed, addresses these issues as it reduces operational costs in addition to producing 8 MW per turbine.

Although there are two major types of land wind turbines, horizontal-axis (which is propeller style) and vertical-axis (known as egg-beater style), almost all large-scale commercial projects are fitted with the horizontal-axis style: a three-bladed rotor that is set atop a tall, tubular steel tower. Today's average land turbines stand 400-500 feet tall, from the foundation to the tip of the blade. The span of an average wind turbine rotor is 250 feet, roughly equal to the wingspan of a 747 jetliner[11].

iv. Future Scope

The construction of offshore wind plants and improvements to those technologies is the focus of future development in wind energy. The actual construction of an offshore wind plant can include building techniques such as offshore platforms, offshore pile foundations, offshore bridges etc. In comparison to traditional vertical and horizontal construction, offshore building is relatively new and so has many uncertainties associated with it.

[9] Energy basics, Wind Turbines, U.S department of Energy, Web. April 2013
[10] Offshore Wind Energy, Environmental and Energy Study Institute,Web. October 2010.
[11]Windworks Northwest - FAQ

Technology developed for land turbines is also dynamic. For example, one of the key aspects of wind turbines is the reliability of the entire system. It is important that the turbine be able to withstand severe weather and non-standard wind power alternating load. One new-style wind turbine, patented by Right Joy Corporation Limited, adopts the fixed pitch wind wheel and doubly salient direct-current generator with weak excitation, high efficiency and low speed. This design will utilize wind power efficiency through the speed of the apex to the variable pitch of the wind turbine. This design does not include a complicated variable pitch system, and requires only simple construction, is lightweight and easy control.

A large part of the turbine is the generator that captures and stores all energy that the turbine blades and rotor generate. The largest unit capacity generator is currently made in by Repower in Germany, with an offshore unit capacity of 5 MW. Another company in Germany, Enercon Company, makes the largest variable speed wind turbines generators, which have large generating capacity and better adaptation to wind speed. These generators are also low in cost and high in efficiency due in part to the fact that they are more sensitive to changing wind speeds (compared to constant speed operation generators). Finally, no gear case (direct driving type) generators enhance the systematic efficiency and the reliability of operation or a wind turbine.

In addition to turbine design, the distribution cost associated with wind energy is something improved technologies aim to decrease. Currently, the distribution price wind energy is higher than that of hydro and thermal power. The further wind energy needs to be disturbed the more expensive it gets, therefore it is better to concentrated wind generation in a remote area.

b. BIOMASS

i. General Introduction

Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-derived materials that are specifically called lignocellulosic biomass[12]. As a renewable energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel. Conversion of biomass to biofuel can be achieved by different methods, which are broadly classified into thermal, chemical, and biochemical methods. The estimated biomass production in the world is 146 billion tons a year, consisting of mostly wild plant growth. Nowadays, wood is the largest biomass energy source and waste energy comes second.

[12] "The Future of Biomass" (2010)

Biofuels for transportation ranges from food crops to plant and tree material to microbes, such as algae, which can be processed into substitutes for liquid transportation fuels.[13] The use of biofuels for transportation dates back to the early years of the modern transportation vehicles, when Rudolf Diesel, who is the inventor of the diesel engine [i.e., compression-ignition (CI) engine], used peanut oil as a fuel in his early engine prototypes. One of Diesel's motivations was to create a source of mechanical power that could utilize a wide variety of fuels, so that small businesses of the day would not be captives of the coal industry for their energy supplies. In recent years, interest in biofuels has surged as nations, such as Brazil, Germany, and the United States, have sought to reduce petroleum imports. Also, many countries see biofuels as a way to prepare for anticipated dwindling petroleum reserves by developing a renewable alternative.

Developing a bioenergy industry should be coupled from local, national, and/or international policies. Communities, societies, and intergovernmental organizations may have very different reasons why they choose to develop bioenergy system rather than to rely on fossil sources for energy carriers.

The presence of a positive net energy balance (NEB) ratio is often used as a criterion for evaluating a biofuel, meaning that a biofuel delivers more energy to the vehicle than it requires in the production life cycle. A biofuel with a considerable positive NEB ratio is considered sustainable, assuming other ecologic and economic requirements of sustainability are satisfied.

ii. Existing Biomass Technology in NW Region

Biomass is the largest source of renewable energy in the United States, with wood being the primary resource. Other sources of biomass include agricultural and forestry residues, dedicated energy crops, native grasses and woody plants, certain municipal or industrial wastes, and gas from anaerobic digesters or landfills[14]. The Northwest pacific region has tremendous potential for Biomass exploitation, which can be a major contributor to the Energy production. The current biomass plants in operation in Oregon and Washington contribute 195.11 MW[15] to energy production in the state. The biomass potential has largely been unexplored and the need to develop it is more relevant now considering the importance of renewable energy resources in today’s times. The existing biomass plants work broadly on three major technologies namely Combustion, Gasification and Anaerobic Digestion which are described in the following paragraphs[16].

Combustion is the oldest technology for biomass conversion, especially for generating

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[13] Energy Systems Engineering: Evaluation and Implementation, *Second Edition*
[14] “Oregon Government Biomass Pages”
[15] “Biomass Power Plants list”
[16] “Review of Biomass Fuels and Technologies”

Heat and steam from woody fuel. A biomass combustion facility can produce steam, electricity, or both (CHP). A boiler furnace burns the biomass to create steam. If electrical output is desired, a steam-turbine generator is used to convert a portion, or all, of the steam to electricity. An example of a plant using this technology is "Biomass One" in Oregon State. The plant has a capacity of 355,000 green tons per year (220,000 BDT per year) and uses primarily woody fuels to power the plant. The plant has been in successful operation since 1981.

Gasification is the thermo-chemical reduction of a fuel without direct combustion. Gasifiers operate at high temperatures and pressures in an oxygen-depleted environment to convert a feedstock to a combustible gas. The immediate product of gasification is synthetic gas, or "syngas." Syngas can be burned to create heat, steam, or electricity. It can be converted to methane and fed into a natural gas distribution system. Syngas can also be converted to methanol, ethanol, and other chemicals or liquid fuels. An example of a plant using this technology is "SEDI Bioenergy Refinery" in La Grande, Oregon. The plant has a capacity of 300,000 green tons per year and uses forest residues to power the plant. The plant was under development in 2003.

Anaerobic digestion is a process that uses bacteria to break down biomass in an Oxygen-free environment. Anaerobic digestion is common in wastewater treatment and industrial waste processing, and can also be effective in treating animal manures and wastes. It is an especially effective way to process dairy manure slurry. Anaerobic digestion produces biogas, sometimes called "digester gas," a mixture of mostly methane and carbon dioxide. The biogas can be flared, used to generate heat or electricity, or can be converted into biofuels such as methanol.

The most common application is to use the biogas to power an internal combustion engine generator to produce electricity. An example of a plant using this technology is "SEDI Bioenergy Refinery" in Boardman, Oregon. The plant has a capacity of 20,000 milking cows and uses dairy industry waste to power the plant. The plant was under development in 2003.

iii. Available Biomass Technology

One of the major advantages of using biomass as energy source is its diversity. While the major source of biomass electricity generation in the Northwest Pacific region comes from combustion of logging activities, other biomass technologies are available in the region or being practiced in other states. In this literature review, four technologies, namely straw biomass feedstock resources[17], bio-methane from diary production[18], co-firing and biomass plants for combined

[17] "Assessment of straw biomass feedstock resources in the Pacific Northwest"
[18] "Fiscalini Farms Biomass Energy Project Final Report 2011"

heat and power (CHP)[19], will be reviewed. For the utility of the research, only the biomass electricity potential is studied, and liquid biofuel for transportation usage has been excluded.

U.S. Department of Agriculture has conducted an assessment of available biomass feedstock from straw production in the Pacific Northwest region in 2005, indicating that over 6.5 Mt of straw is available annually in the region for bioenergy conversion[1]. With over 2.4 ha of land in Idaho, Oregon and Washington State combined for cereal grain and grass seed production, the 6.5 Mt is spread across the region with 2.4 Mg/ha potential each year. Although the low spread density will make transportation of feedstock uneconomical, on-site technologies are available by USDA recommendation to turn excess straw biomass to available energy through combustion power plants. The value-added from the energy conversion is preferable for medium to large sized seed producers who can afford the initial capital cost of the plant construction. Development of small-scale conversion technology has yet been proven at this stage.

In 2010, EPA has estimated an 863 MW energy production potential for biogas-derived power plants from 2,645 targeted dairy farms across US. The Ecological Engineering Research Program at the University of the Pacific, Stockton, CA, has evaluated one particular bio-methane energy power plant in Modesto, CA, and results have shown great economical potential and great sustainability for the plant[2]. The biomass power plant is owned by Fiscalini Farms, which has been in operation in the diary business since 1912. The 710 kW power plant is supported by 1,500 cows in the 480 acres farmland. Approximately 1 million gallon of manure is flushed to the anaerobic digester daily for methane gas production. The plant was estimated to have annual revenue of $390,000 and effectively reduced the volatile waste production of the farm by 42%.

The International Energy Agency (IEA) has made recommendation on biomass technology in US in 2007 regarding two technologies – co-firing biomass with current coal power plants and combined heat and power generating plants. The report indicates that a co-firing power plant at 45% efficiency with regards to biomass content is the most effective biomass use for power generation. Little modification has to be made on the existing coal-fired plant at $50-$250/kW, but with low-cost biomass available, the payback period can be as short as 2 years. The biomass usage is typically at 5-10% of the energy production of the co-firing plant. Any value above 10% requires a significant modification in mills, burners and dryers, which is not recommended for economical purposes. On the other hand, for a typical CHP power plant, the scale is roughly 10 times smaller than a typical coal-fired plant, yet electricity generation efficiency can get up to 40% and even 90% utilization (combined electricity and heat output) for CHP usage. Such configuration requires good matching between heat production and the demand cycle. On average, each ton of municipal solid waste can be combusted to generate 600 kWh while emitting 220-440 kg of CO_2 gas. For the same amount of energy production, coal-fired plant will produce at least 590 kg of CO_2.

[19] "Biomass for Power Generation and CHP"

iv. Future Scope

The future of biomass energy has great potential in both the United States as well as globally. In a 2001 Survey of Energy Resources, the World Energy Council estimated that there are 220 billion oven dry tonnes of biomass on Earth. This is equivalent to 4,500 EJ of energy that could be produced. Although not all of this potential could be consumed at once, a large fraction could be used and then replenished by natural systems. The actual amount used in 2010 was only 50 EJ which is just ten percent of the 500 EJ of total global energy consumption[20]. This means there is a great deal of biomass energy that is not currently being used. This is because the technology is not currently available to both obtain and convert the biomass into energy.

The availability of resources is important for biomass to be able to compete with the electricity, heat, and liquid fuel markets. Currently, biomass is not as prevalent as these other energy sources. There are many labs currently doing biomass research in an attempt to use these fuel sources. The Alternative Fuels User Facility (AFUF) is major player in the United States as it attempts to develop cost-effective biomass-based chemicals. The AFUF is home to an advanced Bioprocessing Pilot Plant which can handle up to a ton of feedstock per day[21]. Developing biomass conversion technologies will help to improve efficiency of generating energy through biomass. The main goal of the laboratories is to work on readily available feedstock and biomass. Increasing the ability to use widely available resources for energy would greatly help the industry and advance the possibilities of biomass energy. This would significantly decrease the cost of obtaining and using biomass. Laboratories such as the AFUF are working to make this a reality in the future of the energy industry.

In 2005, biomass provided around 1.3% of global electricity production. By the year 2050, this could become between 3.4% and 5.8%. By 2050, it is estimated that the potential of abandoned land ranges from 130 to 410 EJ per year. In the year 2100, it can range from 240 to 850 EJ per year. Low and partly productive land combine to provide from 35 to 245 EJ per year in 2050 and 35 to 265 EJ per year in 2100[22]. The technical potential for biomass energy by 2100 is many times greater than the world's current oil consumption. These estimates show that biomass can be an integral part of the energy industry as soon as the year 2050. The growth in the 50 years after that also looks to be significant. If the proper technologies develop to obtain and convert this energy, biomass has the opportunity to become very important in the generation of energy throughout the United States. In the next fifty to a hundred years, biomass could become one of the most widely used energy sources both nationally and across the world.

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[20] "The Future of Biomass" (2010)
[21] "Biomass Technologies of the Future" (2007)
[22] "Potential of Biomass Energy" (2005)

c. Solar Energy

i. General Introduction

Solar energy technology uses the sunlight to generate electricity or thermal energy, which can be divided into photovoltaic or thermal categories. The term "photovoltaic" comes from generating electrical energy (voltage) using the sun's light (photons). A semi-conductor material is coated with an anti-reflective layer creating a photovoltaic cell. These cells are usually grouped into modules and arrays to increase the total power output. In a different solar energy application, solar thermal energy collects energy from the sun to generate thermal energy (heat). The temperature range categorizes thermal energy collectors. There are three thermal categories: low, medium and high. For example, low temperature collectors are often used to warm up swimming pools.

Both solar technologies have zero cost and low maintenance requirements. The main cost of these systems is installation, which can be considered an investment since utility and state incentives are often offered for the use of solar technology. For example all of the states in the Pacific Northwest region of the United States offer incentives. Oregon in particular offers low interest loans for the installation of solar energy technology. Solar energy reduces the dependence on fossil fuels and can create many jobs, which would contribute to the economy.

ii. Existing Solar Technology in NW Region

The Pacific Northwest region is very suitable for solar installations despite being known for its cloudy sky, rainy weather and long winters. According to the Northwest Solar Resource map in Figure 14. Northwest Solar Resource Map[23], all the area has moderate to high potential for solar resources, with southeastern Oregon and southern Idaho having the highest potential. There are three basic categories of existing solar technology including the photovoltaic (PV) system, solar water heating system, and passive solar heating system.[24]

[23] Renewable Northwest Project
[24] Oregon Department of Energy

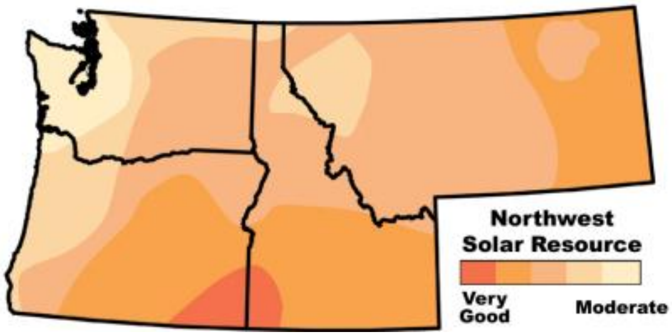

Figure 14. Northwest Solar Resource Map

The PV system generates electricity directly from sunlight using solar cells. The solar panel modules are usually mounted on residential homes, producing electricity at a levelized cost of $0.20 - $0.60/kWh before incentives. Government offers great incentive programs throughout the Pacific Northwest region, in particular the net metering program. Net metering program allows customers to store the extra power generated during the day into the utility's electrical grid, so that they can avoid investing in expensive storage systems and still be able to take the energy out for nighttime usage. Furthermore, Washington State has the greatest incentive program where it offers a production incentive of $0.15/kWh for electricity from solar energy, resulting in 19.6 MW of renewable power from PV systems in 2013.[25]

The second existing technology is solar water heating system, which uses sunlight to heat water for houses or swimming pools. It consists of storage tanks and solar collectors, where the solar collectors transfer the light energy to thermal energy in order to heat the tank of water. Even if there are cloudy days, the solar hot water system still works well because it absorbs a larger spectrum of the sunlight, including the diffused solar radiation.

The last existing technology is passive solar architecture to heat living and working spaces. Without active mechanical system such as water system or solar cells, the passive technology uses all elements of a building to convert sunlight into usable energy. For example, sunspace, operable windows, thermal chimneys are all elements of a passive solar building design. Even in the Pacific Northwest region, a passive home can save up to 60% annually on conventional fuel cost[26].

iii. Available Solar Technology

Various technologies are being developed to maximize the energy output from solar resources. Some of these include solar thermal, PV and hybrid. Major growth is expected for the Concentrated Photovoltaic technology market. While most current CPV projects are still in the

[25] Solar Washington

[26] Wintersundesign

prototype stage, the increased understanding of its technology and high investment in countries like Italy, China and Australia has led to major interest in large-scale CPV projects[27]. However, the technology viability and high interest rates due to a lack of government support are major risks for developing CPV companies. Thin films and crystalline silicon materials may help increase the efficiency of solar panels and reduce manufacturing costs, according to a recent market research by BCC Research[28].

The other technology gaining attention for harnessing solar energy is "concentrating solar-thermal technology". Solar thermal power has several advantages over PV technology. According to Nathaniel Bullard of New Finance Energy[29], it is better able to match a utility's electrical load since they are built on a larger scale and have lower costs. Further, since they use turbines to generate electricity, they can be easily supplemented with natural gas boilers.

Hybrid combines the strength of both technologies to increase efficiency so that solar power is available day and night. According to Technology Review[30], the Advanced Research Projects Agency – Energy has invested approximately $30 million in researching and testing hybrid technologies that combine the two. One idea is be to split up the solar spectrum. Since solar cells work well only at certain wavelengths of light, the others can be redirected to heat water and product steam. Another approach uses nanoparticles suspended in a translucent fluid to absorb certain wavelengths. The heated fluid can then be used to generate steam.

iv. Future Scope

The future for solar technology is looking bright; since 2007 the solar PV market grew at over 50% annually in the United States. The dramatic increase in installation of PV modules is attributed to rapidly falling costs of installed panels from $6/watt to $3/watt[31]. Forecasted future PV installation will increased installed PV by 70% to over 17GW by 2014[16].

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[27] Renewable energy.world.com - Global Concentrated Photovoltaic Market Growth and Investments
[28] http://www.renewableenergyworld.com/rea/news/article/2012/02/c-si-thin-films-vie-for-solar-cell-market
[29] Economist.com – The other kind of solar power
[30] MIT Technology Review – Hybrid Solar power Works even when it's not sunny

[31] Clean Technica-US Passes 10 GW Installed Solar PV Capacity Milestone

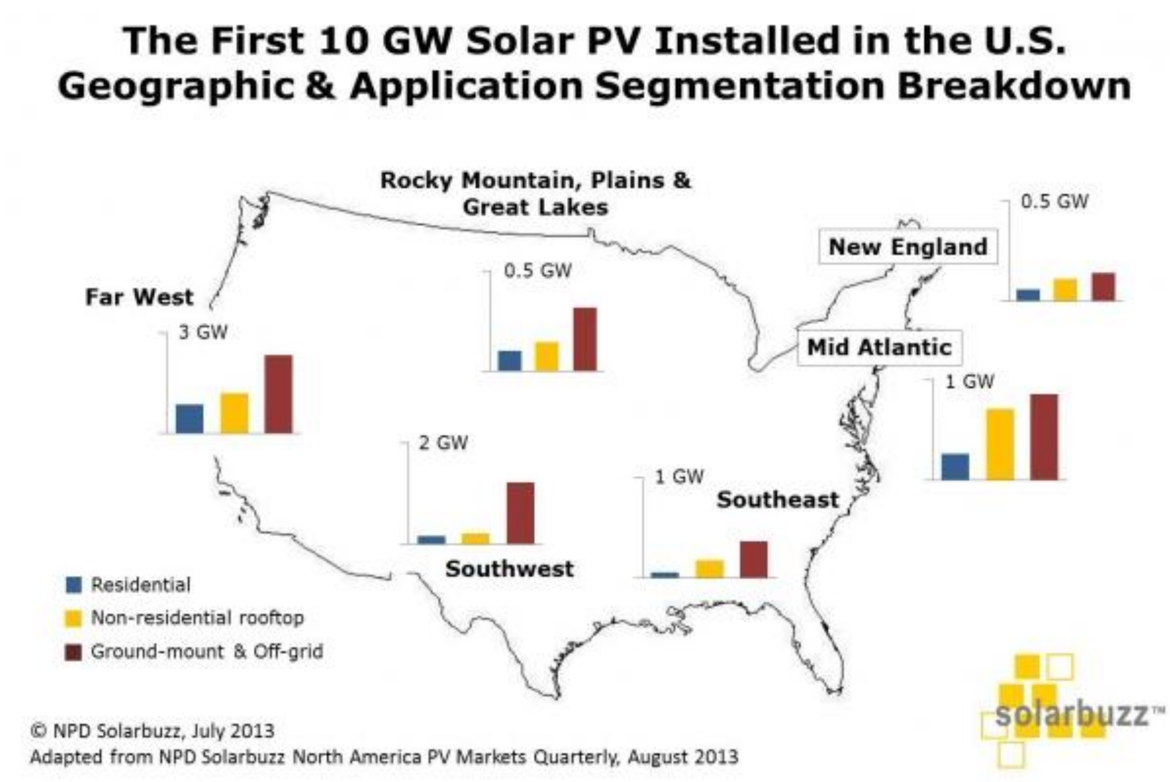

Figure 15. The First 10 GW Solar PV Installed in the US Geographic & Application Segmentation Breakdown

New technologies are increasing the conversion efficiency of solar cells. The Sharp Corporation reached a 44.4% efficiency utilizing a concentrator triple junction compound solar cell[32]. The revolutionary type of solar cell utilizes multiple absorption layers made out of indium and gallium compounds. The layer technology is a break from the silicon cells found in most of the world's PV market[17].

[32] PHYS.Org-Concentrator solar cell with world's highest conversion efficiency of 44.4% Jun 14, 2013

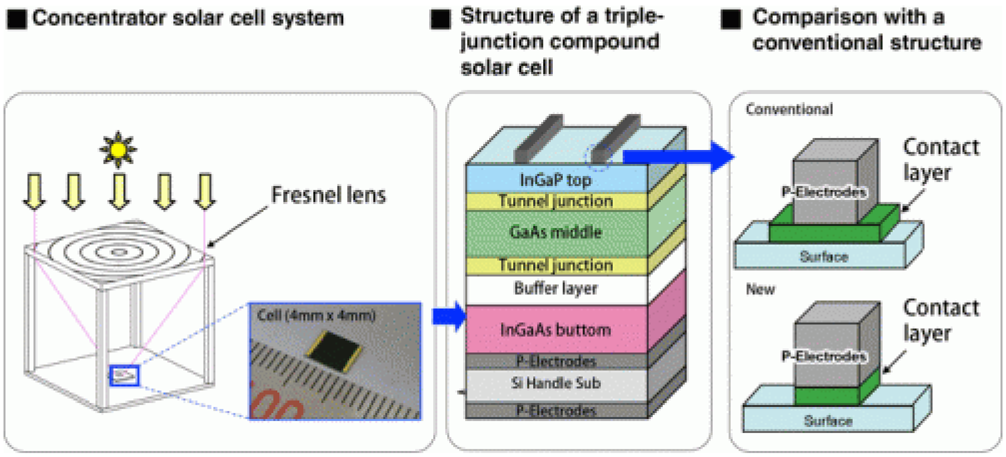

Figure 15. Solar Cell System

Future materials research will decrease the PV manufacturing cost further while increasing conversion efficiencies. University of Wisconsin- Madison materials engineers are developing a nanotube solar cell that can theoretically convert light into electricity at almost 75 percent efficiency[33]. Although their research is still in proof of concept phase dramatic improvements are expected.

[33] University of Wisconsin-Madison News ,Future looks bright for carbon nanotube solar cells June 18, 2013 ,Renee Meiller

Part III: Energy Models

11. Wind Energy Model

a. Major Assumptions & Limitations

When doing our calculation we made the following assumptions:

	OR	WA
Capacity Factor	0.35	0.32
Energy Demand (Million kWh)	20,030	31,827
Energy Demand (MWh)	20,030,000	31,827,000
Discount rate (%)	7.00%	7.00%
Time (yrs)	20	20

Table 2. Major Assumptions and Limitations Summary

As stated in Table 2**Error! Reference source not found.**, the discount rate of 7.00 % is adopted as being a standard rate used by the U.S. federal government, and the lifetime of 20 years is used as a typical energy system investment lifetime. The Integration team determined the Energy Demand. All the numbers and calculations shown below are assuming that we are designing to meet 100% of the energy demand in Washington and Oregon. We also assumed that all land in Oregon and Washington is free of wind turbines at the time of our design. In other words we are assuming that there are currently no wind farms existing in Oregon and Washington.

b. Capacity Factor

The capacity factors for each state were taken from the chart in Figure[34]. We chose to use the maximum capacity factors shown in this chart for both Washington and Oregon. The reason we chose the max, as opposed to the average, was due to the anticipation that as technology improves over the next 20 years so will the capacity factor.

[34] "Montana Energy Currents." *Commerce.mt.gov*. Montana Department of Commerce, 30 Jan. 2013. Web. 10 Oct. 2013.

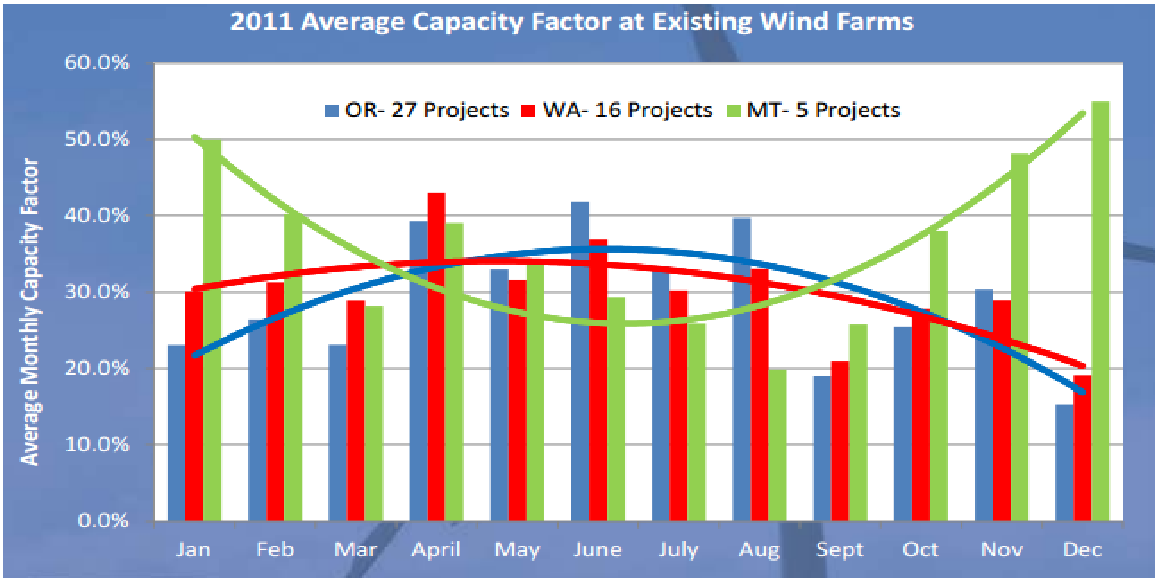

Figure 16. Average Capacity Factor at Existing Wind Farms

c. General Calculations for Cost Analysis

i. Capital Costs

Our capital cost calculations were based on pre-existing wind farms in Oregon and Washington that had the same model of turbines installed. Our sources gave us cost of the turbines and the capacity of the installed turbines, and we divided the two to obtain the cost per MW for each state. The results are summarized in Table 3 below:

	Cost (Mil $)	Capacity (MW)	Cost per MW (Mil $/MW)
OREGON			
Lower Snake River Wind Farm [35]	$535	267	2.00
Windy Point/Windy Flats [36]	$670	262	2.56
AVG			**2.28**
WASHINGTON			
Biglow Canyon Wind Farm [37,38]	$1000	450	2.22
Klondike Wind Farm [2, 39]	$234	101.2	2.31
AVG			**2.26**

Table 3. Average Cost per MW (OR and WA)

The cost per MW and capacity of installed turbine were used to calculate the cost per turbine, using the formula below:

$$Cost\ per\ Turbine\ \left(\frac{\$}{Turbine}\right) = Cost\ per\ MW\ *\ Capacity\ of\ Installed\ Turbine\ \left(\frac{MW}{Turbine}\right)$$

By multiplying the calculated value above with the number of turbines we were able to determine the Capital Cost of the Turbines:

$$Capital\ Cost\ of\ Turbines = Cost\ per\ Turbine * Number\ of\ Turbines\ Needed$$

Using the Capital Cost we calculated above, a discount rate of 7%, time period of 20 years (which are listed in the assumptions section) and the excel function PMT we calculated the Annual Capital Cost.

$$Annual\ Capital\ Cost = -PMT(Discount\ Rate, Time, Capital\ Cost)$$

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[35] "Agri-business." *Sherman County Oregon*. N.p., n.d. Web. 24 Nov. 2013.
[36] "Windy Point/Windy Flats." *Wikipedia*. Wikimedia Foundation, n.d. Web. 24 Nov. 2013.
[37] Sickinger, Ted. "PGE Completes Final Phase of Biglow Canyon Wind Farm." *The Oregonian*. N.p., 08 Sept. 2010. Web. 24 Nov. 2013.
[38] Enk, Terry, Kimberly Bay, Michelle Sonnenberg, Jeanette Flaig, JR Boehrs, and Andrea Palochak. "Biglow Canyon Wind Farm Phase II Sherman County, Oregon."*Oregon.gov*. Portland General Electric Company, 15 June 2012. Web. 15 Nov. 2013.
[39] "PGE Completes Second Phase of Wind Farm." *Widgets RSS*. Portland Business Journal, 20 Aug. 2009. Web. 24 Nov. 2013.

Our final calculation was to determine the cost per kWh, since this is what we will be using to add to the Operating Cost to get the levelized cost of wind energy. We accomplished this by dividing the Annual Capital Cost and dividing it by the kWh per Year (which is listed in the assumptions section).

$$Cost\ per\ kWh = \frac{Annual\ Capital\ Cost}{kWh\ per\ Year}$$

	OR	WA
Cost per MW ($/MW)	$2,280,498.61	$2,264,915.46
Cost per Turbine ($/Turbine)	$5,245,146.81	$5,209,305.56
Capital Cost of Turbines	$14,898,365,044.32	$25,715,419,631.70
Annual Capital Cost	$1,406,300,265	$2,427,353,696
kWh per Year	20,030,000,000	31,827,000,000
Cost per kWh	$0.070	$0.076

Table 4. Capital Cost Results

ii. Operating Costs

Our operating cost was found during our research and is $0.023/kWh for both of the states. Our source got this cost by summing the following:

1. Management and Administration: $4.0/MWh
2. Turbine Operation and Maintenance: $10.6/MWh
3. Balance of Plan: $2.4/MWh
4. Other Direct Costs: $6.1/MWh

We simply converted the sum into kWh from MWh to get the $0.023/kWh as our operating cost.

d. Constraints in Model

The proposed model incorporates certain assumptions and corresponding constraints. The calculations for capacity factor and the grid output are obtained through analyzing the historical data. However, with the advancement of technology, these values may end up on a higher side as systems become more efficient. In the last few years the capacity factor has seen a significant rise. It also depends on the availability of the wind that may vary every year and hence have a significant effect on the power output.

The sensitivity parameters chosen for studying the various possible outcomes like power output to grid and demand satisfied, depend on the capacity factor (see Table 5 below):

Wind	Units	Min	Base (Usual) Value	Max
Capacity Factor (%)	%	18	29	35
Demand Satisfied	Per KW-h	10,015,089,000	16,596,433,200	20,030,178,000
Output to Grid	Per KW-h	10,015,089,000	16,596,433,200	20,030,178,000
Annual Capital cost	$	1,356,659,708	1,356,659,708	1,356,659,708
Cost per kWh (includes operating and capital cost)	$ Per KW-h	0.155	0.102	0.088

Table 5. Summary of Constraints in Model

From Table 5, it is evident that the capacity factor varies from a maximum of 35% to a minimum of 18%. Correspondingly, the output to grid also varies more than 50% in between the maximum and the minimum demand satisfied.

Also, the current model does not incorporate the transmission costs that may become significant, if the maximum demand is to be met using the Wind energy. Along with setting up the wind farms, the infrastructure for transporting the energy to the remote locations is required.

e. Levelized Cost

To obtain the total levelized cost we used the operating and capital costs, obtained above, as well as the Renewable Electricity Production Tax Credit (PTC). The PTC allows for 2.3 cents government tax credit for wind farms, which if not received, can be sold to some other nearby farm. Using the formula below it is evident that the Total Cost ends up being the Capital Cost since the PTC credit negates our Operating Cost [40] .

$$Total\ Cost = Capital\ Cost + Operating\ Cost - PTC\ Credit$$

We determined the Annual Overall Cost by multiplying the Total Cost with our energy demand along with a factor of 10^6 to convert our value into million dollars.

$$Annual\ Overall\ Cost = Total\ Cost * \ Energy\ Demand * 10^6$$

[40] "Federal Renewable Electricity Production Tax Credit (PTC)." *DSIRE USA*. North Carolina University, 2013. Web. 24 Nov. 2013.

The results of the formulas above have been summarized in Table 6 below:

	OR	**WA**
Capital + Operating Cost	$0.093	$0.099
Renewable Electricity Production Tax Credit (PTC) ($/kWh) [7]	$0.023	$0.023
Total Cost ($/kWh)	$0.070	$0.076
Annual Overall Cost ($)	$1,406,300,265	$2,433,719,096

Table 6. Total Cost Summary

f. Potential Sites for Development

General Turbine Calculations

Before we could determine the locations of our wind farms, we needed to determine the total number of turbines and the area they would take up. We first took the Energy Demand that was given to us by the Integration team and converted it into MW using the following formula:

$$Total\ Capacity\ of\ All\ Turbines\ (MW) = \frac{Energy\ Demand\ (MWh)}{\frac{8760\ (\frac{hrs}{yr})}{Capacity\ Factor}}$$

Upon obtaining that value we divided it by the Capacity of the Installed Turbines of the Siemens SWT-2.3-101 turbine (2.3 MW per turbine)[41] to get the total number of turbines needed in each state. See formula below:

$$Number\ of\ Turbines\ Needed = \frac{Total\ Capcaity\ of\ All\ Turbines\ (MW)}{Capacity\ of\ Installed\ Turbine\ (\frac{MW}{Turbine})}$$

After we had the number of turbines we needed to determine how much space they took up so that we could determine the locations of our wind farms. We found a conversion factor [42] that gave us how many acres were required per MW, and converted it to square kilometers (the numbers are listed in Table 7 below). Using this factor and the formula below we determined the area needed for the turbines:

[41] "SIEMENS." *Siemens*. N.p., n.d. Web. 24 Nov. 2013.

[42] "Area Used by Wind Power Facilities [AWEO.org]." *Area Used by Wind Power Facilities [AWEO.org]*. N.p., n.d. Web. 24 Nov. 2013.

$$Area\ Needed\ for\ Turbines\ (km^2) = \ Total\ Capacity\ of\ All\ Turbines\ (MW) * \ km^2/MW$$

	OR	**WA**	**NOTES**
Total Capacity of All Turbines (MW)	6,533	11,354	
Capacity of Installed Turbine (MW/Turbine)	2.30	2.30	Siemens SWT-2.3-101 [43]
Number of Turbines Needed	2,840	4,936	
km ^2 / MW	0.17402	0.13759	used 43 acre/MW (0.174015 km^2/MW) for OR and 34 acre/MW (0.137593 km^2/MW) from WA [44]
Area Needed for Turbines (km^2)	1,137	1,562	

Table 7. General Turbine Results

Turbine Areas

Once we determined the total number of turbines and the area they took up we started looking for potential wind sites. We found a map (Figure and Figure) that showed the wind speeds over Oregon and Washington [45] and decided to place the turbines in the areas that were highest in wind speed (which was between 6 and 7 m/s). We also didn't want to place the turbines on mountain ridges so we chose flat areas. For the areas in Oregon, we chose 1 and 2 because the location was flat, had one of the highest wind speed areas (the lime green areas are the 6-7 m/s areas) and were close together.

[43] "SIEMENS." *Siemens*. N.p., n.d. Web. 24 Nov. 2013.

[44] "Area Used by Wind Power Facilities [AWEO.org]." *Area Used by Wind Power Facilities [AWEO.org]*. N.p., n.d. Web. 24 Nov. 2013.

[45] "Air Sports Net." *Air Sports Net RSS*. N.p., n.d. Web. 24 Nov. 2013.

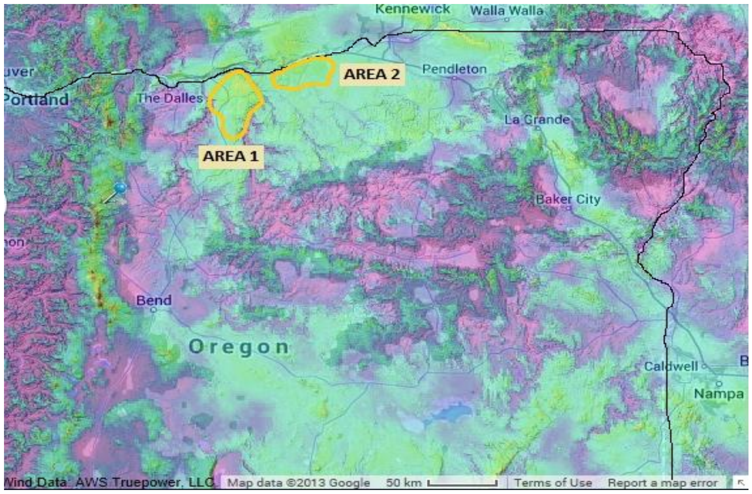

Figure 17. Wind Farm Areas in Oregon

The areas in Washington State were selected in a similar way, yet we chose 3 to spread the turbines out a little more as well as the demand we needed to meet was larger than that in Oregon. We placed most of the turbines in Area 1 because average wind speed was slightly higher in that area.

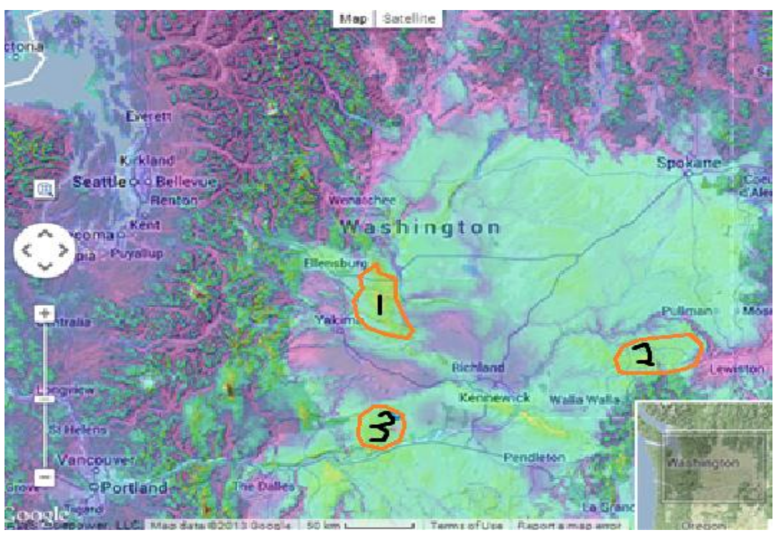

Figure 18. Wind Farm Areas in Washington

Using the 50 km scale we were able to calculate the square kilometers in each chosen area. Dividing that number by the total area we were able to find what percentage of the required area each section took up and then multiplied it by the number of turbines to determine how we were going to allocate the turbines for each state.

$$Percentage\ of\ Total\ Area = \frac{Land\ Occupied\ by\ Turbines}{Area\ Needd\ for\ Turbines\ (km^2)}$$

$$Number\ of\ Turbines\ in\ Area = Percentage\ of\ Total\ Area * Number\ of\ Turbines\ Needed$$

The results of these calculations are listed in Table 8 and Table 9 below:

	AREA 1	**AREA 2**
Land Available (in km^2)	900	450
Land Occupied by Turbines	800	337
Available Land for Turbine Installation to Meet Future Demand	100	113
Percentage of Total Area	0.7037	0.2963
Number of Turbines in Area	1,999	842

Table 8. Turbines Areas in Oregon

	AREA 1	**AREA 2**	**AREA 3**
Land Available (in km^2)	750	650	350
Land Occupied by Turbines	650	600	312
Available Land for Turbine Installation to Meet Future Demand	100	50	38
Percentage of Total Area	0.4161	0.3841	0.1997
Number of Turbines in Area	**2,054**	**1,896**	**986**

Table 9. Turbines Areas in Washington

In Table 8 and Table 9 above there is a row called "Available Land for Turbine Installation to Meet Future Demand". This row shows how many square kilometers in each designated area will be left empty for installation of more turbines to help meet future demand.

The areas we chose are generally the areas where wind farms already exist in the area, and these farms have been profitable. This fact was not considered when we were choosing our locations, instead we placed farms in the areas we thought would be most effective and it just so happened that this is where most of the existing farms in Oregon and Washington currently lie. Wind energy currently supplies energy for a much smaller percentage than we are designing for, meaning, that our wind farms are larger and more in number than the farms required in those areas currently.

Wind Farms if Installed as Distributed Entitles

If we were to install wind farms as distributed entities rather than one large-scale centralized production of power, then the transmission grid would look as follows:

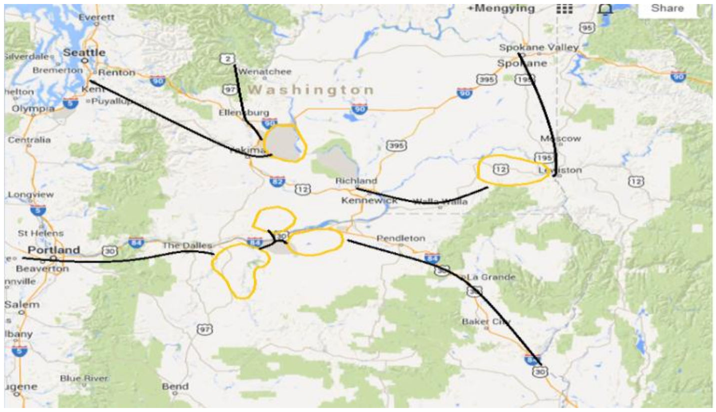

Figure 19. Google Maps Transmission of Distributed Entities

Conversely, for a large scale centralized production of power the transmission grid would look like this:

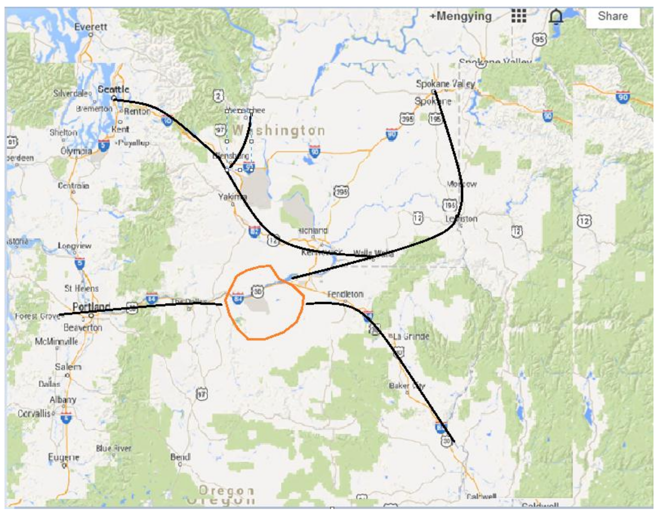

Figure 20. Google Maps Transmission of Large Scale Centralized Production

The Wind farms if installed as distributed entities have less electricity transportation losses on long distance power lines or energy losses from the Joule effect (the process by which the passage of an electric current through a conductor releases heat) in transformers where in general 8-15% of the energy is lost[46]. Therefore, the cost for long distance power lines will be lower and without electricity transportation losses.

Analysis of Hanford reserve in WA State

[46] "Environmental Statement South Kyle Wind Farm." *Vattenfall.com*. N.p., Aug. 2013. Web. 7 Dec. 2013.

The Hanford site is a decommissioned nuclear complex operated by the United States federal government on the Columbia River in the Washington state. According to *Legend and Legacy: Fifty Years of Defense Production at the Hanford Site* the Hanford Site is described as a "large and remote tract of land, a 'hazardous manufacturing area' "[47]. There are "no towns of more than 1,000 people closer than 32 km from the hazardous rectangle, and no main highway, railway, or employee village closer than 16 km from the hazardous rectangle" [14] . Due to the fact that the site is uninhabitable, this would, in theory, serve as a good site to place turbines, except that the wind speed is very low in this area. As is evident from Figure[48], the wind speed in Hanford is around 3 to 5 m/s which is too low.

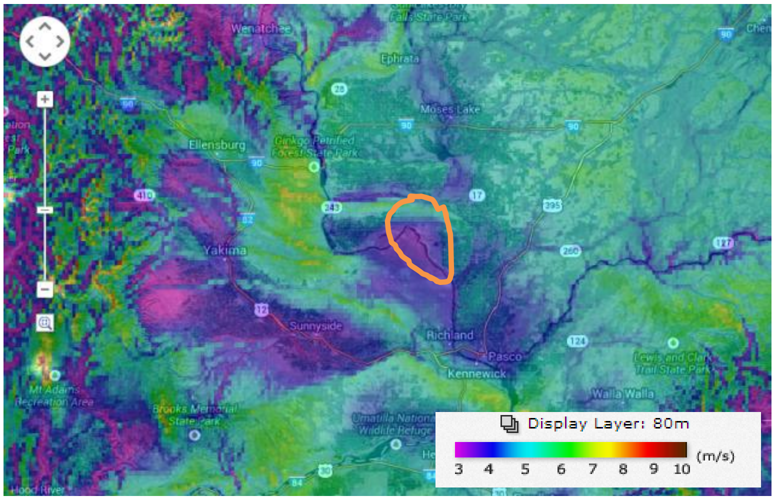

Figure 21. Wind Speed in Hanford, WA

It is also important to realize that a wind farm requires maintenance and operation staff, and it would not be safe to send in workers into that area, neither during construction nor during operation of the wind farm.

g. CO_2 Mitigation

To determine the CO_2 Mitigation we took the number of million metric tons of the current installed capacity in OR[49] and WA[50] (taken from the RNP website), and obtained a conversion

[47] Gerber, Michele (1992). *Legend and Legacy: Fifty Years of Defense Production at the Hanford Site*. Richland, Washington: Westinghouse Hanford Company. p. 6.]
[48] "Air Sports Net." *Air Sports Net RSS*. N.p., n.d. Web. 24 Nov. 2013.
[49] "Oregon Renewable Energy Projects Fact Sheet." *RNP.org*. Renewable Northwest Project, 21 June 2013. Web. 24 Oct. 2013.
[50] "Washington Renewable Energy Projects Fact Sheet." *RNP.org*. Renewable Northwest Project, 29 June 2013. Web. 11 Oct. 2013.

factor to be used in conjunction with our installed capacity, to obtain the CO_2 Mitigation from the turbines we install. We used the two formulas below:

$$CO2\ Mitigation/MW = \frac{CO2\ Mitigation}{Installed\ Capacity} * \frac{1000\ kg}{1\ metric\ ton}$$

$$Our\ CO2\ Mitigation/yr = \frac{CO2\ Mitigation/MW}{Total\ Capacity\ of\ All\ Turbines}$$

Following this calculation, we wanted to determine how much it was costing us to effectively remove this amount from the environment. To determine this number, we divided the Annual Overall Cost ($), which was calculated in the Capital Cost section above, with "Our CO2 Mitigation per Year Number", as is demonstrated with the formula below:

$$Cost\ per\ kg\ of\ CO2\ removed = \frac{Annual\ Overall\ Cost\ (\$)}{10^6 * Our\ CO2\ Mitigation\ per\ Year}$$

The results of these formulas are summarized in Table 10 below:

	OR	WA
CO_2 mitigation (million metric tons)	4.60	4.18
CO_2 mitigation (million kg) / MW	1.459	1.488
Our CO2 Mitigation per Year	9,531	16,889
Annual Overall Cost ($)	$1,406,300,265	$2,433,719,096
Cost per kg of CO2 removed	$0.15	$0.14

Table 10. CO2 Mitigation

h. Social and Economic Impacts

Quieter Turbine

There are two things that create noise in large turbines. The first is mechanical noise from nacelle, which is mainly caused by the gearbox and generator, and may generate tones and low-frequency noise. Generally gearless turbines are quieter than geared turbines[51]. The second source of noise is aerodynamic noise from the blades. This is usually the dominant noise source [18]. When selecting a turbine we compared Siemens wind turbines with GE Energy, Vestas,

[51] Oerlemans, Stefan, and Peter Fuglsang. "Low-noise Wind Turbine Design." *Ewea.org*. Siemens, 2012. Web. 7 Dec. 2013.

Nordex, Enercom. We compared the mechanical noise cause by the gearbox and generator under the same external environment. According to Table 11[52] the mechanical noise caused by the gearbox and generator of the Siemens wind turbines is lowest.

Turbine	Turbine Sound Power Level (dB LWA(eq)) at wind speeds at 10m Height						
	4 m/s	5 m/s	6 m/s	7 m/s	8 m/s	9 m/s	10 m/s
Enercon E-101 3 MW	--	100.0	103.9	106.4	107.0	107.0	107.0
Nordex N100 2.5MW	99.0	101.0	103.5	107.0	108.0	108.0	108.0
Siemens SWT-3.6-101	97.0	101.9	107.1	108.5	108.5	108.5	108.5
Siemens SWT-3.0-101	--	--	105.8	107.0	107.0	107.0	107.0
Vestas V90 3MW	100.2	103.6	107.0	108.4	109.0	108.7	107.5
Vestas V112 3MW	99.5	103.2	106.6	108.5	108.5	108.5	108.5
Assessment	100.2	103.6	107.1	108.5	109.0	108.7	108.5

Table 11. Turbine Sounds Power Level at Wind Speeds at 10 m Height

The Siemens turbine listed is a 3.0 MW turbine and since not every manufacturer has 2.5 MW turbines the closest thing in Table 10 is the 3 MW turbines. Since the 2.5 MW turbines are smaller than the 3.0 MW our turbines are actually even quieter.

Job Creation

One of the large social impacts resulting from the creation of our wind farms will be the creation of jobs, both construction and permanent-on-site jobs. The construction jobs created would be temporary jobs and would only last for the duration of the wind farm construction, whereas the permanent-on-site jobs are considered continuous, in that they will always be relevant as long as the wind farms are being used. Similar to the CO_2 Mitigation calculation, we set up a proportion, using the job creation number for the existing installed capacity in OR [53] and WA[54] to determine the number of jobs created per MW. We then multiplied that number by our installed capacity to obtain the values listed in Table 12

52 "Environmental Statement South Kyle Wind Farm." *Vattenfall.com*. N.p., Aug. 2013. Web. 7 Dec. 2013.
53 "Oregon Renewable Energy Projects Fact Sheet." *RNP.org*. Renewable Northwest Project, 21 June 2013. Web. 24 Oct. 2013.
54 "Washington Renewable Energy Projects Fact Sheet." *RNP.org*. Renewable Northwest Project, 29 June 2013. Web. 11 Oct. 2013.

	OR	WA
Construction Job Creation/MW	0.67	0.72
Construction Job Creation	4,376	8,143
Permanent-On-Site Job Creation/MW	0.06	0.06
Permanent-On-Site Jobs Created	375	727

Table 12. Job Creation

In addition to construction and permanent jobs, there will be more manufacturing jobs created since our farms call for over 5,000 new turbines. According to a case study done by the Copper Development Association, it takes 2-3 days per turbine built[55]. Our design calls for a total of 7776 turbines (assuming that we are supplying 100% of the demand).

$$Time\ for\ Construction = 7776\ turbines * \frac{2\ days}{turbine} * \frac{1\ year}{365\ days} = \ 42.6\ years$$

We estimated a total cumulative construction time for 42.6 years for the turbines. It is important to note that cumulative is assuming that we build one turbine every 2 days and then move on to the next one. If we assume that we have two teams working (therefore 2 turbines get erected every two days) then our time gets cut into half. It is difficult to say exactly how long the construction time period will be since it depends on how much of the demand our wind farms are satisfying and also on the availability of labor. The equivalent construction man-hours that our wind farms would require are:

$$Construtcion\ Man - Hours = 42.6\ years * \frac{365\ Days}{1\ year} * \frac{8\ work\ hours}{1\ day} = 124{,}416\ hours$$

Therefore, even though the time period is difficult to estimate we can say that our wind farms will provide construction jobs worth 124,416 man-hours.

Useable Land for Famers

We also hope that the land that is not occupied physically by a turbine, will be usable to farmers and create yet another stream of revenue for them since the wind farm will have to pay rent to lease the land from them.

Negative Impacts

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[55] "Federal Renewable Electricity Production Tax Credit (PTC)." *DSIRE USA*. North Carolina University, 2013. Web. 24 Nov. 2013.

The only negative impact we have encountered is that of birds flying into the turbines, but that has not been a very large issue with the existing turbines in OR and WA and since we have chosen the same locations we do not view this as major issue.

i. Further Considerations

One thing to consider further is the source of our labor, since many wind farm laborers are specialized and come from states other than Oregon and Washington. This was a very good point since our wind farms were going to create jobs, but they may be out of state, that would be taking money out of state. Therefore the source of labor is one of our considerations.

The current model is based on the demand predicted up to 2034. If the demand changes considerably the model will require revision in terms of installed capacity, therefore the capital cost incurred may change. Also to make up for the gap between demand and supply, hydropower could be an alternative as it is the most flexible model currently in place. Also the power generated can be measured through weather forecast, as the capacity factor and hence the final output to grid depends upon the wind speed.

The advancement of technology would also be a consideration for the future since our demand is expected to grow and we have left areas to install turbines. We would need to look into the new turbine technology and see if it is compatible with our existing system.

j. Reliability of Model

The goal of the model is to meet the forecasted demand that may vary with the advent of new industrial setup and growing population. Currently, the power generated from non-renewable meets more than 40% of the energy demand in United States, which cannot be replaced without a highly reliable and practically feasible model. Also, the power generation from the wind farms depends upon the wind speed and hence may not be able to meet the demand in case of wind deficit. Overcoming these challenges and ensuring that the proposed model meets the energy demand requires the reliability study of the model for various possible scenarios.

The major challenge for the perspective presented is the overwhelming dependency on the non-renewable energy sources. To outdo this problem, the project has been designed to be fully operational gradually in a timeframe of 20 years, which would ensure that there are sufficient sources in case of setbacks in the project.

The capacity factor used for the calculations is conservative, so as to design the model to produce power surplus. Although, it implies overdesigning the wind farms, it would ensure that the power deficit would be met in case the demand spikes which is a possibility with increasing industrial developments and growing population.

The weather conditions for past years have been studied to estimate the average wind speeds in the areas chosen for project setup. In case of an unlikely event of drastic weather change, the power deficit can be supplemented though hydropower. The flexibility and ability of Hydro power plants to regulate the power quickly makes it a perfect choice to work alongside the Wind farms. The weather forecast agencies can also help to predict the weather in advance to help the Wind farms to estimate the power production.

k. Project Milestones

The realization of the proposed model may involve many steps that could be broken down in project milestones. The project can be divided into following milestones:

1) Legal Permissions.
2) Land Acquisition.
3) Component production.
4) Infrastructure
5) Operations.
6) Entry-into-Service
7) Maintenance.

Each of the steps requires careful planning and successful execution of individual steps is essential for implementation of the model. The project will be implemented by considering the equal yearly capacity to be installed in 20 years i.e. each year same capacity will be installed in the wind farms.

Essentially, the project can also be divided into operational and non-operational functions. The non-operational functions may include Legal permissions, land acquisition, component/turbine manufacturing, financial analysis, labor allocation, remunerations and initial setup of the infrastructure required for Power generation and transmission to the proposed areas, whereas, the operational functions can be summarized into power generation, regulation and transmission and maintenance of the wind farms.

12. Solar Energy Model

a. Major Assumptions and Limitations

The energy supply portfolio of renewable energy is continuously increasing as technology allows for the development of reliable systems. Solar energy in particular has advanced with the potential to contribute significantly. The production of solar energy consists of a variety of environmental and technological factors. In our model we simulate the behavior of solar energy production with the effect of unique characteristics. Historical consumption data indicates an increase the in the use of solar energy due to a surge in the development of alternative energy. The increase has caused significant breakthroughs in technology allowing renewable energy to enter a competing market despite its reliability constraints. Allowing a variety of factors to influence the design decisions of our model enables the simulation of a feasible system. An important factor would be the electricity demand of the state of Washington and Oregon. Using an average monthly load similar to an annual peak, we estimate the demand needed for the Pacific Northwest region.

To simulate an increase of solar technology in the energy supply portfolio for such a large region we studied the importance of deterministic characteristics such as the capacity factor, levelized cost, current technology and potential areas of development. To extend our analysis, we have considered possible methods of reducing the levelized cost. General calculations are performed for further cost analysis. The potential areas of development are determined without the consideration of transmission constraints to simplify our analysis by assuming the transmission will be provided. Solar technology is considered to have relatively low operating costs with a high installation cost. Such capital investment must be studied to achieve a feasible and optimal approach.

For the purpose of our simulation the generation of solar energy is performed using a conventional commercial solar panels rated at 300 W. The efficiency of solar panels has significantly increased the past, showing significant breakthrough of 40% efficiency. High efficiency panel are not typical for commercial use because of its high manufacturing cost which translates to capital investment. For our study we have considered a typical efficiency today of 15%. Besides potential costs or sites of operation, we also consider the CO2 mitigation from such solar energy development. The benefits of our model are reflected in the reduction of fossil fuel dependence. Affordable and feasible implementations of solar energy are considered in our model. The development of solar energy has noticeable benefits, as well as the opportunity of CO2 mitigation we have also studied the social and economic impact of our system. Finally, we discuss further considerations for future analysis.

b. Capacity Factor

Solar capacity factor is the maximum possible solar energy output that is actually produced by the plant. Despite the fact that the intensity of sunlight changes on both hourly and seasonal basis, our model assumed a fixed capacity throughout the whole year. We simplified the model by finding the ratio of total solar energy output over a year. The PVWatts[56] site provided us monthly electrical energy produced, from a total of fourteen sites in both Oregon and Washington. Oregon has 9 sites, including stations in Astoria, Portland, Salem, Eugene, North Bend, Medford, Redmond, Burns, and Pendleton. Washington has 5 sites, including sites in Quillayute, Seattle, Spokane, Olympia, Yakima. Per location, we summed up the AC Energy output and divided by the number of hours in a year. Oregon has a higher capacity factor, with an average of 13.27%, where Washington has an average capacity factor of 12.22%. When looking at it on a monthly basis, we really see that different seasons have different amount of sunshine. The peak capacity factor occurs in September, 18.73% and 17.79% for Oregon and Washington, respectively. On the other hand, capacity factor drops dramatically in December to 6.44% and 5.66%. The calculations were based on a fixed tilt array and a 0.77 derate factor, which accounts for all the possible energy losses in the system.

c. General Calculations for Cost Analysis

i. Capital Costs

As with any investment, one of the most essential analysis is the cost analysis. Solar energy uses relatively expensive technology and requires a large initial investment. However, most power generation projects involve high initial capital costs. The energy industry in general has a large gestation period. As one might imagine, attempting to meet such a large portion of two states energy requirement using only solar energy is obviously going to be a costly project. There are two major costs involved here. The capital or equipment cost and the installation costs. Our capital costs are $1000 per kW and installation costs are $900 per kW.

ii. Operating Costs

To figure out our total expenditure we first need to estimate what the requirements are in terms of installed capacity. Given our demand data, we found that we had to meet a requirement of 14 million kWh per day. Given our capacity factor, we needed an installed capacity of 45 million kW. At an estimated $1900 per kW, we get a total cost of 86.5 billion dollars. Now this is a large number, but one must understand that the project will be spaced over several years and no single year will require such large investments. Taking a discount rate of 7% and a conservative

[56] PVWatts http://rredc.nrel.gov/solar/calculators/pvwatts/version1/

lifespan of 20 years we get a capital annuity of around 8 billion dollars. Dividing by our annual production we get a levelized cost of 15.8 cents per kWh. Adding an operating and maintenance cost of around 0.4 cents we get a total levelized cost of 16.2 cents per kWh. The table below summarizes these findings.

Capacity factor	13%
Capital Cost	$1,900
Fuel Cost	$0
Min export (kWh)	51,857,000,000
Output to Grid (kWh)	51,857,000,000
Max Capacity (kW)	45,562,822
Installed Capacity(kW)	45,562,822
Lifespan	20
Discount rate	7%
Electric Market Rate	$0.072
Install Cost	$86,569,000,000
Revenue/yr.	$3,734,000,000
Capital annuity	$8,172,000,000
Levelized cost per kwh	$0.158
Levelized w/maintenance	$0.162

Table 13. Solar Energy Levelized Cost Calculation

d. Levelized Cost

As we can see from the above cost analysis, the levelized cost of solar energy is fairly high at 16.2 cents per kWh. While the non-monetary benefits of solar energy are plenty, and should be taken into consideration when doing a cost benefit analysis, from a purely economic standpoint, solar energy clearly is not economically feasible given the substantially lower cost of generating electricity from alternative sources. Further, it is not completely clear as to how to assign a value to the other benefits provided by solar energy. This makes it even more challenging to justify an investment in solar energy.

Fortunately, there are several programs and means of making solar energy more economical. These are in the form of government (both state and federal) subsidies, tax incentives, reduced land prices, and carbon credits. The Northwest Renewable's Project however, is on an industrial scale, and is hence unable to take advantage of several schemes offered by state governments. Such schemes are targeted towards individual consumers rather than commercial and industrial projects which has been ensured by limiting the scope of the benefits to a level which would only benefit small scale projects. That being said, there are two alternatives for large scale projects which definitely help reduce the economic burden.

Solar Investment Tax Credit

Briefly stated, Solar Investment Tax Credit is a federal government program which reduces the tax liability of entities which make investments in solar projects. Under the scheme, all solar energy projects implemented by 31st December, 2016 would be entitled to take advantage of the program[57]. Currently, the corporate tax rate in the United States is at 35% of the operating profit. This represents a significant portion of a company or individual's profits, and often makes the difference when making a go no go decision. Under the scheme, all qualifying solar energy projects would be allowed to reduce their tax liability by up to 30% of the total investment in solar energy with no maximum credit. This addition of no maximum credit is what allows large scale projects to make use of the scheme, as all other government programs have limits which are so low that they would be economically insignificant for a project of this scale.

So why does the government help? There are several reasons. Reducing the tax on renewable energies, helps create investments in this field which in turn generates a number of new high wage jobs in the economy[58]. It helps make American energy companies more competitive globally, decreases pollution and reduces the energy charges to end use customers, thereby increasing their ability to contribute more productively to the economy. It also ensures continued interest in solar energy and advancements in solar technology which could one day be a major source of energy.

Levelized Cost with Tax Incentive

As described above, the Solar Investment Tax Credit has the potential to decide the economic fate of a project. This happens to be even more so in businesses with high operating margins. As investments are not considered costs, they are not factored in when calculating the taxable income. This results in solar energy projects having a high tax exposure. However, due to this program, the project will not have to make any payments in taxes until 30% of the investment expenditure is covered. Given that our operating profits represent almost all of our revenues, the scheme allows us to pocket nearly our entire revenue. To measure the impact of the tax credit, we decided to look at its impact on the levelized cost by reducing from the installation costs the present values of the future cash flows in the form of tax savings. The issue with using this system is, that since the operating profits vary with the amount of revenues we generate which directly depends on how much are able to produce and sell, the extent to which we can cover our 30% investment costs, varies directly with the percentage of the portfolio we are allowed to

[57] Energy Department. http://energy.gov/savings/business-energy-investment-tax-credit-itc
[58] Solar Energy Industries Association. http://www.seia.org/policy/finance-tax/solar-investment-tax-credit

meet. For instance, at just 1% of the portfolio, our levelized cost drops by just 0.1 cent to 16.1 cents per kWh. But at 100% we are able to take full advantage of the project and the levelized cost drops to 13.5 cents per kWh.

The table below gives an idea of how the levelized cost is impacted by the tax credit.

Price per kwh ($)	0.08
Operating Costs per kwh ($)	0.004
Corporate tax rate	0.35
% Actual Export	0.50
Min Export (kWh)	25,928,500,000
Actual Production (kWh)	12,964,300,000
Savings per year ($)	344,900,000
Years	20
Annual Rate	0.07
Present Value ($)	3,653,000,000
Installation Cost ($)	39,631,000,000
Capital annuity ($)	3,741,000,000
Levelized Cost ($)	0.144
Levelized w/maintenance ($)	0.148

Table 14. Levelized Cost with Tax Incentives

Here are annual savings are 35% of the operating profits per kWh times the amount of the total demand met by solar. Now while one way to make full use of this scheme is to try to maximize our operating profits, there is another way to make use of the scheme. These days, a large number of firms are looking to be environmentally more responsible. By tying up with these companies as partners they would be able to take advantage of the tax reduction. Under such a plan, we would provide the companies the land and the maintenance and operation. The companies will make the initial investment for which they will also get a percentage of the total profits. Thus using the tax credit to its full capacity will help produce energy sustainably.

Carbon Credits

Carbon credits are another interesting way of increasing revenues and profits of solar energy projects. A carbon credit is a tradable security, which allows the owning entity to emit 1 ton of CO_2 or other greenhouse gas equivalent into the atmosphere. These credits are awarded to countries or groups, which have reduced their greenhouse gas emissions below their emission quota[59]. Given their method of generation, one can most certainly expect that solar energy projects generating such a large amount of electricity will have a tremendous potential to benefit from their exchange traded nature. The sellers of these credits are entities which met their resource demands in a more environmentally sustainable way and are thus being rewarded for their effort and economic expenses using these credits. The purchasers of these credits are of varied nature. Some might be companies who are required by the laws in the country to purchase credits to compensate for any damage which their manufacturing process might be doing to the environment. Given the volatile nature of these securities, it often makes for an attractive investment opportunity for those who are bullish about the potential upside.

Now the number of carbon credits actually generated would depend on what form of energy we are replacing. However, to simplify calculations we assume that the emissions from the primary sources are the country wide average. At consumption of 51.9 Billion kWh hours of energy annually, we would generate a total of 26.4 Million carbon credits annually[60]. This represents reducing CO_2 emissions by over 26 million tons. There are several types of carbon credits and they trade for different prices. This difference arises primarily from the validation process used and company sponsoring the project. However, for a project of our scale, we should be able to achieve a European Union Allowance (EUA) classification which would allow us to sell each credit for $6.50 each[61]. This could give us a potential additional profit of $172 million a year. To put the value of the carbon credits in context, they represent a value of about 2% of the total levelized cost for the 51.9 billion kWh.

While $172 million a year is not small, according to analysts and market researchers, carbon credits today trade at much lower than their actual value. Many argue that for carbon credits to actually make a difference in the way people consume and produce, the price should be substantially higher. As the debate on global warming and climate change picks up, it is expected that governments across the world, especially in the developed nations will encourage the concept of carbon credits and possibly make it mandatory to purchase them if emissions are higher than the quotas. Further, the scope for carbon credits is immense. With new forms of trading such as derivatives and spot prices now available, it is expected that the trade in carbon credits will pick up and push the prices.

e. Technology

Photovoltaic cells convert light into electricity utilizing a property known as the photoelectric effect. The photoelectric effect was discovered in 1839 by French physicist Edmund

[59] Investopedia http://www.investopedia.com/terms/c/carbon_credit.asp
[60] Carbonify. http://www.carbonify.com/carbon-calculator.htm
[61] Thomson Reuters. http://www.pointcarbon.com/

Bequerel62; who discovered that certain materials produce an electric current when exposed to light. The electric current is the result of electrons shedding from semiconductor materials when the material is hit with photons. By capturing the released electrons we can utilize the electricity to power loads.

To increase capacity, solar cells can be wired together and supported in a structural frame called a photovoltaic module. The photovoltaic modules can be combined in series and parallel arrangement to create a photovoltaic array producing any necessary voltage and current combination required.

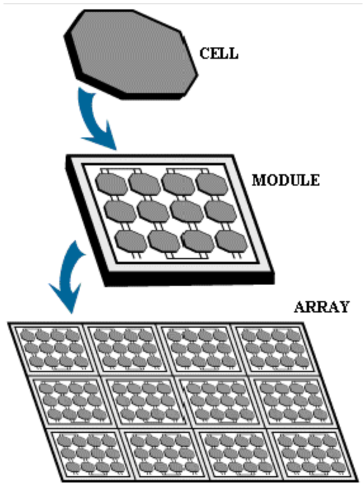

Figure 22. Solar Cell Module Array Diagram

The team investigated three types of commonly installed solar panel arrays. Fixed, adjustable and 2 axis tracking. The 2 axis tracking array is an automated array that tracks the sun horizontally and vertically throughout the year optimizing solar panel angle to receive the maximum possible sunlight throughout the year. This type of system increases the amount of energy captured by 25-30% over the fixed panel, however has higher maintenance costs and a 30% cost premium[63]. The adjustable array allows the owner to adjust the angle of inclination to match the lower angle of the sun in the winter and higher angle in the summer. The adjustable array will increase captured energy by up to 5% over the fixed panel, however maintenance costs are significant. The fixed panel array is mounted at a single optimal horizontal and vertical angle to maximize captured energy. The fixed array has the lowest installation and maintenance cost of the three. Comparing the maintenance and installation costs with the production capacity of the three systems the fixed array was found to have the lowest cost per kwh of electricity produced.

[62] NASA Science http://science1.nasa.gov/science-news/science-at-nasa/2002/solarcells/

[63] Solar Energy Home http://www.solarenergyhome.co.uk/different.php

	Fixed	Adjustable 2 or 4 Season	2-axis Tracker
% of Optimum	71.1%	75.2%-75.7%	100%
Land Availability	Less land required	More land required	Largest area footprint
Cost/kwh	$.16	$.19	$.24

Table 15. Comparison of Three Solar Array Systems

f. Solar Panel Sizing

The first step for solar panel array sizing is to figure out how much demand we are going to meet. We decided to size a photovoltaic solar power system that provides 100% of the total electricity demand for the Northwest region. Then we divided the solar demand by the capacity factor to find the total installed capacity. Assuming a 300 W solar panel, we were able to estimate the number of solar panels needed in both states, which comes out to be around 152 million, as shown in Table 16.

	Oregon	Washington
Daily Electricity Consumption (kW-hr)	54,900,000	87,200,000
% of Solar	100	100
Average Solar Demand (kW)	2,290,000	3,630,000
Capacity Factor from PVWatts Data	0.13	0.13
Total Installed Capacity (kW)	17,600,000	28,000,000
Solar Panels Wattage (kW)	0.3	0.3
# of Solar Panels needed	58,700,000	93,200,000
Total Solar Panels for both states	151,900,000	

Table 16. Solar Panel Array Sizing

In order to maximize our solar energy output, we look at two important features: panel orientation and shading effects. When pointing directly at the sun, solar panels can generate maximum output. However, it is not easy to achieve because sun revolves around the earth and changes its location on an hourly and seasonal basis.

With a fixed-tilt panel, it is even more important to find an optimal tilt angle. This optimal angle will also lead us to plant size estimation later on. In our model, we used the following equation from MACS Lab[64] to calculate our optimal tilt angle:

$$Optimal\ Tilt\ Angle = 0.76 \times Latitude + 3.1$$

[64] Macs Lab http://www.macslab.com/optsolar.html

Secondly, solar panels are extremely sensitive to shading, where small amount of shading obstructions could significantly reduce the amount of sunlight that reaches the panels. Panels should be installed facing the same directions, at the same tilt angle, and with the correct spacing in order to reduce the shading effect. Our spacing approach is to layout the arrays to avoid interrow shading[65] between 9am and 3pm on the winter solstice, where shadows are the longest. Figure is a geometric representation of the layout.

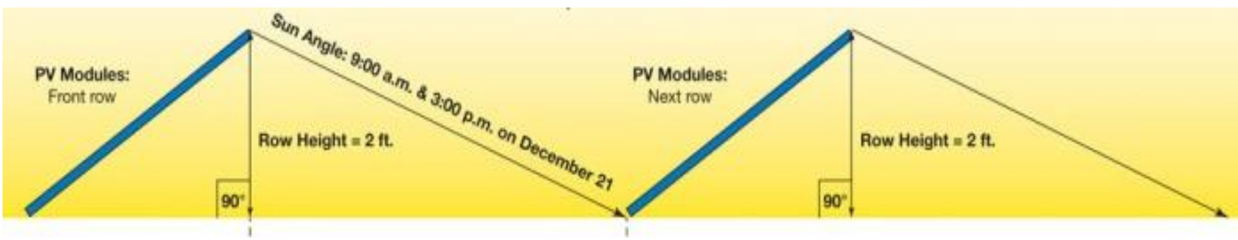

Figure 23. Interrow Spacing[66]

Furthermore, our model utilizes the following equation from Soligent[67] to calculate row spacing:

$$Row\ Spacing = Row\ Height\ \times Spacing\ Factor$$

Our solar panels have a dimension of a typical commercial module of, 2m by 1m. With the fixed tilt angle at about 38 degrees, we get a row height of 1.3m and a row spacing of 4m. Therefore, we estimate that each panel would take about 12 m^2. In order to install 152 million panels, our plant would require an area about 1800 km^2.

g. Potential Sites for Development

In order to understand the scale of our project, we looked into the largest solar farms in the world. The largest solar farm in the world is Ivanpah solar farm with concentrating solar power, using 0.3 million mirrors to provide 370 MW of power. The largest operational PV power plant is the Agua Caliente Solar Project, with a size of 250MW, 5.2 million solar panels, and 10 km^2. Our project requires a solar plant 180 times the size of Agua Caliente Solar Project to meet of our electricity demand of 45560 MW. Our plant would be about 0.7% of the entire Oregon state, which seemed quite unfeasible. Furthermore, we have also assumed that transmission capacity constraints are ignored.

We decided to go with 6 solar sites, where each site occupies about 300 km^2. And we have chosen three big locations: Pendleton and Burns in Oregon, and Yakima in Washington, as

[65] Wholesale Solar http://www.wholesalesolar.com/Information-SolarFolder/solar-panel-efficiency.html
[66] Home Power http://www.homepower.com/articles/solar-electricity/design-installation/interrow-spacing
[67] Soligent http://www.soligent.net/documents/Inter-RowSpacing_v4.pdf

shown in Table 17. The reasons behind these three locations are high capacity factor, large open space, and ease of construction near the highway. Despite the higher demand in Washington, we are installing more sites in Oregon due to higher capacity factor and longer sun hours. Thus, excess production from Oregon will be exported to Washington, especially the ones near the border in Pendleton. The sites are shown as green square box in Figure and Figure.

Cities	Latitude	Fixed Tilt Angle	Capacity Factor
Yakima, Washington	46.6	38.5	14.3%
Pendleton, Oregon	45.7	37.8	14.1%
Burns, Oregon	43.6	36.2	15.1%

Table 17. Potential Solar Sites in Northwest Region

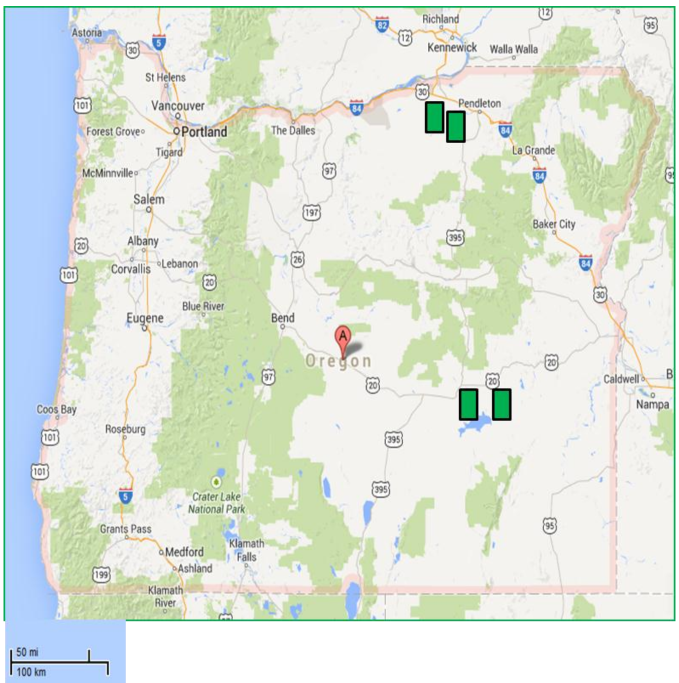

Figure 24. Potential Solar Sites in Oregon

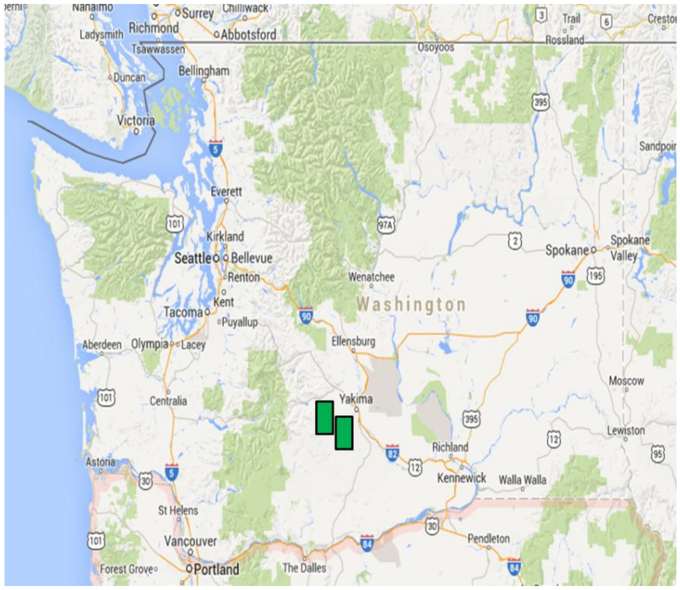

Figure 25. Potential Solar Sites in Washington

h. CO_2 Mitigation

Solar energy will significantly reduce the carbon footprint of the Pacific Northwest region. Installation of sufficient Solar PV to supply a demand of 2.3 million KW in Oregon and 3.6 million KW in Washington will reduce the amount of CO_2 released into the atmosphere by over 11 million tons.

CO_2 Mitigation		
	OR	WA
CO2 Mitigation per year (million metric tons)	4.6	4.18
CO2 Mitigation (million kg)	4,600	4,180
Installed Capacity (MW)	3,153	2,810
CO2 Mitigation (million kg)/MW	1.459	1.488
Our Installed Capacity	6,533	11,354
Our CO2 Mitigation per Year (million kg)	9,531	16,892
Annual Overall Cost ($)	$3,105,000,000	$5,066,000,000
Cost per kg of CO2 removed	$0.33	$0.30

Table 18. CO_2 Mitigation Table

Production of carbon free electricity additionally has an economic benefit through carbon trading. Carbon trading or emissions trading is a market based approach to minimize global emissions by allowing countries that have higher emissions the ability to purchase credits from countries that have low emissions. A carbon credit is equivalent to the reduction of 1 ton of CO_2. Carbon credits are trading currently at a rate below $1; expectation is for the value to increase significantly in the near future. The graph in Figure 26 below shows the effect of the value of carbon credits to the equivalent cost per kwh of electricity produced by solar PV.

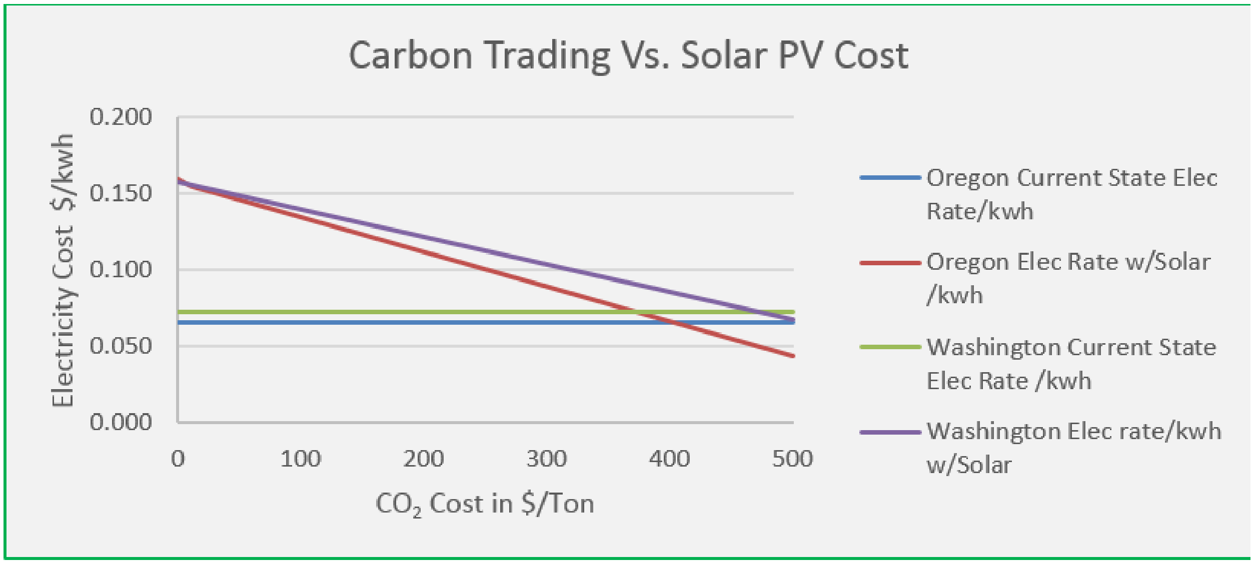

Figure 26. Carbon Trading vs. Solar PV Cost

i. Social and Economic Impacts

The contribution of solar energy not only impacts the dependence on fossil fuel but also benefits society. There are disadvantages such as loss of habitable land where solar plants are to be built but the benefits usually exceed its drawbacks. There are many advantages on the use of solar energy. One of the social benefits from solar energy generation is job creations. The development in such technology would require a substantially large workforce to for both manufacturing and installation service industries. Although maintenance on solar systems is minimal, jobs are still required to maintain and operate solar energy generation. From a health perspective, the mitigation of fossil fuel plants which contribute to the emission of greenhouse gasses could substantially benefit the social heath. With electricity production emitting 33% of total greenhouse gases, the reduction of CO_2 emission, using solar energy, may be low but it could improve the air pollution which affect social health[68]. As technology advances and solar energy production cost drops, the impact to reduce a community's electric bill. The savings from each consumer could potentially increase the economic cash flow as they could spend on other interests. Besides the benefits of commercial development of solar energy, a household can achieve energy independence by installing solar panels to supply energy of their home. Depending on the state laws, the government often gives tax credits for someone pursuing solar energy generation.

[68] EPA http://www.epa.gov/climatechange/ghgemissions/sources.html

j. Further Considerations

Photovoltaic system is currently the favored technology in the solar market. Therefore, we simply just glanced over other available technology out there. One further consideration is to look into concentrating solar system. It is system that is scalable to the size of our project, to the hundreds of MW level. Ivanpah solar farm, the largest solar farm in the world, is a system of concentrating solar power that was able to provide 370 MW of power. The plants use curved mirrors or lenses to concentrate and focus sunlight, creating high temperature that drives traditional engines and generates electricity. The advantages of the system are its ability to store power, to better match supply with demand, and to scale to the hundreds of MW level. Even though the cost could be slightly more expensive than photovoltaic system, it could be potentially be profitable in future considerations. Concentrating solar system requires a considerable amount of desert space. Oregon, as represented in Figure 27 below, has a sufficient amount of high desert land for such installation.

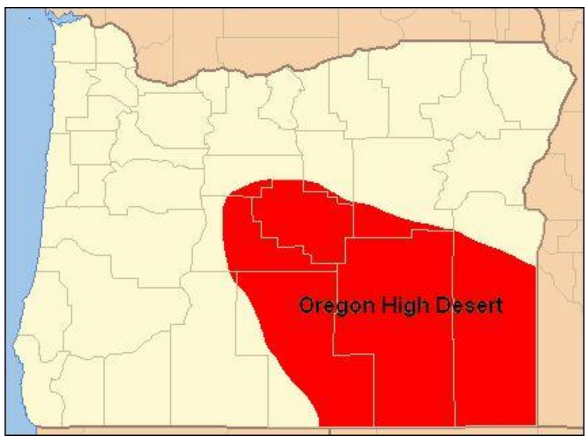

Figure 27. Oregon's High Desert Land

13. Biomass Energy Model

a. Major Assumptions and Limitations

When deciding which sources of biomass to utilize, many different factors were considered. First, the availability of the different types was considered. There had to be enough of the type of biomass for sustained use over a long period of time. The biomass plants to be built had to last at least twenty years and would be rendered useless without a consistent supply of biomass to convert into energy. Second, the ease of access to the chosen biomass was taken into account. A number of factors, ranging from access roads, terrain, and weather all went into making this decision. Finally, the efficiency of the different types of biomass was taken into consideration. It was important to choose a biomass that could give a sizeable return on the investment of harvesting and burning it.

After the area was analyzed and the types of available biomass were researched, it was decided that trees would be used for each state. The specific types of trees were determined based on the types of usable trees that dominated the tree populations in each state. In Washington, pine, fir, cedar hemlock, spruce, and fruit trees were chosen to be used as biomass[69]. In Oregon, the types of trees to be utilized were bigleaf maple, Douglas-fir, larch, lodgepole pine, and mountain hemlock[70]. These trees were easiest to obtain and were abundant enough to be around for a long time even while being gathered for biomass plant usage. For both states, these trees gave us an average density of biomass of one hundred thirty kilograms per cubic meter. This figure was useful in calculating our costs later through our spreadsheet model.

In order to determine the types of biomass plants to build, data from existing plants in the area and across the United States were considered. Based on plant history, the greatest energy generating capacity was assumed to be fifty megawatts. This was mainly due to the available technology in the biomass plant industry and what could be constructed without causing too many issues to arise. Furthermore, these plants were determined to all be combined heat and power plants. These types of plants would be most efficient at generating power for the grid. The heat created in these plants can then be recycled. The exact use of this heat is outside the scope of this project but it is assumed that there will be many uses for it. Whether it goes toward helping with plant operations or is utilized by the local community, the heat from the combined heat and power plants will be put to good use by some means that would be determined on an individual plant basis. If CHP applications cannot be found, it would also be possible to build biomass plants without CHP that generate only electricity, although the financial benefit of selling heat would be lost.

[69] Khan, Tanya
[70] Oregon Department of Forestry, "Dominant Tree Species."

There is some debate as to if biomass is a renewable, carbon neutral energy source. This is because, from a technical standpoint, determining if a type of biomass actually is carbon neutral depends on which form of biomass is utilized and which type of combustion technology is used. It can also depend upon the fossil fuel it is replacing and the extent to which forest management methods are present. Despite all of this, the United States government currently considers all types of biomass to be carbon neutral and, therefore, renewable energy sources[71].

Biomass energy is considered to be renewable because all of the carbon in the biomass is viewed as a component of the natural carbon cycle. The trees use carbon dioxide taken from the atmosphere to produce more biomass. When their life cycle is over and they decompose, the carbon dioxide is put back into the atmosphere. Whether biomass is burned or it decomposes naturally, the same amount of carbon is released. Ideally, if the trees used as biomass are replaced at the same rate as they are burned, the new trees will absorb the carbon that is produced[72]. Therefore, the carbon cycle will remain balanced between its outputs and inputs. In essence, no additional carbon will be added to the atmosphere. This is why biomass is seen as a carbon neutral energy source and as a preferred option to burning fossil fuels. This is a key assumption in the proposed plan because it does not limit the type of biomass used as a renewable energy source.

In order to maintain a constant supply of biomass in Washington and Oregon, forest management plans must be put into place. One important aspect of this is the way biomass is gathered from the forests. It is important not to take too much from one area so that the trees will be able to grow back in time for the next harvest. The standard of biomass gathering to be used in this proposal is that for every square meter of forest area, 0.0254 cubic meters of biomass may be used each year. This will control the amount of trees that are cut annually and ensure that there will be a consistent supply of biomass for the lifetime of the new biomass plants and into the future. Following this standard, it was determined that approximately 2100 square kilometers of forest area will need to be utilized in Washington. This is just over ten percent of all available forest area in the state. In Oregon, it was determined that about 1300 square kilometers was required for biomass harvesting. In this case, the area is slightly under ten percent of available forest area. Because the percentage of available forest for each state is so small, it was concluded that the amount of forest and biomass would not be a limiting factor in the design of these plants. Biomass would be able to be provided throughout the year as necessary in order to meet energy demands in both states.

[71] Khan, Tanya

[72] Cho, Renee

b. Capacity Factor

Capacity factor dictates the actual amount of electricity a biomass power plant, or any other types of power plant, produces as compared to its maximum capacity. The term should not be confused with the 'net plant capacity', which normally comes in units of MW and determines only the maximum electricity production capacity of the plant. Assuming ideal condition when the plant machinery can operate at 100% efficiency, with no heat loss from the feedstock combustion, then the capacity factor of the biomass power plant may come close to 100%. However, in reality, such scenario is highly impossible.

Certain factors affect how much power a biomass power plant can produce – the power to ramp electricity production, demand from the energy grid, plant maintenance and even feedstock supply[73]. A lot of the factors are in fact out of the control of the biomass power sector. For Oregon and Washington, the factor affecting the capacity factor most is the fluctuating energy demand. Both states have clearly defined seasons with unstable weather, which affects the energy demand from households and different industries throughout the year. The biomass plant can be shut down temporarily when the demand for energy is low, but it should be noted that the startup time for the biomass plant from rest to fully operational is 24 hours. The time span prevents the biomass technology to be a truly flexible back up power generation for other power generation technologies. Yet, unlike other renewable energies which dependent on nature and weather, plant operators have full control over the feedstock supply and labor. Thus, they will have the most control over the capacity factor of the power plant to accommodate the daily or monthly energy demand.

Since the capacity factor of a biomass power plant is corresponding to the energy demand, the value will vary day by day in terms of usage. However, we have to determine the average capacity factor for the power plants when we assume having biomass technology to support the full energy demand grid. The demand supporting is 20.3 billion kWh for Oregon and 31.8 billion kWh for Washington. The industry plant efficiency, which is determined by the machinery and combustion technology used for energy production, is set at the industry level of 20%[74]. To determine the average plant capacity factor, we have done analysis on the Emissions & Generation Resource Integrated Database issued by the Environmental Protection Agency, US in 2012[75]. We looked at the 11 existing biomass plants in Oregon and 10 plants in Washington as based comparison. In theory, the capacity factor should be higher in Washington due to the higher demand for heating in the state. The average capacity factor for Oregon is calculated to be 32% and for Washington, it is 45%. Both values are within the acceptable range of 30% to 50%

[73] Hoagland, Kolby
[74] Bothun, Greg
[75] EPA, eGRID report 2012

by the EPA report based on the power generation capacity of the combined heat and power plant[76].

c. General Calculations for Cost Analysis

i. Capital Costs

Capital cost is one of the major factors contributing to the high cost of using biomass technology to produce electricity. An average sized 50 MW combined heat and power biomass plant costs between $50 and $100 million. With newer models, the capacity of the power may increase to 109MW or even 123MW for a biomass plant in Washington. Yet the respective capacity factors of these large plants are correspondingly low. The 109 MW plant in Oregon, owned by Warm Springs Forest Products, only have an average 6.0% capacity factor during 2009, whereas the 123MW plant in Washington, owned by Longview Fibre, have an average of 20.6%[77]. Most resource would be wasted if a power plant were built with such a low capacity factor. Thus our team continued to use the national average capacity of 50MW for our calculation of the capacity factor.

The main fraction of the capital cost comes with the construction of the biomass plant. The Kettle Falls Plant from Washington, a 46 MW plant built in 1983, was used as an example[78]. A common plant schematic will include a blending facility to prepare the fuel, a stoke boiler, a cooler tower, a condenser and an electricity turbine generator (Figure 28). To cope with the EPA standard of emission, a cyclone chamber or other means to treat the fuel gas must be installed as well.

[76] Pew Center – Center for Climate and Energy Solutions
[77] EPA, eGRID report 2012
[78] EPA, EPA Combined Heat and Power Partnership

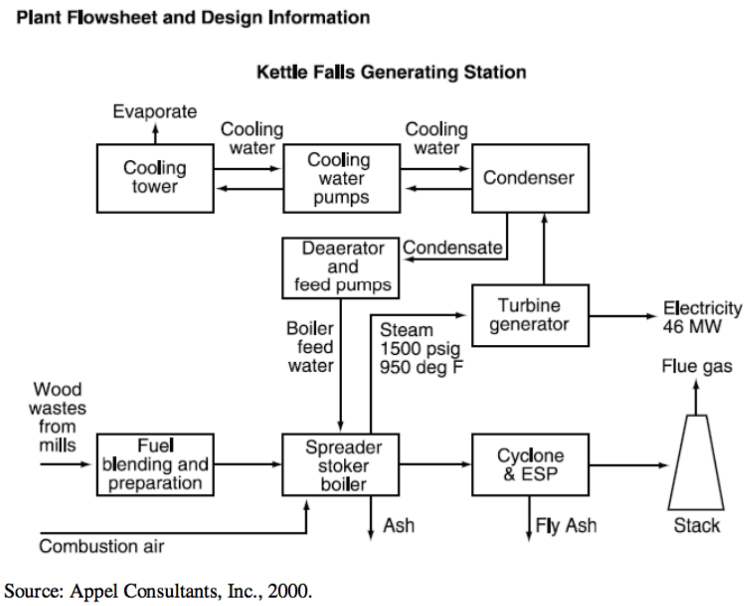

Figure 28. Plant schematics of Kettle Falls Plant, WA

In order to obtain a reasonable value for the capital cost factor, we have looked through the Emissions & Generation Resource Integrated Database 2012 from EPA, which include all biomass plants in Oregon and Washington. We eliminated all biomass plants with less than 10MW capacity and more than 100MW capacity for a more consistent result, a similar mean compared to the capacity factor calculation. The average capital cost factor for Oregon is calculated to be approximately $2,750/kW, and for Washington, it is $2,650/kW capacity. The values match with the EPA Combined Heat and Power Partnership report, which stated that the capital cost varies from $2,000/kW to $2,600/kW, with an increasing trend of the cost due to the tightened regulations regarding power plant emission. Thus the values calculated lie within the safe range for estimation of the total cost for the biomass plant. With ten 50MW plants built in each state, the estimated capital cost is calculated to be $1.38 billion for Oregon, and $1.33 billion for Washington, less any government grants or tax subsidies.

ii. Operating Costs

Operating costs of the biomass power producing unit refers to the expenses related to the operation of the facility. This is the expense required to maintain the existence of the unit. The operating costs of any enterprise can be broadly classified into fixed costs and variable costs.

The fixed costs remain constant, irrespective of the operation of the unit – whether it is closed or running at a full capacity. This cost is borne irrespective of the state of the facility or business. The total fixed cost per year works out to be $1,306,748,858 for Washington and $580,004,281 for Oregon based upon the model created. The fixed costs associated with the biomass power producing unit include – labor costs, maintenance and management costs, insurance and property tax and the utilities cost.

Labor costs cover the expenses, which are to be paid to the staff of the unit. The labor costs considered for the model are $458,508,371/year for Washington and $203,510,274/year for Oregon.

Maintenance and management costs are incurred to keep the unit in an operational state. The maintenance cost has been considered as $343,881,279/year for Washington and $152,632,705/year for Oregon while the considered management or administrative cost for Washington was $45,850,837 and $20,351,027 for Oregon.

Insurance and property tax of the facility is an essential periodic cost. The value considered in the model for insurance or property tax for Washington was $320,955,860/year and $203,510,270/year for Oregon.

Utilities cost covers the expenditure spent in order to run the unit. The value considered in the model for the cost of utilities for Washington was $45,850,837/year and $20,351,027/year for Oregon. The variable cost may change depending upon the production capacity and how it is achieved. Variable costs usually include the overhead costs. The variable costs associated with the biomass power producing unit include the biomass material cost and the transportation cost.

Biomass material cost is essentially the fuel cost. This cost is projected to be highest during the lumbering season when the fuel is obtained. There may be some cost associated with the storage of the biomass material in certain periods of the year.

Transportation cost is incurred in transporting the biomass material from where it is obtained to the facility or storage location. This cost will also be mainly during the lumbering season. The cost will mainly be dependent upon the volume of fuel and distance between the lumbering locations and to where it is transported. A fuel cost of $22.05/tonne and average transportation cost of $0.075/tonne-km have been assumed for both the states.

d. Constraints in Model

In spite of gathering the most up to date data in order to model the requirements for the biomass power producing facility, there were certain restrictions we had to specify which limits the end result to be accurate. The plant data used for spreadsheet modeling covered the capacity factor, capital cost, fixed cost variable cost and the standard size of a single unit.

The value of the capacity factor is not constant. It fluctuates with the power, which is produced, indirectly on demand. The capital cost was considered using the data available from existing units. Labor, maintenance and management, insurance and property tax and utilities have been considered as part of the fixed cost. Variable costs have been further bifurcated into biomass material cost and transportation of biomass. The standard size of a single unit was considered as 50MW.

e. Levelized Cost

For our spreadsheet model calculating, we assumed we are producing the total renewable energy demand for each state, less hydropower generation. The energy demand the model is meeting is at 20.3 billion kWh for Oregon and 31.8 billion kWh for Washington. Along with all the assumptions stated before, we calculated our total net plant capacity for Oregon to be 7,241MW and for Washington to be 8,073MW. Although these numbers suggest that we need to build over 140 biomass plants of average 50MW in each state in order to meet the demand, the linear model is a good starting point to calculate the cost of each kWh of electricity the system produces.

The levelized cost defines how much each kWh of electricity cost for the biomass energy system, which includes both the capital cost and the operating costs. For the capital cost, we are using the universal 6% of discount rate over 20 years of lifespan for the facilities and machineries. The calculated capital cost per kWh per year is 8.6 cents for Oregon and 5.8 cents for Washington. As for the operating costs, they include fixed costs such as labor and maintenance, and variable costs such as biomass feedstock cost and transportation cost. The total operating cost per kWh per year is 12.3 cents for Oregon and 9.7 cents for Washington. Combining the two costs, we have a levelized cost of $0.209/kWh for Oregon, and $0.156/kWh for Washington. Based on the latest report from U.S. Energy Information Administration in November 2013, the cost per kWh in Oregon and Washington is 8.2 cents and 6.8 cents respectively[79], which are both much lower than the calculated cost. Although the biomass energy sector has much potential, the current price they producing are still too high for State Government to consider it as a major option of mitigating fossil fuels emission.

f. Potential Sites for Development

After running the spreadsheet model calculations, it was determined that there would be ten biomass plants built per state. This was the most appropriate and efficient way of producing the biomass energy required in Washington and Oregon. Each of these plants would be 50MW plants which would give each plant the ability to produce a large amount of renewable energy. Since it was determined that the biomass utilized would be various types of trees, the biomass

[79] U.S. Energy Information Administration, "Electric Power Monthly with Data for September 2013"

plants were placed near forests. The ten plants in each state were spaced out so that transportation costs from the forests to the plants would be as small as possible. These sites were also determined based on maps of how overgrown certain areas of these forests were (Figure).

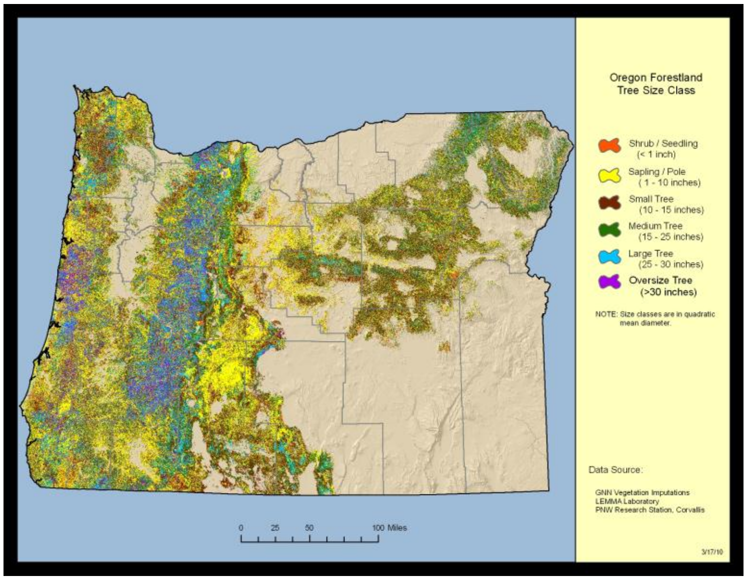

Figure 29. Map of Oregon State showing forestry intensity data

When all of these factors were considered, the ten locations in each site were selected. In Washington, the cities that plants were to be built were Ellensburg, Yakima, Wenatchee, Goldendale, Buckley, North Bend, Eatonville, Castle Rock, Shelton, and Colville (Figure 30). These cities had available land that the biomass plants could be built on relatively easily. They also were close to forest lines that were of use to the plants. Because of this, the harvesting and transportation of the necessary biomass would be a much simpler task. Sites in Oregon were chosen in the same manner. In Oregon, plants were chosen to be built in Eugene, Tigard, Lebanon, Roseburg, Grants Pass, Madras, Redmond, Baker City, Burns, and Heppner (Figure 31). In both states, the landscape and forestry were taken advantage of in order to help the biomass plants be as functional as possible.

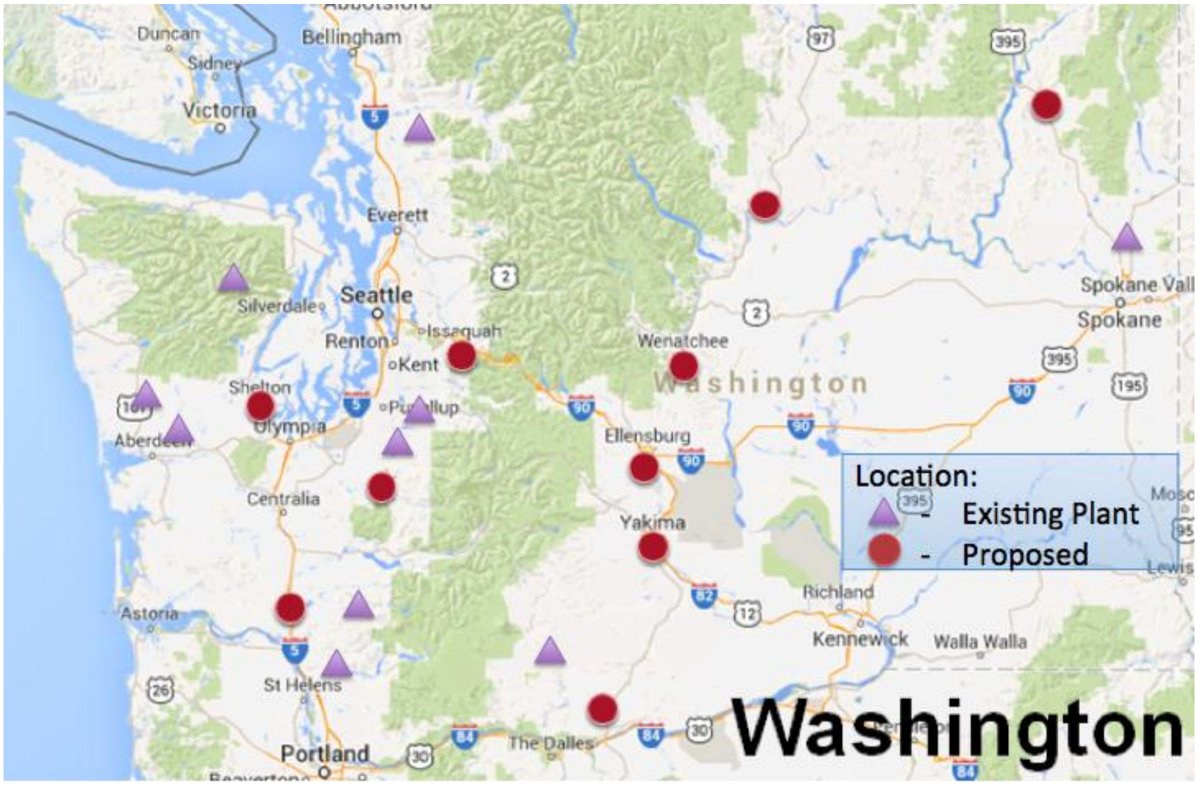

Figure 30. Map of Washington State, showing the location of existing plants and proposed plants

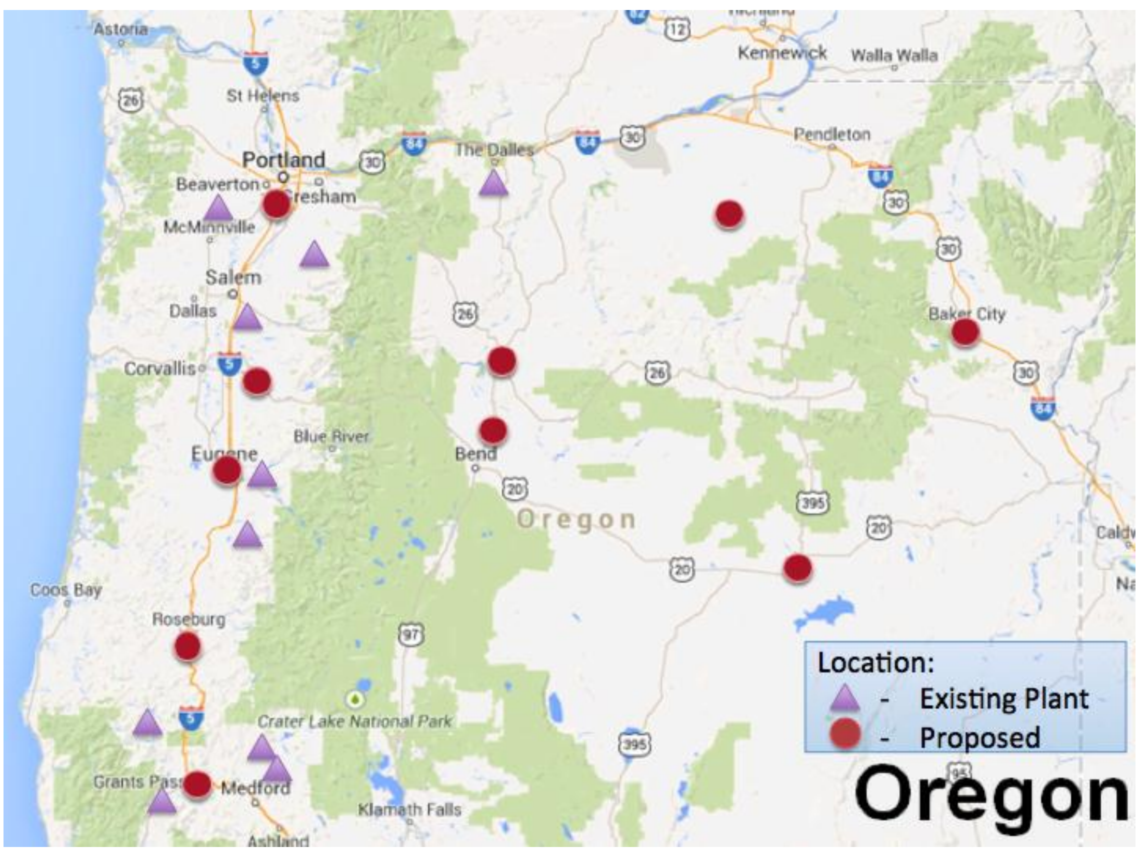

Figure 31. Map of Oregon State, showing the location of existing plants and proposed plants

g. CO_2 Mitigation

The use of biomass will reduce the amount of carbon dioxide released into the atmosphere by the energy sector. One of the most important differences between biomass fuels and fossil fuel has to do with the emission of stable carbon. Fossil fuels release high amounts of carbon dioxide during combustion. Furthermore, burning fossil fuels causes stable carbon sequestered many years ago into atmospheric carbon dioxide. Biomass also releases carbon dioxide when it is burned. This carbon, on the other hand, returns to the atmosphere and is then absorbed by a new plant.

Furthermore, many biomass fuels are able to emit much less atmospheric pollutants like SO_2, which could result in acid rain. Also, biomass is often waste not being used for energy and will usually be left rotting. In this case, carbon dioxide along with methane can be produced. Methane is dangerous because it is a greenhouse gas that can be over twenty times more damaging to the atmosphere than carbon dioxide.

The use of biomass is, in fact, sustainable since all the carbon dioxide released in combusting biomass materials will be recaptured by the growth of new, similar materials. Unlike fossil fuels, the biomass combustion's net increase in carbon is zero.

h. Social and Economic Impacts

While biomass energy may be more expensive to produce than wind or solar energy, it has its benefits from both economic and social perspectives. Using biomass has many monetary incentives that can be taken advantage of in order to reduce its high costs. Washington and Oregon each have many different forms of tax reduction policies in place for biomass plants and renewable energy production. Some of the most lucrative tax incentives can make a sizable impact to the cost of building and maintaining these biomass plants. Washington State offers an incentive of five dollars per green ton harvested that can be applied to the gathering of biomass. In Oregon, biomass plants can earn up to twenty million dollars back per plant constructed. For the proposed ten plants to be built in Oregon, it is possible to see a reduction of two hundred million dollars. Both of these incentives would make biomass a less costly and more appealing option. Generating biomass energy can also lead to obtaining more carbon credits, which can be sold for money to further reduce costs. Finally, the lumber industry would also be able to obtain varying monetary incentives for allowing their lumber to be used in the production of renewable energy. Since this is the case, forest owners will be more willing to sell their lumber to biomass plants rather than other parties who would not be utilizing the trees in such sustainable manners.

There are also many national benefits that are causing the biomass industry to expand quickly. Because all forms of biomass are considered renewable and carbon neutral, all biomass plants qualify for a large number of tax credits, subsidies, and incentives. Some of these involve Renewable Energy Credits, which allows every megawatt hour of electricity generated by biomass to earn a credit which may be sold to utilities. These utilities are eager to purchase Renewable Energy Credits because they are mandated by law to produce a certain amount of renewable energy. Oftentimes, it is easier for them to simply buy the credits rather than earn them the conventional way. The Energy Production Tax Credit grants generators of biomass energy $0.011/kWh for up to a five year time period. Finally, biomass energy is exempt from carbon allowances and qualifies for subsidies from the United States Department of Agriculture[80].

Another significant benefit is the creation of jobs in the area. Jobs will be created for both the construction and the maintenance of these biomass plants. Based on current trends in Washington, the ten new plants will create about one thousand three hundred ten new temporary jobs during the construction and nine hundred eighty on-site permanent jobs. This amounts to nearly forty million dollars in annual salary for permanent employees[81]. In Oregon, the installation of ten new biomass plants will lead to approximately one thousand eight hundred seventy temporary construction jobs and seven hundred ninety permanent jobs. This will generate nearly thirty-five million dollars in annual salary for these employees[82]. The construction jobs will last around two years per biomass plant and, based on the projected salaries, will affect the lives of many people by giving them stable jobs in the Pacific Northwest states.

From an economic perspective, a major drawback of using biomass energy is that it is expensive. In Washington and Oregon, the project team determined that biomass energy would have the highest levelized cost in terms of dollars per kilowatt hour. It also had an incredibly high capital cost which was also greater than the capital costs projected for wind and solar energies. Therefore, it is expected that there will be a slow return on investment for biomass plants. This is why it is recommended not to invest too heavily into this source of renewable energy. If the area committed too much to using biomass energy, it would take a longer time to make back the initial start-up costs.

The use of biomass energy has also seen some backlash from local communities. Harvesting timber for biomass will undoubtedly affect biodiversity in the region. Many environmental groups have voiced their opinions in an effort to stop this from happening. Citizens have shown concerns over both the lack of biodiversity as well as the potential to harm or disrupt the lives of local animals[83]. When gathering trees to be converted into biomass energy in Washington and

[80] Cho, Renee
[81] Renewable Northwest Project, "Washington Renewable Energy Projects Fact Sheet."
[82] Renewable Northwest Project, "Oregon Renewable Energy Projects Fact Sheet."
[83] Gibson, Lisa

Oregon, workers must be careful not to disturb rare or endangered species and will have to be conscious of all animals and their mating habits. This can significantly complicate the process of acquiring the necessary resources for the biomass plants.

Finally, communities are rarely in favor of the idea of cutting back their forests. They see this act as damaging the environment and often take a stance against it. Despite the fact that the biomass is to be cut and harvested sustainably, it is still difficult to change people's minds. Biomass plant projects have been significantly delayed or even cancelled across the United States because of outspoken communities. Recent cases of this have been seen in Florida and Wisconsin which is causing a dangerous precedent to be set[84]. If more people rebel against the idea of using biomass, it could be a matter of time before the source of renewable energy is given an even worse reputation. In Washington and Oregon, there will have to be an emphasis put on taking care of the environment in order to help the local citizens better understand and accept the plans of the new biomass plants.

i. Further Considerations

After analyzing the impact of switching to biomass energy in Washington and Oregon, it is recommended to not solely depend on biomass to power the region. When all factors were taken into consideration, it was found that biomass energy was more expensive than both wind and solar options. Its capital cost was the greatest and powering the entirety of the two states would require over one hundred plants rated at fifty megawatts each. The levelized cost of biomass energy was $0.16/kWh for Washington and $0.21/kWh for Oregon. The current average price of electricity in Washington and Oregon is $0.07/kWh and $0.08/kWh, respectively. Because the difference is so large, it is not feasible to have the states switch to only using biomass as an energy source, without a carbon tax or renewable portfolio standard to reward the carbon benefits of biomass.

However, biomass is much more controllable than wind and solar energy. The supply of biomass energy will be consistent while the other sources of renewable energy will vary greatly each day. Since it was determined that there is more than enough biomass in the two states, there will always be the capacity to generate more biomass energy if the material is harvested in a sustainable manner. One days when there is less sun or wind, biomass will be able to be relied on more heavily and help meet the required energy demand. Biomass is less dependent upon the season or weather, making it useful due to its flexibility of use. This is one of the main benefits of biomass as a renewable energy source and is also why it is such a vital part of Washington and Oregon's effort to reduce carbon emissions. As biomass technology advances, it will only become even more useful to both states as the costs begin to decrease

[84] Austin, Anna

14. Optimization

a. Renewable Portfolio Standard

The renewable energy portfolio standards differ from state to state. Mentioned in brief are the RPS requirements for the states of Oregon and Washington.

Oregon: The 2007 Legislature created a renewable portfolio standard (RPS) that requires the largest utilities in Oregon to provide 25 percent of their retail sales of electricity from newer, clean, renewable sources of energy by 2025. Smaller utilities have similar, but lesser, obligations.

The Renewable Portfolio Standard (RPS) requires that all utilities and electricity service suppliers (ESSs) serving Oregon load must sell a percentage of their electricity from qualifying renewable energy sources. The percentage of qualifying electricity that must be included varies over time, with all utilities and ESSs obligated to include some renewable resources in their power portfolio by 2025. These renewable energy sources include solar, wind, biomass, and ocean, thermal, geothermal and do not include the existing hydroelectricity generation of the state.[85]

The RPS would be phased over a period of time and have a step growth adopted as follows:

- At least 5% of its load by 2011
- At least 15% of its load in 2015
- At least 20% of its load in 2020
- At least 25% of its load in 2025

[85] Summary of Oregon Renewable Portfolio Standard, Oregon Department of Energy http://www.oregon.gov/energy/RENEW/docs/RPS_Long_Summary_July%202012.pdf

RPS obligations on all utilities and electricity service suppliers						
	Percent of Oregon's Total Retail Electric Sales	Utilities[2] and ESSs	Applicable Targets in Year:			
			2011	2015	2020	2025
Large Utilities	Three percent or more	Portland General Electric, PacifiCorp, Eugene Water & Electric Board	**5%**	**15%**	**20%**	**25%**
Small Utilities	At least one and a half percent but less than three percent	Central Lincoln PUD, Idaho Power, McMinnville W&L, Clatskanie PUD, Springfield Utility Board, Umatilla Electric Cooperative	**No Interim Targets**			**10%**
	Below one and a half percent	All other utilities (31 consumer-owned utilities)				**5%**
Electricity Service Suppliers (ESSs)	Any sales in Oregon	Any Electricity Service Supplier (ESS)	If an ESS sells electricity in the service area of more than one utility its targets may calculated as an aggregate of electricity sold in its territory.			

Table 19. RPS Targets and Timelines

Washington[86]: The RPS has set an overall target of 15% renewable energy in the state of Washington by 2020 and also to undertake all cost-effective energy conservation. The first required qualified utilities to "pursue all available conservation that is cost-effective, reliable, and feasible," as well as the more common RPS requirement of producing a set 15% of energy from eligible renewable sources. These eligible renewable energy sources include solar, wind, biomass, but do not include the existing hydroelectricity generation of the state.

"Qualifying utilities" — in the case of the Washington state RPS — refers to electric utilities that serve more than 25,000 Washington customers, which would be required to produce 15% of their electricity from renewable sources by 2020. Enlisted below are additional details on the step growth adopted by the state.

- At least 3% percent of its load by 1/1/2012, and each year thereafter through 12/31/2015;
- At least 9% of its load by 1/1/2016, and each year thereafter through 12/31/2019; and
- At least 15% of its load by 1/1/2020, and each year thereafter.

[86] **The Economic Impact of Washington State's Renewable Portfolio Standard, Washington Policy Center**
http://www.washingtonpolicy.org/publications/brief/economic-impact-washington-states-renewable-portfolio-standard

b. Scenario Analysis

The project required analysis of different scenarios to study how the different energy sources would combine to meet the future demand and how the levelized cost will differ on a year on year basis. For this analysis, we also considered that the mix should have diversity and not be completely dominated by one source of energy.

The preliminary 'what-if analysis', conducted early in the project was key in assisting us foresee the cost variation with the variation in the energy mixes. The consideration for the what-if analysis was a basic framework of correlations between the total costs (capital cost and operating cost), installed capacity of the source, discount rate, lifecycle and energy demand. The objective was to minimize the levelized cost and what-if analysis was conducted by varying the contribution of each source in certain ratios, to observe the variation in the levelized cost.

The cost values in Table 20 were utilized for the purpose of the analysis.

Preliminary Calculations	
Source of Energy	Cost per kWh
Wind	$0.08
Solar	$0.15
Biomass	$0.21

Table 20. Preliminary Cost Calculations

It is clear that the calculations in Table 21 show that the costs of the three sources are in the following order: Wind < Solar < Biomass. This is a major governing factor as it determines the final cost/ kWh for every energy source, which further determines how more/ less cost effective that source proves to be.

For the purpose of this analysis, the following four scenarios were studied:

Variables	W:S:B 60:30:10	W:S:B 40:20:40	W:S:B 30:25:45	W:S:B 45:35:20
Output to Grid (Wind)	3,004,500,000	2,003,000,000	1,502,250,000	2,253,375,000
Output to Grid (Solar)	1,502,250,000	1,001,500,000	1,251,875,000	1,752,625,000
Output to Grid (Biomass)	500,750,000	2,003,000,000	2,253,375,000	1,001,500,000
Cost per kWh($) (Objective)	0.10	0.15	0.16	0.13

Table 21. Preliminary Scenario Analysis

The results shown above indicate the ratios in which the output to grid for wind, solar and biomass are modified, and what effect do they incur on the cost per kWh. The table reflects that as the percentage of wind is reduced in the grid, the levelized cost increases. This shows an inverse relation of wind capacity versus levelized cost output as the cost calculations show that wind is the cheapest source amongst the three sources. At the same time, increasing biomass contribution in the mix causes a proportional rise in the cost, as biomass is the most expensive source of the mix. Even though expensive, it became evident early on, that biomass was going to add the reliability in the model as it is not dependent on seasonal and short-term variations and thus would have an adverse effect on the cost. This is an important consideration because wind and solar are intermittent sources of energy, so that if you have a low-output day with either of them, there is no way to increase output. With biomass, on the other hand, you can run the plant at or near 100% of capacity and it is dispatchable, i.e., in your control.

c. Deterministic Model Analysis

The aim of the deterministic model is to optimize the levelized cost of the renewable mix (i.e. solar, wind and biomass). The deterministic model treats inputs such as prices or capacity factor as fixed, unlike the random model (see below) that treats these values as random and generates them from a known mean and coefficient of variation. The model utilizes an objective function, and tries to satisfy constraints. The approach was to optimize the levelized cost and at the same time achieve a good variability in the source of energy generation. The fixed model analyses the monthly demand generation for Oregon and Washington for the years 2024 and 2034. The model shall determine the capacity that gets built, based on expected demand and thus the model is capacity endogenous in nature.

The model works on the following constraints and objective:

- The summation of the energy generated by the three sources each month should exceed or at least meet the expected monthly energy demand.
- For each source of energy, a minimum contribution to the energy mix has been assumed in order to consider a diverse energy portfolio and also to avoid single energy source dependency. Thus, each resource has to contribute the set minimum to the energy production.
- For each source, a maximum potential capacity has been set. Thus, each source cannot contribute above that value, as that value is the maximum that is assumed to be installed during that particular year. The model is expected to generate the values for the required capacities for that particular year within the maximum and minimum potential capacity limits.

- The varying factor in the deterministic optimization is the energy demand generated each month from January to December. It was mandatory for the three sources to meet this demand for every month.
- The objective is to minimize the levelized cost of this renewable mix.

	W,S,B <=			W,S,B >=			W+S+B>=	
Month	**Potential Capacity(MWh)**			**Minimum Capacity (MWh)**			**Demand (MWh)**	
	Wind	Solar	Biomass	Wind	Solar	Biomass	Demand(1000 MWh)	Demand(MWh)
January	1,049,190	847,411	1,691,667	458,000	0	75,000	3,092	3,092,381
February	1,192,262	1,081,600	1,691,667	458,000	0	64,000	2,517	2,516,617
March	1,430,714	1,663,688	1,691,667	569,000	0	56,000	2,718	2,717,848
April	1,573,786	1,864,034	1,691,667	484,000	0	49,000	2,206	2,205,785
May	1,621,476	2,128,004	1,691,667	619,000	0	48,000	1,391	1,390,642
June	1,669,167	2,102,284	1,691,667	676,000	0	67,000	1,456	1,456,191
July	1,645,321	2,345,949	1,691,667	697,000	0	64,000	1,606	1,605,969
August	1,597,631	2,249,837	1,691,667	676,000	0	67,000	2,698	2,697,760
September	1,478,405	2,035,953	1,691,667	837,000	0	72,000	2,756	2,756,262
October	1,335,333	1,605,479	1,691,667	391,000	0	61,000	3,045	3,045,362
November	1,096,881	888,022	1,691,667	254,000	0	62,000	2,946	2,946,215
December	834,583	774,312	1,691,667	539,000	0	67,000	2,986	2,986,156
Total	**16,524,750.00**	**19,586,574.00**	**20,300,000.00**	**6,658,000.00**	**0.00**	**752,000.00**	**29,417.19**	**29,417,187.99**

Figure 32. Constraint of the Deterministic Model

An interesting aspect of this analysis is that the total cost has been split into capital cost and operating cost. The capital cost is a fixed cost while the operating cost is a variable cost that varies every month. Each individual source was assumed to meet 100 percent demand for the year 2012. Based on this, the installed capacity required was calculated and hence, capital cost was estimated. This cost was split evenly over the basis of 20 years, as we lacked sufficient reliable information on the ramp up percentage of installed capacity that would be required.

The operating cost is a factor of the cost/ kWh and the operating capacity (which is an output of the model) and was calculated by optimizing the constraints and objective function. Since, the cost considers both operating and capital cost; the objective is to minimize the total cost. While capital cost remains fixed for a year, the operating cost varies based on the amount of energy generated. To cite an example, the operating cost of solar is the lowest, but its capital cost is quite high. On the contrary, wind has the lowest capital cost, but higher operating cost than solar. Thus, optimizing this combination involved looking at a feasible solution, which satisfied all the equations.

W	S	B	W+S+B				MIN CW+CS+CB
Operating Capacity (MWh)				Operating + Capital ($)			Objective
Wind (MWh)	Solar (MWh)	Biomass (MWh)	Total Generated (MWh)	Wind	Solar	Biomass	Total Cost
1,049,190	847,411	1,195,779	3,092,381	$ 19,055,579,879.64	$ 12,668,415,963.35	$ 36,740,702,067.72	$ 68,464,697,911
931,694	1,081,600	503,323	2,516,617	$ 21,648,074,978.16	$ 16,169,431,876.55	$ 36,655,544,602.66	$ 74,473,051,457
569,000	1,605,279	543,570	2,717,848	$ 25,965,062,225.49	$ 24,871,145,306.66	$ 36,660,494,032.93	$ 87,496,701,565
484,000	1,280,628	441,157	2,205,785	$ 28,558,304,748.04	$ 27,864,134,075.88	$ 36,647,899,423.15	$ 93,070,338,247
619,000	493,513	278,128	1,390,642	$ 29,426,475,588.89	$ 31,806,161,547.99	$ 36,627,850,329.94	$ 97,860,487,467
676,000	488,953	291,238	1,456,191	$ 30,292,852,429.74	$ 31,421,741,549.97	$ 36,629,462,578.68	$ 98,344,056,558
697,000	587,775	321,194	1,605,969	$ 29,860,802,509.31	$ 35,063,837,696.70	$ 36,633,146,480.37	$ 101,557,786,686
676,000	1,482,208	539,552	2,697,760	$ 28,995,253,668.46	$ 33,630,966,756.62	$ 36,659,999,956.70	$ 99,286,220,382
837,000	1,368,009	551,252	2,756,262	$ 26,836,292,066.34	$ 30,433,905,874.49	$ 36,661,438,845.37	$ 93,931,636,786
830,810	1,605,479	609,072	3,045,362	$ 24,240,952,183.41	$ 24,001,184,237.28	$ 36,668,549,497.96	$ 84,910,685,919
1,096,881	888,022	961,312	2,946,215	$ 19,921,742,601.45	$ 13,275,528,549.46	$ 36,711,867,562.21	$ 69,909,138,713
834,583	774,312	1,377,260	2,986,156	$ 15,157,847,631.53	$ 11,575,613,308.37	$ 36,763,020,489.39	$ 63,496,481,429
9,301,159	**12,503,190**	**7,612,838**	**29,417,188**				**$ 1,032,801,283,121**

Figure 33. Deterministic model variables and objective function without tax incentive

In addition, the effect of tax incentive on the total cost was studied and the difference in both the costs were calculated to analyze the savings as shown below.

Operating + Capital - Tax Incentive				
Wind	Solar	Biomass	Total Cost	Difference
$ 19,031,448,498.69	$ 12,443,004,535.05	$ 36,734,723,173.49	$ 68,209,176,207	$ 255,521,703
$ 21,626,646,021.24	$ 15,881,726,235.63	$ 36,653,027,985.24	$ 74,161,400,242	$ 311,651,215
$ 25,951,975,225.49	$ 24,444,141,224.25	$ 36,657,776,184.80	$ 87,053,892,635	$ 442,808,931
$ 28,547,172,748.04	$ 27,523,487,095.88	$ 36,645,693,638.47	$ 92,716,353,482	$ 353,984,765
$ 29,412,238,588.89	$ 31,674,886,995.97	$ 36,626,459,688.25	$ 97,713,585,273	$ 146,902,194
$ 30,277,304,429.74	$ 31,291,680,008.93	$ 36,628,006,387.23	$ 98,196,990,826	$ 147,065,732
$ 29,844,771,509.31	$ 34,907,489,465.69	$ 36,631,540,511.24	$ 101,383,801,486	$ 173,985,200
$ 28,979,705,668.46	$ 33,236,699,364.39	$ 36,657,302,196.40	$ 98,873,707,229	$ 412,513,153
$ 26,817,041,066.34	$ 30,070,015,384.54	$ 36,658,682,583.66	$ 93,545,739,035	$ 385,897,752
$ 24,221,843,543.79	$ 23,574,126,802.82	$ 36,665,504,135.98	$ 84,461,474,483	$ 449,211,436
$ 19,896,514,339.54	$ 13,039,314,656.53	$ 36,707,061,002.54	$ 69,642,889,999	$ 266,248,714
$ 15,138,652,214.87	$ 11,369,646,316.37	$ 36,756,134,187.29	$ 63,264,432,719	$ 232,048,711

Figure 34. Deterministic model cost calculation with tax incentive

From the model, we can infer that since the overall cost for wind is the least, maximum energy demand is achieved by wind, followed by solar and finally biomass. But, a minimum biomass generation has been ensured, so that at any point of time if either wind fails or there is not enough sunlight, biomass can take over. Another observation is that during the summer, the energy production from solar dominates, as this would be naturally available and sun would be at peak intensity, thereby improving efficiency and reducing levelized cost during that season.
From Figure 35 below, we can estimate the contribution of each resource to the Oregon demand in 2024. The energy demand forecast for Oregon in 2024 is 29.4 million kWh which is satisfied by wind, solar and biomass in the ratio 32:42:26. The levelized cost is expected to be about 35 $/kWh.

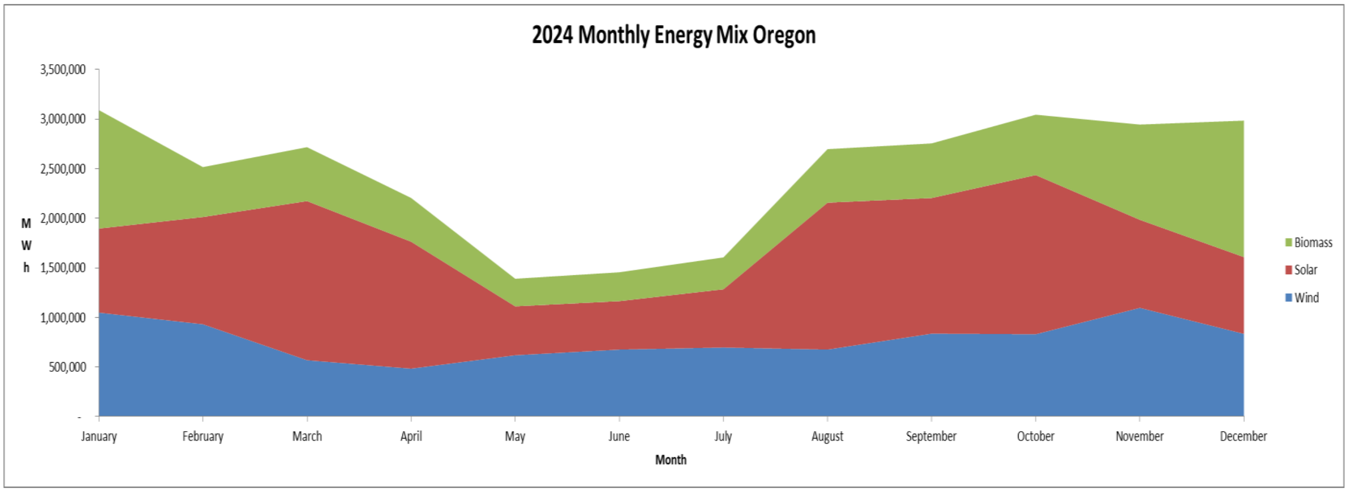

Figure 35. Deterministic model output prediction 2024

This model here shows a total demand of 29,397 MWh for 2024 in Oregon, a total cost of $11,612,320,388 and an overall levelized cost of about 0.035$/kWh. In this model, the ratios of wind, solar and biomass are 28%, 53% and 21% respectively.

d. Stochastic Monthly Model Analysis

In order to study the effect of varying parameters on the model, a randomized optimization model was developed. This model randomizes capacity factors for the three sources and randomizes the required energy demand. Varying these parameters helps us simulate an environment where demand and the output by the energy sources is dynamic, similar to a real life situation, where the energy demand is an ever-changing real-time requirement.

In the model, a hundred iterations were conducted on all the months of the year.
An example of 10 iterations of January 2024, of the state of Oregon is shown below in Table 22, where the capacity factors for the three sources are varied 5% over the entire month and the capacity is calculated. Due to varying climatic conditions, the capacity factor may vary and there may arise a need to substitute energy from a different, reliable source to meet the demand.

January	Capacity Factor			Installed Capacity (MW)		
Iteration	Wind	Solar	Biomass	Wind	Solar	Biomass
1	21.87%	5.94%	27.57%	6,532.9	17,958.0	7,241.7
2	23.20%	5.79%	27.43%	6,532.9	17,958.0	7,241.7
3	21.35%	5.93%	26.36%	6,532.9	17,958.0	7,241.7
4	22.63%	6.45%	28.46%	6,532.9	17,958.0	7,241.7
5	20.43%	6.33%	25.61%	6,532.9	17,958.0	7,241.7
6	21.75%	6.55%	26.62%	6,532.9	17,958.0	7,241.7
7	22.25%	5.81%	26.39%	6,532.9	17,958.0	7,241.7
8	20.14%	5.91%	25.38%	6,532.9	17,958.0	7,241.7
9	21.97%	5.94%	26.13%	6,532.9	17,958.0	7,241.7
10	22.20%	5.95%	26.68%	6,532.9	17,958.0	7,241.7

Table 22. Stochastic Model Iterations

The objective to minimize the cost, decision variables (amount each source contributes to the grid) and minimum and maximum constraints on the potential capacity remain the same as described the fixed model.

The second parameter we randomized is the demand, which is varied 30% over the period of one month, keeping in mind extreme fluctuations, thus in Table 23,we see the demand values are varying for January in 10 iterations. This would help foresee the variation in demand and be able to maintain contingency to suffice the total demand in any particular month. In order to add reliability in the model, we have considered that the minimum biomass must contribute in any month is 20% of the total demand. For solar, we consider that solar will contribute a minimum of 10% of the total demand in any given month. For wind, the minimum constraint is set to its existing installed capacity as on 2012 in the state of Oregon. Table 23 shows the maximum and minimum constraints and the demand values.

	W,S,B <=			W,S,B >=			W+S+B>=	
January	Maximum Capacity (MWh)			Minimum Capacity (MWh)			Demand	
Iteration	Wind	Solar	Biomass	Wind	Solar	Biomass	Demand(1000 MWh)	Demand(MWh)
1	1,043,079	778,740	1,457,672	458,000	258,419	516,838	3,121	3,120,543
2	1,106,373	759,645	1,450,284	458,000	258,419	516,838	1,957	1,956,741
3	1,018,325	777,624	1,393,572	458,000	258,419	516,838	2,059	2,058,941
4	1,079,113	845,127	1,504,347	458,000	258,419	516,838	2,865	2,865,034

5	974,335	830,475	1,353,754	458,000	258,419	516,838	2,019	2,019,098
6	1,037,364	859,148	1,407,344	458,000	258,419	516,838	2,402	2,402,107
7	1,061,061	761,092	1,395,071	458,000	258,419	516,838	2,690	2,689,925
8	960,579	774,947	1,341,507	458,000	258,419	516,838	2,319	2,318,729
9	1,047,799	778,556	1,381,441	458,000	258,419	516,838	2,725	2,724,861
10	1,058,600	780,083	1,410,532	458,000	258,419	516,838	2,912	2,912,494

Table 23. Stochastic Model- Constraint and Randomized Demand

The final output is shown in Table 24, where by meeting the objective and all the constraints, the levelized cost is calculated. When compared with wind, biomass and solar total costs, wind is the cheapest, followed by biomass and then solar energy, as the capital cost of solar is very high. These values also depend on the amount each source contributes to the grid and hence there are iterations where biomass is more expensive than solar as its relative contribution is greater. It is therefore essential that to make a scenario similar to this energy portfolio possible in the future, the capital cost of solar energy should greatly be reduced.

	W	**S**	**B**	**MIN CW+CS+CB**	
January	**Total Costs = Operating + Capital ($)**			**Objective**	
Iteration	Wind	Solar	Biomass	Total Cost	Levelized Cost/KWh (JAN)
1	$142,492,982.12	$271,507,086.09	$310,670,280.72	$724,670,348.93	$ 0.23
2	$134,148,113.56	$271,430,707.27	$214,514,653.68	$620,093,474.52	$ 0.32
3	$136,085,194.37	$271,502,622.45	$214,514,653.68	$622,102,470.51	$ 0.30
4	$143,321,775.22	$271,772,632.79	$266,652,384.14	$681,746,792.15	$ 0.24
5	$133,953,238.47	$271,714,026.70	$214,514,653.68	$620,181,918.86	$ 0.31
6	$142,102,970.67	$271,828,715.68	$214,514,653.68	$628,446,340.03	$ 0.26
7	$142,906,562.80	$271,436,493.71	$257,672,216.01	$672,015,272.53	$ 0.25
8	$140,595,477.66	$271,491,913.20	$222,676,233.15	$634,763,624.00	$ 0.27
9	$142,601,542.73	$271,506,350.76	$261,451,791.59	$675,559,685.08	$ 0.25
10	$142,849,962.90	$271,512,456.35	$283,010,769.75	$697,373,189.00	$ 0.24

Table 24. Wind, Solar, Biomass –Cost Calculations

The randomized optimization shows that overall it varies in range between 0.21 and 0.41 and that there is a more than 50% probability that the levelized cost will range between $0.23/kWh – $0.26/kWh in Oregon in January 2024, subject to the demand and capacity calculations considered above.

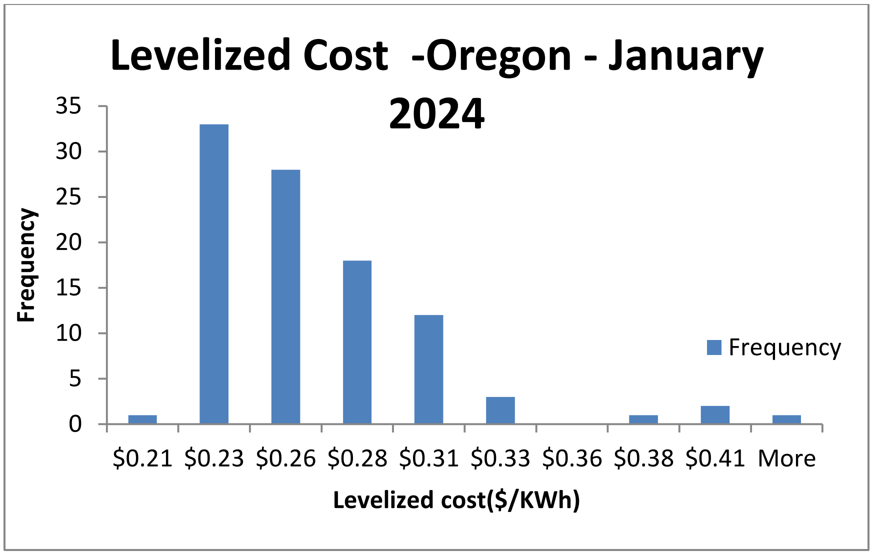

Table 25. Levelized Cost - Oregon - January 2024

e. Randomized Model Analysis

Randomization is incorporated into two scenarios of monthly and hourly fixed models by varying the capacity factor of wind and solar and monthly demand. A monthly randomized model was developed for Oregon and Washington in 2024. Mean monthly capacity factors are known and standard deviation is assumed to be 5% to account for variation in energy generation. Monthly demand was projected and a standard deviation that is 15% of demand was assumed to be sufficient to account for variation in energy demand. The designed installed capacity of wind, solar, and biomass were an upper limit and different installed capacities were tested until overall average levelized cost was minimized and demand still met. However, the installed capacities were limited to specific ratios; two scenarios were studied: 1) wind, solar, biomass ratio of 60:30:10 and 2) wind, solar, biomass ratio of 45:35:20.

Because the maximum installed capacity of wind is the greatest in each scenario, wind's installed capacity was used as the base for calculating installed capacity for solar and biomass. Installed capacity and capacity factors for wind and solar were used to estimate the amount wind and solar energy generated. If more energy generated exceeded energy demand, a proportional amount was reduced from wind and solar so that energy generated would equal energy demand and no biomass would be need. In the case of energy generated falling below energy demand, the gap was set as the amount of biomass energy generated. Because the biomass capacity factor should not exceed 80%, biomass required to be generated beyond this limitation was reassigned to be generated by solar because solar has the least operating cost.

In summary, the following constraints are incorporated in the monthly randomized models:

1. Installed capacity of wind, solar, and biomass are set ratios (either 60:30:10 or 45:35:20).
2. Total wind, solar and biomass energy generated should equal total demand.
3. Biomass capacity factor should not exceed 80%.

To calculate total cost of the system, operating cost was calculated by multiplying the operating cost of each energy source by the suggested energy generation and capital cost was calculated adjusting the total capital cost to the specific time period, either on a monthly or hourly basis.

Microsoft Excel's Risk Solver Platform was used to simulate 1000 trials of randomization with electricity cost per kWh as the uncertain function. Monthly energy mix for Oregon in 2024 under Scenario I and II are shown in Figure 36 and Figure 38 while the distribution of electricity cost from the resulting mixes are shown in Figure 37 and Figure 39.

The average electricity cost for the first Oregon scenario is \$0.277/kWh with a standard deviation of \$0.012. The second Oregon scenario shows a relatively higher average electricity cost of \$0.297/kWh and standard deviation of \$0.013. This scenario was built from an initially more diversified mix which led to a resulting adjusted mix that includes more biomass than solar, especially in the winter months. In Scenario I, the average annual resulting mix of wind, solar, and biomass is 24:66:11 while in Scenario II, it is 25:47:28. Because biomass operating cost is much more than solar operating cost (\$0.123/kWh compared to \$0.004/kWh), increased biomass contribution will cause the resulting mix's average electricity cost is about \$0.01/kWh more.

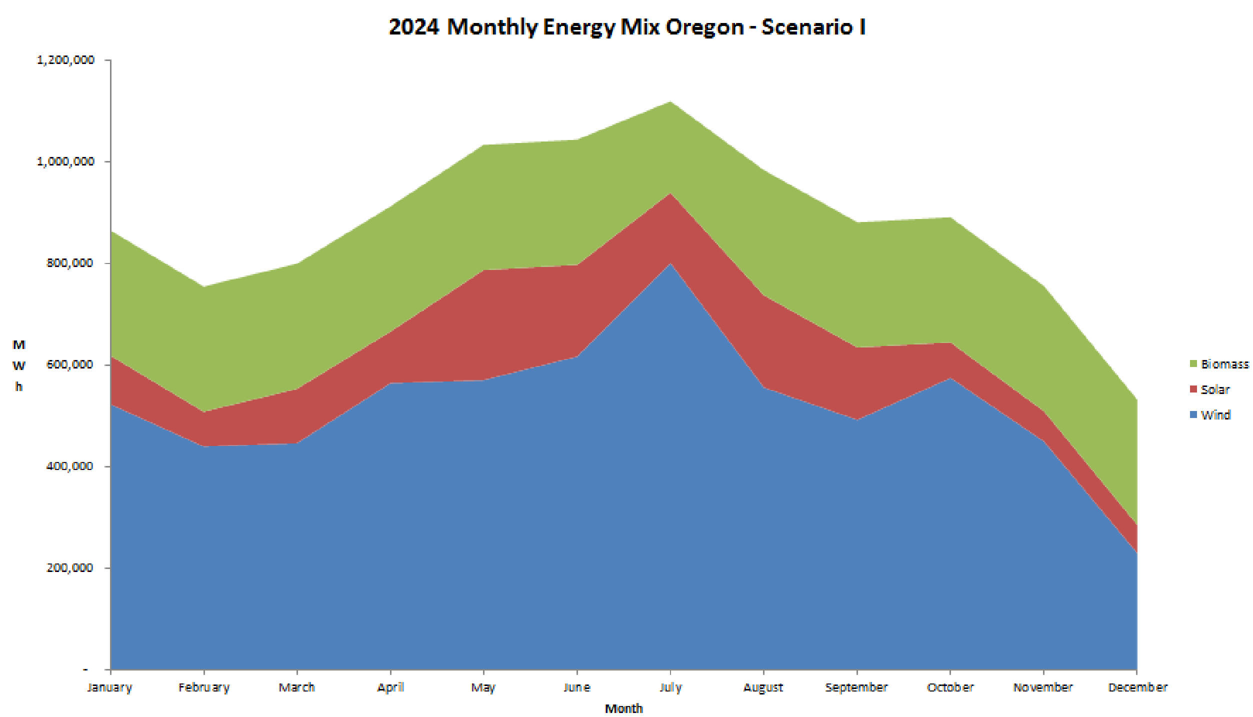

Figure 36. 2024 Monthly Energy Mix Oregon - Scenario I

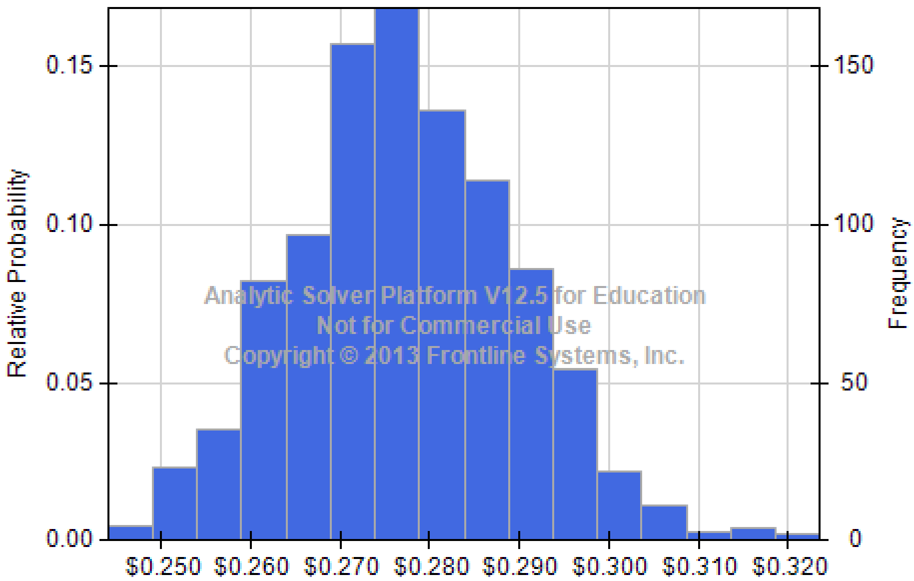

Figure 37. 2024 Monthly Energy Mix Oregon - Scenario I Levelized Cost Distribution

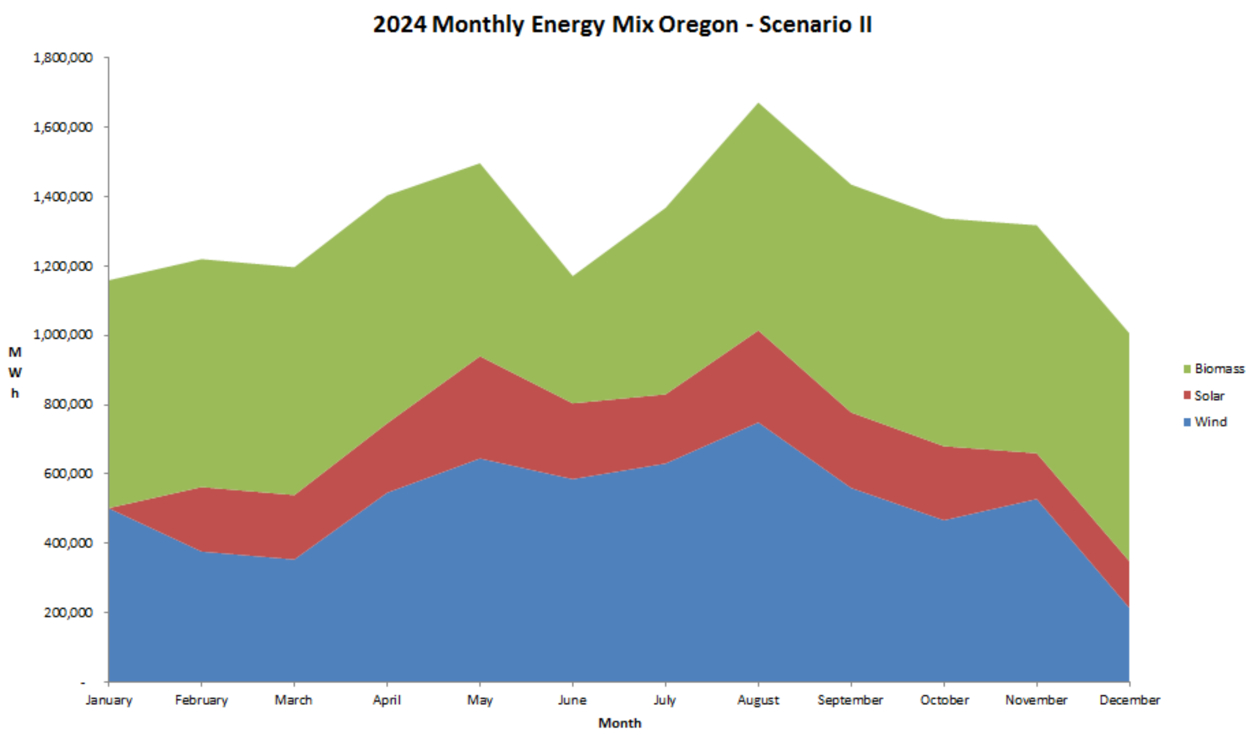

Figure 38. 2024 Monthly Energy Mix Oregon - Scenario II

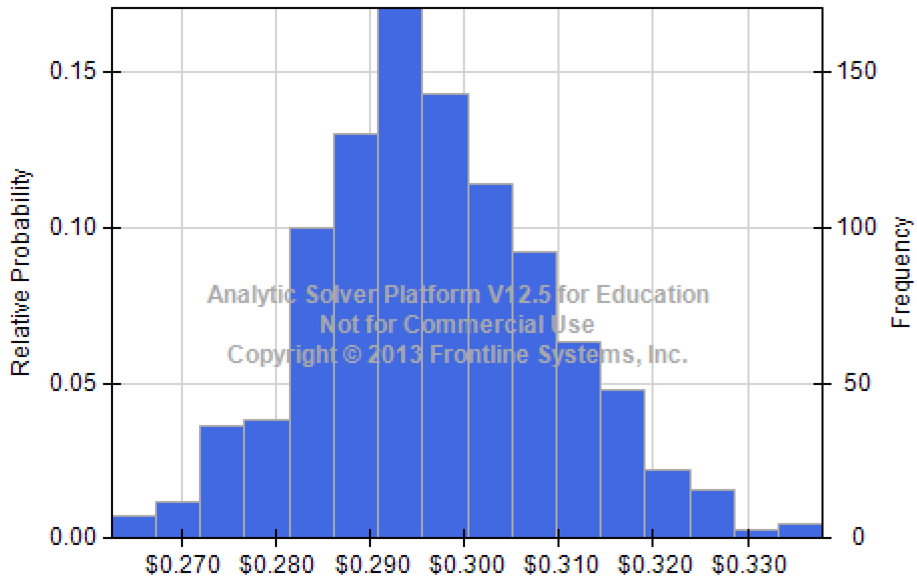

Figure 39. 2024 Monthly Energy Mix Oregon - Scenario II Levelized Cost Distribution

Monthly energy mix for Washington in 2024 under Scenario I and II are shown in Figure 40 and Figure 42 while the distribution of electricity cost from the resulting mixes are shown in Figure 41 and Figure 43Figure . The average electricity cost for the first Washington scenario is $0.255/kWh with a standard deviation of $0.011. The second Washington scenario shows a slightly higher average electricity cost of $0.271/kWh and standard deviation of $0.012. Similar to the Oregon comparison, the second scenario was built from an initially more diversified mix, leading to a resulting adjusted mix that includes more biomass than solar, especially in the winter months. However, the Washington comparison shows a more similar mix compared to Oregon, allowing for the average electricity cost of both scenarios to be more similar. In Scenario I, the average annual resulting mix of wind, solar, and biomass is 66:16:13 while in Scenario II, it is 61:20:19.

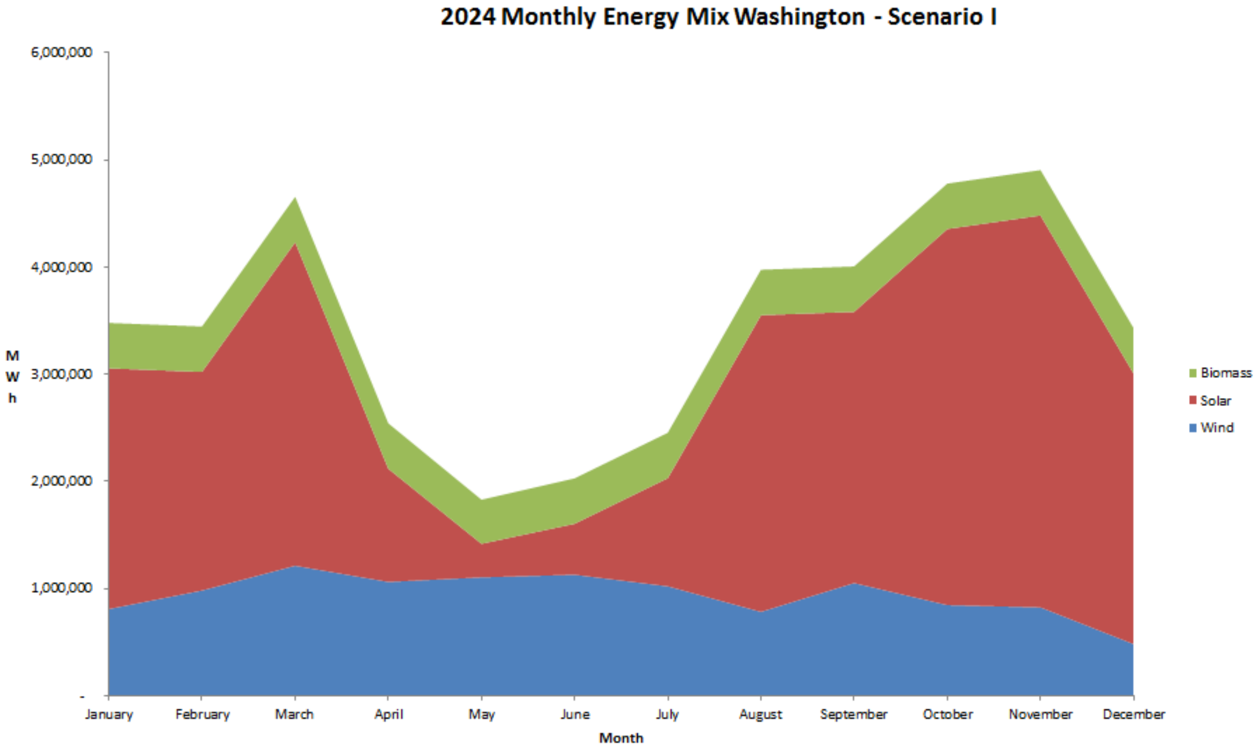

Figure 40. 2024 Monthly Energy Mix Washington - Scenario I

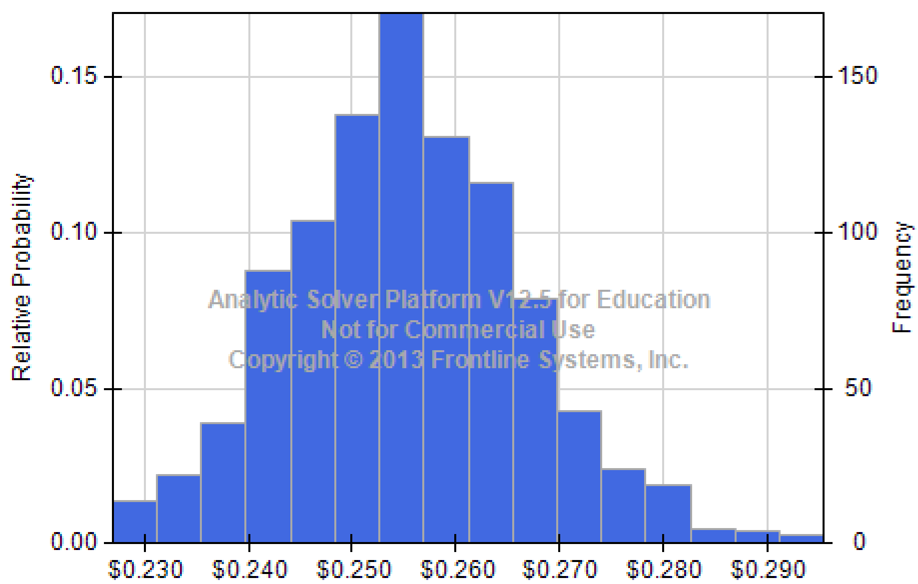

Figure 41. 2024 Monthly Energy Mix Washington - Scenario I Levelized Cost Distribution

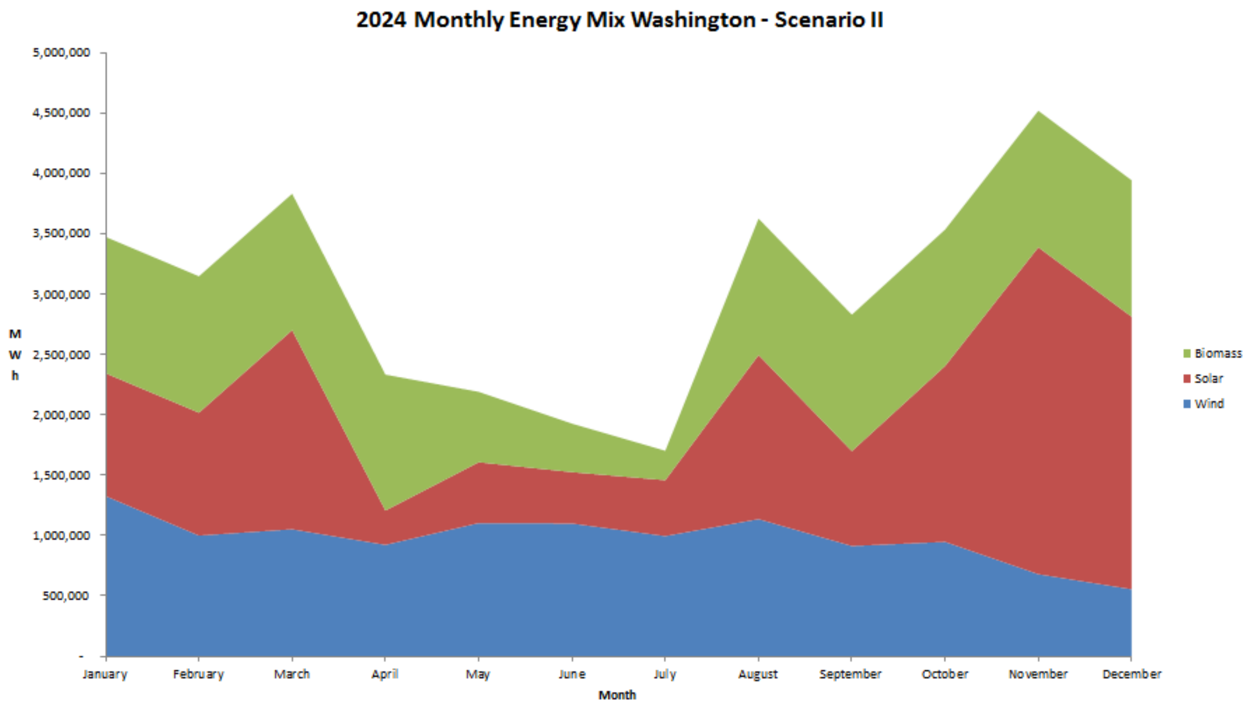

Figure 42. 2024 Monthly Energy Mix Washington - Scenario II

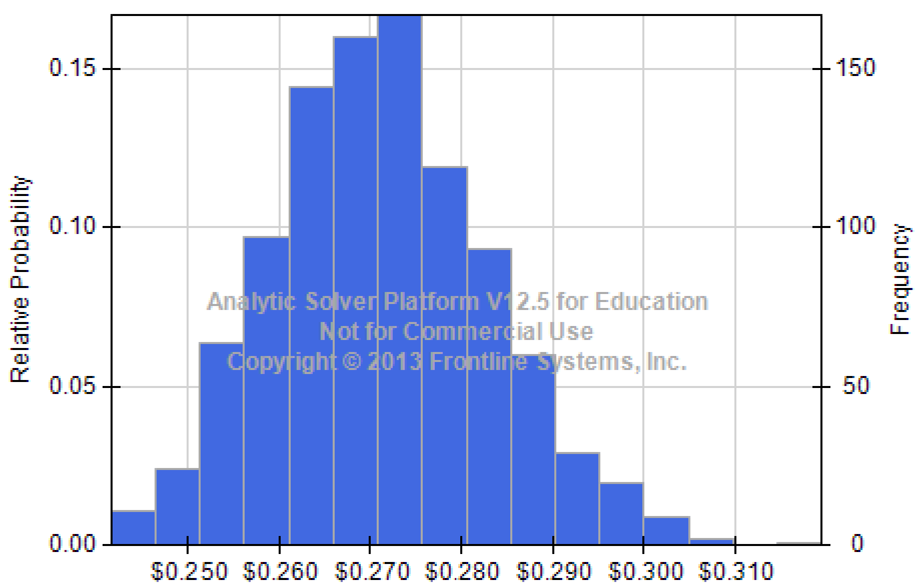

Figure 43. 2024 Monthly Energy Mix Washington - Scenario II Levelized Cost Distribution

A hourly randomized model was developed for Oregon in 2024 for the equinoxes, March 20th and September 22nd. Hourly wind capacity factors were from representative windfarms in Colorado and Wyoming, since values for Oregon or Washington were not available to the project[87] and hourly solar capacity factors were from *Energy Systems Engineering*.[88] Similarly to

[87] www.allenergystocks.com/archives/windperformance.bmp

the monthly randomized model, biomass capacity factor was not to exceed 80% but the standard deviation for each capacity factor was assumed to be 10%. However, only one scenario (wind, solar, biomass mix or ratio 45:35:20) was studied because this scenario is a more distributed mix. Because hourly wind capacity data from other states were used, there is a caveat that 24-hour wind distribution might be different from the one used, which would affect results.

The hourly energy mix for Oregon on March 20th, 2024 and September 22nd, 2024 are shown in Figure 44 and Figure 46Figure while the distribution of electricity cost from the resulting mixes are shown in Figure 45 and Figure 47. Both days show wind as the main energy contributor throughout the day, solar contributing only in the daytime from about 7am to 9pm, and biomass supporting the rest of the contribution when demand peaks in the evening. The mean electricity cost is about $0.12/kWh in March and about $0.11/kWh in September. The standard deviation for each state's electricity cost is about $0.012/kWh so most of the trials resulted in electricity cost that is within a cent of the average cost. Because the majority of electricity cost is attributed to capital cost and the operating cost of each energy source, especially wind and solar, is very small ($0.023/kWh for wind and $0.004/kWh for solar), the relatively larger demand in September allows average electricity cost to be cheaper. The larger demand will lead to increased dependence on wind and solar and reduced dependence on biomass, which has the largest operating cost.

[88] Vanek, Francis M., and Louis D. Albright. *Energy Systems Engineering: Evaluation and Implementation*. NY: McGraw-Hill, 2012. 311

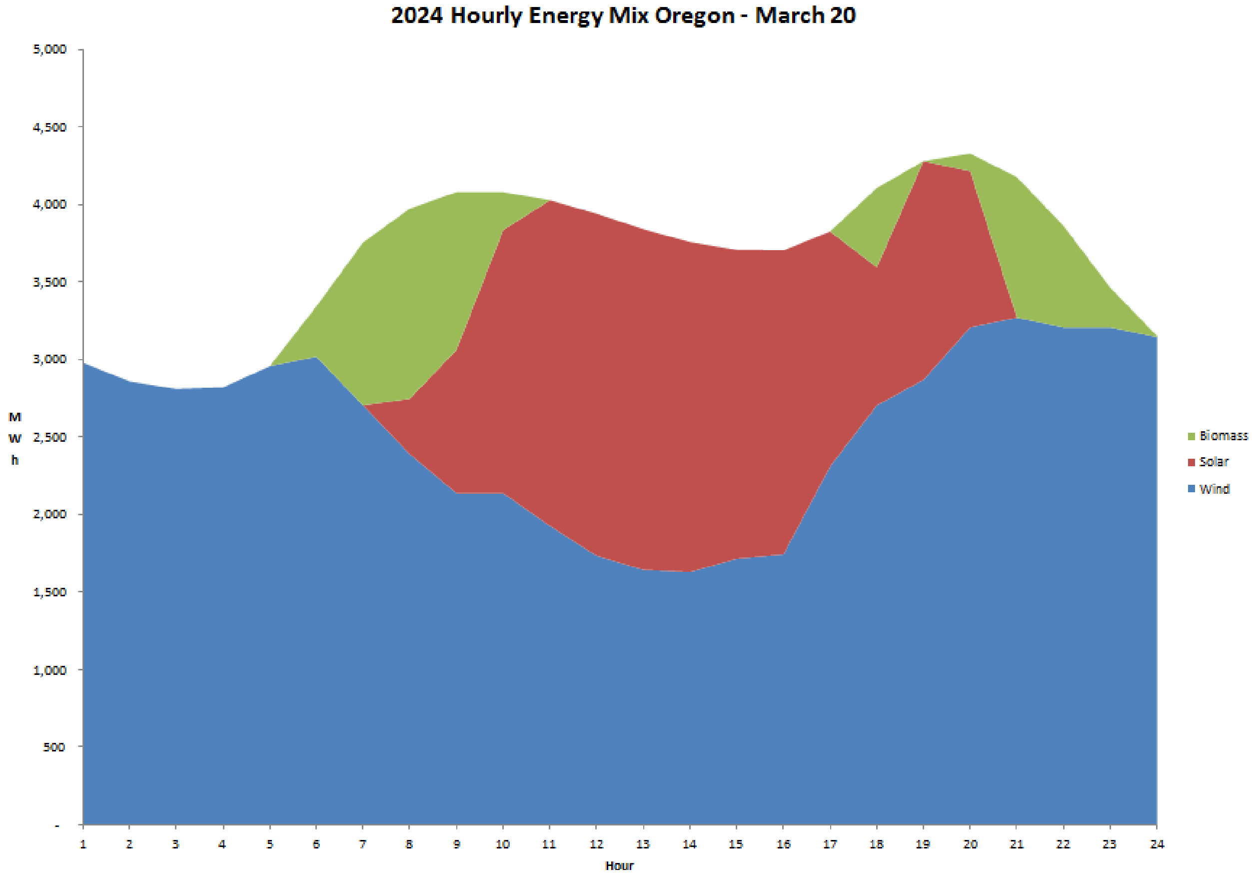

Figure 44. Hourly Energy Mix – Oregon March 20, 2024

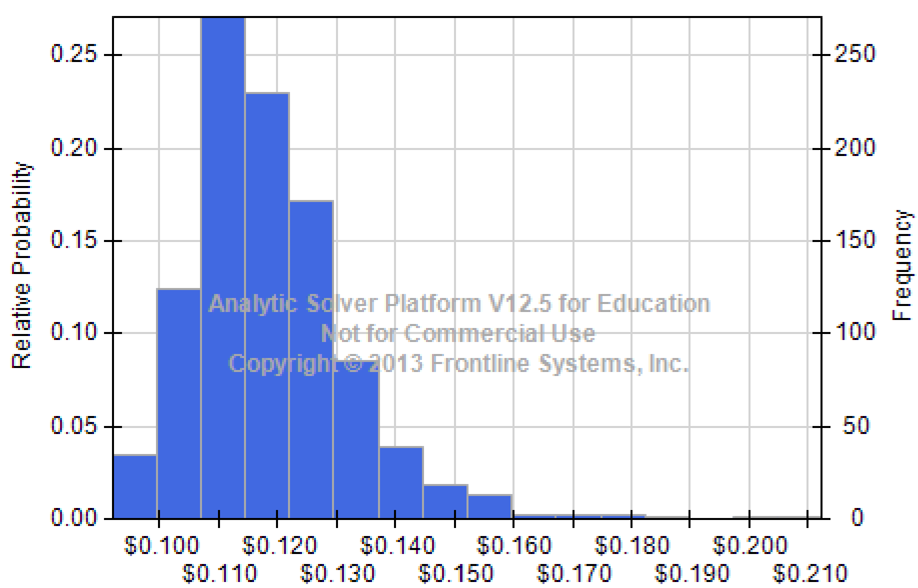

Figure 45. Hourly Energy Mix - Oregon March 20, 2024 Levelized Cost Distribution

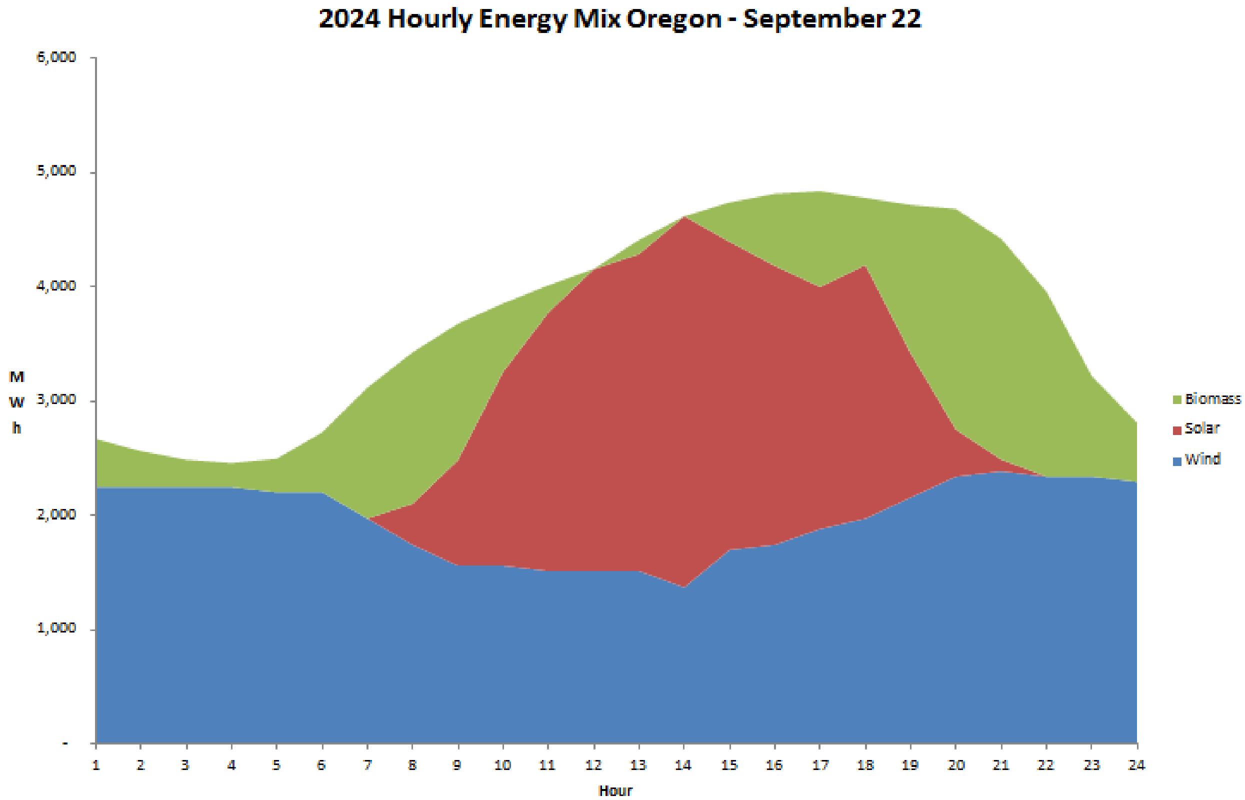

Figure 46. Hourly Energy Mix - Oregon September 22, 2024

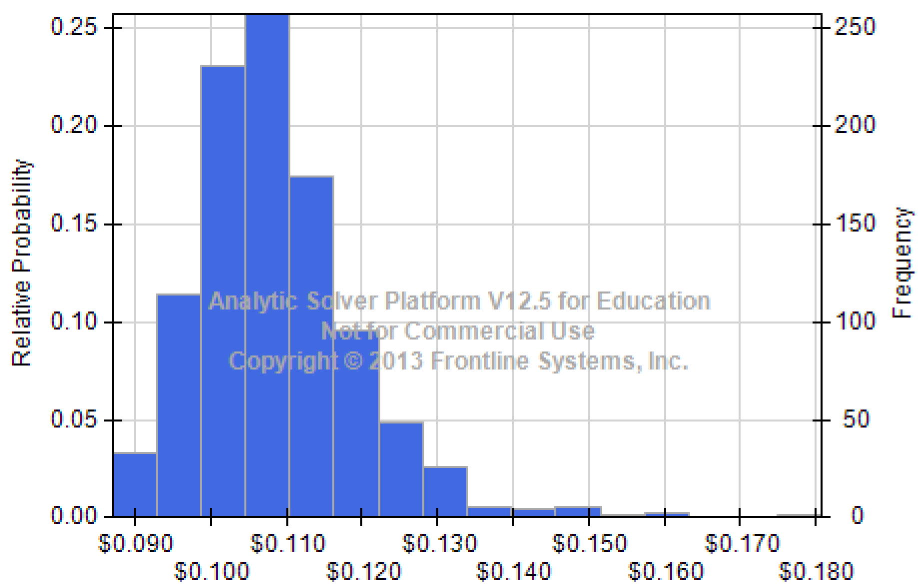

Figure 47. Hourly Energy Mix - Oregon September 22, 2024 Levelized Cost Distribution

Randomization of the fixed model resulted in the proposal of various feasible energy mixes based on an initial ratio recommendation. Only wind and solar capacity factors were randomized while biomass capacity factor was only constrained to be between 0 and 80% because wind and solar are the preferred energies financially while biomass serves more as a backup especially in the winter months when wind and sun are less strong and less reliable or nighttime when there is less sun. Other feasible mixes that incorporate more risky situations could assume larger standard deviations for the factors studied. In addition, other factors that could be randomized are biomass capacity factor and installed capacities for each source.

f. Summary of Tax Incentives in the Model

The tax incentives provided by the U.S. government, encouraging the use of renewable energy, lowered total cost for each source. The calculation of the reduction amount is provided below.

<u>Wind</u>: Total Cost – [$23 * MWh generated]
<u>Solar</u>: Total Cost – [0.35 * $760 * MWh generated]
<u>Biomass</u>: Total Cost – [$5 * MWh generated]

g. Socio-Economic Impact of RPS

There is an optimistic view point that the new energy installations will boost employment and the economy of these two states. In contrast to predictions that job prospects will improve, an RPS study mentioned below give us a contrasting view to the situation and predicts loss of jobs and a negative impact of the economics of Washington and Oregon. It is important to note that there is uncertainty associated with the study and the study seems has a pessimistic outlook on the impact of renewable energy, which may not necessarily be the case, in actual implementation of the plan. There is a chance that the new energy installations might offset some or all of the other loss of jobs.

Oregon[89]

It is predicted that as renewable energy is added into the mix of sources contributing to meet the demand, the cost of electricity will rise proportionally. The anticipated effect of this RPS law on the state electricity framework is as follows:

- The RPS law will raise the cost of electricity for the state's electricity consumers in 2025, within a range of $562 million and $1.404 billion.

89 Economic impact of Oregon's renewable energy portfolio standard, Beacon Hill Institute and Cascade policy Institute Policy Study, http://cascadepolicy.org/pdf/2011-3-9-RPSreport.pdf

- Oregon's cost of electricity will increase by 1.73 cents per kWh or by 23% in 2025.

This would have a negative impact on the state's economy. In 2025, the RPS would:

- Lower employment by an expected 17,530 jobs, within a range of 10,025 jobs and 24,630 jobs
- Reduce real disposable income by $170 million, within a range of $101 million and $230 million
- Decrease investment by $145 million, within a range of $83 million and $204 million; and
- Increase the average electricity bill for households by $247 per year, for commercial businesses by an expected $9,641 per year, and for industrial businesses by an expected $11,585 per year.

Washington

- The current RPS law will raise the cost of electricity by $1.22 billion for the state's electricity consumers in 2020, within a range of $675 million and $1.675 billion.
- Washington's electricity prices will rise by 13.6% by 2020, due to the current RPS law

These increased energy prices will hurt Washington's households and businesses and, in turn, inflict significant harm on the state economy. In 2020, the RPS would:

- Lower employment by an expected 8,650 jobs, within a range of 4,780 jobs and 11,885 jobs
- Reduce real disposable income by $1.005 billion, within a range of $555 million and $1.38 billion
- Decrease investment by $147 million, within a range of $81 million and $203 million; and
  Increase the average electricity bill for households by $170 per year, for commercial businesses by an expected $1,135 per year, and for industrial businesses by an expected $13,225 per year.

Part III: Final Recommendation

15.Recommended Energy Mix

In light of the discussion in the optimization section covering deterministic and stochastic models, several scenarios were studied. As wind is the cheapest source of energy considering capital and operating costs, taking a large contribution from wind, followed by solar and then by biomass is the solution that has surfaced amidst several iterations. As a recommendation for the future energy mix, we recommend a ratio of 60:30:10 for wind, solar and biomass respectively. This energy mix depicts a good diversity and the contribution of biomass adds reliability in the model. This suggested mix is an annual mix and the contribution of each source would vary depending on the seasonal availability each month.

In a brief overview, both the states have sufficient land to install the wind turbines and the solar panels required to meet such a demand in the future and the RPS has continued to place stringent laws to increase the renewable energy contribution in both these states. By 2020, the coal plants in both the states will also be shut. The contribution of solar can be increased further but that is more likely subject to a potential decrease in the capital cost of solar energy. The continued tax incentives will help the growth in these technologies.

Uncertainty in the energy demand must be curbed to avoid blackouts, damage to the grid by having a contingency production and/or relying on the existing hydroelectricity in the states or the biomass energy to contribute to the grid. The energy imbalance markets are an applicable solution that will help deal with the additional uncertainty that an increasing wind and solar contribution will bring in the electrical grid.

16. CO_2 Mitigation

The primary focus of the model is to calculate the feasibility of renewable sources of energy replacing the current sources to fulfill the energy demand. A major benefit obtained from using renewables is that, greenhouse gas emissions are avoided unlike in conventional sources of energy. This CO_2 mitigation model focuses mainly on carbon dioxide (CO_2) reduction. Other gases have not been considered as a part of this analysis. The analysis calculates the cost per ton CO_2 saving obtained from switching over to renewables. The cost benefit of replacing coal by wind and solar individually for the current year has been calculated in the parts above. Here, the renewable mix has been compared with natural gas and not coal as coal is currently being phased out of production.

The basic methodology is to calculate the carbon tax saving. A carbon tax is a tax levied on the carbon content of fuels. It is a form of carbon pricing[90]. Carbon is present in every hydrocarbon fuel (coal, petroleum, and natural gas) and is released as carbon dioxide (CO_2) when they are burnt. In contrast, non-combustion energy sources -wind, sunlight, hydropower, and nuclear—do not convert hydrocarbons to CO_2. CO2 is a heat-trapping "greenhouse" gas. An amount of CO2 pollution is measured by the weight (mass) of the pollution. Sometimes this is measured directly as the weight of the carbon dioxide molecules. This is called a tonne of carbon dioxide and is abbreviated "tCO2". Alternatively, the pollution's weight can be measured by adding up only the weight of the carbon atoms in the pollution, ignoring the oxygen atoms. This is called a tonne of carbon and is abbreviated "tC". Estimates of the dollar cost of carbon dioxide pollution is given per tonne, either carbon, $X/tC, or carbon dioxide, $X/tCO2. One tC is roughly equivalent to 4 tCO2.

[90] Carbon tax -Wikipedia

For our analysis, natural gas fired advanced combined cycle technique has been considered as this is the most efficient of all the known methods of generation[91]. The levelized cost data for natural gas has been considered from the USDOE prediction for plants entering service in 2018. The levelized cost is assumed to remain constant over the 20 year analysis period. For natural gas, a factor of 0.325 $kgCO_2$ per kWh demand has been assumed based on U.S average. The levelized cost for the renewable mix has been sourced from the randomized model. A particular iteration has been considered for both the years and the resultant levelized cost has been considered. The range for both the states in 2024 is 0.25$/kWh - 0.30 $/kWh and for 2034 is 0.31$/kWh - 0.35$/kWh.

The analysis compares natural gas and renewable mix carbon tax saving for the years 2024 and 2034. These two years have been consistently used for analysis in the model as they are the halfway and end stage milestone. The values for Oregon and Washington have been calculated separately. The total cost per tonne of carbon dioxide was calculated in three steps. Firstly, the demand for that year was identified. Secondly, tonne of CO_2 generated was calculated. Lastly, the cost for this amount was calculated. This was done for both natural gas and the renewable mix. To compare both these sources, the ratio of their cost per tonne values was used.

Data from **USDOE**

Total cost is achieved as follows for **NG: Advanced Combined Cycle plant**

Capital cost	0.0174	$/KWh
Fixed Operation & Maintenance cost	0.002	$/KWh
Variable Operation & Maintenance cost(including fuel)	0.045	$/KWh
Transmission cost	0.0012	$/KWh
Total Levelized cost	**0.0656**	$/KWh

Levelized cost from random **model optimization**

Year	OR	WA
2024	$ 0.27	$ 0.28
2034	$ 0.32	$ 0.33

Year **2024**

Demand (OR)	29,417 mil KWh
Demand (WA)	39,946 mil KWh

OREGON			
Source	kgCO2/KWh	Total kgCo2	Total Tonne CO2
Natural Gas	0.325	9560586098	9560586.098
Renewable Mix	0	0	0
Total			9560586.098
Cost/tonne	**$ 628.92**		

WASHINGTON			
Source	kgCO2/KWh	Total kgCo2	Total Tonne CO2
Natural Gas	0.325	12982328578	12982328.58
Renewable Mix	0	0	0
Total			12982328.58
Cost/tonne	**$ 659.69**		

Year **2034**

Demand (OR)	29,397 mil KWh
Demand (WA)	46,711 mil KWh

OREGON			
Source	kgCO2/KWh	Total kgCo2	Total Tonne CO2
Natural Gas	0.325	9554086098	9554086.098
Renewable Mix	0	0	0
Total			9554086.098
Cost/tonne	**$ 782.77**		

WASHINGTON			
Source	kgCO2/KWh	Total kgCo2	Total Tonne CO2
Natural Gas	0.325	15181123227	15181123.23
Renewable Mix	0	0	0
Total			15181123.23
Cost/tonne	**$ 813.54**		

Figure 48. Cost per tonne CO_2 Calculation

[91] 91 Cost of electricity by source -Wikipedia

From the analysis, we gather that both Oregon and Washington have a similar annual cost per tonne saving. In fact Washington has a higher value than Oregon in 2034 due to higher demand. Even though, the cost for renewable seems higher, there is lot of saving in carbon tax for renewable mix. Since, carbon generation is practically zero for the renewable mix, we do not add any pollutant in air.The total cost values initially seem to be higher, but when cost per tonne saving is taken into account , the high margin balances out and in the long run, it is also beneficial for the environment.

17. Direction for further discussion

Reliability

A major issue in energy systems, especially those regarding renewable options, is reliability. An energy source is considered reliable if the source is consistent and able to meet predicted peaks in demand. Consumers in the United States expect constant and consistent power, making reliability a major concern for energy companies.

Diversifying the energy mix is a step towards mitigating the issue of reliability but renewable options such as wind and solar depend on the strength of wind and sunlight respectively and the intermittency of these natural occurrences is impossible to exactly predict. Demand to be met is also difficult to precisely predict. However, historical monthly or hourly data about wind or sunlight capacity factors can help predict when these sources will be stronger or weaker. In our analysis, we considered how wind and solar capacity factors vary seasonally as well as throughout the day on an hourly basis. Historical demand data can be used to project future demand to be met. Because wind and solar are intermittent energy sources, more reliable backup sources are needed to meet demand when wind and sunlight are unexpectedly weak or unexpected peaks in demand occur. Biomass is extremely reliable and can produce energy at any point of any day in any season. Therefore, biomass is a good option as a backup. If the role of biomass as a backup expands in the future, the various biomass plant suppliers will be encouraged to adapt the technology.

Because our energy mix was designed for total demand excluding hydropower, we must still consider reliability of hydropower as a point to look into. However, hydropower is generally reliable and facilities can quickly go from zero power to maximum output, thus meeting rapidly changing demand or demand that cannot be met due to sudden or unexpected reductions in wind or sunlight. So in addition to biomass, hydropower will serve as a good backup to meet demand reliably. Lastly, another way to ensure reliability in energy supply meeting demand is to design energy supply up to 120% of predicted demand. Although this may be costlier, consumers may be willing to pay more for reliability or lack of reliability may lead to lost consumers.

Energy Imbalance Market

An energy imbalance on an electrical grid is the difference between real-time electricity demand and the load consumption that is arranged as per predicted requirement.

As an equation[92], the energy imbalance would be expressed as –
Energy imbalance = Actual Production usage – Scheduled usage

Energy imbalance markets address the problem of increase in variation of generation that increase in solar and wind energy will bring to the electrical grid. A balancing authority maintains load-resource balance and stability of alternating current within an area. If a balancing authority misjudges the required reserves and underestimates, then it may run short of requirement causing several problems of instability and risks.

It is a centralized, automated system that will reduce the requirement of a large buffer to maintain contingencies. It will also improve the operational reliability over a wider area by enabling decision making and response based on near term data inputs. The energy imbalance market will also reduce integration costs and increase economic efficiency. There are speculations that this system may have its own reliability issues and costs that outweigh the estimated benefits.

Part IV : Appendix: Tasks and Timeline

1. 10/14/13 Collect the preliminary data
    a. Available resource
    b. Research the existing technology
    c. Understand the demand
    d. Calculate capacity
    e. Explore other alternatives
    f. Estimate the cost
2. 10/14/13 Cost Analysis
    a. Revenue
    b. Maintenance cost
    c. Installation cost
    d. Government incentives
    e. Payback period
3. 10/14/13 Verify the calculations
4. 10/14/13 Study electric sub-structure of the area

[92] Introduction to Energy imbalance markets

5. 10/24/13 Incorporate the data
6. 10/24/13 Prepare the model
7. 10/24/13 Risk analysis
8. 10/24/13 Midterm management report
9. 10/28/13 Prepare interim presentation
10. 11/14/13 Review the spreadsheet model and optimization techniques
11. 11/14/13 Study the social and economic impact
    a. Consider the carbon footprint of the area
12. 11/21/13 Final presentation
13. 11/28/13 Incorporate comments
14. 12/03/13 Final report draft
15. 12/15/13 Final report contribution

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