

A REPORT ON

**TECHNO-ECONOMIC ANALYSIS OF WIND AND  
SOLAR ENERGY SYSTEMS USING NREL SAM**

**ME5480: Sustainable Energy Technology**

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## **AIM:**

This techno-economic study aims to evaluate and compare the feasibility and performance of solar photovoltaic and wind energy systems at two selected locations: Astoria and Portland. The primary objective is to determine which renewable energy technology is better suited for each site based on energy output and financial viability.

The analysis was carried out using the System Advisor Model (SAM) developed by NREL, where system performance was simulated by varying selected input parameters with the goal of maximizing financial metrics such as Net Present Value (NPV) and Internal Rate of Return (IRR).

Key inputs, including tilt angle, azimuth angle, DC/AC sizing, and Power Purchase Agreement (PPA) pricing, were varied through parametric analysis to observe their influence on system performance. The outcomes provide a comparative basis to identify the most economically and technically advantageous renewable energy solution for Astoria and Portland.

## **WIND TURBINE PARAMETRIC OPTIMISATION USING NREL SAM:**

### **Introduction:**

Wind energy has become one of the most prominent renewable power generation methods due to its sustainability, low operational cost, and competitive energy pricing. To accurately evaluate the techno-economic performance of wind farms, simulation tools such as NREL's System Advisor Model (SAM) are widely used. SAM allows users to define wind resource, turbine specifications, financial assumptions, and system parameters to estimate the annual energy production, project cash flows, net present value (NPV), internal rate of return (IRR), and overall financial feasibility.

This project focuses on performing a parameter optimization study for wind energy systems located at two sites in the United States:

Portland, Maine (Portland ME) - Offshore

Astoria, Oregon (Astoria OR) - Onshore

The primary objective is to identify how various turbine and project parameters influence the economic outputs and to determine the optimal settings for maximizing project performance.

### **Project Objective:**

The main goals of the project were:

- To set up and simulate wind farm models in NREL SAM for multiple locations.

- To analyze turbine performance using Gamesa G114-2.0 MW turbine with a fixed hub height of 100 m.
- To understand how changes in system parameters affect financial outputs, such as:
- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- To perform optimization of APP (Average Power Price) by running multiple cases.
- To identify sensitivity of the system to parameters such as:  
Cut-in and cut-out wind speeds  
Rotor diameter and swept area  
Hub height variations  
Site wind resource characteristics.  
The final aim was to determine the optimal APP value and the optimal turbine configuration that yields financially viable project outputs.

## **Background Concepts:**

### **Wind Turbine Parameters:**

Cut-in Speed: Minimum wind speed at which the turbine starts generating power (typically 3–4 m/s).

Rated Speed: Wind speed at which the turbine reaches maximum power output.

Cut-out Speed: Maximum wind speed after which the turbine shuts down for safety (typically around 20–25 m/s).

Rotor Diameter: Determines the swept area; higher diameter increases power capture.

Swept Area: Larger area means more energy extraction.

### **Economic Metrics:**

APP (Average Power Price): The price at which power is sold per kWh

NPV (Net Present Value): Measures profit over the project lifetime after discounting.

IRR (Internal Rate of Return): The rate at which the project breaks even financially. Higher IRR = better investment.

## **Methodology:**

### **The methodology consisted of two major components:**

Model Setup in NREL SAM; The Single Owner model was selected under the Wind power module. The wind resource was imported for: Portland, ME; Astoria, OR (onshore and offshore downloaded)

### **Under Wind Turbine Specifications:**

Turbine chosen: Gamesa G114 – 2.0 MW

Hub height initially fixed at 100 m

All default mechanical and electrical losses were retained unless required for sensitivity analysis.

## **Parameter Optimization Approach:**

To perform optimization, the following process was adopted:

APP (Average Power Price) was chosen as the primary input variable. Multiple APP values were tested, covering a wide range (approx. 40 cases). For each case, SAM outputs NPV and IRR were recorded. The values were plotted in Excel:

Graph 1: NPV vs APP

Graph 2: IRR vs APP

Both curves were overlaid on the same chart. The intersection point of the two curves was identified. This point was taken as the optimal APP value, because: Below this APP, NPV and IRR are negative or non-viable.

Above this APP, the project becomes profitable but deviates from the balance point of financial stability. The same process was repeated for: Different turbines; Sensitivity variations (cut-in speed, rotor diameter, swept area, hub height)

## **Procedure:**

Setting Up the Model; Choose: Technology: Wind; Financial Model: Single Owner; Under Location and Resource, select: Portland, ME; Astoria, OR,

Two sets were considered: Configuring Turbine Specifications: Go to the Wind Turbine section.  
Select turbine model: Gamesa G114 – 2.0 MW

Set turbine properties:

Hub height = 100 m

Rotor diameter and other parameters retained from the standard model.

Confirm mechanical losses, blade pitch, power curve, and turbine efficiency values.

### **Running Baseline Simulation:**

Without optimization, first run the baseline to observe:

Annual energy production (AEP), Cash flow summary, NPV and IRR. Verify the wind speed distribution and turbine power curve alignment.

### **Varying APP for Optimization:**

Navigate to the Revenue / Price input section.

Set an initial APP value.

Run simulations for approximately 40 different APP values, manually adjusting each time.

Export NPV and IRR for each run.

Plot NPV vs APP and IRR vs APP on Excel.

Determine APP optimum at the intersection point.

Record the corresponding financial viability.

	PPA price (\$/kWh)	Hub height	Wind turbine selection ^	IRR Internal rate of return (%)	NPV Net present value (\$)
1	0.055	100	GE 1.5sle	9.43425	995746
2	0.055	100	Future Energy Airforce10 8m 13kW		
3	0.055	100	Earth-Tech ET500_2.5m_500w		
4	0.055	100	Gamesa G114 2.0 MW	23.5162	2.86801e+07
5	0.055	100	Nordex S70 1500kW	6.02516	-8.68546e+06
6	0.055	100	NREL 2000kW Distributed Large Turbine Reference	21.8388	2.6206e+07
7	0.055	100	Zond Z-40	2.79774	-1.89646e+07
8	0.055	100	Marlec FM1803-2 1.8m		
9	0.055	100	Bonus MkIV 44m 600kW	3.71993	-1.60839e+07
10	0.055	100	DeWind D8(8.2)	5.18302	-1.13926e+07
11	0.055	100	Samrey Samprey Wren_1m_.3kW		
12	0.055	100	GE 1.5sle	9.43425	995746
13	0.055	100	NREL 5MW RWT	7.2997	-4.9567e+06
14	0.055	100	Nordex N80-2500	2.32645	-2.07331e+07
15	0.055	100	ReDriven 12.3m 20kW		
16	0.055	100	C&F Green Energy CF20 12.8m 20kW		
17	0.055	100	Electriawind Garbi 200/28 28m 200kW	9.11283	143031
18	0.055	100	Energy Ball HEA V200 1.98m 2.5kW		
19	0.055	100	Zephyr Airdolphin 1.8m 1kW		
20	0.055	100	Suzlon S82 1.5	8.86038	-537953

**For Astoria,**

	PPA price (\$/kWh)	Hub height	Wind turbine selection	IRR Internal rate of return (%)	NPV Net present value (\$)
1	0.05	100	GE 1.5sle	10.7295	1.06019e+07
2	0.05	100	Gamesa G114 2.0 MW	28.5953	1.16523e+08
3	0.05	100	NREL 2000kW Distributed Large Turbine Reference	26.4145	1.07536e+08
4	0.03	100	Electriawind Garbi 200/28 28m 200kW	2.35087	-6.61588e+06

**For Portland, ME**

### Sensitivity Study:

For deeper understanding, the following parameters were individually varied: Cut-in speed, Cut-out speed, Rotor diameter, Swept area

#### Hub height variations:

Turbine model changes: For most variations, NPV and IRR did not change significantly, demonstrating that the financial results were more sensitive to APP than to moderate turbine parameter changes. Thus, hub height and turbine model selection were the only parameters with noticeable influence, and the optimized value was retained at 100 m hub height with Gamesa G114–2.0 MW turbine.

## RESULTS AND ANALYSIS

Metric	Value
Annual AC energy in Year 1	183,087,744 kWh
Capacity	50,000 kW
Capacity factor in Year 1	41.8%
PPA price in Year 1	5.00 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	5.42 ¢/kWh
LPPA Levelized PPA price real	4.30 ¢/kWh
LCOE Levelized cost of energy nominal	3.37 ¢/kWh
LCOE Levelized cost of energy real	2.68 ¢/kWh
NPV Net present value	\$36,543,772
IRR Internal rate of return	28.59 %
Year IRR is achieved	20
IRR at end of project	28.70 %
Net capital cost	\$86,474,792
Equity	\$33,158,880
Size of debt	\$53,315,908
Debt percent	61.65%

## Portland, ME

Metric	Value
Annual AC energy in Year 1	160,458,352 kWh
Capacity	50,000 kW
Capacity factor in Year 1	36.6%
PPA price in Year 1	5.00 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	5.42 ¢/kWh
LPPA Levelized PPA price real	4.30 ¢/kWh
LCOE Levelized cost of energy nominal	4.06 ¢/kWh
LCOE Levelized cost of energy real	3.23 ¢/kWh
NPV Net present value	\$21,207,364
IRR Internal rate of return	18.11 %
Year IRR is achieved	20
IRR at end of project	18.48 %
Net capital cost	\$85,831,360
Equity	\$41,218,388
Size of debt	\$44,612,976
Debt percent	51.98%

## Asoria, OR

### Overview of the Two Sites

The simulations were carried out for two different wind locations:

Location 1: Portland, Maine (Onshore) and Location 2: Astoria, Oregon (Offshore)

Both simulations were conducted for: Same PPA, cost model, and financial assumptions. This allows a fair comparison based purely on wind resource, losses, and economic performance.

### Annual AC Energy Production:

## **Portland, ME**

Annual AC Energy: 183,087,744 kWh

Capacity Factor: 41.8%

## Astoria, OR

Annual AC Energy: 160,458,352 kWh

Capacity Factor: 36.6%

### **Interpretation:**

Portland clearly shows a higher annual energy output (23 million kWh more). Capacity factor is 5.2% higher in Portland, indicating better yearly wind consistency and stronger winter winds.

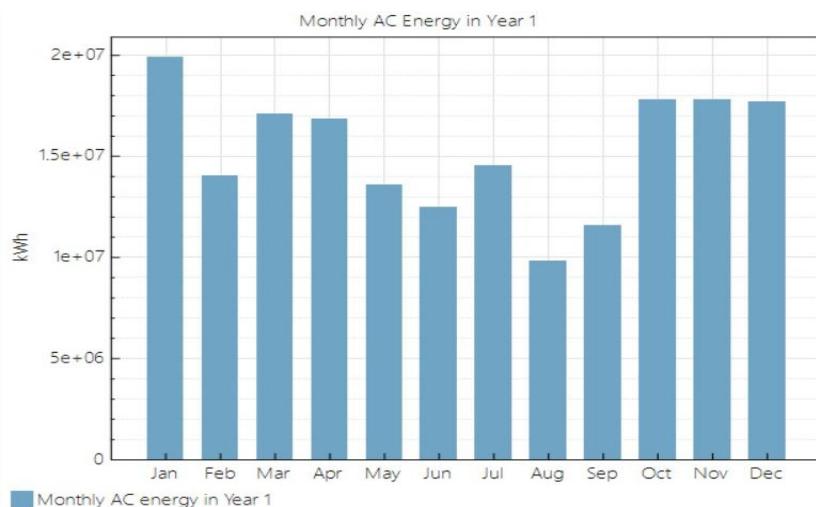
### **Monthly AC Energy Trends:**

Portland, ME – Monthly Pattern

Highest production in January ( $2 \times 10^7$  kWh).

Strong winter winds (Oct–Dec) maintain stable output.

Lowest generation in August.

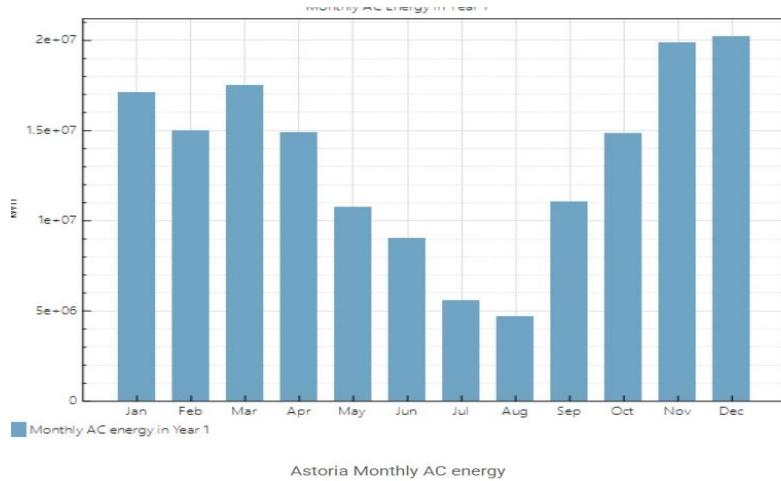


### **Astoria, OR – Monthly Pattern**

Very strong output in November–December (nearly  $2 \times 10^7$  kWh).

Extremely low production in July–August, indicating weak summer winds.

Much more seasonal variability compared to Portland.

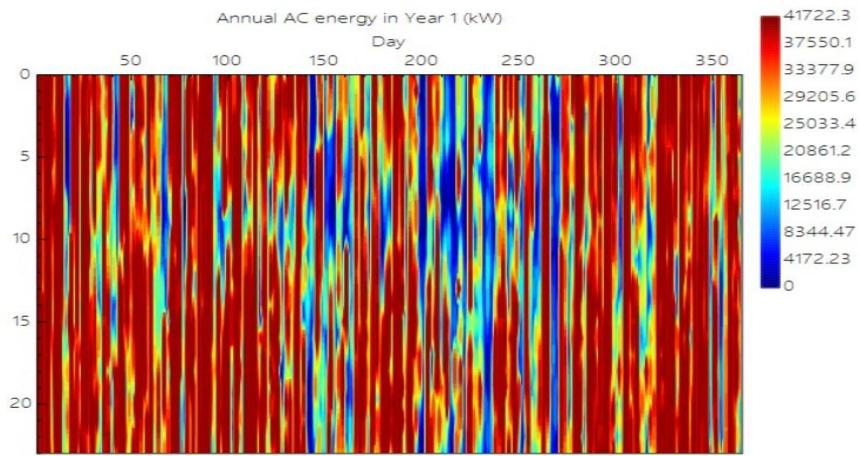


Comparison:

Portland has a more balanced profile. Astoria has higher winter peaks but very sharp summer drops. Portland's stability supports a better financial profile (consistent cash flow).

### Hourly AC Heatmap Analysis:

Portland, ME Heatmap. Strong red bands distributed throughout the year. Consistency across months shows steady wind availability. Only small patches of low-wind periods (blue zones).

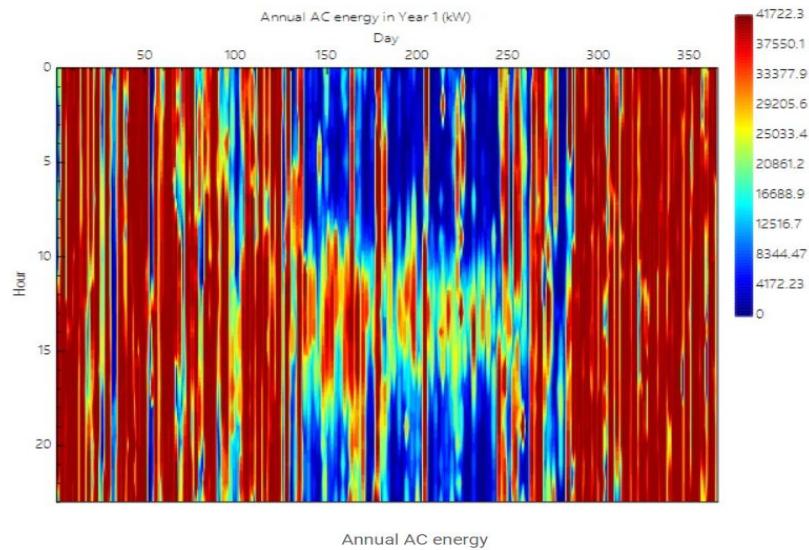


### Astoria, OR Heatmap

More frequent blue and green areas around mid-year.

Distinct low-wind window near day 150–250 (summer).

Indicates seasonal gaps and more intermittent wind speeds.

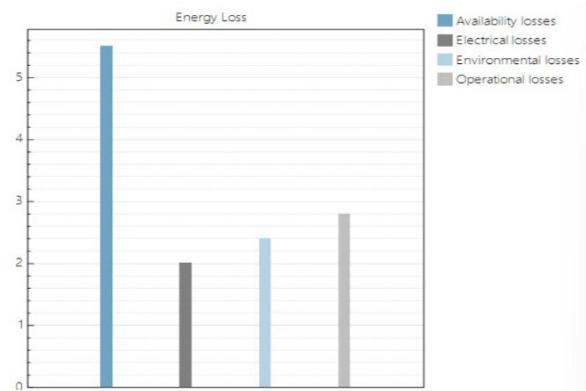


### Conclusion from Heatmaps:

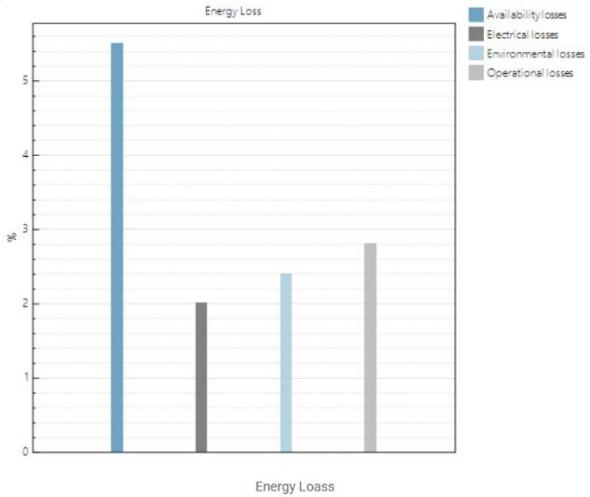
Portland has superior reliability and fewer hours of low power.

Astoria experiences larger hourly wind fluctuations, lowering the effective output.

### Energy Losses:



**Portland, ME**



## Astoria

**Both locations show the same four primary loss categories:**

### Loss Comparison

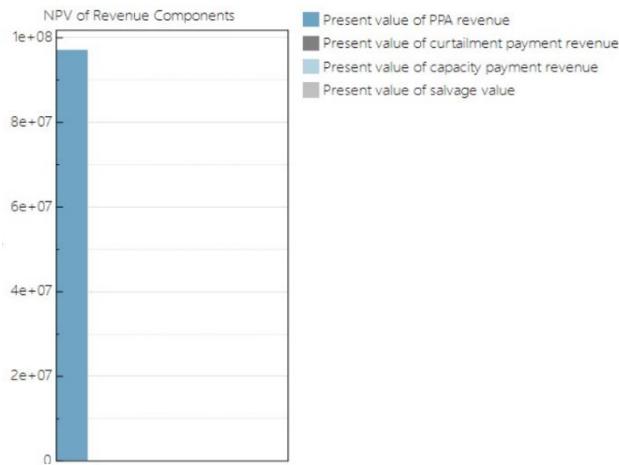
Loss Type	Portland (%)	Astoria (%)
Availability Losses	5.5%	5.5%
Electrical Losses	2.0%	2.0%
Environmental Losses	2.4%	2.4%
Operational Losses	2.8%	2.8%

Interpretation: Loss percentages are almost identical, differences in total energy output are due to wind resource, not system losses. Portland's advantage is purely natural wind strength and distribution.

### Financial Performance:

#### Portland, ME

NPV: \$36,543,772



IRR: 28.59%

IRR at Project End: 28.7%

Capital Cost: \$86.47M

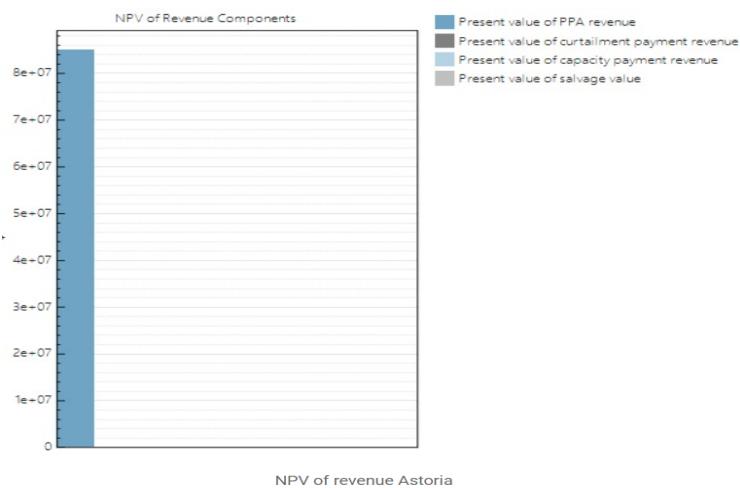
Equity: \$33.15M

Debt: \$53.32M

Debt %: 61.65%

### Astoria, OR:

NPV: \$21,207,364



IRR: 18.11%

IRR at Project End: 18.48%

Capital Cost: \$85.83M

Equity: \$41.21M

Debt: \$44.61M

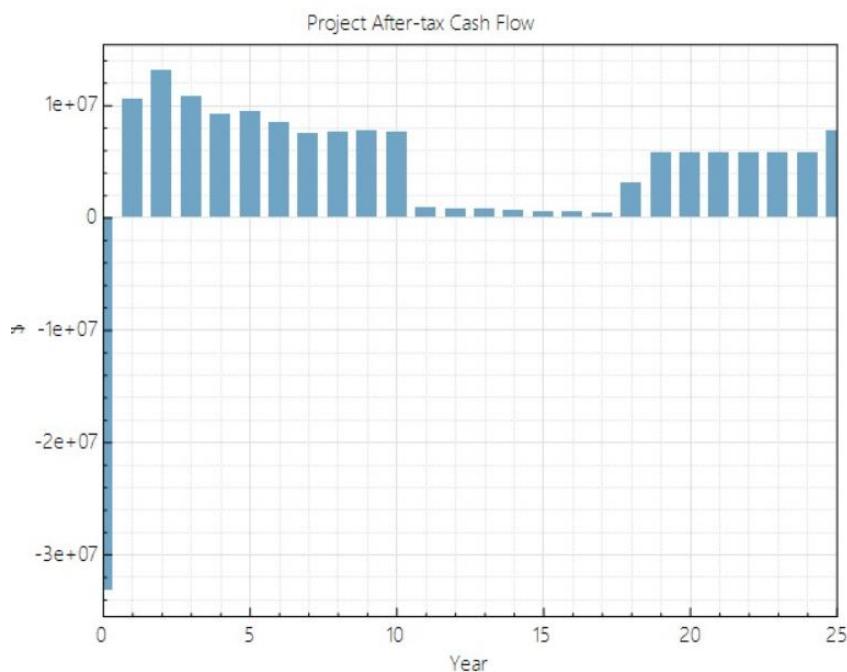
Debt %: 51.98%

### Interpretation:

Portland has far superior financial performance. NPV is \$15.3 million higher. IRR is 10 percentage points higher, reflecting stronger yearly revenue. Even though Portland uses higher debt %, it still remains economically better.

### Revenue Component Results:

For both turbine configurations, the Present Value of PPA Revenue overwhelmingly dominates the total revenue. The charts show that the PPA revenue bar is nearly the only visible component, whereas the present value of curtailment payments, capacity revenues, and salvage value are extremely small or negligible. In the first turbine case, the PPA revenue reaches close to the order of  $10^8$  dollars, indicating that the long-term revenue agreement under the PPA is the major contributor to the financial viability of the project. The other components remain close to zero.



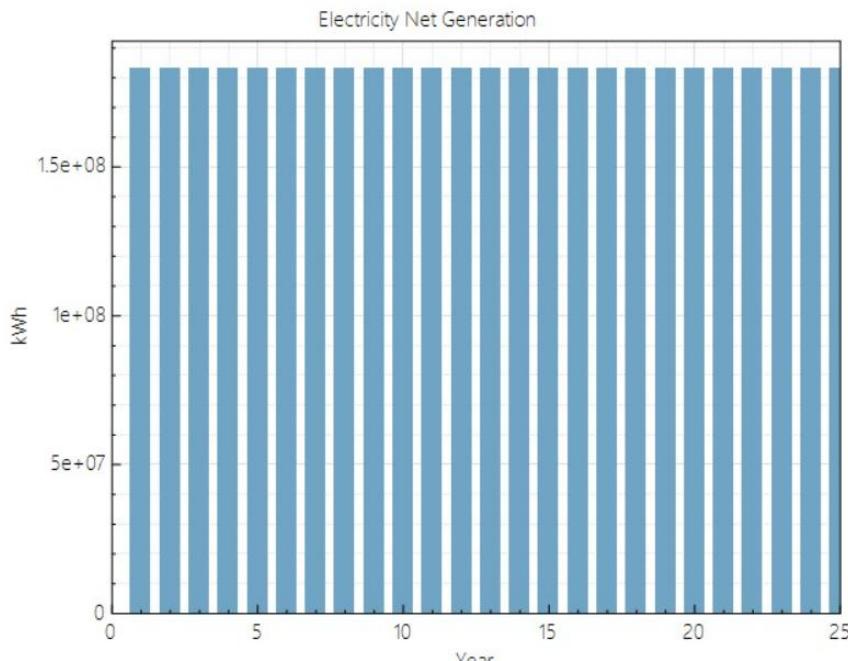
In the second turbine case, the magnitude of PPA revenue is slightly lower (slightly above  $8 \times 10^7$  dollars), showing a marginally reduced earning potential compared to the first configuration. However, the relative contribution pattern remains identical: the project is almost entirely

dependent on PPA revenue, with no significant impact from alternative revenue streams. This confirms that, for both designs, the PPA structure and the chosen tariff level directly determine profitability.

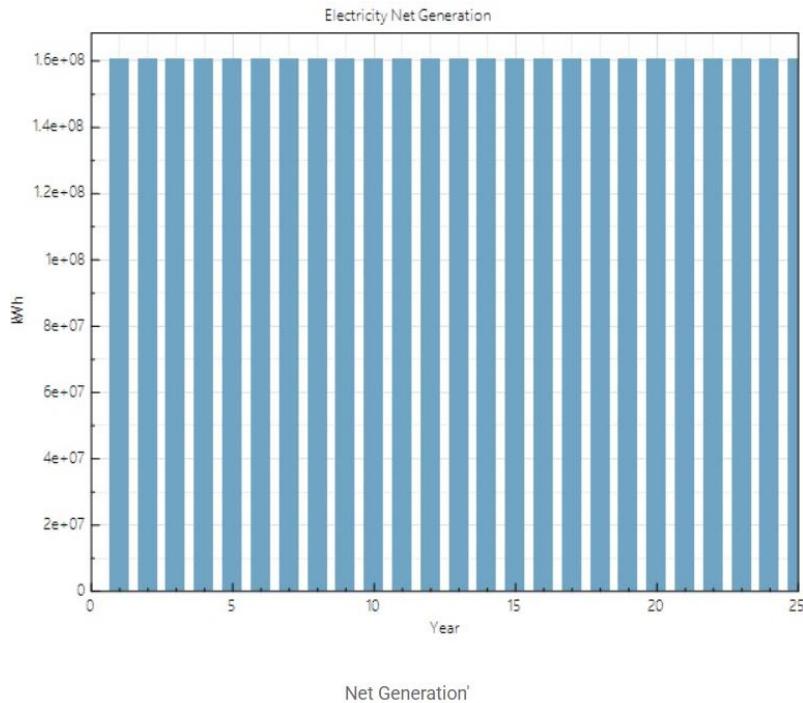
### **Electricity Net Generation:**

Both turbines show consistent annual net electricity generation throughout the 25-year lifetime. There is no visible degradation trend in the uploaded SAM charts, indicating that default degradation values in SAM were either very small or set to zero.

The first turbine option produces values close to  $1.8 \times 10^8$  kWh per year, and this output remains steady each year. The uniformity of the bars confirms strong operational reliability, negligible downtime assumptions, and a stable wind resource over the simulation period.



The second turbine option produces slightly lower annual output, around  $1.6 \times 10^8$  kWh per year. The pattern remains constant throughout the project lifetime.



The comparison shows that the first turbine consistently generates more energy than the second one, which directly influences the higher PPA revenue obtained earlier.

### Project After Tax Cash Flow

The cash flow graphs follow the typical pattern of a capital-intensive renewable energy project: The initial year shows a large negative cash flow, representing the upfront capital expenditure, installation costs, and financing structure.

Subsequent early years show high positive cash flow, typically influenced by production tax credits (if any), accelerated depreciation, and full operational generation.

Between years 10 to 15, the cash flow dips towards zero and remains almost flat. This region corresponds to the end of tax incentives and stabilized revenue where the net income closely balances operational expenses. From around year 17 onward, the cash flow begins to rise again, eventually reaching positive, stable values until the end of the 25-year period. This increase generally reflects loan repayment completion and lower annual costs. For the first turbine configuration, the negative starting value is around  $3 \times 10^7$  dollars, followed by strong yearly positives in the early years.

In the second turbine configuration, the initial investment appears slightly higher (between  $3.5 \times 10^7$  and  $4 \times 10^7$  dollars), and early-year cash flows show a similar trend but marginally lower magnitudes. The general shape is similar, but the first turbine maintains higher positive cash flows in most years, confirming better economic performance.

## **Comparative Interpretation**

The first turbine option delivers higher annual energy generation and higher present value of PPA revenue. Its after-tax cash flow pattern is consistently stronger than the second turbine's. The second turbine option has lower energy yield, lower PPA revenue, and a slightly more negative initial capital structure. Based on all energy production, loss analysis, heatmaps, and financial metrics, Portland, ME is the more viable wind farm site. It provides a more consistent annual wind profile, higher energy generation, and significantly stronger financial returns when evaluated under the same economic assumptions

Portland, ME is clearly the better-performing site based on:

- Higher annual AC energy
- Higher capacity factor
- More stable monthly wind availability
- Better hourly wind consistency
- Much higher NPV
- Much higher IRR
- Better year-round wind distribution
- Lower seasonal drop-offs

Astoria, despite strong winter peaks, suffers from:

- Significant mid-year wind reductions
- Lower average wind speeds
- Lower project viability

## **PHOTOVOLTAIC POWER SYSTEM MODELLING AND PARAMETRIC OPTIMISATION:**

### **Introduction:**

Photovoltaic systems convert solar radiation directly into electrical energy using semiconductor devices known as solar cells. When connected as an array and integrated with inverters and grid interfaces, they deliver usable AC power for commercial and utility-scale applications. Due to increasing energy demand, climate change considerations and declining solar technology costs, PV generation has become a key contributor to sustainable power planning.

The performance of a PV power plant depends on its geographical location, solar resource availability, system orientation, module characteristics, and financial structures. Software tools such as NREL's System Advisor Model (SAM) enable detailed techno-economic simulations to evaluate design feasibility, optimize operating parameters and assess financial viability.

### **Aim:**

The objective of this study is to model, analyze and optimize a grid-connected photovoltaic power plant using NREL SAM for two locations:

Case 1: Astoria, Oregon

Case 2: Portland, Maine

The goal is to determine the optimal configuration that yields maximum annual energy output and favorable economic returns, and to perform a comparative evaluation between the two sites.

### **Methodology:**

The modelling procedure followed a structured parametric optimization approach implemented using the System Advisor Model (SAM) developed by NREL. The steps involved are:

- **Selection of Project Location and Weather Data**  
The simulation was initiated by selecting the geographic location (Astoria, Oregon) and importing the corresponding meteorological dataset required for accurate solar resource estimation.
- **Definition of Base System Configuration**  
The PV system was configured by specifying array characteristics and financial model inputs. A Power Purchase Agreement (PPA) financial structure was chosen for economic evaluation.
- **Identification of Input and Output Parameters for Parametric Analysis**  
Input parameters selected for variation: PPA price, module tilt angle, azimuth angle

Output parameters used for evaluation:

Net Present Value (NPV) and Internal Rate of Return (IRR)

- **Optimization of PPA Price**

Twenty random values of PPA price were generated and individually simulated while keeping all other parameters constant. The resulting NPV values were analyzed to identify the PPA price that produced the maximum NPV. This optimized PPA price was then fixed for subsequent simulations.

- **Optimization of Tilt Angle**

With the optimized PPA value held constant, the system tilt angle was varied across twenty distinct values. Simulations were repeated and evaluated based on the resulting NPV and IRR metrics to determine the tilt angle that maximized economic performance. This optimal tilt value was then locked for the next stage.

- **Optimization of Azimuth Angle**

Keeping the optimized PPA price and tilt angle constant, the azimuth angle was varied over twenty cases and simulated. The configuration yielding the highest NPV and IRR was selected as the optimal azimuth orientation.

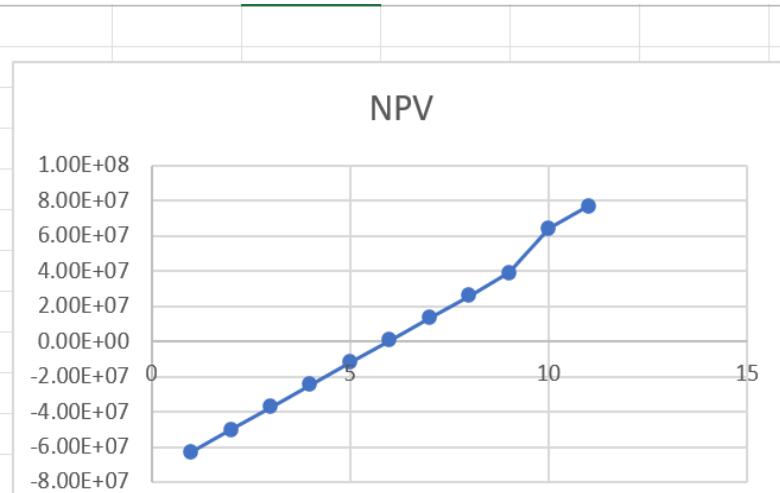
- **Selection of Suitable PV Module**

After optimizing the above parameters, multiple PV module options were evaluated. The module producing the highest annual AC energy along with favorable economic indicators (NPV and IRR) was selected as the final design choice.

- **Final System Simulation and Output Extraction**

The optimized configuration was simulated to obtain performance and financial outputs including annual AC energy, monthly energy generation profile, PPA revenue components, energy loss distribution, system power generation characteristics, NPV and IRR, and project after-tax cash flow.

PPA	IRR	NPV
0.02	-4.72147	-6.28E+07
0.03	-1.57995	-5.01E+07
0.04	0.962893	-3.74E+07
0.05	3.42671	-2.47E+07
0.06	6.09123	-1.20E+07
0.07	9.26008	719945
0.08	13.4264	1.34E+07
0.09	19.5738	2.61E+07
0.1	29.9071	3.88E+07
0.12	106.491	6.43E+07
0.13	1754.63	7.70E+07



**PPA\_opt**    0.065

PPA	TILT ANGLE	IRR	NPV
0.065	1.25	7.74247	-5.02E+06
0.065	2.5	7.89078	-4.44E+06
0.065	3.75	8.03454	-3.88E+06
0.065	5	8.17347	-3.34E+06
0.065	6.25	8.30529	-2.83E+06
0.065	7.5	8.43525	-2.33E+06
0.065	8.75	8.55706	-1.87E+06
0.065	10	8.67183	-1.44E+06
0.065	11.25	8.78387	-1.02E+06
0.065	12.5	8.88807	-633517
0.065	13.75	8.99003	-256962
0.065	15	9.08177	79799.7
0.065	16.25	9.17127	406591
0.065	17.5	9.2556	712912
0.065	18.75	9.33199	989051
0.065	20	9.40383	1.25E+06
0.065	21.25	9.56654	1.83E+06
0.065	22.5	9.6248	2.04E+06
0.065	23.75	9.68394	2.25E+06
0.065	25	9.73096	2.41E+06

PPA	AZIMUTH	TIILT	IRR	NPV
0.065	230	14.875	7.42774	-6.29E+06
0.065	225	14.875	7.71405	-5.14E+06
0.065	220	14.875	7.98767	-4.06E+06
0.065	215	14.875	8.24181	-3.08E+06
0.065	210	14.875	8.46587	-2.22E+06
0.065	205	14.875	8.65852	-1.49E+06
0.065	200	14.875	8.81777	-894632
0.065	195	14.875	8.93933	-444001
0.065	190	14.875	9.02222	-138598
0.065	185	14.875	9.06674	24759.6
0.065	180	14.875	9.07291	47346.4
0.065	175	14.875	9.04048	-71554.5
0.065	170	14.875	8.96736	-340616
0.065	165	14.875	8.85362	-761458
0.065	160	14.875	8.70119	-1.33E+06
0.065	155	14.875	8.51208	-2.04E+06
0.065	150	14.875	8.28659	-2.90E+06
0.065	145	14.875	8.0273	-3.91E+06
0.065	140	14.875	7.73869	-5.05E+06
0.065	135	14.875	7.42383	-6.31E+06

**tilt\_OPT**    14.875

**Azimuth\_Opt**    180

PPA	Name of Module	Azimuth	Tilt Angle	IRR	NPV
0.065	ALTERNATIVE ENERGY (AE) SOLAR CO. LTD. AE535MD-144BS	180	14.875	9.07291	47346.4
0.065	Ablytek 6MN6A270	180	14.875	9.21619	286301
0.065	Advance Power API-P220	180	14.875	7.22774	-2.90E+06
0.065	AIMS Power PV555MONO	180	14.875	8.53221	-2.04E+06
0.065	Alps Technology ATI-M660-240	180	14.875	6.42793	-4.68E+06
0.065	Amerisolar-Worldwide Energy and Manufacturing USA Co. Ltd AS-6P30-245W	180	14.875	7.83042	-2.13E+06
0.065	Anhui Rinengzhongtian Semiconductor Development QJM160-72	180	14.875	8.29062	-857838
0.065	Andalay Solar ST-175-1AC1-A-A	180	14.875	9.40318	402507
0.065	Anji Dasol Solar Energy Science & Technology DS-A4-210	180	14.875	4.80635	-6.93E+06
0.065	Apollo Renewables Inc Apollo-M660BH-350BB	180	14.875	9.81557	1.76E+06
0.065	APOS Energy AP130	180	14.875	NaN	-2.83E+07
0.065	ALTERNATIVE ENERGY (AE) SOLAR CO. LTD. AE535MD-144BS	180	14.875	9.07291	47346.4

Opt\_Mod Alternative Energy (AE) Solar Co. Ltd.

## Output and Results:

### Astoria

Metric	Value
Annual AC energy in Year 1	146,584,560 kWh
DC capacity factor in Year 1	16.6%
Energy yield in Year 1	1,452 kWh/kW
Performance ratio in Year 1	0.83
PPA price in Year 1	6.50 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	7.03 ¢/kWh
LPPA Levelized PPA price real	5.61 ¢/kWh
LCOE Levelized cost of energy nominal	7.02 ¢/kWh
LCOE Levelized cost of energy real	5.60 ¢/kWh
NPV Net present value	\$47,346
IRR Internal rate of return	7.63 %
Year IRR is achieved	20
IRR at end of project	9.07 %
Net capital cost	\$121,094,608
Equity	\$64,854,824
Size of debt	\$56,239,784
Debt percent	46.44%

## **Portland:**

Metric	Value
Annual AC energy in Year 1	135,558,176 kWh
DC capacity factor in Year 1	21.4%
Energy yield in Year 1	1,871 kWh/kW
Performance ratio in Year 1	0.88
PPA price in Year 1	5.50 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	5.94 ¢/kWh
LPPA Levelized PPA price real	4.75 ¢/kWh
LCOE Levelized cost of energy nominal	5.06 ¢/kWh
LCOE Levelized cost of energy real	4.04 ¢/kWh
NPV Net present value	\$11,216,746
IRR Internal rate of return	13.07 %
Year IRR is achieved	20
IRR at end of project	13.84 %
Net capital cost	\$87,296,232
Equity	\$42,423,856
Size of debt	\$44,872,376
Debt percent	51.40%

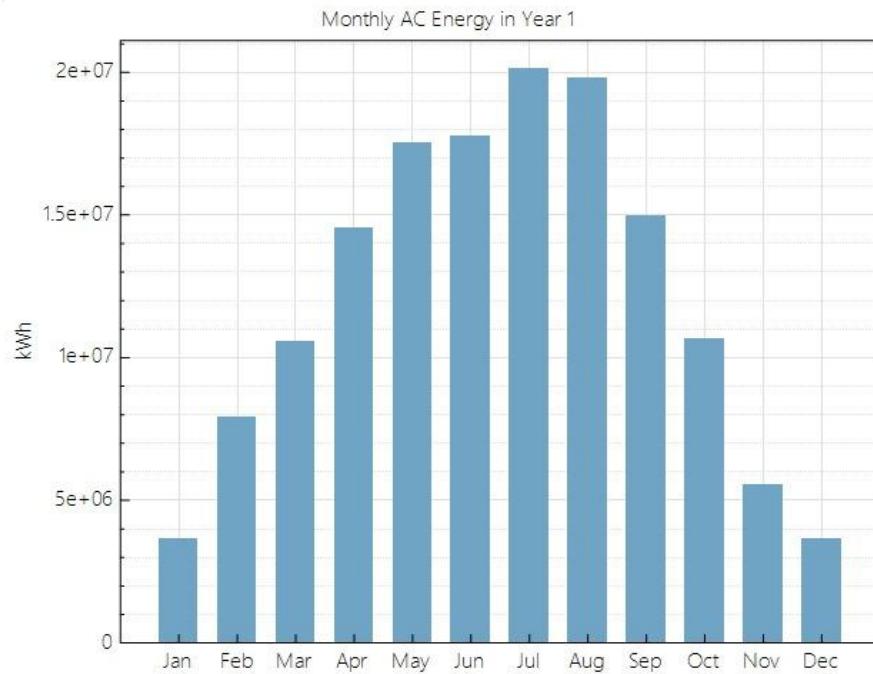
For the Astoria site, the system demonstrated strong performance with an annual AC energy output of 146,584,560 kWh in Year 1 and a performance ratio of 0.83. The PPA price in Year 1 was \$6.50/kWh, resulting in an IRR of 9.07% at the end of the project. The levelized cost of energy (LCOE) was \$5.60/kWh, and NPV was \$47,346. The project required a debt size of \$56,239,784.

In comparison, the Portland site generated 135,558,176 kWh of annual AC energy in Year 1, with a higher performance ratio of 0.88 and a DC capacity factor of 21.4%. The project achieved a significantly higher IRR of 13.84% and NPV of \$11,216,746, indicating improved financial performance. The LCOE for Portland was \$4.04/kWh, and the size of debt required was \$44,872,376, with 51.40% debt financing.

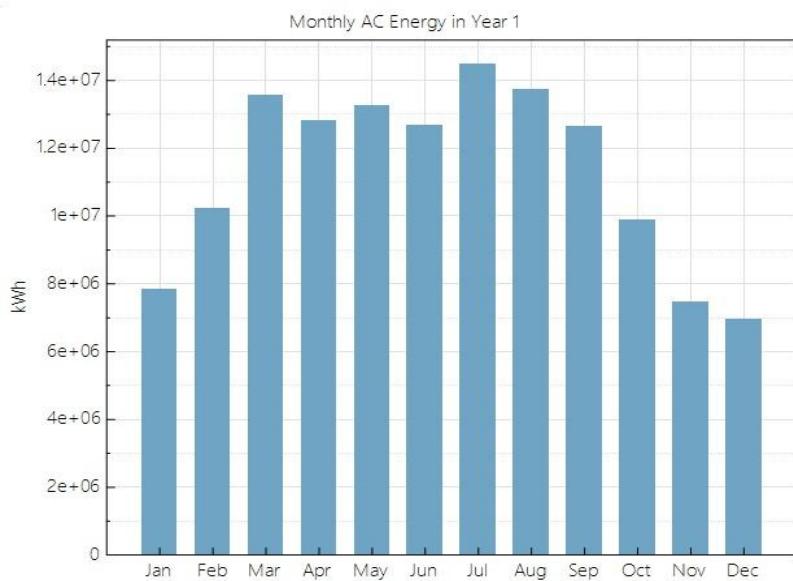
In summary, Astoria produced higher energy output, whereas Portland delivered stronger economic returns with lower LCOE and higher IRR and NPV.

## **Monthly AC energy in year 1:**

### **Astoria**



### **Portland:**



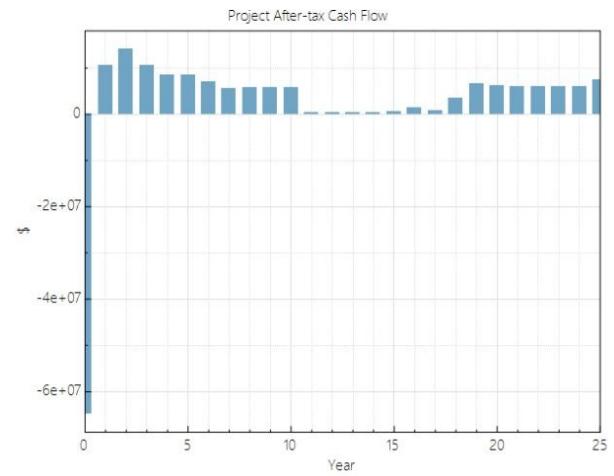
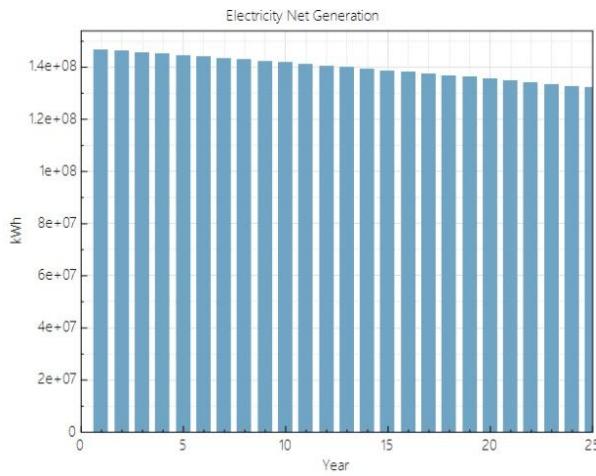
For the Astoria site, monthly AC energy generation in Year 1 shows a maximum output in July, reaching approximately  $2 \times 10^7$  kWh, while the minimum output occurs in January and December, each around  $4 \times 10^6$  kWh. This indicates strong seasonal dependence, with peak production during summer and significantly reduced output in winter.

In contrast, for the Portland site, the highest monthly AC energy generation occurs in August, reaching about  $1.4 \times 10^7$  kWh, and the lowest value occurs in December at approximately  $7 \times 10^6$  kWh. Although Portland exhibits seasonal variation as well, the difference between peak and minimum values is smaller compared to Astoria.

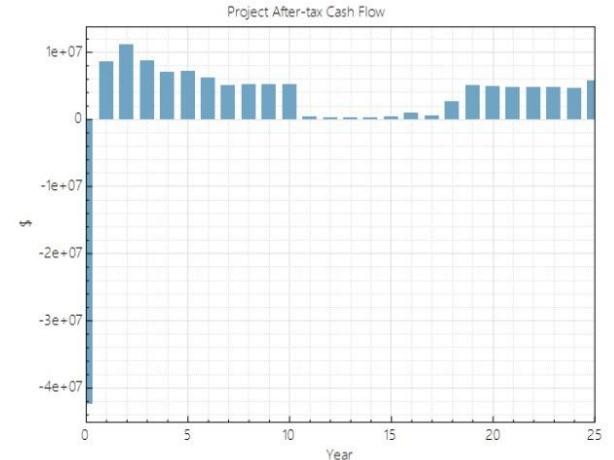
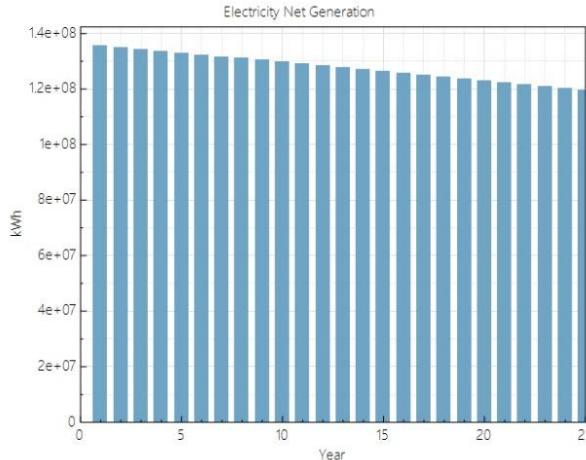
Overall, Astoria delivers a higher summer peak but suffers a sharper decline during winter months. Portland shows more consistent year-round output with narrower seasonal fluctuation.

### **Electricity net generation:**

#### **Astoria:**



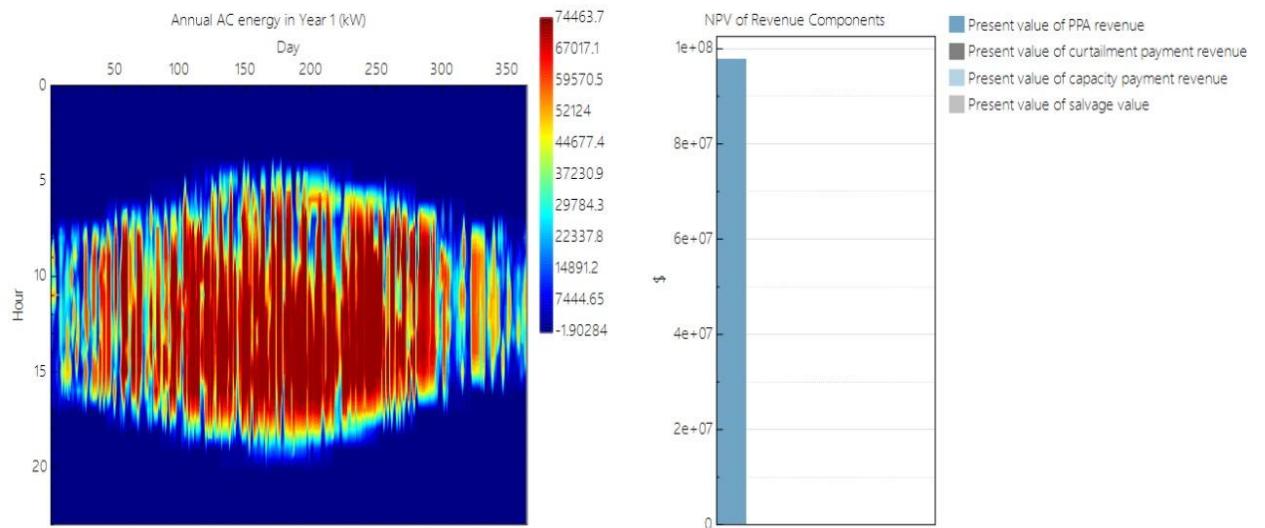
#### **Portland:**



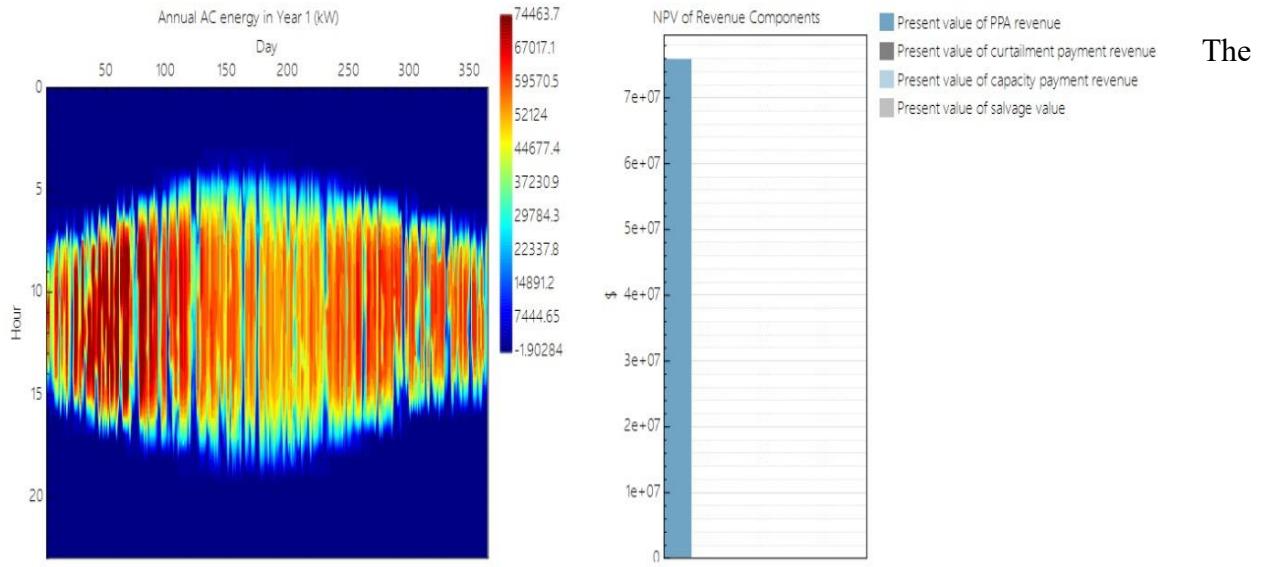
In comparison, Astoria shows a higher annual electricity net generation than Portland, starting at approximately  $1.45 \times 10^8$  kWh in Year 1 and declining to about  $1.3 \times 10^8$  kWh by Year 25, whereas Portland begins slightly lower at around  $1.37 \times 10^8$  kWh and reduces to about  $1.2 \times 10^8$  kWh by Year 25. For both projects, the after-tax cash flow is negative between Year 0 and Year 1, becomes positive from Year 2 onward, and follows a similar trend where the maximum cash flow occurs in Year 2 and the minimum positive value appears around Year 13, approaching near zero. Overall, Astoria demonstrates higher energy generation, while Portland achieves better financial returns with a stronger cash flow recovery pattern.

### **Annual AC energy in year 1:**

#### **Astoria:**



#### **Portland:**



contour plot for Portland shows moderate intensity zones concentrated between hours 5–15 (approximately 7 AM to 2 PM) with peak activity around day 100, indicating steady but comparatively lower irradiance concentration.

Correspondingly, the NPV of revenue components reaches about  $7.5 \times 10^7$  USD. In contrast, Astoria exhibits significantly higher intensity regions, with widespread red zones between hours 5–15 and particularly strong peaks around day 250, signifying superior solar resource availability and higher annual AC generation potential.

As a result, Astoria achieves a comparatively higher NPV of nearly  $1 \times 10^8$  USD, indicating a stronger revenue return due to improved irradiance performance.

## CONCLUSION:

Parameter	Astoria	Portland
Annual AC Energy (Year 1)	146,584,560 kWh	135,558,176 kWh
Performance Ratio (Year 1)	0.83	0.88
NPV (Project Lifetime)	\$47,346,000	\$11,216,746

Parameter	Astoria	Portland
IRR (End of Project)	9.07%	13.84%
LCOE (Real)	\$5.60 / kWh	\$4.04 / kWh
Size of Debt	\$56,239,784	\$44,872,376
Electricity-Net Generation for Year 1	$1.45 \times 10^8$ kWh	$1.37 \times 10^8$ kWh
Electricity-Net Generation for Year 25	$1.3 \times 10^8$ kWh	$1.2 \times 10^8$ kWh
Monthly AC Energy Peak	July – $2 \times 10^7$ kWh	August – $1.4 \times 10^7$ kWh
Monthly AC Energy Minimum	Jan/Dec – $4 \times 10^6$ kWh	December – $7 \times 10^6$ kWh
Project After-Tax Cash Flow Trend	Max: Year 2, Min: Year 13, negative before Y1	Max: Year 2, Min: Year 13, negative before Y1
NPV of Revenue Components	$1 \times 10^8$ dollars	$\sim 7.5 \times 10^7$ dollars

A comparative techno-economic and energy performance assessment was conducted for the deployment of a utility-scale photovoltaic system at Astoria and Portland. Based on the simulation results and financial optimization metrics, Astoria emerges as the more suitable location for installation.

Astoria demonstrates a higher annual AC energy generation of  $1.46 \times 10^8$  kWh in Year 1, compared to  $1.36 \times 10^8$  kWh for Portland. This superior energy yield translates into significantly greater financial returns, reflected in the Net Present Value (NPV) of \$47.346 million at Astoria versus \$11.216 million at Portland. Furthermore, the NPV of revenue components for Astoria approaches  $\$1 \times 10^8$ , whereas Portland reaches only around  $\$7.5 \times 10^7$ , indicating a stronger revenue-earning capacity.

Although Portland displays a higher Internal Rate of Return (IRR) of 13.84% and a lower Levelized Cost of Energy (LCOE) of \$4.04/kWh, these advantages are offset by its substantially lower total energy production and reduced overall profitability. The absolute return on investment, represented by long-term cash flow and cumulative NPV, is significantly greater for Astoria, making it the more favorable economic and sustainable choice.

From a sustainable energy technology perspective, maximizing lifetime energy contribution and long-term financial benefit is essential. Therefore, considering the performance indicators — annual energy yield, monthly distribution patterns, generation degradation behavior, NPV, IRR, and cash-flow dynamics. Astoria provides superior overall project viability, while Portland is comparatively less advantageous due to reduced generation potential and lower profitability despite its higher IRR.

Astoria is the most suitable site for photovoltaic system installation owing to its significantly higher energy output and stronger economic performance over the project lifetime.

To conclude, from our analysis, wind energy is the most suitable renewable technology for both Astoria and Portland.

- In Astoria, wind delivers competitive annual energy generation and provides financially viable returns, making it the most practical choice compared to solar.
- In Portland, wind clearly outperforms with very high annual AC energy generation, a strong capacity factor, and the highest NPV and IRR values, making it the most profitable option.
- So, to conclude, Wind energy is the optimal renewable technology for both Astoria and Portland, although the performance is significantly stronger in Portland.

