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WIND

Initial Project Assessment

Yellowstone Wind Park

August 10, 2010

FOR
Client

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3TIER

Contents

1 INTRODUCTION

1.1 Overview

3TIER has been retained by Client to assess the wind resource over the Yellowstone Wind Park region, and our analysis is presented in this report. This summary section discusses the overall properties of the project. Following it, section 2 shows the mean wind speed and capacity factor over the entire Yellowstone Wind Park region, at $200m$ resolution, and displays turbine and reference point locations. Section 3 contains mean wind speeds and wind and power roses at the five reference points provided by Client. Project-wide monthly, hourly, and annual means for wind speed and capacity factor can be seen in section 4.

In section 5, tabular data for the turbines are available, including location, base elevation, mean wind speed (at hub height), mean air density (also at hub height), and wind shear between $30m$ and $80m$. The turbine power curve for the SWT23 (with hub height $80m$) is also provided, in Table 6. For overall project data and production statistics, see Table 1 directly below. These quantities are computed over every turbine location (see section 5), and do not include data from the reference points.

Project mean wind speed	10.34	m/s
Project mean air density	0.89	kg/m^3
Mean turbine base elvation	3025	m
Project gross capacity factor	57.1	%
Project gross power production	77489.3	kW
Project net capacity factor	48.2	%
Project net power production	65461.1	kW

Table 1: Project statistics

Probability exceedance values for ten year and one year mean windspeed and gross capacity factor (CF) can be seen below, in Table 2. For each value (P50, P75, P90) there is a 50, 75, or 90 percent chance, respectively, that the same quantity (mean wind speed or capacity factor) computed over a randomly selected time period of the same length (one or ten calendar years) will exceed the given probability exceedance value. For example, according to Table 2, there is a 90% probability that the mean windspeed computed over any single calendar year will exceed 7.03 m/s.

	Ten year mean windspeed ($\frac{m}{s}$)	Ten year mean gross CF (%)	One year mean windspeed ($\frac{m}{s}$)	One year mean gross CF (%)
P50	10.34	57.1	10.34	57.1
P75	9.61	53.1	8.03	44.3
P90	9.29	51.3	7.03	38.8

Table 2: Probability exceedance values

1.2 Data provided by Client

Client has provided 3TIER with 59 turbine locations to be used in an analysis of the wind resource across the Yellowstone Wind Park region (see section 2 for location information). At the turbine locations, timeseries data were extracted from the model output and used to compute the capacity factor for that turbine. Detailed turbine information can be seen in Table 5, and the overall production statistics for the project can be seen on the previous page in Table 1. For reference purposes, the power curve for the SWT23 turbine is provided in Table 6.

The loss factors listed in Table 3 below have been specified by Client. These were used to compute the net production statistics, which can be seen in Table 1 on the previous page, as well as in Figure 8 in section 4.

Client has also specified five meteorological reference points, labeled on the maps in section 2. Wind speed and direction timeseries were extracted at the reference points, and an analysis is presented in section 3, which includes the overall mean wind speeds and wind and power roses showing the distribution of wind direction. Section 3 is meant to provide an easily readable overview of the wind resource over the area.

Curtailment (low temp, utility, etc)	100.0	%
Wake from existing wind farms	100.0	%
Electrical efficiency	96.0	%
Wake effect	96.0	%
Substation maintenance	99.0	%
Icing and blade degradation	98.5	%
Turbine performance	100.0	%
Availability	94.0	%

Table 3: Loss factors

1.3 Methodology

3TIER used a numerical weather prediction model, the Weather Research and Forecasting model (WRF), to analyze the wind resource across the Yellowstone Wind Park region, and downscaled that dataset to $200m$ using our proprietary Time-Varying Microscale (TVM) model. WRF enables a very sophisticated but computationally intensive simulation of the dynamical and physical processes of the atmosphere, and the TVM model complements it by using diagnostic techniques to analyze microscale processes without the prohibitive computational cost of running WRF at high resolution. Initial and lateral boundary conditions for WRF were extracted from the NCEP/NCAR Reanalysis data, a multi-decadal coarse-resolution observational dataset sufficient to provide accurate representation of synoptic-scale processes. In this case, a WRF dataset at $2.0km$ resolution, covering January 2000 – December 2009, was downscaled to a $200m$ grid using TVM.

After the spatial dataset was generated, the wind resource was analyzed at each reference point and turbine location (as provided by Client), and the results are presented in this report. Additionally, several project-wide statistics are computed (see Table 1 above).

Since no observational data were provided within the Yellowstone Wind Park region, the data in this report represent raw model output only.

2 WIND RESOURCE AND CAPACITY FACTOR MAPS AT $80M$

This section presents spatial maps of the average simulated wind speed and capacity factor at $80m$ across the Yellowstone Wind Park region. All maps within this section represent the raw model output of the $200m$ domain. The red box denotes the valid study area.

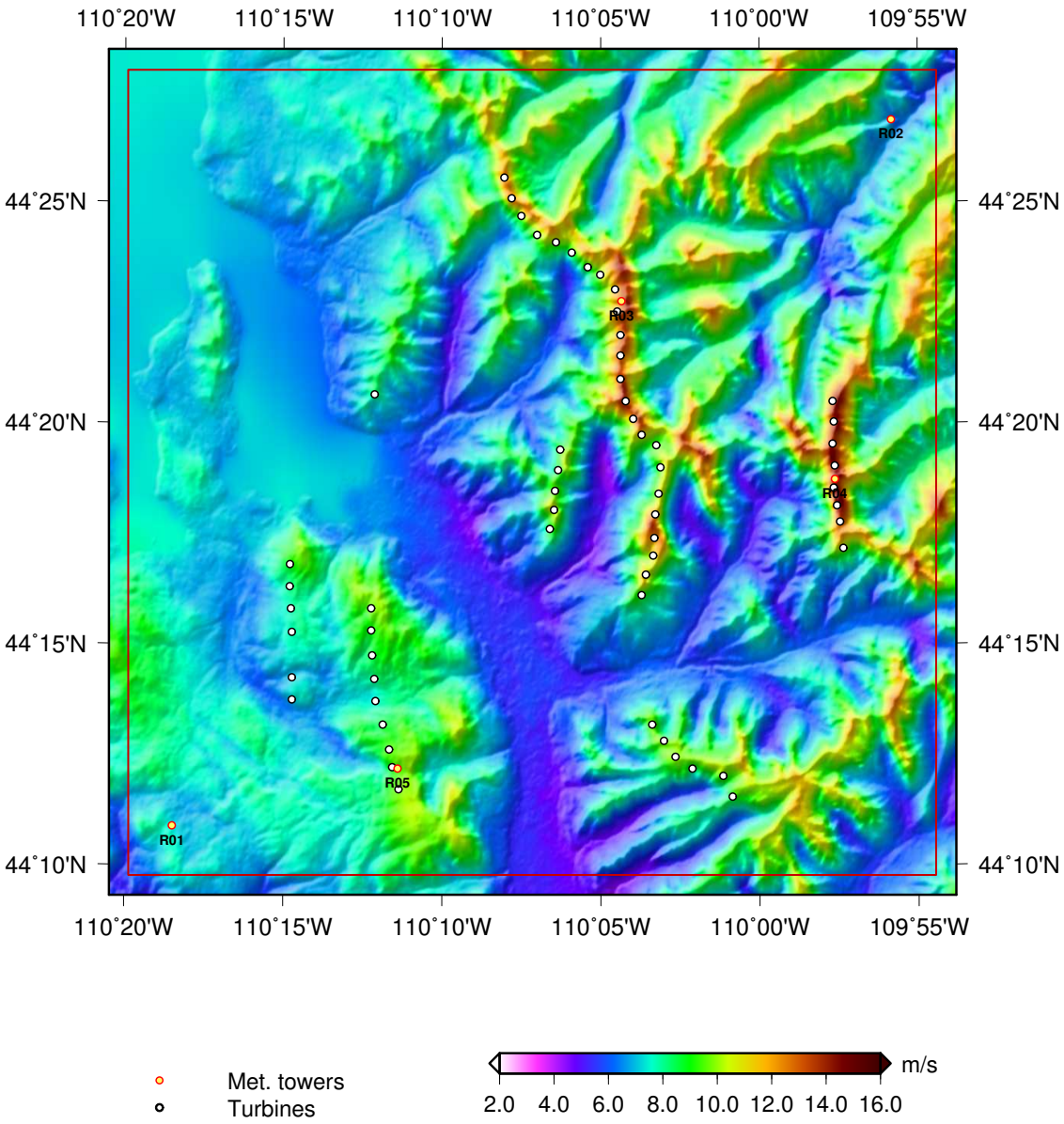

Figure 1: Mean wind speed at $80m$.

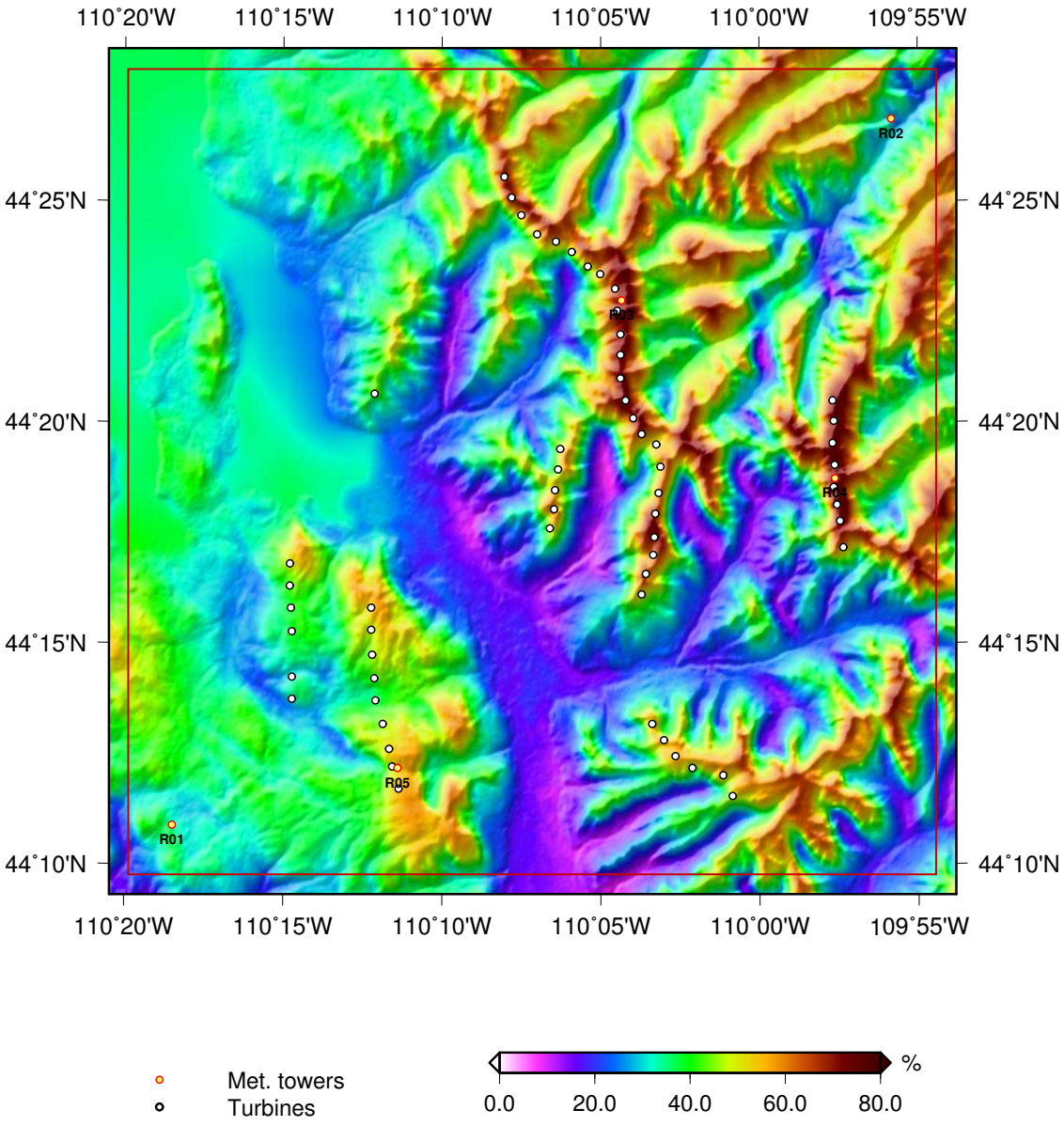

Figure 2: Mean capacity factor for the SWT23 turbine at $80m$.

3 REFERENCE POINT ANALYSIS

The data presented in this section are derived from the five reference points provided by Client. In Table 4 below, location information and mean wind speed are summarized for each reference point, and the following pages contain annual wind speed and power roses for each reference point and monthly wind and power roses for the first reference point specified. In addition to the coordinates given in this table, reference point locations are labeled on the maps in section 2.

ID	Latitude	Longitude	Elevation (m)	Reference height (m)	Mean wind speed (m/s)
R01	44.1812	-110.3082	2720	80	7.31
R02	44.4475	-109.9306	2203	80	6.27
R03	44.3790	-110.0725	3175	80	13.29
R04	44.3120	-109.9605	3354	80	13.78
R05	44.2027	-110.1900	2917	80	9.45

Table 4: Reference point information

3.1 Wind roses

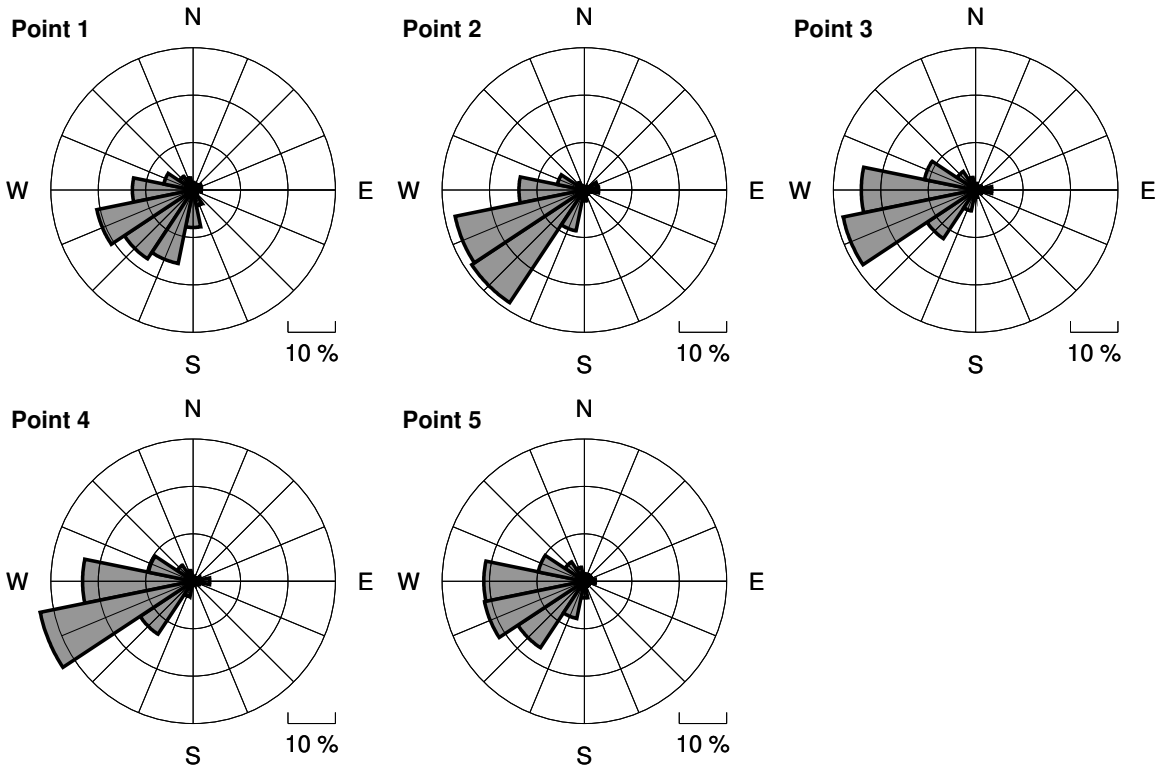

Figure 3: Annual wind roses for all reference points

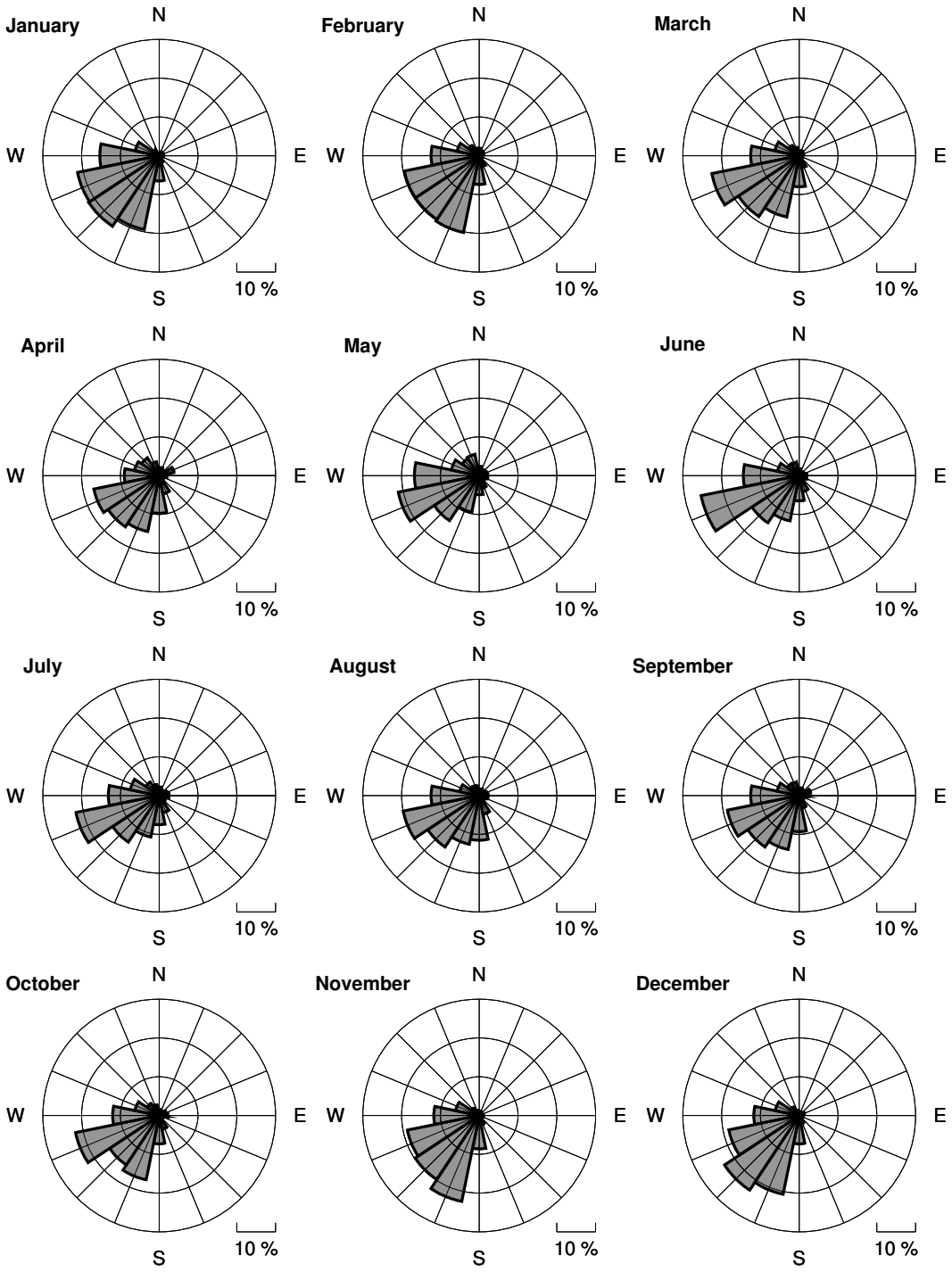

Figure 4: Monthly wind roses for reference point R01

3.2 Power roses

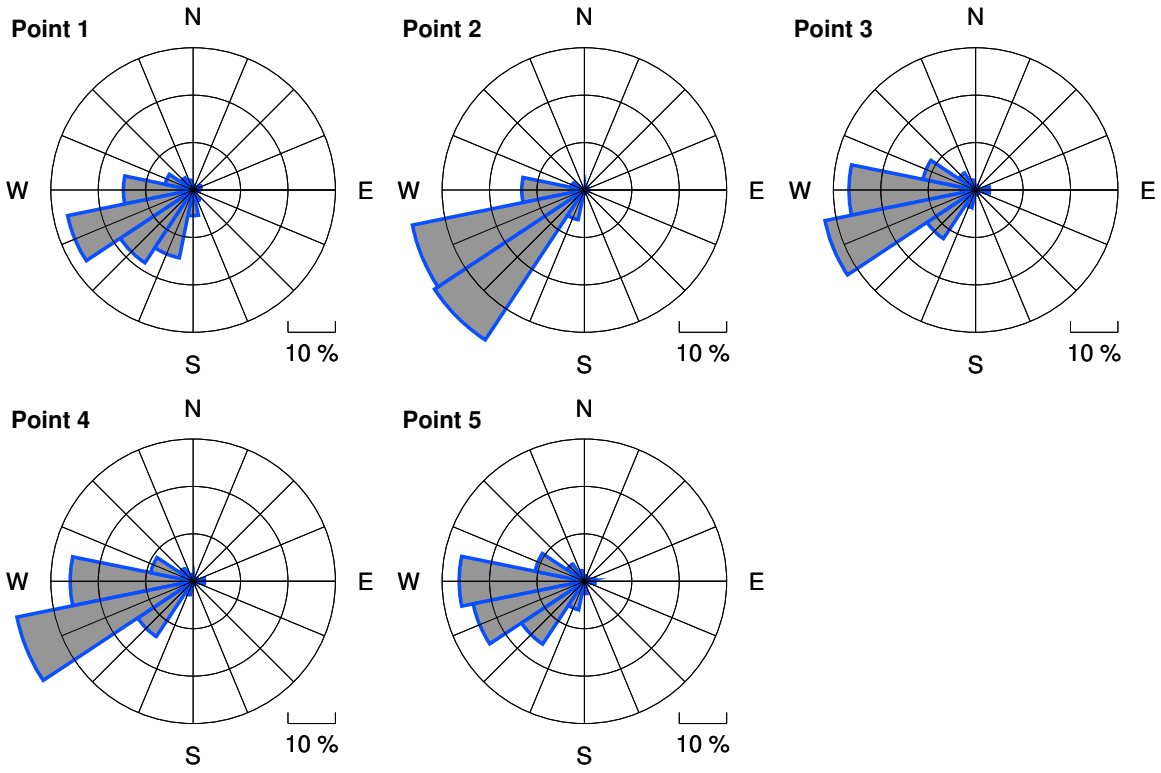

Figure 5: Annual power roses (for the SWT23 turbine) for all reference points

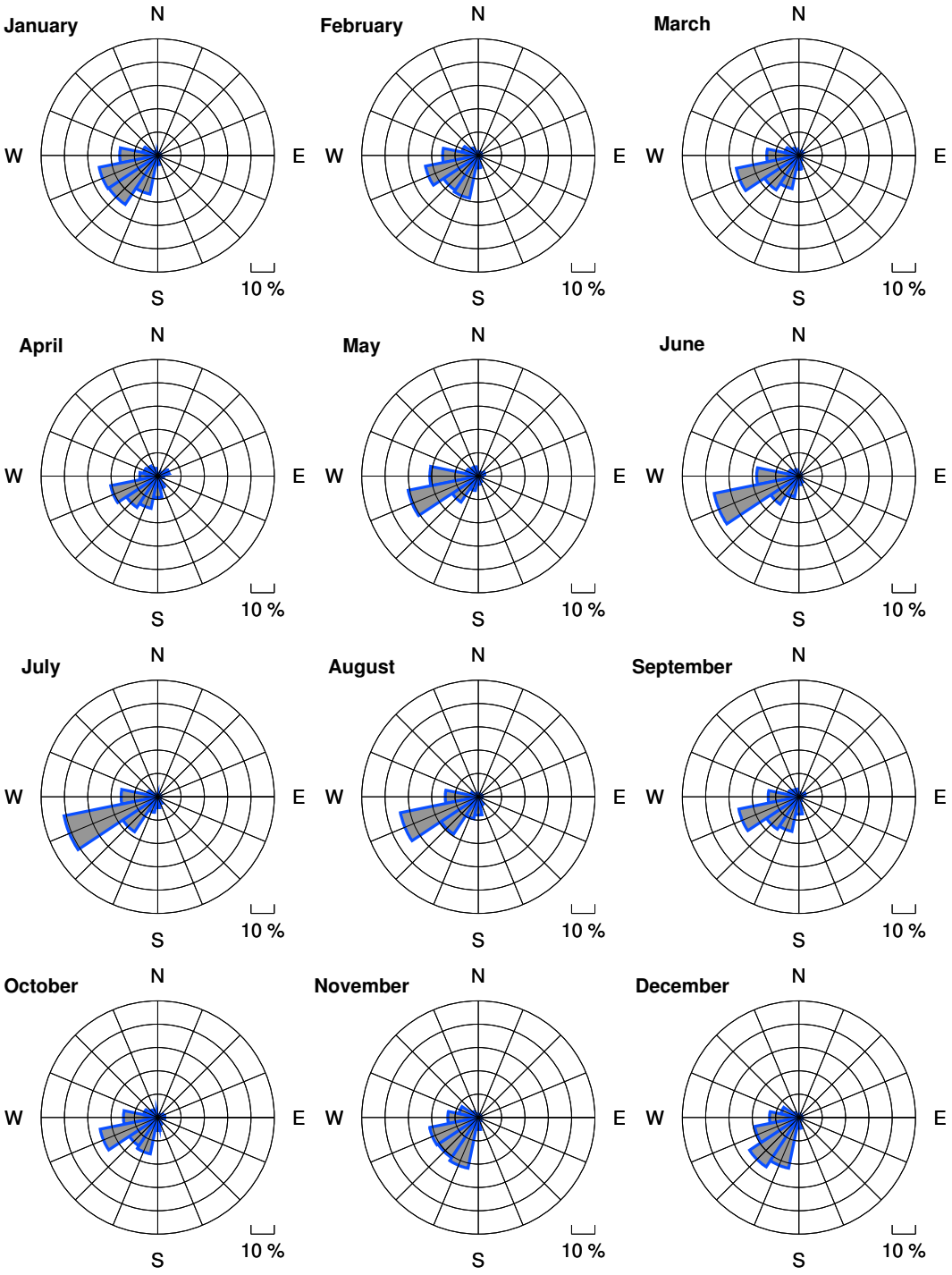

Figure 6: Monthly power roses (for the SWT23 turbine) for reference point R01

4 12X24 TABLES

These tables contain the mean of each hour (0 through 24) from each month in the year. Each column, therefore, shows that month's mean diurnal cycle, and the annual mean diurnal cycle can be read down the rightmost column, which is composed of the overall means of each hour. The bottom row contains each month's mean, and in the bottom right cell is the overall mean. These means are computed across the 59 turbine locations provided by Client, and do not include the reference points.

Hour of Day (UTC)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	12.27	11.41	11.75	11.04	12.15	11.73	9.67	9.66	10.35	11.14	11.72	11.90	11.23
1	12.26	11.45	11.59	10.47	11.57	11.28	9.10	8.92	9.63	10.98	11.66	11.84	10.89
2	12.22	11.39	11.48	10.18	10.62	10.12	7.97	8.10	9.27	10.79	11.58	11.83	10.46
3	12.23	11.33	11.35	10.01	10.21	9.45	7.35	7.57	8.82	10.61	11.51	11.84	10.18
4	12.26	11.31	11.26	9.87	9.78	8.97	6.79	7.12	8.49	10.48	11.50	11.89	9.97
5	12.35	11.33	11.25	9.83	9.46	8.66	6.43	6.96	8.32	10.44	11.52	11.99	9.87
6	12.45	11.38	11.28	9.81	9.33	8.49	6.35	7.00	8.29	10.44	11.57	12.10	9.87
7	12.51	11.39	11.29	9.73	9.19	8.42	6.36	7.08	8.31	10.43	11.55	12.16	9.86
8	12.49	11.37	11.21	9.62	9.06	8.37	6.35	7.09	8.29	10.37	11.51	12.15	9.81
9	12.45	11.33	11.13	9.54	8.97	8.27	6.31	7.09	8.26	10.28	11.46	12.11	9.76
10	12.37	11.27	11.08	9.47	8.89	8.15	6.27	7.07	8.24	10.20	11.42	12.04	9.70
11	12.29	11.19	11.02	9.43	8.78	8.06	6.24	7.06	8.21	10.14	11.38	12.00	9.64
12	12.23	11.10	10.96	9.41	8.73	7.99	6.25	7.07	8.19	10.08	11.34	11.97	9.60
13	12.16	11.03	10.94	9.37	8.64	7.82	6.17	7.06	8.18	10.06	11.32	11.96	9.55
14	12.11	10.95	10.97	9.23	8.45	7.67	5.76	6.75	8.19	10.10	11.32	11.95	9.45
15	12.10	10.90	10.89	9.12	8.96	8.57	6.55	6.72	7.97	10.08	11.37	11.96	9.59
16	12.07	10.78	10.94	9.45	10.03	9.53	7.62	7.75	8.40	10.07	11.39	12.01	10.00
17	12.09	10.79	11.29	10.04	10.84	10.23	8.42	8.61	9.28	10.47	11.42	11.99	10.46
18	12.15	10.93	11.73	10.65	11.49	10.80	9.09	9.27	9.95	11.05	11.58	12.00	10.89
19	12.23	11.14	12.09	11.08	11.90	11.30	9.64	9.76	10.41	11.51	11.73	12.06	11.24
20	12.31	11.35	12.38	11.35	12.21	11.67	10.01	10.06	10.71	11.76	11.88	12.08	11.48
21	12.32	11.46	12.49	11.46	12.40	11.88	10.18	10.20	10.85	11.86	11.94	12.08	11.60
22	12.26	11.42	12.43	11.43	12.46	11.92	10.15	10.19	10.88	11.82	11.89	12.03	11.58
23	12.27	11.25	12.19	11.23	12.41	11.87	10.00	10.03	10.73	11.61	11.79	12.03	11.45
Avg	12.27	11.22	11.46	10.12	10.27	9.63	7.71	8.09	9.09	10.70	11.56	12.00	10.34

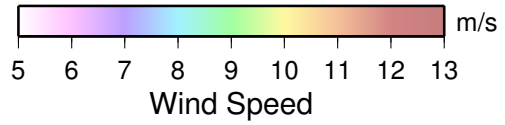

Figure 7: 12 month by 24 hour table of wind speed

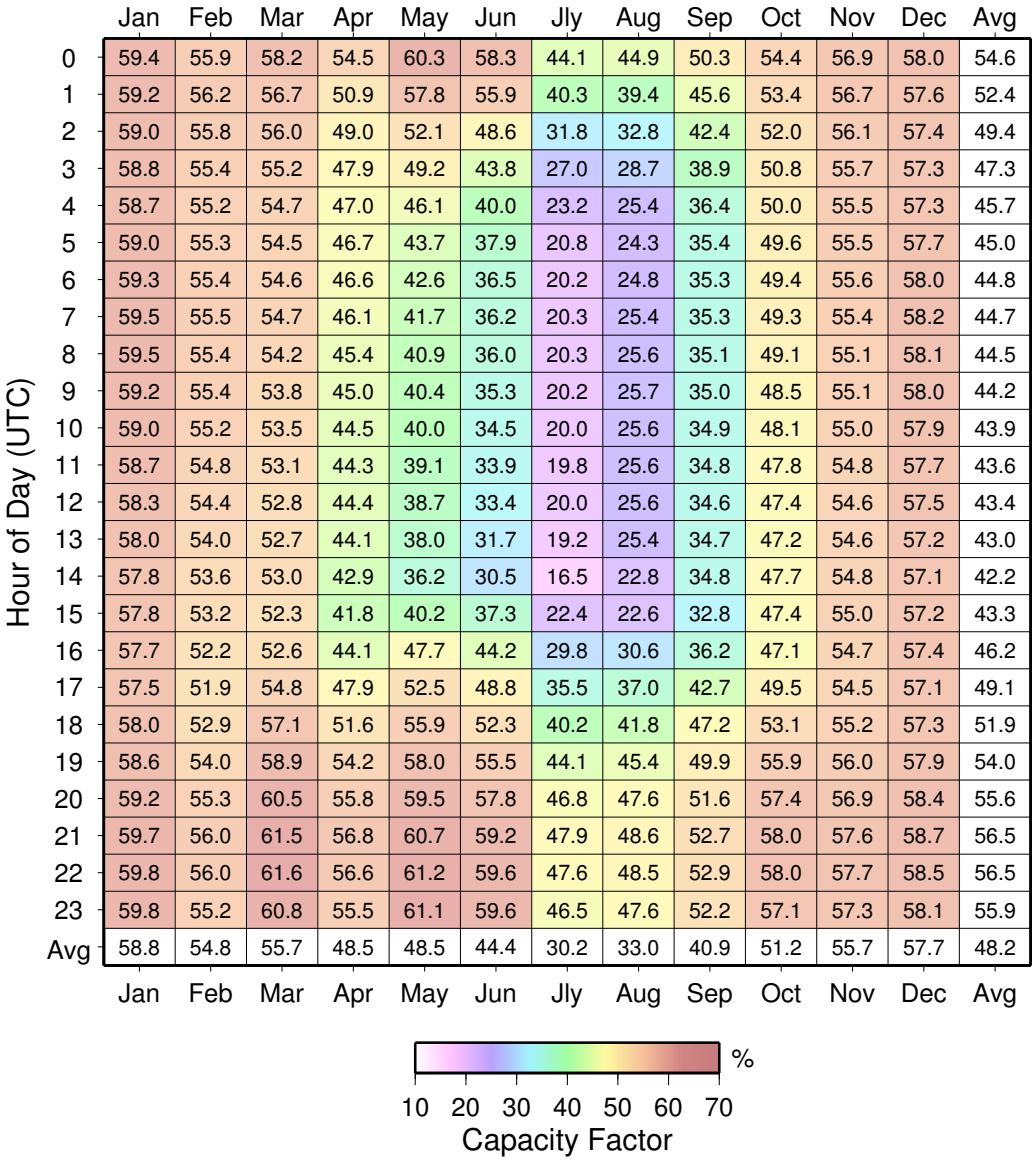

Figure 8: 12 month by 24 hour table of net capacity factor for the SWT23 turbine. These net values are derived from the gross values using the loss factors in Table 3.

5 TURBINE INFORMATION

5.1 Individual turbine information

All wind speed, capacity factor, and air density values in this table are the overall mean values for that turbine. Shear is computed between $30m$ and $80m$. Each turbine is color-coded according to its gross capacity factor, so that the best-performing turbines can be easily identified. Note that the color-coding corresponds to the key used in Figure 8 on the previous page.

ID	Latitude	Longitude	Elevation (m)	Wind Speed ($\frac{m}{s}$)	Gross Capacity (%)	Air Density ($\frac{kg}{m^3}$)	Shear
T001	44.3439	-110.2021	2704	8.09	42.1	0.923	0.14
T002	44.2798	-110.2465	2743	8.85	48.7	0.919	0.14
T003	44.2715	-110.2465	2680	8.05	41.5	0.926	0.16
T004	44.2632	-110.2460	2703	7.82	39.3	0.924	0.17
T005	44.2543	-110.2454	2722	7.71	38.1	0.922	0.17
T006	44.2371	-110.2454	2598	7.02	31.5	0.934	0.19
T007	44.2288	-110.2454	2584	6.95	30.8	0.935	0.16
T008	44.2632	-110.2038	2853	9.59	54.4	0.910	0.16
T009	44.2549	-110.2038	2837	8.87	48.5	0.911	0.17
T010	44.2454	-110.2033	2806	8.56	45.8	0.914	0.17
T011	44.2366	-110.2022	2724	8.07	41.4	0.922	0.18
T012	44.2282	-110.2016	2662	7.58	36.9	0.928	0.19
T013	44.2194	-110.1977	2844	8.62	46.2	0.911	0.18
T014	44.2100	-110.1944	2946	9.37	52.3	0.901	0.17
T015	44.2033	-110.1928	2897	9.04	49.6	0.906	0.19
T016	44.1950	-110.1894	2993	9.75	55.0	0.897	0.18
T017	44.2194	-110.0564	3049	9.70	55.0	0.891	0.14
T018	44.2133	-110.0503	3162	9.94	56.5	0.882	0.14
T019	44.2072	-110.0442	3268	9.97	56.6	0.872	0.15
T020	44.2027	-110.0353	3111	8.17	41.5	0.887	0.20
T021	44.2000	-110.0192	3187	9.66	54.5	0.880	0.19
T022	44.1922	-110.0142	3191	9.02	49.2	0.880	0.19
T023	44.4256	-110.1340	3048	12.38	70.8	0.893	0.13

Table 5: Individual turbine information

ID	Latitude	Longitude	Elevation (m)	Wind Speed ($\frac{m}{s}$)	Gross Capacity (%)	Air Density ($\frac{kg}{m^3}$)	Shear
T024	44.4178	-110.1301	3099	12.33	70.6	0.888	0.14
T025	44.4112	-110.1251	2907	9.74	55.3	0.906	0.20
T026	44.4040	-110.1168	2987	9.55	53.8	0.899	0.21
T027	44.4012	-110.1068	2977	9.78	55.7	0.900	0.19
T028	44.3973	-110.0985	2884	8.73	47.4	0.908	0.21
T029	44.3918	-110.0902	2886	8.88	48.8	0.908	0.22
T030	44.3890	-110.0835	2950	9.93	56.9	0.902	0.20
T031	44.3835	-110.0758	3024	11.52	66.8	0.895	0.17
T032	44.3752	-110.0747	3191	12.43	70.9	0.880	0.14
T033	44.3663	-110.0730	3073	12.65	72.0	0.891	0.15
T034	44.3585	-110.0730	3142	13.06	73.6	0.885	0.14
T035	44.3497	-110.0730	3232	13.44	74.8	0.876	0.13
T036	44.3413	-110.0702	3256	13.86	75.8	0.874	0.09
T037	44.3347	-110.0664	3137	12.44	70.9	0.885	0.12
T038	44.3286	-110.0619	3118	10.76	62.3	0.887	0.17
T039	44.3247	-110.0542	2919	9.20	51.6	0.905	0.18
T040	44.3164	-110.0519	3019	9.39	52.6	0.896	0.19
T041	44.3064	-110.0530	3055	10.48	60.8	0.892	0.15
T042	44.2987	-110.0547	3169	11.92	68.8	0.882	0.10
T043	44.2898	-110.0553	3266	12.31	70.7	0.873	0.11
T044	44.2831	-110.0558	3147	10.90	63.4	0.884	0.13
T045	44.2759	-110.0597	3204	11.11	64.4	0.879	0.09
T046	44.2682	-110.0619	3005	8.98	49.3	0.896	0.14
T047	44.3230	-110.1046	3022	8.95	48.9	0.895	0.18
T048	44.3153	-110.1057	3008	8.54	45.4	0.897	0.19
T049	44.3075	-110.1074	3034	9.65	54.6	0.894	0.15
T050	44.3003	-110.1079	3152	10.82	62.5	0.883	0.09
T051	44.2931	-110.1101	2916	8.52	45.4	0.905	0.15
T052	44.3413	-109.9616	3265	13.28	74.3	0.872	0.10
T053	44.3336	-109.9610	3331	13.97	76.1	0.867	0.13

Table 5: Individual turbine information (continued from previous page)

ID	Latitude	Longitude	Elevation (m)	Wind Speed ($\frac{m}{s}$)	Gross Capacity (%)	Air Density ($\frac{kg}{m^3}$)	Shear
T054	44.3253	-109.9616	3367	14.07	76.6	0.864	0.09
T055	44.3169	-109.9605	3297	14.70	78.0	0.870	0.09
T056	44.3086	-109.9610	3355	14.40	77.3	0.865	0.08
T057	44.3020	-109.9594	3304	13.78	76.1	0.870	0.11
T058	44.2959	-109.9577	3311	13.12	73.9	0.869	0.10
T059	44.2859	-109.9560	3184	9.92	56.6	0.881	0.13

Table 5: Individual turbine information (continued from previous page)

5.2 Power curve

Wind Speed ($\frac{m}{s}$)	Capacity (kW)
0.0	0
1.0	0
2.0	0
3.0	0
4.0	90
5.0	229
6.0	436
7.0	725
8.0	1108
9.0	1523
10.0	1896
11.0	2148
12.0	2257
13.0	2290
14.0	2298
15.0	2300
16.0	2300
17.0	2300
18.0	2300
19.0	2300
20.0	2300
21.0	2300
22.0	2300
23.0	2300
24.0	2300
25.0	2300

Table 6: Power curve for the SWT23 turbine, with a reference density of $1.225 \frac{kg}{m^3}$