ReGenerate
RENEWABLE ENERGY CONSULTING

Shadow Flicker Assessment

PROJECT: BOWMAN (ND)

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Revision History

Issue	Date	Revision Purpose
1	18-Feb-21	Original
2	23-Feb-21	Updated Turbine Layout
3	10-Mar-21	Minor Report Revisions
4	22-Mar-21	Minor Report Revisions
5	22-Jun-21	Updated Turbine Layout/Receptors

1. Executive Summary

The Bowman Wind Project (Project) in southwestern North Dakota has been studied for the potential impact of shadow flicker on surrounding residences. Modeling and topographic reviews were completed to determine potential cumulative results at receptor locations in and around the Project.

The Project consists of 86 GE 2.82-127 Enhanced LNTE turbines at 88.6 m hub-height, this includes 74 primary and 12 alternate locations all of which were included in the modeling. Shadow flicker was studied at sensitive locations (receptors) to quantify the potential impact.

ReGenerate used WindPRO to model the potential impact of shadow flicker at 140 receptors.

The effect on receptors has been quantified with the results shown in the table below.

Shadow Flicker [hr/yr]	Participating		Non-Participating		Total	
	№ Receptors	% of Receptors	№ Receptors	% of Receptors	№ Receptors	% of Receptors
0	13	65.00%	116	96.69%	129	92.14%
0.1 to 5	0	0.00%	2	1.67%	2	1.43%
5.1 to 10	4	20.00%	1	0.83%	5	3.57%
10.1 to 15	3	15.00%	1	0.83%	4	2.86%
15.1 to 30	0	0.00%	0	0.00%	0	0.00%
30.1 or more	0	0.00%	0	0.00%	0	0.00%

The maximum value of shadow flicker was found to be 14.0 hr/yr for participating receptors, the maximum for non-participating receptors was found to be 13.9 hr/yr.

All receptors are below maximum limits set forth in County regulations.

Appendix I shows the spatial mapping for shadow flicker results. Appendix II shows turbine coordinates provided for the Project. Appendix III shows the results at each receptor analyzed for this study.

2. Introduction

The Project is being developed by Apex Clean Energy (Client) in southwestern North Dakota. Merjent (on behalf of Apex) has retained ReGenerate Consulting (ReGenerate) to carry out an independent analysis of the potential shadow flicker effects of the proposed Project.

The objective of this assessment is to predict the total amount of shadow flicker generated by the Project at all receptors within or near the Project area and in accordance with any applicable regulations as described in further detail later in the report. This report describes the Project site, modeling methodology and results of the analysis.

ReGenerate Consulting is an independent engineering consulting agency. The principal investigator for this report, Chris Nuckols, has 20-years' engineering and management experience and 15-years of wind and solar resource assessment experience working for renewable energy developers, owners, and OEMs, He has provided engineering support to more than 100 renewable energy projects large and small, on five continents.

3. Background

The cumulative effects of turbine-generated shadow flicker throughout the Project area were studied to determine the impact on sensitive receptors. This effect occurs when wind turbine blades cast a moving shadow across the ground and nearby structures; this is perceived as a flickering effect due to the constant rotation of the blades. Flicker occurs when the following conditions are met: turbine is operating, sun is shining with insignificant cloud cover, turbine blades are positioned directly between the sun and receptor, and the receptor is close enough to distinguish the shadow created.

Calculation of potential shadow impact is carried out by simulating the position of the sun relative to the turbine rotor swept area with the resulting shadow calculated in steps of 1 minute throughout a complete year. If the shadow at any time casts a shadow reflection on the window defined for the receptor, this step will be registered as 1 minute of potential shadow impact. Information required in this calculation includes position of wind turbines, turbine hub height and rotor diameter, position of receptor, terrain elevation, window information (height, size, azimuth, and tilt), time zone and daylight-saving time information and simulation model which holds information about the earth's orbit and rotation relative to the sun. A diagram of this simulation is presented in Figure 1 below.

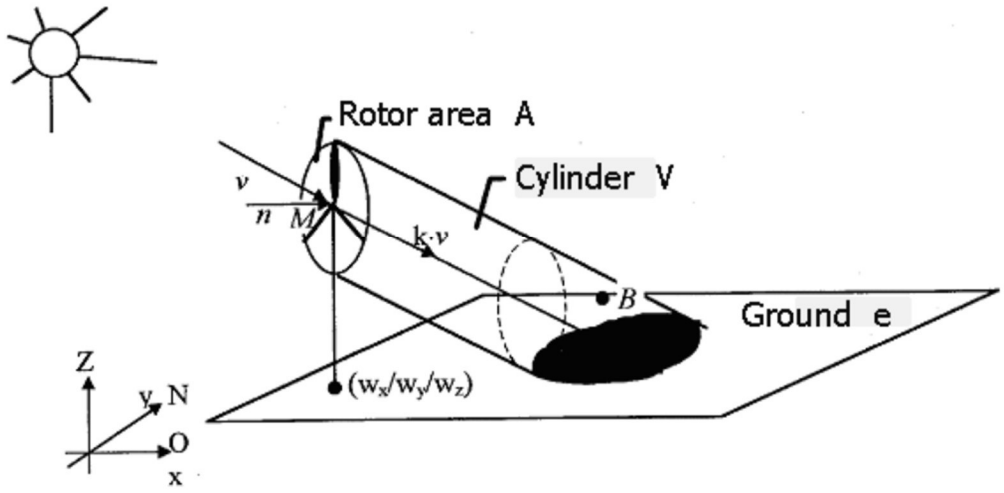

Figure 1: Diagram of Shadow Flicker Model Simulation [1]

4. Project Details

The Project is located near Rhame, North Dakota in agricultural land consisting mostly of rolling hills. There are scattered dwellings, farm buildings and trees throughout the Project area.

The Client provided ReGenerate with the coordinates of turbines and receptors for the Project. The layout (LAY-067) features 86 GE 2.82-127 Enhanced LNTE turbines at 88.6 m hub-height, this includes 74 primary and 12 alternate locations all of which were included in the modeling. Turbine coordinates provided for the Project are shown in Appendix II. Coordinates for individual receptors can be found in Appendix III.

Neighboring projects that are currently operational were reviewed as part of this analysis based upon the U.S. Wind Turbine Database by USGS. [2] The nearest neighboring wind project, Cedar Hills, is over five miles away and therefore will not have any impact on receptors analyzed.

5. Project Regulations

The Bowman County Ordinance states the maximum acceptable level of shadow flicker exposure is 30 hours per year for non-participating residences. [3]

6. Modeling Procedures

ReGenerate used the WindPRO software [1] to model shadow flicker for this Project. Modeling assumptions for the shadow flicker analysis include:

- Turbine is operating 100% of the time.
- Flicker is modeled out to ten times the rotor diameter from each respective turbine.
- Flicker is excluded if sun is less than 3° above horizon.
- Default observer eye level is 1.5 m.
- Receptors are perpendicular to all turbines, also known as greenhouse mode.
- Monthly sunshine probability has been modeled from nearest meteorological station.
- Data source for monthly sunshine hours was from the average of Fargo, ND and Bismark, ND locations using annual climate normals.
- Turbine orientation is considered.
- Obstacles (like trees or buildings) are not considered.

ReGenerate studied nearby meteorological reference stations available from usclimatedata.com (USCD) historical norms and from the Global Historical Climatology Network (GHCN) for this analysis; see the table below. [4,5]

Station	State	Data Source	Average Sunshine [hr/day]	Distance from Project [km]
FARGO	ND	GHCN	7.3	527
BISMARCK	ND	GHCN	6.9	226
RAPID CITY	SD	GHCN	7.9	230
MINNEAPOLIS-ST.PAUL	MN	USCD	7.1	820

Table 1: Meteorological Reference Stations

The Bismarck station was the closest to the Project area, but appeared to be a bit of an outlier with lower average sunshine. Therefore, based on their proximity and similar latitude, the average of the Fargo and Bismarck meteorological stations was chosen as most representative. Monthly average sunshine hours per month used in modeling are shown in the table below.

Average Sunshine [hr/month]											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
140	155	213	232	276	289	328	308	240	181	111	119

Table 2: Average Sunshine Hours per Month

The wind direction frequency was considered to account for turbine orientation of the rotor area relative to the sun. This data was taken from local meteorological data adjusted to Project hub height. The wind frequency rose is shown in the figure below.

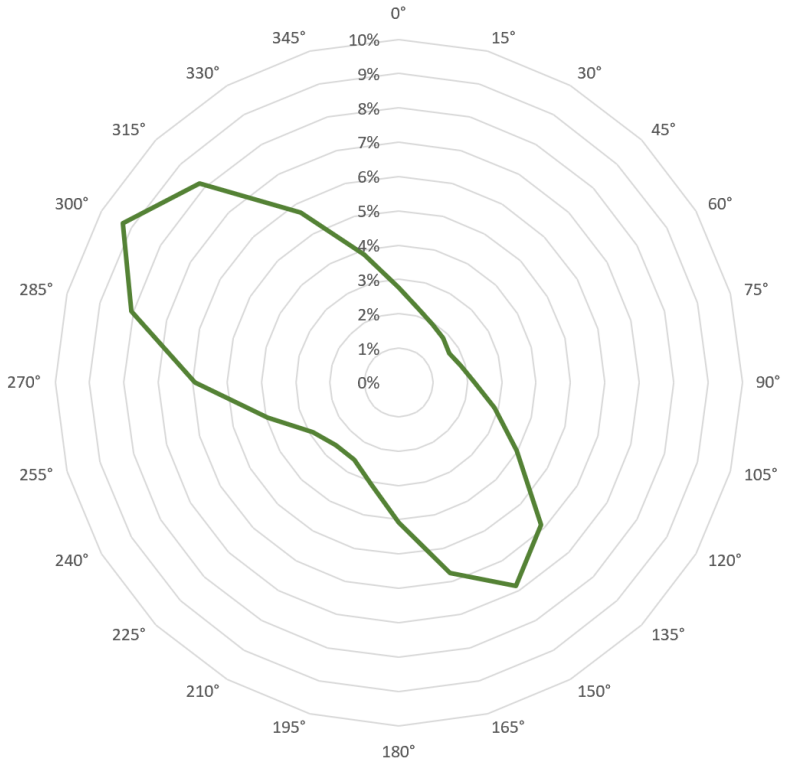

Figure 2: Wind Frequency Rose for Project

This model is likely to produce estimates higher than those which will be experienced. Factors that will lower the impact, but were not modeled include:

- Availability of the turbines.
- Turbines not operating below cut-in and above cut-out wind speeds.
- The impact of obstacles (like trees or buildings).
- Dust or aerosols in the air which reduce the impact of shadow flicker.

7. Modeling Results

The effect on receptors has been quantified using the methodology described above and the maximum value of shadow flicker at any receptor location was found to be 14.0 hr/yr. A summary of the results can be seen below in the table below; detailed results can be found in Appendix III.

Shadow Flicker [hr/yr]	Participating		Non-Participating		Total	
	№ Receptors	% of Receptors	№ Receptors	% of Receptors	№ Receptors	% of Receptors
0	13	65.00%	116	96.69%	129	92.14%
0.1 to 5	0	0.00%	2	1.67%	2	1.43%
5.1 to 10	4	20.00%	1	0.83%	5	3.57%
10.1 to 15	3	15.00%	1	0.83%	4	2.86%
15.1 to 30	0	0.00%	0	0.00%	0	0.00%
30.1 or more	0	0.00%	0	0.00%	0	0.00%

Table 3: Shadow Flicker Results Summary

8. Conclusions

Shadow flicker has been studied for receptors in the vicinity of the Project. The maximum value of shadow flicker was found to be 14.0 hr/yr for participating receptors, the highest non-participating receptor is expected to have 13.9 hr/yr.

The maximum value of shadow flicker is below the limits set forth in the County regulations.

9. References

[1] EMD International A/S. (Apr 2019). WindPRO 3.3 User Manual – 6 Environment. Retrieved from http://help.emd.dk/WindPRO/content/windPRO3.3/c6-UK_WindPRO3.3-Environment.pdf.

[2] United States Geological Survey. "The U.S. Wind Turbine Database." Retrieved from https://eerscmap.usgs.gov/uswtdb/.

[3] Email from Brie Anderson to Chris Nuckols and Ryan McDevitt. 17-Feb-2021.

[4] U.S climate data. (January 2021). Climate data for Minneapolis, MN - 1981-2010 normals – weather. Retrieved from https://www.usclimatedata.com/climate/minneapolis/minnesota/united-states/usmn0503

[5] National Oceanic and Atmospheric Administration. (March 2019). Global Historical Climatology Network (GHCN). Retrieved from https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn.

Appendix I – Maps

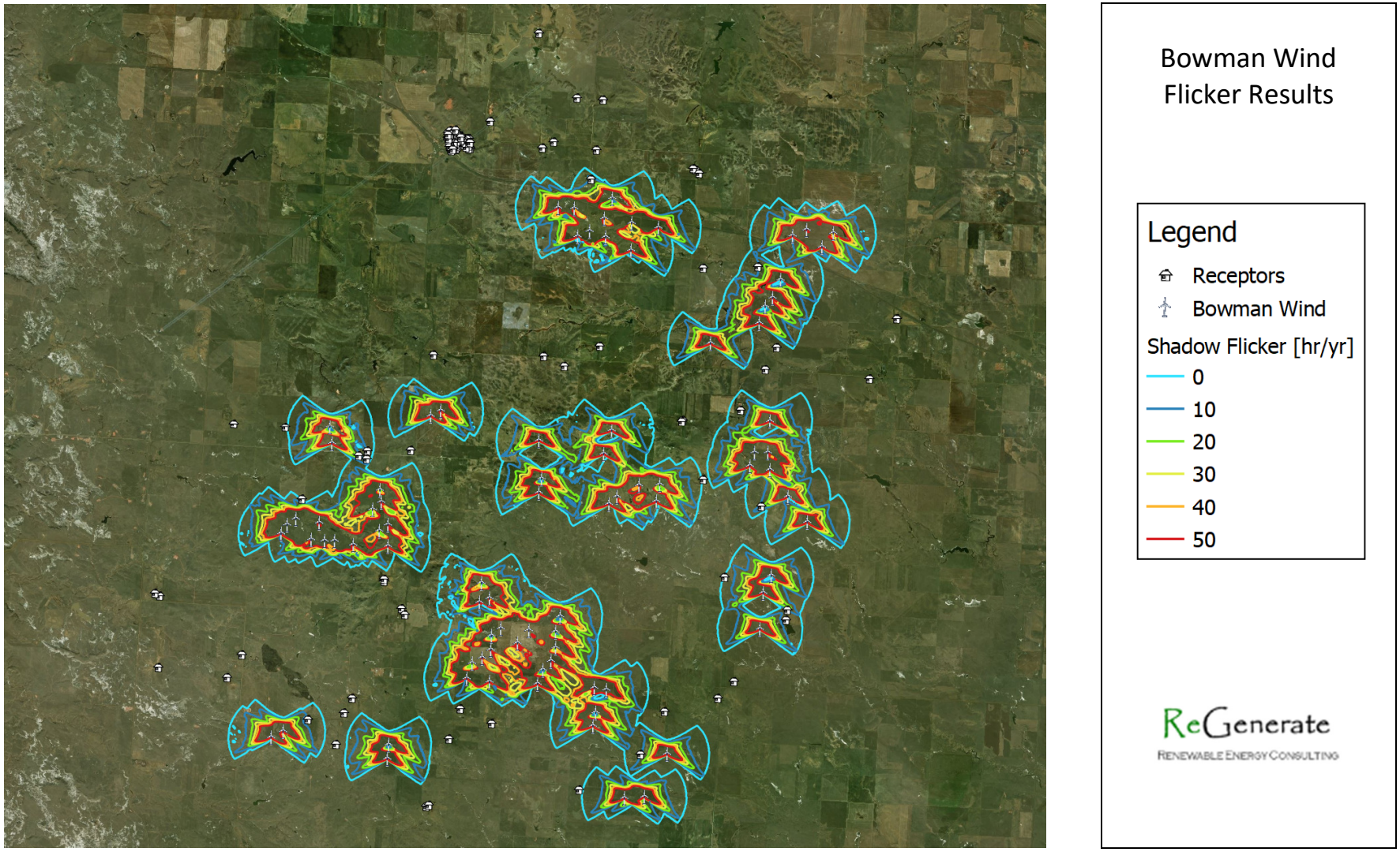

Figure 3: Shadow Flicker Map of Bowman Wind Project

Appendix II – Project Turbine Coordinates (UTM WGS84 Zone 13)

Turbine ID	X [m]	Y [m]	Turbine Type
T1	608840	5119564	GE 2.82 - 127 LNTE-Enhanced
T2	607222	5119163	GE 2.82 - 127 LNTE-Enhanced
T3	614751	5119077	GE 2.82 - 127 LNTE-Enhanced
T4	615575	5119024	GE 2.82 - 127 LNTE-Enhanced
T5	607711	5119179	GE 2.82 - 127 LNTE-Enhanced
T6	608643	5118955	GE 2.82 - 127 LNTE-Enhanced
T7	609469	5118868	GE 2.82 - 127 LNTE-Enhanced
T8	614344	5118851	GE 2.82 - 127 LNTE-Enhanced
T9	610290	5118792	GE 2.82 - 127 LNTE-Enhanced
T10	615253	5118591	GE 2.82 - 127 LNTE-Enhanced
T11	608227	5118542	GE 2.82 - 127 LNTE-Enhanced
T12	608710	5118383	GE 2.82 - 127 LNTE-Enhanced
T13	607880	5118354	GE 2.82 - 127 LNTE-Enhanced
T14	609507	5118052	GE 2.82 - 127 LNTE-Enhanced
T15	614094	5117507	GE 2.82 - 127 LNTE-Enhanced
T16	613884	5116934	GE 2.82 - 127 LNTE-Enhanced
T17	613688	5116670	GE 2.82 - 127 LNTE-Enhanced
T18b	614088	5113222	GE 2.82 - 127 LNTE-Enhanced
T19	612115	5115426	GE 2.82 - 127 LNTE-Enhanced
T20	604150	5112776	GE 2.82 - 127 LNTE-Enhanced
T21	603861	5112601	GE 2.82 - 127 LNTE-Enhanced
T22	609338	5112554	GE 2.82 - 127 LNTE-Enhanced
T23	614099	5112243	GE 2.82 - 127 LNTE-Enhanced
T24	613689	5112222	GE 2.82 - 127 LNTE-Enhanced
T25	607180	5112089	GE 2.82 - 127 LNTE-Enhanced
T26	600850	5112020	GE 2.82 - 127 LNTE-Enhanced
T27	609163	5111833	GE 2.82 - 127 LNTE-Enhanced
T28	613587	5111791	GE 2.82 - 127 LNTE-Enhanced
T29	600938	5111538	GE 2.82 - 127 LNTE-Enhanced
T30	610910	5111022	GE 2.82 - 127 LNTE-Enhanced
T31	607343	5110935	GE 2.82 - 127 LNTE-Enhanced
T32	610283	5110961	GE 2.82 - 127 LNTE-Enhanced
T33	609659	5110563	GE 2.82 - 127 LNTE-Enhanced
T34	607283	5110522	GE 2.82 - 127 LNTE-Enhanced
T35	610844	5110516	GE 2.82 - 127 LNTE-Enhanced
T36	609429	5110338	GE 2.82 - 127 LNTE-Enhanced
T37	602506	5110240	GE 2.82 - 127 LNTE-Enhanced

Turbine ID	X [m]	Y [m]	Turbine Type
T38	602562	5109873	GE 2.82 - 127 LNTE-Enhanced
T39	602325	5109633	GE 2.82 - 127 LNTE-Enhanced
T40	602827	5109198	GE 2.82 - 127 LNTE-Enhanced
T41	600036	5109180	GE 2.82 - 127 LNTE-Enhanced
T42	601244	5108593	GE 2.82 - 127 LNTE-Enhanced
T43	600738	5109102	GE 2.82 - 127 LNTE-Enhanced
T44	602573	5109005	GE 2.82 - 127 LNTE-Enhanced
T45	599788	5108975	GE 2.82 - 127 LNTE-Enhanced
T46	599617	5108695	GE 2.82 - 127 LNTE-Enhanced
T47	600946	5108585	GE 2.82 - 127 LNTE-Enhanced
T48	600532	5108578	GE 2.82 - 127 LNTE-Enhanced
T49	601812	5108523	GE 2.82 - 127 LNTE-Enhanced
T50	602860	5108557	GE 2.82 - 127 LNTE-Enhanced
T51	605772	5107673	GE 2.82 - 127 LNTE-Enhanced
T52	606053	5107219	GE 2.82 - 127 LNTE-Enhanced
T53	605751	5107087	GE 2.82 - 127 LNTE-Enhanced
T54a	608210	5106838	GE 2.82 - 127 LNTE-Enhanced
T55	608119	5106370	GE 2.82 - 127 LNTE-Enhanced
T56	607300	5106342	GE 2.82 - 127 LNTE-Enhanced
T57	606453	5106347	GE 2.82 - 127 LNTE-Enhanced
T58	606179	5106110	GE 2.82 - 127 LNTE-Enhanced
T59	606984	5105936	GE 2.82 - 127 LNTE-Enhanced
T60	608148	5105887	GE 2.82 - 127 LNTE-Enhanced
T61	606191	5105679	GE 2.82 - 127 LNTE-Enhanced
T62	608046	5105484	GE 2.82 - 127 LNTE-Enhanced
T63	605949	5105422	GE 2.82 - 127 LNTE-Enhanced
T64	607819	5105203	GE 2.82 - 127 LNTE-Enhanced
T65	605669	5105224	GE 2.82 - 127 LNTE-Enhanced
T66	609408	5104768	GE 2.82 - 127 LNTE-Enhanced
T67	609766	5104726	GE 2.82 - 127 LNTE-Enhanced
T68	605545	5104754	GE 2.82 - 127 LNTE-Enhanced
T69	607697	5104754	GE 2.82 - 127 LNTE-Enhanced
T70	606238	5104714	GE 2.82 - 127 LNTE-Enhanced
T71	600122	5102755	GE 2.82 - 127 LNTE-Enhanced
T72	603350	5102590	GE 2.82 - 127 LNTE-Enhanced
T73	599775	5102549	GE 2.82 - 127 LNTE-Enhanced
T74	603331	5102160	GE 2.82 - 127 LNTE-Enhanced
S1	615448	5110235	GE 2.82 - 127 LNTE-Enhanced
S2	614268	5108014	GE 2.82 - 127 LNTE-Enhanced
S3	614475	5108543	GE 2.82 - 127 LNTE-Enhanced

Turbine ID	X [m]	Y [m]	Turbine Type
S4	614803	5110965	GE 2.82 - 127 LNTE-Enhanced
S5	609496	5104030	GE 2.82 - 127 LNTE-Enhanced
S6	611745	5102937	GE 2.82 - 127 LNTE-Enhanced
S7	611156	5101598	GE 2.82 - 127 LNTE-Enhanced
S8	614268	5106908	GE 2.82 - 127 LNTE-Enhanced
S9	610565	5101517	GE 2.82 - 127 LNTE-Enhanced
S10	609445	5103616	GE 2.82 - 127 LNTE-Enhanced
S11	614202	5111718	GE 2.82 - 127 LNTE-Enhanced
S18a	613543	5116151	GE 2.82 - 127 LNTE-Enhanced

Appendix III – Individual Receptor Results (UTM WGS84 Zone 13)

Receptor ID	X [m]	Y [m]	Status	Shadow Flicker [hr/yr]
R-1	598290	5104260	Non-Participant	0
R-2	600826	5103183	Participant	7.1
R-3	601891	5103470	Participant	0
R-4	602113	5103942	Participant	0
R-5	604593	5100843	Non-Participant	0
R-6	604671	5100889	Non-Participant	0
R-7	605115	5102926	Non-Participant	0
R-9	605383	5103866	Participant	0
R-10	606371	5103492	Participant	0
R-11	602810	5107529	Participant	0
R-12	602807	5107584	Participant	0
R-13	611554	5104249	Non-Participant	0
R-14	613992	5110631	Participant	12.0
R-15	601761	5111255	Non-Participant	13.9
R-16	602011	5111415	Non-Participant	4.8
R-17	602001	5111159	Participant	7.4
R-18	611420	5113065	Non-Participant	0
R-19	611415	5113038	Non-Participant	0
R-20	613145	5113499	Non-Participant	3.9
R-21	613815	5114783	Non-Participant	0
R-22	608753	5115123	Non-Participant	0
R-23	603773	5114469	Non-Participant	0
R-24	613349	5117871	Non-Participant	8.0
R-25	611703	5117711	Non-Participant	0
R-27	606912	5121157	Participant	0
R-28	608220	5121017	Non-Participant	0
R-29	611264	5120638	Non-Participant	0
R-30	611177	5120681	Non-Participant	0
R-31	611358	5120553	Non-Participant	0
R-32	617660	5116624	Non-Participant	0
R-33	616971	5114750	Non-Participant	0
R-34	607517	5122547	Participant	0
R-35	608309	5122556	Non-Participant	0
R-37	608128	5120127	Participant	11.9
R-38	614096	5115483	Pending Participant	0
R-39	599477	5111955	Non-Participant	0
R-40	614996	5107278	Participant	6.6
R-41	615025	5107578	Participant	14.0
R-42	613120	5104763	Non-Participant	0

Pending Participant is currently in the process of executing administrative documents for a participation agreement.

Receptor ID	X [m]	Y [m]	Status	Shadow Flicker [hr/yr]
R-43	597921	5111924	Non-Participant	0
R-44	601725	5102516	Non-Participant	0
R-45	610923	5102894	Participant	8.9
R-46	613577	5105296	Non-Participant	0
R-47	604953	5121650	Non-Participant	0
R-48	604368	5120913	Non-Participant	0
R-49	604349	5121070	Non-Participant	0
R-50	604213	5121073	Non-Participant	0
R-51	604365	5120814	Non-Participant	0
R-52	604381	5120816	Non-Participant	0
R-53	604397	5120815	Non-Participant	0
R-54	604420	5120773	Non-Participant	0
R-55	604361	5120775	Non-Participant	0
R-56	604001	5120773	Non-Participant	0
R-57	603960	5120722	Non-Participant	0
R-58	604134	5120869	Non-Participant	0
R-59	612193	5111320	Non-Participant	0
R-61	607087	5114693	Non-Participant	0
R-63	606220	5124416	Non-Participant	0
R-64	603312	5111519	Participant	0
R-65	604294	5121067	Non-Participant	0
R-66	604182	5121033	Non-Participant	0
R-67	604130	5121043	Non-Participant	0
R-68	604063	5121124	Non-Participant	0
R-69	604085	5121075	Non-Participant	0
R-71	604363	5120859	Non-Participant	0
R-72	604296	5120815	Non-Participant	0
R-73	604357	5120934	Non-Participant	0
R-74	604401	5120957	Non-Participant	0
R-75	604023	5121081	Non-Participant	0
R-76	604000	5121061	Non-Participant	0
R-77	603977	5121074	Non-Participant	0
R-78	603985	5121116	Non-Participant	0
R-79	603853	5121246	Non-Participant	0
R-80	603893	5121201	Non-Participant	0
R-81	603857	5121056	Non-Participant	0
R-82	603891	5121093	Non-Participant	0
R-83	603938	5121036	Non-Participant	0
R-84	604000	5121036	Non-Participant	0
R-85	603923	5121129	Non-Participant	0
R-86	603926	5121161	Non-Participant	0
R-87	603828	5121192	Non-Participant	0

Receptor ID	X [m]	Y [m]	Status	Shadow Flicker [hr/yr]
R-88	603880	5120786	Non-Participant	0
R-89	603960	5120800	Non-Participant	0
R-90	603924	5120769	Non-Participant	0
R-91	603954	5120711	Non-Participant	0
R-92	603981	5120747	Non-Participant	0
R-93	604023	5120801	Non-Participant	0
R-94	603983	5120828	Non-Participant	0
R-95	603901	5120811	Non-Participant	0
R-96	603834	5120823	Non-Participant	0
R-97	603824	5120712	Non-Participant	0
R-98	603807	5120782	Non-Participant	0
R-99	603853	5120737	Non-Participant	0
R-100	603834	5120758	Non-Participant	0
R-101	603863	5120859	Non-Participant	0
R-102	603876	5120870	Non-Participant	0
R-103	603865	5120962	Non-Participant	0
R-104	603886	5120919	Non-Participant	0
R-105	603970	5120920	Non-Participant	0
R-106	604022	5120989	Non-Participant	0
R-107	603996	5120963	Non-Participant	0
R-108	603880	5120969	Non-Participant	0
R-109	603916	5120744	Non-Participant	0
R-110	603882	5120704	Non-Participant	0
R-111	603872	5120733	Non-Participant	0
R-112	603787	5120787	Non-Participant	0
R-113	603916	5120957	Non-Participant	0
R-114	603916	5120923	Non-Participant	0
R-115	603718	5121050	Non-Participant	0
R-116	603730	5121065	Non-Participant	0
R-117	603764	5121112	Non-Participant	0
R-118	603810	5121098	Non-Participant	0
R-119	603826	5121075	Non-Participant	0
R-120	603776	5121055	Non-Participant	0
R-121	603747	5121085	Non-Participant	0
R-122	603729	5120978	Non-Participant	0
R-123	603743	5121020	Non-Participant	0
R-124	603707	5121201	Non-Participant	0
R-125	603811	5121163	Non-Participant	0
R-126	603770	5121271	Non-Participant	0
R-127	603722	5121150	Non-Participant	0
R-128	603963	5121214	Non-Participant	0
R-129	603948	5121164	Non-Participant	0

Receptor ID	X [m]	Y [m]	Status	Shadow Flicker [hr/yr]
R-130	603966	5121185	Non-Participant	0
R-131	603926	5121302	Non-Participant	0
R-132	604108	5121142	Non-Participant	0
R-133	604110	5121099	Non-Participant	0
R-134	603853	5120665	Non-Participant	0
R-135	603894	5120716	Non-Participant	0
R-136	607753	5114434	Non-Participant	0
R-137	596075	5106565	Non-Participant	0
R-138	595936	5106647	Non-Participant	0
R-139	596205	5104410	Non-Participant	0
R-140	613059	5108413	Non-Participant	0
R-141	603495	5106573	Non-Participant	0
R-143	598695	5104987	Participant	0
R-144	606584	5120957	Participant	0
R-146	603386	5106731	Non-Participant	0
R-147	609152	5101700	Non-Participant	0
R-148	600142	5109806	Pending Participant	0

Pending Participant is currently in the process of executing administrative documents for a participation agreement