Appendix 19-B

Ice Throw Study

DNV

PROJECT NUJIO’QONIK

Ice Throw Analysis

World Energy GH2 Inc.

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This report presents the results of an ice throw analysis conducted by DNV on behalf of World Energy GH2 Inc.

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1 INTRODUCTION

World Energy GH2 Inc. (“World Energy”) retained DNV Canada Ltd.. (“DNV”) to undertake an ice throw assessment for Project Nujio’qonik (the “Project”), to assess the potential impacts of ice shedding from the turbines on the surrounding areas. Project Nujio’qonik is located in Newfoundland, Canada, near Stephenville, and expected to be in production by 2025.

The Project consists of two different wind farm sites, Port au Port to the north of St George’s Bay on Port au Port Peninsula and Codroy to the south of St George’s Bay in the Anguille Mountains of the Codroy Valley, NL.

The Wind Farm layout under consideration for Port au Port consists of 171 turbine locations. The final layout will ultimately consist of up to 164 turbines when constructed. The final total nameplate capacity for the Port au Port wind farm is expected to be approximately 1 GW.

The Wind Farm layout under consideration for Codroy consists of 143 turbine locations. The final layout will ultimately consist of up to 164 turbines when constructed. The final total nameplate capacity for the Codroy wind farm is expected to be approximately 1 GW.

This assessment was performed with the Siemens Gamesa Renewable Energy (SGRE) SG 6.6-155 wind turbine model, with a hub height of 120 m, and a rotor RPM ranging from 5.4 RPM to a maximum of 9.31 RPM, as confirmed by SGRE. The final hub height may be lower and will not exceed 120 m when constructed.

1.1 Ice Throw Context

During various weather conditions, ice can accumulate on the wind turbine blades. Accumulated ice may be shed from the turbine structure by means of:

- “Ice drop”, and refers to ice dropping from a wind turbine in its immediate vicinity when the wind turbine is idle. This phenomenon can happen under specific meteorological conditions for any type of stationary outdoor structure.
- “Ice throw”, and refers to ice fragments detaching from rotating wind turbine blades and being projected out to a certain distance away from the tower. This distance varies based on several operational, meteorological, and physical variables.

Ice drop is typically limited to a distance slightly beyond one blade length from the turbine base while ice throw is subject to larger distances, as modelled within this report. In this study, an assumption on the ratio of ice “drops” versus “throws” was considered by DNV. This assumption can vary based on the overall effectiveness of the icing operation protocol.

Winter operating protocols and controls for modern turbines seek to reduce unwanted loads from iced blades, as well as reduce the risk of ice fragments striking a person or other structures by automatically or manually stopping the wind turbine when higher icing risk conditions exist. This type of operational protocol effectively results in the reduction of ice throw hazard. As a result, a proportion of the detached ice is shed locally (i.e., drops) as it thaws and slips off the blades, with most of the ice fragments dropping in the immediate vicinity of the turbine, rather than being thrown.

The probability of ice being shed from a turbine blade at a given location is a result of the combination of the following probabilities:

- The probability of the turbine having ice accumulated on the blades (based on number of site-specific icing days, ice mass, and the blade’s total ice accumulation area); and,

- The probability of ice becoming detached from the blades and landing at a given location (a function of rotor RPM, cut-in wind speed, cut-out wind speed, rated wind speed, temperature, air density, etc.).

To the calculated probability of ice fragments landing in the vicinity of the turbine, the probability of human or external sensitive infrastructure presence and the probability of a harmful impact can be included in order to determine the overall "*risk"*. In general, the *risk* will be lower than the *probability* of an ice fragment landing at a specific location. The current analysis provides *probability* distributions only.

The following sections provide the Project details, methodology and results of the assessment.

2 PROJECT DETAILS

2.1 Site Location of Proposed Wind Farm

The proposed Project is located in western Newfoundland, immediately west and southwest of the town of Stephenville. The proposed Project layout currently consists of 171 turbine locations at Port au Port wind farm, located north of St George's Bay on Port au Port Peninsula and 143 turbines at Codroy wind farm in the Anguille Mountains of the Codroy Valley, NL. However, the final layouts will each consist of up to 164 turbines when constructed, totaling a final expected nameplate capacity of approximately 1 GW each. DNV recommends that the analysis be updated for the final layouts, particularly once the remaining turbine locations for Codroy have been determined.

The terrain of the Project sites and surrounding areas consists or rolling hills, with a mix of rock outcrops, low lying vegetation and forested areas.

The layouts for the Project were provided by World Energy [1] [2]. Turbine locations are interspersed across both sites, with base elevations varying in the order of approximately 30 m to over 330 m above mean sea level (amsl) for Port au Port and between approximately 290 m to 530 m amsl for Codroy, which is in a relatively more mountainous area.

Figure 2-1 and Figure 2-2 provide a general overview of the Project area and layout for both wind farms.

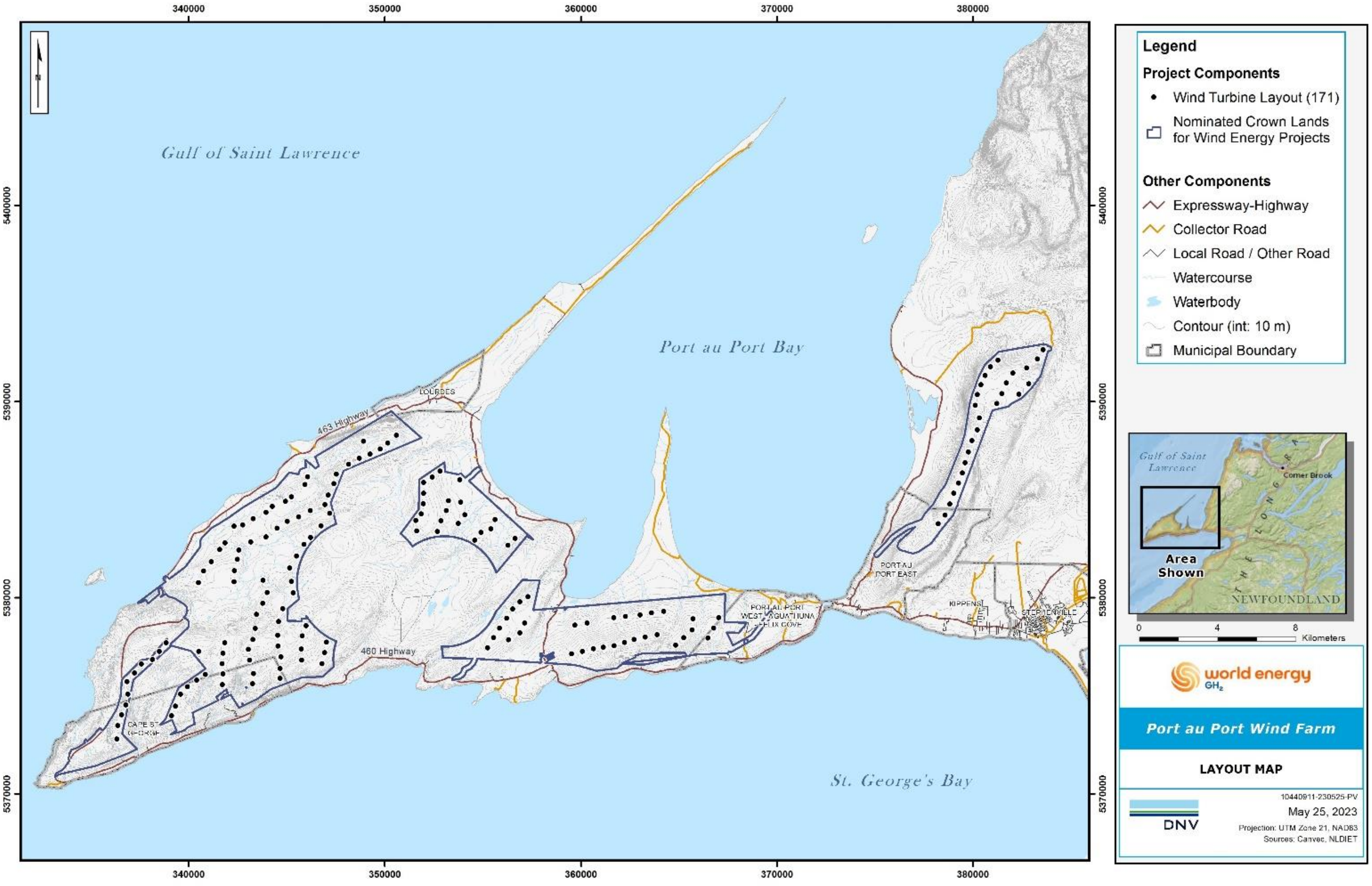

Figure 2-1 Port au Port wind farm location map

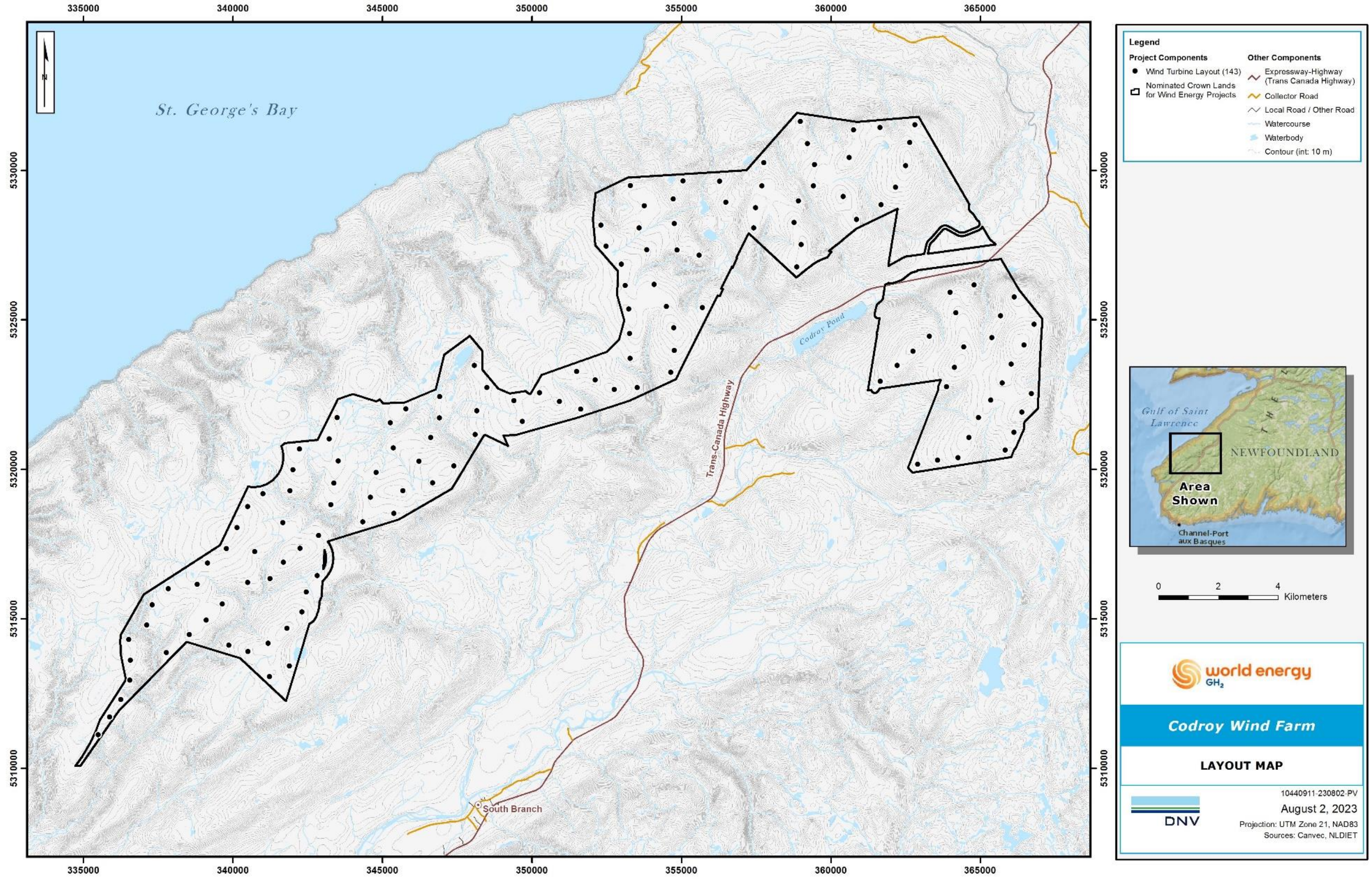

Figure 2-2 Codroy wind farm location map

2.2 Turbine Characteristics and Operation

Ice drop and throw by wind turbines are driven by their dimensions (height and diameter), structural characteristics and operational protocol. For this analysis, DNV used the technical specifications of the SGRE SG 6.6-155 turbine model, which are summarized below in Table 2-1.

Table 2-1 Wind Turbine Parameters

Wind turbine	**SG 6.6-155**
Rated power (MW)	6.6
Rotor diameter (m)	155
Hub height (m)	120
Cut-in wind speed (m/s)	3
Rated RPM wind speed (m/s) (at maximum Cp*)	8
Cut-out wind speed (m/s)	27
Rotor speed range (rpm)	5.4 to 9.31

*Cp = Coefficient of power

DNV notes that modern wind turbines will typically indirectly detect blade icing by monitoring the aerodynamic performance of the blades through examination of *expected* power output versus *actual* power output, in combination with temperature and humidity monitoring, as reported by the wind farm Supervisory Control and Data Acquisition program (SCADA). Additionally, to detect and monitor unbalance resulting from significant ice build-up on blades, vibration sensor signals are used to stop the wind turbine to prevent structural damages to the turbine. In climates prone to significant icing, or with significant risk to the public, ice detection sensors can be outfitted on the turbine nacelle or blades, as well as an anti-icing or de-icing system to actively melt and shed the ice can be installed.

The probability of ice throw, as opposed to ice drop, may also be increased at turbine restart. As such, blade inspection before turbine restart is considered a best practice in areas where members of the public may be present in the vicinity of the turbines during or immediately after periods of heavy icing events.

DNV conservatively assumed within this analysis that risk mitigation from the wind farm icing operation protocol would be based on the wind turbine “indirect” detection of icing through its control algorithms and SCADA only, which is provided as standard with the wind turbine. A turbine shutdown effectiveness of 25% was conservatively assumed which effectively turns those ice *throw* events into less impactful ice *drop* events. Should more comprehensive icing operation protocols be put in place, the analysis can be revisited to quantify the probability decreases of these events.

Turbine icing protocol options are discussed later in Section 4.

2.3 Site Conditions

Ice drop and throw at a given site is also influenced by the site’s meteorological conditions. Meteorological conditions were considered using raw lidar and met mast data at the Port au Port site, and consultation of nearby long-term environmental stations. No site data was available for the Codroy site, therefore the Port au Port data was applied to both sites. DNV expects that the site condition results at Codroy will be relatively similar to Port au Port, and will not significantly change the conclusions of this report.

According to DNV, the analysis showed that instrument icing generally occurred for a total cumulative average period of 21.4 days per year. Based on literature review [3], IEA Task 19 recommendations [4], and DNV’s experience in site resource assessments, instrument (i.e., from met mast data) icing corresponds on average to approximately double the active blade icing days. Hence, DNV concluded that an average of 10.7 active blade icing days per year are expected for turbines at the Project.

In addition, a site-specific long-term seasonal wind rose at a height of 120 m for the complete months of December to April[1] inclusively was determined by DNV, based on lidar data on site from Lidar 3, and adjusted for long term. With the available site data, the air density for winter months was evaluated to be 1.24 kg/m^3.

The wind Weibull distribution parameters and wind direction distributions are presented in Table 2-2. The corresponding wind frequency rose is shown in Figure 2-3.

Table 2-2 Long-Term Winter Wind Characteristics at 120 m Height

Sector Number	Orientation[1] (°)	Frequency (%)	Weibull-A (m/s)	Weibull-k
1	**0**	8.5	8.9	3.23
2	**30**	11.9	10.0	3.06
3	**60**	8.9	9.8	2.24
4	**90**	7.3	9.3	2.16
5	**120**	6.1	9.0	1.97
6	**150**	6.3	11.9	1.92
7	**180**	4.8	10.5	2.32
8	**210**	5.4	10.5	1.97
9	**240**	8.7	10.9	2.84
10	**270**	13.5	11.5	2.46
11	**300**	12.8	10.5	2.57
12	**330**	5.9	8.5	2.11

[1]The orientation is defined as the center of the sector from which the wind is blowing (i.e. 0 represents winds from the north, between 345 to 15 degrees)

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[1] Icing months on site correspond approximately to the October to May period, based on recorded statistics from the Stephenville Environment Canada station. However, the measurement campaign on site began at the end of November 2022, therefore some Uncertainty exists in the meteorological inputs used in this report, which may not capture the variations across all the icing months from October to May, but nonetheless provides broadly representative inputs to DNV's model.

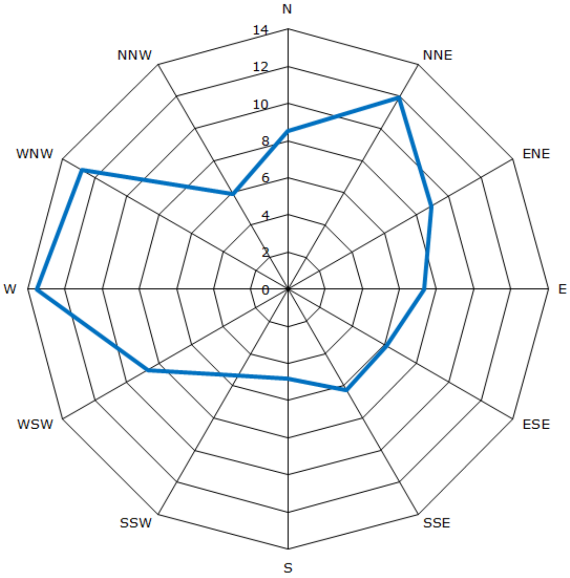

Figure 2-3 Long Term Hub Height Wind Frequency Rose (December to April)

3 METHODOLOGY AND RESULTS

3.1 Ice Throw and Drop Probability Model

The assessment methodology used in this report is based on the approach developed by DNV in conjunction with the Finnish Meteorological Institute and Deutsches Windenergie-Institut (DEWI) as part of a research project on the implementation of wind energy in cold climates (WECO). This research project was primarily funded by the European Union and was also supported, in part, by the United Kingdom Department of Trade and Industry [5]. The guidelines for safety assessments related to ice throw were developed by DNV in the context of the WECO project and the work was summarized in a series of conference papers [6], [7] and [8]. The guidelines were further considered for the North American market as per recommendations by DNV to the Canadian Wind Energy Association (CanWEA) [9] and are broadly consistent with the recent IEA Wind International Recommendations for Ice Fall and Ice Throw Risk Assessments [4].

These guidelines have been widely applied to projects located in North America and have been applied to the Project site by considering the proposed turbine type, site conditions and Project details.

The overall method is based on the following staged approach:

1. Determine the periods when ice accretion on structures might occur, based on historical climatic observations;
2. Within those periods, determine when the wind speed conditions are within the operational range of the wind turbines;
3. Based on the above-described estimate of icing occurrence, use an ice throw model and a Monte-Carlo statistical analysis[2] to derive the probability of fragments landing at distances and directions from the turbines which are of interest;

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[2] Refers to a repeated random sampling, by varying the input parameters. For ice-throw assessments, DNV will run 1,000,000 (each) of ice throws and drops to simulate the spatial distribution of these events.

4. Within the resultant periods, if applicable, assume ice drop when the wind turbines are automatically shut down by the wind turbine control system or by remote operators; and
5. Derive the total probability of an area of 1 square meter (m^2) being struck by ice fragments.

As previously noted, the probability of human or external sensitive infrastructure presence and the probability of a harmful impact can be included to the calculated probability (i.e., result under point 5. above) of ice fragments landing in the vicinity of the turbine in order to determine the overall “*risk”*. In general, the *risk* of harmful impact will be lower compared to the *probability* of an ice fragment landing at a specific location. The current analysis provides *probability* distributions only.

Terrain complexity around each individual turbine location can have an impact on the modeled results, but such terrain complexity was not accounted for in this analysis. A flat site has been assumed, since only two turbine locations (Turbine 6 and 18) were deemed within range of a possible risk area (highway or community pasture), with the terrain separating the turbine and risk area being relatively flat.

3.2 Summary of Modeling Assumptions

Table 3-1 presents the main assumptions used by DNV to model the cumulative probability of ice throw on the ground by the wind turbine model being considered. Wind turbine parameters are presented in Table 2-1.

Table 3-1 Ice Throw Modeling Assumptions (General)

Parameters			Comments
Site Conditions	Instrument icing [days/year]	21.4	DNV analysis. Applicable to period from December to April
	Assumed blade ice build-up [days/year]	10.7	
	Air density (at 281 m amsl) [kg/m3]	1.24	
	Drag Coefficient (Cd)	1.0	
Ice Fragments	Density [kg/m^3]	920	DNV assumptions
	Mass [kg]	1	
	Ice frontal area [m^2]	0.01	

It is noted that the DNV model includes a number of assumptions, some of which are conservative. These are outlined below:

- The ice fragment mass is assumed to be 1 kg. In practice, some fragments will have different masses and can fly shorter or longer ranges than modelled. The most common ice fragment weights are typically in the order of 0.5 kg to 1 kg based on literature and DNV’s experience;
- The model assumes that all ice accreted on the blade is thrown or dropped. In practice, some fraction will thaw and fall in the immediate vicinity of the turbine as water or turn to vapor;
- The wind turbine was considered operational (i.e., rotor spinning if wind speed is within operational range) during 75% of icing events. The remaining 25% of events were assumed to be ice drops caused by turbine icing shutdowns;
- The blade ice density is assumed to be 920 kg/m^3, which corresponds to very dense ice without air bubbles. In practice, it is expected that some of the actual ice accreted on the blades will contain some amount of air bubbles (e.g. rime ice) with a lower density. Ice density is very site-specific and will vary from one event to the other. Should DNV model be used with a lower ice density, fewer ice fragments would be thrown. However, in the absence of on-site ice density data, the conservative ice density of 920 kg/m^3 was used; and
- With the exception of the wind turbine indirect ice detection through control algorithms, and temperature/humidity sensors, no specific operational protocols designed to mitigate the risk of ice throw were considered in this analysis. Other icing protocol options are presented in Section 4.

3.3 Results

The results from the analysis are shown in Table 3-2, Figure 3-1, and Figure 3-2. These results summarize and illustrate the probability of occurrence of ice fragments striking the ground when the turbine is operating under the assumed conditions and climate described in the previous sections.

According to the results shown in this table, 90% of the nearest fragments will land between 0 m to 170 m (defined as the *typical range* by DNV) from the center of the wind turbine (SG 6.6-155). This range extends to 200 m and 235 m for the nearest 95% and 99% of fragments, respectively.

The farthest 1% of fragments would land at a distance ranging from 235 m to 290 m (defined as the *exceptional range* by DNV). While DNV's model indicates that it is theoretically possible that a fragment can land at a maximum distance of 290 m, it is improbable that a fragment will reach this distance during the Project life. Refer to additional commentary under Section 4.

This data represents the total for all direction sectors on flat terrain.

Table 3-2 Typical and Exceptional Ranges at Ground Level

Item	SG 6.6-155 (120 m HH)
Ice fragment mass [kg]	1
Number of estimated 1 kg ice fragments [per year]	2289
Typical range 1 [m] (90% of nearest events)	0-170
Typical range 2 [m] (95% of nearest events)	0-200
Typical range 3 [m] (99% of nearest events)	0-235
Exceptional range [m] (1% of farthest events)	235-290

That said, it can be seen from Figure 3-1 that ice throw events are not distributed evenly as a function of distance from the turbine, and become much less frequent with distance.

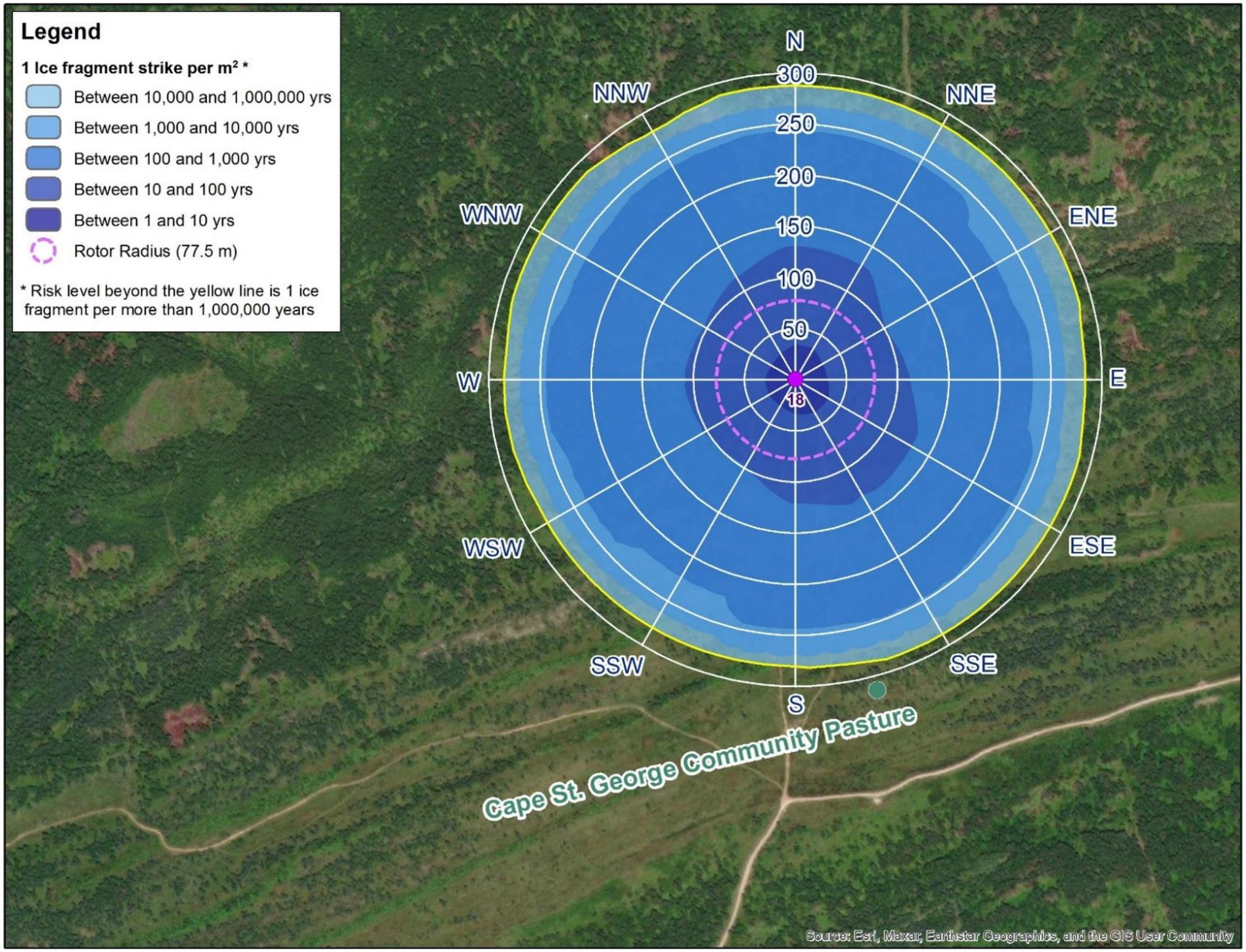
Areas at risk:

World Energy informed DNV that no turbines will be sited within 1 km from any residence in the final layouts used for construction at both sites. At such distances, ice throw risk is essentially nil for those inhabited structures.

Nonetheless, other risk areas (i.e., apart from inhabited structures) were evaluated separately for ice throw risk. As such, based on a review of the Project layouts and information provided by World Energy, the only turbines that are deemed to be within range of a potential risk area at the Port au Port site are turbine T6 (near highway 463) and turbine T18 (near Cape St George Community Pasture). Turbine T18 is near the Cape St George community pasture, which is part of Benoit First Nation – Mi'kmaq Heritage Park and Farm, and is deemed the worst-case location in terms of potential ice throw in the vicinity to the public for the current wind farm layout and turbine model under analysis.

For the Codroy wind farm, World Energy provided a list of 9 field verified potentially inhabited structures [10] (cabins, lodges, campgrounds). These structures are located at varying distances from turbines, with the closest one being approximately 510 m from turbine T84. Additionally, the proximity to the TransCanada Highway, which intersects the Project to the southeast, was measured to be at 560 m or more from any Codroy wind turbine. DNV assessed the ice throw radius for the turbines located closest to the TransCanada Highway, including the influence of terrain elevation differences. The maximum ice throw radius was calculated to be 400 m at those locations, in the direction of the highway. DNV therefore considers the risk of ice throw at a distance of 560 m or more to be negligible for the turbine layout and model considered in this analysis.

Figure 3-1 presents a visual representation of the results for ice fragments landing per unit area (1 square meter) at ground level for the SG 6.6-155 turbine at the T18 turbine location at Port au Port. The results are based on a 25%-75% split between ice drop and ice throw events, respectively and as discussed in previous Sections of the report. The various probability levels are presented, from 1 strike every 1 to 10 years (dark blue), to one strike every 100,000 to 1,000,000 years (light blue).



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Figure 3-1 Probability of 1 kg Ice Fragment Strikes per m^2 by Direction (Turbine 18 location)

Note: Concentric white circles are shown to illustrate 50 m intervals.

Figure 3-2 shows that the probability per square meter averaged for all directions; per direction results are visually represented in Figure 3-1 above. Figure 3-2 shows that the probability generally decreases with distance from the turbine, and sharply decreases at approximately 270 m. As an example, the yearly probability at a distance of 100 m is approximately 0.01, which equates to a probability of 1 in every 100 years per m^2. In other terms, there is a probability that one 1 kg fragment may land on a 1 square meter area, at a distance of 100 m for the turbine, every 100 years.

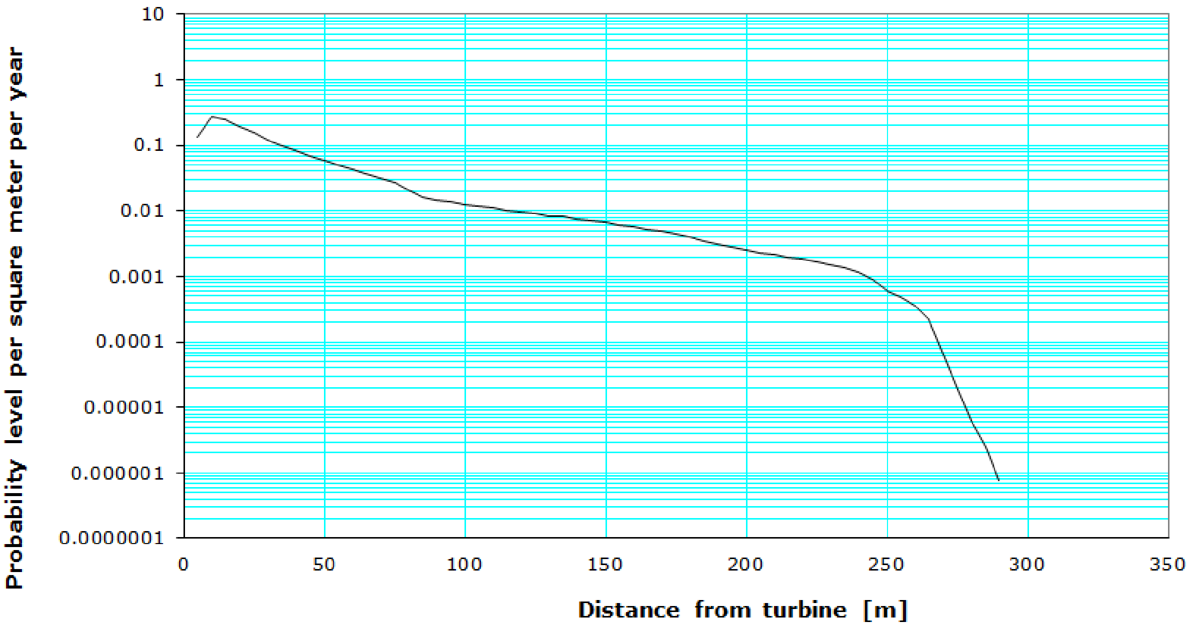


Figure 3-2 Probability of 1 kg Ice Fragment Strikes per m^2 by distance

It is emphasized that the probability maps do not directly represent the *risk* levels for members of the public or non-stationary structures. Instead, they represent the *probability* of an ice hit (per unit area). *Risk* levels are based on the combined probability of the ice and a member of the public (or a vehicle, etc.) being present in the same location at the same time, as well as the probability of a harmful impact.

Assumptions have been made in the context of this report. The effectiveness of the implementation of an icing operation protocol will have significant impact on end-results, however, some conservative assumptions have been made to reduce the impact of the applicable uncertainties.

It can also be noted that with over 90,000[3] wind turbines operating in cold climates globally, DNV is not aware of any injury to the public from ice throw or drop.

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[3] DNV estimate based on total installed capacity as of 2022, and [4].

4 ICE THROW MITIGATION AND ICING PROTOCOLS

Winter operating protocols and controls for modern turbines seek to reduce unwanted loads from iced blades, as well as reduce the risk of ice fragments striking a person or other structure, by automatically or manually stopping the wind turbine when higher icing risk conditions exist. This type of operational protocol effectively results in the reduction of ice throw hazard. As a result, a substantial proportion of the detached ice is shed locally as it thaws and slips off the blades, with most of the ice fragments dropping in the immediate vicinity of the turbine, rather than being thrown.

In DNV's experience, probability of ice *drop* decreases sharply beyond the wind turbine blade overhang distance, and under extreme wind conditions can extend to distances of up to 1.5 to 1.75 blade lengths from the wind turbine tower, without exceeding one rotor diameter from the tower. The typical drop radius (i.e., >90% of events when turbine is idle) is within one blade length. That said, DNV recommends a minimum safety setback of rotor radius length + 10 m to any sensitive structure or frequently accessed area by the public. No person should encroach this setback during icing conditions, even when the turbine is idle.

Ice *throw* distance and strike location depends on multiple factors such as wind direction and wind speed, but also the blade rotational speed, location on blade where the ice detaches, the shape/ice type of the ice fragments, and others. In the absence of a detailed risk assessment, which includes a computer simulation of ice throw events for a given site and turbine model, a formula can be used to define a safety zone for ice throw on relatively flat terrain, based on the rotor diameter and hub height. Early studies suggested a simple empirical formula to determine the potential risk area without further site-specific modelling, as explained under Seifert et al. [11] and repeated in CanREA's Best Practices guide for wind farm icing and cold climate health and safety [12]. The empirical formula is still used by some turbine manufacturers to determine the "safe area" around wind turbines during icing events. The area was defined as follows:

$$\text{ice throw safety radius} = (\text{hub height} + \text{rotor diameter}) \times 1.5$$

For the SG 6.6-155 wind turbine at 120 m hub height, this would be equivalent to a distance of 412.5 m, which, in DNV's experience, is a conservative setback for ice throw. As stated under [9] and as proposed under the IEA's ice throw risk assessment recommendations report [4], detailed risk modeling through advanced simulations is recommended in order to properly account for site-specific parameters and the probability of the presence of humans or sensitive infrastructure. The area with non-negligible risk is typically a fraction of the empirical worst case safety radius mentioned above. Based on DNV's ice throw modeling experience, as well as field observations and literature review, the "typical" ice throw distance for modern turbines (i.e., >90% of events landing within this distance), are often less than 200 m from the base of the wind turbine (170 m for the case evaluated in this report). Based on DNV's experience and literature review in the public domain, fragments have been observed at a maximum distance of approximately 200 m from a turbine, with one occasion at a distance of 225 m, however DNV notes that ice fragment throw observation campaign are tedious and rarely performed.

According to the Project data, turbine blade icing occurs approximately 11 days per year in total, typically between October and May. Blade icing events typically last one to two days before the ice naturally thaws. According to literature and DNV's experience, this can equate to approximately 2300 ice fragments thrown per year, if a wind turbine is operating (i.e., spinning at intended rpm) continuously during ice events, and the expected median fragment size in the range of 0.5 kg to 1.0 kg.

5 CONCLUSION

DNV assessed the probability of ice throw and drop by the turbine blades at the Project Nujio’qonik by considering the specifications of a selected wind turbine model and local site conditions. The SG 6.6-155 turbine model was applied to all turbine locations.

Monte-Carlo simulations showed that in the event of ice throw by turbine blades, throw distances would be typically less than 170 m from the wind turbine bases, and the maximum throw distance was simulated as being up to 290 m, considering various technical assumptions. However, it is improbable that this maximum distance would be reached during the Project life for this turbine model, as it is expected to occur at a rate as low as once every 1,000,000 years per m^2 at this distance.

The only turbines that were deemed to be within range of a potential risk area for the Port au Port site were turbine T6 (near highway 463) and turbine T18 (near Cape St George Community Pasture). Depending on the residual risk level once human presence is accounted for, it is recommended that ice throw mitigation strategies be reviewed and considered for those two turbines, if they remain part of the Project.

For Codroy, none of the currently proposed turbine locations were found to be within the calculated ice throw striking distance of any risk areas identified during a field survey completed by World Energy. The risk areas reviewed included 9 potentially inhabited structures (lodges, cabins, campgrounds) and the TransCanada Highway.

The maximum ice throw radius was calculated to be 400 m for the turbines closest to TransCanada Highway (in the direction of the highway), including the influence of terrain elevation differences. Since those turbines are located >560 m from the highway, DNV considers the risk of ice throw to be negligible for the turbine layout and model considered in this analysis.

World Energy informed DNV that no turbines will be sited within 1 km from any residence in the final layouts used for construction at both sites. At such distances, ice throw risk is essentially nil for those inhabited structures.

DNV recommends that these results be updated for the final layouts and reviewed with consideration of public presence and sensitive infrastructure, and that mitigations, if deemed necessary, be implemented accordingly. DNV also notes that using a different turbine model or different modeling assumptions, may cause the results in this report to vary.

It can also be noted that with over approximately 90,000 wind turbines operating in cold climates globally, DNV is not aware of any injury to the public from ice throw or drop.

6 REFERENCES

[1] *Site_A_Port_au_Port_Turbines.shp*, sent April 2023

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Appendix 19-C

Codroy Wind Farm, Shadow Flicker Assessment

PROJECT NUJIO'QONIK
Codroy Wind Farm, Shadow Flicker Assessment

August 2023

Prepared for:

world energy GH2

Prepared by:

Stantec Consulting Ltd.

File: 121417575

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Anna Kozicky, P.Eng

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Abbreviations

EA	environmental assessment
ECCC	Environment and Climate Change Canada
EIS	Environmental Impact Statement
GW	gigawatt
m	meters
Mt	megatonnes
MW	megawatt
NL	Newfoundland and Labrador
Stantec	Stantec Consulting Ltd.
the Project	Project Nujio’qonik
the Proponent	World Energy GH2
WTG	wind turbine generator

1.0 Introduction

Project Nujio'qonik (the Project) involves the development, construction, operation and maintenance, and eventual decommissioning and rehabilitation of one of the first Canadian, commercial-scale, "green hydrogen"[1] and ammonia production plants powered by renewable wind energy. Located on the western coast of the island of Newfoundland, Newfoundland and Labrador (NL) (Figure 2.1), the Project will have a maximum production of up to approximately 206,000 t of green hydrogen (equivalent to approximately 1.17 megatonnes (Mt) of ammonia) per year. The hydrogen produced by the Project will be converted into ammonia and exported to international markets by ship. The hydrogen / ammonia plant and associated storage and export facilities will be located at the Port of Stephenville (in the Town of Stephenville, NL) on a privately-owned brownfield site and at an adjacent existing marine terminal, both of which are zoned for industrial purposes.

Renewable energy from two approximately 1,000 megawatt (MW) / 1 gigawatt (GW) onshore wind farms on the western coast of Newfoundland will be used to power the hydrogen and ammonia production processes. These wind farms (referred to herein as the "Port au Port area wind farm" and the "Codroy area wind farm") will include up to 328 turbines and collectively produce approximately 2,000 MW / 2 GW of renewable electricity. The Port au Port wind farm layout under consideration consists of 171 turbine locations on the Port au Port Peninsula, NL and adjacently on the Newfoundland "mainland" (i.e., northeast of the isthmus at Port au Port, on Table Mountain). The final layout of the Port au Port wind farm will ultimately consist of up to 164 turbines when constructed. The Codroy wind farm layout under consideration consists of 143 turbine locations. The final layout of the Codroy wind farm will also consist of up to 164 wind turbines located on Crown land in the Anguille Mountains of the Codroy Valley, NL. The final total nameplate capacity for each wind farm is expected to be approximately 1,000 MW / 1 GW. The modelling and assessment work is based on preliminary layouts for both wind farm sites (i.e., 171 potential turbine locations at the Port au Port wind farm and 143 potential turbine locations at Codroy wind farm). Final wind farm layouts will be dependent on results of the wind campaign and more detailed field investigations. Once the layout and number of turbines are finalized, the results of models will be reviewed and updated as required. If additional turbine locations are added to the Codroy wind farm in the future, it will be done in consideration of the mitigation measures, compliance with regulations, and such that the conclusions of the effects assessment do not change.The Project is subject to provincial environmental assessment (EA) requirements under the NL *Environmental Protection Act* and associated *Environmental Assessment Regulations* (EA Regulations). This document is the daytime Shadow Flicker Study for the Codroy wind farm, prepared in support of an Environmental Impact Statement (EIS) and required under section 4.3.1 of the EIS Guidelines.

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[1] "Green hydrogen" is produced via electrolysis using renewable electricity to split water into hydrogen and oxygen. This type of hydrogen, which is referred to by the European Commission (n.d.) as "renewable fuel of non-biological origin", is often called "green hydrogen" in industry.

Shadow flicker is a temporary condition resulting from the sun casting intermittent shadows from the rotating blades of a wind turbine onto a receptor such as a window in a building. The flicker is due to alternating light intensity between the direct beam of sunlight and the shadow from the turbine blades. Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensity diminishes with greater receptor-to-turbine separation distance. Shadow flicker for receptor-to-turbine distances beyond 1,500 metres (m) is very low intensity and generally considered imperceptible by the human eye.

This document provides an analysis of daytime shadow flicker. The Project Light Assessment (Stantec 2023) provides information on nighttime illumination. The analysis of potential shadow flicker was conducted using the Windfarmer Version 5.3 software package. The purpose of this report is to estimate the impact of shadow flicker on receptors for both the 'expected case' and 'worst case' modelling scenarios for the Codroy wind farm. The report is structured as follows:

- Section 1 provides a brief introduction.
- Section 2 describes the Codroy wind farm site and turbine layout.
- Section 3 provides a description of the assessment cases.
- Section 4 identified the potential shadow receptors near the Codroy wind farm
- Section 5 summarizes the shadow flicker analysis method and presents the results from the shadow flicker analysis.

Currently there are no provincial regulations in NL regarding limits for shadow flicker. In the absence of provincial guidance, the Codroy wind farm shadow flicker assessment compared the predicted shadow flicker to a worst case exposure limit of 30 hours per year (Koppen et al. 2017). Analysis by Koppen et al. identified that while many international regulatory regimes do not have legislated thresholds or guidance, most use a 30 hour per year limit for worst case scenario analysis. This is largely based on German guideline - "Guideline for Identification and Evaluation of the Optical Emissions of Wind Turbines" that is considered to be a common international standard., and is currently used by regulators in Nova Scotia.[2]

The analysis provided in this report focuses on the total amount of time (hours and minutes per year) the shadow flicker can potentially occur at receptors, regardless of whether the shadow flicker is barely noticeable or clearly distinct. As a result of this conservative approach, it is likely that receptors will experience less shadow flicker impact than modeled and reported, especially those that are farther away from the turbines. It is likely that marginally affected receptors may not be able to identify shadow flicker as the shadows become more diffuse with increased distance.

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[2] https://novascotia.ca/nse/ea/docs/EA.Guide-Proponents-WindPowerProjects.pdf accessed May 23, 2023.

2.0 Project Details

2.1 Site Description

The Codroy wind farm is located on the west coast of the Island of Newfoundland, in the province of NL, in the Anguille Mountains of the Codroy Valley and will have a footprint of approximately 14,665 ha. The terrain is generally hilly, with steep slopes and river valleys. There are exposed areas at elevation, forested areas, barrens, wetlands, and low-lying shrubs. Surface water is limited to several small ponds. The Codroy wind farm is shown in Figure 2.1.

There are 28 receptors located within 1,500 m of the Codroy wind farm (Figure 2.1). For additional information on receptors, please see Section 4.

2.2 Turbine Description

The Codroy wind farm will consist of up to 143 turbines. This study assumes that Siemens Gamesa SG-155 6.6-megawatt (MW) wind turbine generators (WTG) will be used. These wind turbines consist of three-blade rotors and tubular towers. The SG-155 WTG have a nominal rated capacity of 6.6 MW, maximum hub heights of 122.5 m, and blade rotor diameters of 155 m. Use of this turbine model represents a “worst case” conservative input to the assessment of shadow flicker.

2.3 Turbine Locations

The proposed layout of the Codroy wind farm is shown in Figure 2.1 and coordinates for the 143 turbines are provided in Appendix A [3].

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[3] Turbine locations provided by the Proponent. Siting analysis not completed as part of shadow flicker assessment.

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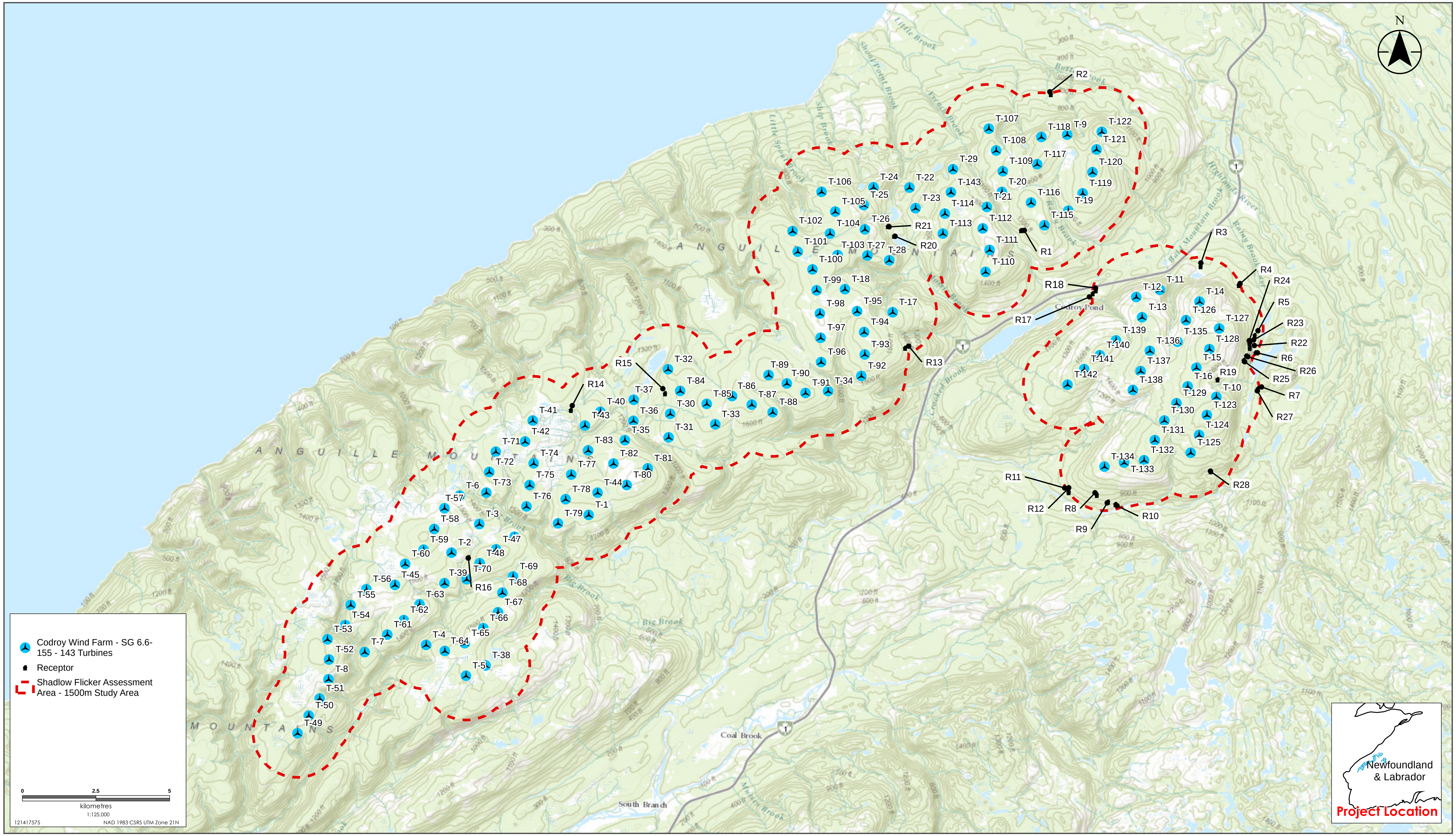


Sources: Base Data -Government of Canada, CanVec, ESRI
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Stantec
CODROY WIND FARM

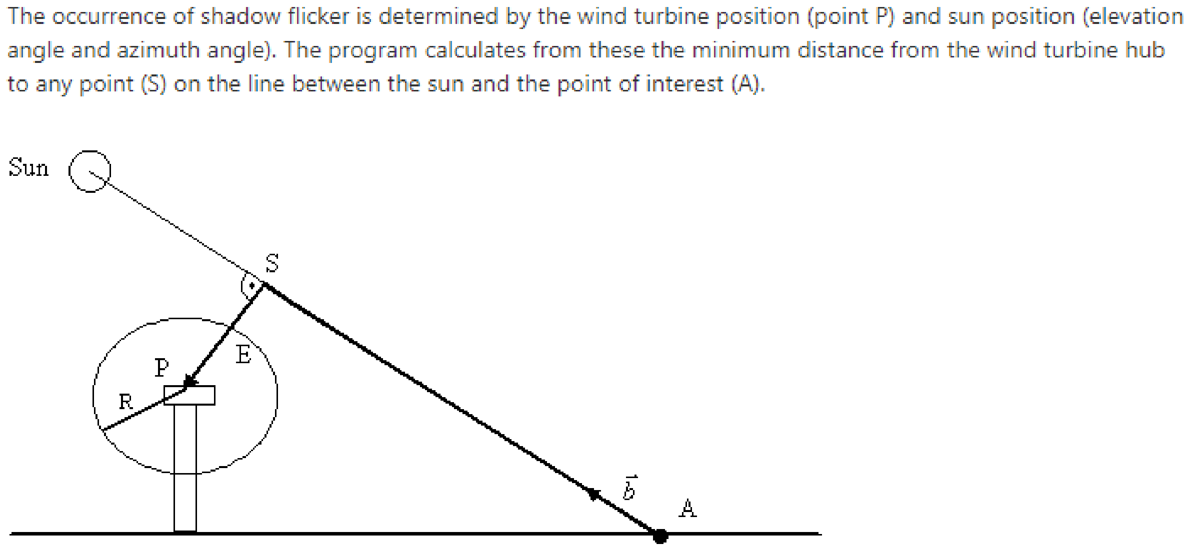
Codroy Wind Farm Shadow Flicker Project Location

Figure 2.1

3.0 Assessment Cases

Shadow flicker occurs when the spinning rotor of a wind turbine is located between the sun and a receptor such as a window at a residence. As the turbine blades alternately block sunlight and allow sunlight to shine through, the shadow at the receptor point may be observed to flicker under certain environmental conditions. For shadow flicker to occur, the sun must be shining, the sun must be low enough in the sky that the shadow from the wind turbine falls across the receptor, the wind turbine must be active (i.e., the rotor must be spinning), and the turbine rotor must be oriented such that the blades are not parallel to the line joining the sun and the receptor. Obstacles such as terrain, trees, or buildings between the wind turbine and a potential receptor may reduce or eliminate shadow flicker effects. By considering the spatial relationship between the turbines and the receptors (geographic locations and ground elevations) as well as the geometry of the turbines (hub height and rotor size), the occurrence of shadow flicker can be modeled and predicted to within a few minutes at any location around the wind farm.

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensity diminishes with greater receptor-to-turbine separation distance. Shadow flicker for receptor-to-turbine distances beyond 1,500 m is very low intensity and is generally considered imperceptible to the human eye. A 1,500 m receptor-to-turbine boundary was used for this analysis (Figure 3.1).



The occurrence of shadow flicker is determined by the wind turbine position (point P) and sun position (elevation angle and azimuth angle). The program calculates from these the minimum distance from the wind turbine hub to any point (S) on the line between the sun and the point of interest (A).

Figure 3.1 Diagram of Sun Angle Relative to the Turbine and Shadow Receptor[4]

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[4] Shadow Flicker | WindFarmer Documentation (azureedge.net) accessed May 2023

The shadow flicker assessment considered two assessment cases representing two different sets of environmental conditions:

- "Worst Case" assumes that the sun is always shining during daylight hours (i.e., there are no cloudy periods), all Project wind turbines are always active (i.e., rotors spinning), and all Project wind turbines are always oriented with their rotors perpendicular to the line joining the sun and all receptor points. "Worst Case" is highly conservative (i.e., likely to overestimate potential shown flicker effects) because the sun is not always visible, and Project wind turbines are not always active. In addition, the orientation of the Project wind turbines will change continuously based on wind direction, so turbine rotors are not always oriented perpendicular to the line joining the sun and receptor.
- "Expected Cases" makes use of statistical weather data to reduce some of the conservatism inherent in the "Worst Case" assessment. In particular, "Expected Case" uses statistical weather data to estimate the probability of sunshine for each month of the year. Even with the use of statistical weather data, "Expected Case" is still a conservative evaluation of potential shadow flicker effects because it assumes that Project wind turbines are always active (i.e., turbine rotors are always spinning), and turbine rotors are always oriented perpendicular to the line joining the sun and receptor, which is not the case.

4.0 Shadow Receptors

The Project shadow flicker assessment considered potentially active dwellings located within 1,500 m of the proposed turbine locations for the Project. A total of 28 potential receptors (buildings visible on imagery that may be residences or seasonal dwellings) were identified through review of google imagery are included in this study for the Codroy wind farm. The receptor locations and the 1,500 m criteria boundary are shown in Figure 1 and coordinates for the 28 receptors are provided in Table 1.

Table 1 Receptor Locations within 1,500 m Assessment Area for the Codroy Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	Northing (m)
R1	360069	5328186
R2	361088	5332795
R3	366172	5326966
R4	367468	5326331
R5	368008	5324629
R6	367716	5323937
R7	368091	5322772
R8	362650	5319216
R9	363027	5318978
R10	363284	5318900
R11	361697	5319303
R12	361683	5319334
R13	356132	5324205
R14	344785	5322091
R15	347980	5322660
R16	341307	5317087
R17	362509	5326045
R18	362617	5326145
R19	366750	5323127
R20	355764	5328001
R21	355550	5328327
R22	367842	5324198
R23	367826	5324350
R24	367868	5324420
R25	368039	5324043

Table 1 Receptor Locations within 1,500 m Assessment Area for the Codroy Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	**Northing (m)**
R26	367639	5323779
R27	368125	5322829
R28	366518	5320011

5.0 Shadow Flicker Analysis

5.1 Methods

Shadow flicker modeling was performed with the Windfarmer Version 5.3 software package. The Windfarmer shadow flicker model determines the theoretical maximum amount of shadow flicker, in total hours of flicker per year, at any point up to the specified calculation distance, specified in the model, from the turbines. By defining the specific shadow receptor locations, the model can also determine the time of day, day of year, and duration of every possible occurrence of shadow flicker at a receptor.

The shadow flicker model uses the following inputs:

- Latitude where the wind farm is located
- Longitude where the wind farm is located
- Time zone
- Minimum elevation angle of the sun
- Calculation time interval
- Distance from turbine for calculation
- Resolution of calculation points
- Turbine and shadow receptor locations
- Turbine dimensions (hub height, rotor diameter, distance between rotor and turbine tower centre)

The amount of shadow flicker determined by the model is the theoretical maximum amount due to the following assumptions:

- Every day is sunny and cloudless
- The turbines are always operating
- The rotor plane is always perpendicular to the sun
- There are no obstacles such as trees or walls between the receptors and the turbines
- The limits of human perception of changing light intensity are not considered

The theoretical maximum amount of shadow flicker is unlikely to occur due to the low probability of the above combination of assumptions. To more realistically evaluate the number of hours that a receptor will be affected by the shadow flicker effect, some assumptions about the actual working conditions can be considered. The most common method used to evaluate real shadow flicker conditions is to include long-term climate records about bright sunshine hours or cloud cover that are available from Environment and Climate Change Canada (ECCC) reference stations. In reality, the sun is often covered by clouds, and the actual number of shadow flicker hours that a receptor experience is lower than what the model predicts. Table 2 provides the probability of bright sunshine hours for the ECCC 1981-2010 Climate Normals and Averages Stephenville, NF Station located approximately 55 km from the centre of the Codroy wind farm.

Table 2 Probability of Bright Sunshine Hours for the ECCC Stephenville, NL Station

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Average
Probability of Bright Sunshine Hours (%)	15.4	25.6	31.7	34.6	43.5	42.4	42.4	45.4	38.5	33.9	18	10.2	31.8
Hours	41.9	73.3	116.7	141.7	205.2	204.2	206.2	201.6	145.7	114.1	50.1	26.6	1,527
Days with Bright Sunshine	18.5	19.1	24	24.1	26.3	25.2	27.5	27.3	26.1	25.1	19.8	15.3	278.2
Source: ECCC 2023													

5.2 Model Parameters

The parameters used in the Windfarmer shadow flicker model are presented in Table 3.

Table 3 Model Parameters

Latitude	47 deg 59 min North
Longitude	59 deg 0 min West
Time zone from GMT	-03 hours 30 minutes
Default for Receptors: Max minutes per day	984
Default for Receptors: Max hours per year	2,544
Calculation time interval	10 minutes
Maximum distance from centre of each turbine	1,500 m
Minimum sun elevation	3 deg
Receptor window height	2 m
Year of calculation	2023
Model the sun as a disc	No
Consider distance between rotor and tower	Yes
Turbine orientation	Rotor plane facing azimuth +180
Terrain: consider sun and turbine visibility	Yes
Visibility line of sign algorithm checks every	10.0 m

The Windfarmer model predicted shadow flicker effects at each of the 15 receptors. In the "worst case," the model assumed that the sun was always shining, the wind turbines were always active, and the turbine rotors were always oriented perpendicular to the line joining the sun and each receptor point. In the "expected case," the model was adjusted to account for statistical monthly sunshine data. Modeling for both the "worst case" and "expected case" considered screening by terrain features (i.e., hills and valleys), but neither assessment case considered screening effects from trees, outbuildings, or other local structures.

6.0 Results

The shadow flicker assessment considered dwellings located within 1,500 m of the proposed turbine locations for the Codroy wind farm. A shadow flicker contour map was produced to show the “Expected Case” maximum hours of shadow flicker throughout the Codroy wind farm at 2 m above ground level. The shadow flicker contour map is shown in Figure 3.

Table 4 presents the shadow flicker modelling results for the “Worst Case” and the “Expected Case” at the receptor locations. Receptors not shown in Table 4 do not have expected shadow flicker impact. For the “Worst Case,” results are presented in the form of total hours of shadow flicker per year, the number of days per year with shadow flicker, and the maximum minutes of shadow flicker on a single day. Since the statistics used to calculate results for the “Expected Case” include annual averages, results for this case are presented in the form of total hours of shadow flicker **per year only**.

Table 4 Shadow Flicker Results for Codroy Wind Farm

Receptor Identification Code	“Worst Case”			Turbine(s) Causing Shadow Flicker	“Expected Case” * Total Hours of Shadow Flicker Per Year “HH:MM”
	Total Hours of Shadow Flicker Per Year “HH”	Number of Days Per Year with Shadow Flicker	Maximum Minutes of Shadow Flicker on a Single Day “MM”		
R1	76	182	40	111, 112, 115	29:23
R2	2	15	10	9	00:15
R3	24	55	40	14	02:58
R4	1	11	10	14	00:37
R5	7	35	20	127	03:22
R6	3	23	10	128	01:40
R7	9	30	30	10	03:23
R13	27	82	30	93, 94	11:04
R14	106	173	60	40, 41, 43	21:45
R15	153	220	70	36, 37, 84, 85	59:17
R16	261	264	100	2, 39, 47, 48	97:51
R17	9	30	20	12	03:35
R18	9	31	30	12	03:20
R19	83	139	60	10, 15, 16	17:54
R20	73	153	50	26, 27, 28	20:51
R21	58	115	40	26, 27	15:04
R22	<1	4	10	128	00:16
R26	8	49	10	128	03:27
R27	10	29	30	10	03:33

Note:
* Annual Predicted Shadow Flicker adjusted by monthly probability of bright sunshine hours.

Based on the results of the assessment of shadow flicker levels for the Codroy wind farm, it was determined that nine (9) of the 28 receptors in near the Codroy wind farm will experience no shadow flicker, and 19 receptors may be affected by shadow flicker to varying degrees.

The expected shadow flicker from the Codroy wind farm WTGs experienced by the 19 affected receptors will be lower than the theoretical maximum values since there will be times when the turbine blades are not spinning, and since clouds, wind direction, trees and obstacles reduce the potential for shadow flicker. Given the conservative assumptions used in the shadow flicker model, it is likely that site specific conditions will further reduce the amount of shadow flicker that is actually observed throughout the year.

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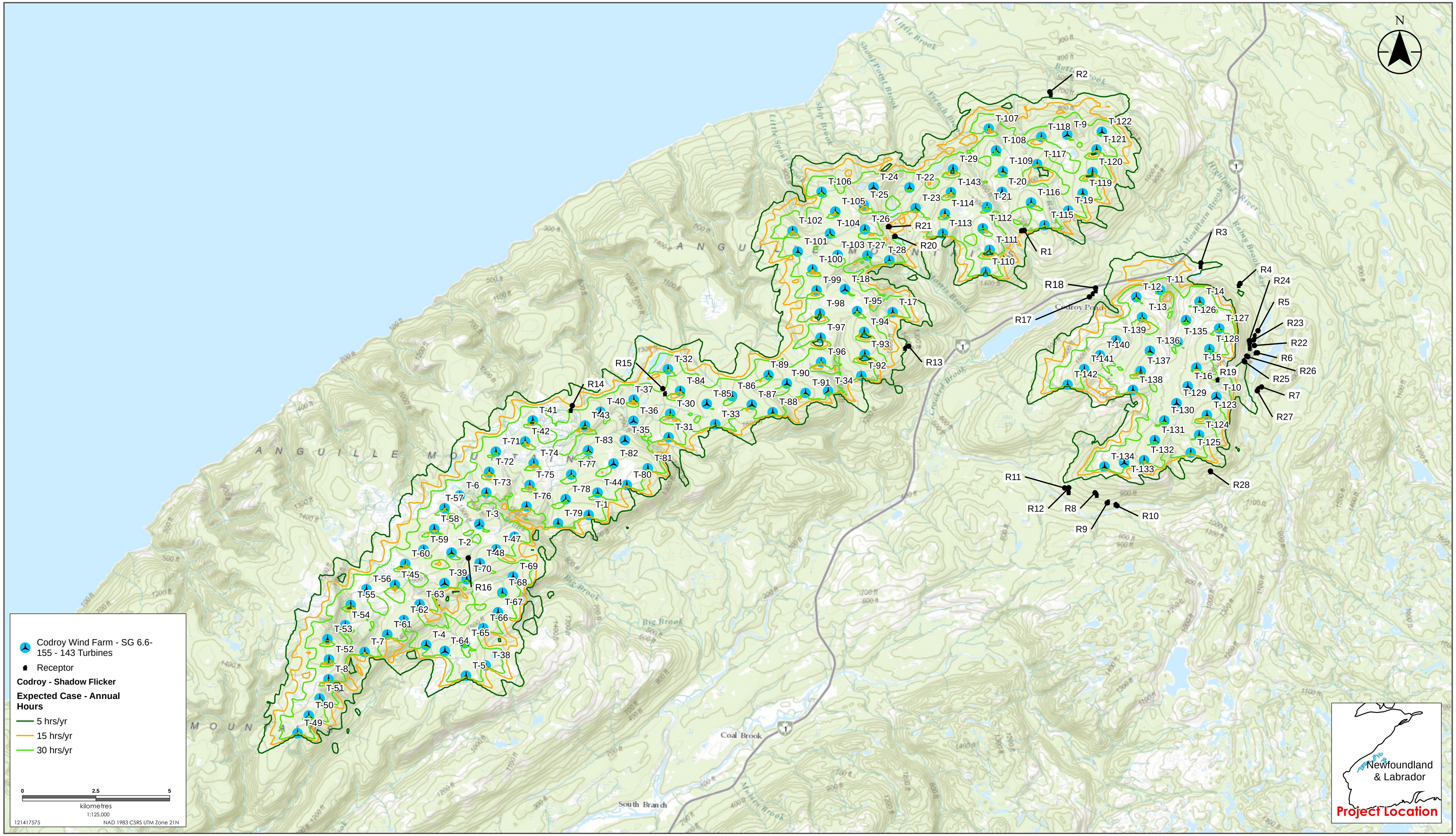

Sources: Base Data -Government of Canada, CanVec, ESRI
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

CODROY WIND FARM

Codroy Wind Farm Shadow Flicker - Expected Case - Annual Hours per Year

Figure 6.1

7.0 Conclusions

A shadow flicker assessment was completed for the Codroy wind farm. The shadow flicker assessment evaluated two conservative modelling scenarios: “Worst Case” and “Expected Case.” The receptors with modelled shadow flicker for the Codroy wind farm are listed in Table 4.

The “Worst Case” assessment assumed that the sun is always shining during daylight hours (i.e., there are no cloudy periods), all Project wind turbines are always active (i.e., rotors spinning), and all Project wind turbines are always oriented with their rotors perpendicular to the line joining the sun and all receptors. The “Expected Case” assessment used statistical weather data to estimate the probability of sunshine for each month of the year. Both assessment cases assumed that receptors are sensitive to shadow flicker in any direction and neither assessment case accounted for the screening of shadow flicker by vegetation, outbuildings, or other structures.

In the “Expected Case” assessment, receptors R15 and R16 are predicted to have the highest levels of shadow flicker, however, actual shadow flicker experienced by the receptors is likely to be reduced by the presence of vegetation, which may provide partial screening for the Codroy turbines during those hours when the sun is low enough to create long shadows. The shadow flicker assessment evaluated the current turbine layout and initial identified receptor locations, however, World Energy GH2 is committed to not constructing turbines within 1 km from a receptor location, and the proximity of these turbines to receptors will either require a turbine relocation or engagement with receptor owners.

A commonly used assessment criterion or allowable limit for shadow flicker is 30 hours per year (Koppen et al 2017). This analysis indicates that approximately 92.8 percent, or 26 of the 28 receptor locations evaluated have less than 30 hours per year of predicted shadow flicker impact when taking into account cloud cover. .

Given the conservative assumptions used in the shadow flicker model, it is likely that site specific conditions will further reduce the amount of shadow flicker that is actually observed throughout the year. Site specific conditions that may mitigate shadow flicker impact include trees or buildings that block the line of sight to the proposed turbine locations, seasonal or intermittent use, or the absence of windows facing the direction of the wind farm.

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APPENDIX A

Codroy Wind Farm Turbine Locations

Appendix A Codroy Wind Farm Turbine Locations

Table A.1 Codroy Wind Farm Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	Northing (m)	
T-01	Siemens Gamesa SG-155 6.6 MW	345388	5318536	122.5
T-02	Siemens Gamesa SG-155 6.6 MW	340731	5317258	122.5
T-03	Siemens Gamesa SG-155 6.6 MW	341672	5318222	122.5
T-04	Siemens Gamesa SG-155 6.6 MW	339867	5314129	122.5
T-05	Siemens Gamesa SG-155 6.6 MW	341221	5313079	122.5
T-06	Siemens Gamesa SG-155 6.6 MW	341003	5319191	122.5
T-08	Siemens Gamesa SG-155 6.6 MW	337777	5313883	122.5
T-09	Siemens Gamesa SG-155 6.6 MW	336552	5312964	122.5
T-10	Siemens Gamesa SG-155 6.6 MW	361641	5331440	122.5
T-11	Siemens Gamesa SG-155 6.6 MW	366708	5322543	122.5
T-12	Siemens Gamesa SG-155 6.6 MW	364790	5326171	122.5
T-13	Siemens Gamesa SG-155 6.6 MW	363987	5325930	122.5
T-14	Siemens Gamesa SG-155 6.6 MW	364182	5325241	122.5
T-15	Siemens Gamesa SG-155 6.6 MW	366134	5325769	122.5
T-16	Siemens Gamesa SG-155 6.6 MW	366030	5323530	122.5
T-17	Siemens Gamesa SG-155 6.6 MW	365732	5322899	122.5
T-18	Siemens Gamesa SG-155 6.6 MW	355709	5325413	122.5
T-19	Siemens Gamesa SG-155 6.6 MW	354091	5326194	122.5
T-20	Siemens Gamesa SG-155 6.6 MW	361679	5328857	122.5
T-21	Siemens Gamesa SG-155 6.6 MW	359418	5329489	122.5
T-22	Siemens Gamesa SG-155 6.6 MW	358912	5328984	122.5
T-23	Siemens Gamesa SG-155 6.6 MW	356283	5329638	122.5
T-24	Siemens Gamesa SG-155 6.6 MW	356490	5328938	122.5
T-25	Siemens Gamesa SG-155 6.6 MW	355059	5329650	122.5
T-26	Siemens Gamesa SG-155 6.6 MW	354730	5329045	122.5
T-28	Siemens Gamesa SG-155 6.6 MW	354768	5328226	122.5
T-30	Siemens Gamesa SG-155 6.6 MW	354852	5327338	122.5
T-32	Siemens Gamesa SG-155 6.6 MW	355594	5327170	122.5
T-33	Siemens Gamesa SG-155 6.6 MW	357761	5330262	122.5
T-35	Siemens Gamesa SG-155 6.6 MW	348155	5321965	122.5

Table A.1 Codroy Wind Farm Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N) Easting (m)	Northing (m)	Hub Height (m)
T-36	Siemens Gamesa SG-155 6.6 MW	348101	5321169	122.5
T-37	Siemens Gamesa SG-155 6.6 MW	348079	5323481	122.5
T-38	Siemens Gamesa SG-155 6.6 MW	349686	5321613	122.5
T-39	Siemens Gamesa SG-155 6.6 MW	353520	5322738	122.5
T-40	Siemens Gamesa SG-155 6.6 MW	346617	5321073	122.5
T-41	Siemens Gamesa SG-155 6.6 MW	346905	5321730	122.5
T-42	Siemens Gamesa SG-155 6.6 MW	346915	5322440	122.5
T-43	Siemens Gamesa SG-155 6.6 MW	341887	5313431	122.5
T-44	Siemens Gamesa SG-155 6.6 MW	340492	5316223	122.5
T-45	Siemens Gamesa SG-155 6.6 MW	345782	5322034	122.5
T-46	Siemens Gamesa SG-155 6.6 MW	343486	5321736	122.5
T-47	Siemens Gamesa SG-155 6.6 MW	343226	5321024	122.5
T-48	Siemens Gamesa SG-155 6.6 MW	345262	5321567	122.5
T-49	Siemens Gamesa SG-155 6.6 MW	345687	5319294	122.5
T-50	Siemens Gamesa SG-155 6.6 MW	338802	5316164	122.5
T-51	Siemens Gamesa SG-155 6.6 MW	342866	5317794	122.5
T-52	Siemens Gamesa SG-155 6.6 MW	342246	5317365	122.5
T-53	Siemens Gamesa SG-155 6.6 MW	341688	5316898	122.5
T-56	Siemens Gamesa SG-155 6.6 MW	335496	5311135	122.5
T-57	Siemens Gamesa SG-155 6.6 MW	335878	5311732	122.5
T-58	Siemens Gamesa SG-155 6.6 MW	336246	5312314	122.5
T-59	Siemens Gamesa SG-155 6.6 MW	336567	5313630	122.5
T-60	Siemens Gamesa SG-155 6.6 MW	336528	5314216	122.5
T-61	Siemens Gamesa SG-155 6.6 MW	337276	5314859	122.5
T-62	Siemens Gamesa SG-155 6.6 MW	337302	5315482	122.5
T-63	Siemens Gamesa SG-155 6.6 MW	337838	5316018	122.5
T-64	Siemens Gamesa SG-155 6.6 MW	340494	5318766	122.5
T-66	Siemens Gamesa SG-155 6.6 MW	340142	5318062	122.5
T-67	Siemens Gamesa SG-155 6.6 MW	339782	5317358	122.5
T-68	Siemens Gamesa SG-155 6.6 MW	339154	5316875	122.5
T-69	Siemens Gamesa SG-155 6.6 MW	338542	5314480	122.5
T-71	Siemens Gamesa SG-155 6.6 MW	339108	5314970	122.5
T-72	Siemens Gamesa SG-155 6.6 MW	339644	5315505	122.5

Table A.1 Codroy Wind Farm Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	Northing (m)	
T-73	Siemens Gamesa SG-155 6.6 MW	340501	5313921	122.5
T-74	Siemens Gamesa SG-155 6.6 MW	341182	5314189	122.5
T-75	Siemens Gamesa SG-155 6.6 MW	341810	5314694	122.5
T-76	Siemens Gamesa SG-155 6.6 MW	342308	5315237	122.5
T-77	Siemens Gamesa SG-155 6.6 MW	342456	5315903	122.5
T-78	Siemens Gamesa SG-155 6.6 MW	342820	5316454	122.5
T-79	Siemens Gamesa SG-155 6.6 MW	341244	5316355	122.5
T-80	Siemens Gamesa SG-155 6.6 MW	342231	5320687	122.5
T-81	Siemens Gamesa SG-155 6.6 MW	342009	5319998	122.5
T-83	Siemens Gamesa SG-155 6.6 MW	341910	5319294	122.5
T-84	Siemens Gamesa SG-155 6.6 MW	343521	5320290	122.5
T-85	Siemens Gamesa SG-155 6.6 MW	343381	5319551	122.5
T-86	Siemens Gamesa SG-155 6.6 MW	343275	5318830	122.5
T-87	Siemens Gamesa SG-155 6.6 MW	344795	5319906	122.5
T-88	Siemens Gamesa SG-155 6.6 MW	344604	5319072	122.5
T-89	Siemens Gamesa SG-155 6.6 MW	344343	5318249	122.5
T-90	Siemens Gamesa SG-155 6.6 MW	346678	5319554	122.5
T-91	Siemens Gamesa SG-155 6.6 MW	347390	5320121	122.5
T-92	Siemens Gamesa SG-155 6.6 MW	346226	5320281	122.5
T-93	Siemens Gamesa SG-155 6.6 MW	345369	5320725	122.5
T-94	Siemens Gamesa SG-155 6.6 MW	348492	5322746	122.5
T-95	Siemens Gamesa SG-155 6.6 MW	349395	5322302	122.5
T-96	Siemens Gamesa SG-155 6.6 MW	350260	5322570	122.5
T-97	Siemens Gamesa SG-155 6.6 MW	350926	5322279	122.5
T-98	Siemens Gamesa SG-155 6.6 MW	351638	5322019	122.5
T-99	Siemens Gamesa SG-155 6.6 MW	351500	5323282	122.5
T-100	Siemens Gamesa SG-155 6.6 MW	352120	5322998	122.5
T-101	Siemens Gamesa SG-155 6.6 MW	352755	5322677	122.5
T-102	Siemens Gamesa SG-155 6.6 MW	354647	5323249	122.5
T-103	Siemens Gamesa SG-155 6.6 MW	354761	5323984	122.5
T-104	Siemens Gamesa SG-155 6.6 MW	354744	5324740	122.5
T-105	Siemens Gamesa SG-155 6.6 MW	354504	5325448	122.5
T-106	Siemens Gamesa SG-155 6.6 MW	353284	5323720	122.5

Table A.1 Codroy Wind Farm Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	Northing (m)	
T-107	Siemens Gamesa SG-155 6.6 MW	353266	5324546	122.5
T-108	Siemens Gamesa SG-155 6.6 MW	353241	5325367	122.5
T-109	Siemens Gamesa SG-155 6.6 MW	353126	5326159	122.5
T-110	Siemens Gamesa SG-155 6.6 MW	352992	5326864	122.5
T-111	Siemens Gamesa SG-155 6.6 MW	352487	5327468	122.5
T-112	Siemens Gamesa SG-155 6.6 MW	352311	5328169	122.5
T-113	Siemens Gamesa SG-155 6.6 MW	353842	5327353	122.5
T-114	Siemens Gamesa SG-155 6.6 MW	353583	5328082	122.5
T-115	Siemens Gamesa SG-155 6.6 MW	353765	5328823	122.5
T-116	Siemens Gamesa SG-155 6.6 MW	353298	5329496	122.5
T-117	Siemens Gamesa SG-155 6.6 MW	358977	5331639	122.5
T-118	Siemens Gamesa SG-155 6.6 MW	359222	5330897	122.5
T-119	Siemens Gamesa SG-155 6.6 MW	359452	5330193	122.5
T-120	Siemens Gamesa SG-155 6.6 MW	358866	5326779	122.5
T-121	Siemens Gamesa SG-155 6.6 MW	359004	5327526	122.5
T-122	Siemens Gamesa SG-155 6.6 MW	358772	5328258	122.5
T-123	Siemens Gamesa SG-155 6.6 MW	357417	5328082	122.5
T-124	Siemens Gamesa SG-155 6.6 MW	357485	5328754	122.5
T-125	Siemens Gamesa SG-155 6.6 MW	360864	5328364	122.5
T-126	Siemens Gamesa SG-155 6.6 MW	360409	5329129	122.5
T-127	Siemens Gamesa SG-155 6.6 MW	360615	5330430	122.5
T-128	Siemens Gamesa SG-155 6.6 MW	360761	5331356	122.5
T-129	Siemens Gamesa SG-155 6.6 MW	362169	5329443	122.5
T-130	Siemens Gamesa SG-155 6.6 MW	362498	5330162	122.5
T-131	Siemens Gamesa SG-155 6.6 MW	362636	5330935	122.5
T-132	Siemens Gamesa SG-155 6.6 MW	362816	5331532	122.5
T-133	Siemens Gamesa SG-155 6.6 MW	366386	5321923	122.5
T-134	Siemens Gamesa SG-155 6.6 MW	366122	5321246	122.5
T-135	Siemens Gamesa SG-155 6.6 MW	365835	5320649	122.5
T-136	Siemens Gamesa SG-155 6.6 MW	365674	5325138	122.5
T-137	Siemens Gamesa SG-155 6.6 MW	366800	5324862	122.5
T-138	Siemens Gamesa SG-155 6.6 MW	366467	5324162	122.5
T-139	Siemens Gamesa SG-155 6.6 MW	365353	5322325	122.5

Table A.1 Codroy Wind Farm Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	Northing (m)	
T-140	Siemens Gamesa SG-155 6.6 MW	364940	5321739	122.5
T-141	Siemens Gamesa SG-155 6.6 MW	364618	5321073	122.5
T-142	Siemens Gamesa SG-155 6.6 MW	364251	5320396	122.5
T-143	Siemens Gamesa SG-155 6.6 MW	357692	5329481	122.5

Appendix 19-D

Port au Port Wind Farm, Shadow Flicker Assessment

PROJECT NUJIO'QONIK
Port au Port Wind Farm, Shadow Flicker Assessment

August 2023

Prepared for:

world energy GH$_2$

Prepared by:

Stantec Consulting Ltd.

File: 121417575

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Anna Kozicky, P.Eng

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Abbreviations

EA	environmental assessment
ECCC	Environment and Climate Change Canada
EIS	Environmental Impact Statement
GW	Gigawatt
km	kilometers
m	meters
MW	megawatt
NL	Newfoundland and Labrador
Stantec	Stantec Consulting Ltd.
the Project	Project Nujio'qonik
The Proponent	World Energy GH2
WTG	wind turbine generator

1.0 Introduction

Project Nujio'qonik (the Project) involves the development, construction, operation and maintenance, and eventual decommissioning and rehabilitation of one of the first Canadian, commercial-scale, "green hydrogen"[1] and ammonia production plants powered by renewable wind energy. Located on the western coast of the island of Newfoundland, Newfoundland and Labrador (NL) (Figure 2.1), the Project will have a maximum production of up to approximately 206,000 t of green hydrogen (equivalent to approximately 1.17 megatonnes (Mt) of ammonia) per year. The hydrogen produced by the Project will be converted into ammonia and exported to international markets by ship. The hydrogen / ammonia plant and associated storage and export facilities will be located at the Port of Stephenville (in the Town of Stephenville, NL) on a privately-owned brownfield site and at an adjacent existing marine terminal, both of which are zoned for industrial purposes.

Renewable energy from two approximately 1,000 megawatt (MW) / 1 gigawatt (GW) onshore wind farms on the western coast of Newfoundland will be used to power the hydrogen and ammonia production processes. These wind farms (referred to herein as the "Port au Port area wind farm" and the "Codroy area wind farm") will include up to 328 turbines and collectively produce approximately 2,000 MW / 2 GW of renewable electricity. The Port au Port wind farm layout under consideration consists of 171 turbine locations on the Port au Port Peninsula, NL and adjacently on the Newfoundland "mainland" (i.e., northeast of the isthmus at Port au Port, on Table Mountain). The final layout of the Port au Port wind farm will ultimately consist of up to 164 turbines when constructed. The Codroy wind farm layout under consideration consists of 143 turbine locations. The final layout of the Codroy wind farm will also consist of up to 164 wind turbines located on Crown land in the Anguille Mountains of the Codroy Valley, NL. The final total nameplate capacity for each wind farm is expected to be approximately 1,000 MW / 1 GW. The modelling and assessment work is based on preliminary layouts for both wind farm sites (i.e., 171 potential turbine locations at the Port au Port wind farm and 143 potential turbine locations at Codroy wind farm). Final wind farm layouts will be dependent on results of the wind campaign and more detailed field investigations. Once the layout and number of turbines are finalized, the results of models will be reviewed and updated as required. If additional turbine locations are added to the Codroy wind farm in the future, it will be done in consideration of the mitigation measures, compliance with regulations, and such that the conclusions of the effects assessment do not change.

The Project is subject to provincial environmental assessment (EA) requirements under the NL *Environmental Protection Act* and associated *Environmental Assessment Regulations* (EA Regulations). This document is the daytime Shadow Flicker Study for the Port au Port wind farm, prepared in support of an Environmental Impact Statement (EIS) and required under section 4.3.1 of the EIS Guidelines.

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[1] "Green hydrogen" is produced via electrolysis using renewable electricity to split water into hydrogen and oxygen. This type of hydrogen, which is referred to by the European Commission (n.d.) as "renewable fuel of non-biological origin", is often called "green hydrogen" in industry.

Shadow flicker is a temporary condition resulting from the sun casting intermittent shadows from the rotating blades of a wind turbine onto a receptor such as a window in a building. The flicker is due to alternating light intensity between the direct beam of sunlight and the shadow from the turbine blades. Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensity diminishes with greater receptor-to-turbine separation distance. Shadow flicker for receptor-to-turbine distances beyond 1,500 metres (m) is very low intensity and generally considered imperceptible by the human eye.

This document provides an analysis of daytime shadow flicker for the Port au Port wind farm. Nightime illumination is provided in the lighting assessment. The analysis of potential shadow flicker was conducted using the Windfarmer Version 5.3 software package. The purpose of this report is to estimate the impact of shadow flicker on receptors for both the 'expected case' and 'worst case' modelling scenarios for the Port au Port wind farm. The report is structured as follows:

- Section 1 provides a brief introduction.
- Section 2 describes the Port au Port wind farm site and turbine layout.
- Section 3 provides a description of the assessment cases.
- Section 4 identified the potential shadow receptors near the Port au Port wind farm.
- Section 5 summarizes the shadow flicker analysis methodology and presents the results from the shadow flicker analysis.

Currently there are no provincial regulations in NL regarding exceedance limits for shadow flicker. In the absence of provincial guidance, the Codroy wind farm shadow flicker assessment compared the predicted shadow flicker to a worst case exposure limit of 30 hours per year (Koppen et al. 2017). Analysis by Koppen et al. identified that while many international regulatory regimes do not have legislated thresholds or guidance, most use a 30 hour per year limit for worst case scenario analysis. This is largely based on German guideline - "Guideline for Identification and Evaluation of the Optical Emissions of Wind Turbines" that is considered to be a common International standard, and is currently used by regulators in Nova Scotia[2].

The analysis provided in this report focuses on the total amount of time (hours and minutes per year) the shadow flicker can potentially occur at receptors regardless of whether the shadow flicker is barely noticeable or clearly distinct. As a result of this conservative approach, it is likely that receptors will experience less shadow flicker impact than modeled and reported, especially those that are farther away from the turbines. It is likely that marginally affected receptors may not be able to identify shadow flicker as the shadows become more diffuse with increased distance.

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[2] https://novascotia.ca/nse/ea/docs/EA.Guide-Proponents-WindPowerProjects.pdf accessed May 23, 2023.

2.0 Project Details

2.1 Site Description

The Port au Port wind farm is located on the west coast of the Island of Newfoundland, in the province of NL. The Port au Port wind farm is located on the Port au Port Peninsula, in a rural region with approximately 20 insular communities. The terrain on the Port au Port Peninsula is generally hilly, with many steep slopes and cliffs along the coastline. There are several areas with exposed, weathered bedrock and barrens with low-lying shrubs. There are forested areas, as well as some wetlands. The Port au Port wind farm is shown in Figure 2.1.

There are 790 receptors located within 1,500 m of the Port au Port wind farm (Figure 2.1). For additional information on receptors, please see Section 4.

2.2 Turbine Description

The Port au Port wind farm will consist of up to 171 turbines. This study assumes that Siemens Gamesa SG-155 6.6 MW wind turbines generators (WTGs) will be used. These wind turbines will consist of three-blade rotors, and tubular towers. The SG-155 WTG have a nominal rated capacity of 6.6 MW, maximum hub heights of 122.5 m, and a blade rotor diameter of 155 m. Use of this turbine model represents a "worst case" conservative input to the assessment of shadow flicker.

2.3 Turbine Locations

The proposed layout of the Port au Port wind farm is shown in Figure 2.1 and coordinates for the 171 turbines are provided in Appendix A [3].

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[3] Turbine locations provided by the Proponent. Siting analysis not completed as part of shadow flicker assessment.

Z:\World_Energy_Shadow_Flicker\Figure1_PortauPort.mxd 4/24/2023 2:03:51 PM dimunroe

Sources: Base Data -Government of Canada, CanVec, ESRI
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Stantec

CODROY WIND FARM

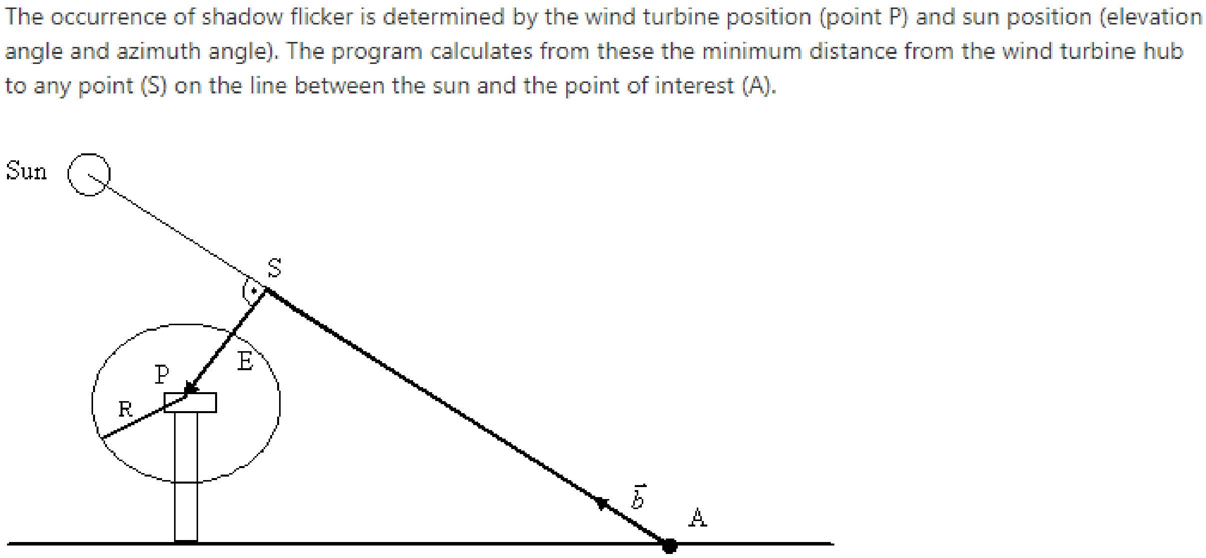
Port au Port Wind Farm Shadow Flicker Project Location

Figure 2.1

3.0 Assessment Cases

Shadow flicker occurs when the spinning rotor of a wind turbine is located between the sun and a receptor such as a window at a residence. As the turbine blades alternately block sunlight and allow sunlight to shine through, the shadow at the receptor point may be observed to flicker under certain environmental conditions. For shadow flicker to occur, the sun must be shining, the sun must be low enough in the sky that the shadow from the wind turbine falls across the receptor, the wind turbine must be active (i.e., the rotor must be spinning), and the turbine rotor must be oriented such that the blades are not parallel to the line joining the sun and the receptor. Obstacles such as terrain, trees, or buildings between the wind turbine and a potential receptor may reduce or eliminate shadow flicker effects. By considering the spatial relationship between the turbines and the receptors (geographic locations and ground elevations) as well as the geometry of the turbines (hub height and rotor size), the occurrence of shadow flicker can be modeled and predicted to within a few minutes at any location around the wind farm.

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensity diminishes with greater receptor-to-turbine separation distance. Shadow flicker for receptor-to-turbine distances beyond 1,500 m is very low intensity and is generally considered imperceptible to the human eye. A 1,500 m receptor-to-turbine boundary was used for this analysis.



The occurrence of shadow flicker is determined by the wind turbine position (point P) and sun position (elevation angle and azimuth angle). The program calculates from these the minimum distance from the wind turbine hub to any point (S) on the line between the sun and the point of interest (A).

Figure 3.1 Diagram of Sun Angle Relative to the Turbine and Shadow Receptor [4]

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[4] Shadow Flicker | WindFarmer Documentation (azureedge.net) accessed May 2023.

The shadow flicker assessment for the Project considered two assessment cases representing two different sets of environmental conditions:

- "Worst Case" assumes that the sun is always shining during daylight hours (i.e., there are no cloudy periods), all Project wind turbines are always active (i.e., rotors spinning), and all Project wind turbines are always oriented with their rotors perpendicular to the line joining the sun and all receptor points. "Worst Case" is highly conservative (i.e., likely to overestimate potential shown flicker effects) because the sun is not always visible, and Project wind turbines are not always active. In addition, the orientation of the Project wind turbines will change continuously based on wind direction, so turbine rotors are not always oriented perpendicular to the line joining the sun and receptor.
- "Expected Cases" makes use of statistical weather data to reduce some of the conservatism inherent in the "Worst Case" assessment. In particular, "Expected Case" uses statistical weather data to estimate the probability of sunshine for each month of the year. Even with the use of statistical weather data, "Expected Case" is still a conservative evaluation of potential shadow flicker effects because it assumes that Project wind turbines are always active (i.e., turbine rotors are always spinning), and turbine rotors are always oriented perpendicular to the line joining the sun and receptor, which is not the case.

4.0 Shadow Receptors

The Project shadow flicker assessment considered potentially active dwellings located within 1,500 m of the proposed turbine locations for the Project. A total of 790 potential receptors (buildings visible on imagery that may be residences or seasonal dwellings) that were identified per google imagery are included in this study for the Port au Port wind farm. The receptor locations and the 1,500 m criteria boundary are shown in Figure 2.1 and coordinates for the 790 receptors are provided in Appendix A.

5.0 Shadow Flicker Analysis

5.1 Methods

Shadow flicker modeling was performed with the Windfarmer Version 5.3 software package. The Windfarmer shadow flicker model determines the theoretical maximum amount of shadow flicker, in total hours of flicker per year, at any point up to the specified calculation distance, specified in the model, from the turbines. By defining the specific shadow receptor locations, the model can also determine the time of day, day of year, and duration of every possible occurrence of shadow flicker at a receptor.

The shadow flicker model uses the following inputs:

- Latitude where the wind farm is located
- Longitude where the wind farm is located
- Time zone
- Minimum elevation angle of the sun
- Calculation time interval
- Distance from turbine for calculation
- Resolution of calculation points
- Turbine and shadow receptor locations
- Turbine dimensions (hub height, rotor diameter, distance between rotor and turbine tower centre)

The amount of shadow flicker determined by the model is the theoretical maximum amount due to the following assumptions:

- Every day is sunny and cloudless
- The turbines are always operating
- The rotor plane is always perpendicular to the sun
- There are no obstacles such as trees or walls between the receptors and the turbines
- The limits of human perception of changing light intensity are not considered

The theoretical maximum amount of shadow flicker is unlikely to occur due to the low probability of the above combination of assumptions. To more realistically evaluate the number of hours that a receptor will be affected by the shadow flicker effect, some assumptions about the actual working conditions can be considered. The most common method used to evaluate real shadow flicker conditions is to include long-term climate records about bright sunshine hours or cloud cover that are available from Environment and Climate Change Canada (ECCC) reference stations. In reality, the sun is often covered by clouds, and the actual number of shadow flicker hours that a receptor experience is lower than what the model predicts. Table 5.1 provides the probability of bright sunshine hours for the ECCC 1981-2010 Climate Normals and Averages Stephenville, NF Station located approximately 30 kilometers (km) from the centre of the Port au Port wind farm.

Table 5.1 Probability of Bright Sunshine Hours for the ECCC Stephenville, NL Station

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Average
Probability of Bright Sunshine Hours (%)	15.4	25.6	31.7	34.6	43.5	42.4	42.4	45.4	38.5	33.9	18	10.2	31.8
Hours	41.9	73.3	116.7	141.7	205.2	204.2	206.2	201.6	145.7	114.1	50.1	26.6	1,527
Days with Bright Sunshine	18.5	19.1	24	24.1	26.3	25.2	27.5	27.3	26.1	25.1	19.8	15.3	278.2
Source: ECCC 2023													

5.2 Model Parameters

The parameters used in the Windfarmer shadow flicker model are presented in Table 5.2.

Table 5.2 Model Parameters

Latitude	47 deg 59 min North
Longitude	59 deg 0 min West
Time zone from GMT	-03 hours 30 minutes
Default for Receptors: Max minutes per day	984
Default for Receptors: Max hours per year	2,544
Calculation time interval	10 minutes
Maximum distance from centre of each turbine	1,500 m
Minimum sun elevation	3 deg
Receptor window height	2m above ground level
Year of calculation	2023
Model the sun as a disc	No
Consider distance between rotor and tower	Yes
Turbine orientation	Rotor plane facing azimuth +180
Terrain: consider sun and turbine visibility	Yes
Visibility line of sign algorithm checks every	10.0 m

The Windfarmer model predicted shadow flicker effects at each of the receptors listed in Table 5.2. In the "worst case," the model assumed that the sun was always shining, the wind turbines were always active, and the turbine rotors were always oriented perpendicular to the line joining the sun and each receptor point. In the "expected case," the model was adjusted to account for statistical monthly sunshine data, to account for turbine orientation based on wind direction data and the probability that the turbine is in motion. Modeling for both the "worst case" and "expected case" considered screening by terrain features (i.e., hills and valleys), but neither assessment case considered screening effects from trees, outbuildings, or other local structures.

6.0 Results

The shadow flicker assessment considered active dwellings located within 1,500 m of the proposed turbine locations for the Port au Port wind farm. A shadow flicker contour map was produced to show the "Expected Case" maximum hours of shadow flicker throughout the Port au Port wind farm at 2 m above ground level, the height of a typical outdoor facing window. The shadow flicker contour map is shown in Figure 6.1.

Table 6.1 presents the shadow flicker modelling results for the "Worst Case" and the "Expected Case" at the receptor locations. Receptors not shown in Table 6.1 do not have expected shadow flicker impact. For the "Worst Case," results are presented in the form of total hours of shadow flicker per year, the number of days per year with shadow flicker, and the maximum minutes of shadow flicker on a single day. Since the statistics used to calculate results for the "Expected Case" include annual averages, results for this case are presented in the form of total hours of shadow flicker **per year only**.

Based on the results of the assessment of shadow flicker levels for the Port au Port wind farm, it was determined that 498 of the 790 receptors in the near the Port au Port wind farm will experience no shadow flicker, and 292 receptors may be affected by shadow flicker to varying degrees.

The expected shadow flicker from the Port au Port WTGs experienced by the 292 affected receptors will be lower than the theoretical maximum values since there will be times when the turbine blades are not spinning, and since clouds, wind direction, trees and obstacles reduce the potential for shadow flicker. Given the conservative assumptions used in the shadow flicker model, it is likely that site specific conditions will further reduce the amount of shadow flicker that is actually observed throughout the year.

Sources: Base Data -Government of Canada, CanVec, ESRI
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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Port au Port Wind Farm Shadow Flicker - Expected Case - Annual Hours per Year

Figure 6.1

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

Receptor Identification Code	“Worst Case”			Turbine(s) Causing Shadow Flicker	“Expected Case” * Total Hours of Shadow Flicker Per Year “HH:MM”
	Total Hours of Shadow Flicker Per Year “HH”	Number of Days Per Year with Shadow Flicker	Maximum Minutes of Shadow Flicker on a Single Day “MM”		
R48	3	20	10	1	01:41
R49	3	18	10	1	01:16
R50	1	9	10	1	00:38
R110	1	7	10	186	00:24
R111	<1	2	10	186	00:06
R113	<1	1	10	186	00:03
R114	1	7	10	186	00:22
R115	<1	5	10	186	00:15
R116	<1	5	10	186	00:17
R117	1	7	10	186	00:22
R118	1	9	10	186	00:26
R119	3	21	10	31, 186	01:08
R120	<1	5	10	186	00:18
R121	2	17	10	31, 186	00:56
R122	3	18	10	31, 186	00:59
R123	1	10	10	186	00:29
R125	3	19	10	31, 186	00:58
R126	3	21	10	31, 186	01:04
R127	1	9	10	186	00:24
R128	1	8	10	31, 186	00:18
R129	1	10	10	31, 186	00:25
R130	2	15	10	31, 186	00:39
R131	3	19	10	31, 186	00:53
R132	2	16	10	31, 186	00:44
R133	3	18	10	31, 186	00:46
R134	3	20	10	31, 186	00:53
R135	2	15	10	31, 186	00:45
R136	1	10	10	31, 186	00:30
R137	2	16	10	31, 186	00:37
R138	2	17	10	31, 186	00:35
R139	3	20	10	31, 186	00:44

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

Receptor Identification Code	"Worst Case"			Turbine(s) Causing Shadow Flicker	"Expected Case" * Total Hours of Shadow Flicker Per Year "HH:MM"
	Total Hours of Shadow Flicker Per Year "HH"	Number of Days Per Year with Shadow Flicker	Maximum Minutes of Shadow Flicker on a Single Day "MM"		
R140	1	10	10	31, 186	00:19
R141	2	15	10	31, 186	00:39
R142	4	27	10	31, 186	00:51
R143	4	28	10	31, 186	00:47
R144	5	30	10	31, 186	00:43
R145	6	37	10	31, 186	00:55
R146	2	13	10	31, 186	00:20
R147	1	10	10	31	00:30
R148	2	12	10	31	00:35
R149	2	13	10	31	00:39
R150	1	9	10	31	00:26
R151	1	9	10	31	00:27
R152	1	8	10	31	00:22
R153	1	9	10	31	00:27
R154	<1	4	10	31	00:11
R155	2	12	10	31	00:35
R156	3	19	10	30, 31	00:46
R157	1	10	10	31	00:17
R158	3	23	10	30, 31	00:51
R159	3	22	10	30, 31	00:51
R160	2	16	10	30, 31	00:37
R161	4	28	10	30, 31	00:57
R162	5	34	10	30, 31	00:48
R163	5	32	10	30, 31	00:46
R164	4	26	10	30, 31	00:43
R165	1	9	10	31	00:09
R166	1	9	10	30	00:27
R168	<1	5	10	30	00:15
R169	1	11	10	30	00:32
R171	1	11	10	30	00:33
R172	1	6	10	30	00:13

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

Receptor Identification Code	“Worst Case” Total Hours of Shadow Flicker Per Year “HH”	Number of Days Per Year with Shadow Flicker	Maximum Minutes of Shadow Flicker on a Single Day “MM”	Turbine(s) Causing Shadow Flicker	“Expected Case” * Total Hours of Shadow Flicker Per Year “HH:MM”
R175	<1	2	10	30	00:03
R176	<1	2	10	30	00:05
R177	1	9	10	30	00:15
R178	1	8	10	30	00:14
R179	2	15	10	30	00:25
R180	2	12	10	30	00:20
R181	1	10	10	30	00:21
R182	2	16	10	29, 30	00:37
R183	2	13	10	30	00:21
R184	<1	5	10	30	00:07
R185	1	7	10	30	00:11
R186	1	7	10	30	00:12
R187	1	9	10	30	00:16
R188	2	13	10	30	00:21
R189	2	13	10	30	00:21
R190	2	14	10	30	00:22
R191	3	18	10	30	00:28
R192	3	19	10	30	00:30
R193	7	44	10	29, 30	00:74
R194	6	35	20	29, 30	00:56
R195	2	13	10	30	00:21
R196	4	25	10	30	00:29
R197	<1	4	10	29	00:13
R198	1	10	10	29	00:16
R199	2	12	10	29	00:19
R200	2	12	10	29, 39	00:26
R201	2	13	10	29, 39	00:30
R202	1	7	10	29	00:11
R203	3	23	10	29, 39	00:38
R204	3	19	10	29, 39	00:29
R205	3	18	10	29	00:19

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

Receptor Identification Code	"Worst Case" Total Hours of Shadow Flicker Per Year "HH"	"Worst Case" Number of Days Per Year with Shadow Flicker	"Worst Case" Maximum Minutes of Shadow Flicker on a Single Day "MM"	Turbine(s) Causing Shadow Flicker	"Expected Case" * Total Hours of Shadow Flicker Per Year "HH:MM"
R206	6	37	10	29, 39	00:48
R207	1	9	10	39	00:24
R208	2	13	10	29, 39	00:19
R209	<1	4	10	39	00:08
R210	2	12	10	39	00:32
R211	1	11	10	39	00:24
R212	2	12	10	39	00:20
R213	1	6	10	38, 39	00:14
R214	2	14	10	38, 39	00:24
R215	4	28	10	38, 39	00:38
R216	4	25	10	39	00:26
R217	3	23	10	38, 39	00:32
R218	<1	1	10	38	00:03
R219	<1	1	10	38	00:03
R220	<1	1	10	38	00:03
R221	<1	2	10	38	00:07
R222	<1	5	10	38	00:16
R223	<1	3	10	38	00:08
R224	<1	2	10	37	00:06
R225	1	9	10	37	00:20
R227	2	16	10	47	00:16
R229	1	8	10	124	00:13
R231	2	13	10	124. 125	00:22
R232	1	8	10	124. 125	00:19
R233	5	35	10	124. 125	00:53
R234	1	7	10	124	00:07
R235	2	14	10	124. 125	00:26
R236	1	11	10	125	00:24
R237	<1	4	10	125	00:08
R239	1	8	10	125	00:13
R240	2	14	10	125	00:22

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

Receptor Identification Code	“Worst Case” Total Hours of Shadow Flicker Per Year “HH”	Number of Days Per Year with Shadow Flicker	Maximum Minutes of Shadow Flicker on a Single Day “MM”	Turbine(s) Causing Shadow Flicker	“Expected Case” * Total Hours of Shadow Flicker Per Year “HH:MM”
R241	3	18	10	125	00:29
R242	5	33	10	125	00:45
R243	1	11	10	125	00:24
R244	2	12	10	126	00:22
R245	2	14	10	126	00:26
R246	1	6	10	126	00:10
R247	2	15	10	126	00:24
R248	2	13	10	126	00:21
R249	1	8	10	126	00:14
R250	4	25	10	126	00:55
R251	1	9	10	115, 126	00:15
R252	3	22	10	126	00:34
R253	6	40	10	126	00:35
R254	3	20	10	115, 126	00:38
R255	5	30	10	115, 126	00:32
R257	2	17	10	115, 126	00:32
R258	1	8	10	115	00:17
R259	1	8	10	115	00:15
R260	2	14	10	115	00:28
R261	2	16	10	115	00:27
R262	2	13	10	115	00:23
R263	2	17	10	115	00:28
R264	6	34	10	115	00:45
R265	3	22	10	115	00:32
R266	4	28	10	115	00:30
R267	1	9	10	115	00:09
R270	<1	5	10	114	00:14
R272	3	19	10	113, 114	00:49
R273	1	6	10	113, 114	00:12
R274	3	21	10	113, 114	00:39
R275	1	11	10	113	00:29

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

	"Worst Case"				
Receptor Identification Code	**Total Hours of Shadow Flicker Per Year "HH"**	**Number of Days Per Year with Shadow Flicker**	**Maximum Minutes of Shadow Flicker on a Single Day "MM"**	**Turbine(s) Causing Shadow Flicker**	**"Expected Case" * Total Hours of Shadow Flicker Per Year "HH:MM"**
R276	5	32	10	113, 114	00:46
R277	1	9	10	113	00:14
R278	4	27	10	113	00:29
R279	1	8	10	113	00:08
R280	3	22	10	113	00:23
R281	<1	4	10	113	00:04
R284	1	7	10	113	00:07
R334	3	18	10	91	00:23
R335	<1	3	10	91	00:04
R337	<1	2	10	91	00:06
R338	<1	4	10	91	00:10
R339	<1	4	10	91	00:12
R340	<1	1	10	91	00:03
R341	<1	1	10	91	00:03
R343	<1	1	10	91	00:03
R344	<1	1	10	91	00:03
R379	4	26	10	145	00:31
R380	2	14	10	145	00:20
R381	1	8	10	145	00:13
R382	1	8	10	145	00:13
R384	1	8	10	145	00:22
R385	1	6	10	145	00:17
R386	1	8	10	145	00:23
R387	<1	3	10	145	00:09
R388	1	10	10	144, 145	00:26
R389	2	13	10	144, 145	00:34
R390	1	6	10	145	00:18
R391	1	9	10	144, 145	00:24
R392	<1	5	10	145	00:16
R393	1	11	10	144, 145	00:29
R394	<1	4	10	145	00:13

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

Receptor Identification Code	“Worst Case”			Turbine(s) Causing Shadow Flicker	“Expected Case” * Total Hours of Shadow Flicker Per Year “HH:MM”
	Total Hours of Shadow Flicker Per Year “HH”	**Number of Days Per Year with Shadow Flicker**	**Maximum Minutes of Shadow Flicker on a Single Day “MM”**		
R395	<1	4	10	145	00:13
R396	1	7	10	145	00:23
R397	<1	2	10	145	00:07
R399	<1	3	10	145	00:10
R400	<1	2	10	145	00:06
R401	<1	1	10	145	00:03
R415	3	20	10	147	00:23
R416	<1	3	10	147	00:04
R441	2	17	10	148	00:17
R442	4	28	10	148	00:32
R443	5	31	10	148	00:35
R444	4	28	20	148	00:30
R445	3	20	10	148	00:31
R446	2	17	10	148	00:27
R447	2	12	10	148	00:20
R448	0	4	10	148	00:07
R449	2	16	10	148	00:30
R450	2	14	10	148	00:30
R451	2	13	10	148	00:22
R452	2	13	10	148	00:21
R453	2	15	10	148	00:24
R454	1	7	10	148	00:11
R455	<1	3	10	148	00:04
R456	1	8	10	148	00:12
R463	2	13	10	148	00:21
R464	2	13	10	148	00:21
R466	2	13	10	148	00:26
R467	1	10	10	148	00:21
R468	1	7	10	148	00:14
R469	2	14	10	148	00:29
R470	2	12	10	148	00:25

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

Receptor Identification Code	"Worst Case"			Turbine(s) Causing Shadow Flicker	"Expected Case" * Total Hours of Shadow Flicker Per Year "HH:MM"
	Total Hours of Shadow Flicker Per Year "HH"	Number of Days Per Year with Shadow Flicker	Maximum Minutes of Shadow Flicker on a Single Day "MM"		
R471	1	10	10	148	00:21
R472	2	13	10	148	00:28
R473	1	10	10	148	00:22
R474	2	14	10	148	00:30
R475	1	8	10	148	00:17
R476	2	12	10	148	00:29
R477	1	10	10	148	00:28
R478	2	12	10	148	00:35
R479	2	15	10	148	00:33
R480	1	8	10	148	00:24
R481	2	13	10	66, 148	00:40
R482	1	7	10	148	00:23
R483	<1	5	10	148	00:15
R484	2	12	10	66, 148	00:40
R485	1	9	10	148	00:29
R486	1	11	10	66, 148	00:37
R487	1	10	10	66, 148	00:34
R488	4	25	10	65, 66, 148	01:21
R489	2	15	10	65, 66, 148	00:49
R490	1	8	10	65, 66	00:26
R491	3	20	10	65, 66, 148	01:11
R492	4	27	10	65, 66, 148	01:36
R493	3	18	10	65, 66, 148	01:03
R494	3	18	10	65, 66, 148	01:04
R495	3	21	10	65, 66, 148	01:14
R496	2	17	10	65, 66, 148	01:06
R497	1	11	10	65, 66	00:44
R498	4	29	10	65, 66, 148	01:51
R499	5	32	10	65, 66, 148	02:03
R500	2	14	10	65, 66, 148	00:52
R501	5	33	10	65, 66, 148	02:16

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

	“Worst Case”				
Receptor Identification Code	**Total Hours of Shadow Flicker Per Year “HH”**	**Number of Days Per Year with Shadow Flicker**	**Maximum Minutes of Shadow Flicker on a Single Day “MM”**	**Turbine(s) Causing Shadow Flicker**	**“Expected Case” * Total Hours of Shadow Flicker Per Year “HH:MM”**
R502	4	24	10	65, 66, 148	01:34
R503	2	17	10	66	01:12
R504	6	41	10	65, 66	02:47
R505	7	46	10	65, 66	03:09
R506	3	19	10	65, 66	01:16
R508	1	9	10	65	00:34
R509	1	7	10	65	01:31
R510	3	22	10	65, 82	01:22
R511	<1	5	10	65	00:21
R512	5	33	10	65	02:20
R513	<1	4	10	65	00:16
R514	3	22	10	65	01:34
R515	1	6	10	65	00:25
R517	<1	1	10	82	00:03
R518	<1	1	10	82	00:03
R519	<1	1	10	82	00:03
R520	1	7	10	82	00:25
R521	<1	4	10	82	00:13
R522	1	6	10	82	00:21
R523	<1	4	10	82	00:13
R524	1	8	10	82	00:31
R525	1	9	10	82	00:36
R526	<1	5	10	82	00:22
R527	<1	5	10	82	00:19
R528	1	6	10	82	00:27
R531	2	12	10	82	00:51
R532	1	10	10	82	00:42
R533	5	31	10	82	02:11
R649	<1	1	10	151	00:01
R650	1	10	10	151	00:10
R651	2	14	10	151	00:14

Table 6.1 Shadow Flicker Results for Port au Port Wind Farm

Receptor Identification Code	**"Worst Case"**			**Turbine(s) Causing Shadow Flicker**	**"Expected Case" * Total Hours of Shadow Flicker Per Year "HH:MM"**
	Total Hours of Shadow Flicker Per Year "HH"	**Number of Days Per Year with Shadow Flicker**	**Maximum Minutes of Shadow Flicker on a Single Day "MM"**		
R652	2	13	10	151	00:16
R767	2	13	10	61	00:55
R768	3	19	10	61	01:21
R769	6	41	10	61	02:53
R773	5	33	10	61	02:19
R775	1	10	10	61	00:43
R776	3	19	10	61	01:21
R777	2	13	10	61	00:56
R778	2	13	10	61	00:57
R779	<1	4	10	61	00:18
R780	1	9	10	61	00:35
R781	1	7	10	61	00:26
R790	<1	1	10	168	00:04

Note:
* Annual Predicted Shadow Flicker adjusted by monthly probability of bright sunshine hours

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7.0 Conclusions

A shadow flicker assessment was completed for the Port au Port wind farm. The shadow flicker assessment evaluated two conservative modelling scenarios: “Worst Case” and “Expected Case.” The receptors with modelled shadow flicker for the Port au Port wind farm are listed in Table 6.1.

The “Worst Case” assessment assumed that the sun is always shining during daylight hours (i.e., there are no cloudy periods), all Project wind turbines are always active (i.e., rotors spinning), and all Project wind turbines are always oriented with their rotors perpendicular to the line joining the sun and all receptors. The “Expected Case” assessment used statistical weather data to estimate the probability of sunshine for each month of the year. Both assessment cases assumed that receptors are sensitive to shadow flicker in any direction and neither assessment case accounted for the screening of shadow flicker by vegetation, outbuildings, or other structures.

A commonly used assessment criterion or allowable worst-case limit for shadow flicker is 30 hours per year (Koppen et al. 2017). The theoretical maximum (Worst Case) for Port au Port wind farm receptors does not exceed 30 hours per year at any receptor location. In the “Expected Case” assessment, the highest levels of shadow flicker are less than 3 hours per year for any of the receptors. However, actual shadow flicker experienced by the receptors is likely to be reduced by the presence of vegetation, which may provide partial screening for the Port au Port turbines during those hours when the sun is low enough to create long shadows.

Given the conservative assumptions used in the shadow flicker model, it is likely that site specific conditions will further reduce the amount of shadow flicker that is actually observed throughout the year. Site specific conditions that may mitigate shadow flicker impact include trees or buildings that block the line of sight to the proposed turbine locations, seasonal or intermittent use, or the absence of windows facing the direction of the wind farm.

8.0 References

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APPENDIX A

Port au Port Wind Farm Turbine and Receptor Locations

Appendix A Port au Port Wind Farm Turbine and Receptor Locations

Table A.1 Port au Port Wind Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	Northing (m)	
T-1	Siemens Gamesa SG-155 6.6 MW	336339	5372811	122.5
T-2	Siemens Gamesa SG-155 6.6 MW	336386	5373488	122.5
T-3	Siemens Gamesa SG-155 6.6 MW	336586	5374048	122.5
T-4	Siemens Gamesa SG-155 6.6 MW	336806	5374549	122.5
T-5	Siemens Gamesa SG-155 6.6 MW	336901	5375099	122.5
T-6	Siemens Gamesa SG-155 6.6 MW	336856	5375735	122.5
T-7	Siemens Gamesa SG-155 6.6 MW	337242	5376170	122.5
T-8	Siemens Gamesa SG-155 6.6 MW	337591	5376631	122.5
T-9	Siemens Gamesa SG-155 6.6 MW	338157	5376867	122.5
T-10	Siemens Gamesa SG-155 6.6 MW	338502	5377283	122.5
T-11	Siemens Gamesa SG-155 6.6 MW	338854	5377710	122.5
T-13	Siemens Gamesa SG-155 6.6 MW	340862	5376095	122.5
T-14	Siemens Gamesa SG-155 6.6 MW	340415	5375808	122.5
T-15	Siemens Gamesa SG-155 6.6 MW	339948	5375476	122.5
T-16	Siemens Gamesa SG-155 6.6 MW	339583	5375099	122.5
T-17	Siemens Gamesa SG-155 6.6 MW	339335	5374492	122.5
T-18	Siemens Gamesa SG-155 6.6 MW	339139	5373992	122.5
T-25	Siemens Gamesa SG-155 6.6 MW	341756	5377191	122.5
T-26	Siemens Gamesa SG-155 6.6 MW	341714	5376643	122.5
T-27	Siemens Gamesa SG-155 6.6 MW	341755	5376135	122.5
T-28	Siemens Gamesa SG-155 6.6 MW	341730	5375580	122.5
T-29	Siemens Gamesa SG-155 6.6 MW	341581	5382475	122.5
T-30	Siemens Gamesa SG-155 6.6 MW	341157	5381854	122.5
T-31	Siemens Gamesa SG-155 6.6 MW	340765	5381374	122.5
T-32	Siemens Gamesa SG-155 6.6 MW	343276	5377880	122.5
T-33	Siemens Gamesa SG-155 6.6 MW	343047	5377381	122.5
T-34	Siemens Gamesa SG-155 6.6 MW	343109	5376834	122.5
T-35	Siemens Gamesa SG-155 6.6 MW	343304	5376153	122.5

Table A.1 Port au Port Wind Turbine Locations

		Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		
Turbine ID	**Description**	**Easting (m)**	**Northing (m)**	**Hub Height (m)**
T-36	Siemens Gamesa SG-155 6.6 MW	343262	5375629	122.5
T-37	Siemens Gamesa SG-155 6.6 MW	342759	5383718	122.5
T-38	Siemens Gamesa SG-155 6.6 MW	342318	5383664	122.5
T-39	Siemens Gamesa SG-155 6.6 MW	341865	5382816	122.5
T-40	Siemens Gamesa SG-155 6.6 MW	344008	5380282	122.5
T-41	Siemens Gamesa SG-155 6.6 MW	343789	5379723	122.5
T-42	Siemens Gamesa SG-155 6.6 MW	343464	5379164	122.5
T-43	Siemens Gamesa SG-155 6.6 MW	342557	5382445	122.5
T-44	Siemens Gamesa SG-155 6.6 MW	342487	5381968	122.5
T-45	Siemens Gamesa SG-155 6.6 MW	342329	5381391	122.5
T-46	Siemens Gamesa SG-155 6.6 MW	342321	5380834	122.5
T-47	Siemens Gamesa SG-155 6.6 MW	343295	5384043	122.5
T-48	Siemens Gamesa SG-155 6.6 MW	345891	5382729	122.5
T-49	Siemens Gamesa SG-155 6.6 MW	346229	5383086	122.5
T-50	Siemens Gamesa SG-155 6.6 MW	344549	5378102	122.5
T-51	Siemens Gamesa SG-155 6.6 MW	344560	5377543	122.5
T-52	Siemens Gamesa SG-155 6.6 MW	344721	5376999	122.5
T-53	Siemens Gamesa SG-155 6.6 MW	344661	5376413	122.5
T-54	Siemens Gamesa SG-155 6.6 MW	344661	5375902	122.5
T-55	Siemens Gamesa SG-155 6.6 MW	346002	5378594	122.5
T-56	Siemens Gamesa SG-155 6.6 MW	345801	5378068	122.5
T-57	Siemens Gamesa SG-155 6.6 MW	345745	5377397	122.5
T-58	Siemens Gamesa SG-155 6.6 MW	345768	5376827	122.5
T-59	Siemens Gamesa SG-155 6.6 MW	347031	5377755	122.5
T-60	Siemens Gamesa SG-155 6.6 MW	346942	5377218	122.5
T-61	Siemens Gamesa SG-155 6.6 MW	346796	5376648	122.5
T-62	Siemens Gamesa SG-155 6.6 MW	356526	5379438	122.5
T-63	Siemens Gamesa SG-155 6.6 MW	356893	5379805	122.5
T-64	Siemens Gamesa SG-155 6.6 MW	357311	5380069	122.5
T-65	Siemens Gamesa SG-155 6.6 MW	356893	5378224	122.5
T-66	Siemens Gamesa SG-155 6.6 MW	357146	5378717	122.5
T-67	Siemens Gamesa SG-155 6.6 MW	365724	5378942	122.5
T-69	Siemens Gamesa SG-155 6.6 MW	356312	5377873	122.5

Table A.1 Port au Port Wind Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	**Northing (m)**	
T-70	Siemens Gamesa SG-155 6.6 MW	355249	5377452	122.5
T-71	Siemens Gamesa SG-155 6.6 MW	355552	5377984	122.5
T-72	Siemens Gamesa SG-155 6.6 MW	355856	5378464	122.5
T-73	Siemens Gamesa SG-155 6.6 MW	356223	5378970	122.5
T-75	Siemens Gamesa SG-155 6.6 MW	347406	5385824	122.5
T-76	Siemens Gamesa SG-155 6.6 MW	347539	5386313	122.5
T-77	Siemens Gamesa SG-155 6.6 MW	348162	5386823	122.5
T-78	Siemens Gamesa SG-155 6.6 MW	348716	5387129	122.5
T-79	Siemens Gamesa SG-155 6.6 MW	349261	5387344	122.5
T-80	Siemens Gamesa SG-155 6.6 MW	349770	5387598	122.5
T-81	Siemens Gamesa SG-155 6.6 MW	350165	5387903	122.5
T-82	Siemens Gamesa SG-155 6.6 MW	359538	5377153	122.5
T-83	Siemens Gamesa SG-155 6.6 MW	360090	5377274	122.5
T-84	Siemens Gamesa SG-155 6.6 MW	360641	5377408	122.5
T-85	Siemens Gamesa SG-155 6.6 MW	361152	5377489	122.5
T-86	Siemens Gamesa SG-155 6.6 MW	361704	5377570	122.5
T-87	Siemens Gamesa SG-155 6.6 MW	362235	5377732	122.5
T-88	Siemens Gamesa SG-155 6.6 MW	362726	5377879	122.5
T-89	Siemens Gamesa SG-155 6.6 MW	363291	5378014	122.5
T-90	Siemens Gamesa SG-155 6.6 MW	363896	5378135	122.5
T-91	Siemens Gamesa SG-155 6.6 MW	353832	5386029	122.5
T-92	Siemens Gamesa SG-155 6.6 MW	351631	5383419	122.5
T-93	Siemens Gamesa SG-155 6.6 MW	352820	5386467	122.5
T-94	Siemens Gamesa SG-155 6.6 MW	352432	5386172	122.5
T-95	Siemens Gamesa SG-155 6.6 MW	351985	5385885	122.5
T-96	Siemens Gamesa SG-155 6.6 MW	351985	5385346	122.5
T-97	Siemens Gamesa SG-155 6.6 MW	351968	5384806	122.5
T-98	Siemens Gamesa SG-155 6.6 MW	351859	5384283	122.5
T-99	Siemens Gamesa SG-155 6.6 MW	351583	5383952	122.5
T-100	Siemens Gamesa SG-155 6.6 MW	346761	5383676	122.5
T-101	Siemens Gamesa SG-155 6.6 MW	347206	5384320	122.5
T-102	Siemens Gamesa SG-155 6.6 MW	346959	5384764	122.5
T-103	Siemens Gamesa SG-155 6.6 MW	347128	5385244	122.5

Table A.1 Port au Port Wind Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	Northing (m)	
T-104	Siemens Gamesa SG-155 6.6 MW	364842	5377597	122.5
T-105	Siemens Gamesa SG-155 6.6 MW	365255	5377973	122.5
T-106	Siemens Gamesa SG-155 6.6 MW	365679	5378374	122.5
T-107	Siemens Gamesa SG-155 6.6 MW	366493	5377960	122.5
T-108	Siemens Gamesa SG-155 6.6 MW	366775	5378471	122.5
T-109	Siemens Gamesa SG-155 6.6 MW	367044	5378996	122.5
T-110	Siemens Gamesa SG-155 6.6 MW	345243	5380842	122.5
T-111	Siemens Gamesa SG-155 6.6 MW	345152	5381529	122.5
T-112	Siemens Gamesa SG-155 6.6 MW	345503	5382138	122.5
T-113	Siemens Gamesa SG-155 6.6 MW	346065	5386181	122.5
T-114	Siemens Gamesa SG-155 6.6 MW	345937	5385787	122.5
T-115	Siemens Gamesa SG-155 6.6 MW	345245	5385163	122.5
T-116	Siemens Gamesa SG-155 6.6 MW	340525	5377275	122.5
T-118	Siemens Gamesa SG-155 6.6 MW	341840	5377722	122.5
T-120	Siemens Gamesa SG-155 6.6 MW	345334	5380260	122.5
T-123	Siemens Gamesa SG-155 6.6 MW	343409	5378447	122.5
T-124	Siemens Gamesa SG-155 6.6 MW	343949	5384363	122.5
T-125	Siemens Gamesa SG-155 6.6 MW	344269	5384675	122.5
T-126	Siemens Gamesa SG-155 6.6 MW	344939	5384928	122.5
T-127	Siemens Gamesa SG-155 6.6 MW	344522	5383562	122.5
T-128	Siemens Gamesa SG-155 6.6 MW	345028	5383904	122.5
T-129	Siemens Gamesa SG-155 6.6 MW	345610	5384144	122.5
T-130	Siemens Gamesa SG-155 6.6 MW	346204	5384460	122.5
T-131	Siemens Gamesa SG-155 6.6 MW	343800	5380908	122.5
T-132	Siemens Gamesa SG-155 6.6 MW	343956	5383108	122.5
T-133	Siemens Gamesa SG-155 6.6 MW	343168	5382854	122.5
T-135	Siemens Gamesa SG-155 6.6 MW	353254	5384967	122.5
T-136	Siemens Gamesa SG-155 6.6 MW	353140	5384452	122.5
T-137	Siemens Gamesa SG-155 6.6 MW	352871	5383937	122.5
T-138	Siemens Gamesa SG-155 6.6 MW	352693	5383389	122.5
T-139	Siemens Gamesa SG-155 6.6 MW	353882	5384883	122.5
T-140	Siemens Gamesa SG-155 6.6 MW	354097	5384249	122.5
T-141	Siemens Gamesa SG-155 6.6 MW	353756	5383802	122.5

Table A.1 Port au Port Wind Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	Northing (m)	
T-142	Siemens Gamesa SG-155 6.6 MW	354599	5382942	122.5
T-143	Siemens Gamesa SG-155 6.6 MW	354911	5383339	122.5
T-144	Siemens Gamesa SG-155 6.6 MW	355417	5383524	122.5
T-145	Siemens Gamesa SG-155 6.6 MW	355637	5383996	122.5
T-146	Siemens Gamesa SG-155 6.6 MW	356294	5382681	122.5
T-147	Siemens Gamesa SG-155 6.6 MW	356649	5383043	122.5
T-148	Siemens Gamesa SG-155 6.6 MW	359701	5378616	122.5
T-149	Siemens Gamesa SG-155 6.6 MW	360325	5378726	122.5
T-151	Siemens Gamesa SG-155 6.6 MW	361692	5378996	122.5
T-152	Siemens Gamesa SG-155 6.6 MW	362282	5379063	122.5
T-153	Siemens Gamesa SG-155 6.6 MW	363023	5379134	122.5
T-154	Siemens Gamesa SG-155 6.6 MW	363614	5379249	122.5
T-155	Siemens Gamesa SG-155 6.6 MW	364230	5379316	122.5
T-156	Siemens Gamesa SG-155 6.6 MW	378236	5383792	122.5
T-157	Siemens Gamesa SG-155 6.6 MW	378582	5384229	122.5
T-158	Siemens Gamesa SG-155 6.6 MW	378828	5384799	122.5
T-159	Siemens Gamesa SG-155 6.6 MW	379030	5385347	122.5
T-160	Siemens Gamesa SG-155 6.6 MW	379264	5385861	122.5
T-161	Siemens Gamesa SG-155 6.6 MW	379466	5386386	122.5
T-162	Siemens Gamesa SG-155 6.6 MW	379600	5386901	122.5
T-163	Siemens Gamesa SG-155 6.6 MW	379768	5387448	122.5
T-164	Siemens Gamesa SG-155 6.6 MW	379946	5388019	122.5
T-165	Siemens Gamesa SG-155 6.6 MW	380226	5388578	122.5
T-166	Siemens Gamesa SG-155 6.6 MW	380327	5389181	122.5
T-167	Siemens Gamesa SG-155 6.6 MW	380114	5389830	122.5
T-168	Siemens Gamesa SG-155 6.6 MW	380233	5390378	122.5
T-169	Siemens Gamesa SG-155 6.6 MW	380405	5390877	122.5
T-170	Siemens Gamesa SG-155 6.6 MW	380621	5391354	122.5
T-171	Siemens Gamesa SG-155 6.6 MW	380904	5391787	122.5
T-172	Siemens Gamesa SG-155 6.6 MW	381277	5392133	122.5
T-173	Siemens Gamesa SG-155 6.6 MW	381225	5389916	122.5
T-174	Siemens Gamesa SG-155 6.6 MW	381471	5390423	122.5
T-175	Siemens Gamesa SG-155 6.6 MW	381702	5390974	122.5

Table A.1 Port au Port Wind Turbine Locations

Turbine ID	Description	Universal Transverse Mercator (UTM) Coordinates (NAD83 CSRS UTM Zone 21N)		Hub Height (m)
		Easting (m)	Northing (m)	
T-176	Siemens Gamesa SG-155 6.6 MW	382045	5391466	122.5
T-177	Siemens Gamesa SG-155 6.6 MW	382738	5391734	122.5
T-178	Siemens Gamesa SG-155 6.6 MW	383297	5392189	122.5
T-179	Siemens Gamesa SG-155 6.6 MW	383580	5392659	122.5
T-180	Siemens Gamesa SG-155 6.6 MW	382350	5390385	122.5
T-181	Siemens Gamesa SG-155 6.6 MW	382850	5390929	122.5
T-182	Siemens Gamesa SG-155 6.6 MW	344806	5379454	122.5
T-183	Siemens Gamesa SG-155 6.6 MW	344594	5378806	122.5
T-184	Siemens Gamesa SG-155 6.6 MW	350598	5388298	122.5
T-185	Siemens Gamesa SG-155 6.6 MW	348927	5387989	122.5
T-186	Siemens Gamesa SG-155 6.6 MW	340506	5380788	122.5

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	Northing (m)		Easting (m)	Northing (m)		Easting (m)	Northing (m)
R1	336011	5371390	R265	344304	5386032	R529	358187	5376655
R2	336065	5371367	R266	344392	5386074	R530	358259	5376674
R3	336059	5371410	R267	344386	5386118	R531	358353	5376548
R4	336120	5371415	R268	344413	5386161	R532	358396	5376649
R5	336195	5371442	R269	344455	5386200	R533	358543	5376645
R6	336262	5371516	R270	344535	5386254	R534	358511	5376499
R7	336323	5371507	R271	344466	5386225	R535	358564	5376541
R8	336367	5371539	R272	344683	5386522	R536	358583	5376511
R9	336418	5371562	R273	344717	5386639	R537	358505	5376428
R10	336463	5371582	R274	344836	5386769	R538	358600	5376466
R11	336498	5371609	R275	344827	5386828	R539	358599	5376432
R12	336530	5371626	R276	344886	5386817	R540	358546	5376374
R13	336567	5371649	R277	345015	5386909	R541	358485	5376308
R14	336617	5371672	R278	345189	5387058	R542	358548	5376298
R15	336645	5371692	R279	345132	5387136	R543	358413	5376277
R16	336694	5371725	R280	345178	5387080	R544	358539	5376261
R17	336760	5371742	R281	345201	5387094	R545	358498	5376262
R18	336795	5371758	R282	345157	5387150	R546	358605	5376268
R19	336832	5371769	R283	345187	5387157	R547	358521	5376146
R20	336870	5371788	R284	345234	5387062	R548	358676	5376214
R21	336913	5371802	R285	345370	5387035	R549	358895	5376007
R22	336955	5371819	R286	345269	5387098	R550	360739	5376007
R23	336963	5371891	R287	345238	5387114	R551	360810	5376017
R24	337025	5371888	R288	345247	5387179	R552	360901	5376029
R25	337058	5371915	R289	345274	5387125	R553	360923	5375972
R26	337098	5371957	R290	345297	5387221	R554	361032	5376051
R27	337177	5371922	R291	345300	5387142	R555	361099	5376023
R28	337212	5371925	R292	345324	5387172	R556	361133	5376032
R29	337230	5371950	R293	345388	5387212	R557	361338	5376166
R30	337262	5371924	R294	345448	5387247	R558	361180	5376063
R31	337292	5371948	R295	345427	5387301	R559	361220	5376069
R32	337331	5371897	R296	345570	5387302	R560	361415	5376076

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	Northing (m)		Easting (m)	Northing (m)		Easting (m)	Northing (m)
R33	337345	5371965	R297	345611	5387383	R561	361453	5376083
R34	337374	5371949	R298	345704	5387417	R562	361470	5376070
R35	337392	5371926	R299	345702	5387362	R563	361537	5376077
R36	337380	5371903	R300	345729	5387415	R564	361626	5376170
R37	337405	5371892	R301	345743	5387355	R565	361671	5376149
R38	337454	5371944	R302	345798	5387338	R566	361757	5376172
R39	337466	5371917	R303	345849	5387333	R567	361796	5376173
R40	337486	5371941	R304	345897	5387424	R568	361827	5376193
R41	337481	5371970	R305	345952	5387427	R569	361912	5376191
R42	337515	5371980	R306	345956	5387469	R570	361943	5376189
R43	337549	5372028	R307	346059	5387395	R571	361971	5376216
R44	337578	5372058	R308	346275	5387387	R572	361944	5376107
R45	337591	5372083	R309	346221	5387443	R573	362016	5376209
R46	337609	5372085	R310	346150	5387488	R574	362160	5376186
R47	337632	5372074	R311	346182	5387521	R575	362183	5376194
R48	337630	5372117	R312	346217	5387557	R576	362220	5376217
R49	337639	5372158	R313	346454	5387578	R577	362333	5376262
R50	337613	5372196	R314	347979	5388713	R578	362325	5376322
R51	336248	5371388	R315	348954	5389197	R579	362378	5376340
R52	336447	5371513	R316	349878	5389557	R580	362474	5376380
R53	336494	5371533	R317	349957	5389589	R581	362589	5376355
R54	336535	5371550	R318	349984	5389609	R582	362643	5376481
R55	336567	5371573	R319	350065	5389633	R583	362826	5376518
R56	336631	5371575	R320	350117	5389656	R584	363110	5376523
R57	336664	5371629	R321	350195	5389671	R585	364324	5376376
R58	336707	5371642	R322	350230	5389694	R586	364374	5376361
R59	336729	5371656	R323	350406	5389705	R587	364525	5376335
R60	336747	5371638	R324	350342	5389711	R588	364581	5376332
R61	336833	5371645	R325	350705	5389715	R589	364664	5376389
R62	336882	5371633	R326	350796	5389683	R590	364637	5376332
R63	336848	5371708	R327	350759	5389719	R591	364725	5376397
R64	336912	5371701	R328	350889	5389531	R592	364734	5376343

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	**Northing (m)**		**Easting (m)**	**Northing (m)**		**Easting (m)**	**Northing (m)**
R65	336921	5371676	R329	350962	5389655	R593	364781	5376407
R66	336932	5371738	R330	350995	5389565	R594	365470	5376587
R67	336956	5371667	R331	351154	5389636	R595	365681	5376725
R68	336997	5371685	R332	354718	5387216	R596	365899	5376692
R69	337009	5371715	R333	354732	5387026	R597	365928	5376691
R70	337000	5371793	R334	354766	5386756	R598	365951	5376692
R71	337078	5371827	R335	354888	5386722	R599	365969	5376698
R72	337152	5371862	R336	354957	5386457	R600	366336	5376874
R73	337183	5371806	R337	355010	5386316	R601	366390	5376856
R74	337205	5371794	R338	354952	5386322	R602	366385	5376793
R75	337193	5371754	R339	354964	5386255	R603	366435	5376797
R76	337176	5371744	R340	355200	5385999	R604	366465	5376793
R77	337232	5371730	R341	355130	5385996	R605	366570	5376811
R78	337240	5371799	R342	355234	5385985	R606	366653	5376832
R79	337256	5371772	R343	355235	5385868	R607	366680	5376842
R80	337276	5371741	R344	355287	5385952	R608	366712	5376866
R81	337326	5371733	R345	355301	5385833	R609	366797	5376900
R82	337343	5371710	R346	355301	5385440	R610	366839	5376936
R83	337289	5371832	R347	355296	5385409	R611	366872	5376966
R84	337332	5371835	R348	355522	5385287	R612	366920	5376959
R85	337304	5371777	R349	355489	5385299	R613	366966	5376966
R86	337320	5371803	R350	355550	5385212	R614	367014	5376955
R87	337308	5371745	R351	355639	5385263	R615	367170	5377033
R88	337311	5371728	R352	355681	5385227	R616	367184	5376931
R89	337340	5371768	R353	355643	5385189	R617	367265	5377023
R90	337340	5371749	R354	355672	5385180	R618	367518	5376951
R91	337397	5371771	R355	355737	5385186	R619	367463	5377213
R92	337361	5371822	R356	355687	5385149	R620	367435	5380324
R93	337378	5371832	R357	355728	5385133	R621	367391	5380371
R94	337369	5371802	R358	355765	5385180	R622	367354	5380372
R95	337390	5371813	R359	355781	5385163	R623	367389	5380324
R96	337395	5371833	R360	355811	5385164	R624	367315	5380380

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	Northing (m)		Easting (m)	Northing (m)		Easting (m)	Northing (m)
R97	337382	5371786	R361	355711	5385077	R625	367289	5380324
R98	337452	5371837	R362	355826	5385128	R626	367292	5380445
R99	337480	5371844	R363	355838	5385063	R627	367229	5380347
R100	337515	5371890	R364	355688	5385028	R628	367208	5380379
R101	337536	5371911	R365	355766	5385019	R629	367241	5380416
R102	337552	5371935	R366	355914	5385082	R630	367086	5380459
R103	337569	5371960	R367	355905	5385028	R631	367069	5380407
R104	336596	5371761	R368	356062	5385100	R632	367026	5380318
R105	334905	5372636	R369	356106	5385115	R633	366993	5380395
R106	335006	5372726	R370	356204	5385113	R634	366928	5380359
R107	339042	5380891	R371	356210	5385034	R635	366782	5380440
R108	339093	5381030	R372	356276	5385072	R636	366719	5380341
R109	339111	5380977	R373	356312	5385059	R637	366630	5380336
R110	339051	5381088	R374	356343	5385049	R638	366602	5380322
R111	339036	5381020	R375	356357	5385031	R639	366562	5380328
R112	339053	5381045	R376	356380	5385018	R640	366546	5380309
R113	339059	5381006	R377	356365	5384989	R641	366495	5380313
R114	339079	5381163	R378	356551	5384823	R642	366603	5380290
R115	339086	5381236	R379	356532	5384714	R643	366469	5380368
R116	339160	5381266	R380	356599	5384727	R644	366444	5380298
R117	339174	5381347	R381	356640	5384693	R645	366377	5380316
R118	339242	5381357	R382	356604	5384657	R646	366184	5380336
R119	339266	5381386	R383	356908	5384715	R647	361175	5380259
R120	339421	5381350	R384	356700	5384472	R648	360811	5380074
R121	339373	5381365	R385	356659	5384422	R649	360779	5380058
R122	339333	5381386	R386	356707	5384425	R650	360747	5380038
R123	339248	5381424	R387	356712	5384382	R651	360723	5380030
R124	339245	5381450	R388	356644	5384333	R652	360707	5380021
R125	339375	5381439	R389	356623	5384316	R653	360656	5379977
R126	339302	5381476	R390	356734	5384309	R654	360293	5376399
R127	339212	5381512	R391	356643	5384282	R655	338620	5372594
R128	339286	5381516	R392	356803	5384226	R656	338654	5372601

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	Northing (m)		Easting (m)	Northing (m)		Easting (m)	Northing (m)
R129	339301	5381535	R393	356733	5384213	R657	338687	5372612
R130	339305	5381579	R394	356778	5384180	R658	338714	5372627
R131	339283	5381603	R395	356944	5384168	R659	338707	5372576
R132	339376	5381543	R396	356846	5384145	R660	338743	5372648
R133	339388	5381565	R397	356974	5384111	R661	338764	5372578
R134	339468	5381529	R398	357048	5384146	R662	338814	5372567
R135	339490	5381451	R399	357017	5384102	R663	338857	5372582
R136	339523	5381422	R400	357063	5384091	R664	338773	5372560
R137	339312	5381669	R401	357108	5384132	R665	338920	5372640
R138	339343	5381711	R402	357102	5384062	R666	338927	5372579
R139	339400	5381688	R403	357136	5384065	R667	338983	5372632
R140	339458	5381695	R404	357164	5384134	R668	338967	5372666
R141	339429	5381750	R405	357180	5384166	R669	338990	5372580
R142	339464	5381764	R406	357175	5384054	R670	338965	5372563
R143	339460	5381806	R407	357255	5384095	R671	339014	5372641
R144	339477	5381811	R408	357283	5384018	R672	339055	5372588
R145	339495	5381826	R409	357374	5384066	R673	339037	5372648
R146	339551	5381848	R410	357422	5383983	R674	339057	5372663
R147	339555	5381881	R411	357345	5384009	R675	339070	5372586
R148	339625	5381872	R412	357523	5384020	R676	339088	5372650
R149	339636	5381850	R413	357468	5383951	R677	339082	5372610
R150	339558	5381918	R414	357631	5383949	R678	339104	5372658
R151	339494	5381913	R415	357718	5383913	R679	339111	5372594
R152	339512	5381943	R416	357839	5383893	R680	339122	5372672
R153	339592	5381932	R417	359172	5379965	R681	339160	5372612
R154	339644	5381957	R418	359171	5379950	R682	339204	5372608
R155	339600	5381881	R419	359143	5379890	R683	339246	5372705
R156	339737	5382038	R420	359127	5379872	R684	339287	5372728
R157	339754	5382119	R421	359095	5379850	R685	339276	5372650
R158	339726	5382251	R422	358951	5379905	R686	339320	5372672
R159	339780	5382244	R423	359015	5379858	R687	339362	5372768
R160	339729	5382301	R424	358996	5379843	R688	339282	5372811

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	Northing (m)		Easting (m)	Northing (m)		Easting (m)	Northing (m)
R161	339817	5382270	R425	358969	5379856	R689	339406	5372731
R162	339855	5382319	R426	358969	5379831	R690	339455	5372754
R163	339773	5382352	R427	358940	5379777	R691	339398	5372797
R164	339872	5382350	R428	358992	5379722	R692	339422	5372826
R165	339816	5382408	R429	358908	5379776	R693	339421	5372871
R166	339877	5382408	R430	358975	5379709	R694	339479	5372876
R167	339899	5382457	R431	358925	5379736	R695	339506	5372836
R168	339961	5382428	R432	358907	5379711	R696	339553	5372875
R169	339856	5382515	R433	358932	5379652	R697	339565	5372903
R170	339987	5382491	R434	358865	5379666	R698	339617	5372913
R171	339989	5382464	R435	358863	5379636	R699	339667	5372938
R172	339889	5382568	R436	358827	5379656	R700	339705	5372901
R173	340013	5382481	R437	358780	5379667	R701	339710	5372960
R174	339967	5382504	R438	358789	5379636	R702	339742	5372918
R175	339923	5382613	R439	358822	5379629	R703	339770	5372918
R176	339978	5382596	R440	358899	5379599	R704	339790	5372987
R177	339944	5382683	R441	358805	5379584	R705	339796	5372928
R178	340000	5382648	R442	358792	5379554	R706	339844	5372956
R179	340023	5382672	R443	358819	5379531	R707	339886	5372972
R180	340047	5382639	R444	358881	5379503	R708	339920	5373026
R181	340021	5382576	R445	358754	5379469	R709	339870	5373015
R182	340097	5382549	R446	358774	5379444	R710	339908	5372959
R183	339961	5382716	R447	358750	5379339	R711	339959	5372992
R184	340030	5382720	R448	358672	5379395	R712	340037	5373067
R185	339989	5382763	R449	358723	5379308	R713	340919	5374408
R186	340070	5382702	R450	358704	5379264	R714	341171	5374419
R187	340032	5382747	R451	358634	5379388	R715	341064	5374361
R188	340081	5382742	R452	358615	5379406	R716	341241	5374386
R189	340050	5382673	R453	358566	5379443	R717	341491	5374545
R190	340060	5382779	R454	358549	5379473	R718	341585	5374572
R191	340090	5382789	R455	358535	5379507	R719	341749	5374553
R192	340067	5382799	R456	358554	5379561	R720	341730	5374380

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	**UTM Coordinates (NAD83 CSRS UTM Zone 21N)**		**Receptor Name**	**UTM Coordinates (NAD83 CSRS UTM Zone 21N)**		**Receptor Name**	**UTM Coordinates (NAD83 CSRS UTM Zone 21N)**	
	Easting (m)	**Northing (m)**		**Easting (m)**	**Northing (m)**		**Easting (m)**	**Northing (m)**
R193	340317	5382679	R457	358487	5379610	R721	341880	5374397
R194	340344	5382707	R458	358463	5379669	R722	343084	5374165
R195	340072	5382824	R459	358418	5379638	R723	343200	5374244
R196	340094	5382854	R460	358450	5379559	R724	343226	5374176
R197	340181	5382996	R461	358466	5379540	R725	343195	5374163
R198	340410	5383276	R462	358474	5379532	R726	343235	5374286
R199	340396	5383360	R463	358494	5379504	R727	343481	5374447
R200	340450	5383277	R464	358514	5379475	R728	343434	5374493
R201	340491	5383365	R465	358449	5379466	R729	343507	5374412
R202	340503	5383311	R466	358515	5379389	R730	343524	5374537
R203	340593	5383344	R467	358469	5379405	R731	343522	5374509
R204	340529	5383381	R468	358470	5379357	R732	343550	5374541
R205	340632	5383421	R469	358548	5379368	R733	343546	5374510
R206	340671	5383340	R470	358583	5379354	R734	343591	5374570
R207	340666	5383428	R471	358617	5379336	R735	343639	5374542
R208	340692	5383383	R472	358587	5379321	R736	343805	5374631
R209	340674	5383467	R473	358565	5379289	R737	343738	5374605
R210	340765	5383388	R474	358607	5379317	R738	344332	5374878
R211	340742	5383477	R475	358631	5379272	R739	344242	5374839
R212	340771	5383546	R476	358588	5379262	R740	346207	5375672
R213	340920	5383603	R477	358591	5379226	R741	347193	5375617
R214	340861	5383565	R478	358705	5379115	R742	347154	5375601
R215	340972	5383632	R479	358755	5379221	R743	347113	5375583
R216	340981	5383659	R480	358600	5379128	R744	347141	5375555
R217	341041	5383609	R481	358531	5379043	R745	347291	5375663
R218	341069	5383649	R482	358502	5379020	R746	347345	5375673
R219	341016	5383680	R483	358472	5379005	R747	347372	5375705
R220	341055	5383732	R484	358449	5378969	R748	347398	5375689
R221	341074	5383790	R485	358530	5378944	R749	347660	5375700
R222	341197	5383942	R486	358509	5378917	R750	347687	5375853
R223	341259	5384015	R487	358382	5378885	R751	347728	5375850
R224	341317	5384100	R488	358279	5378719	R752	347725	5375784

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	Northing (m)		Easting (m)	Northing (m)		Easting (m)	Northing (m)
R225	341722	5384351	R489	358280	5378693	R753	347752	5375744
R226	342057	5384582	R490	358263	5378680	R754	347783	5375715
R227	342512	5384813	R491	358268	5378654	R755	347851	5375718
R228	342703	5385079	R492	358265	5378638	R756	347875	5375795
R229	342781	5385159	R493	358259	5378615	R757	347913	5375804
R230	342757	5385135	R494	358229	5378588	R758	347899	5375846
R231	342880	5385161	R495	358239	5378561	R759	347929	5375838
R232	342921	5385220	R496	358258	5378535	R760	347949	5375791
R233	342995	5385257	R497	358198	5378526	R761	347984	5375823
R234	343033	5385283	R498	358241	5378437	R762	348005	5375845
R235	343099	5385232	R499	358299	5378421	R763	348024	5375870
R236	343150	5385327	R500	358308	5378551	R764	347972	5375917
R237	343225	5385330	R501	358241	5378313	R765	347836	5376048
R238	343191	5385362	R502	358243	5378283	R766	347833	5376102
R239	343224	5385409	R503	358239	5378264	R767	347950	5376060
R240	343265	5385430	R504	358226	5378156	R768	347952	5376174
R241	343361	5385438	R505	358217	5378128	R769	347980	5376115
R242	343428	5385447	R506	358253	5378047	R770	347969	5375996
R243	343663	5385693	R507	358243	5378001	R771	348006	5376012
R244	343725	5385727	R508	358185	5377957	R772	348055	5375931
R245	343774	5385698	R509	358197	5377851	R773	348091	5376025
R246	343769	5385755	R510	358148	5377671	R774	348074	5375888
R247	343845	5385733	R511	358047	5377658	R775	348085	5376147
R248	343815	5385769	R512	358060	5377528	R776	348136	5376109
R249	343850	5385794	R513	358074	5377572	R777	348192	5376167
R250	343919	5385756	R514	358191	5377485	R778	348128	5376268
R251	343917	5385727	R515	358063	5377468	R779	348229	5376308
R252	343963	5385781	R516	358046	5377398	R780	348233	5376348
R253	344010	5385803	R517	358074	5377265	R781	348253	5376377
R254	344016	5385746	R518	358164	5377262	R782	355251	5376019
R255	344054	5385821	R519	358149	5377308	R783	355333	5376227
R256	343932	5385906	R520	358146	5377098	R784	355375	5376209

Table A.2 Receptor Locations within 1,500 m Assessment Area for the Port au Port Wind Farm

Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)		Receptor Name	UTM Coordinates (NAD83 CSRS UTM Zone 21N)	
	Easting (m)	**Northing (m)**		**Easting (m)**	**Northing (m)**		**Easting (m)**	**Northing (m)**
R257	344098	5385847	R521	358065	5377029	R785	355407	5376121
R258	344056	5385886	R522	358140	5377056	R786	355469	5376052
R259	344136	5385920	R523	358131	5377031	R787	355476	5375990
R260	344162	5385880	R524	358160	5376961	R788	384278	5393645
R261	344168	5385939	R525	358171	5376891	R789	384287	5393719
R262	344204	5385894	R526	358192	5376873	R790	378877	5390458
R263	344256	5386021	R527	358168	5376735			
R264	344394	5386001	R528	358220	5376811			

Appendix 19-E

Letters from Meteorological Service of Canada

Meteorological Service of Canada
Service météorologique du Canada

April 21, 2023

Todd Pickett
World Energy GH2

Subject: World Energy GH2 Wind Farm Proposals (Codroy Valley – Area C) – Updated Preliminary Analysis of Impacts on ECCC Radars (Marble Mountain Radar)

Dear Mr. Pickett,

Thank you for contacting the Meteorological Service of Canada, a branch of Environment and Climate Change Canada (ECCC), regarding your wind energy intentions.

When assessing the potential impact of all new wind farm projects, ECCC's main goal is to avoid significant interference that would hinder the timely and accurate production of watches and warnings of significant weather.

We have reviewed the information you have provided to us via email on April 3, 2023, for the proposed Codroy Valley – Area C Wind Farm Project (located 117 km away from ECCC's Marble Mountain Radar - Marble Mountain, NL). Our preliminary assessment of the proposed project indicates that any potential interference that may be created, should not be severe for our radar operations. Consequently, we do not have objections to the current proposal.

If your plans are modified in any manner (e.g. number of turbines, height, placement or materials) this analysis would no longer be valid and an updated analysis must be conducted. Please contact us at: radarsmeteo-weatherradars@ec.gc.ca

Thank you for your ongoing cooperation and we wish you success with your wind energy project.

Sincerely,

David Bradley
A-Directeur, Surveillance atmosphérique et services de données
Service Météorologique du Canada, Environnement et Changement Climatique Canada
Director-I, Atmospheric Monitoring and Data Services
Meteorological Service of Canada, Environment and Climate Change Canada

Meteorological Service of Canada
Service météorologique du Canada

April 21, 2023

Todd Pickett
World Energy GH2

Subject: World Energy GH2 Wind Farm Proposals (Port Au Port – Area A) – Updated Preliminary Analysis of Impacts on ECCC Radars (Marble Mountain Radar)

Dear Mr. Pickett,

Thank you for contacting the Meteorological Service of Canada, a branch of Environment and Climate Change Canada (ECCC), regarding your wind energy intentions.

When assessing the potential impact of all new wind farm projects, ECCC's main goal is to avoid significant interference that would hinder the timely and accurate production of watches and warnings of significant weather.

We have reviewed the information you have provided to us via email on April 3, 2023, for the proposed Port Au Port – Area A Wind Farm Project (located 62 km away from ECCC's Marble Mountain Radar - Marble Mountain, NL). Our preliminary assessment of the proposed project indicates that any potential interference that may be created, should not be severe for our radar operations. Consequently, we do not have objections to the current proposal.

If your plans are modified in any manner (e.g. number of turbines, height, placement or materials) this analysis would no longer be valid and an updated analysis must be conducted. Please contact us at: radarsmeteo-weatherradars@ec.gc.ca

Thank you for your ongoing cooperation and we wish you success with your wind energy project.

Sincerely,

David Bradley
A-Directeur, Surveillance atmosphérique et services de données
Service Météorologique du Canada, Environnement et Changement Climatique Canada
Director-I, Atmospheric Monitoring and Data Services
Meteorological Service of Canada, Environment and Climate Change Canada

Appendix 19-F

Human Health Risk Assessment of Air Contaminants Technical Data Report

PROJECT NUJIO'QONIK
Human Health Risk Assessment of Air Contaminants
Technical Data Report

August 2023

Prepared for:

Prepared by:

Stantec Consulting Ltd.

File: 121417575

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Abbreviations

AQMP	Air Quality Management Plan
ATSDR	Agency for Toxic Substances and Disease Registry
B(a)P	benzo(a)pyrene
CALMET	California Meteorological Model
CALPUFF	California Puff Model
CO	carbon monoxide
COHb	carboxyhaemoglobin
COPC	contaminant of potential concern
COPD	chronic obstructive pulmonary disorder
CSM	conceptual site model
DE	diesel exhaust
DPM	diesel particulate matter
EIS	Environmental Impact Statement
ER	exposure ratio
HEI	Health Effects Institute
HHRA	human health risk assessment
IARC	International Agency for Research on Cancer
ILCR	incremental lifetime cancer risk
IUR	inhalation unit risk
LAA	local assessment area
NL	Newfoundland and Labrador
NLAAQS	Newfoundland and Labrador Ambient Air Quality Standards
NO_2	nitrogen dioxide
NOAEL	no observed adverse effect level
NOEL	no observed effect level

NTP	National Toxicity Program
OEHHA	Office of Environmental Health Hazard Assessment
PAH	polycyclic aromatic hydrocarbon
PEF	potency equivalency factor
PM_{10}	particulate matter with particles having an aerodynamic diameter less than 10 μm
$PM_{2.5}$	particulate matter with particles having an aerodynamic diameter less than 2.5 μm
PMR	peak-to-mean ratio
PQRA	preliminary quantitative risk assessment
RAA	regional assessment area
RIVM	Dutch National Institute for Public Health and the Environment
RPF	relative potency factor
RSC	risk-specific concentration
SO_2	sulphur dioxide
SOP	standard operating procedure
TCEQ	Texas Commission on Environmental Quality
TPE	total potency equivalents
TPH	total petroleum hydrocarbons
TPHCWG	total petroleum hydrocarbons criteria working group
TRV	toxicity reference value
TSP	total suspended particulate
US EPA	United States Environmental Protection Agency
VOC	volatile organic compound
WHO	World Health Organization

1.0 Introduction

This human health risk assessment (HHRA) is an appendix to the Environmental Impact Statement (EIS) prepared in support of Project Nujio'qonik GH2 ("the Project"). The purpose of this HHRA is to evaluate the potential for Project-related emissions of air quality contaminants to affect human health during Project construction, operation and maintenance, decommissioning and rehabilitation.

To determine the potential for Project-related emissions of air quality contaminants (i.e., chemicals of potential concern for the Project (COPC)) to affect human health, a standard human health risk assessment (HHRA) approach was applied, which consists of the following components:

- **Problem Formulation**: The problem formulation identifies the spatial and temporal boundaries for this HHRA, the COPC in air, the human receptors and the locations of these receptors within the boundaries, and applicable operable/inoperable exposure pathways linking receptors to COPC in air. The objective of the problem formulation stage is to develop a conceptual site model (CSM) that aids in further stages of quantitative analyses.
- **Toxicity Assessment**: The toxicity assessment characterizes the potential toxic effects of each COPC and identifies toxicological reference values (TRVs) or health-based limits for use in the HHRA. Toxicological reference values are dose or exposure concentration benchmarks to which a human receptor can be exposed to without an appreciable risk of adverse health effects. The toxicological reference values applied in this HHRA are guidelines and objectives published by provincial, federal or international regulatory agencies.
- **Exposure Assessment**: The exposure assessment characterizes the COPC dose or exposure concentration for each operable exposure pathway in the CSM. The objective is to quantify the amount of COPC to which people could be exposed.
- **Risk Characterization**: The risk characterization stage qualitatively and/or quantitatively characterizes potential risk to human receptors from each operable exposure pathway. The risk characterization compares the results of the exposure assessment to the TRVs to quantify potential health risk.
- **Uncertainty Assessment**: The uncertainty assessment provides an indication of the validity and confidence in the risk estimates. Uncertainties associated with the data, predictive modelling and other factors that could affect the final risk estimate are described. When uncertainties exist, professional judgment is applied in a conservative manner to reduce the risk of underestimating the health risk.

The risk assessment methodology for conducting this HHRA is based on Health Canada guidance including (but not limited to) the following documents:

- Guidance for Evaluating Human Health Impacts in Environmental Assessment: Human Health Risk Assessment (Health Canada 2019)
- Guidance to Evaluating Human Health Impacts in Environmental Assessments: Air Quality (Health Canada 2016a)
- Federal Contaminated Sites Risk Assessment in Canada, Part I: Guidance on Human Health Risk Preliminary Quantitative Risk Assessment, Version 3.0 (Health Canada 2021b)
- Federal Contaminated Sites Risk Assessment in Canada, Part V: Guidance on Complex Human Health Detailed Quantitative Risk Assessment for Chemicals (Health Canada 2010a)

2.0 Problem Formulation

The purpose of the problem formulation is to identify the spatial and temporal boundaries for this HHRA, develop a focused understanding of which substances in air constitute COPCs, identify the human receptors and the locations of these receptors within the HHRA boundaries, and identify the operable/inoperable exposure pathways linking receptors to COPC in air. This information is then summarized in a human health conceptual site model (CSM), which provides a visual depiction of the relevant pathways linking COPCs to the human receptors of interest in the HHRA.

2.1 Identification of Study Boundaries

As part of the problem formulation, both spatial and temporal boundaries for the HHRA are defined to confirm that human health risks are adequately characterized (Health Canada 2019).

2.1.1 Spatial Boundaries

To evaluate the human health risk due to Project-related emissions of air quality contaminants, the study boundaries for the HHRA include a Project Area, Local Assessment Area (LAA) and Regional Assessment Area (RAA).

The Project Area encompasses the immediate area in which the Project activities and components occur and is comprised of following distinct areas: the Port au Port Wind Farm, the Codroy Wind Farm, the Hydrogen/Ammonia Production and Storage Facility (hydrogen / ammonia plant), Port Facilities, and the 230 kV Transmission Lines, as well as associated infrastructure including roads, substations, and water supply infrastructure. The Project Area is the anticipated area of direct physical disturbance associated with the construction, operation and decommissioning, rehabilitation and closure of the Project. In addition to encompassing the immediate area in which Project components and activities will occur, the Project Area also includes a buffer of up to 300 m for access roads and turbines and a 350 m corridor to accommodate the 70 to 75 m wide RoW for the transmission line. These buffers allow flexibility for the micro-siting of Project components during detailed design, based on technical considerations as well as the avoidance of environmentally sensitive areas, where practicable.

The LAA is the area where Project-specific environmental effects on air quality can be predicted or measured with a reasonable degree of accuracy and confidence. The RAA represents the area within which cumulative effects on air quality are likely to occur, depending on the location of other past, present or reasonably foreseeable future projects or activities. As defined in EIS Chapter 6 (Atmospheric Environment), the LAA and RAA are the same and are defined as a 90 km by 100 km area which encompasses the hydrogen/ ammonia plant and the Codroy and Port au Port wind farm sites. This LAA/RAA represents the modelling domain for air contaminant dispersion modelling and includes sensitive receptors as well as other past, present, or reasonably foreseeable projects/activities that could interact cumulatively with the Project. The LAA/RAA for the HHRA are therefore same as the LAA/RAA used in EIS Chapter 6 (Atmospheric Environment).

2.1.2 Temporal Boundaries

The temporal boundaries for the HHRA reflect the timing and lifespan of the Project and are defined by the following Project phases:

- Construction: The construction phase of the Project will be from Q4 2023 through Q2 2027, pending Environmental Assessment approval and receipt of other required permits and approvals. Early civil works are planned to start Q4 2023 through Q3 2024. Construction of the Port au Port Wind Farm and associated infrastructure is expected to start in Q3 2024 with completion of the construction in Q4 2026. Construction of the Codroy Wind Farm and associated infrastructure is expected to start Q4 2025 with completion in Q1 2027. The hydrogen / ammonia plant will be constructed in phases from Q2 2024 to Q1 2026. Grid power sources are planned for hydrogen production in 2025 until March 2026, when the electrolyzer is commissioned.
- Operation and maintenance: Wind farm commissioning is anticipated to start Q1 2026 at the Port au Port Wind Farm and Q3 2027 at the Codroy Wind Farm. The 600 MW electrolyzer expected to be commissioned in Q1 2026. The operational life of the Project is 30 years at each site.
- Decommissioning and rehabilitation: The decommissioning phase is anticipated to take two years, occurring between 2056 and 2058. Decommissioning is anticipated to begin Q1 2056 at the Port au Port Wind Farm, with completion in Q3 2058 at the Codroy Wind Farm

2.2 Identification of Chemicals of Potential Concern

For this HHRA, chemicals that may be released to air by Project activities and can affect human health are defined as COPC. During construction, activities result in releases of air contaminants from fuel combustion in heavy equipment and stationary equipment (e.g., generators), and fugitive dust due to earth moving and site preparation activities. During operation and maintenance, air contaminants are released from the plant flare (pilot and flaring events), the cooling towers, the biodiesel fueled back-up emergency generator, and marine vessels. The air contaminants released during decommissioning and rehabilitation are typically the same as those during construction (i.e., air contaminants from fuel combustion and fugitive dust).

As described in EIS Chapter 6 (Atmospheric Environment), air emission inventories were prepared for the construction and operation phases of the Project using operational and design information, and emission factors published by regulatory agencies such as the US EPA or Environmental and Climate Change Canada. Based on the emissions inventories, the following air contaminants were identified that may be released by Project activities:

- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Sulphur dioxide (SO_2)
- Ammonia (NH_3)

- Particulate matter:
    - Total suspended particulate (TSP)
    - Particulate matter (PM_{10}) with particles having an aerodynamic diameter less than 10 µm
    - Particulate matter ($PM_{2.5}$) with particles having an aerodynamic diameter less than 2.5 µm
- Diesel particulate matter (DPM)
- Select speciated VOCs (benzene, toluene, xylene, acrolein, formaldehyde)
- Total polycyclic aromatic hydrocarbons (PAHs) and select speciated PAHs (acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[g,h,i]perylene benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-c,d]pyrene, naphthalene, phenanthrene, pyrene)

While TSP (i.e., total particulate matter with an aerodynamic diameter less than 30 µm) and total PAHs were identified as air contaminants that may be released by Project activities, they were not identified as COPC for the following reasons.

- Existing evidence related to health effects due to inhalation of particulate matter indicates that health effects are most strongly correlated with smaller particulate size (Health Canada 2016c). For example, the World Health Organization notes that, "the effects of long-term particulate matter exposure on mortality seem to be attributable to $PM_{2.5}$ rather than coarse particles" (WHO 2006). Therefore, PM_{10} and $PM_{2.5}$ were retained to assess the potential for particulate matter to affect human health in this HHRA.
- While total PAHs was evaluated as an air contaminant, the assessment of PAH mixtures is typically based on the speciated PAHs as different PAHs have different effects and toxicities. Total PAHs was therefore not identified as a COPC.

While Health Canada (2019) notes that if the modelled concentrations plus the baseline concentrations (see below in Section 4.1 and EIS Chapter 6 (Atmospheric Environment) for details on modelling and baseline data) are calculated to be below guidelines/standards/criteria for the impacted media, the problem formulation phase of the risk assessment may conclude that the chemicals do not need to be carried forward as COPCs in a quantitative risk assessment. However, for the purposes of this HHRA, the air contaminants identified above (with the noted exceptions of TSP and total PAHs) were carried forward as COPCs in the HHRA.

2.3 Identification of Human Receptors and Receptor Locations

Human receptors are people within the LAA/RAA that could be exposed to COPCs, while human receptor locations are the places where they are likely to be present. The characterization of human receptors is important because distinct groups of people (e.g., infants, elderly, people with existing health conditions) may have varying degrees of sensitivity to a COPC, or their behaviours may cause them to be exposed to COPCs in different ways. For many air contaminants, children with asthma, people with chronic obstructive pulmonary disorder (COPD), and the elderly are considered the sensitive sub-groups. Members of these sensitive sub-groups may be present at any residential location; however, their presence is more likely at institutional facilities such as schools, hospitals, retirement complexes, and assisted care homes.

Human receptor locations are important because exposure to a COPC is dependent on the location of the person since the concentration of the COPC may vary throughout the LAA/RAA.. Special receptor locations, identified as representative of areas where people live, work, or otherwise spend time in the LAA/RAA are shown on Figure 2.1. Locations in the LAA/RAA that are farther away than these special receptor locations would experience less change in air quality, and there would be a lower degree of change in the health risk.

Human receptors are hypothetical people of all age groups (e.g., infant, toddler, child, adolescent, or adult) who could potentially be exposed to the COPC within the LAA/RAA. The duration of exposure at the modelled location may vary depending on the receptor location type (e.g., residential location vs. recreational location). For this assessment, it will generally be assumed that people may be present at the special receptor locations 24 hours a day, 7 days a week, over a lifetime of exposure unless otherwise noted.

Workers for the Project are not included as human receptors in the HHRA. Worker health and safety is addressed through compliance with applicable provincial and federal legislation. Non-work-related exposures of these persons (e.g., recreational activities within the study area during non-work hours) would be the same as the other human receptors already identified.

Stantec

- • Sensitive Receptor Location
- ☐ Local Assessment Area/ Regional Assessment Area

Proposed Project Features

- • Wind Turbine
- ☆ Hydrogen / Ammonia Plant Location
- ☐ Project Area

Other Features

- Trans-Canada Highway
- Road
- Watercourse
- Waterbody
- Wetland
- Forested Area

N

0 12 Kilometres
(At original document size of 8.5x11)
1:600,000

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec

Project Location
Stephenville
NL

Prepared by MER on 2023-07-20
QR by AW on 2023-07-20

Client/Project
World Energy GH2
Project Nujio'qonik

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Figure No.
2.1

Page 1 of 1

Local Assessment Area/Regional Assessment Area Air Quality

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2.4 Identification of Exposure Pathways

Exposure pathways are the means by which human receptors may be exposed to COPCs from the Project. The exposure pathway screening examines the potential exposure pathways for each type of COPC that applies to this HHRA.

Exposure to the identified COPC associated with this Project would occur primarily via inhalation of air (i.e., deposition of gases is considered a negligible transport mechanism and therefore there are no secondary exposure media). Because people within the LAA/RAA could inhale the airborne COPC, each of the identified COPC in air are assessed for inhalation exposures. Although people who visit the LAA/RAA for work or recreation could be exposed to the COPCs via inhalation, residents in the LAA/RAA are expected to be the sensitive receptors as this group is more highly exposed (due to their longer exposures in the area) and more likely to include sensitive subgroups such as children, the elderly, and those with chronic illnesses such as asthma or COPD.

2.5 Conceptual Site Model

The CSM below illustrates the plausible pathways by which human receptors could be exposed to COPCs from Project activities (Figure 2.2). The CSM combines key information regarding COPC sources (from EIS Chapter 6 (Atmospheric Environment)), human receptors or human receptor locations, and operable exposure routes for COPCs.

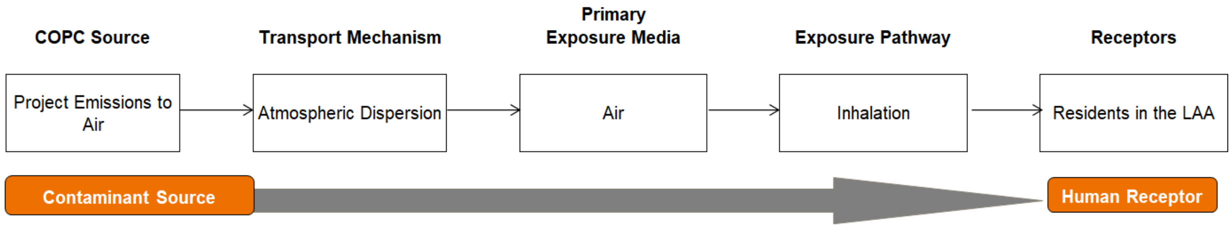

Figure 2.2 Conceptual Site Model

3.0 Toxicity Assessment

The toxicity assessment characterizes the potential toxic effects of each COPC and identifies TRVs or health-based exposure limits for use in the HHRA. The TRVs are estimates of the maximum exposure dose or exposure concentration to which the human population (including members of sensitive subgroups such as infants, children, the elderly) could be exposed without an appreciable risk of adverse effects.

3.1 Methods

When establishing TRVs for a COPC, the type of dose-response relationship leading to a possible effect needs to be considered as well as the duration of exposure. Effects are typically classified as threshold or non-threshold based on a chemical's mode of action (Health Canada 2021b).

3.1.1 Threshold Effects

A threshold effect is one where a certain dose must be exceeded for toxicity to occur. A no observable adverse effect level (NOAEL) can be identified for threshold contaminants, which is the dose or amount of the contaminant that results in no obvious response in the most sensitive test species and test endpoint. At exposures below the NOAEL, biological processes in the human body effectively metabolize, detoxify, sequester, or excrete the COPC without a toxic effect to the human body. When exposure to the COPC is greater than the NOAEL, the human body is unable to manage the COPC and an adverse health effect is observed.

When developing a TRV for a COPC with threshold effects, uncertainty factors are applied to the NOAEL to provide an added level of protection. This results in the derivation of a TRV that is lower than the NOAEL, and thus reasonably expected to be protective of the general public (including health-sensitive members of the population such as children, seniors, and people with existing health conditions) following exposure for a prescribed period of time. TRVs for threshold contaminants in air are typically provided in terms of an acceptable concentration such as a tolerable concentration or reference concentration (expressed as a concentration, e.g., $\mu g/m^3$) or an acceptable dose, most commonly expressed in terms of the total intake of the contaminant per unit of body weight per day (mg/kg-day).

3.1.2 Non-Threshold Effects

A non-threshold effect is one where there is no clear threshold dose that results in a toxic effect. This means that any level of exposure to a non-threshold COPC carries some degree of risk; therefore, there is no NOAEL or threshold associated with non-threshold effects. The dose-response relationship associated with non-threshold COPCs is typically conceptualized as linear. At low doses, the adverse health effect may need to be mathematically extrapolated from the effects observed at higher doses or from a larger sample population. Non-threshold effects are further categorized into carcinogenic (i.e., carcinogens) and non-carcinogenic effects.

3.1.2.1 Carcinogens

Regulatory agencies such as Health Canada and the US EPA assume that any level of long-term exposure to carcinogens is associated with some "hypothetical cancer risk". As a result, regulatory agencies have typically employed acceptable incremental lifetime cancer risk levels (ILCR) (i.e., levels over and above those that one would expect to be exposed to from background sources other than related to the Project). When exposure occurs in air, generic nomenclature for TRVs for carcinogens includes inhalation unit risk (IUR), defined as the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a unit concentration of 1 1 µg/m^3.

It is also appropriate to express TRVs for carcinogens in terms of a risk-specific dose or risk-specific concentration (RSC). For this HHRA, IUR factors were also expressed as risk-specific concentrations associated with the ILCR level that Health Canada considers to be "essentially negligible" of 1 in 100,000 (Health Canada 2021b). The RSC for continuous lifetime exposure that would be associated with 1 in 100,000 ILCR is calculated with the following equation:

$$RSC\ \left({}^{\mu g}\!/_{m^3}\right) = \frac{10^{-5}}{IUR\ \left({}^{\mu g}\!/_{m^3}\right)^{-1}}$$

Where:

RSC	Risk-specific concentration	µg/m^3
10^{-5}	Target level of risk	unitless
IUR	Inhalation unit risk	(µg/m^3)$^{-1}$

3.1.2.2 Non-Carcinogens

For non-threshold non-carcinogens, there is also no clear threshold dose that results in a toxic effect. Any level of exposure to a non-threshold non-carcinogen carries some degree of risk. At extremely low doses, the toxic effect may be at the cellular level with no observable presentation of adverse health effects. As the dose increases, the adverse health effect can increase in severity and additional health effects can manifest. For example, low concentrations of a respiratory irritant can cause mild irritation of the lungs and eyes, while higher concentrations may cause severe irritation to the lungs and eyes in addition to coughing, shortness of breath, or exacerbation of asthma symptoms. For these COPC, TRVs may not be available, in which case exposures may be benchmarked against exposure limits or air quality guidelines that are based on protection of public health.

3.1.3 Acute and Chronic Exposures

The toxicity of a chemical depends on duration of exposure. Thus, it is important to differentiate TRVs based on acute (short-term) and chronic (long-term) duration, as described below:

- Acute: The amount or dose of a chemical that can be tolerated without evidence of adverse health outcomes on a short-term basis. These limits are routinely applied to conditions in which exposures extend from minutes through several hours or several days only (ATSDR 2018). For the HHRA, risks are evaluated based upon 1- to 24-hour exposure periods, where a relevant acute TRV for that time period is available.
- Chronic: The amount of a chemical that is expected to be without health outcomes, even when exposure occurs continuously or regularly over extended periods, possibly lasting for periods of at least a year, and possibly extending over an entire lifetime (ATSDR 2018).

3.2 Toxicity Assessment

As noted by Health Canada (Health Canada 2016a), the predicted COPC concentrations should be analyzed in relation to appropriate air quality standards and, after estimating the changes in air quality, the assessment should examine and consider the risks to human health due to these changes. An analysis of the changes in air quality concentrations in relation to the appropriate air quality standards (e.g., the Newfoundland and Labrador (NL) Ambient Air Quality Standards, NLAAQS, and the federal Canadian Ambient Air Quality Standards), which are often based on statistical representations of existing airshed data and not necessarily health based is provided in EIS Chapter 6. In contrast, this HHRA relies on TRVs/exposure limits that are based on human health effects to support the characterization of risks to human health. The TRVs/ exposure limits relied on in this HHRA for each COPC are described in detail below. Much of the provided information comes from comprehensive toxicity evaluations that have been prepared by agencies such as the Agency for Toxic Substances and Disease Registry (ATSDR), Health Canada, US EPA, California EPA (OEHHA), Texas Commission on Environmental Quality (TCEQ), and the World Health Organization (WHO).

3.2.1 Nitrogen Dioxide (NO_2)

NO_2 is an orange-reddish gas produced from most types of combustion processes (e.g., fuel combustion, fires). NO_2 has a pungent and irritating odour that can be toxic and potentially corrosive. Most atmospheric NO_2 is formed by the oxidation of nitric oxide, which is emitted from the exhaust of motor vehicles and the burning of fossil fuels including coal, oil, and natural gas (ATSDR 2002). Natural sources of NO_2 include forest fires, lightning strikes, and anaerobic processes.

Inhalation exposure to NO_2 increases the likelihood of respiratory problems because it inflames the lining of the lungs and can reduce immunity to lung infections. Human receptors that are sensitive to NO_2 include people with asthma and people with chronic obstructive pulmonary disease. For these individuals, exposure to low concentrations can irritate the eyes, nose, throat and lung as well as causing shortness of breath, fluid build-up in the lungs, tiredness and nausea (ATSDR 2002). Inhalation of high concentrations can cause burning, spasms and swelling of the throat and upper respiratory tract, reduced oxygenation of body tissues and in extreme cases, death (ATSDR 2002). Exercise can exacerbate symptoms due to the increased rate of ventilation.

In 2016, Health Canada completed a review of scientific studies that characterize the potential health effects from exposure to varying levels of NO_2 in ambient air (Health Canada 2016b). When considering short-term (1-hour) exposures to NO_2, the lowest concentration cited in Health Canada's review that resulted in airway hyper-responsiveness in asthmatic adults was 190 $\mu g/m^3$ (100 parts per billion) with most studies showing effects around 560 $\mu g/m^3$ (300 parts per billion) or greater (Health Canada 2016b).

Health Canada's review of the scientific studies concludes that the evidence supports the establishment of both short-term and long-term standards to protect against the range of health effects associated with ambient NO_2. Health Canada recognizes NO_2 as a non-threshold contaminant, meaning adverse health effects may occur at any concentration of NO_2, but the severity of effects increases incrementally with exposure concentration and exposure duration. The WHO also acknowledges that despite the large number of acute controlled NO_2 exposure studies on humans, there is no evidence for a clearly defined concentration-response relationship (WHO 2006). The absence of a clearly defined concentration-response relationship for NO_2 presents a technical challenge for health regulatory agencies and health risk practitioners on how to assess the incremental increase in health risk resulting from modelled or measured NO_2 concentrations.

The WHO ambient air quality guidelines are used in this HHRA as the health-based exposure limits for the assessment of human health risk. These limits are defined by the WHO as, "*The lowest exposure level of an air pollutant above which the guideline development group is confident that there is an increase in adverse health effects*," and that, "*It is assumed that adverse health effects do not occur or are minimal below this concentration level.*" The WHO air quality guideline is essentially the lowest level of exposure for which there is evidence of adverse health effects (WHO 2021).

The WHO ambient air quality guidelines for 1-hour, 24-hour and annual NO_2 are 200 $\mu g/m^3$, 25 $\mu g/m^3$ and 10 $\mu g/m^3$, respectively. The 1-hour guideline concentration is based upon the health outcome of an increase in asthma-related hospital admissions and emergency room visits among all ages, noting that the potential health outcome is more prominent among asthmatic children and those with pre-existing diseases such as COPD (WHO 2021; 2006). Potential effects of short-term NO_2 exposure are less pronounced in healthy individuals with no history of asthma or pre-existing respiratory conditions. The WHO guideline for 24-hr NO_2 is based upon all-cause non-accidental mortality and asthma hospital admissions and emergency room visits, and the annual value is based on all-cause non-accidental mortality and cause specific respiratory mortality (WHO 2021).

In summary, for the purposes of assessing the risks to human health from Project-related exposures to NO_2, the following WHO ambient air quality guidelines have been used in this HHRA as the health-based exposure limits have been used:

- Acute, 1-hour NO_2: 200 $\mu g/m^3$, based on maximum 1-hour average concentrations (WHO 2021)
- Acute, 24-hour NO_2: 25 $\mu g/m^3$, based on the 99th percentile of the annual distribution of 24-hour average concentrations (WHO 2021)
- Chronic, Annual NO_2: 10 $\mu g/m^3$, based on the annual mean (WHO 2021)

3.2.2 Sulphur Dioxide (SO_2)

SO_2 is a colorless gas with a pungent odor. The combustion of fossil fuel is the dominant source of SO_2 emissions in the world, primarily emitted at power plants and other industrial facilities, as well as fuel combustion in automobiles, locomotives, ships, and other types of machines and equipment. Natural sources of SO_2 include volcanoes and forest fires.

Health Canada and other health agencies recognize SO_2 as a non-threshold non-carcinogen (Health Canada 2016e). As the exposure concentration increases, the severity of respiratory effects also increases to the respiratory tract (e.g., nose, throat, trachea, bronchi, and lungs) and the eyes. The types of health effect can progress from simple respiratory irritation, coughing, and shortness of breath to exacerbation of asthma symptoms or other respiratory illnesses such as COPD (Health Canada 2016e).

Assessing the potential inhalation health risk from SO_2 typically focuses on short-term exposure because there is a strong causal relationship between respiratory morbidity and short-term exposure to SO_2. Health Canada (Health Canada 2016e) concluded that there is inadequate evidence to infer a causal relationship between long-term SO_2 exposure and cardiovascular effects, reproductive and development effects, total mortality, or cancer. Similarly, the US EPA (2017b) concluded that evidence is suggestive of, but not sufficient to infer, a causal relationship between long-term SO_2 exposure and respiratory effects. In the absence of evidence of a causal relationship, a chronic assessment of SO_2 for human health has not been conducted.

Health Canada (2016e) provides a 10-minute SO_2 reference concentration of 175 $\mu g/m^3$ (or 67 parts per billion). This reference concentration is based on controlled human exposure studies, which showed a lowest observed adverse effect concentration of 1,050 $\mu g/m^3$, with an uncertainty factor of 6 (i.e., 1,050 $\mu g/m^3$ divided by 6 equals 175 $\mu g/m^3$). This 10-minute SO_2 reference concentration is expected to be protective of respiratory effects in humans, including sensitive populations like people with asthma.

The WHO derived an ambient air quality guideline for 24-hour SO_2 exposure of 40 $\mu g/m^3$ based upon the health outcome of an increase in asthma-related hospital admissions and emergency room visits among all ages, noting that the potential health outcome is more prominent among asthmatic children (WHO 2021).

In summary, for the purposes of assessing the risks to human health from Project-related exposures to SO_2, the following Health Canada reference concentration and WHO ambient air quality guideline have been used in this HHRA as the TRV/health-based exposure limits:

- Acute, 10-min SO_2: 175 $\mu g/m^3$ (Health Canada 2016e)
- Acute, 24-hour SO_2: 40 $\mu g/m^3$, based on the 99th percentile of the annual distribution of 24-hour average concentrations (WHO 2021)
- Chronic, Annual SO_2: not assessed due to absence of evidence of a causal relationship

3.2.3 Particulate Matter ($PM_{2.5}$ and PM_{10})

PM_{10} refers to particles with a diameter of 10 µm (micrometres) or less while $PM_{2.5}$ refers to particles with a diameter of 2.5 µm or less. When inhaled, larger particles are trapped in the upper respiratory system while smaller particle sizes ($\leq PM_{2.5}$) can penetrate deeper into the respiratory system and into the alveoli of the lungs.

Health Canada completed a review of scientific studies that characterize the potential health effects from exposure to varying levels of particulate matter in ambient air (Health Canada 2016c; 2013a). Health Canada's review of studies includes a description of the link between the inhalation of $PM_{2.5}$ with various health effects such as premature death in people with heart or lung disease, non-fatal heart attack, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms (e.g., irritation of the airways, coughing, or difficulty breathing (Health Canada 2013a). People with heart or lung disease, children, and older adults are the most likely to be affected by exposure to $PM_{2.5}$ (US EPA 2004). $PM_{2.5}$ is a non-threshold contaminant, and adverse health effects may occur at any exposure concentration. With respect to PM_{10}, Health Canada (2016c) concluded that "*… it cannot be dismissed that there are health effects on the respiratory system resulting from short-term exposure to coarse particles"* based on evidence of an association between PM_{10} and respiratory morbidity but acknowledged that the data on health effects of coarse particles are weaker than for fine particles and subject to large measurement errors.

The WHO ambient air quality guideline for 24-hour $PM_{2.5}$ is 15 µg/m^3 and for annual $PM_{2.5}$ is 5 µg/m^3. The 24-hour guideline concentration is based upon the health outcome of an increase in all types of mortality, with a more prominent effect on respiratory and cardiovascular mortalities (WHO 2021). The annual average guideline is based upon the health outcome of an increase in all types of mortality with a more prominent effect on respiratory mortalities (related to COPD and acute lower respiratory infections), cardiovascular mortalities (related to cerebrovascular and ischemic heart disease), and also lung cancer mortalities.

The WHO air quality guideline for annual PM_{10} is 15 µg/m^3, based on an evaluation of the studies of long-term effects of PM_{10} on mortality only, without taking into consideration that a large portion of PM_{10} is made up of $PM_{2.5}$ (WHO 2021). The WHO (2021) recommend a short-term (24-hour) PM_{10} air quality guideline of 45 µg/m^3, defined as the 99th percentile of the annual distribution of 24-hour average concentrations, but note that in all situations where both $PM_{2.5}$ and PM_{10} measurements are available, preference should be given to the $PM_{2.5}$ air quality guideline level.

For the purposes of this HHRA, the assessment of health risks associated with particulate matter focused on $PM_{2.5}$ since the data that support an evaluation of health effects from PM_{10} are weaker than for $PM_{2.5}$ and subject to larger measurement errors (Health Canada 2016c); and WHO indicates preference should be given to air quality guidelines for $PM_{2.5}$ (WHO 2021). In summary, the following WHO ambient air quality guidelines have been used in this HHRA as the health-based exposure limits for acute and chronic exposures:

- Acute, 24-hour $PM_{2.5}$= 15 µg/m^3 based on the 99th percentile of the annual distribution of 24-hour average concentrations (WHO 2021)
- Chronic, Annual $PM_{2.5}$ = 5 µg/m^3 based on the annual mean (WHO 2021)

3.2.4 Diesel Particulate Matter

Diesel exhaust (DE) is a complex mixture of hundreds of chemicals (Health Canada 2016d) including airborne particles and gases from the combustion products of diesel fuel. The exact composition of the mixture is variable, and depends on the nature of the engine, operating conditions, fuel composition, emission control system, and additives (NTP 2021).

In Chapter 6 (Atmospheric Environment), the identified sources of DE during Project operation are:

- Backup Power Generation (50 MW biodiesel combustion turbine). The backup generator would only be used during emergencies, for approximately 13 hours per event. It was assumed this may occur four events per year (52 hours/year).
- Marine Vessel – hoteling at port. Four vessels per month at maximum production, loading was estimated (from loading pipe rate and ship volume capacity) to take 43 hours.
- Assist Tug Boats (two tugs). Present when vessels are in port.

For these sources, chemicals associated with DE with applicable air quality criteria (i.e., NO_2, CO, SO_2, PM_{10}, $PM_{2.5}$, VOCs, PAHs) were modelled in Chapter 6 (Atmospheric Environment) and the toxicity of each of these individual components of DE is discussed in this section. The risk characterization presented in Section 5.0 of this HHRA for each of these individual components of DE provides a partial evaluation of potential risks associated with exposure to DE (i.e., assessing toxicity of DE via the toxicity of some of its components). However, a human health risk assessment for diesel exhaust that was completed by Health Canada in 2016 (Health Canada 2016d) concluded that "*the component or components of DE that are the most relevant toxicologically…have not yet been identified*" and that "[*t]he most appropriate metric for DE exposure remains unknown*." Thus, an evaluation of the toxicity of DE as a mixture, and DPM as a surrogate, is provided below.

Health Canada reviewed a number of studies on the health effects of exposure to DE and diesel exhaust particles (DEP; synonymous with DPM for the purpose of this HHRA) ranging from rural farm, urban city, and occupational exposures (Health Canada 2016d). Inhalation of DE may result in a variety of health effects, in part due to the mixture of chemical hazards, where each chemical hazard may have different types of health effects and at different concentrations. Sensitive groups of people generally include children, asthmatics, and people with chronic obstructive pulmonary disease.

Acute inhalation of DE shows a causal relationship with respiratory effects, and a likely relationship with cardiovascular and immunological effects. There is some evidence to suggest a relationship between exposure to diesel exhaust and reproductive, developmental, and central nervous system effects. However, long-term relationships are more difficult to distinguish due to the co-exposure to other airborne hazards in the air.

For non-cancer health effects, Health Canada (2016d) chose DPM as the basis for development of acute and chronic exposure guidance values as:

- toxicological studies have demonstrated DPM to be the main causative agent of many of the health effects associated with diesel exhaust exposure
- removal of the particulate component of diesel exhaust resulted in fewer or less severe health effects
- the DPM component of exhaust contains compounds known to be hazardous to human health, and DPM contributes to ambient PM, which is also known to be harmful to human health
- DPM is typically the parameter used to set experimental exposure levels

Health Canada (2016d) acknowledges that it would be preferable to use epidemiological data for large populations for characterization of the exposure–response relationship between short-term and long-term diesel exhaust exposure and non-cancer health effects; however, the current data are not deemed adequate for this purpose.

Health Canada (2016d) reviewed controlled human exposure studies to determine the critical effect associated with short-term exposure to diesel exhaust, and concluded that respiratory endpoints are the most sensitive, with effects demonstrated at lower concentrations than for other types of endpoints (such as cardiovascular health). Based on multiple studies conducted with healthy and/or mildly asthmatic participants, increased measures of airway resistance and/or respiratory inflammation were observed at 100 µg/m^3 diesel exhaust particulate for a 2-hour exposure period (Behndig et al. 2006; Riedl et al. 2012; Mudway et al. 2004; Behndig et al. 2011; Stenfors et al. 2004). Based on this lowest-observed adverse effect level of 100 µg/m^3, Health Canada (2016d) derived a short-term exposure (2-hour) guidance value for diesel exhaust particulate of 10 µg/m^3. This Health Canada value was used as the TRV for short-term exposures in this HHRA.

For chronic exposure to DE, a consistent exposure–response relationship for respiratory effects were observed in studies with animal test species, and epidemiological studies also indicate that respiratory health effects are associated with human exposures (Health Canada 2016d). Health Canada (2016d) derived a chronic exposure limit using the NOAEL of 0.46 mg/m^3 DEP from the inhalation study on rats by Ishinishi et al. (1986) by performing dosimetric modelling to derive a human equivalent concentration of 0.12 mg/m^3 DEP. Based on the human equivalent concentration of 0.12 mg/m^3 DEP and applying a composite uncertainty factor of 25, Health Canada derived a chronic exposure guidance value of 5 µg/m^3 DEP. This value is consistent with values previously developed by the World Health Organization, the US EPA and the California EPA, and was used as the TRV for DPM in this HHRA.

In addition to the non-cancer health effects described above, the International Agency for Research on Cancer (IARC) has classified DE as a Group 1 human carcinogen. The Group 1 classification indicates that there is sufficient evidence to conclude carcinogenicity in humans. Specifically, DE has exhibited a causal relationship with lung cancer, and a suggested relationship with bladder cancer (Health Canada 2016d; IARC 2014). However, within their most recent human health risk assessment for DE, Health Canada (2016d) did not evaluate studies for use in a quantitative exposure–response analysis of lung cancer risk with DEP.

While there appears to be consensus within the scientific community that DE should be considered as a human carcinogen, a scientifically sound IUR that can be used to quantitatively assess the carcinogenic risk associated with inhalation exposures to DE is currently unavailable. Therefore, in this HHRA, cancer risks of exposure to DE (using DPM as a surrogate) will be evaluated qualitatively.

In summary, the following Health Canada guidelines have been used in this HHRA as the health-based exposure limits for acute and chronic exposures:

- Short-term exposure (2-hour): 10 μg/m^3 (Health Canada 2016d)
- Chronic exposure: 5 μg/m^3 (Health Canada 2016d)

3.2.5 Ammonia (NH_3)

Ammonia occurs naturally and is produced by human activity. Ammonia is a colorless gas with a very distinct odour that may be familiar to many people because it is used in smelling salts, many household and industrial cleaners, and window-cleaning products (ATSDR 2004). No health effects have been found in humans exposed to typical environmental concentrations of ammonia; however, exposure to elevated levels of ammonia in air may irritate skin, eyes, throat, and lungs and cause coughing and burns, and exposure to very high concentrations may cause lung damage and death (ATSDR 2004). Some people with asthma may be more sensitive to breathing ammonia than others (ATSDR 2004).

The available studies (occupational and experimental) indicate that acute exposure to low to moderate concentrations of ammonia (less than 100 ppm or 740 mg/m^3) can cause sensory irritation (discomfort in the eyes and/or nose) in humans but are not related to functional respiratory deficits (TCEQ 2014). Exposure concentration, and not exposure duration, appears to determine ammonia's acute local irritation effects (ATSDR 2004). TCEQ (2014) derived an acute (1-hour) reference value for ammonia of 590 μg/m^3 based in a study by Sundblad et al. (2004) on 12 health volunteers (men and women). The critical effects were mild, transient upper respiratory symptoms and central nervous system effects (eye discomfort, smell, headache, dizziness, and feelings of intoxication).

Few studies have been conducted on the effect of long-term exposure to ammonia at low concentrations (TCEQ 2014). A key study used by US EPA (2005), ATSDR (2004) and TCEQ (2014) is a cross-sectional occupational exposure study conducted by Holness et al. (1989) to determine effects of ammonia on 58 workers who had chronic exposure to ammonia compared with 31 control workers (from stores and office areas of the plant) in a soda ash plant in Canada. The agencies used Holness et al. (1989) to derive NOAELs ranging from 9.2 ppm to 12.5 ppm (6.4 mg/m^3 to 8.7 mg/m^3) for lack of significant differences in self-reported symptoms and/or measured lung function parameters, and chronic toxicity values of 70 μg/m^3 to 320 μg/m^3, with differences related to methodologies in selecting the point of departure and composite uncertainty factors.

The US EPA also derived a provisional subchronic reference concentration for ammonia based on Holness et al. (1989) and a subchronic study conducted in rats by Broderson et al. (1976) where the endpoint measured was pulmonary function. The US EPA (2005) derived a subchronic provisional reference concentration of 100 μg/m^3 by applying a composite uncertainty factor of 30 to a human NOAEL of 2.3 mg/m^3 (Holness, Purdham, and Nethercott 1989).

For the purposes of assessing the risks to human health from Project-related exposures to ammonia, the following reference concentrations from TCEQ and US EPA have been used:

- Acute, 1-hour ammonia: 590 µg/m^3 (TCEQ 2014)
- Sub-chronic and chronic, 24-hour ammonia: 100 µg/m^3 (US EPA 2005)

3.2.6 Carbon Monoxide (CO)

Carbon monoxide (CO) is a colorless, non-irritating, odorless and tasteless gas that can be found in both indoor and outdoor air. The main source of CO comes from incomplete combustion of carbon-containing fuels such as natural gas, oil, wood, propane and kerosene (Kampa and Castanas 2008) as well as from photochemical reactions in the atmosphere (US EPA 2010).

Inhaled CO can bind to a number of heme-containing molecules, mainly hemoglobin in red blood cells, resulting in decreased oxygen availability to critical tissues and organs. Exposure to low CO concentrations might induce fatigue while exposure to high levels of CO might lead to impaired vision, impaired coordination, headaches, dizziness, confusion, nausea and flu-like symptoms. At extremely high levels, CO can cause death (US EPA 2010).

Several controlled studies on human test subjects have been conducted and the best data describing the effects of exposure to low CO concentration are those for individuals diagnosed with coronary disease. Following CO exposure, myocardial ischemia (for carboxyhaemoglobin (COHb) level of 2.4%), a reduction in the duration of the exercise caused by chest pains (for COHb level of over 3%) and an increase in the number and complexity of arrhythmia (for COHb level of 6%) were observed (US EPA 2010). Based on these studies, Health Canada suggests that, in order to protect the entire population, COHb levels should not exceed 2% to 2.5% and derived carbon monoxide exposure limits of 28,600 µg/m^3 and 11,500 µg/m^3 for 1-hour and 24-hour exposures times, respectively (Health Canada 2010b). Health Canada (2010b) indicates that the 24-hour exposure limit of 11,500 µg/m^3 is protective of long-term (chronic) effects.

The WHO (2000) also states that to protect non-smoking, middle-aged and elderly population groups with documented or latent coronary artery disease from acute ischaemic heart attacks, and to protect the fetuses of non-smoking pregnant women from untoward hypoxic effects, a COHb level of 2.5% should not be exceeded and recommended exposure limits of 35,000 µg/m^3 for 1-hour exposures and 10,000 µg/m^3 for 8-hour exposures. More recently, the WHO (2021) recommended a 24-hour air quality guideline of 4,000 µg/m^3 for CO based on a new evaluation of the effects of short-term carbon monoxide concentrations on hospital admissions for myocardial infarctions. WHO (2021) did not re-evaluate the short-term averaging times for CO and therefore remain valid.

For the purposes of this HHRA, the following Health Canada and WHO health-based exposure limits for 1-hour and 8-hour exposures were used:

- Acute, 1-hour CO = 28,6000 µg/m^3 (Health Canada 2010b)
- Acute, 8-hour CO = 10,000 µg/m^3 (WHO 2021)

3.2.7 Volatile Organic Compounds

VOCs are organic compounds with a high vapour pressure at ambient temperatures that allow these substances to volatilize or evaporate into the air relatively quickly. Fuel-based VOCs associated with Project-related activities that have been identified as COPC are: benzene, toluene, ethylbenzene, xylenes, acrolein and formaldehyde.

Benzene

Benzene is a colourless liquid with a high vapour pressure and a sweet odour at room temperature, which is produced by natural (e.g., volcanoes and forest fires) and anthropogenic activities (ATSDR 2007b). Incomplete combustion of gasoline, coal, oil and other petroleum--based fuels are the most significant sources of benzene released into the environment (ATSDR 2007b). Inhalation is the general public's primary route of exposure to benzene (ATSDR 2007b). Acute exposure to benzene may cause dizziness, headaches, and drowsiness while chronic inhalation exposure to benzene affects the bone marrow, and the immune and central nervous systems (ATSDR 2007b).

In both human and animal non-carcinogenic studies, data suggest the most sensitive endpoint for short-term inhalation exposure to benzene is hematotoxicity (ATSDR 2007b; TCEQ 2015b). A lowest-observed-adverse-effect-level of approximately 10 ppm for hematotoxic effects of benzene in mice was indicated in a key study by Rozen et al. (1985), which was selected as the key study by both the TCEQ (2015b) in their derivation of an acute exposure limit (1 hour) of 580 µg/m^3, and by ATSDR (2007b) in their derivation of an acute (1 to 14 day) exposure limit of 30 µg/m^3 (0.009 ppmv), both of which were used in this HHRA.

Health Canada (2021a) provides an IUR for benzene of 0.016 (mg/m^3)$^{-1}$, which corresponds to a risk-specific concentration of 0.625 µg/m^3. This value was derived based on the incidence of leukemia observed in human occupational studies (Rinsky et al. 1987; Paxton et al. 1994; Hayes et al. 1997). The risk-specific concentration of 0.625 µg/m^3 was selected to conservatively screen for potential carcinogenic health risks associated with long-term exposure to benzene via inhalation.

While the US EPA (2003c) also derived a chronic inhalation exposure limit (30 µg/m^3) based on a decreased lymphocyte count observed during a human occupational inhalation study (Rothman et al. 1996), this value is the same as the acute exposure limit derived by ATSDR. As such, the Health Canada TRV was used in this HHRA.

Toluene

Toluene is a clear to amber colourless liquid at room temperatures or in the ambient environment (ATSDR 2017). Anthropogenic sources of toluene include processes such as the refinement of gasoline and other fuels from crude oil, coke production, and the manufacture of styrene (ATSDR 2017). Toluene released to the environment does not persist; rather it is readily volatilized or degraded by micro-organisms (ATSDR 2017).

The most sensitive endpoints following acute inhalation of toluene are neurological, and are supported by numerous toxicity studies conducted on both animals and humans (ATSDR 2017; TCEQ 2015c). The key study used by TCEQ (2015c) and Health Canada (2011) for assessment of acute exposures is Andersen et al.(1983), who reported impaired reaction time and symptoms of headache, dizziness, a feeling of intoxication and slight eye and nose irritation in human volunteers following 6-hour exposures to toluene at 100 ppm (on day four of four consecutive days of increasing exposure ranging from 0, 10, 40 and 100 ppm). The study was used to identify a NOAEL of 40 ppm, from which TCEQ (2015c) derived an acute 1-hour exposure limit of 15,000 µg/m^3 and Health Canada (2011) derived an acute 8-hour exposure limited of 15,000 µg/m^3. The TCEQ 1-hour exposure limit of 15,000 µg/m^3 was used in this HHRA.

ATSDR (2017) derived an acute (1 to 14 day) exposure limit of 7,600 µg/m^3 based on a study by Little et al. (1999) in which human volunteers were subjected to neuropsychological tests prior to and after 20-minute exposures to toluene. This ATSDR acute exposure limit of 7,600 µg/m^3 was used to assess 24-hour exposures to toluene in this HHRA.

Health Canada (2021a; 2011) provides a reference concentration of 2,300 µg/m^3 for toluene based on neurotoxicity. In deriving a reference concentration for chronic exposure to toluene, Health Canada (2011) selected the point of departure of 23 mg/m^3 (equal to the NOAEL for neurobehavioural performance in the studies by Seeber et al. (2005; 2004), adjusted to account for the difference in the duration of exposure for people in a workplace compared to those in a residence) and applied an uncertainty factor of 10. This chronic TRV was used in this HHRA.

Xylenes

Xylenes are a group of three isomers of dimethyl benzene: o-, m-, and p- xylene, which evaporate easily into air from other environmental media. Xylenes are released into the environment from fugitive industrial emissions (e.g., petroleum refineries, chemical plants), car exhaust, and from its use as a solvent in commercial and industrial products. It can also be released from the use and storage of petroleum products.

Neurological and respiratory effects have been identified as critical endpoints following acute inhalation exposure to xylenes and have been observed in humans after xylene inhalation. Both TCEQ (2015d) and (ATSDR 2007c) identified Ernstgård et al. (2002) as the key study for their derivations of acute exposure limits. In this study, human volunteers were exposed to m-xylene and clean air (controls) for two hours in an inhalation chamber (TCEQ 2015d). Subjects exposed to xylene reported mild respiratory effects and subjective symptoms of neurotoxicity (headaches, dizziness, and a feeling of intoxication). Using these findings, the TCEQ (2015d) derived an acute 1-hour exposure limit of 7,400 µg/m^3 and the (ATSDR 2007c) derived an acute (1 to 14 day) exposure limit of 8,700 µg/m^3. For this HHRA, the 1-hour exposure limit of 7,400 µg/m^3 was used to assess 1-hour acute exposures.

Because available human data are insufficient for deriving a chronic exposure limit and chronic animal inhalation data are lacking, Health Canada (2021a) and US EPA (2003b) relied on a subchronic inhalation study in male rats as the key study in their derivation of a chronic exposure limit. Korsak et al. (1994) identical a NOAEL of 50 ppm (217 mg/m^3) for impaired motor coordination (39 mg/m^3 as an adjusted human equivalent continuous exposure). Health Canada and US EPA applied an uncertainty factor of 300 to derive a chronic inhalation concentration of 100 µg/m^3. This value was used as the chronic inhalation TRV for xylenes in this HHRA.

Acrolein

Acrolein is a clear to yellowish liquid with an acrid odour and vaporizes readily due to its high vapour pressure. Acrolein degrades easily and hence it is not persistent in the environment. The primary use of acrolein is in the synthesis of acrylates, a family of vinyl polymers. Acrolein is released into the environment primarily through combustion processes, which include motor vehicles, waste incinerators, furnaces, coal-based electric power generation plants, and cigarette smoking (ATSDR 2007a).

Several studies describe the acute effects of acrolein on human volunteers (Health Canada 2021c). Eye irritation was the most sensitive endpoint reported, occurring at concentrations of 0.14– 0.23 mg/m^3 for exposure durations as short as five minutes (Darley, Middleton, and Garber 1960; Weber-Tschopp et al. 1977; Dwivedi et al. 2015; Claeson and Lind 2016). Nasal, throat, and respiratory irritation occurred at higher concentrations (Weber-Tschopp et al. 1977).

The OEHHA (2008) derived an acute (1-hour) hour exposure limit of 2.3 µg/m^3 for acrolein based on the study by Darley et al. (1960), who evaluated subjective reports of eye irritation in human volunteers exposed to acrolein for five minutes. The lowest observed adverse effect level in the study was 140 µg/m^3 (although Health Canada (2021c) notes that the overall irritation score at this concentration was still considered in the range of “no irritation”). More recently, Health Canada (2021c) identified eye irritation as the most sensitive endpoint, and identified the NOAEL of 0.12 mg/m^3 for eye irritation from Dwivedi et al. (2015) as the point of departure for the acute reference concentrations. With the application of an uncertainty factor of 3 to account for sensitive individuals Health Canada (2021c) then derived an acute reference concentration of 38 µg/m^3(0.038 mg/m^3). This Health Canada acute reference concentration was selected for the HHRA.

A chronic RfC for acrolein of 0.02 µg/m^3 was derived by the US EPA (2003a) based upon nasal lesions observed in a subchronic inhalation study on rats by Feron et al. (1978). More recently, the OEHHA (2008), the TCEQ (2015a), and Health Canada (2021c) assessed the potential chronic effects from inhalation of acrolein and relied on a more recent chronic inhalation study on rats by Dorman et al. (2008). The agencies derived chronic (annual average) exposure limits ranging from 0.35 µg/m^3 and 2.7 µg/m^3 (differences were related to dosimetric adjustments and selection of uncertainty factors). The chronic value of 0.44 µg/m^3 derived by Health Canada was used in the HHRA.

Formaldehyde

Formaldehyde is a gaseous pollutant that is a natural product of biogenic and catabolic biological processes including the natural breakdown of vegetable matter in the environment. Outdoors, combustion emissions, including motor vehicle and other exhausts can be a significant source of the exposure for the general public (WHO 1989). The critical target for toxicity to airborne formaldehyde is the respiratory tract, especially the upper respiratory tract (ATSDR 1999).

Health Canada (2006) established a 1-hour exposure limit for formaldehyde of 123 µg/m^3 and an 8-hour exposure limit of 50 µg/m^3. The 1-hour exposure limit recommended by Health Canada represents one fifth of the NOAEL for eye irritation in a human clinical study by Kulle (1993). The 8-hour exposure limit is the lower end of the exposure category associated with no significant increase of asthma hospitalization (Rumchev et al. 2002).

More recently, the TCEQ (2008) developed an acute (1-hour) exposure limit of 50 µg/m^3 for formaldehyde based on key inhalation studies on human volunteers by Pazdrak et al. (1993) and Krakowiak et al. (1998). The critical health effect in these studies was eye and nose irritation. The TCEQ (2008) 1-hour exposure limit was selected as the acute exposure limit in this HHRA and is considered protective of the eye irritation and asthma effects identified by Health Canada (2006).

To derive a chronic exposure limit protective of non-carcinogenic health effects, the TCEQ (2008) relied on a key study by Wilhelmsson and Holmstrom (1992), who identified the specific critical effects of formaldehyde exposure in the key study as increased rates of symptoms such as eye, nasal, and lower airway discomfort (e.g., cough, wheezing) in a study of exposed workers. The TCEQ derived a chronic exposure limit of 11 µg/m^3, which is considered appropriate to assess the potential threshold effects of chronic exposure to formaldehyde.

Health Canada did not assign a cancer classification to formaldehyde, but derived a unit risk of 5.3 x 10^{-6} (µg/m^3)$^{-1}$ (which equates to a risk-specific concentration of 2 µg/m^3 at the 1-in-100,000 risk level) based upon the incidence of nasal squamous tumours and the exposure-response observed during a rat inhalation study (Environment Canada and Health Canada 2001; Monticello et al. 1996). This risk specific concentration is sufficiently low to prevent non-cancer effects such as irritation and inflammation and therefore was used in this HHRA to evaluate the risk associated with chronic exposure to formaldehyde.

3.2.8 Polycyclic Aromatic Hydrocarbons

PAHs are a class of organic compounds containing only carbon and hydrogen, where the carbon atoms form multiple aromatic rings. PAHs are ubiquitous in the environment and are formed by incomplete combustion of organic matter. Natural processes that produce PAHs include volcanic activity, forest fires, and lightning strikes. PAHs are also found naturally in fossil fuels such as oil and coal. Human activities including the combustion of fossil fuels, barbequing, flame cooking or smoking food, and tobacco smoking can also produce PAHs and release it into the air through the formation of smoke and soot. Among the PAHs, naphthalene is the predominant PAH found in gasoline and diesel exhaust (Marr et al. 1999).

Some PAHs are associated with non-carcinogenic effects (e.g., anthracene) and some are associated with carcinogenic effects (e.g., benzo(a)pyrene).

Threshold (Non-carcinogenic) Effects of PAHs

Non-carcinogenic PAHs potentially emitted by Project-related activities and assessed as individual compounds include: acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, phenanthrene and pyrene. Health Canada (2021a) has identified threshold (non-carcinogenic) effects associated with benzo(a)pyrene, which is also associated with carcinogenic effects. Toxicologically relevant exposure limits are associated with inhalation exposure to individual PAHs is limited to naphthalene and benzo(a)pyrene.

Health Canada (2013b) reviewed the literature related to the health effects associated with inhalation of naphthalene and concluded that naphthalene has been shown to cause tissue damage and cancer in the nasal passages and lungs of rats and mice exposed to high levels in laboratory studies. It is considered a possible carcinogen for humans, although there is not yet sufficient evidence to prove it causes cancer in humans (Health Canada 2013b). Importantly, Health Canada concluded that a short-term indoor air exposure limit is not necessary as prevention of initial cytotoxicity is considered likely to prevent tumour development and lesions on chronic exposure. Health Canada derived a chronic TRV of 10 μg/m^3 based on an adjusted lowest observed adverse effect level of 9.3 mg/m^3 from chronic inhalation study on rats by NTP (2000) and an uncertainty factor of 1000 (Health Canada 2013b; 2021a). The critical effect was respiratory tract toxicity. This chronic exposure limit was used in this HHRA.

The US EPA (2017a) developed a chronic exposure limit for benzo(a)pyrene of 0.002 μg/m^3 for developmental toxicity. The key study was an inhalation study in rats exposed for four hours per day for 10 days during gestation that identified decreases in embryo/fetal survival as the critical effect (Archibong et al. 2002). Health Canada (2021a) cited this TRV and it was used in this HHRA.

Although inhalation exposure limits and TRVs were not available for the other specific non-carcinogenic PAHs, a TRV representative of aromatic hydrocarbons ranging from C_9 to C_{16} (which would include PAHs such as acenaphthene, acenaphthylene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene) was identified by the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) (1997). The TPHCWG (1997) acknowledges that data for this group of compounds is limited; however, of the available information the TPHCWG (1997) selected an inhalation study using rats (Clark et al. 1989) as the key study to set a chronic reference concentration (RfC) of 200 μg/m^3. This chronic reference concentration is based on a NOAEL of 900,000 μg/m^3 for increased liver and kidney weights in male rats. This NOAEL was adjusted to account for continuous exposure (rats were only exposed for 6 hrs/d, 5d/week for 1 year) and applied a 1,000 fold uncertainty factor (including an uncertainty factor of 10 to account for sensitive subpopulations, a factor of 10 to account for animal to human extrapolation, and a factor of 10 to account for converting a subchronic exposure to a chronic exposure). The chronic reference concentration of 200 μg/m^3 developed by the TPHCWG (1997) was used as the chronic TRV in this HHRA.

Non-Threshold (Carcinogenic) PAHs

Although there is strong evidence of carcinogenicity for several PAH compounds, benzo(a)pyrene is the compound that has been most reliably studied for carcinogenicity. The International Agency for Research on Cancer classifies benzo(a)pyrene as a Group 1 human carcinogen. The Group 1 classification indicates that there is sufficient evidence to conclude carcinogenicity in humans. Studies on the carcinogenic potential of other PAHs in humans is less certain, and many other PAHs that are suspected carcinogens such as benz(a)anthracene, are classified as Group 2B human carcinogens. Group 2B carcinogens are those that are considered possible human carcinogens based on limited evidence in human studies, or inadequate evidence in human studies but strong evidence in animal studies.

The mechanism of carcinogenicity among PAHs is believed to be similar. However, the carcinogenic potential differs between PAHs. Health Canada (2021a) recommends assessing exposures to mixtures of carcinogenic PAHs according to the relative potency factors (RPF) approach, also known as potency equivalency factor approach, in which carcinogenic PAHs are adjusted for their carcinogenic potency relative to benzo(a)pyrene (B(a)P). Concentrations of each compound are multiplied by their RPF and summed to give a B(a)P total potency equivalents (TPE), which represents the carcinogenic potency of the entire mixture. The following RPFs were used for the following PAHs:

- Benz(a)anthracene = 0.1
- Benzo(a)pyrene = 1.0
- Benzo(b)fluoranthene = 0.1
- Benzo(g,h,i)perylene = 0.01
- Benzo(k)fluoranthene = 0.1
- Chrysene = 0.01
- Dibenz(a,h)anthracene = 1.0
- Fluoranthene = 0.001
- Indeno (1,2,3-c,d)pyrene = 0.1
- Phenanthrene = 0.001

All but one RPF were obtained from (2021a); for acenaphthylene, the RPF of 0.01 was selected based on RIVM (2001). The final B(a)P TPE is then compared to the chronic carcinogenic exposure limit for B(a)P.

The US EPA (2017a) developed a IUR for benzo(a)pyrene of 0.6 $(mg/m^3)^{-1}$ based on a study by Thyssen et al. (1981) Thyssen et al. (1981) exposed groups of Syrian golden hamsters B(a)P in air. Exposure-related neoplasms were found in the nasal cavity, larynx, pharynx, esophagus, and forestomach. Health Canada (2021a) cited this IUR of 0.6 $(mg/m^3)^{-1}$, which equates to a RSC of 0.017 µg/m^3. Therefore, this RSC was selected as the TRV for B(a)P TPE.

3.2.9 Summary

The TRVs and health-based exposure limits applied in this HHRA are summarized in Table 3.1.

Table 3.1 Toxicological Reference Values and Exposure Limits

Chemical of Potential Concern	Exposure Period	Toxicological Reference Value or Exposure Limit	Critical Effect	Reference
Nitrogen Dioxide (NO_2)	Acute (1-hour) [a]	200 μg/m^3	Respiratory effects	WHO (2021)
	Acute (24-hour)[a]	25 μg/m^3	Mortality and respiratory effects	WHO (2021)
	Chronic (Annual)	10 μg/m^3	Mortality	WHO (2021)
Sulphur Dioxide (SO_2)	Acute (10-minute)	175 μg/m^3	Respiratory effects	Health Canada (2016e)
	Acute (24-hour)[a]	40 μg/m^3	Respiratory effects	WHO (2021)
Particulate Matter ($PM_{2.5}$)	Acute (24-hour) [a]	15 μg/m^3	Mortality	WHO (2021)
	Chronic (Annual) [a]	5 μg/m^3	Mortality	WHO (2021)
Diesel Exhaust (DPM)	Acute (2-hour) [b]	10 μg/m^3	Respiratory effects	Health Canada (2016d)
	Chronic (Annual)	5 μg/m^3	Respiratory effects	Health Canada (2016d)
Ammonia (NH_3)	Acute (1-hour)	590 μg/m^3	Respiratory effects, central nervous system effects	TCEQ (2014)
	Sub-chronic, chronic (24-hour)	100 μg/m^3	Respiratory effects	US EPA (2005)
Carbon Monoxide (CO)	Acute (1-hour)	28,600 μg/m^3	Oxygen carrying capacity of blood	Health Canada (2010b)
	Acute (8-hour)	10,000 μg/m^3	Oxygen carrying capacity of blood	WHO (2021)
Volatile Organic Compounds				
Benzene	Acute (1-hour)	580 μg/m^3	Blood toxicity (bone marrow depression)	TCEQ (2015b)
	Acute (24-hour)	30 μg/m^3	Blood toxicity (bone marrow depression)	ATSDR (2007b)
	Chronic (Annual)	0.625 μg/m^3	Leukemia	Health Canada (2021a)
Toluene	Acute (1-hour)	15,000 μg/m^3	Neurological	TCEQ (2015c)
	Acute (24-hour)	7,600 μg/m^3	Neurological	ATSDR (2017)
	Chronic (Annual)	2,300 μg/m^3	Neurotoxicity	Health Canada (2021a)
Xylenes	Acute (1-hour)	7,400 μg/m^3	Neurological and mild respiratory effects	TCEQ (2015d)
	Chronic (Annual)	100 μg/m^3	Neurotoxicity	Health Canada (2021a)

Table 3.1 Toxicological Reference Values and Exposure Limits

Chemical of Potential Concern	Exposure Period	Toxicological Reference Value or Exposure Limit	Critical Effect	Reference
Acrolein	Acute (1-hour)	38 µg/m^3	Eye irritation	Health Canada (2021a)
	Chronic (Annual)	0.44 µg/m^3	Nasal lesions	(Health Canada 2021a)
Formaldehyde	Acute (1-hour)	50 µg/m^3	Eye and nose irritation	TCEQ (2008)
	Chronic (Annual)	2 µg/m^3	Nasal squamous tumours	Environmental Canada and Health Canada (2001)
Polycyclic Aromatic Hydrocarbons (PAHs)				
Naphthalene	Chronic (Annual)	10 µg/m^3	Nasal effects (hyperplasia and metaplasia in respiratory and olfactory epithelium, respectively)	Health Canada (2021a)
Benzo(a)pyrene	Chronic (Annual)	0.002 µg/m^3	Developmental effects	Health Canada (2021a)
Aromatic C_9-C_{16}[c]	Chronic (Annual)	200 µg/m^3	Liver and kidney effects	TPHCWG (1997)
Benzo(a)pyrene TPE	Chronic (Annual)	0.017 µg/m^3	Cancer	Health Canada (2021a)

NOTES:

[a] value is based on a statistical comparison; refer to details in individual contaminant write-up

[b] although guideline applies to 2-hour exposure time, in the HHRA, 1-hour exposures were compared to this value

[c] sum of acenaphthene, acenaphthylene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, pyrene

4.0 Exposure Assessment

The objective of the exposure assessment is to estimate the concentrations of each COPC to which the identified human receptors could be exposed. For airborne COPCs, the exposure assessment includes the predicted COPC concentrations in air within the LAA/RAA that encompasses the hydrogen / ammonia plant, the Codroy and Port au Port wind farm sites, and the special receptor locations identified as representative of areas where people live, work, or otherwise spend time as reported in EIS Chapter 6 (Atmospheric Environment). Additional details and results of this modelling are presented in EIS Chapter 6 (Atmospheric Environment).

4.1 Assessment Scenarios

To quantify the overall potential risks to human health, the HHRA considers different assessment scenarios: baseline (existing conditions), project alone, and baseline plus project. A baseline plus project plus reasonably foreseeable future development (i.e., cumulative scenario) was not considered as no reasonably foreseeable future development was identified.

The baseline scenario describes the existing conditions for the study area. Comparing predicted COPC concentrations for the Project alone scenario to baseline concentrations provides information on the potential impact of the Project. Baseline conditions for air quality were characterized using a combination of publicly available data and literature, as described in EIS Chapter 6 (Atmospheric Environment). The 90th percentile hourly ambient monitoring data was the metric used to estimate baseline 1-hour ambient concentrations and the maximum 24-hour concentrations excluding the hourly values greater than the 90th percentile was used to estimate the baseline 24-hour ambient concentrations, consistent with standard air modelling practice. Additional details regarding the baseline ambient air quality are provided in the Atmospheric Environment Baseline Report (BSA-1).

The Project alone scenario relies on predictions of the COPC concentrations in air from the Project without considering the additive effects from the baseline scenario. The California Meteorological Model (CALMET) / California Puff (CALPUFF) modelling system was used to determine the potential effects of the air contaminant releases during operation of the Project on ambient air quality in the LAA/RAA. There were several conservative assumptions made during the air dispersion modelling, as such, the actual exposure concentrations are not expected to be as high as predicted. Further information on modelling assumptions and CALMET and CALPUFF methods are included in EIS Chapter 6 (Atmospheric Environment). Additional discussion of how modeling uncertainty may influence the HHRA is provided in Section 6.2.

The baseline plus Project scenario reflects the effects of the project in addition to the existing conditions, which involves combining the baseline and the Project alone scenarios.

4.2 Project Phases

The HHRA considered potential exposures associated with each of the Project phases, as described below.

4.2.1 Construction

The air contaminant release estimates during construction were evaluated quantitatively and the potential changes in air quality from construction activities were evaluated qualitatively (as described in EIS Chapter 6 (Atmospheric Environment)). Therefore, for this HHRA, risk associated with air contaminant releases during construction were also discussed qualitatively (refer to Section 5.2).

4.2.2 Operation and Maintenance

In EIS Chapter 6 (Atmospheric Environment), the CALMET and CALPUFF dispersion modelling system was used to predict the maximum ground level concentrations of the COPCs in the LAA/RAA during the normal operation of the Project. Further information on modelling assumptions and CALMET and CALPUFF methods are included in EIS Chapter 6 (Atmospheric Environment). The predicted maximum ground level concentrations of COPCs are summarized as follows:

- The maximum predicted concentrations of the air contaminants of concern released during normal operation of the Project combined with baseline concentrations (to account for existing conditions) are provided in Table 4.1 below. The modelled maximums were predicted for areas outside the hydrogen / ammonia plant property boundary (fenceline) for each COPC and relevant exposure duration. The maximum predicted concentrations generally occur at or near the hydrogen / ammonia plant property boundary, mainly occurring to the south (near the proposed emergency generator) or the south-west side of the property (near the port).
- The maximum predicted concentrations, combined with baseline concentrations, at a location of human residence (located at Little Port Harmon or Stephenville area) are provided in Table 4.2, below. Results were generated at other residential areas; however, the concentrations provided in Table 4.2 represent the locations in which the maximum concentration (combined with background) were predicted; concentrations at other residential areas would be equal or less than these values. The concentrations in Table 4.2 are the maximum concentrations predicted at residential areas in the LAA/RAA. The locations vary depending on the air contaminant as not all sources emitted all modelled contaminants. The maximum concentration does not necessarily occur at the nearest receptor; rather, this depends on the sources contributing to the maximum concentration of each contaminant.

Table 4.1 Maximum Predicted Ground Level Concentrations at the Hydrogen / Ammonia Plant Property Boundary

Chemical of Potential Concern	**Exposure Period**	**Maximum Predicted Ground Level Concentration (µg/m^3)**		
		Baseline	**Project**	**Project + Baseline** [a]
Nitrogen Dioxide (NO_2)	1 hour	5.6	109	115
	24 hour	3.8	93	96
	1 year	3.8	10	14
Carbon Monoxide (CO)	1 hour	206	35	241
	8 hour	206	29	235
Sulphur Dioxide (SO_2)	10 minute[c]	4.0	2.0	6.0
	24 hour	2.1	0.5	2.6
Ammonia (NH_3)	1 hour	N/A	224	224
	24 hour	N/A	49	49
Particulate Matter ($PM_{2.5}$)	24 hour	6.1	12	18
	1 year	4.5	0.8	5.3
Diesel Exhaust (DPM)	2 hour	N/A	47	47
	1 year	N/A	0.7	0.7
Volatile Organic Compounds				
Benzene	1 hour	N/A	3.8E-02	3.8E-02
	24 hour	N/A	2.3E-02	2.3E-02
	1 year	N/A	5.4E-04	5.4E-04
Toluene	1 hour	N/A	1.4E-02	1.4E-02
	24 hour	N/A	8.3E-03	8.3E-03
	1 year	N/A	1.9E-04	1.9E-04
Xylenes	1 hour	N/A	9.5E-03	9.5E-03
	1 year	N/A	1.3E-04	1.3E-04
Acrolein	1 hour	N/A	3.9E-04	3.9E-04
	1 year	N/A	5.4E-06	5.4E-06
Formaldehyde	1 hour	N/A	1.0E-01	1.0E-01
	1 year	N/A	5.5E-05	5.5E-05

Table 4.1 Maximum Predicted Ground Level Concentrations at the Hydrogen / Ammonia Plant Property Boundary

Chemical of Potential Concern	Exposure Period	Maximum Predicted Ground Level Concentration (µg/m^3)		
		Baseline	Project	Project + Baseline [a]
Polycyclic Aromatic Hydrocarbons				
Naphthalene	1 year	N/A	9.0E-05	9.0E-05
Benzo(a)pyrene	1 year	N/A	1.8E-07	1.8E-07
Aromatic C_9-C_{16}[b]	1 year	N/A	1.4E-04	1.4E-04
Benzo(a)pyrene TPE	1 year	N/A	6.9E-07	6.9E-07

Notes:

N/A: Not available. In Chapter 6 (Atmospheric Environment), representative baseline data were obtained from the nearest and most representative National Air Pollutant Surveillance Program (NAPS) ambient air quality monitoring station, which was determined to be the NAPS station at Grand Falls-Windsor, approximately 220 km east-northeast from the Project. For parameters that are not measured at the Grand Falls-Windsor station, no baseline data were available.

[a] 'Project + Baseline' values presented in this table may not be equivalent to the sum of presented "Baseline' values plus 'Project' values due to rounding and significant figures.

[b] sum of Acenaphthene, Acenaphthylene, Anthracene, Fluoranthene, Fluorene, Naphthalene, Phenanthrene, Pyrene

[c] The shortest averaging period available from the air dispersion model is 1-hour; therefore, the 10-minute SO_2 concentration was extrapolated by multiplying the 1-hour average concentrations with a Peak-to-Mean Ratio (PMR) of 1.43. established by the US EPA

Table 4.2 Maximum Predicted Ground Level Concentrations at a Residential Location

Chemical of Potential Concern	Exposure Period	Concentration at the Maximum Residential Location (µg/m^3)		
		Baseline	Project	Project + Baseline[a]
Nitrogen Dioxide (NO_2)	1 hour	5.6	82	87
	24 hour	3.8	48	52
	1 year	3.8	1.7	5.5
Carbon Monoxide (CO)	1 hour	206	8.8	215
	8 hour	206	7.2	213
Sulphur Dioxide (SO_2)	10 minute[c]	4.0	0.6	4.6
	24 hour	2.1	0.1	2.2
Ammonia (NH_3)	1 hour	N/A	54	54
	24 hour	N/A	13	13
Particulate Matter ($PM_{2.5}$)	24 hour	6.1	2.3	8.4
	1 year	4.5	0.10	5.0

Table 4.2 Maximum Predicted Ground Level Concentrations at a Residential Location

Chemical of Potential Concern	Exposure Period	Concentration at the Maximum Residential Location (µg/m^3)		
		Baseline	Project	Project + Baseline[a]
Diesel Exhaust (DPM)	2 hour	N/A	5.7	5.7
	1 year	N/A	0.11	0.11
Volatile Organic Compounds				
Benzene	1 hour	N/A	9.7E-03	9.7E-03
	24 hour	N/A	4.7E-03	4.7E-03
	1 year	N/A	9.0E-05	9.0E-05
Toluene	1 hour	N/A	3.5E-03	3.5E-03
	24 hour	N/A	1.7E-03	1.7E-03
	1 year	N/A	3.2E-05	3.2E-05
Xylenes	1 hour	N/A	2.4E-03	2.4E-03
	1 year	N/A	2.2E-05	2.2E-05
Acrolein	1 hour	N/A	9.8E-05	9.8E-05
	1 year	N/A	9.1E-07	9.1E-07
Formaldehyde	1 hour	N/A	3.7E-03	3.7E-03
	1 year	N/A	9.2E-06	9.2E-06
Polycyclic Aromatic Hydrocarbons				
Naphthalene	1 year	N/A	1.5E-05	1.5E-05
Benzo(a)pyrene	1 year	N/A	3.0E-08	3.0E-08
Aromatic C_9-C_{16}[b]	1 year	N/A	2.4E-05	2.4E-05
Benzo(a)pyrene TPE	1 year	N/A	1.2E-07	1.2E-07

Notes:

N/A: Not available. In Chapter 6 (Atmospheric Environment), representative baseline data were obtained from the nearest and most representative National Air Pollutant Surveillance Program (NAPS) ambient air quality monitoring station, which was determined to be the NAPS station at Grand Falls-Windsor, approximately 220 km east-northeast from the Project. For parameters that are not measured at the Grand Falls-Windsor station, no baseline data were available.

[a] 'Project + Baseline' values presented in this table may not be equivalent to the sum of presented "Baseline' values plus 'Project' values due to rounding and significant figures.

[b] sum of Acenaphthene, Acenaphthylene, Anthracene, Fluoranthene, Fluorene, Naphthalene, Phenanthrene, Pyrene

[c] The shortest averaging period available from the air dispersion model is 1-hour; therefore, the 10-minute SO_2 concentration was extrapolated by multiplying the 1-hour average concentrations with a Peak-to-Mean Ratio (PMR) of 1.43. established by the US EPA (US EPA 1992)

For both the maximum predicted ground level concentration at the hydrogen / ammonia plant property boundary and the maximum predicted ground level concentrations at a residential location, the specific geographical location of these points may differ between COPCs due to variation in the sources contributing to the maximum concentration of each contaminant.

In addition to the summary tables, isopleth plots (concentration contour plots) were generated for the following COPCs and averaging periods: $PM_{2.5}$ (24-hour, annual), PM_{10} (24-hour), NO_2 (hourly, 24-hour, annual) and DPM (2-hour, annual). The generated contour plots are shown in Figure 4.1 through Figure 4.8.

As discussed in EIS Chapter 6, there were several conservative assumptions made in the development of the emission inventory and during the modelling; these results are considered conservative. Flaring events and the use of the back-up generator are infrequent releases, while the marine vessel shipping is periodic and not continuous. The results presented are not expected to occur routinely, but instead, on an infrequent basis. Emergency events (e.g., NH_3 flaring and the operation of the back-up generator) would typically not be assessed as part of the air quality assessment in an EIS. They were included in this assessment as these sources may be operated during periods of routine maintenance. Their inclusion is conservative.

Stantec

● Maximum Concentration: 18.1 $\mu g/m^3$

Particulate Matter (with a diameter less than 2.5 microns), maximum predicted 24-hour concentration, with the background concentration (6.1 $\mu g/m^3$) included. (Regulatory Limit 25 $\mu g/m^3$)

Modelled Site Boundary

Proposed Project Features

☆ Hydrogen / Ammonia Plant Location

Project Area

Other Features

Electrical Generation, Existing

Road

Transmission Line 230 kV

Transmission Line, Existing

Watercourse

Waterbody

Wetland

Forested Area

N

0 0.8 Kilometres

(At original document size of 8.5x11)
1:40,000

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec

Project Location
Stephenville
NL

Prepared by MER on 2023-07-06
QR by AW on 2023-07-19

Client/Project
World Energy GH2 Inc.,
Project Nujio'qonik

121417233_219

Figure No.
4-1

Page 1 of 1

Isopleth plot $PM_{2.5}$ maximum predicted 24-hour concentration, with the background concentration (6.1 $\mu g/m^3$) included

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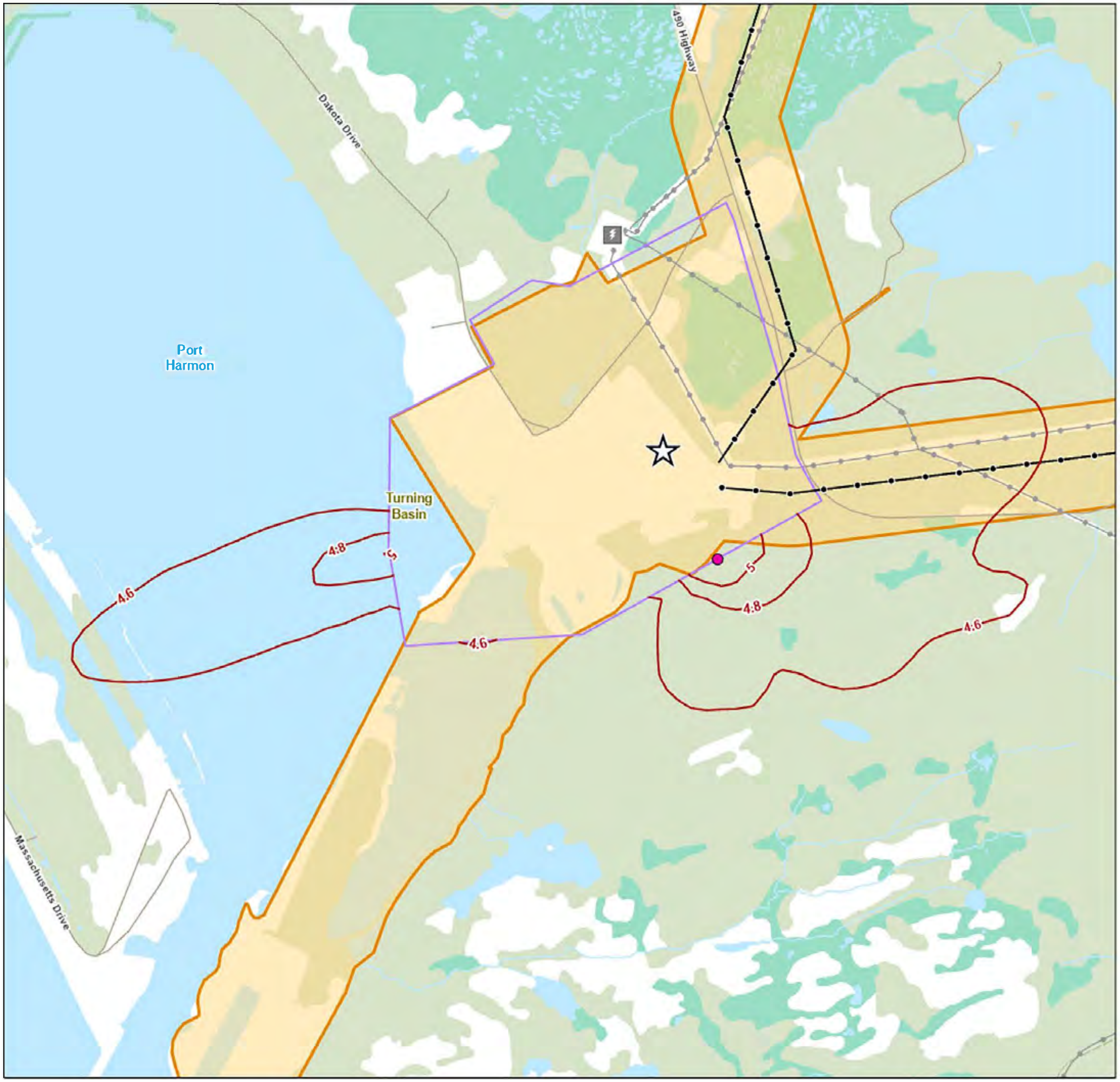

Stantec

● Maximum Concentration: 5.3 µg/m³

Particulate Matter (with a diameter less than 2.5 microns), maximum predicted annual concentration, with the background concentration (4.5 µg/m³) included. (Regulatory Limit 9 µg/m³)

Modelled Site Boundary

Proposed Project Features

☆ Hydrogen / Ammonia Plant Location

☐ Project Area

Other Features

Electrical Generation, Existing

Road

Transmission Line 230 kV

Transmission Line, Existing

Watercourse

🟦 Waterbody

🟩 Wetland

🟩 Forested Area

N

0 0.4 Kilometres
(At original document size of 8.5x11)
1:20,000

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec

Project Location
Stephenville
NL

Prepared by MER on 2023-07-06
QR by AW on 2023-07-21

Client/Project
World Energy GH2 Inc.,
Project Nujio'qonik

121417233_217

Figure No.
4-2

Page 1 of 1

Isopleth plot $PM_{2.5}$ maximum predicted annual concentration, with the background concentration (4.5 µg/m³) included

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Stantec

● Maximum Concentration: 33.2 µg/m³

Particulate Matter (with a diameter less than 10 microns), maximum predicted 24-hour concentration, with the background concentration (19.5 µg/m³) included. (Regulatory Limit 50 µg/m³)

Modelled Site Boundary

Proposed Project Features

☆ Hydrogen / Ammonia Plant Location

☐ Project Area

Other Features

Substation, Existing

Electrical Generation, Existing

Road

Transmission Line 230 kV

Transmission Line, Existing

Watercourse

Waterbody

Wetland

Forested Area

N

0 1.2 Kilometres

(At original document size of 8.5x11)
1:60,000

Notes

1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec

Project Location
Stephenville
NL

Prepared by MER on 2023-07-06
QR by AW on 2023-07-19

Client/Project
World Energy GH2 Inc.,
Project Nujio'qonik

121417233_216

Figure No.
4-3

Page 1 of 1

Isopleth plot PM_{10} maximum predicted 24-hour concentration, with the background concentration (19.5 µg/m³) included

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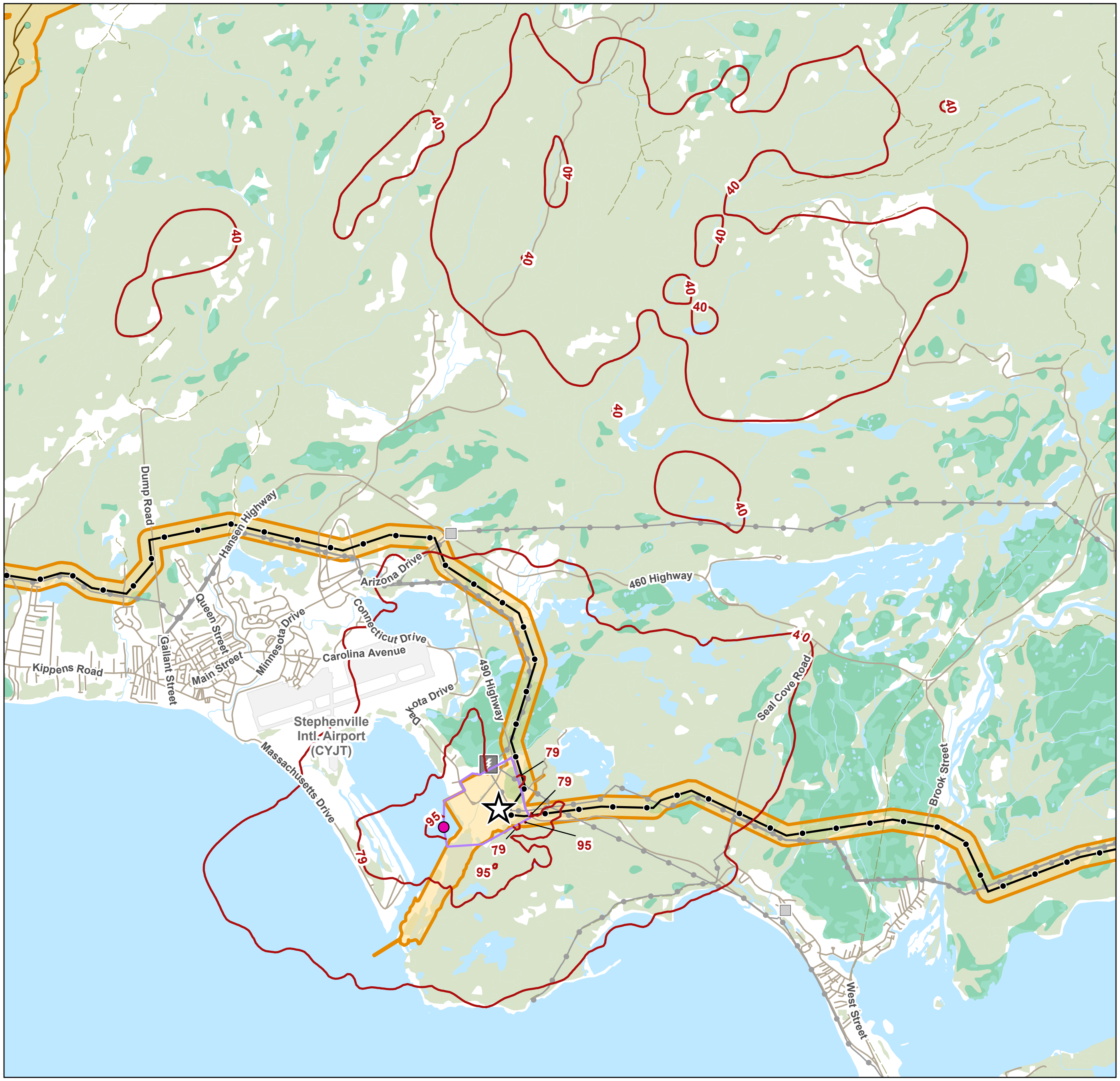


Stantec

● Maximum Concentration: 114.7 µg/m^3

Nitrogen Oxide (Calculated from NO_x via the Ozone Limiting Method), maximum predicted hourly concentration,with the background concentration (5 µg m^3) included (Regulatory Limit 401 µg/^{3})

Modelled Site Boundary

Proposed Project Features

☆ Hydrogen / Ammonia Plant Location

Project Area

Other Features

Substation, Existing

Electrical Generation, Existing

Road

Transmission Line 230 kV

Transmission Line, Existing

Watercourse

Waterbody

Wetland

Forested Area

N

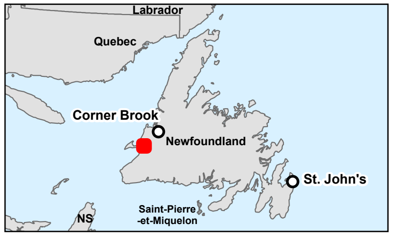
0 2 Kilometres

(At original document size of 8.5x11)

1:100,000

Notes

1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec



Project Location

Stephenville

NL

Prepared by JSC on 2023-07-14

QR by AW on 2023-07-19

Client/Project

121417233 _213

World Energy GH2

Project Nujio'qonik

Figure No.

4-4

Page 1 of 1

Isopleth plot NO_2 maximum predicted 1-hour concentration, with the background concentration (5 µg/m^3) included

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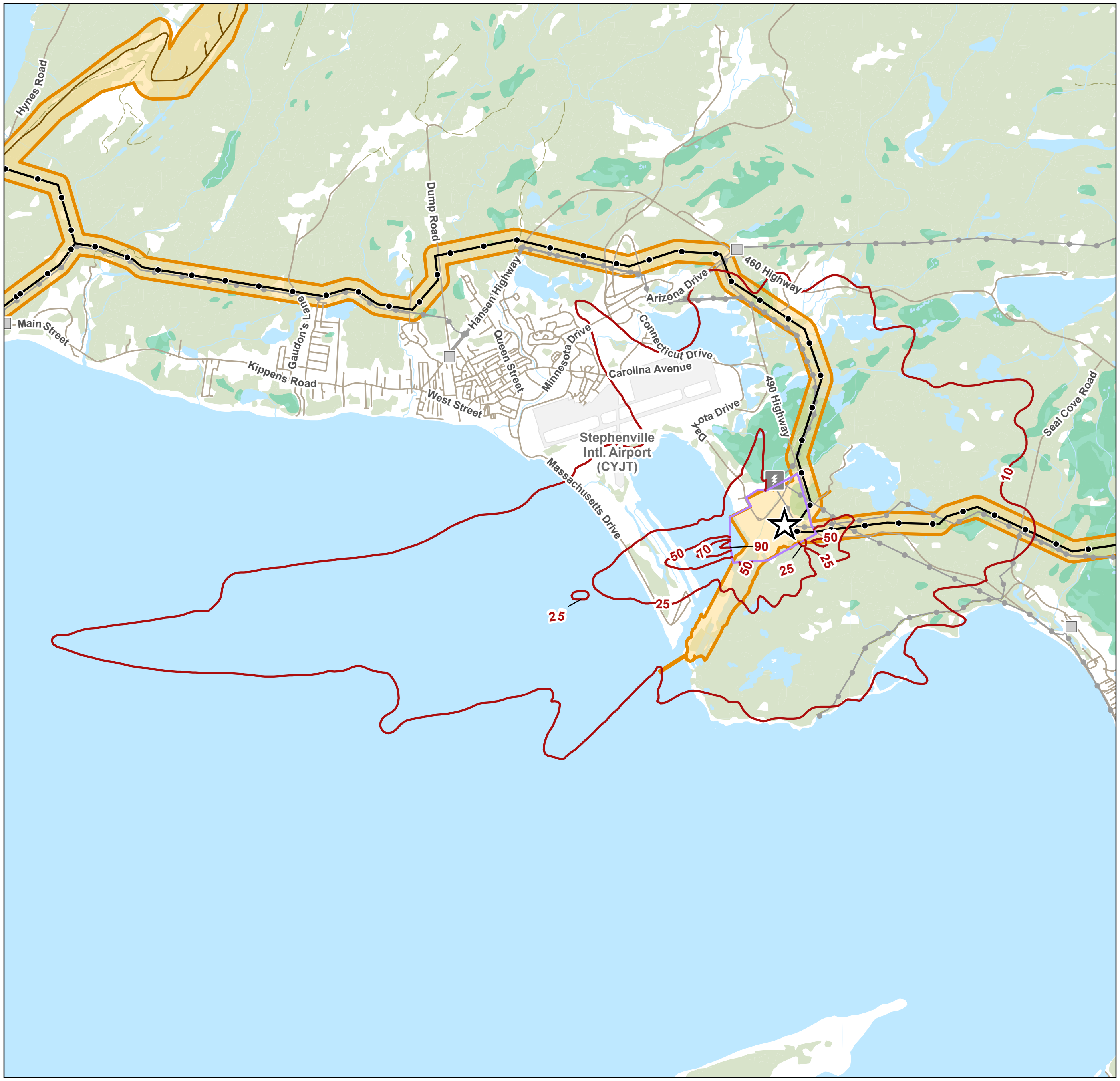


Stantec

- ● Maximum Concentration: 96.3 µg/m^3
- Nitrogen Oxide (Calculated from NO$_x$ via the Ozone Limiting Method), maximum predicted 24-hour concentration, with the background concentration (3.8 µg/m^3) included (Regulatory Limit 199 µg/m^3)
- Modelled Site Boundary

Proposed Project Features

- ☆ Hydrogen / Ammonia Plant Location
- Project Area

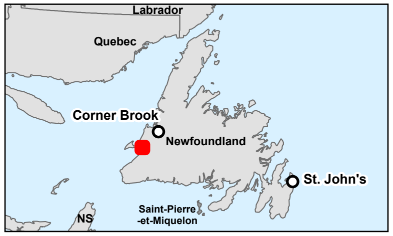
Other Features

- Substation, Existing
- Electrical Generation, Existing
- Road
- Transmission Line 230 kV
- Transmission Line, Existing
- Watercourse
- Waterbody
- Wetland
- Forested Area

N

0 2 Kilometres
(At original document size of 8.5x11)
1:100,000

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec



Project Location
Stephenville
NL

Prepared by JSC on 2023-07-14
QR by AW on 2023-07-19

Client/Project
World Energy GH2
Project Nujio'qonik

121417233 _215

Figure No.
4-5

Page 1 of 1

Isopleth plot NO$_2$ maximum predicted 24-hour concentration, with the background concentration (3.8 µg/m^3) included

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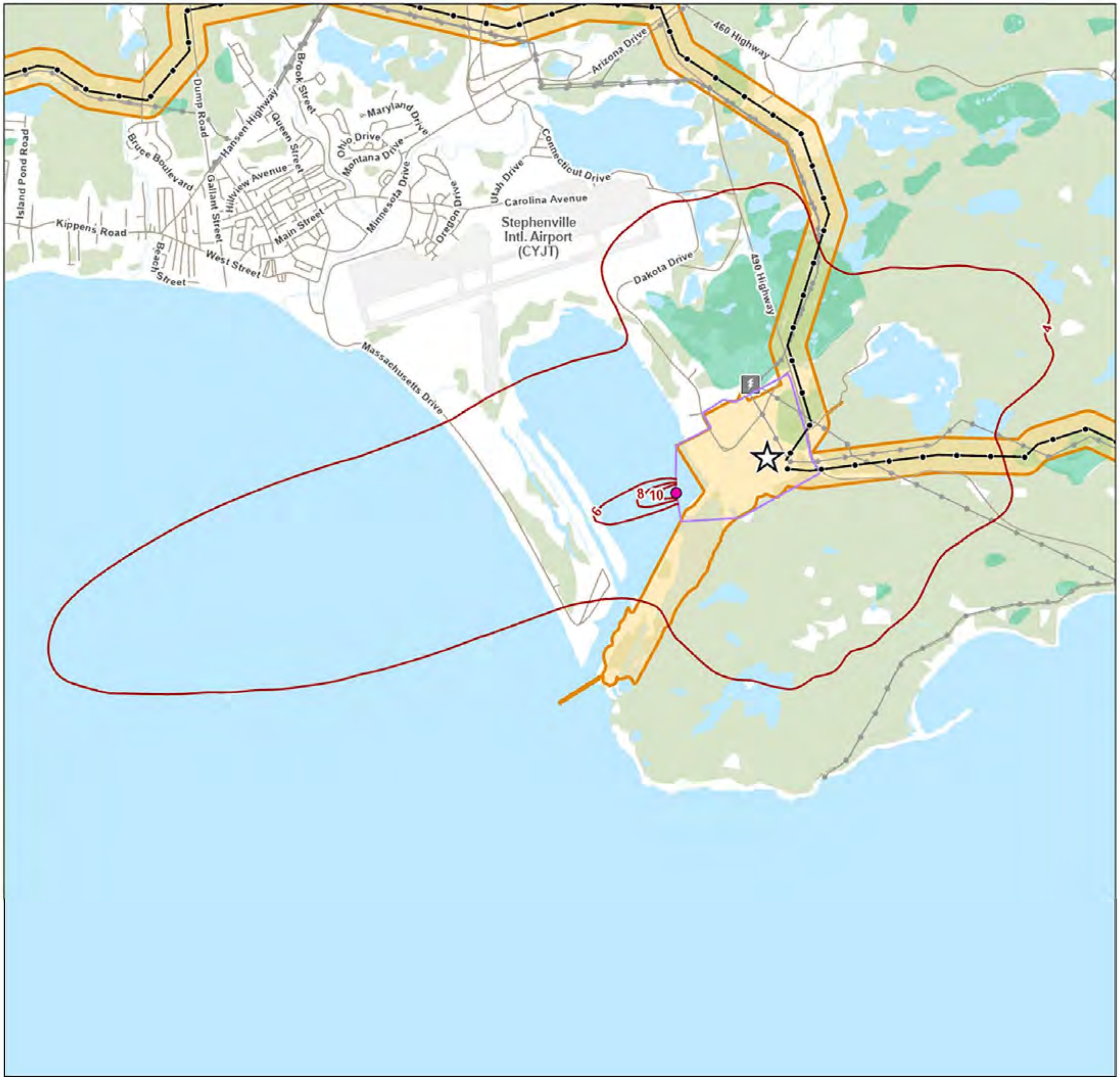

Stantec

● Maximum Concentration: 13.6 ug/m^3

Nitrogen Oxide (Calculated from NO_x via the Ozone Limiting Method), maximum predicted annual concentration, with the background concentration (3.8 µg/m^3) included. (Regulatory Limit 100 µg/m^3)

Modelled Site Boundary

Proposed Project Features

☆ Hydrogen / Ammonia Plant Location

Project Area

Other Features

Electrical Generation, Existing

Road

Transmission Line 230 kV

Transmission Line, Existing

Watercourse

Waterbody

Wetland

Forested Area

N

0 1.2 Kilometres

(At original document size of 8.5x11)
1:60,000

Notes

1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec

Project Location
Stephenville
NL

Prepared by MER on 2023-07-06
QR by AW on 2023-07-19

Client/Project
World Energy GH2 Inc.,
Project Nujio'qonik

121417233_214

Figure No.
4-6

Page 1 of 1

Isopleth plot NO_2 maximum predicted annual concentration, with the background - concentration (3.8 µg/m^3) included

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Stantec

● Maximum Concentration: 46.6 µg/m^3

Diesel Particulate Matter, maximum predicted 2-hour concentration without background concentration (Regulatory Limit Not Available)

Modelled Site Boundary

Proposed Project Features

☆ Hydrogen / Ammonia Plant Location

☐ Project Area

Other Features

Electrical Generation, Existing

Road

Transmission Line 230 kV

Transmission Line, Existing

Watercourse

Waterbody

Wetland

Forested Area

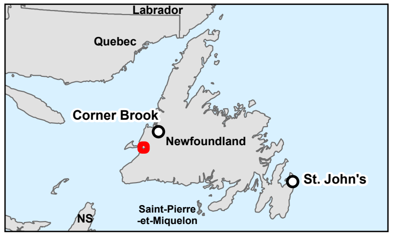
N

0 1 Kilometres

(At original document size of 8.5x11)
1:50,000

Notes

1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec



Project Location
Stephenville
NL

Prepared by JSC on 2023-07-14
QR by AW on 2023-07-19

Client/Project
World Energy GH2
Project Nujio'qonik

121417233_212

Figure No.
4-7

Page 1 of 1

Isopleth plot DPM maximum predicted 2-hour concentration, without background concentration

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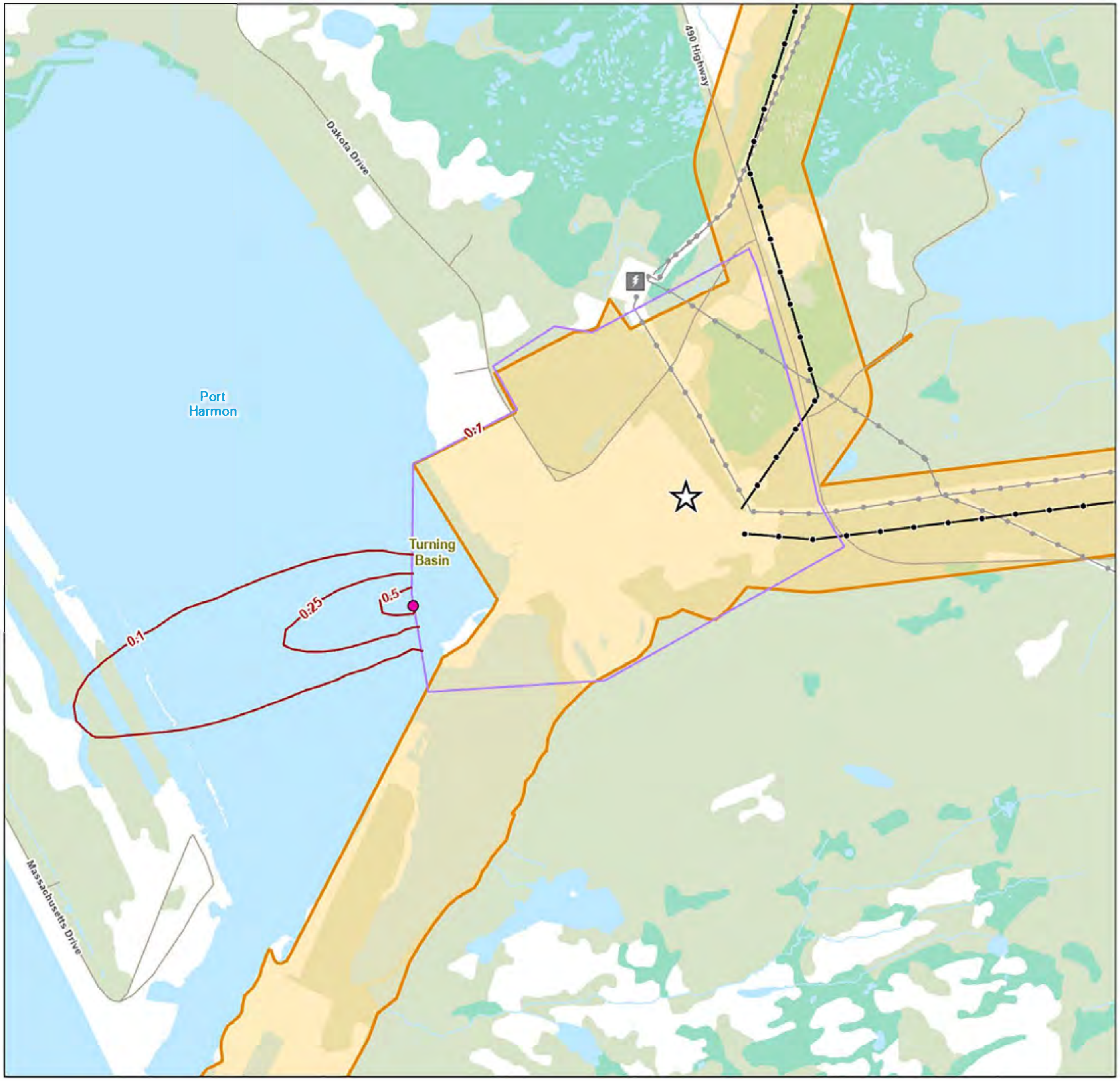

Stantec

● Maximum Concentration: 0.65 µg/m^3

Diesel Particulate Matter, maximum predicted annual concentration without background concentration (Regulatory Limit Not Available)

Modelled Ste Boundary

Proposed Project Features

☆ Hydrogen / Ammonia Plant Location

Project Area

Other Features

Electrical Generation, Existing

Road

Transmission Line 230 kV

Transmission Line, Existing

Watercourse

Waterbody

Wetland

Forested Area

N

0 0.4 Kilometres

(At original document size of 8.5x11)
1:20,000

Notes

1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec

Project Location
Stephenville
NL

Prepared by JSC on 2023-07-14
QR by AW on 2023-07-19

Client/Project
World Energy GH2
Project Nujio'qonik

121417233 _211

Figure No.
4-8

Page 1 of 1

Isopleth plot DPM maximum predicted annual concentration, without background concentration

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4.2.3 Decommissioning and Rehabilitation

The air contaminant release estimates during construction were evaluated quantitatively. However, the potential changes in air quality from construction activities were evaluated qualitatively, as described in EIS Chapter 6 (Atmospheric Environment). Therefore, risk associated with air contaminant releases during decommissioning and rehabilitation will be discussed qualitatively in Section 5.4.

5.0 Risk Characterization

The risk characterization stage combines the outcomes of the toxicity assessment and exposure assessment to provide a numeric estimate of risk. The results of the risk characterization are not predictions of health outcomes for individuals but rather an indication of whether an established safe or acceptable level of exposure (the TRV or health-based limit) has been exceeded for a hypothetical human receptor based on modelled/predicted concentrations of air quality contaminants.

5.1 Methods

5.1.1 Threshold Effects

To evaluate the risk of threshold effects from inhalation, risk was characterized using an exposure ratio (ER) calculated as the quotient of estimated exposure to the TRV or health-based exposure limit:

$$\underset{\text{(unitless)}}{\text{ER}} = \frac{\text{Exposure } (\mu\text{g/m}^3)}{\text{TRV } (\mu\text{g/m}^3)}$$

Where baseline data were available, ERs were compared to a target benchmark of 1.0 (Health Canada 2019). Where baseline data were not available, ERs were compared to a target benchmark of 0.2 to account for possible exposure of people to these chemicals from sources other than the Project, per Health Canada guidance (Health Canada 2019)

Per Health Canada (2019), if the ER for the baseline plus Project scenario is less than the target benchmark for a particular COPC (ER<1.0 or 0.2, as applicable), the risks associated with this contaminant are likely negligible and generally no further assessment is considered necessary. If the ER is greater than the target for the baseline plus Project scenario for a particular COPC, further consideration is warranted regarding either reducing uncertainty in the risk assessment or identifying mitigation measures to reduce exposure to the COPC.

5.1.2 Non-Threshold Effects: Carcinogens

As noted in Section 3.1.2, the TRVs for carcinogens may be expressed in terms of a RSC for continuous lifetime exposure that would be associated with 1 in 100,000 incremental lifetime cancer risk (ILCR), the level that Health Canada considers to be "essentially negligible". In this case, the ER is expressed as:

$$\underset{\text{(unitless)}}{\text{ER}} = \frac{\text{Exposure } (\mu\text{g/m}^3)}{\text{TRV expressed as RSC } (\mu\text{g/m}^3)}$$

For carcinogens, an ER less than 1.0 indicates the ILCR is essentially negligible and generally no further assessment is considered necessary.

For the assessment of carcinogenic effects, the risk-specific concentrations (and the ER) are only applicable to the predicted Project contributions (i.e., excluding background concentrations) as they were developed to address cancer risks that are above existing conditions (i.e., the ILCR). However, Health Canada (2019) notes that the evaluation of overall risk (background exposure plus incremental risks) will help to understand how the Project plus baseline may affect human health.

If the ER for a particular non-threshold carcinogen for a Project alone scenario is greater than 1.0, this is indicative of a potential health concern that should be more closely examined.

5.1.3 Non-threshold Effects: Non-Carcinogens

Several COPCs (i.e., NO_2, SO_2, $PM_{2.5}$, and PM_{10}) are non-threshold, non-carcinogenic contaminants, meaning that there is no specific threshold concentration that elicits an adverse health effect. Adverse health effects may occur at any concentration of these COPCs, and the severity of effects increases incrementally with exposure concentration and exposure duration. The absence of a clearly defined concentration-response relationship for these COPCs presents a technical challenge for health regulatory agencies and health risk practitioners on how to assess the incremental increase in health risk. As noted in Section 3.2, WHO ambient air quality guidelines are used in this HHRA as health-based exposure limits for the assessment of human health risk. In this case, the ER is expressed as:

$$\text{ER (unitless)} = \frac{\text{Exposure } (\mu g/m^3)}{\text{Health-based Exposure Limit } (\mu g/m^3)}$$

As noted in Section 3, the WHO (2021) indicates that, in interpreting their air quality guidelines, "It is assumed that adverse health effects do not occur or are minimal below this concentration level." For these COPCs, an ER less than 1.0 indicates that the health risk is minimal. However, it is acknowledged that human health impacts may occur at concentrations that are less than the applicable air quality criteria. Mitigation measures to limit emissions therefore remain important.

In cases where predicted concentrations of COPCs are greater than the exposure limit (i.e., ER greater than 1.0), it does not necessarily indicate an adverse health effect is expected; rather, it triggers a more in-depth review of the assumptions used in the assessment to make conclusions about possible human health effects.

5.1.4 Step-wise Approach

In this HHRA, the first step in characterizing health risks from potential exposure to Project-related COPCs is to review the ERs calculated using the maximum predicted concentrations at or beyond the hydrogen / ammonia plant property boundary. If the ER is less than 1.0 for Project + Baseline using the maximum predicted concentration (or less than 0.2 for threshold contaminants for Project Alone if background concentrations were not available), it means that the ER has also been met throughout the entire LAA/RAA. In most cases, this means that there would be no unacceptable risk to human health, and the COPC is not assessed further. However, as discussed above, additional discussion may be appropriate where exposure estimates have been compared to air quality criteria for non-threshold non-carcinogenic contaminants (i.e., NO_2, SO_2, and particulate matter).

If the ER for the maximum predicted concentration is greater than the target (i.e., 1.0 or 0.2, as appropriate), the second step is to review the maximum ground level concentration at a residential area to determine whether there may be an unacceptable risk in locations where people are regularly present. If the ER is greater than the target at a residential human receptor location, a more detailed evaluation of the health risk is provided.

As quantitative exposure modelling was not completed during Project construction or decommissioning and rehabilitation, risks during these Project phases are evaluated qualitatively.

5.2 Health Risk During Construction Phase

As discussed in EIS Chapter 6 (Atmospheric Environment), potential air contaminant releases during construction were estimated rather than modelled because these releases are expected to be short-term and intermittent as construction of the turbines moves around the Project Area in a staggered approach. A dust management plan, including ambient monitoring of particulate matter, will be implemented during construction as part of the greater air quality management plan (AQMP). To mitigate potential significant effects to air quality, the results of the ambient particulate matter monitoring will be used to assess the effectiveness of the dust mitigation and to evaluate the potential need for more rigorous dust mitigation during construction. If the monitoring program indicates that ground-level TSP, PM_{10} or $PM_{2.5}$ concentrations are greater than the NLAAQS, additional mitigation measures to reduce particulate matter emissions will be implemented. The final ambient air quality monitoring plan would be developed and reviewed with regulatory agencies during the permitting process. Additional details are provided in EIS Chapter 6 (Atmospheric Environment).

Whether the level of risk is acceptable or unacceptable is determined by individual and societal values, and in the context of HHRA, acceptable versus unacceptable risk is frequently defined by public policy and regulation. Therefore, although particulate matter is a non-threshold contaminant and adverse health effects may occur at any exposure concentration, concentrations of particulate matter that meet applicable air quality criteria or standards may be considered "acceptable".

5.3 Health Risk During Operation and Maintenance Phase

To evaluate the potential health risk during the operation and maintenance phase of the Project, ERs were calculated based on the maximum predicted ground level concentrations at the hydrogen / ammonia plant property boundary (Table 4.1) as well as the maximum predicted ground level concentrations at a residential location (Table 4.2). These ERs are summarized in Tables 5.1 and 5.2, respectively.

Table 5.1 Exposure Ratios based on Maximum Predicted Ground Level Concentrations at the Hydrogen / Ammonia Plant Property Boundary

		Exposure Ratio for the Maximum Predicted Ground Level Concentration at the Hydrogen / Ammonia Plant Property Boundary		
Chemical of Potential Concern	**Exposure Period**	**Baseline**	**Project**	**Project + Baseline[a,b]**
Nitrogen Dioxide (NO_2)	1 hour	0.03	0.55	0.57
	24 hour	0.15	3.7	**3.9**
	1 year	0.38	0.98	**1.4**
Carbon Monoxide (CO)	1 hour	7.2E-03	1.2E-03	8.4E-03
	8 hour	2.1E-02	2.9E-03	2.3E-02
Sulphur Dioxide (SO_2)	10 minute	2.3E-02	1.2E-02	3.4E-02
	24 hour	5.3E-02	1.3E-02	6.5E-02
Ammonia (NH_3)	1 hour	N/A	0.38	**0.38**
	24 hour	N/A	0.49	**0.49**
Particulate Matter ($PM_{2.5}$)	24 hour	0.41	0.80	**1.2**
	1 year	0.90	0.17	**1.1**
Diesel Exhaust (DPM)	2 hour	N/A	4.66	**4.7**
	1 year	N/A	0.13	0.13
Volatile Organic Compounds				
Benzene	1 hour	N/A	6.6E-05	6.6E-05
	24 hour	N/A	7.6E-04	7.6E-04
	1 year	N/A	8.6E-04	8.6E-04
Toluene	1 hour	N/A	9.2E-07	9.2E-07
	24 hour	N/A	1.1E-06	1.1E-06
	1 year	N/A	8.4E-08	8.4E-08
Xylenes	1 hour	N/A	1.3E-06	1.3E-06
	1 year	N/A	1.3E-06	1.3E-06
Acrolein	1 hour	N/A	1.0E-05	1.0E-05
	1 year	N/A	1.2E-05	1.2E-05
Formaldehyde	1 hour	N/A	2.1E-03	2.1E-03
	1 year	N/A	2.7E-05	2.7E-05

Table 5.1 Exposure Ratios based on Maximum Predicted Ground Level Concentrations at the Hydrogen / Ammonia Plant Property Boundary

Chemical of Potential Concern	Exposure Period	Exposure Ratio for the Maximum Predicted Ground Level Concentration at the Hydrogen / Ammonia Plant Property Boundary		
		Baseline	Project	Project + Baseline[a,b]
Polycyclic Aromatic Hydrocarbons				
Naphthalene	1 year	N/A	9.0E-06	9.0E-06
Benzo(a)pyrene	1 year	N/A	8.9E-05	8.9E-05
Aromatic C_9-C_{16}[c]	1 year	N/A	7.1E-07	7.1E-07
Benzo(a)pyrene TPE	1 year	N/A	4.0E-05	4.0E-05

Notes:

N/A: Not available. In Chapter 6 (Atmospheric Environment), representative baseline data were obtained from the nearest and most representative National Air Pollutant Surveillance Program (NAPS) ambient air quality monitoring station, which was determined to be the NAPS station at Grand Falls-Windsor. For parameters that are not measured at that NAPS station, no baseline data were available and therefore no ERs were generated for the Baseline condition alone.

[a] ‘Project + Baseline’ values presented in this table may not be equivalent to the sum of presented “Baseline’ values plus ‘Project’ values due to rounding and significant figures.

[b] ERs for Project + Baseline that are greater than their applicable target value (i.e., 0.2 if no baseline data available and 1.0 if baseline data available) are **shaded and bolded**

[c] sum of acenaphthene, acenaphthylene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, pyrene

Table 5.2 Exposure Ratios based on Maximum Predicted Ground Level Concentrations at a Residential Location

Chemical of Potential Concern	Exposure Period	Exposure Ratio at the Maximum Predicted Ground Level Concentration at a Residential Location		
		Baseline	Project	Project + Baseline[a,b]
Nitrogen Dioxide (NO_2)	1 hour	0.03	0.41	0.44
	24 hour	0.15	1.9	**2.1**
	1 year	0.38	0.17	0.5
Carbon Monoxide (CO)	1 hour	7.2E-03	3.1E-04	7.5E-03
	8 hour	2.1E-02	7.2E-04	2.1E-02
Sulphur Dioxide (SO_2)	10 minute	2.3E-02	3.4E-03	2.6E-02
	24 hour	5.3E-02	2.8E-03	5.5E-02
Ammonia (NH_3)	1 hour	N/A	0.09	0.09
	24 hour	N/A	0.13	0.13
Particulate Matter ($PM_{2.5}$)	24 hour	0.41	0.15	0.56
	1 year	0.90	0.02	0.92

Table 5.2 Exposure Ratios based on Maximum Predicted Ground Level Concentrations at a Residential Location

Chemical of Potential Concern	Exposure Period	Exposure Ratio at the Maximum Predicted Ground Level Concentration at a Residential Location		
		Baseline	Project	Project + Baseline[a,b]
Diesel Exhaust (DPM)	2 hour	N/A	0.57	**0.57**
	1 year	N/A	0.02	0.02
Volatile Organic Compounds				
Benzene	1 hour	N/A	1.7E-05	1.7E-05
	24 hour	N/A	1.6E-04	1.6E-04
	1 year	N/A	1.4E-04	1.4E-04
Toluene	1 hour	N/A	2.3E-07	2.3E-07
	24 hour	N/A	2.3E-07	2.3E-07
	1 year	N/A	1.4E-08	1.4E-08
Xylenes	1 hour	N/A	3.2E-07	3.2E-07
	1 year	N/A	2.2E-07	2.2E-07
Acrolein	1 hour	N/A	2.6E-06	2.6E-06
	1 year	N/A	2.1E-06	2.1E-06
Formaldehyde	1 hour	N/A	7.4E-05	7.4E-05
	1 year	N/A	4.6E-06	4.6E-06
Polycyclic Aromatic Hydrocarbons				
Naphthalene	1 year	N/A	1.5E-06	1.5E-06
Benzo(a)pyrene	1 year	N/A	1.5E-05	1.5E-05
Aromatic C_9-C_{16}[c]	1 year	N/A	1.2E-07	1.2E-07
Benzo(a)pyrene TPE	1 year	N/A	6.8E-06	6.8E-06

Notes:

N/A: Not available. In Chapter 6 (Atmospheric Environment), representative baseline data were obtained from the nearest and most representative National Air Pollutant Surveillance Program (NAPS) ambient air quality monitoring station, which was determined to be the NAPS station at Grand Falls-Windsor. For parameters that are not measured at that NAPS station, no baseline data were available and therefore no ERs were generated for the Baseline condition alone.

[a] ‘Project + Baseline’ values presented in this table may not be equivalent to the sum of presented “Baseline’ values plus ‘Project’ values due to rounding and significant figures.

[b] ERs for Project + Baseline that are greater than their applicable target value (i.e., 0.2 if no baseline data available and 1.0 if baseline data available) are **shaded and bolded**

[c] sum of acenaphthene, acenaphthylene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, pyrene

5.3.1 Nitrogen Dioxide (NO_2)

Although ER for 1-hour NO_2 is less than 1.0 at the hydrogen / ammonia plant property boundary and residential locations, the ERs for 24-hour and 1-year exposures for Project and Project + Baseline scenarios are greater than 1.0 at the hydrogen / ammonia plant property boundary and the ER for 24-hour NO_2 is also greater than 1.0 at the maximum residential location. NO_2 is a non-threshold non-carcinogen for which health effects may exist at concentrations less than the applicable guideline, which means that an increase above baseline required a more detailed characterization of the risk.

Isopleth contours for 1-hour, 24-hour, and annual NO_2 concentrations for Project + Baseline are provided on Figure 4.4, Figure 4.5, and Figure 4.6, respectively. Maximum ground level concentrations are predicted to occur along the western hydrogen / ammonia plant property boundary of the Project and over water: it is therefore unlikely that people would spend substantive time in this area. Isopleth contours indicate that emissions of NO_2 are predicted to disperse to the west of the Project, towards Little Port Harmon. The maximum predicted concentrations at a residential location are located in Little Port Harmon.

Concentrations of NO_2 were compared to exposure limits for 1-hour, 24-hour and annual durations of 200 µg/m^3, 25 µg/m^3 and 10 µg/m^3, respectively, based on ambient air quality guidelines established by the WHO. The 1-hour exposure limit is based upon the health outcome of an increase in asthma-related hospital admissions and emergency room visits among all ages, with the potential health outcome more prominent among asthmatic children and those with pre-existing diseases such as chronic obstructive pulmonary disorder (WHO 2006). The newer 24-hour exposure limit is based on all-cause non-accidental mortality and asthma hospital admissions and emergency room visits (WHO 2021). Potential effects of short-term NO_2 exposure are less pronounced in healthy individuals with no history of asthma or pre-existing respiratory conditions (WHO 2021; 2006; Health Canada 2016e) The WHO guideline for annual NO_2 is based upon the health outcome of increased respiratory mortality and an increase in all types of health mortality in a population (WHO 2021).

The maximum predicted 1-hour NO_2 concentration is 115 µg/m^3, which is well-below the WHO ambient air quality guideline of 200 µg/m^3 . The location of the predicted maximum concentration is over water, where people are less likely to be exposed to even short-term, 1-hour concentrations. The maximum predicted concentration at a residential location, where people are more likely to be exposed, is 87 µg/m^3. This indicates that the potential health risk throughout the LAA/RAA is minimal for acute 1-hour exposure.

The maximum predicted 24-hour and annual average NO_2 concentrations for Project + Baseline of 96 µg/m^3 and 14 µg/m^3 are greater than exposure limits; however, as previously noted, these concentrations are in an area where exposures are unlikely to occur. As indicated in Figure 4.6, the isopleth for maximum annual average NO_2 concentrations of 10 µg/m^3 (the exposure limit for chronic NO_2 exposures) is limited to a small area over water. Maximum annual average NO_2 concentrations at a residential location is 5.5 µg/m^3, indicating that concentrations in residential areas will remain below levels that the WHO identified as the level adverse health effects do not occur or are minimal.

In contrast, as indicated in Figure 4.5, although the extent of the predicted maximum 24-hour NO_2 concentrations for Project + Baseline greater than the exposure limit of 25 µg/m^3 is small relative to the LAA/RAA, it extends to the residential area of Little Port Harmon. Maximum predicted ground level concentrations at a residential area for Project + Baseline is 52 µg/m^3.

Although model predictions indicate that residents in some areas of Little Port Harmon may be exposed to 24-hour NO_2 concentrations greater than the WHO ambient air quality guideline, the potential for effects is unclear. As noted by the WHO (2021), when the long-term exposures are compliant with the long-term guideline of 10 µg/m^3, days with concentrations approaching or exceeding the 24-hour guideline of 25 µg/m^3 will correspond to the far upper tail of the distribution of daily exposures and most days will have much lower values, with close to half having concentrations below or far below the annual exposure limit. The health burden related to a few days with higher concentrations corresponds to a very small fraction of the total pollution related burden (WHO 2021).

Although human controlled exposure studies demonstrate a relationship between exposure to NO_2 and adverse respiratory effects in asthmatics or people with COPD, the dose–response relationship at concentrations below NO_2 concentrations of 1,880 µg/m^3 (1 ppm) is unclear (Health Canada 2016b). The respiratory effects observed in the controlled human exposure studies were mild, transient and reversible. Generally, healthy adults were three-fold less sensitive to the respiratory effects of NO_2 than other subpopulations. Therefore, 1,880 µg/m^3 (1 ppm) is considered to be the level below which adverse effects have not been observed in healthy individuals, with the acknowledgment that some individuals may be more sensitive to some endpoints at 1,100 µg/m^3 (0.6 ppm) ppm or less (Health Canada 2016b). Health Canada (2016b) concluded that while it is possible that individual asthmatic children or adults with COPD could be more sensitive to exposures below 560 µg/m^3 (0.3 ppm) NO_2, the respiratory effects would be mild and transient.

The limitation of the human controlled studies is that they are generally limited to examining short-term, mild, reversible alterations in health endpoints, typically in small groups of relatively healthy individuals who do not include those who may be most at risk (e.g., those with severe pre-existing disease) (Health Canada 2016b). They are therefore unable to capture the full range of severities of effects and the profiles of affected populations, and they do not have the statistical power to identify relatively small risks (Health Canada 2016b)

As discussed in EIS Chapter 6 (Atmospheric Environment), there were several conservative assumptions made during the air dispersion modelling, and as such, the actual exposure concentrations are not expected to be as high as predicted. Additional discussion of the uncertainties associated with the modelled air quality are provided in Section 6.2.

In summary, maximum predicted 1-hour and annual NO_2 concentrations in areas frequented by the public are less than concentrations associated with a minimal risk of effects. Although maximum predicted 24-hour NO_2 concentrations in a residential area are higher than the levels associated with effects in epidemiological studies, the monitoring and adaptive management is considered appropriate since:

- concentrations are well below levels associated with adverse effects in healthy individuals

- annual exposure limit is not exceeded and the health burden related to a few days with higher concentrations is relatively very small
- while it is possible that individual asthmatic children or adults with COPD could be more sensitive, the respiratory effects would likely be mild and transient
- the geographical extent of the maximum predicted 24-hour concentrations that are greater than the exposure limit is relatively small
- exposure concentrations are expected to be less than those predicted by the CALMET/CALPUFF modeling system

The AQMP will measure NO_2 during operations and will specify the mitigation measures for the management and reduction of air emissions during Project operation. Ambient air monitoring will be implemented in conjunction with emissions mitigation to provide an understanding of the offsite NO_2 concentrations, and to evaluate the need for more rigorous mitigation. Additional details are provided in EIS Chapter 6 (Atmospheric Environment). The AQMP typically relies on provincial or federal ambient air quality standards; however, because the NLAAQS for 1-hour, 24-hour, and annual NO_2 of 400 µg/m^3, 200 µg/m^3, and 100 µg/m^3 are not based solely on health effects, it may be more appropriate to compare air monitoring results to health-based exposure limits at residential areas.

5.3.2 Sulphur Dioxide (SO_2)

The ERs for 10-min and 24-hour SO_2 at the hydrogen / ammonia plant property boundary and at residential locations are less than 1.0. However, SO_2 is a non-threshold non-carcinogen for which health effects may exist at concentrations less than the applicable guideline. As a result, a more detailed characterization of the risk associated with SO_2 is provided.

The reference concentration for 10-minute SO_2 is 175 µg/m^3, which is expected to be protective of respiratory effects in humans, including sensitive populations like people with asthma (Health Canada 2016e). The maximum 10-minute SO_2 concentration is predicted to be 6.0 µg/m^3 at Project + Baseline. This indicates that the maximum 10-minute SO_2 concentration is predicted to be less than 3% of the reference concentration of 175 µg/m^3 throughout the entire LAA/RAA.

The WHO ambient air quality guideline of 40 µg/m^3 for 24-hour exposures is based upon the health outcome of an increase in asthma-related hospital admissions and emergency room visits among all age groups (WHO 2021). Although any exposure to SO_2 carries some degree of risk, adverse health effects from 24-hour exposures are considered minimal below 40 µg/m^3 based on the WHO's definition for this guideline. As indicated in Table 4.1, the maximum 24-hour SO_2 concentration is predicted to increase from 2.1 µg/m^3 at Baseline to 2.6 µg/m^3 at Project + Baseline. Changes at residential locations are even smaller (i.e., from 2.1 µg/m^3 at Baseline to maximum of 2.2 µg/m^3 at Project + Baseline, as indicated in Table 4.2).

As noted in Section 3.2, chronic assessment of SO_2 for human health has not been conducted as there is a lack of evidence of causal relationship between long-term SO_2 exposure and respiratory effects.

Based on these findings, the potential risk associated with short-term exposures to SO_2 is minimal.

5.3.3 Particulate Matter

The ERs for 24-hour and annual $PM_{2.5}$ are greater than 1.0 at the hydrogen / ammonia plant property boundary. Also, particulate matter is a non-threshold chemical for which health effects may exist at concentrations less than the applicable guideline. As a result, a more detailed characterization of the risk associated with particulate matter is provided.

The assessment of health risks associated with particulate matter focused on $PM_{2.5}$. The data that support an evaluation of health effects from PM_{10} are weaker than for $PM_{2.5}$ and subject to larger measurement errors (Health Canada 2016c). The WHO indicates preference should be given to air quality guidelines for $PM_{2.5}$(WHO 2021). As a result, the following discussion of health risks associated with exposure to $PM_{2.5}$ encapsulates the potential health risks associated with exposure to PM_{10}.

The WHO 24-hour $PM_{2.5}$ guideline of 15 $\mu g/m^3$ is based upon the health outcome of an increase in all types of mortality with a more prominent effect on respiratory and cardiovascular mortalities (WHO 2021). As indicated in Table 4.1, the maximum 24-hour $PM_{2.5}$ concentration increases from the Baseline of 6.1 $\mu g/m^3$ to 18 $\mu g/m^3$ for Baseline + Project. However, the extent of 24-hour $PM_{2.5}$ concentrations greater than the WHO guideline is limited to a small area near the hydrogen / ammonia plant property boundary, primarily over water, where people are unlikely to be present for 24-hours (Figure 4.1). The maximum predicted 24-hour $PM_{2.5}$ concentration for Baseline + Project at a residential location is 8.4 $\mu g/m^3$, as indicated in Table 4.2. While this is an increase over Baseline, most residential areas, including Stephenville, are predicted to experience negligible increases in 24-hour $PM_{2.5}$ concentrations, as shown in Figure 4.1.

The WHO annual average $PM_{2.5}$ guideline of 5 $\mu g/m^3$ is based upon the health outcome of an increase in all types of mortality with a more prominent effect on respiratory mortalities (related to COPD and acute lower respiratory infections), cardiovascular mortalities (related to cerebrovascular and ischemic heart disease), and also lung cancer mortalities. As indicated in Table 4.1, the maximum annual average $PM_{2.5}$ concentration is predicted to increase from the Baseline of 4.5 $\mu g/m^3$ to 5.3 $\mu g/m^3$ for Baseline + Project. However, the extent of annual average $PM_{2.5}$ concentrations greater than the WHO guideline is limited to a small area near the hydrogen / ammonia plant property boundary where people would not be present for the year (Figure 4.2). The maximum predicted annual average $PM_{2.5}$ concentration for Baseline + Project at a residential location is 4.6 $\mu g/m^3$, which is only slightly higher than the Baseline concentration of 4.5 $\mu g/m^3$, as indicated in Table 4.2. Changes in annual average $PM_{2.5}$ concentrations throughout most of the LAA/RAA are negligible, as shown in Figure 4.2.

Overall, the predicted change in $PM_{2.5}$ concentrations throughout much of the LAA/RAA is negligible and concentrations are well-below the WHO guideline at each residential receptor location for both short-term and long-term exposure periods. Based on the WHO definition of their ambient air quality guidelines, it can be assumed that adverse health effects would be minimal throughout the LAA/RAA from short-term and long-term exposure to $PM_{2.5}$.

5.3.4 Diesel Particulate Matter (DPM)

In the absence of baseline concentration data for DPM, ERs were compared to a target value of 0.2 in Table 5.1 and Table 5.2. The ERs for annual DPM are less than 0.2, while the ERs for 2-hour DPM are greater than 0.2 both for the maximum predicted ground level concentration at the hydrogen / ammonia plant property boundary (Table 5.1) and at the maximum residential location (Table 5.2). These results suggest that the risk of threshold effects associated with long-term exposure to DPM are negligible, but a more detailed characterization of the risk of short-term exposures is needed. Also, long-term exposure to diesel exhaust has exhibited a causal relationship with lung cancer, and a suggested relationship with bladder cancer. As a result, a more detailed characterization of the risk associated with short-term and long-term exposure to DPM is provided below.

Risk from Short-term (Acute) Exposure

As indicated in Table 4.1, the maximum 2-hour DPM concentration of 47 μg/m^3 is higher than the TRV of 10 μg/m^3, which is protective of mild, reversible respiratory effects (Health Canada 2016d). The maximum predicted 2-hour concentrations of DPM during operations are illustrated on Figure 4.7. As evidenced by the 10 μg/m^3 isopleth, the extent of predicted maximum 2-hour DPM concentrations that are greater than the TRV is very limited and located near the hydrogen / ammonia plant property boundary, in an area where people are unlikely to linger for an appreciable length of time. Predicted 2-hour DPM concentrations in residential areas are less than the TRV of 10 μg/m^3 (maximum concentration of 5.7 μg/m^3, Table 4.2). Therefore, it is unlikely that a member of the public will be exposed to 2-hour DPM concentrations related to the Project that are greater than the TRV. Although baseline concentrations for DPM are not available, there are no substantive sources of diesel emissions in the residential area. Therefore, it is unlikely that a member of the public will be exposed to 2-hour DPM concentrations related to the Project that are greater than the TRV. Therefore, non-cancer risk from short-term acute exposure to DPM are considered negligible.

Cancer Risk

As described above in Section 3.2.4, DE has exhibited a causal relationship with lung cancer, and a suggested relationship with bladder cancer (Health Canada 2016d; IARC 2014). However, Health Canada (2016d) did not identify an IUR to be used to evaluate cancer risk based on exposure to diesel exhaust. Similarly, when the US EPA reviewed the available data on this topic in 2002, they concluded that the uncertainties in the human exposure-response data for DE were too large to derive a quantitative estimate of cancer unit risk with any degree of confidence (US EPA 2002).

Additional review of the available epidemiological evidence regarding DE and carcinogenic effects is available in a report prepared by the Health Effects Institute (HEI Diesel Epidemiology Panel 2015). The HEI Diesel Epidemiology Panel (HEI Diesel Epidemiology Panel 2015) report identified and reviewed two large epidemiological studies that they determined could provide a useful basis for quantitative risk assessment (HEI Diesel Epidemiology Panel 2015). However, the HEI Diesel Epidemiology also noted that major changes in technology and the composition of diesel fuels have occurred since those studies were conducted and that the exposure-response relationships in those studies should be considered most applicable to older diesel engine exhaust (HEI Diesel Epidemiology Panel 2015). This is a critical point to consider given that emissions from new technology diesel engines (i.e., post-2006) such as those most likely to be used in Project activities have been substantially reduced and have also changed in composition. For example, emissions of particulate matter have been reduced by about 99% and emissions of PAHs, metals and other compounds have been reduced by 80 to 90% (HEI Diesel Epidemiology Panel 2015; Khalek et al. 2011; 2015). The health effects of emissions from new technology diesel may therefore differ substantially from those associated with older diesel fuels. For example, McDonald et al. (2015) found no evidence of carcinogenicity and few other biological effects in rodents following chronic exposure to emissions from 'new' diesel engines (i.e., 2007 technology).

Given the identified uncertainties quantifying cancer risks associated with exposure to DE described above, it is acknowledged that long-term exposure to DPM at concentrations less than the chronic non-cancer guideline may be related to an increased cancer risk. The level of exposure that would be associated with an acceptable ILCR is not known. As discussed in EIS Chapter 6 (Atmospheric Environment), there were several conservative assumptions made during the air dispersion modelling, and as such, the actual exposure concentrations are not expected to be as high as predicted. Additional discussion of the uncertainties associated with the modelled air quality are provided in Section 6.3 In light of the uncertainty, monitoring and adaptive management of fine particulate (which includes DPM) is considered appropriate. The AQMP will measure $PM_{2.5}$ during operations and will specify the mitigation measures for the management and reduction of air emissions during Project operation. Ambient air monitoring will be implemented in conjunction with emissions mitigation to provide an understanding of the offsite $PM_{2.5}$ concentrations, and to evaluate the need for more rigorous mitigation. Additional details are provided in EIS Chapter 6 (Atmospheric Environment).

5.3.5 Ammonia (NH_3)

In the absence of baseline concentration data for NH_3, ERs were compared to a target value of 0.2 in Table 5.1 and Table 5.2. The ERs for 1 hour and 24-hour NH_3 were greater than 0.2 for the maximum predicted ground level concentration (Table 5.1) but less than 0.2 at the maximum residential location (Table 5.2). However, NH_3 is a short-lived pollutant and normally doesn't travel far from its source. As there are no known sources of NH_3 near the Project area, it is reasonable to assume that it is negligible in background. Therefore, given that the ERs for 1 hour and 24-hour NH_3 do not exceed 1.0, it is concluded that exposure for residents and recreational users in the LAA/RAA will remain below the applicable health-based guidelines and risks to human health from NH_3 will be negligible.

5.3.6 Carbon Monoxide (CO)

As indicated in Table 5.1, the ERs for the Baseline and Project + Baseline scenarios are similar, suggesting that the Project contribution to exposures in the LAA/RAA is low. ERs for 1-hour and 8-hour CO are less than 1.0 all three scenarios. Based on these results, the risks associated with CO are considered negligible.

5.3.7 VOCs and PAHs

Baseline concentrations were not available for the VOC and PAH COPCs; however, given the lack of other substantive sources of these chemicals, background concentrations are expected to be negligible. As indicated in Table 5.1, the ERs for VOCs and PAHs for both short-term and long-term exposures were less than 0.01, indicating that predicted maximum ground level concentrations associated Project-related exposures were less than 1% of health-based targets. Exposures at residential locations are lower still, as indicated in Table 5.2. Based on these predicted exposures, the risk associated with inhalation of VOCs and PAHs is negligible.

5.4 Health Risk During Decommissioning and Rehabilitation

As discussed in EIS Chapter 6 (Atmospheric Environment), potential air contaminant releases during decommissioning and rehabilitation were not modelled for this assessment because the release of air contaminants during decommissioning and rehabilitation is typically less than during construction and can be effectively managed through the application of standard operating procedures and best management practices. Therefore, with this proactive mitigation and monitoring applied, no unacceptable risks to human health are predicted during the decommissioning and rehabilitation phase of the Project.

6.0 Uncertainty Analysis

The process of evaluating human health risks involves multiple steps. Inherent to each of these steps are uncertainties that affect the final assessment of human health risk. These uncertainties may include data gaps, estimated or modelled data or the derivation and applicability of TRVs from different regulatory agencies. Where uncertainties existed, a conservative approach was taken, where appropriate, to overestimate the calculation of potential risk. This section describes each of the identified uncertainties and its influence on the characterization of potential human health risk.

6.1 Uncertainty in the Toxicological Reference Values

There is a very limited amount of toxicological information on the effects associated with human exposures to low levels of chemicals in the environment. The information based on human exposures that is available is often based on epidemiological studies of occupationally exposed workers or controlled lab-based studies with people. These studies are generally limited in scope and provide results that may not be applicable to chronic or continuous exposures to low levels of chemicals. Because human toxicological information is limited, TRVs for many compounds are based on the results of dose-response assessment studies using animals.

The use of experimental animal data to estimate potential biological effects in humans introduces uncertainties into the evaluation of potential human health effects. These estimations require that the following number of assumptions be made:

- The toxicological effect reported in animals is relevant and could occur in humans
- The assumption that extrapolation from high-dose studies to low-dose environmental exposures adequately represents the shape of the dose-response curve in the low-dose exposure range
- Short-term exposures used in animal studies can be extrapolated to chronic or long-term exposures in humans
- The pharmacokinetic processes that occur in the test animals also occur in humans

There are a number of uncertainties associated with extrapolating from experimental animal data to humans. In order to address these weaknesses, regulatory agencies incorporate a large number of conservative assumptions to account for the uncertainties associated with this process. The uncertainties are accounted for by the use of Uncertainty Factors that are used to lower the reference dose or TRV well-below the level at which adverse health effects have been reported in the test species. Uncertainty factors are generally applied as factors of 10 and are used to account for the following types of uncertainties:

- Variation within the population (protection of sensitive members of the population)
- Differences between humans and the test species

- Differences in using short or medium-term studies to estimate the health effects associated with long-term or chronic exposures
- Limitations in the available toxicological information.

The magnitude of the uncertainty factors applied provides an indication of the level of confidence that should be placed in the reference value. Uncertainty factors typically range between 100 and 10,000, although some can be lower than 10.

The application of uncertainty factors is intended to introduce a high degree of conservatism into the risk assessment process and to ensure, to the extent feasible, that limited exposures that exceed the TRV will not result in adverse human health effects. Because risk assessments that use these regulatory limits incorporate the conservatism used in the development of the toxicological information, the results can generally be viewed as being conservative.

6.2 Uncertainties with Modelled Air Quality

The air quality model introduces several uncertainties with regard to the accuracy of the predicted air quality outputs. Emission rates employed in the modelling are based on a combination of available baseline air quality data from provincial databases or regional monitoring stations, meteorological data, emission factors from the project inventory of equipment, vehicles and machines.

The CALMET and CALPUFF modelling program and its limitations will also influence the output. CALPUFF modelling is typically used for long distance dispersion of plumes. Generally, CALMET and CALPUFF modelling results are less accurate for locations that are close to the emission source because a sufficient amount of modelled time and air space is needed to properly predict the plume dispersion. While such models employ assumptions to simplify the random behavior of the atmosphere into short periods of average behavior, they are designed to have a bias towards overestimation of contaminant concentrations (i.e., to be conservative under most conditions). Consequently, model predictions along the hydrogen / ammonia plant property boundary are likely to be more conservative (i.e., overpredicted) compared to locations farther from the Project.

Another uncertainty with air quality modelling is for VOC emissions. For most types of vehicles, machines and equipment, VOCs are measured as “total VOCs”. This means that air dispersion modelling also models VOCs as “total VOCs”. Individual chemical components that comprise VOCs are not individually modelled, as is the case for SO_2, NO_2, CO and $PM_{2.5}$. The predicted total VOC concentrations are subsequently fractioned into individual VOCs afterward, based on literature on the composition of VOCs in combustion engine exhaust.

The details of the construction equipment to be used, including the frequency and timing of vehicles and emission standards of the equipment, are not currently known. Conservative estimates of these emissions were made to ensure that the resulting predicted air concentrations would tend to overstate, rather than understate, potential exposures.

6.3 Health Risk Associated with Multiple COPCs

The current understanding of the toxicity of certain compounds is based primarily on toxicity studies performed in laboratory animals exposed to a single toxic agent, or occupation exposures involving a single compound. However, the human population is exposed to complex mixtures of contaminants generally at much lower concentrations than those routinely examined in animal toxicity studies. The effects of any chemical interactions between multiple substances on their toxicity is virtually unknown. As a result, guidelines for the protection of human health are almost exclusively based on exposure to single substances. An uncertainty factor is usually used to develop guidelines and objectives and it assumes that the degree of any synergistic increase in toxicity will not exceed the safety factors applied.

Substances in a mixture may interact in the following ways to elicit a biological response:

- Non-interacting: when substances have no effect in combination with each other; the toxicity of the mixture is the same as the toxicity of the most toxic substance in the mixture
- Additive: when substances have similar targets and modes of action but do not interact; the hazard for exposure to the mixture is simply the sum of hazards for the individual substances
- Potentiation: when a non-toxic substance enhances the toxicity of another
- Synergistic: when there is a positive interaction among the substances such that the response is greater than would be expected if the substances acted independently
- Antagonistic: when there is a negative interaction among the substances such that the response is less than would be expected if the substances acted independently.

There is no clear guidance on how to evaluate the interaction amongst substances in a mixture and their potential effects to human health risk. For example, criteria air contaminants such as SO_2 and NO_2 are typically produced simultaneously in combustion products, and they are both respiratory irritants that act on the lungs. Although scientific literature recognizes that SO_2 and NO_2 are likely to act on the lungs in an additive or synergistic manner, Health Canada recently released two reports that assess the health effects of SO_2 and NO_2 independently (Health Canada 2016b; 2016e).

There are exceptions for chemical groups such as PAHs, polychlorinated biphenyls, dioxins and furan, where variants of a chemical group have the exact mode of action and toxic endpoint but at different levels of potency. In such cases, regulatory agencies provide guidance in the form of equivalency factors, as is the case for carcinogenic PAHs. In these instances, each chemical in the group is assigned a toxic equivalence that is relative to the most studied substance in the group (and typically amongst the highest toxicity) with a relative toxicity of 1.0. For example, benzo(a)pyrene is the most studied carcinogenic PAH with a toxic equivalence of 1.0, while chrysene has a toxic equivalence of 0.01 (i.e., chrysene has 1% of the toxic potential relative to benzo(a)pyrene).

7.0 Conclusion

This HHRA evaluated the potential human health risk associated with inhalation exposures to identified air contaminant COPCs during Project construction, operation and maintenance, and decommissioning and rehabilitation. Exposure would occur primarily via inhalation of air because deposition of gases is considered a negligible transport mechanism and therefore there are no secondary exposure media.

For the Project construction phase and the Project decommissioning and rehabilitation phase, the HHRA was based on a qualitative evaluation of potential for air quality contaminants to be generated during these Project phases. Risks were contextualized through consideration of the effectiveness of planned implementation of a detailed dust management plan, ambient monitoring and adaptive management during these Project phases. With these mitigation and monitoring approaches applied, it was concluded that risks to human health during the construction phase and the decommissioning and rehabilitation phase are considered acceptable.

For the Project operation phase, the HHRA was based on a quantitative comparison of predicted air quality concentrations to applicable TRVs or health-based exposure limits. Of the evaluated COPCs, the only ones that exceeded a target exposure ratio (0.2 in the absence of baseline data and 1.0 if baseline data were available) were NO_2, $PM_{2.5}$, DPM, and NH_3.

For NO_2, concentrations higher than the annual average NO_2 health-based guideline established by WHO (2021) were limited to a small area over the water where people will not be present for long-term duration. Although concentrations higher than the 24 hour NO_2 health-based guideline established by WHO (2021) were predicted to overlap with a portion of the residential area of Little Port Harmon, additional review indicated that the predicted 24-hour concentrations in the residential area of Little Port Harmon were low relative to concentrations that are associated with respiratory, inflammatory, and immunology effects in controlled human exposure studies per Health Canada (Health Canada 2016b). Monitoring and adaptive management is considered appropriate to protect human health since:

- concentrations are well below levels associated with adverse effects in healthy individuals
- since annual exposure limit is not exceeded, the health burden related to a few days with higher concentrations is relatively very small
- while it is possible that individual asthmatic children or adults with COPD could be more sensitive, the respiratory effects would likely be mild and transient
- the geographical extent of the maximum predicted 24-hour concentrations that are greater than the exposure limit is relatively small
- exposure concentrations are expected to be less than those predicted by modeling system

For $PM_{2.5}$, concentrations higher than the 24 hour and annual average health-based guidelines established by WHO (2021) were limited to small areas near the hydrogen / ammonia plant property boundary, primarily over water, where people are unlikely to be present for 24 hour or annual exposures. Therefore, it can be assumed that adverse health effects would be low throughout the LAA/RAA from short-term and long-term exposure to $PM_{2.5}$.

For DPM, the health-based guideline that was exceeded was related to short-term exposure (2 hour) for a guideline protective of non-cancer effects. The spatial extent of concentrations greater than the 2-hour non-cancer guideline was very limited and located near the hydrogen / ammonia plant property boundary, in an area where people are unlikely to linger for an appreciable length of time. The chronic non-cancer health-based guideline was not exceeded in the LAA/RAA. Therefore, non-cancer risk from exposure to DPM from the Project was considered to be acceptable. For carcinogenic risks of exposure to DPM, a qualitative assessment was completed. This evaluation determined that long-term exposure to DPM at concentrations less than the chronic non-cancer guideline provided by Health Canada (2016d) may be related to an increased cancer risk and the level of exposure that would be associated with an acceptable incremental lifetime cancer risk is not known There were several conservative assumptions made during the air dispersion modelling, and as such, the actual exposure concentrations are not expected to be as high as predicted. In light of the uncertainty, monitoring and adaptive management of fine particulate (which includes DPM) is considered appropriate. The AQMP will measure $PM_{2.5}$ during operations and will specify the mitigation measures for the management and reduction of air emissions during Project operation. Ambient air monitoring will be implemented in conjunction with emissions mitigation to provide an understanding of the offsite $PM_{2.5}$ concentrations, and to evaluate the need for more rigorous mitigation.

For NH_3, ERs were compared to a target value of 0.2 in the absence of baseline data and the ERs for 1 hour and 24-hour NH_3 were greater than 0.2 for the maximum predicted ground level concentration but less than 0.2 at the maximum residential location. However, NH_3 is a short-lived pollutant and as such, it normally doesn't travel far from its source. As there are no known sources of NH_3 near the Project area, it is reasonable to assume that it is negligible in baseline. Therefore, given that the ERs for 1 hour and 24-hour NH_3 do not exceed 1.0, it is concluded that exposure for residents and recreational users in the LAA/RAA will remain below the applicable health-based guidelines and risks to human health from NH_3 will be negligible.

It is expected that the AQMP will measure NO_2 during operations and will specify the mitigation measures for the management and reduction of air emissions during Project operation. Ambient air monitoring will be implemented in conjunction with emissions mitigation to provide an understanding of the offsite NO_2 concentrations, and to evaluate the need for more rigorous mitigation. Additional details are provided in EIS Chapter 6 (Atmospheric Environment). The AQMP typically relies on provincial or federal ambient air quality standards; however, because the NLAAQS are not based solely on health effects, it may be more appropriate to compare air monitoring results to health-based exposure limits at residential areas.

Finally, it is acknowledged that concurrent exposure to the mixture of COPCs predicted to occur in ambient air is a potential source of uncertainty, and some health risks may be present at concentrations lower than the applicable TRVs or health-based exposure limits for non-carcinogenic non-threshold contaminants (NO_2, SO_2, $PM_{2.5}$) and for carcinogenic endpoints associated with DPM. Therefore, planned monitoring and mitigation efforts during all phases of the Project remain valuable to limit exposure and potential for risks. In particular, the results of this HHRA suggest that targeted monitoring for NO_2 and DPM in the residential areas of the LAA/RAA may be necessary to support adaptive management.

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