Figure 9-37: Location of Receptors

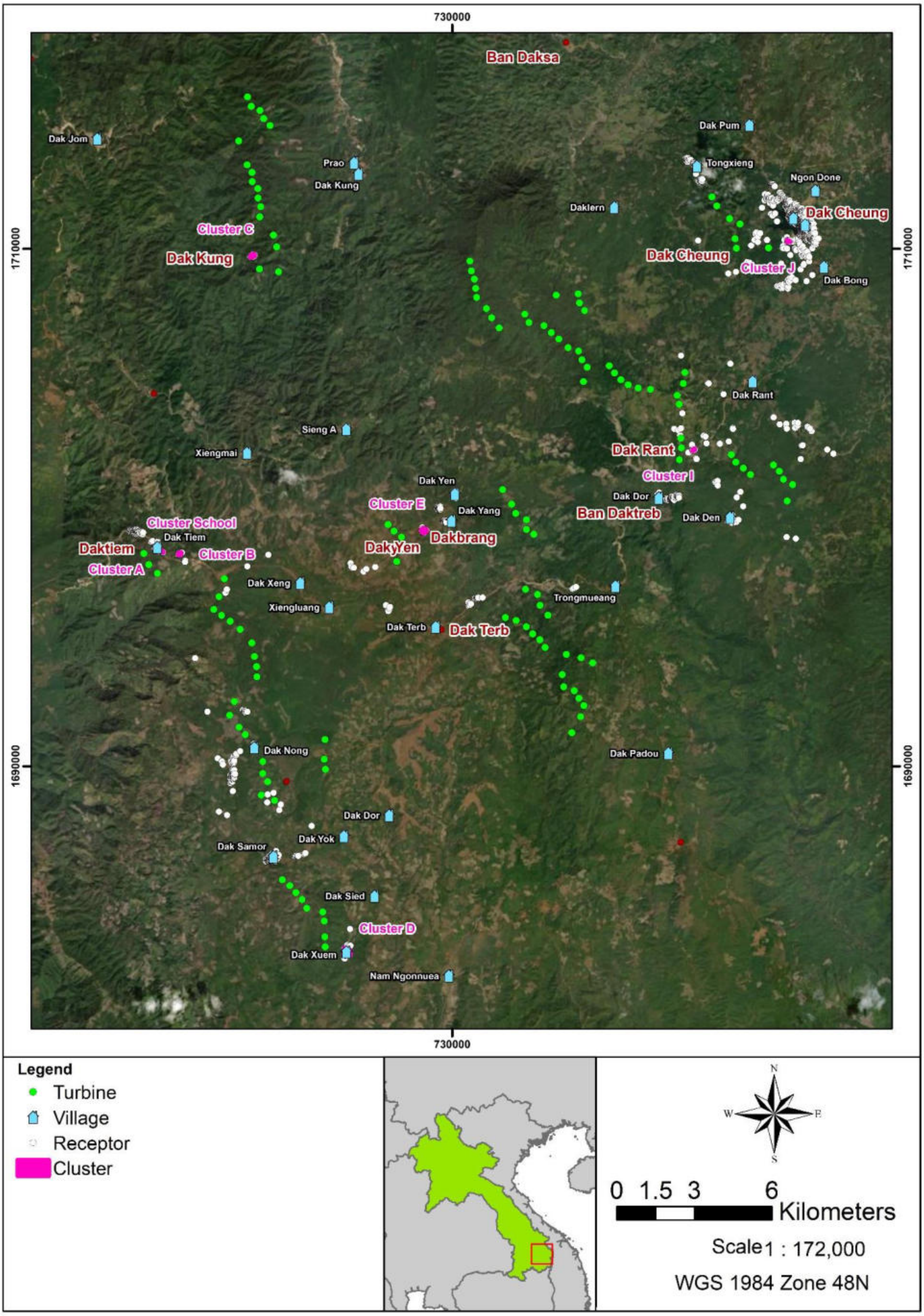


Figure 9-38: Photos of Forests Surrounding Receptors

Shadow Flicker Analysis and Results

WindPro Model: Scenarios and Input Criteria

This assessment has been undertaken using the WindPro 3.5©; a computer package widely used in the wind industry. The software package includes a Shadow Flicker Module (SHADOW) that calculates how often and the intervals in which a specific neighbor or area will be affected by one or more wind turbines.

As reported in the introduction, two main scenarios have been modelled: Worst Case Scenario and Real Case Scenario.

Within the Worst Case Scenario, the calculations are based on conditions that would provide the maximum amount of shadow flicker with no parameters characterizing the local settings and conditions, as well as project specific characteristics, such as:

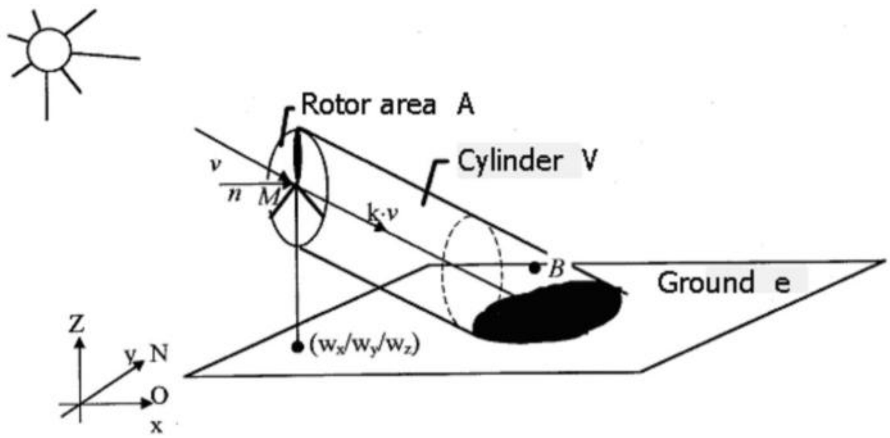
- The presence of physical barriers is not considered;
- Natural vegetation screening is not included;
- Cloud cover, and humidity is not included;
- The sun is shining all the day, from sunrise to sunset;
- Rotor is not turned off for low winds or high winds; and
- Shadow receptors are modelled using the greenhouse mode, meaning that each receptor will face all directions (360 degree visibility).

Within the Real Case Scenario, calculations are based on a more realistic situation where the sun shining probability is based on real datasets. However, it should be stated that such modelling assumptions are not taking into consideration other parameters characterizing the local settings (e.g., wind speed or monsoons) and in any case may lead to an overestimation of the shadow flickering occurrence.

All scenarios have been carried out with a temporal resolution of 1 minute, meaning if shadow flicker is predicted to occur in any 1-minute period, the model records this as 1 minute of shadow flicker.

Independent of the selected scenario, the model calculates outputs according to the principles presented in ***Figure 9-39***.

Figure 9-39: Shadow flickering theory



Source: WindPro user manual

All dwellings/group of dwellings on site have been modelled taking into consideration the following:

- Single story buildings, and so shadow flicker has been calculated at a height of 1 m (equivalent to the first floor windows);
- Slope of the window has been set to 90°; and
- The identified receptors are simulated as fixed points with the possibility to view 360°C, representing an unrealistic scenario, as real windows would be facing only a particular direction.

Worst Case Scenario

The following assumptions have been considered in the modelling setting for Worst Case Scenario:

- Rotors are always turning;
- Sun is always shining, all the day, from sunrise to sunset;
- Local topography has been obtained from digital terrain model (DTM)
- No cloud cover or any other meteorological conditions that could potentially reduce visibility and sunlight;
- Receptors modelled using greenhouse mode (the receptor is not facing one particular direction, but instead is facing all directions); and
- No physical barriers are considered.

Real Case by Statistics Scenario

The following assumptions have been considered in the modelling setting for Real Case Scenario:

- Data about the average daily sunshine hours presented in below (derived statistically for the site from ERA5 cloud cover data):

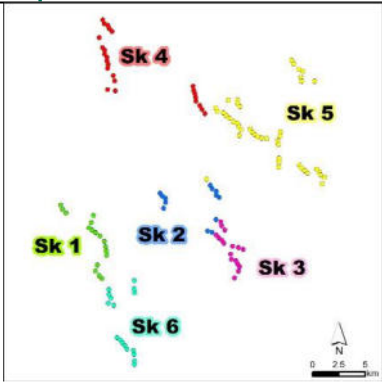
Sunshine probability S (Average daily sunshine hours) []

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4,98	7,98	6,98	2,79	2,56	1,24	2,13	0,53	1,41	0,47	3,63	2,78

- Local topography has been obtained from SRTM DTM;
- Estimation of indicative annual cloud coverage, no other meteorological conditions that could potentially reduce visibility and the sunlight have been assumed;
- Receptors modelled using greenhouse mode;
- No existing physical barriers have been considered such as forests; and
- Rotors are always turning; the site was divided into six areas and the operational hours for each sector depends on the area of the site in which the turbine is located (***Table 9-37***).

Table 9-37: Operational Hours by Dector for Every Site Areas

Map	Area	Operational time												
	Sk 1	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
		147	262	3.015	686	200	281	424	957	1.937	439	221	191	8.760
	Sk 2	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
		136	314	3.584	417	135	270	742	858	781	686	508	329	8.760
	Sk 3	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
		159	164	3.182	1.175	146	201	359	495	1.157	1.043	363	314	8.758
	Sk 4	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
		223	367	2.810	686	230	286	519	914	1.363	710	416	236	8.760
	Sk 5	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
		142	2.813	688	94	81	96	432	1.408	2.111	590	184	121	8.760

Map	Area	Operational time																
		N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum				
	Sk 6	159	1.110	2.432	258	166	416	1.314	1.190	614	437	403	260	8.759				

It should be noted that for the Real Case Scenario the shadow flickering assessment performed with such assumptions is still likely an over estimation in terms of the annual number of hours of flickering experienced at a specific location due to the following reasons:

- The occurrence of cloud cover has the potential to significantly reduce the number of hours during which the observer is experiencing the flickering;
- The presence of fog and high humidity can reduce the visibility and consequently reduce the effects of flickering on the observer;
- The presence of aerosols in the atmosphere have the ability to influence the flickering duration, as the length of the shadow cast by a wind turbine is dependent on the degree that direct sunlight is diffused, which is strictly dependent on the amount of dispersant in between the observer and the rotor; and
- The analysis has not considered the presence of vegetation or other physical barriers around a receptor that are able to shield the view (at least partially) of the turbine.

Table 9-38 outlines the modeling settings adopted for each scenario.

Table 9-38: WindPro Shadow Module Inputs (The Key Differences Between the Scenarios are in Bold)

Inputs	Worst Case Scenario	Real Case Scenario
Rotor diameter and hub height	171m / 110m	171m / 110m
Wind turbine operation	Rotors are always turning	Rotors are always turning
Wind turbine visibility	A WTG will be visible if it is visible from any part of the receiver window (greenhouse mode)	A WTG will be visible if it is visible from any part of the receiver window (greenhouse mode)
Window stories dimensions	1m height / 1 m large / 1 m from the first floor	1 m height / 1 m large / 1 m from the first floor
Cloud cover	Not considered	ERA5 cloud cover data
Physical barriers (i.e., vegetation)	Not considered	Not considered
Minimum sun height over horizon for influence	3°	3°
Day step for calculation	1 day	1 day
Time step for calculation	1 minute	1 minute

Inputs	Worst Case Scenario	Real Case Scenario
Shining period	**The sun is always shining all day, from sunrise to sunset**	**The sun is shining as per local sunshine data provided**
Height contour	SRTM DTM	SRTM DTM
Eye height	1.5 m	1.5 m

Model Results

As presented above, two scenarios have been modelled using Shadow Flickering WindPro Module to identify the receptors potentially affected by the flickering. The project area is characterized by the presence of different dwellings/group of dwellings, mainly in the Dak Cheung Village.

The following sections outline the number of potentially affected receptors for each scenario.

1. Worst Case Scenario – Results

As reported above, the modelling package calculates the predicted shadow flickering durations at receptors. The Worst Case Scenario has considered a fully worst case scenario with unrealistic conditions leading to a potential of 488 impacted receptors (both for hours/year and minutes/day) among the 2,513 mapped receptors. For these, IFC thresholds have been exceeded for both parameters: hours/year and minutes/day.

The following maps present the distribution of areas where flickering is calculated according to the Worst Case Scenario (***Figure 9-40*** and ***Figure 9-41***). For further detailed modeling results, refer to ***Appendix V.***

Figure 9-40: Map of Predicted Shadow Flicker (hours/year) – Worst Case Scenario

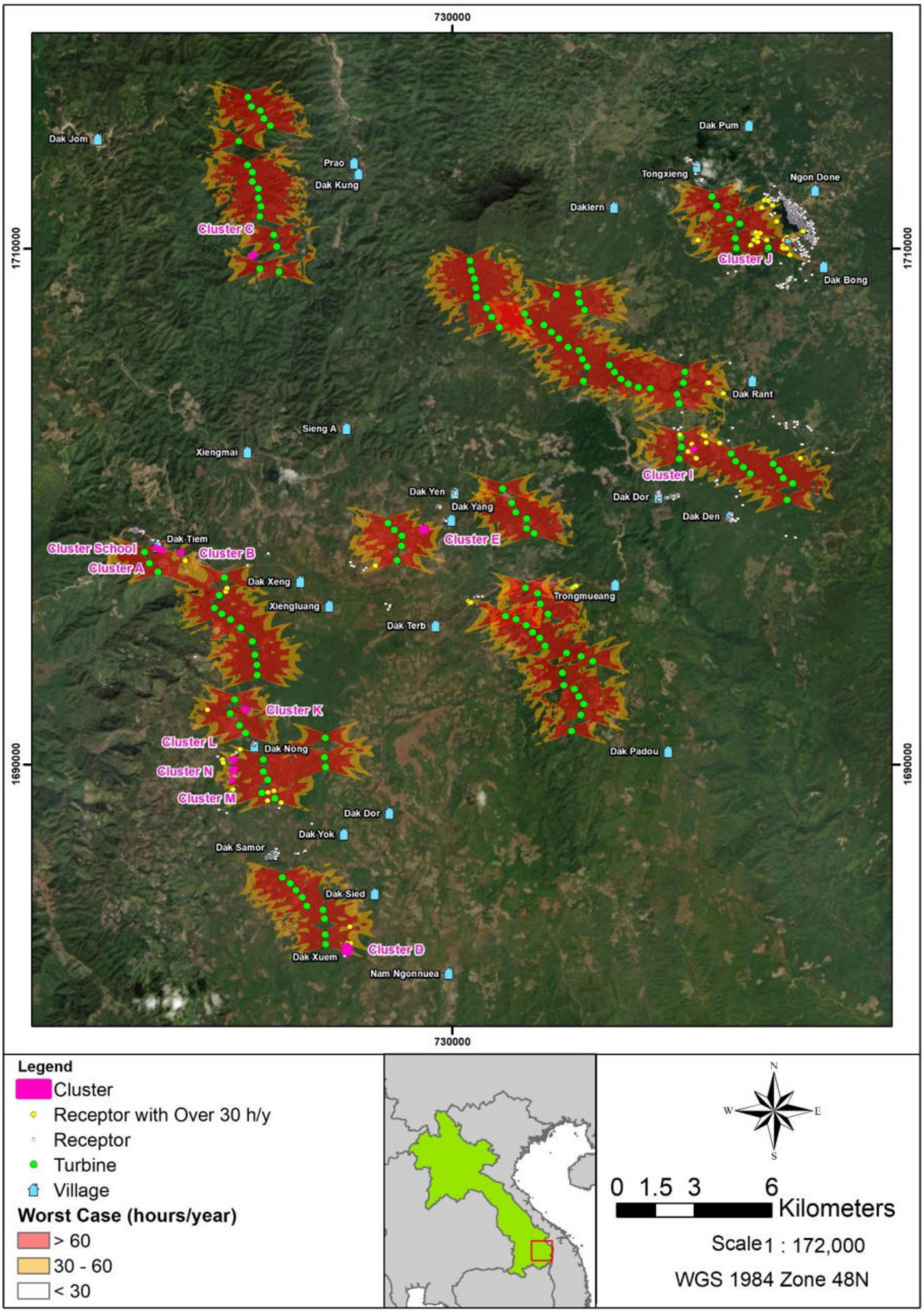
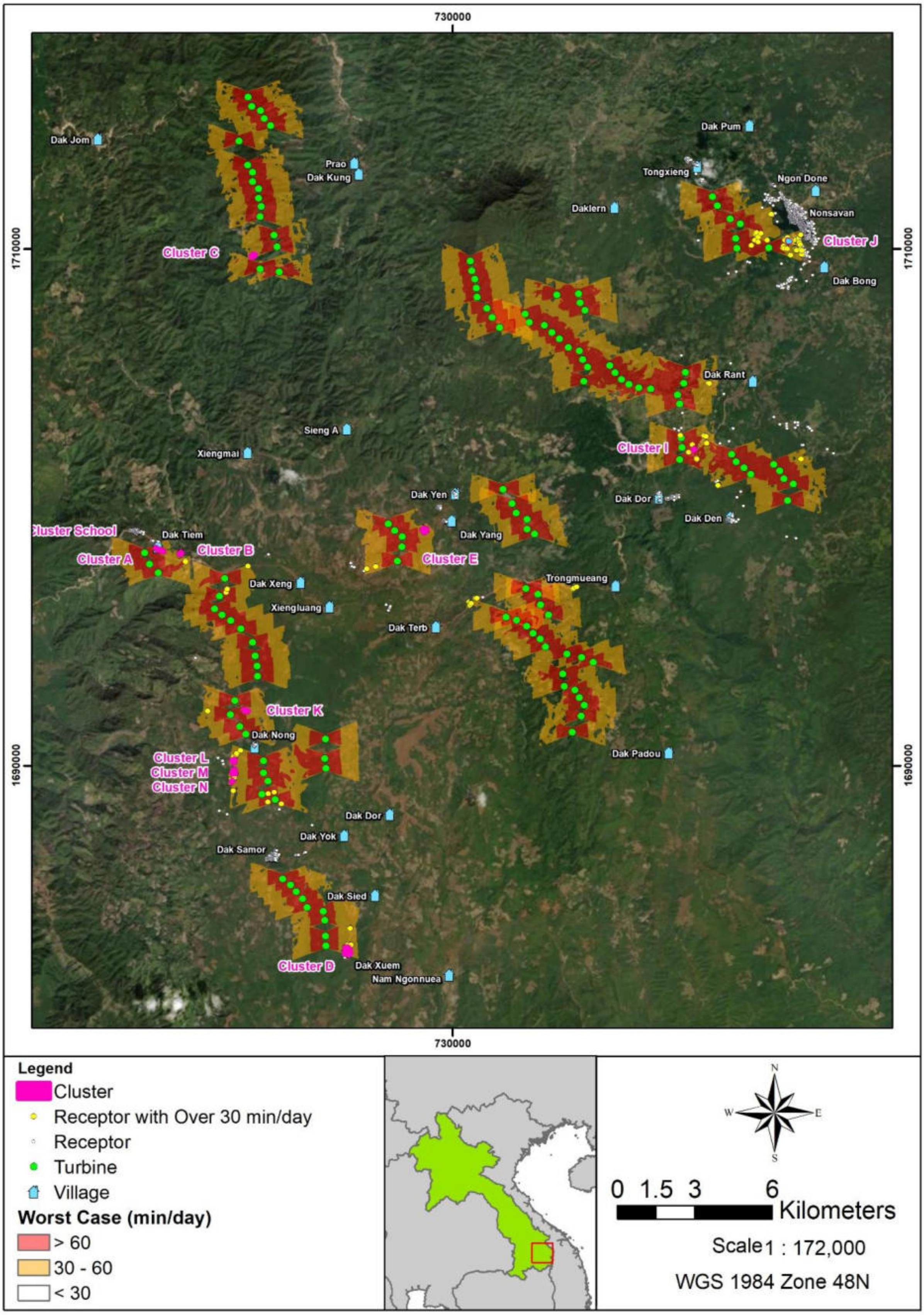


Figure 9-41: Map of Predicted Shadow Flicker (min/day) – Worst Case Scenario



2. Real Case by Statistics Results – Real Case Scenario

Following the results of the Worst Case Scenario presented in the previous section, a second scenario was calculated in order to assess the effect raised by the inclusion of more local conditions (the average daily sunshine hours and wind direction) on the 484 receptors that exceeded the threshold defined by the World Bank EHS for shadow flicker issues.

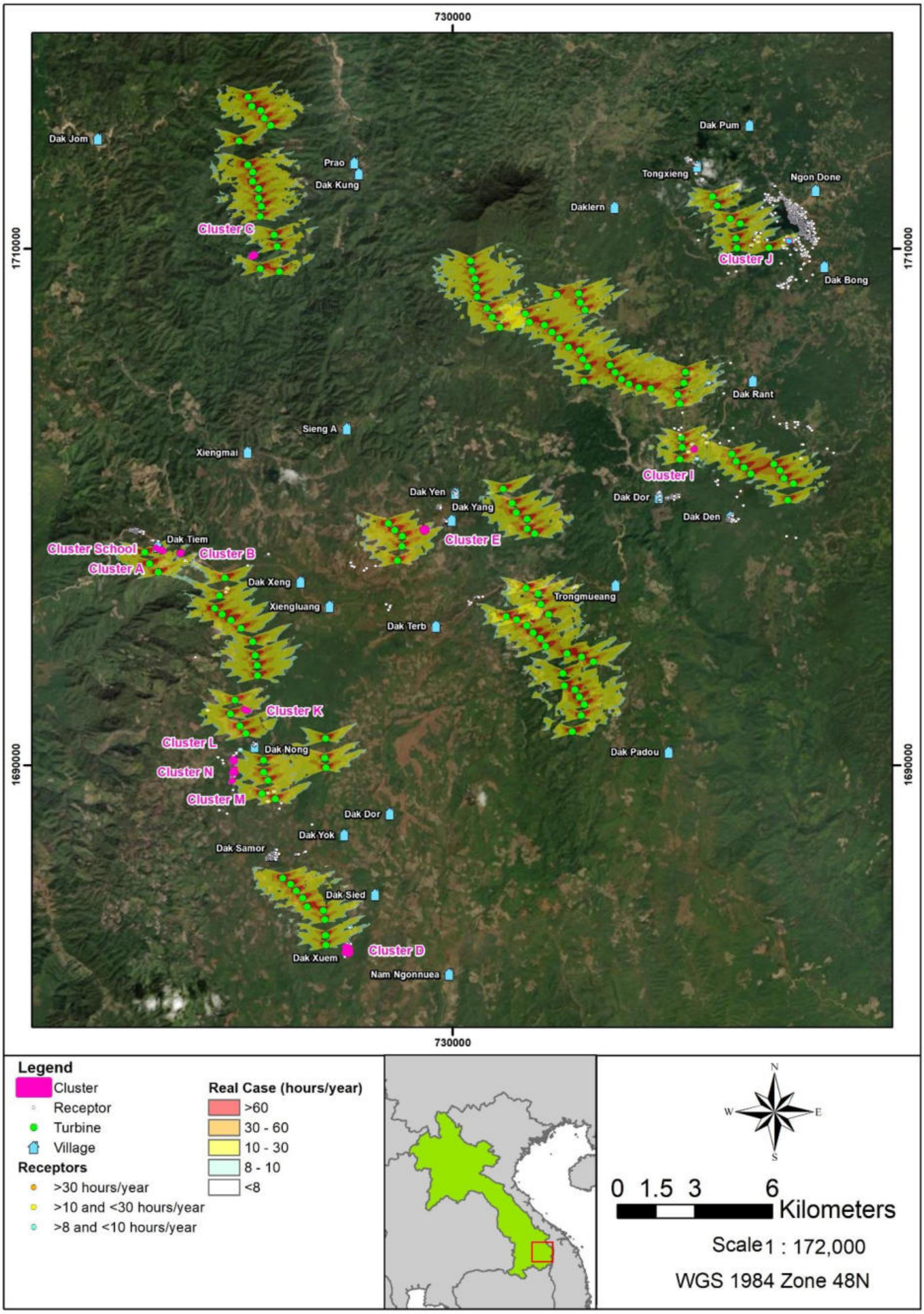
There are no international guidelines on standards to be followed internationally for the Real Case Scenario, and we decided to take into consideration the most conservative standards that place the annual limits at 8 or 10 hours.

Based on the annual limit of 8 or 10 hours the Real Case Scenario leads to a potential of 267 impacted receptors (see ***Appendix V*** for more detailed results), with:

- 72 impacted receptors experiencing between 8-10 hours/year;
- 170 impacted receptors experiencing between 10-30 hours/year; and
- 17 impacted receptors more than 30 hours/year.

The predicted shadow flicker durations at receptors are presented in ***Figure 9-42.***

Figure 9-42: Map of predicted shadow flicker (hours/year) – Real Case Scenario



9.3.8.2 Potential Impacts

The association between shadow flicker caused by wind turbines and the effect on human health is highly debated.

Some studies suggest that flicker from turbines pose a potential risk of inducing photosensitive seizures (Harding et al, 2008; Smedley et al., 2010).

However, in 2011, the UK Department of Energy and Climate Change concluded in their Update Shadow Flicker Evidence Base report that "*On health effects and nuisance of the shadow flicker effect, it is considered that the frequency of the flickering caused by the wind turbine rotation is such that it should not cause a significant risk to health."*

Despite such conclusions, other reports state that although shadow flicker from wind turbines is unlikely to lead to a risk of photo-induced epilepsy, the potential for annoyance and disturbance are still present, leading to stress (Cope et al., 2009; Minnesota Department of Health, 2009; National Research Council, 2007).

9.3.8.3 Existing Controls

There are no existing controls.

9.3.8.4 Significance of Impacts

Methodology for Assessment of Impact Significance

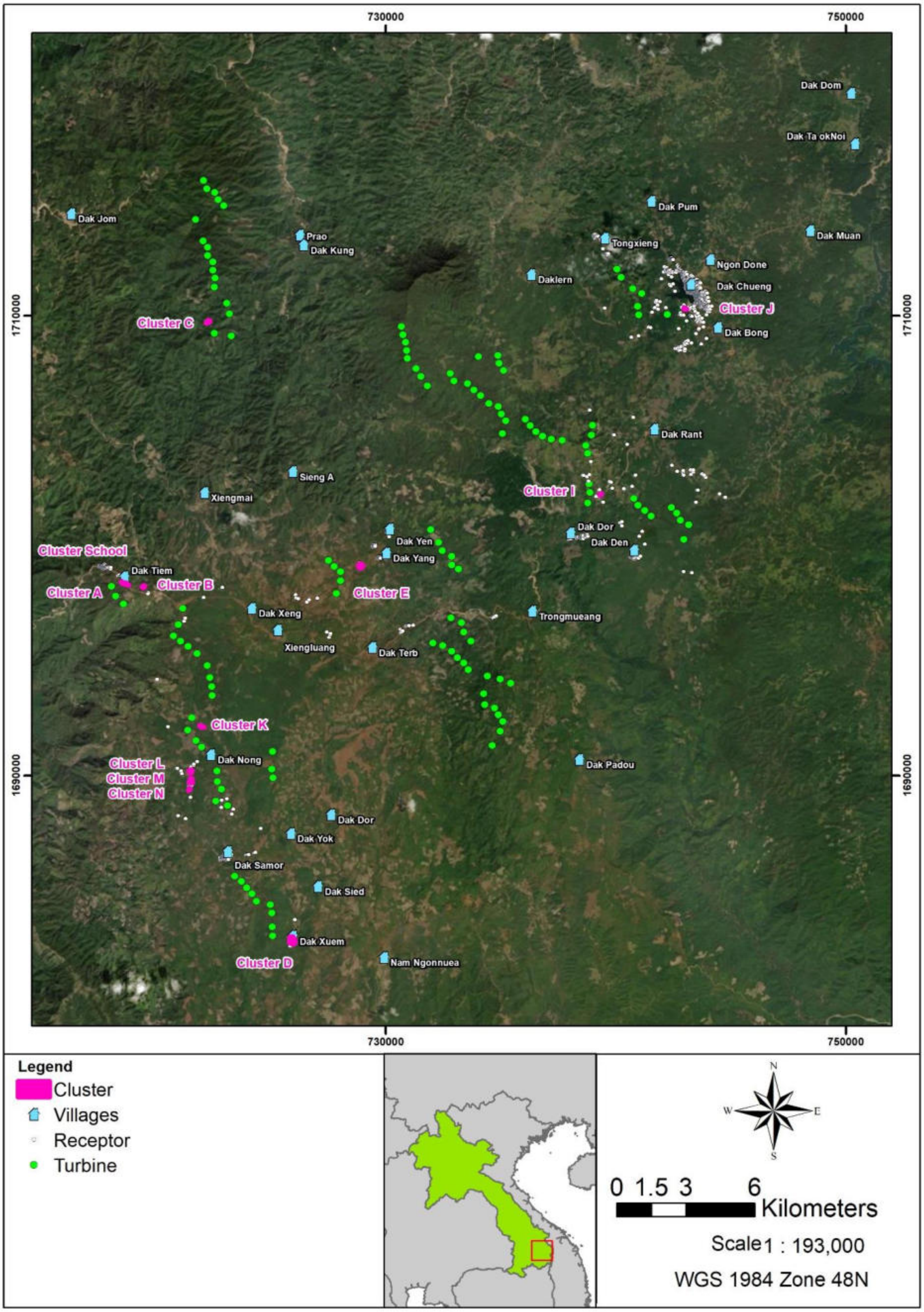
The Impact Assessment Methodology is a quantitative methodology, generated through a spreadsheet provided by a model, and backed up by professional judgement in the application of the criteria.

The shadow flickering assessment has taken into consideration two scenarios: a worst case scenario and a more realistic one embedding local meteorological conditions. In both scenarios, many receptors are considered to be potentially impacted by shadow flickering above international guidance levels.

Shadow flicker impacts are negative, direct and long-term during the operation phase of the Project. The impact scale is within 1,300 m of the WTGs on the receptors in the north-northwest of the WTGs. Impact magnitude varies based on the distance of receptors from the WTGs and their orientation.

Based on the modelling results, it should be noted that the shadow flickering occurrence is limited to 12 clusters of potentially affected receptors (***Figure 9-43***).

Figure 9-43: Cluster Locations



Some general considerations are provided, based on the outcomes of the field photo survey, that can prevent/reduce shadow flickering once the Project is in operation:

- A majority of receptors were observed to have no windows facing the shadow direction of the turbines.
- Most of the typical houses are equipped with awnings.
- There are existing natural barriers (i.e., forest, vegetation patches) surrounding the receptors.

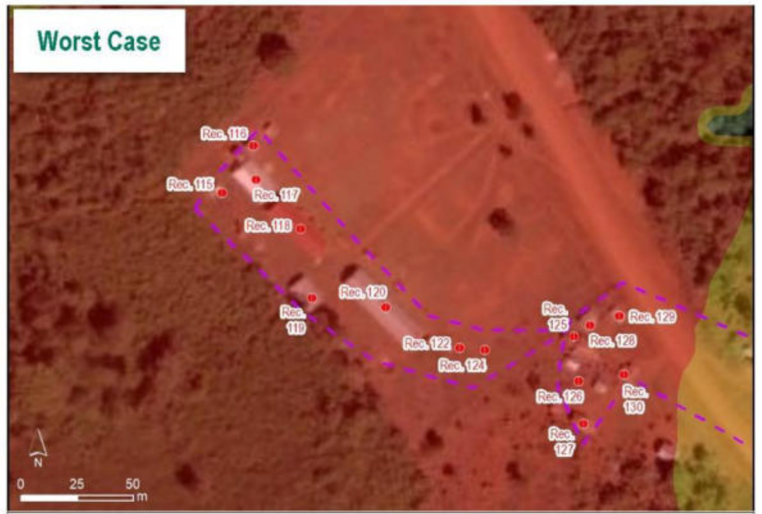
As outlined above, the real case is still affected by conservative results. Specific considerations were made within each cluster, and the results can be viewed in the graphic sheets presented below.

The graphic sheets are organized as presented in ***Figure 9-44***:

1. Cluster location;
2. Cluster name;
3. Distance and positioning of the turbine with respect to the cluster on which it impacts;
4. Turbine calendar telling when (hours, days and months) the flickering problems may occur (worst case);
5. Worst case cluster map;
6. Real case cluster map;
7. Assumptions;
8. Considerations;
9. Photos of some receptors of the cluster.

Figure 9-44: Legend of Cluster Graphic Sheets

Figure 9-45: Shadow Flicker Results – Cluster: School

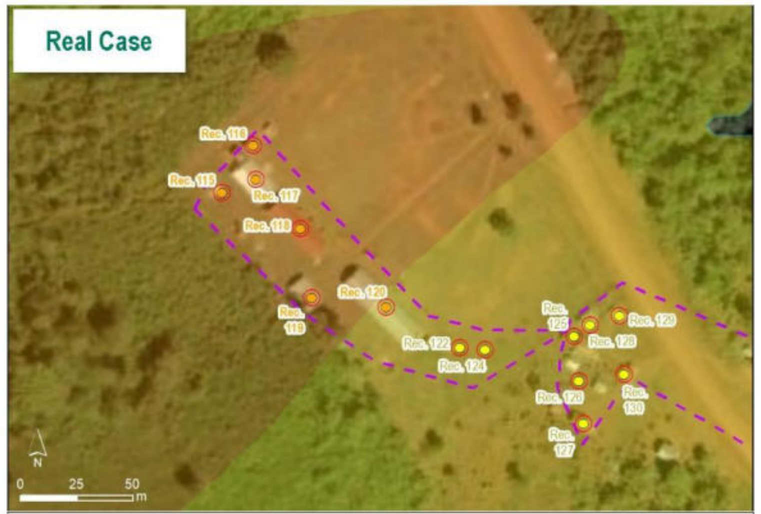


Worst Case - receptors

- Over 30 hours/year and minutes/day
- Over 30 hours/year
- Over 30 minutes/day
- Below 30 hours/year and minutes/day

Worst Case (hours/year)

- > 60
- 30 - 60
- < 30



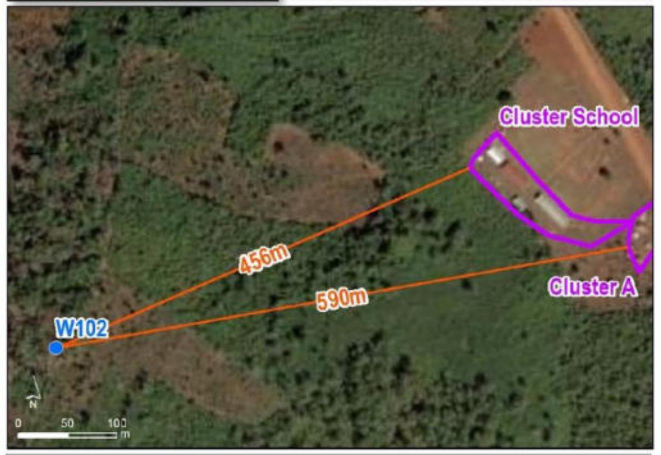
Real case - receptor

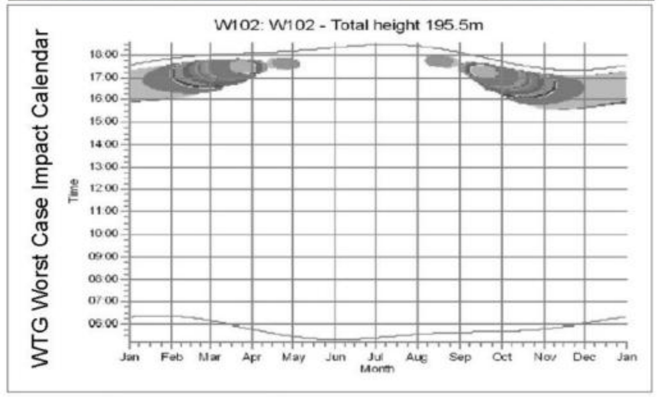
- >30 hours/year
- >10 and <30 hours/year
- >8 and <10 hours/year
- >30 hours/year and 30 min/day in Worst Case
- <8 hours/year

Real Case (hours/year)

- >30
- 10 - 30
- 8 - 10
- <8

Cluster School





Assumptions:

⇒ Shadow receptors are modelled using the greenhouse mode (*each receptor will face all directions)*

⇒ Natural vegetation screening or presence of physical barriers is not considered *(e.g. the nearby building)*

⇒ Rotor is not turning off for low winds or high winds *(e.g. Monsoon period)*

so the results value are very conservative and can be seen as a worst-case scenario.

Considerations:

The potential impact will occur in a limited time frame from 4:00 pm to 6:00 pm from September through mid-April

The receptors were observed to have windows facing the shadow direction of the turbines, but there were also existing natural barriers observed in the form of trees covering the receptor group area, which may reduce the impact.

Rec. 117

Rec. 118

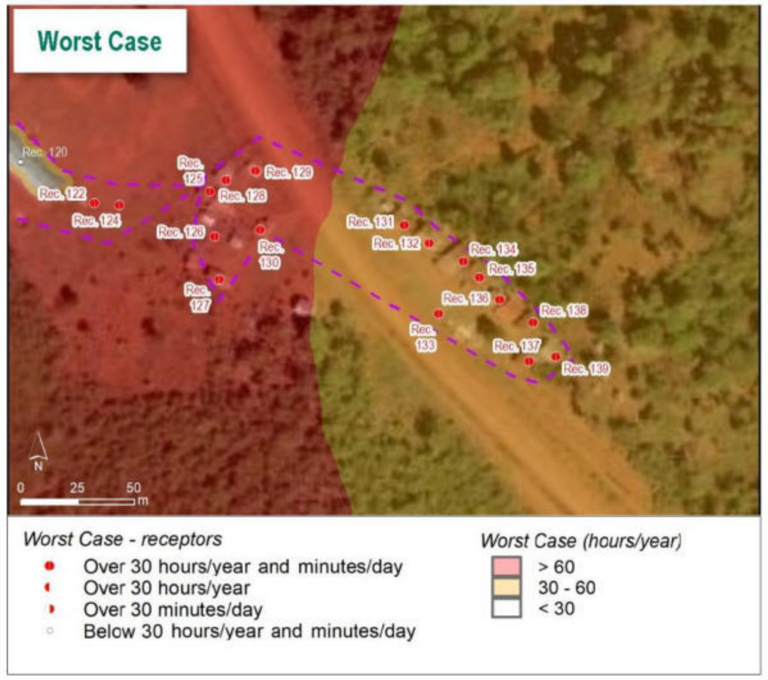
Rec. 119

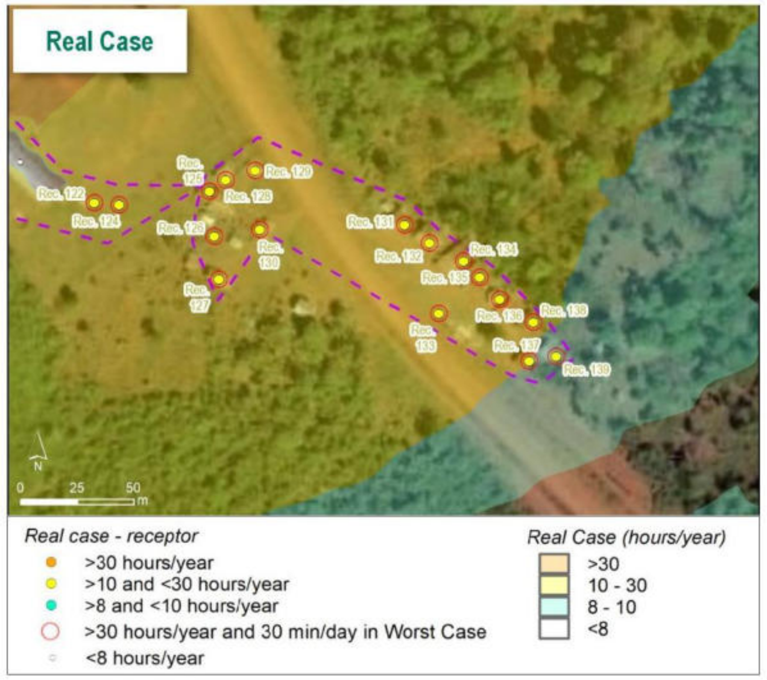
Rec. 120

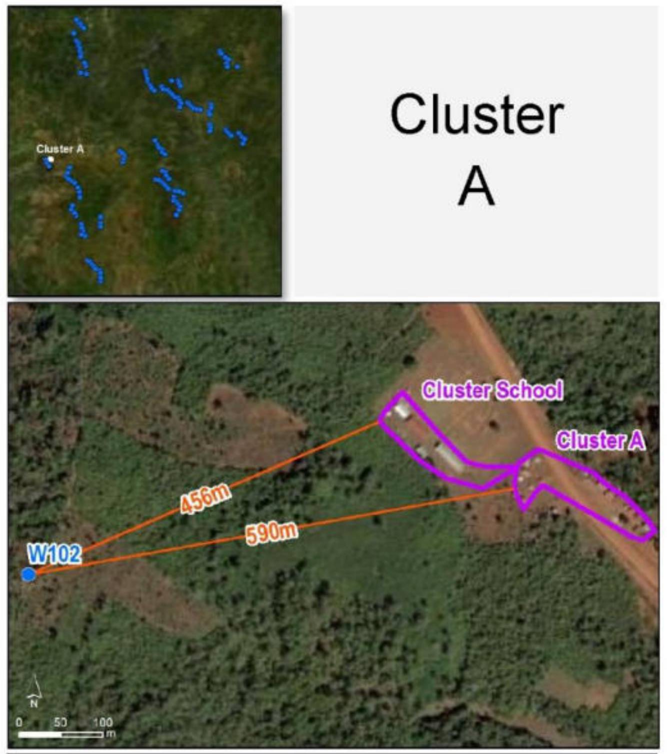
Environmental and Social Impact Assessment – Shadow Flicker Component

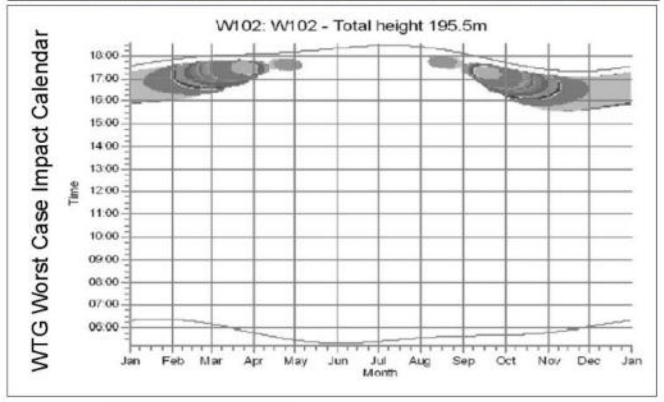
ERM

Figure 9-46: Shadow Flicker Results – Cluster: A









Assumptions:

⇒ Shadow receptors are modelled using the greenhouse mode (*each receptor will face all directions)*

⇒ Natural vegetation screening or presence of physical barriers is not considered *(e.g. the nearby building)*

⇒ Rotor is not turning off for low winds or high winds *(e.g. Monsoon period)*

so the results value are very conservative and can be seen as a worst-case scenario.

Considerations:

The potential impact will occur in a limited time frame from 4:00 pm to 6:00 pm from September through mid-April

Some of the receptors observed not to have windows facing the shadow direction of the turbines (e.g. photo 3).

Even if the houses is observed to have windows, the shadow flicker impact should not be a concern for the house is equipped with awning or a sloping roof sheltering (e.g. rec 127)

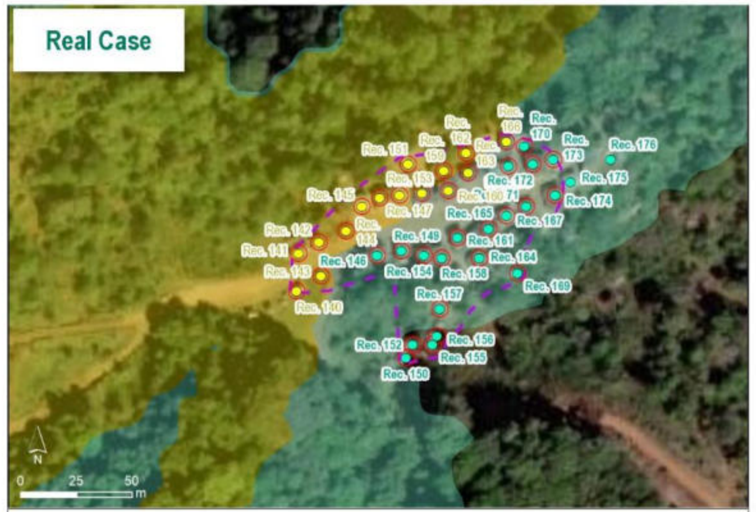
ddd

Environmental and Social Impact Assessment – Shadow Flicker Component

Figure 9-47: Shadow Flicker Results – Cluster: B

Worst Case - receptors
- Over 30 hours/year and minutes/day
- Over 30 hours/year
- Over 30 minutes/day
- Below 30 hours/year and minutes/day

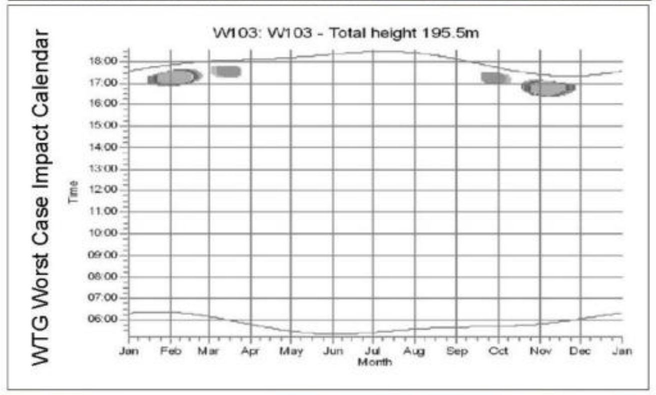
Worst Case (hours/year)
- > 60
- 30 - 60
- < 30



Real case - receptor
- >30 hours/year
- >10 and <30 hours/year
- >8 and <10 hours/year
- >30 hours/year and 30 min/day in Worst Case
- <8 hours/year

Real Case (hours/year)
- >30
- 10 - 30
- 8 - 10
- <8

Cluster
B



Assumptions:

⇒ Shadow receptors are modelled using the greenhouse mode *(each receptor will face all directions)*

⇒ Natural vegetation screening or presence of physical barriers is not considered *(e.g. the nearby building)*

⇒ Rotor is not turning off for low winds or high winds *(e.g. Monsoon period)*

so the results value are very conservative and can be seen as a worst-case scenario.

Considerations:

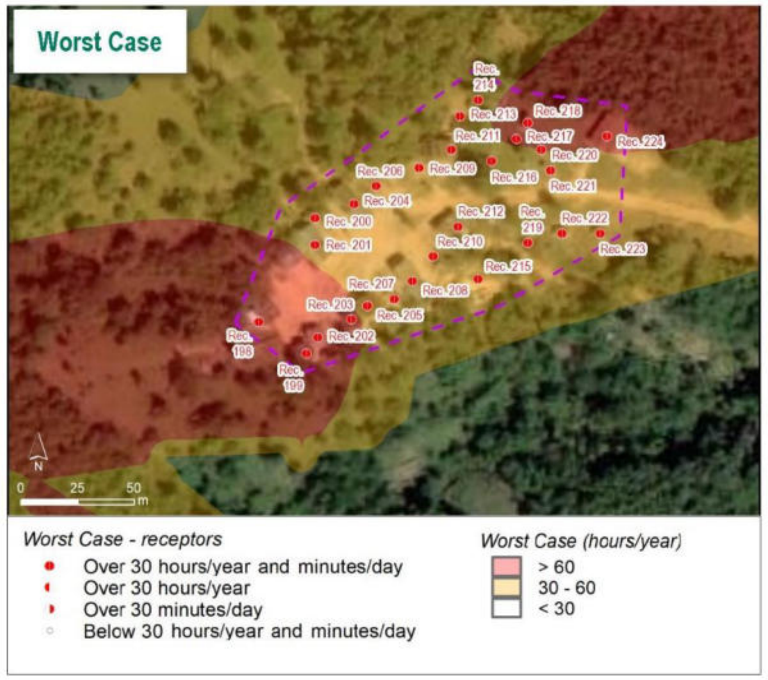
The potential impact will occur in a limited time frame from 4:30 pm to 6:30 pm in January, February, March, October and November

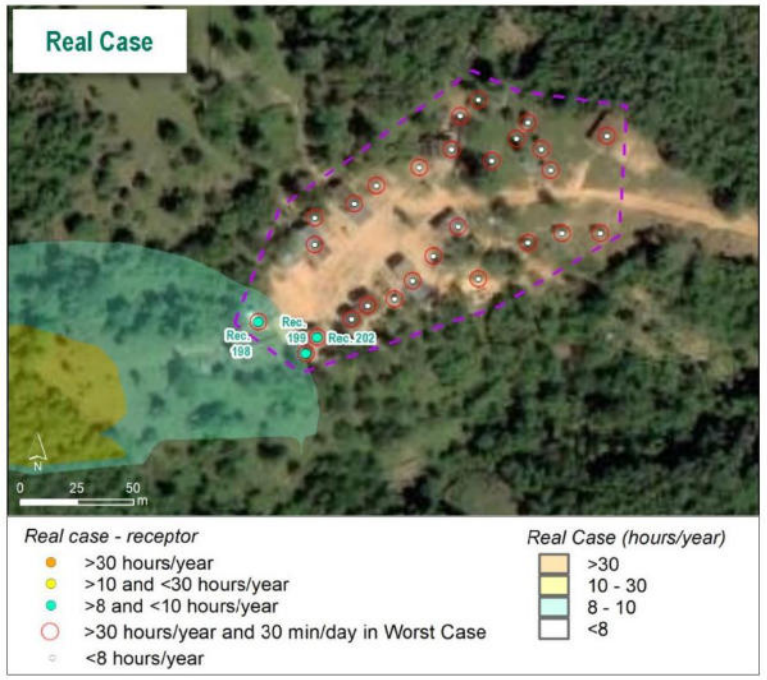
There were many natural barriers in the form of trees covering the receptors group area which is considered to be able to reduce the impact.

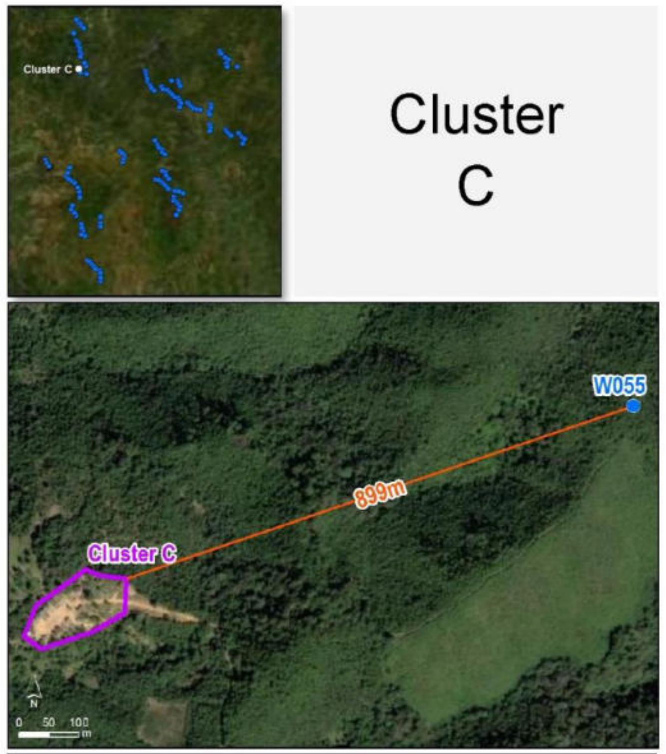
Even if the houses is observed to have windows, the shadow flicker impact should not be a concern for the house is equipped with awning or a sloping roof sheltering

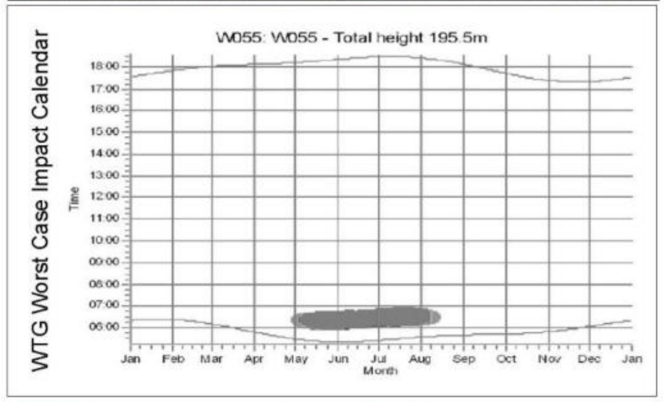
Environmental and Social Impact Assessment – Shadow Flicker Component ERM

Figure 9-48: Shadow Flicker Results – Cluster: C









Assumptions:

⇒ Shadow receptors are modelled using the greenhouse mode (*each receptor will face all directions)*

⇒ Natural vegetation screening or presence of physical barriers is not considered *(e.g. the nearby building)*

⇒ Rotor is not turning off for low winds or high winds *(e.g. Monsoon period)*

so the results value are very conservative and can be seen as a worst-case scenario.

Considerations:

The potential impact will occur in a limited time frame from 6:00 am to 7:00 am from May through mid-August

There were many natural barriers in the form of trees covering the receptors group area which is considered to be able to reduce the impact.

Even if the houses is observed to have windows, the shadow flicker impact should not be a concern for the house is equipped with awning or a sloping roof sheltering

Environmental and Social Impact Assessment – Shadow Flicker Component