# Taroborah Coal Project

## Appendix 16 –

Greenhouse Gas Assessment

Adaptation to Climate Change and Variability Assessment

# Greenhouse Gas Assessment for the Taroborah Coal Project

Prepared for

**AARC**

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**Final**

Prepared by

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## Glossary

| Term | Definition |
|---|---|
| **Units of measurement** | |
| % | Percentage |
| GJ | Gigajoule |
| PJ | Petajoule |
| TJ | Terajoule |
| kg | Kilogram |
| kL | Kilolitre |
| ML | Megalitre |
| MWh | Megawatt hour |
| Mt | Million tonnes |
| Mtpa | Million tonnes per annum |
| t | tonne |
| tpa | tonnes per annum |
| $tCO_2$-e | tonnes of $CO_2$ equivalent |
| $W/m^2$ | Watts per square metre |
| h/day | Hours per day |
| d/year | Days per year |
| **Air pollutants and chemical nomenclature** | |
| $CH_4$ | Methane |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| HFCs | Hydrofluorocarbons |
| $H_2O$ | Water vapour |
| $N_2O$ | Nitrous oxide |
| NMVOCs | Non-methane volatile organic compounds |
| PFCs | Perfluorocarbons |
| **Other abbreviations** | |
| AARC | AustralAsian Resource Consultants |
| ACCUs | Australian Carbon Credit Units |
| ANFO | Ammonium Nitrate Fuel Oil |
| DCC | Department of Climate Change |
| DCCEE | Commonwealth Department of Climate Change and Energy Efficiency |
| EEO | Energy Efficiency Opportunities |
| GWP | Global warming potential |
| LULUCF | Land Use, Land Use Change and Forestry |
| NGA | National Greenhouse Accounts |
| NGER | National Greenhouse and Energy Reporting Act 2007 |
| ROM | Run of mine |
| Shenhuo | Shenhuo International Group Pty Ltd |
| ToR | Terms of Reference |
| UNFCCC | United Nations Framework Convention on Climate Change |

# Executive Summary

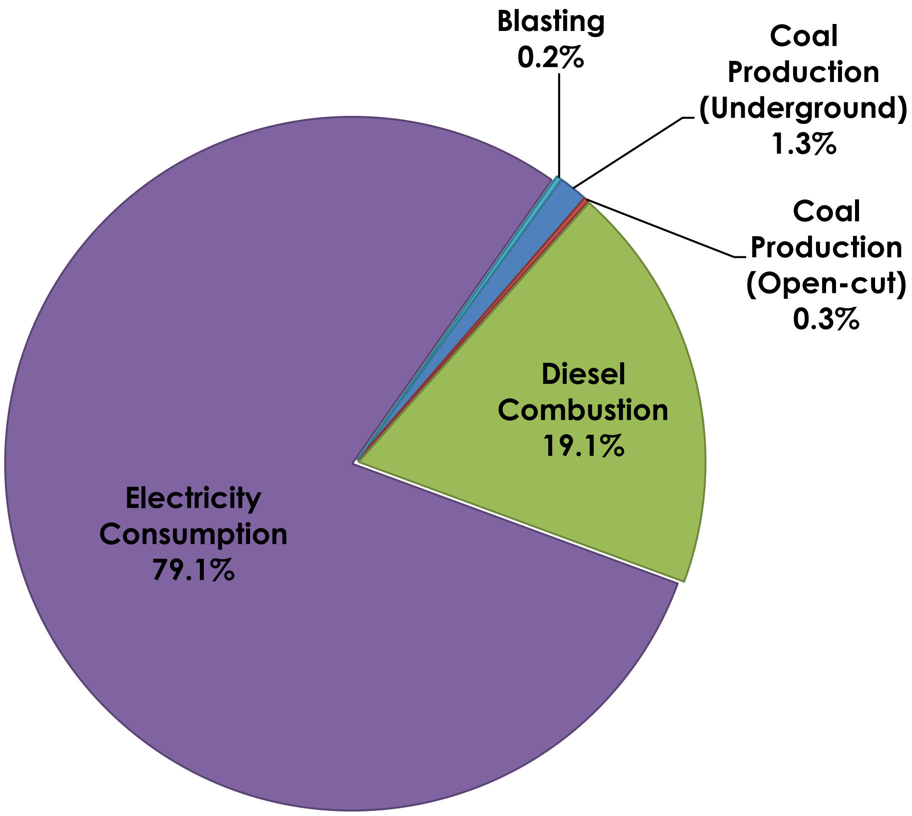
*Katestone was commissioned by AARC, on behalf of Shenhuo, to conduct a greenhouse gas assessment for the Taroborah Coal Project (the Project), suitable for inclusion in an EIS and application for Environmental Approval.*

*The Project consists of a combination of an underground and open-cut mine producing up to 5.75 Mtpa of ROM coal. The Project tenure is MDL467, which is located approximately 22 km west of Emerald and encompasses an area of approximately 7,966 hectares.*

*On an annual basis, greenhouse gas emissions for the Project peak at 92 kt$CO_2$-e during the sixth year of operation, coinciding with the parallel extraction of coal from both open-cut and underground mining operations. The lowest annual greenhouse gas emissions associated with the Project have been estimated to be 23 kt$CO_2$-e. Table 1 provides a summary of the annual emissions from the facility.*

**Table 1 Summary of annual greenhouse gas emissions (t $CO_2$-e)**

| Operational Year | Scope 1 | Scope 2 | Total attributable emissions (Scope 1 & 2) |
|---|---|---|---|
| 1 | 16,087 | 10,108 | 26,195 |
| 2 | 37,865 | 20,216 | 58,081 |
| 3 | 38,472 | 20,216 | 58,689 |
| 4 | 44,999 | 20,216 | 65,215 |
| 5 | 44,638 | 24,964 | 69,603 |
| 6 | 50,234 | 41,920 | 92,154 |
| 7 | 25,470 | 51,231 | 76,701 |
| 8 | 4,973 | 70,192 | 75,166 |
| 9 | 5,015 | 70,192 | 75,207 |
| 10 | 5,028 | 70,192 | 75,221 |
| 11 | 5,036 | 74,818 | 79,853 |
| 12 | 5,015 | 79,443 | 84,458 |
| 13 | 5,200 | 79,443 | 84,643 |
| 14 | 4,770 | 79,443 | 84,213 |
| 15 | 4,900 | 80,599 | 85,500 |
| 16 | 4,555 | 80,599 | 85,154 |
| 17 | 4,168 | 79,956 | 84,123 |
| 18 | 3,998 | 79,956 | 83,954 |
| 19 | 3,978 | 79,956 | 83,934 |
| 20 | 3,924 | 74,687 | 78,610 |
| 21 | 824 | 22,406 | 23,230 |
| Max | 50,234 | 80,599 | 92,154 |
| **Total** | **319,149** | **1,210,756** | **1,529,904** |




*The facility is estimated to trigger the threshold for NGER reporting in its first year of operation and will have an ongoing obligation to estimate and report greenhouse gas emissions under the NGER Act. Energy usage at the site will also require Shenhuo to register the Project for participation in EEO.*

# 1. Introduction

Katestone Environmental Pty Ltd (Katestone) was commissioned by AustralAsian Resource Consultants (AARC), on behalf of Shenhuo International Group Pty Ltd (Shenhuo), to conduct a greenhouse gas assessment for the Taroborah Coal Project (the Project), suitable for inclusion in an EIS and application for Environmental Approval.

The Project consists of a combination of an underground and open-cut mine producing up to 5.75 Mtpa of ROM coal. The Project tenure is MDL467, which is located approximately 22 km west of Emerald and encompasses an area of approximately 7,966 hectares.

This report has been prepared to address the Terms of Reference (ToR) (Queensland Government) for the Taroborah Coal Project. The relevant components of the Project ToR are:

*Assess the potential impacts of the project on the state and national greenhouse gas inventories and propose greenhouse gas abatement measures, including:*

- *a description of the proposed measures (alternatives and preferred) to avoid and/or minimise greenhouse emissions directly resulting from activities of the project, including such activities as transportation of products and consumables, and energy use by the project*
- *an assessment of how the preferred measures minimise emissions and achieve energy efficiency*
- *a comparison of the preferred measures for emission controls and energy consumption with best practice environmental management in the relevant sector of the industry*
- *a description of any opportunities for further offsetting greenhouse gas emissions through indirect means*

*Means of reducing greenhouse gas emissions could include such measures as:*

- *minimising clearing at the site (which also has imperatives besides reducing greenhouse gas emissions)*
- *using less carbon-emitting transport modes or fuels*
- *integrating transport for the project with other local industries such that greenhouse gas emissions from the construction and running of transport infrastructure are minimised*
- *maximising the use of renewable energy sources*
- *co-locating coal seam methane use for energy production with coal extraction*
- *carbon sequestration at nearby or remote locations.*

Katestone has made suggestions and recommendations for the mitigation of greenhouse gas emissions in this report.

# 2. Greenhouse gas assessment

## 2.1 Background

This greenhouse gas assessment considers the potential impact of the Project on the global climate system by changes that it may cause to net greenhouse gas emissions. Climate change is an environmental concern at a global level. Any source or sink of greenhouse gases has a nominally equivalent effect no matter where on Earth it occurs. While few if any individual projects would make a noticeable change to the Earth's climate, the summation of human activities increasing the concentrations of greenhouse gases in the upper atmosphere does. Governments and the global scientific community have established conventions for accounting for greenhouse gas emissions to enable pollution control among all global jurisdictions. This assessment employs these established conventions so that the relative impact of the Project on greenhouse gas emissions can be properly understood.

The term greenhouse gases comes from the 'greenhouse effect', which refers to the process whereby greenhouse gases in the atmosphere absorb the radiation released by the Earth's surface and then radiate some heat back towards the ground, increasing the surface temperature (Rapston, 2011). Human activity, especially burning fossil fuels, is increasing the concentration of greenhouse gases and hence increasing the absorption of outgoing heat energy. Even a small increase in long-term average surface temperatures has numerous direct and indirect consequences for climate.

The main greenhouse gases influenced directly by human activities and included in carbon accounting are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$) and synthetic gases, such as sulphur hexafluoride ($SF_6$) hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (Raupach and Fraser 2011; pp. 15-20). These gases vary in effect and longevity in the atmosphere, but scientists have devised a system named Global Warming Potential to allow them to be described in equivalent terms to $CO_2$ (the most prevalent greenhouse gas) called equivalent carbon dioxide emissions ($CO_2$-e). A unit of one tonne of $CO_2$-e is the basic unit used in carbon accounting. An emissions inventory, or 'carbon footprint', is calculated as the sum of the emission rate of each greenhouse gas multiplied by the global warming potential. For example:

$$\text{tonnes } CO_2\text{-e} = \text{tonnes } CO_2 \times 1.0 + \text{tonnes } CH_4 \times 21 + \text{tonnes } N_2O \times 310$$

$CO_2$ and $CH_4$ are part of the carbon cycle, which refers to the natural movement of carbon among the ocean, plants, soil and the atmosphere. Fossil fuels such as coal, oil and natural gas are the product of prehistoric deposits of organic matter. When combusted, their stored carbon is released again to the atmosphere at an extremely rapid rate in comparison to the rate at which it became stored.

Burning fossil fuels always causes greenhouse gas emissions and energy from fossil fuels underpins the global economy and the human development gained from it. Consequently, changing this pattern to reduce emissions and protect climate is extremely difficult. The need for a global solution to this problem has led to the United Nations Framework Convention on Climate Change (UNFCCC), the associated Kyoto Protocol and the world scientific body, the Intergovernmental Panel on Climate Change (IPCC). In 2009, governments agreed that emissions need to be reduced so that global temperature increases are limited to below two degrees Celsius (UNFCCC, 2009). Australia is an active participant in these global arrangements and this has a strong effect on domestic economic and environmental policy.

## 2.2 Australian policy and regulation

### 2.2.1 Australian international commitments

The following discussion of Australia's global commitments to respond to climate change is derived from information published by the Commonwealth Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIICCSRTE) on its website (DIICCSRTE, 2013).

The United Nations Framework Convention on Climate Change (UNFCCC) provides the basis for global action 'to protect the climate system for present and future generations'. Australia ratified the Convention in 1992. The Convention entered into force in 1994 after a requisite 50 countries had ratified it. There are now 193 Parties to the UNFCCC - almost all of the members of the United Nations.

Parties to the Convention have agreed to work towards stabilising 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.

Under the convention, Australia is committed to:

- Submitting a national inventory of emissions and removals of greenhouse gases
- Implementing national programs to mitigate climate change and adapt to its impacts
- Conducting research related to the climate system and promoting relevant technologies
- Raising public awareness about climate change
- Submitting comprehensive National Communications (i.e. reports).

The Kyoto Protocol is an international agreement created under the UNFCCC in Kyoto, Japan in 1997. Australia's ratification of the protocol came into effect on 11 March 2008. The protocol aims to reduce the collective greenhouse gas emissions of developed country parties by at least five per cent below 1990 levels during 2008 to 2012 – referred to as the first commitment period. Australia has a target for emissions of 108 percent of estimated emissions for 1990 or 591.5 Mt $CO_2$-e.

At the United Nations climate change negotiations in Durban, South Africa in 2011, Parties to the Kyoto Protocol decided to establish a second commitment period from 1 January 2013. On 9 November 2012, the Australian Government announced its intention to join a second commitment period under the Kyoto Protocol, conditional on a number of factors to be negotiated at the Doha Conference of the Parties in late 2012. All countries that are party to the UNFCCC are negotiating a new global agreement that is intended to have legally binding commitments for all major emitters. This agreement is due for finalisation by 2015 and come into effect in 2020 (Combet, 2012).

The Australian Government has a constitutional power to ensure that Australia meets its international commitments, including those made under the UNFCCC. For the purposes of this discussion, it is assumed that Shenhuo will operate the mine. Due to the scale of the Project, there are several related national policies, statutes and regulations that are important to Shenhuo's development and operation of the mine, including:

- The *National Greenhouse and Energy Reporting (NGER) Act 2007* and regulations – Shenhuo must participate in the national emissions reporting process

- The *Clean Energy Act 2011* – Under current legislation, Shenhuo will become a liable entity for the Carbon Pricing Mechanism, and based on its NGER report, have to surrender emissions units or pay a shortfall charge for each tonne of covered emissions each year. It is the stated intention of the new federal government to change this legislation; however, its policy is to retain NGER reporting
- The *Energy Efficiency Opportunities Act 2006* – Shenhuo will have to identify, evaluate and report publicly on cost effective energy savings opportunities.

This legislation is enforced by Australian Government agencies and penalties apply for non-compliance.

### 2.2.2 National Greenhouse and Energy Reporting

The *National Greenhouse and Energy Reporting Act 2007* (NGER Act) established a national framework for corporations to report greenhouse gas emissions and energy consumption. Registration and reporting is mandatory for corporations that have energy production, energy use or greenhouse gas emissions that exceed specified thresholds. Figure 1 shows the National Greenhouse and Energy Reporting thresholds for facilities and operations. The Project would exceed the threshold for energy use and greenhouse gas emissions. Year 1 produces an estimated 26.2 kt$CO_2$-e of greenhouse gas emissions and has an estimated energy use of 270 TJ (11,487 MWh of electricity and 5,835 kL of diesel), which exceeds the threshold of 100 TJ.

The NGER Act is administered by the Clean Energy Regulator and the scheme will also be the basis for the *Clean Energy Act 2011* and associated carbon pricing mechanism (i.e. emissions trading). Shenhuo will have to register for NGER reporting. Applications for registration are due by 31 August following the reporting (financial) year in which a corporation first triggered one of the thresholds. Corporations are only required to register under the NGER Act for the first year in which a threshold is triggered. A corporation remains registered until an application for deregistration is approved. Once registered, corporations are required to report by 31 October following the reporting year, and must submit an NGER Report for every year that it remains registered (CER, 2012a).

### 2.2.3 Clean Energy Act (Carbon Pricing Mechanism)

The *Clean Energy Act 2011* has established a carbon emissions trading system for Australia including a fixed price period, a ‘collar’ period (with ceiling and floor prices) and full emissions trading from 1 July 2015, where the market will determine prices (with some restrictions).

Following the September 2013 election the repeal of the Clean Energy Act and associated legislation is currently under consideration. The 2013/14 reporting period is planned to be the final period that a carbon price will be applied to ‘covered emission’ under the Clean Energy Act. It has been proposed that if an agreement cannot be reached by this time that any ongoing payments from ‘liable entities’ will be refunded once the Act has been repealed.

Construction activities for the Project are not expected to commence until 2012, it is most likely that by this time the Clean Energy Act will have been repealed. It is likely that the Clean Energy Act will be replaced by other obligations relating to the management of greenhouse gas emissions. The development and enactment of new legislation should be monitored by Shenhuo in the lead up to the commencement of the Project.

### 2.2.4 Energy Efficiency Opportunities

The Energy Efficiency Opportunities (EEO) program encourages large energy-using businesses to improve their energy efficiency. It does this by requiring businesses to identify, evaluate and report publicly on cost effective energy savings opportunities (DRET, 2011). Participation in Energy Efficiency Opportunities is mandatory for corporations that use more than 0.5 petajoules (PJ) of energy per year.

Electricity consumption and diesel combustion contribute towards the energy usage for the Project facility. Based on current mine plans the Project will trigger the EEO threshold in its second year of operation. At this point the total energy usage for the year will be 0.61 PJ, consisting of 0.53 PJ (13.7 megalitres (ML)) of diesel and 0.08 PJ (23 GWh) of electricity.

Under EEO, Shenhuo would be required to undertake detailed energy assessments to identify opportunities to improve energy use, and to report publicly on the outcomes. Shenhuo will have to:

- Register with the Department of Resources, Energy and Tourism
- Prepare and submit an Assessment Plan
- Conduct assessments
- Report on assessment outcomes and business response.

The program operates on a five year cycle.

### 2.2.5 Reporting tools

The DCCEE monitors and compiles databases on anthropogenic activities that produce greenhouse gases in Australia. The DCCEE has published greenhouse gas emission factors for a range of anthropogenic activities. The DCCEE methodology for calculating greenhouse gas emissions is published in the National Greenhouse Accounts (NGA) Factors workbook (DCCEE, 2010 and 2011a) and is based on Australian data. This workbook is updated annually to reflect current compositions in fuel mixes and evolving information on emission sources.

The scope that emissions are reported under, and the subsequent emission factors used are determined by whether an activity is within an organisation's boundary or not. Direct emission factors are used to calculate Scope 1 emissions from activities within the organisation's boundary. Indirect emission factors are used to calculate Scope 2 emissions from the generation of electricity purchased and consumed by an organisation.

Scope 3 emissions occur as an indirect result of an activity. Scope 3 emissions related to electricity transmission losses and the off-site production of fuel have been accounted for.

# 3. Sources of Greenhouse Gas Emissions

## 3.1 Construction

The Project's construction phase will include the preliminary clearing of vegetation and construction of the mining infrastructure, including:

- CHPP facilities
- Rail loop
- Haul roads
- Site buildings (such as workshops and administration buildings)
- Exhaust ventilation shaft (production year 5)

Construction activities will emit greenhouse gas emissions through, for example, the consumption of diesel fuel and the consumption of electricity to power equipment. The emissions associated with the construction phase have not been quantified within this assessment as details of the quantity of diesel fuel or electricity consumption are unknown at this time.

## 3.2 Operations

AARC has provided details of the annual ROM coal tonnage, diesel fuel consumption, electricity consumption and the amount of ANFO explosives to be used for each year of the operational mine life. The data are summarised in Table 2.

Greenhouse gas emissions have been calculated for the following activities associated with the Project:

- Production of coal - activities related to the extraction of coal (fugitive) – open cut and underground mines
- Consumption of diesel
- Consumption of electricity
- Explosives usage

**Table 2 Summary of ROM coal production and usage of diesel, electricity and explosives for the life of the mine**

| Year | ROM coal production (tpa) | | Diesel usage (kL) | Electricity usage (MWh) | Explosives usage (t) |
|---|---|---|---|---|---|
| | Underground | Open-cut | | | |
| 1 | | 511,179 | 5,835 | 11,487 | 1,112 |
| 2 | | 1,456,517 | 13,689 | 22,973 | 2,909 |
| 3 | | 1,905,988 | 13,822 | 22,973 | 3,573 |
| 4 | | 2,278,491 | 16,159 | 22,973 | 4,211 |
| 5 | 98,460 | 2,177,615 | 16,040 | 28,369 | 3,988 |
| 6 | 370,905 | 1,988,289 | 18,077 | 47,637 | 4,425 |
| 7 | 2,693,072 | 793,847 | 8,928 | 58,217 | 1,972 |
| 8 | 4,989,940 | | 1,288 | 79,764 | 0 |
| 9 | 5,129,130 | | 1,288 | 79,764 | 0 |
| 10 | 5,172,949 | | 1,288 | 79,764 | 0 |
| 11 | 5,198,559 | | 1,288 | 85,020 | 0 |
| 12 | 5,130,576 | | 1,288 | 90,276 | 0 |
| 13 | 5,746,405 | | 1,288 | 90,276 | 0 |
| 14 | 4,312,098 | | 1,288 | 90,276 | 0 |
| 15 | 4,747,456 | | 1,288 | 91,590 | 0 |
| 16 | 4,754,496 | | 1,160 | 91,590 | 0 |
| 17 | 5,201,350 | | 966 | 90,859 | 0 |
| 18 | 4,636,380 | | 966 | 90,859 | 0 |
| 19 | 4,569,902 | | 966 | 90,859 | 0 |
| 20 | 4,388,030 | | 966 | 84,871 | 0 |
| 21 | 1,506,275 | | 138 | 25,461 | 0 |

# 4. Method used to estimate greenhouse gas emissions

DCCEE has published greenhouse gas emission factors for a range of anthropogenic activities. The DCCEE methodology for calculating greenhouse gas emissions is published in the National Greenhouse Accounts (NGA) Factors workbook (DCCEE, 2010 and 2011a) and is based on Australian data. This workbook is updated regularly to reflect current compositions in fuel mixes and evolving information on emission sources.

The greenhouse gas intensity of each activity has been calculated using the simplified equation as follows:

$$GHG = E \times EF$$

Where:

*GHG*: Annual greenhouse gas emissions in tonnes of carbon dioxide equivalent ($tCO_2$-e)

*E:* Annual fuel input energy (GJ/yr)

*EF:* Emission factors for $CO_2$, $CH_4$ and $N_2O$ (kg $CO_2$-e /GJ)

The total annual $CO_2$-e emissions are the sum of the $CO_2$-e emissions for each of the three greenhouse gases, $CO_2$, $CH_4$ and $N_2O$.

The emission factors that have been used to calculate greenhouse gas emissions are presented in Table 3 to Table 6. Local gas content and composition analysis for the coal seams to be mined at Taroborah was available for this assessment which provided greater specificity for fugitive methane emissions (GeoGAS, 2009). The assessment established fugitive emission factors based on the seam gas testing results contained in the GeoGAS report.

**Table 3 Production of coal (fugitive) – open cut and underground**

| Activities related to extraction of coal | Greenhouse gas emission factor (t $CO_2$-e/ t ROM) |
|---|---|
| Open cut mining/Underground mining | 0.0003 |

**Table 4 Fuel combustion – fuels used for transport energy purposes (DCCEE, 2011a)**

| Diesel consumption | | Energy content (GJ/kL) | Greenhouse gas emission factors (kg $CO_2$-e/GJ) | |
|---|---|---|---|---|
| | | | Scope 1 | Scope 3 |
| Euro i design standard | Diesel oil | 38.6 | 69.9 | 5.3 |

**Table 5 Consumption of purchased electricity (DCCEE, 2011a)**

| Purchased electricity | Greenhouse gas emission factor (kg $CO_2$-e/kWh) | |
|---|---|---|
| | Scope 2 | Scope 3 |
| Queensland | 0.88 | 0.12 |

### Table 6 Explosives usage due to blasting (DCC, 2008)

| Explosive type | Greenhouse gas emission factor (tonnes $CO_2$-e/ tonne ANFO) |
|---|---|
| ANFO | 0.17 |

# 5. Greenhouse gas inventory

## 5.1 Project greenhouse gas inventory

The greenhouse gas emissions estimated for each year of operation of the mine are presented in Table 7 and Table 8. These figures include Scope 1 and 2 as well as Scope 3 components for which factors are included in the National Greenhouse Account Factors (electricity transmission losses and emissions related to fuel generation). A summary of the total greenhouse gas emissions is presented in Table 9.

Figure 2 shows the projected annual greenhouse gas emissions for the Project. Figure 3 shows the percentage contribution of each activity to the total projected greenhouse gas emissions (Scope 1, 2 and 3 as described above) for the life of the Project. It can be seen from Figure 3 that the emissions from electricity consumption are expected to have the greatest contribution to the total greenhouse gas emissions from the Project. Gases emitted from diesel combustion are the next largest contributor. Fugitive emissions and blasting emissions make up for the remainder of emissions. Fugitive emissions occur during the mining process due to the fracturing of coal seams, overburden and underburden strata. Direct measurement methods are required for reporting during mine operation.

The peak annual emission rate of greenhouse gases (Scope 1 and 2) from the Taroborah Coal Project is 0.092 Mt $CO_2$-e in operational year 6. This represents 0.02% of Australia's estimated 546.3 Mt $CO_2$-e of greenhouse gas emissions for 2011 (DCCEE, 2011b). The total greenhouse gas emissions reported for Queensland were 134.3 Mt $CO_2$-e in the 2009/2010 reporting period (DCCEE, 2012), excluding emissions and removals from Land Use, Land Use Change and Forestry (LULUCF). With the inclusion of emissions and removals from LULUCF, the total greenhouse gas emissions were 157.3 Mt $CO_2$-e. The peak annual emission rate of greenhouse gases from the Taroborah Coal Project would contribute approximately 0.06 % to this total.

## Table 7 Estimated Scope 1 greenhouse gas emissions for the Project (t $CO_2$-e)

| Operational Year | Scope 1 emissions | | | | | | | Total emissions for Scope 1 |
|---|---|---|---|---|---|---|---|---|
| | Fugitive emissions from extraction of coal (underground) | Fugitive emissions from extraction of coal (open-cut) | Blasting of material | Fuel combustion | | | | |
| | | | | $CO_2$ | $CH_4$ | $N_2O$ | Total $CO_2$-e | |
| 1 | 0 | 153 | 189 | 15,587 | 45 | 113 | 15,744 | 16,087 |
| 2 | 0 | 437 | 495 | 36,564 | 106 | 264 | 36,934 | 37,865 |
| 3 | 0 | 572 | 607 | 36,920 | 107 | 267 | 37,293 | 38,472 |
| 4 | 0 | 684 | 716 | 43,163 | 125 | 312 | 43,599 | 44,999 |
| 5 | 30 | 653 | 678 | 42,844 | 124 | 310 | 43,277 | 44,638 |
| 6 | 111 | 596 | 752 | 48,285 | 140 | 349 | 48,774 | 50,234 |
| 7 | 808 | 238 | 335 | 23,848 | 69 | 172 | 24,089 | 25,470 |
| 8 | 1,497 | 0 | 0 | 3,441 | 10 | 25 | 3,476 | 4,973 |
| 9 | 1,539 | 0 | 0 | 3,441 | 10 | 25 | 3,476 | 5,015 |
| 10 | 1,552 | 0 | 0 | 3,441 | 10 | 25 | 3,476 | 5,028 |
| 11 | 1,560 | 0 | 0 | 3,441 | 10 | 25 | 3,476 | 5,036 |
| 12 | 1,539 | 0 | 0 | 3,441 | 10 | 25 | 3,476 | 5,015 |
| 13 | 1,724 | 0 | 0 | 3,441 | 10 | 25 | 3,476 | 5,200 |
| 14 | 1,294 | 0 | 0 | 3,441 | 10 | 25 | 3,476 | 4,770 |
| 15 | 1,424 | 0 | 0 | 3,441 | 10 | 25 | 3,476 | 4,900 |
| 16 | 1,426 | 0 | 0 | 3,097 | 9 | 22 | 3,129 | 4,555 |
| 17 | 1,560 | 0 | 0 | 2,581 | 7 | 19 | 2,607 | 4,168 |
| 18 | 1,391 | 0 | 0 | 2,581 | 7 | 19 | 2,607 | 3,998 |
| 19 | 1,371 | 0 | 0 | 2,581 | 7 | 19 | 2,607 | 3,978 |
| 20 | 1,316 | 0 | 0 | 2,581 | 7 | 19 | 2,607 | 3,924 |
| 21 | 452 | 0 | 0 | 369 | 1 | 3 | 372 | 824 |
| Max | 1,724 | 684 | 752 | 48,285 | 140 | 349 | 48,774 | 50,234 |
| **TOTAL** | **20,594** | **3,334** | **3,772** | **288,530** | **834** | **2,085** | **291,449** | **319,149** |

**Table 8 Estimated Scope 2 and 3 greenhouse gas emissions for the Project (t $CO_2$-e)**

| Operational Year | Scope 2 emissions | Total emissions for Scope 2 | Scope 3 emissions | | Total emissions for Scope 3 |
|---|---|---|---|---|---|
| | Electricity consumption | | Electricity transmission losses | Fuel generation | |
| 1 | 10,108 | 10,108 | 1,378 | 1,194 | 2,572 |
| 2 | 20,216 | 20,216 | 2,757 | 2,800 | 5,557 |
| 3 | 20,216 | 20,216 | 2,757 | 2,828 | 5,584 |
| 4 | 20,216 | 20,216 | 2,757 | 3,306 | 6,063 |
| 5 | 24,964 | 24,964 | 3,404 | 3,281 | 6,686 |
| 6 | 41,920 | 41,920 | 5,716 | 3,698 | 9,415 |
| 7 | 51,231 | 51,231 | 6,986 | 1,826 | 8,813 |
| 8 | 70,192 | 70,192 | 9,572 | 264 | 9,835 |
| 9 | 70,192 | 70,192 | 9,572 | 264 | 9,835 |
| 10 | 70,192 | 70,192 | 9,572 | 264 | 9,835 |
| 11 | 74,818 | 74,818 | 10,202 | 264 | 10,466 |
| 12 | 79,443 | 79,443 | 10,833 | 264 | 11,097 |
| 13 | 79,443 | 79,443 | 10,833 | 264 | 11,097 |
| 14 | 79,443 | 79,443 | 10,833 | 264 | 11,097 |
| 15 | 80,599 | 80,599 | 10,991 | 264 | 11,254 |
| 16 | 80,599 | 80,599 | 10,991 | 237 | 11,228 |
| 17 | 79,956 | 79,956 | 10,903 | 198 | 11,101 |
| 18 | 79,956 | 79,956 | 10,903 | 198 | 11,101 |
| 19 | 79,956 | 79,956 | 10,903 | 198 | 11,101 |
| 20 | 74,687 | 74,687 | 10,185 | 198 | 10,382 |
| 21 | 22,406 | 22,406 | 3,055 | 28 | 3,084 |
| Maximum | 80,599 | 80,599 | 10,991 | 3,698 | 11,254 |
| **Total** | **1,210,756** | **1,210,756** | **165,103** | **22,098** | **187,201** |

Table 9 A summary of the total greenhouse gas emissions for the Project (t $CO_2$-e)

| Operational Year | Scope 1 | Scope 2 | Scope 3 | Total attributable emissions (Scope 1 & 2) |
|---|---|---|---|---|
| 1 | 16,087 | 10,108 | 2,572 | 26,195 |
| 2 | 37,865 | 20,216 | 5,557 | 58,081 |
| 3 | 38,472 | 20,216 | 5,584 | 58,689 |
| 4 | 44,999 | 20,216 | 6,063 | 65,215 |
| 5 | 44,638 | 24,964 | 6,686 | 69,603 |
| 6 | 50,234 | 41,920 | 9,415 | 92,154 |
| 7 | 25,470 | 51,231 | 8,813 | 76,701 |
| 8 | 4,973 | 70,192 | 9,835 | 75,166 |
| 9 | 5,015 | 70,192 | 9,835 | 75,207 |
| 10 | 5,028 | 70,192 | 9,835 | 75,221 |
| 11 | 5,036 | 74,818 | 10,466 | 79,853 |
| 12 | 5,015 | 79,443 | 11,097 | 84,458 |
| 13 | 5,200 | 79,443 | 11,097 | 84,643 |
| 14 | 4,770 | 79,443 | 11,097 | 84,213 |
| 15 | 4,900 | 80,599 | 11,254 | 85,500 |
| 16 | 4,555 | 80,599 | 11,228 | 85,154 |
| 17 | 4,168 | 79,956 | 11,101 | 84,123 |
| 18 | 3,998 | 79,956 | 11,101 | 83,954 |
| 19 | 3,978 | 79,956 | 11,101 | 83,934 |
| 20 | 3,924 | 74,687 | 10,382 | 78,610 |
| 21 | 824 | 22,406 | 3,084 | 23,230 |
| Max | 50,234 | 80,599 | 11,254 | 92,154 |
| **Total** | **319,149** | **1,210,756** | **187,201** | **1,529,904** |

## 5.2 Greenhouse gas emissions associated with the mine product

The end use of the product of this mine is outside the scope of development, operation or rehabilitation of the mine; however, the combustion of the coal will contribute greenhouse gas emissions to the global atmosphere. Coal is the second source of primary energy in the world after oil, and the first source of electricity generation (IEA, 2012a). In 2011, coal accounted for 45 percent of total energy-related carbon dioxide emissions in the world (IEA, 2012b). The Taroborah Coal Project is expected to produce 77.8 Mt of saleable coal over a 21 year period to be used for electricity generation. Based on Australian Government emission factors (DCCEE, 2011a) the combustion of this volume of coal would release total Scope 1 emissions of 186 Mt $CO_{2}$-e to the atmosphere. Dividing the total emissions associated with combustion of the coal product by the anticipated mine life yields 8.85 Mt $CO_{2}$-e per year. For illustration purposes, this would equate to 1.6 percent of Australia's estimated domestic emissions in 2011, estimated to be 546.3 Mt (DCCEE, 2011b).

# 6. Greenhouse gas minimisation strategies

The following greenhouse gas minimisation strategies will be implemented where appropriate:

Equipment purchase and energy efficiency

- An energy efficiency audit will be undertaken, where appropriate, during the detailed design phase
- The use of high efficiency electrical motors throughout the mine site and the use of variable speed drive pumps with high efficiency linings at the coal handling and preparation plant will be considered and implemented where practicable
- Installing light sensitive switches on lighting equipment and energy efficient lamps throughout the Project site where practicable
- Installation of energy saving devices will be undertaken within the on-site buildings, where practicable

Mine planning

- Haul truck scheduling, routing and idling times will be optimised to minimise the amount of diesel consumed
- Pit access ramps will be optimised to minimise the amount of effort required for fully-laden trucks to climb
- Haul roads will be compacted to reduce rolling distance, where practicable
- The location of ROM and overburden dumps will be optimised to minimise the amount of distance haul trucks need to cover whilst heavily laden
- Adoption of a mining method that uses large equipment and economies of scale to significantly reduce greenhouse emissions
- Extracting and transporting coal and overburden efficiently, thereby minimising the number of trips and fuel consumption
- Recycling of refrigerants in equipment and air conditioning
- Minimising burning of vegetation

Auditing and management

- A greenhouse gas reduction management plan will be developed
- Greenhouse awareness training at induction
- Development and maintenance of an inventory of emissions and sinks

These greenhouse gas minimisation strategies are consistent with best practice environmental management practices for the coal mining sector.

A greenhouse gas reduction management plan will be developed for the Taroborah Coal Project that will include reporting and auditing procedures with the objective of achieving continual improvement in greenhouse gas emissions.

Auditing will include regular benchmarking studies to allow mine performance to be gauged relative to industry standards and where the mine is not achieving these standards, programs will be implemented to achieve reductions.

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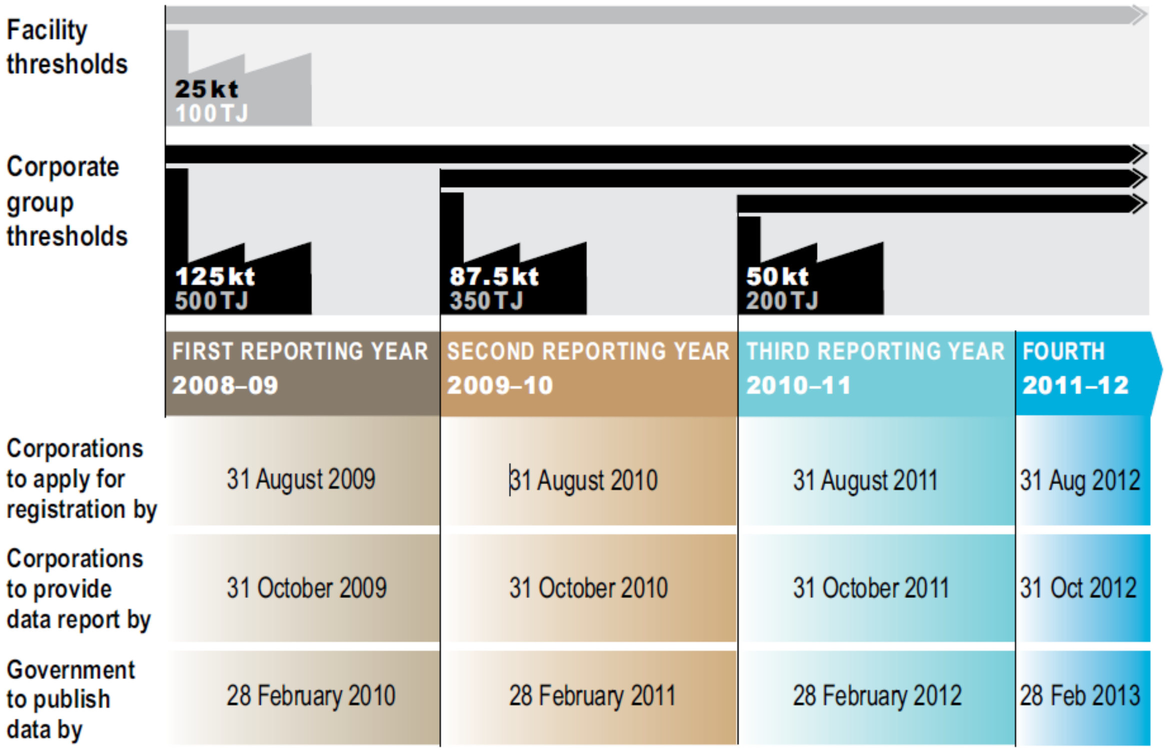
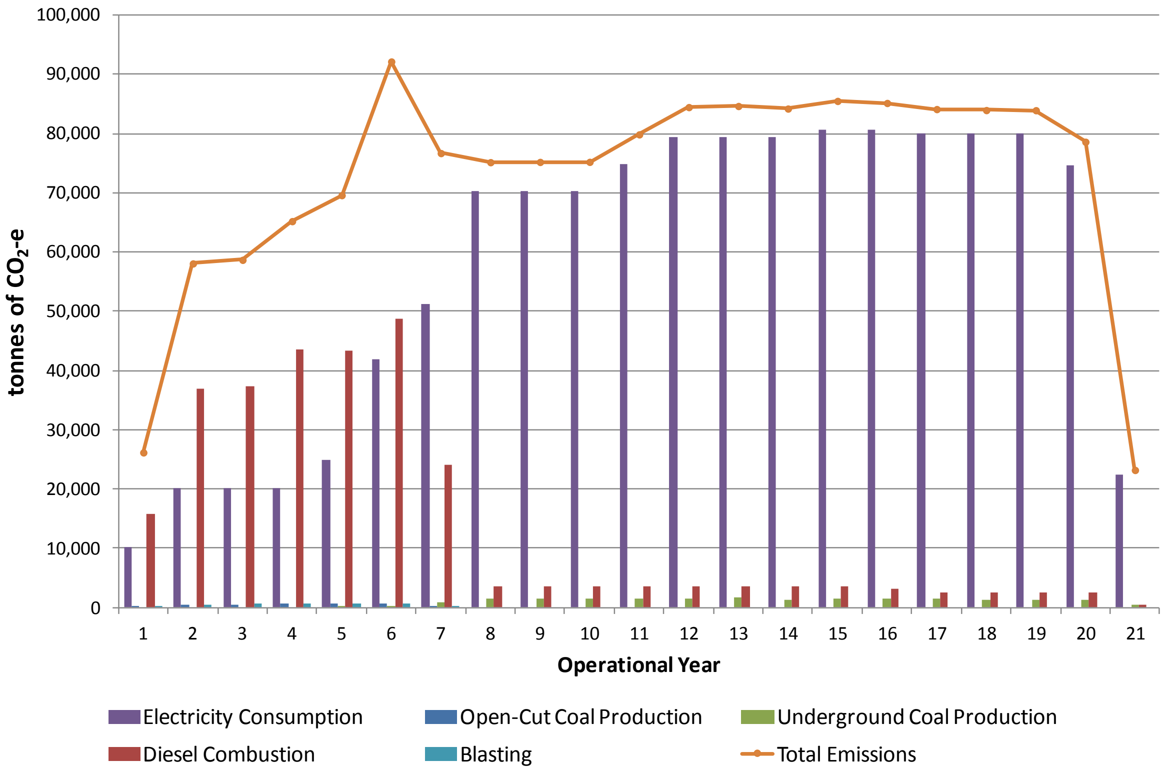


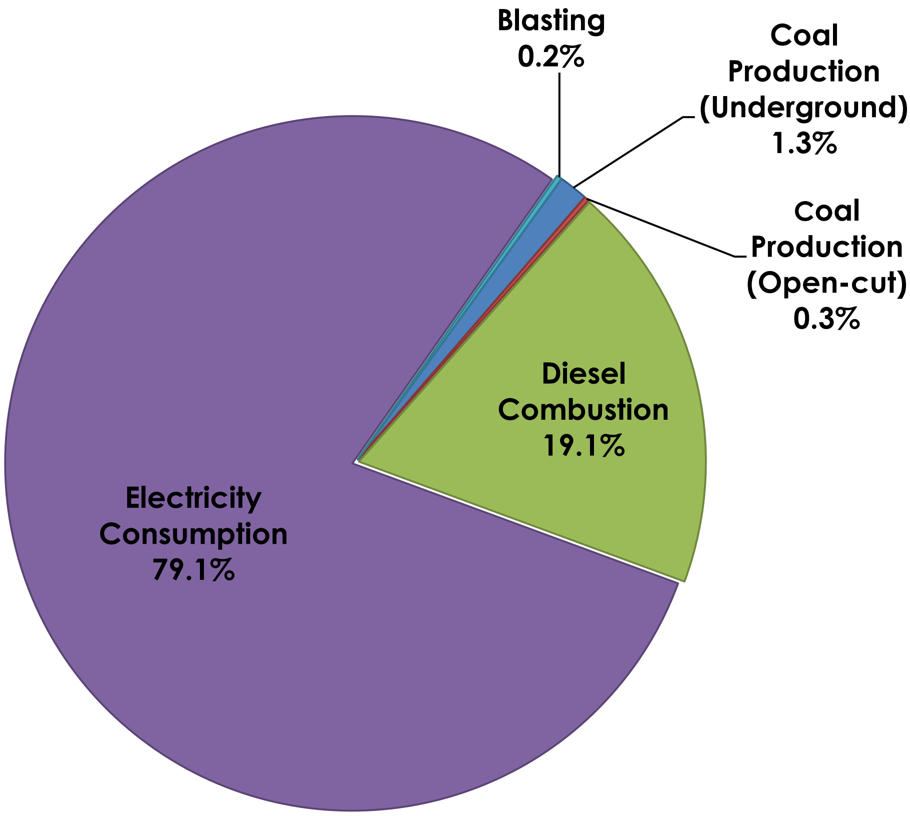

**Notes:** TJ = terajoule ($10^{12}$ joules) of energy consumed or produced; kt = kilotonne ($10^6$ kilograms) $CO_2$-e equivalent of greenhouse gases emitted.Conversion factors: Energy—1 terajoule = 1000 gigajoules, 1 gigajoule = 1000 megajoules, 1 megajoule = 1000 kilojoules, 1 kilojoule = 1000 joules; $CO_2$-e emissions—1 kilotonne = 1000 tonnes, 1 tonne = 1000 kilograms.

**Figure 1 The National Greenhouse and Energy Reporting thresholds for facilities and corporations**

| | | |
|---|---|---|
| **Location:**<br>N/A | **Data source:**<br>Department of Climate Change, 2008b | **Units:**<br>N/A |
| **Type:**<br>Schematic diagram | **Prepared by:**<br>SJ. Donnelly | **Date:**<br>July 2012 |




| | | | |
|---|---|---|---|
| **Figure 2** **Projected annual greenhouse gas emissions for the Project** | | | |
| **Location:**<br>Taroborah Coal Project, QLD | **Period:**<br>Year 1 to year 21 | **Data source:**<br>AARC | **Units:**<br>Tonnes $CO_2$-e |
| **Type:**<br>Bar chart | **Averaging Period:**<br>Annual | **Prepared by:**<br>Lisa Smith | **Date:**<br>September 2013 |




| **Figure 3** | **Percentage contribution of each activity to the total projected greenhouse gas emissions (Scope 1, 2 and 3) for the lifetime of the Project** | | |
|---|---|---|---|
| **Location:**<br>Taroborah Coal Project, QLD | **Period:**<br>Year 1 to Year 21 | **Data source:**<br>AARC | **Units:**<br>Percentage |
| **Type:**<br>Pie chart | **Averaging period:**<br>Annual | **Prepared by:**<br>Lisa Smith | **Date:**<br>September 2013 |

# Adaptation to Climate Change and Variability Assessment for the Taroborah Coal Project

Prepared for

**AARC**

**May 2013**

**Final**


Prepared by

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|---|---|---|---|
| Rev 1.1 | 14/05/2013 | Simon Welchman | |

# Contents

## Tables

## Figures

# Glossary

| Term | Definition |
|---|---|
| **Symbols and abbreviations** | |
| AARC | AustralAsian Resource Consultants |
| BoM | Bureau of Meteorology |
| CHPP | Coal Handling and Preparation Plant |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DPI | Department of Primary Industries |
| EIS | Environmental Impact Statement |
| EPC | Exploration Permit for Coal |
| GCM | Global Circulation Model |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| IPCC | Intergovernmental Panel on Climate Change |
| MDLA | Mineral Development License Application |
| $MJ/m^2$ | megajoules per square metre |
| MJO | Madden-Julian Oscillation |
| mm/day | millimetres per day |
| NCDC | National Climate Data Centre (US) |
| NCIG | Newcastle Coal Infrastructure Group |
| PPD | Patched Point Datasets |
| Shenhuo | Shenhuo International Group Pty Ltd |
| ToR | Terms of Reference |
| **Definitions** | |
| Cool phase PDO | negative PDO values |
| ENSO | El Niño Southern Oscillation |
| El Niño | Warm phase ENSO associated with negative values of the SOI |
| La Niña | Cool phase ENSO associated with positive values of the SOI |
| PDO | Pacific Decadal Oscillation |
| SOI | Southern Oscillation Index – difference in surface air pressure between Tahiti and Darwin |
| Warm phase PDO | positive PDO values |
| **Timescales** | |
| Short term | 1-7 year timescales to account for analysis of annual variability and ENSO phases |
| Medium term | 20-30 year timescales to account analysis of variability of PDO phases |
| Long term | 70-100+ year timescales to account for climate model projections and trends |

# Executive summary

*The Taroborah Coal Project is located approximately 22 km west of Emerald in central Queensland. It consists of a combination of underground and open-cut mining activities to be developed and operated over a period of approximately 25 years, including two years for construction, 22 years for operations and one for decommissioning.*

*This study has assessed climate risks for the Project based on an investigation into the likely range in climate that may be experienced in the region over the Project lifespan. The desktop risk assessment considers project vulnerabilities and describes risk mitigation and adaptation strategies, with the intent to avoid potential adverse effects on project operations and the environment. The method employed responds to the Department of Environment and Heritage Protection's Terms of Reference for this project (dated August 2012) regarding climate vulnerability, risk and adaptation.*

*There is a need to distinguish between the average climate projected for the future and the variability within the climate experienced along the way. The difference in the Projected average state from the observed average state at present is termed climate change. Climate variability is the range of climatic states experienced between these two average states. To manage and mitigate the effects of a changing climate the variability between these states needs to be identified and the influence on the operations of a project determined.*

*The year 2035 is the future date for which climate modelling information is available that best matches the development of the Taroborah mine. According to the modelling and analysis conducted for this study of future climate change, the climate in the Emerald area in 2035 will see:*

- *Average seasonal rainfall will be more similar to historical neutral and El Niño years than La Niña years*
- *Daily average minimum and maximum temperatures for all seasons are predicted to be higher than historical values (by approximately 0.2-2°C).*
- *Increased evaporation relative to historical levels*
- *Similar solar radiation to historical levels.*

*However, when considering climate influences over the life of the Taroborah Coal Project, extreme weather due to the influence of general circulation patterns (especially El Niño and La Niña) present a more significant climate risk consideration than the effects of climate change.*

*The study delineated six key climate parameters that had the potential to influence the likelihood of impacts considered in the risk assessment; namely:*

- *Intense rainfall (days above 25 mm)*
- *Cyclones (number within 400 km of project site per cyclone season)*
- *High temperatures (days above 35°C)*
- *Drought (months with rainfall at or below 5$^{th}$ percentile for that month)*
- *Strong winds and damaging winds (days with over 8 m/s and 25 m/s, respectively)*

*For each, the probability of the long-term average for the parameter being exceeded under El Niño or La Niña conditions was estimated, which revealed several significant differences. La Niña conditions would suggest an 80 percent probability of exceeding the intense rainfall threshold and 70 percent probability of exceeding the cyclone and strong winds parameters. The corresponding probabilities under El Niño conditions were 30*

*percent for intense rainfall, 40 percent for cyclones and 30 percent for strong winds. The probability of drought under El Niño is 80 percent, but only 30 percent under La Niña.*

*During the mine life, both La Niña and El Niño are possible. However, the evidence is that the region is moving into a La Niña phase and the extreme weather associated with La Niña should be considered rather than just the long term changes in averages associated with climate change (e.g. increased drought) as the impact of the latter may not be significant within the life of the Project.*

*A risk assessment method was employed, drawing upon the DR AS5334, Climate change adaptation for settlements and infrastructure.*

- ***Impacts:*** *An array of climate risk impacts were identified from desktop research and a risk workshop*
- ***Likelihood****: The probabilities determined for each source of climate risk were the main determinant of the likelihood term in the risk equation, combined with qualitative likelihood criteria from the draft standard.*
- ***Consequence:*** *The consequence for each risk was assigned based on the qualitative criteria table from the draft standard.*

*The following table provides a summary of the results of the risk assessment.*

| **Impact Description** | **Likelihood** | **Consequence** | **Risk rating** |
|---|---|---|---|
| Disruption of operations due to flooding | Likely | Minor | **MODERATE** |
| Reduced water availability for mine site operations | Possible | Moderate | **MODERATE** |
| Increased equipment outages due to storm activity | Almost certain | Minor | **MODERATE** |
| Infrastructure damage due to cyclones and severe storm events | Likely | Moderate | **MODERATE** |
| Disruption of operations issues due to bushfire | Possible | Minor | **LOW** |
| Increased dust levels causing disruption to operations | Possible | Minor | **LOW** |
| Decreased workforce productivity relating to higher temperatures | Possible | Minor | **LOW** |
| Higher instance of spontaneous combustion in stockpiles | Possible | Minor | **LOW** |
| Increased operations costs relating to energy requirements | Possible | Minor | **LOW** |
| Power outages due to increased energy demand caused by higher temperatures | Possible | Minor | **LOW** |

*It is envisaged that residual risk for each of the impacts identified can be managed to an acceptable level through sound engineering and design as well as active management involving inspection, maintenance and monitoring of stresses and weather activity.*

*Risk mitigation actions were identified for each individual risk. In response to these individual mitigation options, an integrated program of climate adaptation for the mine may incorporate:*

1. *A next stage of risk assessment prior to completion of design and commencement of works.*
2. *Prioritisation of hydrologic design and water management with recognition of the implications of La Niña conditions*
3. *Implementation of a weather intelligence system*
4. *Water conservation measures*
5. *Incorporation of climate risk management in core management systems*
6. *Periodic update of risk assessment and adaptation actions to incorporate emerging information and site experience*

*It is recognised that a cooperative approach with government, other industry and sectors is necessary to address adaptation to climate change effectively.*

# 1. Introduction

## 1.1 Background

Katestone has been commissioned by AustralAsian Resource Consultants (AARC), on behalf of Shenhuo International Group Pty Ltd (Shenhuo), to conduct a climate change adaptation assessment of the Taroborah Coal Project (the Project).

The Project is located approximately 22 km west of Emerald in Central Queensland in the Bowen Basin. It consists of a combination of underground and open-cut mining activities. The proposed open-cut mine has an anticipated 8 year life, possibly commencing in 2016 with a production rate of up to 2.3 Mtpa of ROM coal. The proposed underground longwall mine has an anticipated 17 year life, possibly commencing in 2021 and producing up to 5.6 Mtpa of ROM coal. The open-cut mining activities are located in the southern part of the proposed mining area and the underground mining is located to the north. The Mineral Development License application (MDLA) tenure encompasses an area of approximately 8,652 hectares.

The Project is proposed to comprise of one open pit, in-pit and out of pit overburden/rejects dumps, a ROM stockpile, a Coal Handling and Preparation Plant (CHPP), haul roads from the pit to stockpiles and a rail loop and train loading facility. The coal will be transported to the port of Gladstone via the Central West and Blackwater Rail Systems. The open-cut mining operations will consist of conventional open-cut mining techniques, which will include topsoil stripping, drill and blast, truck and shovel operations, dozer push waste removal, coal extraction and progressive rehabilitation.

According to the Department of Environment and Heritage Protection, climate change, through alterations to weather patterns and rising sea level, has the potential for long-term impacts on developments. The department notes that developments such as the proposed Taroborah Coal Project involve the use of a community resource, such as granting a non-renewable resource or the approval to discharge contaminants to air, water or land. Therefore, it is important that the Project design be adaptive to climate change so that community resources are not depreciated by projects that would be abandoned or require costly modification before their potential to provide a full return to the community is realised.

Rising sea level has not been assessed in this report. The Project is located approximately 220km inland from east coast of Queensland and therefore, is not considered to be at risk from changes in sea level.

## 1.2 Aim

This study aims to assess the climate risks for the Project based on an investigation into the likely range in climate that may be experienced in the region over the Project lifespan and post-mining rehabilitation. The desktop risk assessment will consider project vulnerabilities and describe risk mitigation and adaptation strategies, with the intent to avoid potential adverse effects on project operations and the environment. The desktop method employed is for the purposes of impact assessment and the study responds to the final Terms of Reference (TOR, dated August 2012) regarding climate vulnerability, risk and adaptation.

## 1.3 Scope

Consistent with the Department TOR for the Taroborah Environmental Impact Statement (EIS), this study has assessed the Project's vulnerabilities to climate change and describes possible adaptation strategies for the activity including:

- A risk assessment of how changing patterns of rainfall and hydrology, temperature, and extreme weather may affect the viability and environmental management of the Project
- Preferred and alternative adaptation strategies
- Description of how the proponent can adopt a cooperative approach with government, other industry and sectors to address adaptation to climate change

The effects of climate risk on the mine site, its operations, environmental management and contribution to the economy can be wide ranging. Accordingly, this climate change and variability assessment focuses on the operation of the mine and how it might be influenced during the design phase. Similarly, the focus is on primary impacts but consideration is also given to secondary impacts. Spatially, the focus is on the defined study area for the EIS (generally the area that may be directly affected by development of the mine). However, the study recognises that climate risks that affect the mine may not be restricted to the study area. For example, impacts on transport access to or from the mine could affect operations through interference with supplies or labour, or impede export of the mine's product. Temporally, the analysis has focussed on the time period of 2015 to 2038 (covering mine development and operation) and using all available historical climate data for the Emerald area to inform the analysis.

The study has proceeded using a desktop method; that is, the risk assessment element was completed at arm's length from personnel who may be leading the development or operation of the mine. Closer involvement of proponent personnel concerned with design, operation and rehabilitation of the mine would improve the value of a climate risk analysis. Accordingly, this study recommends the completion of a more detailed risk assessment involving internal and external stakeholders prior to finalisation of design and commencement of works. Nonetheless, the desktop method was informed by in depth climate research for the Emerald area.

## 1.4 Approach

In general, the approach taken was to conduct a desktop risk assessment process informed by extensive research into the historical local climate, projection of future climate scenarios and climatological analysis. Available literature and a limited risk workshop provided for the identification of risks. The likelihood of impacts was related to the results of climate analysis and consequences were evaluated using available information and a matrix of criteria. The development of possible adaptation strategies was based on the risk workshop, literature and discussions with industry professionals.

# 2. Regional climate influences

## 2.1 General Global Circulation and Climate Variability

Weather and climate are two commonly used terms that are sometimes not clearly understood and, are at times, used incorrectly as an interchangeable term. Weather and climate can be defined as:

> *Weather is the state of the atmosphere at a particular point in time over a given region, while climate is the synthesis or generalisation of the weather observed over a longer period. (Sturman and Tapper, 2005, pp.3-4)*

The weather system is based on the general circulation of the atmosphere and its interaction with the Earth's surface. Due to the differential heating of the Earth's surface and the spatial variability of the oceans and land surface, including terrain features, the idealized general circulation of the atmosphere is perturbed by random variations in the flow. These disruptions develop into weather systems and their frequency and magnitude determine the climate of regions over varying timescales. Two such variations that are important in understanding the climate in the Australia-Pacific region are the ENSO (El Niño Southern Oscillation) and PDO (Pacific Decadal Oscillation). These two climatic variations occur on very different timescales, and as they overlap in particular ways, can have a significant influence on seasonal and annual weather patterns. The general circulation of the atmosphere, ENSO and PDO are discussed below.

## 2.2 General Circulation

The general circulation is a global-scale wind system that largely determines the broad patterns of climate on Earth with wind being defined as the horizontal motion of air relative to the Earth's surface. At the global or synoptic scale the main forces that generate wind are pressure gradients, the Earth's rotation and friction.

In general, differential heating of the Earth's surface between the equator and the poles generates large pressure gradients in each hemisphere that initiate winds and lead to the formation of air circulation cells. The warm air heated by the surface near the equator rises and begins to move poleward, before cooling and subsiding. As the subsiding air nears the surface, it begins to move back toward the equator creating a circulation cell. The rotation of the Earth, as well as the non-uniform nature of the Earth's terrain, modifies this circulation. Instead of one simple circulation, or cell, in each hemisphere the circulation is broken down into three latitudinal cells in each hemisphere known as the Hadley cell, the Ferrel cell and the Polar cell.

Configuration of sea and land masses, seasonal and decadal variations and chaotic perturbations within the cells establish the climate and weather of a region.

## 2.3 El Niño Southern Oscillation

The ENSO is known to have significant impacts on the Australian climate, particularly on rainfall, temperature, tropical cyclone formation and the onset of the Australian monsoon (Sturman and Tapper, 1996). The Southern Oscillation Index (SOI) is a measure of the intensity of the ENSO phenomenon where values of greater than +8 represent La Niña conditions, values less than -8 represent El Niño conditions and values that lie between +8 and -8 are considered neutral. The SOI is derived from the mean sea-level pressure

difference between Tahiti and Darwin. The SOI is recorded as a running monthly mean with records extending from the present back to 1876.

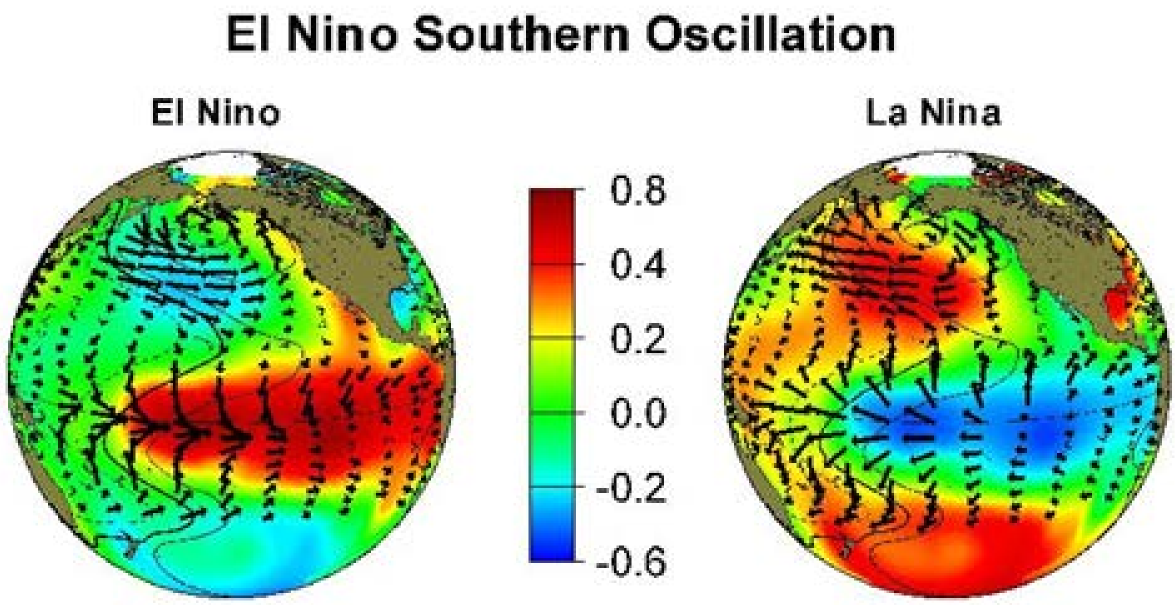



**Figure 1** **Sea surface temperature anomalies associated with the El Niño Southern Oscillation**

| | | |
|---|---|---|
| **Location:** Pacific Ocean | **Data source:** Image courtesy of the Bureau of Meteorology | **Units:** Sea surface temperature °C above or below the long term average |
| **Type:** Diagram | **Prepared by:** B. Lilley | **Date:** September 2011 |

The term El Niño refers to the extensive warming of the central and eastern tropical Pacific Ocean, which leads to a major shift in weather patterns across the Pacific (Figure 1). This occurs every three to eight years and is associated with a weaker Walker Circulation. The Walker Circulation is an east-west circulation of the atmosphere above the tropical Pacific, with air rising above warmer ocean regions (normally in the west), and descending over the cooler ocean areas (normally in the east). The easterly trade winds are part of the low-level component of the Walker Circulation. During El Niño years, the trade winds weaken and the central and eastern tropical Pacific warms up. This change in ocean temperature sees a shift in cloudiness and rainfall from the western to the central tropical Pacific Ocean.

El Niño periods are generally associated with below average rainfall, particularly in winter and spring, across eastern and northern Australia. Daily maximum temperatures during the winter/spring of an El Niño period tend to be above average. Reduced cloudiness and rainfall also means that overnight cooling is more rapid and effective, leading to below average overnight minimum temperatures.

La Niña is the reverse phase of the ENSO. It is associated with extensive cooling of the surface across the eastern and central equatorial Pacific Ocean and a stronger than average Walker Circulation. La Niña periods are generally associated with above average winter, spring and early summer rainfall across much of Australia. Daily maximum temperatures during a La Niña period tend to be below average, particularly in the months between October and March. Increased cloudiness and rainfall leads to increased overnight minimum temperatures. La Niña phases tend to have a stronger effect on temperatures than El Niño phases.

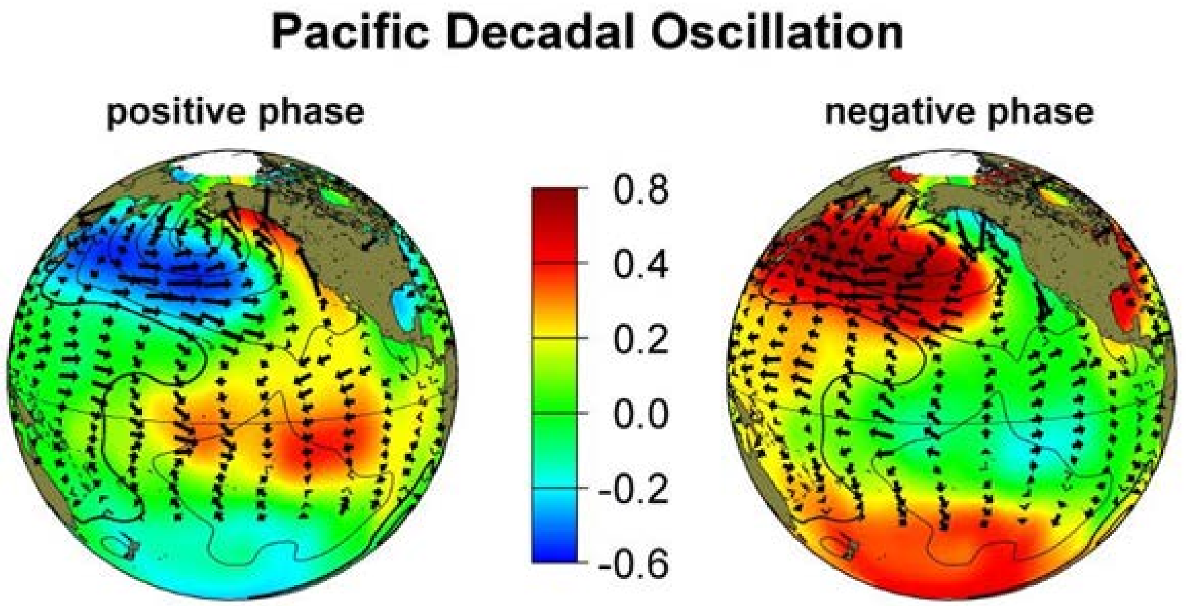
El Niño and La Niña events tend to begin in autumn, mature during winter and spring then begin to decay in summer, with the event generally ending in the autumn of the following year. As such any analysis of ENSO variations excludes the Autumn season as it is the build up and decay period and not representative of ENSO related effects. Events normally last for around one year; however, they can be shorter, or much longer. The greatest impact generally occurs during the winter/spring period. Figure 1 illustrates the typical affects of El Niño and La Niña on global circulation and sea surface temperatures.

## 2.4 Pacific Decadal Oscillation

The PDO is a long-lived El Niño-like pattern of Pacific region climate variability. The two main characteristics that distinguish the PDO from ENSO are:

1. Phase changes tend to occur at 20 to 30 year intervals while ENSO phases persist for only six to 18 months and occur over three to eight year periods.
2. The climatic signature of the PDO is located in the North Pacific with secondary signatures in the tropics, while ENSO is a tropical event.

The general influence of the PDO on global circulation and sea surface temperatures is illustrated in Figure 2.



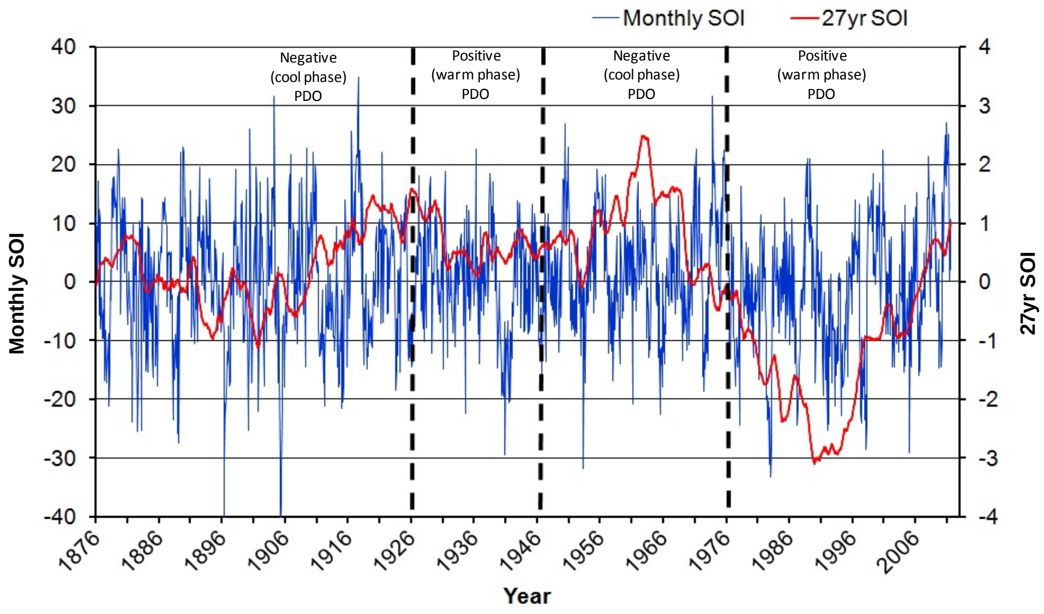

| | |
|---|---|
| **Figure 2** | **Sea surface temperature anomalies associated with the Pacific Decadal Oscillation** |

| | | |
|---|---|---|
| **Location:**<br>Pacific Ocean | **Data source:**<br>Image courtesy of the Bureau of Meteorology | **Units:**<br>Sea surface temperature °C above or below the long term average |
| **Type:**<br>Diagram | **Prepared by:**<br>B. Lilley | **Date:**<br>September 2011 |

A review of the scientific literature indicated that there have been only two full phases of the PDO in the past century (Mantua *et al.* 1997 and Minobe 1997):

- Negative (or cool) phase PDO regimes prevailed from 1890-1924 and again from 1947-1976; and
- Positive (or warm) phase PDO regimes dominated from 1925-1946 and from 1977 through to the mid-1990s and possibly up to 2008.

It is important to note that, while a clear signal of a northern to central Pacific Ocean oscillation with a 20 to 30 year phase interval can be observed in the climate record (Figure 3), the cause of the PDO is not well understood. In fact recent research indicates that the PDO may not be a dynamic aspect of the climate in its own right, instead being the signature of sea surface temperature fluctuations from a variety of sources, one of which is the ENSO (Schneider & Cornuelle, 2005). Consequently, forecasting the effect of the PDO is difficult for long term projections such as multi-decadal timescales. Notwithstanding this, recognition of the PDO is important because it shows that the climate is variable over time periods comparable to the length of a human's lifetime or projects timeline.




| | | |
|---|---|---|
| **Figure 3** | **Monthly Southern Oscillation Index (SOI) with the 27 year running mean of the SOI overlain in red. The 27 year running mean approximates the phase of the Pacific Decadal Oscillation (PDO) marked by the dashed lines.** | |
| **Location:**<br>N/A | **Data source:**<br>Image courtesy of the Bureau of Meteorology | **Units:**<br>SOI |
| **Type:**<br>Time-series chart | **Prepared by:**<br>A.Wiebe | **Date:**<br>July 2012 |

## 2.5 Interpretation of regional climate influences

The dynamic relationship between the different scales of atmospheric motion influence the conditions experienced at any given location. There are a number of synoptic scale features that affect the climate and weather of a region. The following section outlines the most significant Australian climate influences for the Project region.

The coastal climate of sub-tropical Queensland is largely driven by the southeast trade winds and their variations between seasons. These trade winds bring moist oceanic air masses to the coastal regions of eastern Australia and are the main drivers of rainfall and climate variability in the region. The trade wind also interacts with the Great Dividing Range influencing the formation of the east coast trough. The trough is linked to a heat low located near Cloncurry. The Cloncurry (east coast) and Pilbara (west coast) heat lows are linked with the on-set of the Australian monsoon.

The position of the sub-tropical ridge[1] varies over the continent with the seasons, which in turn, influences the continental penetration of systems such as cold fronts and the monsoon trough. During the cooler months the ridge is located over central parts of the country, leading to generally dry and stable conditions for central and northern parts. As the continent heats up and summer approaches the sub-tropical ridge moves to the south of the continent. The southward movement of the ridge is related through atmospheric circulation to the development of the monsoon over northern Australia.

The Australian monsoon is a major driver of regional rainfall in the tropics and sub-tropics. The monsoon refers to the reversal of winds across the tropical region of Australia from a drier south-easterly trade-wind flow to a moist tropical north-westerly flow. The onset mechanism for the Australian monsoon is complex and not fully understood; however, steady development of the Cloncurry and Pilbara heat-lows are a pre-requisite for the development of the monsoon circulation. In broad terms as the continent heats up and the sub-tropical ridge migrates to the south of the continent, an area of low pressure is created, which effectively draws the monsoon trough over northern Australia. The mean monsoon onset date at Darwin is 28 December, with the earliest onset on 22 November and the latest 25 January (Drosdowsky, 1996).

The east coast trough and associated low pressure systems form largely due to the intense heating of Australia's northern regions during the summer months. Terrain and the southeast trade winds also play a part in the formation of the trough. The movement of the trough can provide sufficient instability to initiate thunderstorm activity. The presence of an upper level trough can further enhance the effect of the surface trough leading to widespread rainfall over Queensland.

The Australian monsoon has an active and a break phase, where the active phase tends to bring heavy rains and movement of the trough poleward, while the break phase tends to bring lighter rains and a retreat of the trough towards the equator. This motion is thought to be influenced by the Madden-Julian Oscillation (MJO) an eastward pulse of convection that occurs on average every 30 to 90 days and tends to coincide with the active phases of the monsoon. The interaction between the ENSO, the monsoon and the MJO tends to dominate the meteorology in the tropics. These interactions are largely responsible for heavy rains and the poleward migration of tropical air masses, which generally bring warmer temperatures and high levels of relative humidity to the tropics, sub-tropics and at times to the mid-latitudes.

The MJO can also modulate the trade winds during the winter and spring, when it is active over the Indian monsoon region generating a mean region of low pressure in the Indian Ocean, which contrasts with the mean high pressure region to the east of Australia. This imbalance can cause a net increase in the trade wind flow and enhance rainfall along the east coast of Australia (Klingaman 2012).

[1] The sub-tropical ridge runs across a belt of high pressure that encircles the globe in the middle latitudes. It is part of the global circulation of the atmosphere. The sub-tropical ridge brings dry and stable conditions to large parts of Australia. The sub-tropical ridge is a dynamic feature of the atmospheric circulation, which is present all year round (BoM, 2012).

# 3. Regional climate assessment

## 3.1 Method

### 3.1.1 Overview

To investigate the likely characteristics of the climate in the future, observations of past climate variability were analysed alongside the Projections of an array of climate models. This study has focussed on three main areas:

1. The variability of key climate parameters over approximately 120 years at Emerald:
   - Temperature
   - Rainfall
   - Solar radiation
   - Evaporation
   - Relative humidity

   The investigation also included analysis of wind speed and tropical cyclone data, and featured an analysis of each parameter based on season and the affect of the ENSO and PDO.
2. Climate model projections for the region were analysed to find a potential range of values for the key parameters in 2035
3. The future climate has been considered in terms of:
   - The variability and extremes of climate over the shorter term (i.e. 10–20 year period) based on projected trends in the PDO and ENSO and past variability and extremes
   - Climate averages in the medium term based on model projections for 2035 that take into account warming caused by greenhouse gas (GHG) emissions
   - Comparison of model projections with the observations of the past climate. The annual and seasonal outlooks are compared and take into consideration the effect of the ENSO and PDO

### 3.1.2 Historical Climate

The analysis of the historical variability of the regional climate was based on data from the following sources:

- Solar radiation, relative humidity and evaporation were analysed using Patched Point Datasets (PPD) for the period 1889 to 2012 at the Emerald Department of Primary Industries (DPI) field station. The PPD use original measurements for a particular meteorological station, but with interpolated data used to fill ('patch') any gaps in the observation record (SILO, 2011)
- Rainfall and temperature were analysed using combined Bureau of Meteorology (BoM) monitoring data from the Emerald Post Office (1889-1992) and the Emerald Airport (1992-2012)
- Analysis of the occurrence of tropical cyclones was based on Bureau of Meteorology cyclone track data from 1906-2007
- Wind speed analysis was based on data from the US National Climate Data Centre (NCDC), extracted at the US Air Force Catalog station number 943630 (Emerald Airport). The data is from 1957-1964 (two records per day) and from 1973-2012, averaging 2-4 records per day until the 1990s, when records improve to 6 or more records per day

The analysis provides an assessment of temperature, solar radiation, rainfall, relative humidity, evaporation, tropical cyclone activity and the occurrence of strong and dangerous winds in the region of the Taroborah Coal Project. Variation in temperature and rainfall for each season and for each phase of the ENSO and PDO have been investigated, excluding the autumn season as it is considered a transition period and not representative of ENSO and PDO influences. Analysis of climate variables has been provided seasonal and annual timescales and for variations in climate due to changes in global circulations such as the shift between El Niño, neutral and La Niña phases of the ENSO and warm and cool phases of the PDO.

### 3.1.3 Future Climate Assessment

The Projected future climate was assessed based on analysis of the outputs of 23 Global Circulation Models (GCM). Projections have been made for the year 2035 to identify trends over the medium term, and are based on the Intergovernmental Panel on Climate Change's (IPCC) A2 GHG emissions scenario[2]. This scenario assumes a 'business as usual' trend in population growth, economic growth and demand for energy.

The model data analysed for this study was the OzClim data set for the A2 emissions scenario. The Queensland Government also used the OzClim model data to produce a climate change report for the central Queensland region (Queensland Government, 2009). The OzClim data set is generated from 23 coupled GCMs supplied by modelling centres from across the world including CSIRO and BoM. The models were run at various resolutions, and to facilitate comparison, were rescaled in OzClim to a grid with 0.25° resolution in latitude and longitude over Australia. Of the 23 models in the data set, 17 provide projections of all the variables included in this assessment and have been used here.

There is significant variation between OzClim model predictions for the A2 emissions scenario due to differences in equations and parameterisations. In the future, the range of projections will narrow as the models improve and uncertainty in climate dynamics diminishes. To reduce variability in the model predictions, an ensemble approach was taken in which data from relevant models was combined. An area representative of the Project region was extracted by Katestone from each model output for each climate characteristic. These subsets spanned 1° latitude by 1° longitude (4 by 4 grid points, giving 16 grid points in total) and were centred on the Taroborah Coal Project site. The mean, minimum and maximum data over each subset were extracted and averaged over all the models, to provide estimates using data from the entire ensemble of models

### 3.1.4 Comparison of projected and past climate

A description of the future regional climate is provided by comparing the Projected climate characteristics for 2035 to observed and interpolated data for the past 110 years. The Projected averages for each climate variable have been placed in the context of past observations and discussed in terms of seasonal variations as well as the ENSO and PDO.

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[2] The A2 scenario was based on: relatively slow demographic transition and relatively slow convergence in regional fertility patterns; relatively slow convergence in inter-regional GDP per capita differences; relatively slow end-use and supply-side energy efficiency improvements; delayed development of renewable energy; and no barriers to the use of nuclear energy (Nebojsa and Swart, 2000).

## 3.2 Historical climate

### 3.2.1 Identification of ENSO and PDO Phases and their Effect on the Climate

Climate statistics have been analysed to identify the El Niño and La Niña periods of the ENSO and their variability by PDO phase. Only canonical El Niño and La Niña periods according to the BoM classification scheme have been identified. The canonical periods are defined as the strongest ENSO events on record that display the classic autumn to autumn evolution of the ENSO phenomenon (Rasmusson and Carpenter 1982). Table 1 presents the years when the canonical El Niño and La Niña periods were recorded during cool phases of the PDO since 1900 and indicates the strength of the SOI, the sea surface temperature gradient between the eastern and western Pacific Ocean and the relative impact of the El Niño or La Niña on the region's climate for the year. Table 2 presents the same information for the warm phases of the PDO since 1900.

**Table 1 El Niño and La Niña periods and their impacts during cool phases of the PDO from 1900 to 2011**

| Period | ENSO | Years | Impact on | | |
|---|---|---|---|---|---|
| | | | Southern Oscillation Index | Sea surface temperature | Climate |
| 1900 - 1924 | La Niña periods | 1903-04 | Moderate | N/A | Moderate to strong |
| | | 1906-07 | Weak to Moderate | N/A | Moderate |
| | | 1909-11 | Moderate to Strong | N/A | Strong |
| | | 1916-18 | Strong | N/A | Strong |
| | | 1924-25 | Weak | N/A | Weak |
| | El Niño periods | 1902-03 | Weak | N/A | Very strong |
| | | 1905-06 | Strong | N/A | Moderate |
| | | 1911-12 | Moderate to strong | N/A | Moderate to strong |
| | | 1913-14 | Weak | N/A | Weak to moderate |
| | | 1914-15 | Strong | N/A | Strong |
| | | 1919-20 | Weak to moderate | N/A | Strong |
| 1947 - 1976 | La Niña periods | 1949-51 | Moderate to strong | Moderate | Strong |
| | | 1954-57 | Moderate | Moderate | Strong |
| | | 1964-65 | Moderate | Moderate | Moderate |
| | | 1970-72 | Moderate | Moderate | Weak to moderate |
| | | 1973-76 | Moderate to strong | Moderate to strong | Strong |
| | El Niño periods | 1951-52 | Weak | Weak | Strong |
| | | 1957-58 | Weak | Weak to moderate | Moderate to strong |
| | | 1963-64 | Weak | Weak | Moderate |
| | | 1965-66 | Moderate to strong | Moderate | Moderate |
| | | 1969-70 | Weak | Weak | Moderate |
| | | 1972-73 | Moderate | Moderate to strong | Strong |

**Table 2 El Niño and La Niña periods and their impacts during warm phases of the PDO from 1900 to 2011**

| Period | ENSO | Year | Impact on | | |
|---|---|---|---|---|---|
| | | | Southern Oscillation Index | Sea surface temperature | Climate |
| 1925 - 1946 | La Niña periods | 1928-30 | Weak to moderate | N/A | Weak (dry) |
| | | 1938-39 | Moderate | N/A | Weak (dry) |
| | | 1942-43 | Weak | N/A | Moderate |
| | El Niño periods | 1925-26 | Moderate | N/A | Strong |
| | | 1940-41 | Strong | N/A | Strong |
| | | 1941-42 | Strong | N/A | Moderate to strong |
| | | 1946-47 | Weak to moderate | N/A | Strong |
| 1977 - 2011 | La Niña periods | 1988-89 | Moderate | Moderate to strong | Strong |
| | | 1998-01 | Moderate | Moderate | Moderate to strong |
| | | 2007-08 | Weak to moderate | Moderate | Moderate |
| | | 2008-09 | Weak to moderate | Weak | Weak |
| | | 2010-11 | Strong | Strong | Strong |
| | El Niño periods | 1977-78 | Moderate | Weak | Moderate to strong |
| | | 1982-83 | Very strong | Very strong | Very strong |
| | | 1987-88 | Moderate to strong | Moderate to strong | Weak |
| | | 1991-92 | Moderate to strong | Moderate to strong | Strong |
| | | 1993-94 | Moderate | Weak | Very weak |
| | | 1994-95 | Strong | Weak to moderate | Strong |
| | | 1997-98 | Strong | Very strong | Weak |
| | | 2002-03 | Weak | Weak to moderate | Very strong |
| | | 2006-07 | Weak | Weak | Very strong |
| | | 2009-10 | Weak to moderate | Moderate | Weak |

Table 3 shows the frequency of La Niña, El Niño and Neutral ENSO conditions for all years that coincide with a cool phase PDO and a warm phase PDO. A distinct change in frequency from a La Niña dominated climate to an El Niño dominated climate is seen as the PDO phase changes from cool to warm. The frequency of neutral years; however, remains the same across all phases.

A time series of the SOI between January 1876 and August 2011 and the 27 year running average of the SOI, which corresponds to the mean PDO phase length is presented in Figure 3. Figure 3 also shows the years when the PDO is thought to have shifted phases, i.e. during the mid-1920s, the mid-1940s and the mid 1970s.

The analysis indicates that the cool phases of the PDO are generally dominated by positive values of the SOI (or La Niña periods) while warm phases are generally dominated by negative values of the SOI (or El Niño periods). A comparison of the proportion of months of the neutral, El Niño and La Niña phases in Australia for each known phase of the PDO is presented in Table 3.

**Table 3 Frequency of La Niña, El Niño and Neutral ENSO conditions by PDO phase**

| PDO | ENSO | Frequency of occurrence |
|---|---|---|
| Cool | La Niña | 26% |
| | El Niño | 18% |
| | Neutral | 56% |
| Warm | La Niña | 19% |
| | El Niño | 24% |
| | Neutral | 57% |

On average, the regional climate tends to be cool and dry in the winter and warmer and wetter in the summer, with the spring and autumn temperatures and rainfall falling between these conditions. The ENSO and PDO add further complexity to the seasonal shift in climate and, in particular, have a strong influence on temperature and rainfall.

In general, El Niño events tend to lead to warmer, drier daytime conditions and La Niña events tend to lead to cooler, wetter conditions. The ENSO tends to occur on a three to seven year timescale and is superimposed by the longer term PDO, which occurs on a 20 to 30 year timescale. The frequency of El Niño and La Niña events appears to be moderated by the PDO where La Niña events tend to dominate during cool phase PDO and El Niño events are dominant during warm phase PDO. A comparison of temperature and rainfall seasonal averages and variance illustrates that there is a significant amount of variability in the climate from year to year as the ENSO shifts between El Niño, neutral and La Niña phases, along with variability between the frequencies of the ENSO phases illustrated by the PDO.

### 3.2.2 Temperature

The analysis indicates that a significant effect on temperature due to the ENSO is on the number of days when the maximum daily temperature exceeds 30°C and 35°C. During a cool PDO phase, El Niño years on average have 4 more days above 30°C than La Niña and neutral years, and 28 more days above 35°C than La Niña years (Table 4). During a warm PDO phase, the difference is even larger, with El Niño years on average including 26 more days above 30°C than La Niña years, and 33 more days above 35°C than La Niña years. Neutral years tend to have a number of hot days intermediate between those of El Niño and La Niña years.

**Table 4 Average number of days per year above 30 °C and 35 °C (excluding Autumn)**

| PDO phase | Average number of days with maximum temperature > 30 °C | | | Average number of days with maximum temperature > 35 °C | | |
|---|---|---|---|---|---|---|
| | El Niño | La Niña | Neutral | El Niño | La Niña | Neutral |
| Cool | 130 | 126 | 126 | 59 | 31 | 46 |
| Warm | 144 | 118 | 138 | 63 | 30 | 55 |

During a warm PDO phase daily minimum temperatures tend to be 0.5 - 0.9°C higher on average than during a cool PDO phase, regardless of the ENSO phase (Table 5). Additionally, during a warm PDO phase the daily maximum temperatures during an El Niño event are on average 0.5°C higher than during a La Niña event.

**Table 5 Minimum and maximum daily temperatures by PDO and ENSO phase (excluding Autumn)**

| PDO phase | ENSO phase | Minimum daily temperature (°C) | | Maximum daily temperature (°C) | |
|---|---|---|---|---|---|
| | | Minimum | Average | Average | Maximum |
| Cool | El Niño | -3.9 | 14.5 | 30.0 | 46.2 |
| | La Niña | -2.7 | 14.7 | 29.1 | 42.8 |
| | Neutral | -3.9 | 14.6 | 29.4 | 44.5 |
| Warm | El Niño | -3.6 | 15.4 | 30.2 | 45.6 |
| | La Niña | -1.7 | 15.2 | 28.7 | 41.9 |
| | Neutral | -1.7 | 15.5 | 29.8 | 45.5 |

### 3.2.3 Rainfall

La Niña conditions on average contribute much more rain than El Niño conditions during winter, spring and summer regardless of PDO phase (Table 6). Cool PDO phase La Niña summers average 386 mm of rain and are on average wetter than any season during any PDO or ENSO phase. Warm phase El Niño winters average 45 mm of rain and are on average drier than any season during any PDO or ENSO phase.

**Table 6 Average rainfall (mm) by season, PDO phase and ENSO phase**

| PDO phase | Season[1] | ENSO phase | | |
|---|---|---|---|---|
| | | El Niño | La Niña | Neutral |
| Cool | Winter | 52 | 86 | 90 |
| | Spring | 66 | 173 | 128 |
| | Summer | 244 | 386 | 339 |
| Warm | Winter | 45 | 109 | 76 |
| | Spring | 91 | 180 | 125 |
| | Summer | 260 | 337 | 234 |

**Note**:
[1] Autumn was excluded from the ENSO analysis as it is a transition period

Table 7 shows that La Niña years see more rain days in winter, spring and summer than El Niño years during both PDO phases. The largest seasonal difference occurs for spring during cool PDO phases, for which there are on average 11 more rain days in La Niña years than El Niño years. Neutral years tend to have a number of rain days intermediate between those of El Niño and La Niña years.

**Table 7 Average number of rain days (> 0.2 mm) by season, PDO phase and ENSO phase**

| PDO phase | Season[1] | ENSO phase | | |
|---|---|---|---|---|
| | | El Niño | La Niña | Neutral |
| Cool | Winter | 6 | 10 | 10 |
| | Spring | 8 | 19 | 13 |
| | Summer | 21 | 26 | 24 |
| Warm | Winter | 6 | 12 | 8 |
| | Spring | 10 | 16 | 14 |
| | Summer | 20 | 25 | 20 |

**Note**:
[1] Autumn was excluded from the ENSO analysis as it is a transition period

A significant finding is that not only the number of rain days, but also the proportion of heavy rain days (greater than 25 mm) is higher during winter, spring and summer during La Niña events compared to El Niño events (Table 8).

**Table 8 Percentage of rain days greater than 25 mm by season, PDO phase and ENSO phase**

| PDO phase | Season[1] | ENSO phase | | |
|---|---|---|---|---|
| | | El Niño | La Niña | Neutral |
| Cool | Winter | 9% | 9% | 9% |
| | Spring | 7% | 9% | 10% |
| | Summer | 12% | 18% | 16% |
| Warm | Winter | 5% | 11% | 12% |
| | Spring | 8% | 15% | 9% |
| | Summer | 15% | 16% | 13% |

**Note**:
[1] Autumn was excluded from the ENSO analysis as it is a transition period

### 3.2.4 Humidity, solar radiation and evaporation

The variability in relative humidity, solar radiation and evaporation in relation to PDO and ENSO phases are presented in Table 9. The SILO dataset only lists relative humidity at the daily maximum and minimum temperatures. The data shows that ENSO and PDO phase has only a minor influence on relative humidity measured at the maximum temperature. However, there is a slight variation in relative humidity at the minimum temperature during cool phase PDO when the relative humidity is higher by approximately 2-4% compared to the warm PDO phase. This is likely due to the increased rainfall during these periods. Evaporation is higher during El Niño periods, which is related to the higher level of solar radiation reaching the surface during El Niño periods. There appears to be no significant variation in solar radiation or evaporation between PDO phases.

**Table 9 Average relative humidity, solar radiation and evaporation by PDO phase and ENSO phase**

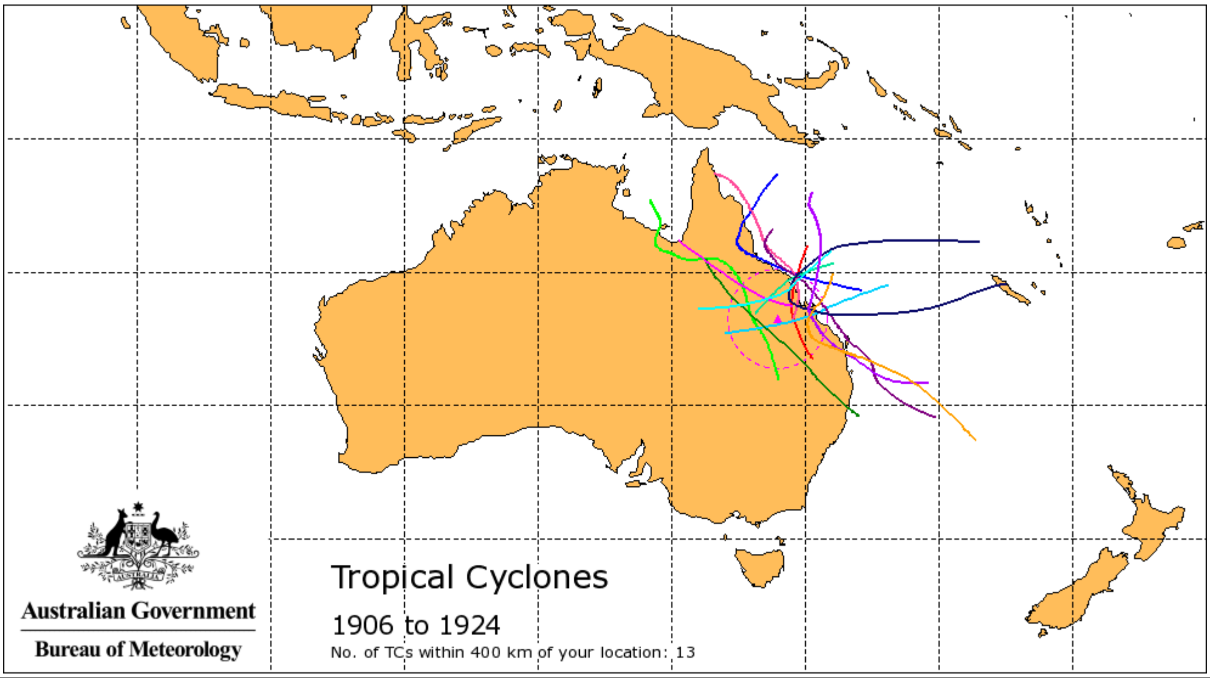
| PDO phase | ENSO phase[a] | Relative humidity (%) | | Solar radiation ($MJ/m^2$) | Evaporation (mm/day) |
|---|---|---|---|---|---|
| | | At maximum temperature | At minimum temperature | | |
| Cool | El Niño | 37 | 89 | 22 | 6.2 |
| | La Niña | 41 | 92 | 20 | 5.9 |
| | Neutral | 40 | 91 | 21 | 6.0 |
| | Undefined | 44 | 94 | 18 | 5.2 |
| Warm | El Niño | 36 | 85 | 21 | 6.4 |
| | La Niña | 42 | 90 | 20 | 5.5 |
| | Neutral | 39 | 88 | 21 | 6.2 |
| | Undefined | 42 | 90 | 18 | 5.3 |

Note:

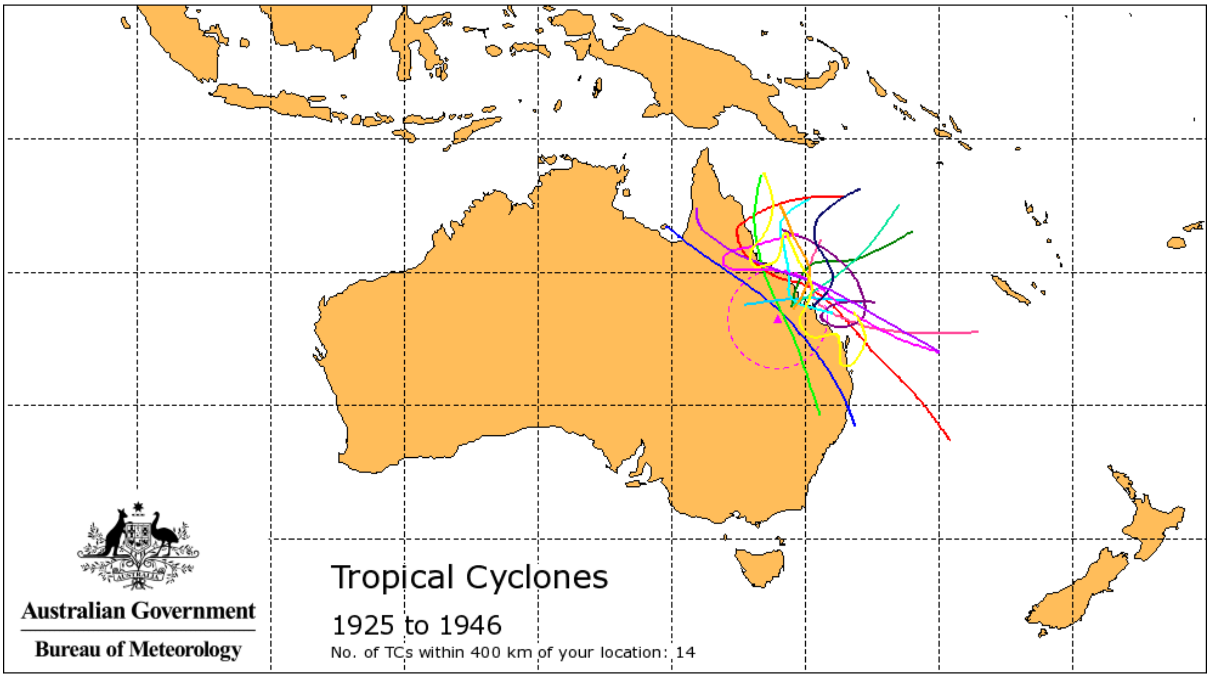
[a] Data for El Niño, La Niña and neutral phases excludes autumn. Data for the "Undefined" category is for autumn only.

### 3.2.5 Tropical Cyclone Activity

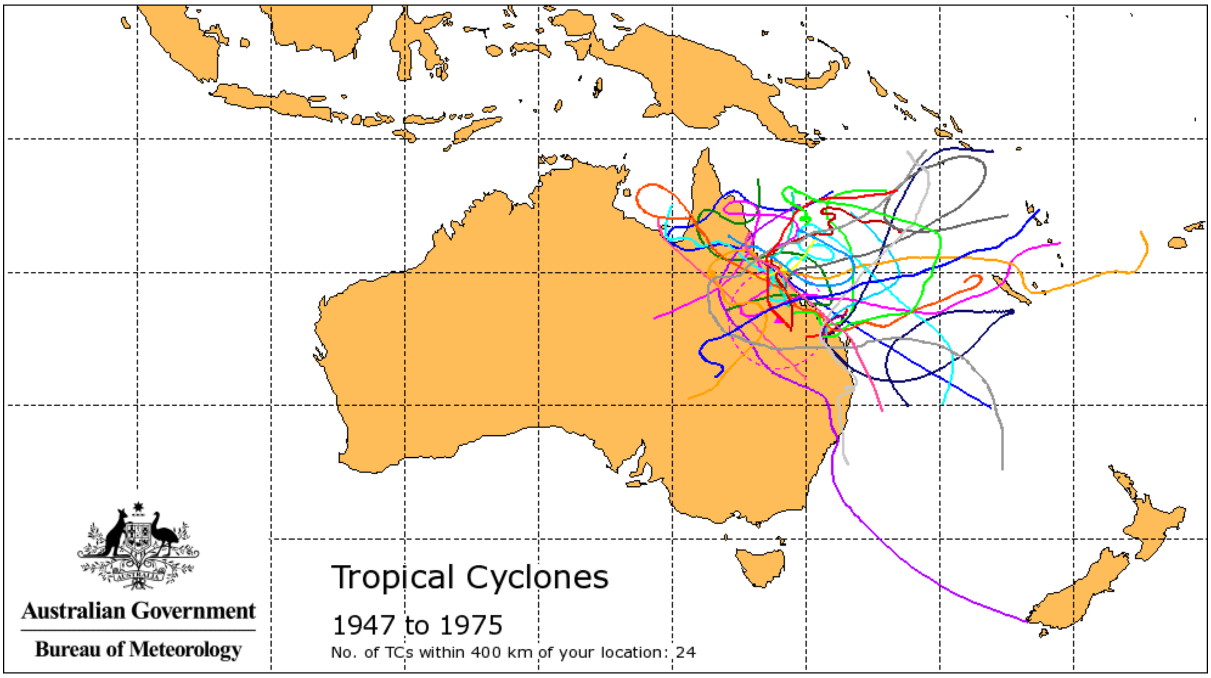
Tropical cyclone activity within 400 km of the Project area has been analysed based on the phases of the PDO. Storm tracks for PDO warm phases and cool phases are presented in Figure 4 to Figure 7. A total of 63 tropical cyclones have tracked within 400 km of the Project area in the period 1906-2007. A significant finding of the analysis is that 24 tropical cyclones were tracked within 400 km of the Project during the previous cool phase of the PDO between 1947 and 1976. In contrast, only 13 cyclones were recorded during the 1906 to 1923 cool phase of the PDO. Comparatively for the PDO warn phase 14 and 12 cyclones were recorded during the 1925 to 1945 and 1976 to 2006, respectively. This analysis suggests that the frequency of tropical cyclone events may be higher during the cool phase of the PDO. Tropical cyclones are more frequent in La Niña years than El Niño years (see Table 15).



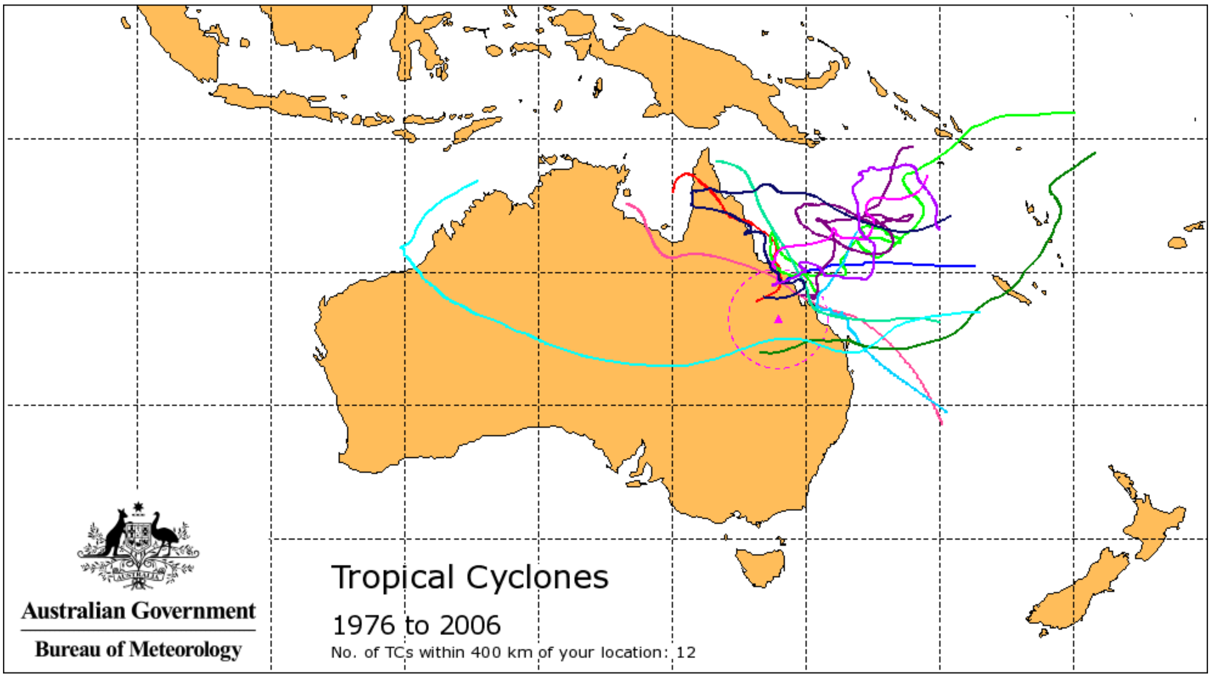

| **Figure 4** | **Historical tropical cyclones affecting the study area** | | |
|---|---|---|---|
| **Location:**<br>Taroborah Coal Project site, QLD | **Period:**<br>1906 - 1924 | **Data source:**<br>BoM | **Units:**<br>-- |
| **Type:**<br>Climate map | **PDO:**<br>Cool phase | **Prepared by:**<br>Adam Thomas | **Date:**<br>November 2012 |




| **Figure 5** | **Historical tropical cyclones affecting the Study Area** | | |
|---|---|---|---|
| **Location:**<br>Taroborah Coal Project site, QLD | **Period:**<br>1925 - 1946 | **Data source:**<br>BoM | **Units:**<br>-- |
| **Type:**<br>Climate map | **PDO:**<br>Warm phase | **Prepared by:**<br>Adam Thomas | **Date:**<br>November 2012 |




| **Figure 6** | **Historical tropical cyclones affecting the Study Area** | | |
|---|---|---|---|
| **Location:** Taroborah Coal Project site, QLD | **Period:** 1947 - 1975 | **Data source:** BoM | **Units:** -- |
| **Type:** Climate map | **PDO:** Cool phase | **Prepared by:** Adam Thomas | **Date:** November 2012 |




| **Figure 7** | **Historical tropical cyclones affecting the Study Area** | | |
|---|---|---|---|
| **Location:** Taroborah Coal Project site, QLD | **Period:** 1976 - 2006 | **Data source:** BoM | **Units:** -- |
| **Type:** Climate map | **PDO:** Warm phase | **Prepared by:** Adam Thomas | **Date:** November 2012 |

## 3.3 Future climate assessment

### 3.3.1 Climate change and climate variability

According to the CSIRO, important advances in climate science at both the global and regional scale in recent years have enabled us to investigate with increasing confidence the effect various greenhouse gas (GHG) emission scenarios may have on the future climate. The key uncertainties that will continue to qualify projections of future climate are (CSIRO, 2012):

- The level of future GHG emissions from anthropogenic sources
- The precise response of the Earth's climate system to those emissions

At present, global GHG emissions from anthropogenic sources are growing strongly, with observed emissions during the past decade exceeding almost all assumed emission scenarios generated in the late 1990s. The extent and rate to which the climate is affected by those emissions will depend on whether global emissions continue to rise steeply or emitters can manage to control and reduce their emissions. For this study, projections are based on the IPCC's A2 emissions scenario, which assumes a 'business as usual' trend in population growth, economic growth and demand for energy (Nebojsa and Swart, 2000).

There is a need to distinguish between the average climate projected for the future and the variability within the climate experienced along the way. Climate model projections serve the purpose of quantifying the average state of the atmosphere for some point in the future. Each model has a different outcome and their combined outputs provide an ensemble average for the climate. It is the difference in this projected average state from the observed average state at present that is termed climate change. Climate variability on the other hand is the range of climatic states experienced between these two average states.

In the near-term (20 – 30 years) it is variability in the climate system that poses the most significant risk to infrastructure, development and management of existing and proposed projects. This is typically the operational lifespan of these projects, hence they will not be operating in the same manner or at all by the time the Projected climate becomes the average condition.

Climate change is therefore the long-term variation in the average state and climate variability is the near-term variability between climatic states. To manage and mitigate the effects of a changing climate the variability between these states needs to be identified and the influence on the operations of a project quantified.

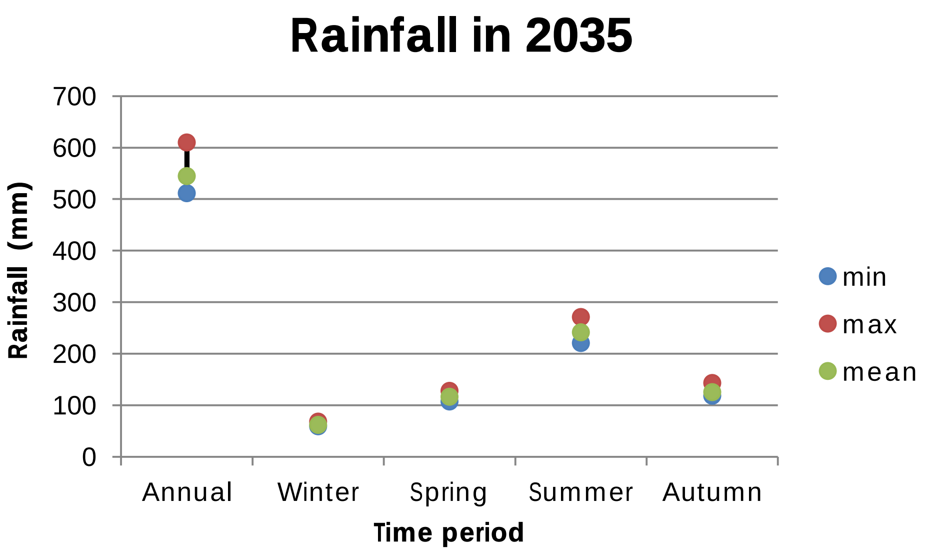
### 3.3.2 Climate Outlook based on Model Projections and GHG Emissions

The following sections present the predictions of the OzClim models for the average values of various meteorological parameters in 2035[3]. The minimum, maximum and mean predictions are displayed in order to show the range of predictions made by the various models. The ensemble average values for the minimum, maximum and mean of each climate parameter along with associated standard deviations are presented in Appendix A.

[3] The year 2035 is the future date for which climate modelling information is available that best matches the development of the Taroborah mine.

### 3.3.3 Rainfall

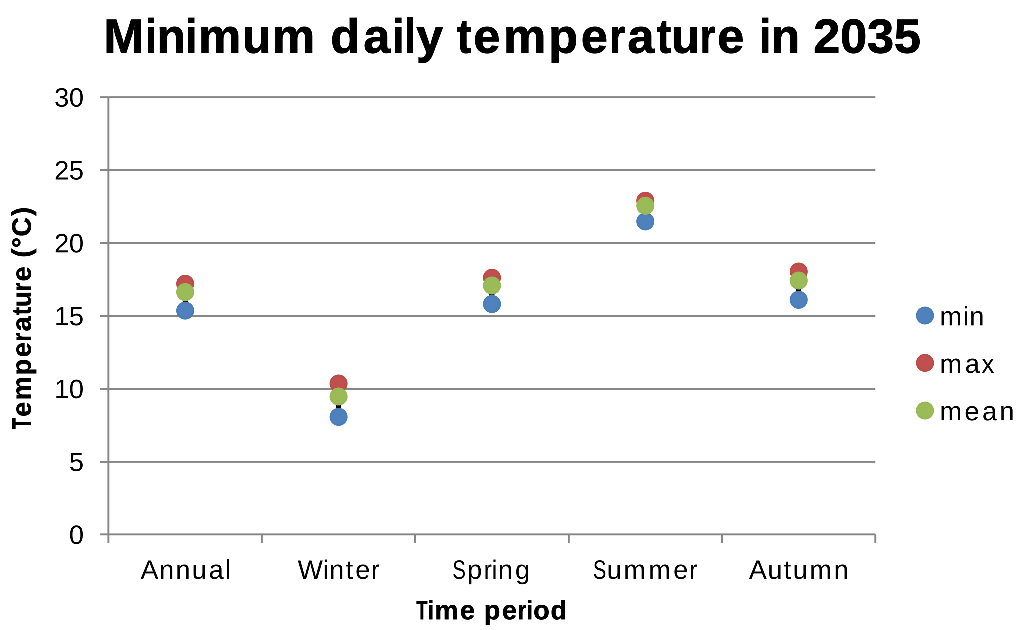
The Projected annual and seasonal rainfall for 2035 is given in Figure 8. The large range in projected annual rainfall is the result of the fact it is the sum of all the seasons, each with a projected rainfall. Summer is expected to be the wettest season and winter the driest. The largest variation in rainfall is associated with the summer and autumn seasons. Predictions for average summer rainfall vary from approximately 200 to 280 mm, whereas predictions for average winter rainfall vary between approximately 60-80 mm. Average annual rainfall is predicted to lie between 500 and 600 mm.



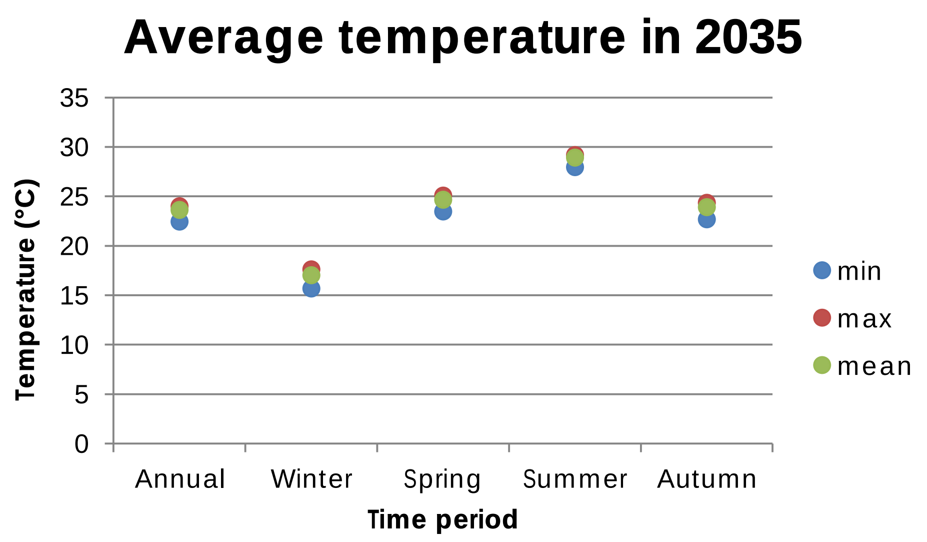

| **Figure 8** | **Projected rainfall in 2035** | | |
|---|---|---|---|
| **Location:**<br>Taroborah Coal Project Site, QLD | **Period:**<br>2035 | **Data source:**<br>OzClim – ranges reflect variations in predictions from climate models. | **Units:**<br>mm |
| **Type:**<br>Plot | | **Prepared by:**<br>Adam Thomas | **Date:**<br>November 2012 |

### 3.3.4 Temperature

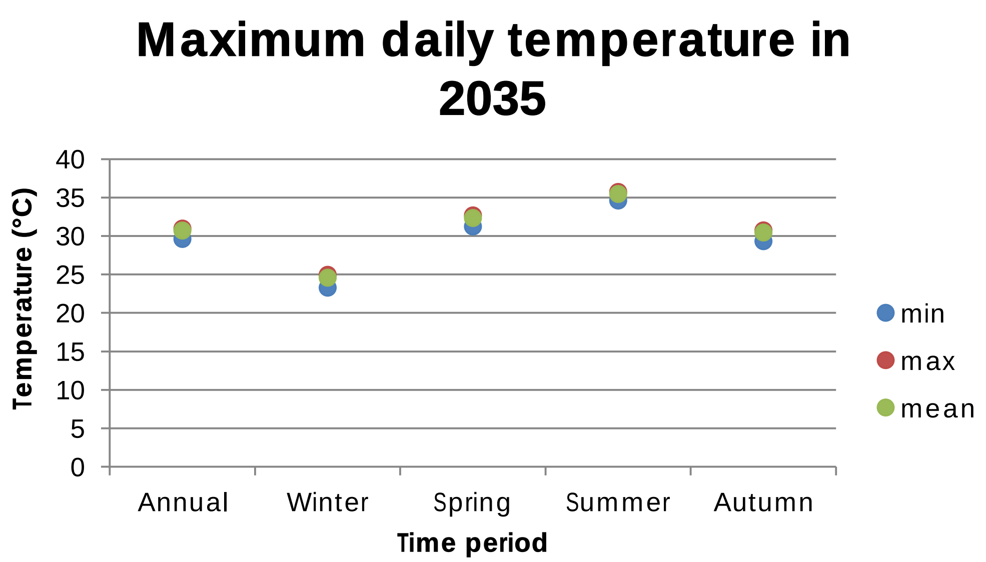
The OzClim models split temperature into three categories; each contains a projection of a minimum, maximum and average temperature. The results are presented in Figure 9 to Figure 11. The results show the expected seasonal variation from cooler winters through to warmer summers. The maximum temperature shows a difference of approx 11°C between summer and winter. The minimum temperature shows a 13°C difference between summer and winter. The average shows an 11°C difference between summer and winter.




| **Figure 9** | **Projected minimum temperature 2035** | | |
|---|---|---|---|
| **Location:** Taroborah Coal Project Site, QLD | **Period:** 2035 | **Data source:** OzClim – ranges reflect variations in predictions from climate models. | **Units:** °C |
| **Type:** Plot | | **Prepared by:** Adam Thomas | **Date:** November 2012 |




| | | | |
|---|---|---|---|
| **Figure 10** | **Projected average temperature 2035** | | |
| **Location:**<br>Taroborah Coal Project Site, QLD | **Period:**<br>2035 | **Data source:**<br>OzClim – ranges reflect variations in predictions from climate models. | **Units:**<br>°C |
| **Type:**<br>Plot | | **Prepared by:**<br>Adam Thomas | **Date:**<br>November 2012 |

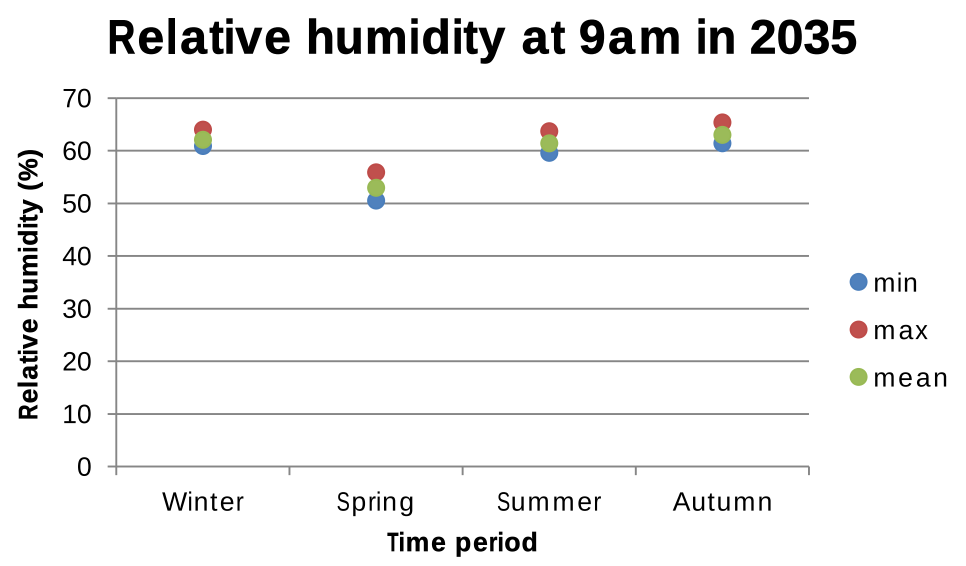



| | | | |
|---|---|---|---|
| **Figure 11** | **Projected maximum temperature 2035** | | |
| **Location:**<br>Taroborah Coal Project Site, QLD | **Period:**<br>2035 | **Data source:**<br>OzClim – ranges reflect variations in predictions from climate models. | **Units:**<br>°C |
| **Type:**<br>Plot | | **Prepared by:**<br>Adam Thomas | **Date:**<br>November 2012 |

### 3.3.5 Relative humidity

The models produce three projected values for the relative humidity, which are the relative humidity at 9am, relative humidity at 3pm and average relative humidity. The model predictions for these parameters are summarised in Figure 12 to Figure 14.

The models predict little seasonal variation in relative humidity. The average relative humidity is generally higher than the 9am relative humidity, which is in turn higher than the 3 pm relative humidity. Spring has the largest variation of the seasons in predicted relative humidity at 9am and on average. The largest variations in model predictions occur for average relative humidity at 3pm for all seasons.




| **Figure 12** | **Projected average relative humidity at 9am in 2035** | | |
|---|---|---|---|
| **Location:** Taroborah Coal Project Site, QLD | **Period:** 2035 | **Data source:** OzClim – ranges reflect variations in predictions from climate models. | **Units:** % |
| **Type:** Plot | | **Prepared by:** Adam Thomas | **Date:** November 2012 |

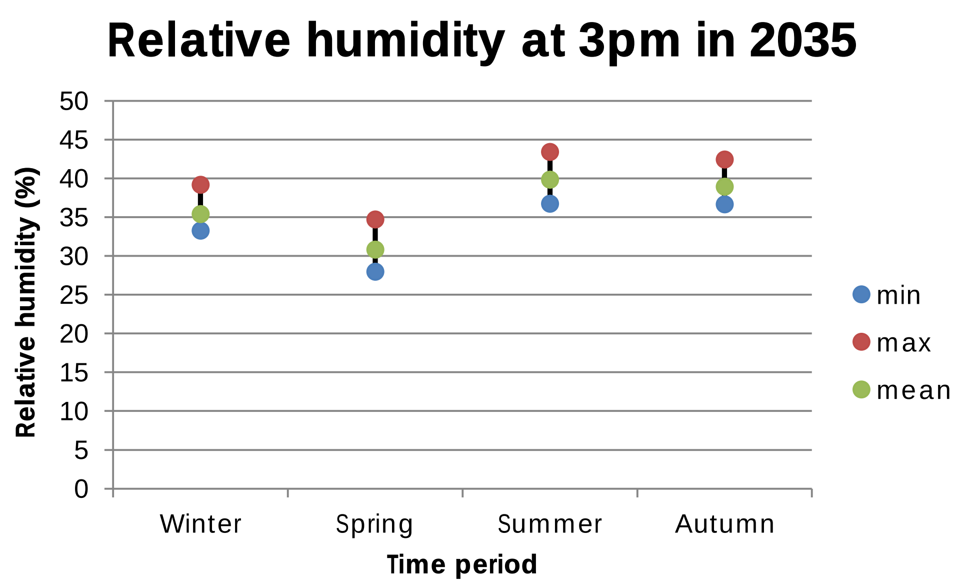



**Figure 13** Projected average relative humidity at 3pm in 2035

| **Location:** Taroborah Coal Project Site, QLD | **Period:** 2035 | **Data source:** OzClim – ranges reflect variations in predictions from climate models. | **Units:** % |
|---|---|---|---|
| **Type:** Plot | | **Prepared by:** Adam Thomas | **Date:** November 2012 |

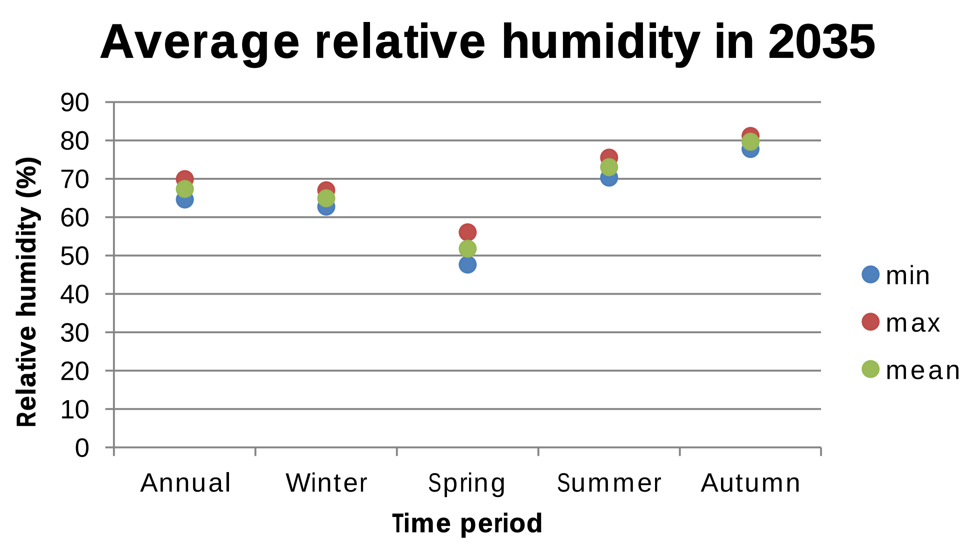



**Figure 14** Projected average relative humidity in 2035

| **Location:** Taroborah Coal Project Site, QLD | **Period:** 2035 | **Data source:** OzClim – ranges reflect variations in predictions from climate models. | **Units:** % |
|---|---|---|---|
| **Type:** Plot | | **Prepared by:** Adam Thomas | **Date:** November 2012 |

### 3.3.6 Evaporation

Evaporation is defined as the total quantity of water evaporated (in mm) over a given time period. The Projected average values for evaporation for each season and annually in 2035 are presented in Figure 15.

Evaporation in spring and summer is predicted to be higher than in autumn and winter. This is a consequence of the fact that summer is the warmest and wettest season; and winter the driest and coolest season. Average annual evaporation is predicted to range between approximately 2200 – 2300 mm.

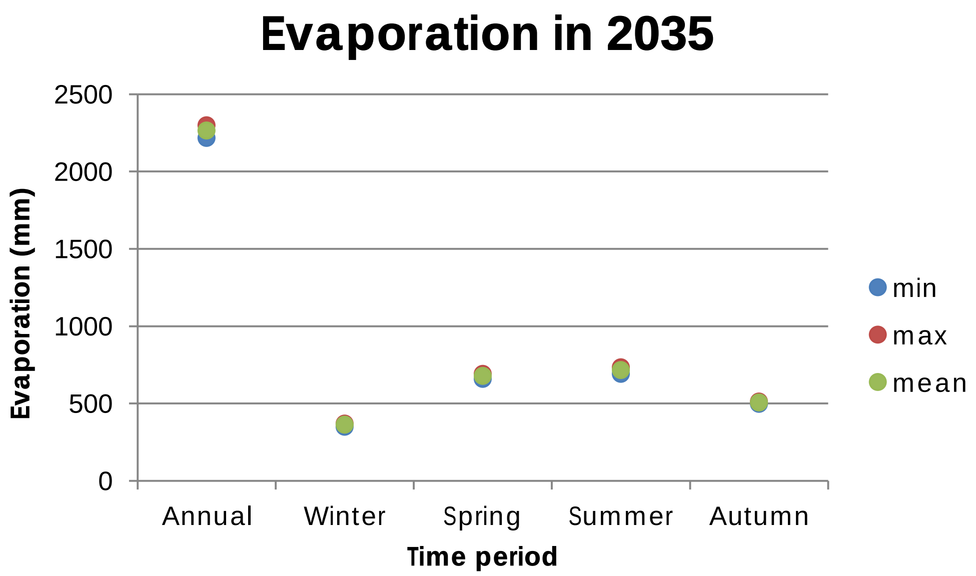



**Figure 15** **Projected evaporation in 2035**

| **Location:** Taroborah Coal Project Site, QLD | **Period:** 2035 | **Data source:** OzClim – ranges reflect variations in predictions from climate models | **Units:** mm |
|---|---|---|---|
| **Type:** Plot | | **Prepared by:** Adam Thomas | **Date:** November 2012 |

### 3.3.7 Solar radiation

The OzClim models predict solar radiation in terms of the average solar energy received each day per unit area. The predictions are displayed in Figure 16. More solar radiation is received in spring and summer than in autumn and winter. This difference between seasons is a reflection of the longer days and stronger sun (because the sun is higher in the sky) in summer compared to winter. Cloud cover also affects the received solar radiation. Average annual daily solar radiation is predicted to be approximately 20 MJ/m$^2$ in 2035.

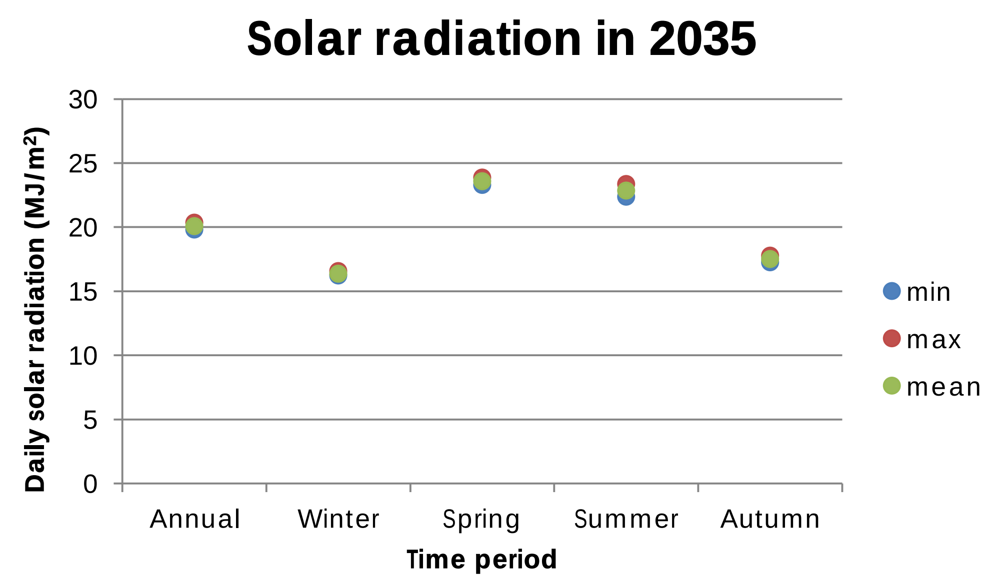



**Figure 16** **Projected average daily solar radiation in 2035**

| **Location:** Taroborah Coal Project Site, QLD | **Period:** 2035 | **Data source:** OzClim – ranges reflect variations in predictions from climate models | **Units:** MJ/m$^2$ |
|---|---|---|---|
| **Type:** Plot | | **Prepared by:** Adam Thomas | **Date:** November 2012 |

## 3.4 Comparison of projected and past climate

Section 3.3 presented analysis of the Projected climate characteristics for the study area in the year 2035, by considering averaged values of an ensemble of climate models (the OzClim data set). The following sections are concerned with comparing past climate characteristics with the Projected climate characteristics for 2035. This may indicate whether climate change may provide challenges additional to those posed by climate variability over the life of the Taroborah Coal Project.

### 3.4.1 Rainfall

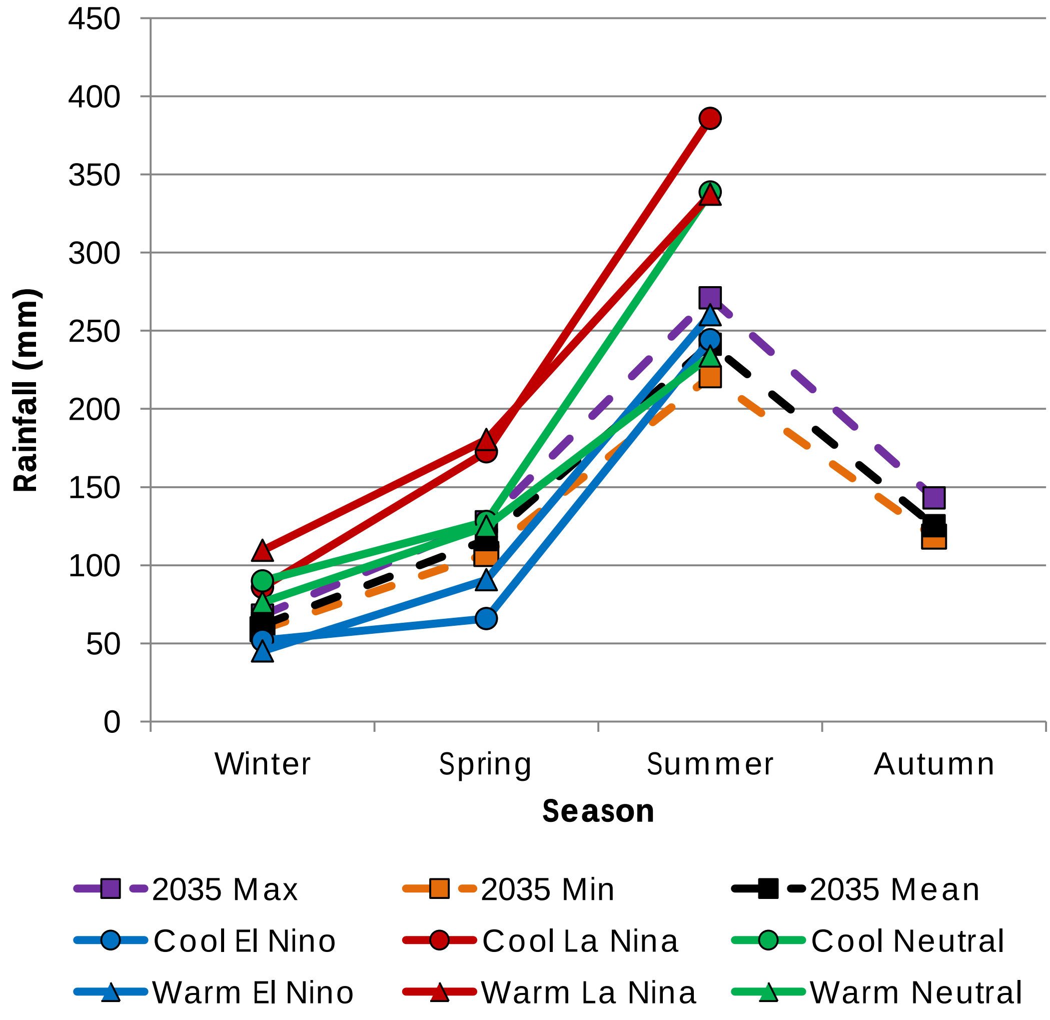
**Table 10 Summary of historical average rainfall by season, PDO phase and ENSO phase**

| PDO phase | ENSO phase | Season | Average rainfall (mm) |
|---|---|---|---|
| Cool | El Niño | Winter | 52 |
| | | Spring | 66 |
| | | Summer | 244 |
| | La Niña | Winter | 86 |
| | | Spring | 173 |
| | | Summer | 386 |
| | Neutral | Winter | 90 |
| | | Spring | 128 |
| | | Summer | 339 |
| | Undefined | Autumn | 132 |
| Warm | El Niño | Winter | 45 |
| | | Spring | 91 |
| | | Summer | 260 |
| | La Niña | Winter | 109 |
| | | Spring | 180 |
| | | Summer | 337 |
| | Neutral | Winter | 76 |
| | | Spring | 125 |
| | | Summer | 234 |
| | Undefined | Autumn | 134 |

A summary of historical average rainfall is reproduced in Table 10. Comparing the Projected average mean seasonal rainfall from the summary table in Appendix A with the historical rainfall from Table 10, we can attempt to draw a conclusion about whether the climate in 2035 might be like historical El Niño or La Niña conditions. Projected summer rainfall is lower than La Niña conditions (cool or warm PDO phase) or with a neutral ENSO phase during a cool PDO phase. However projected summer rainfall is consistent with historical El Niño conditions or neutral ENSO conditions during a warm PDO phase, i.e. with generally lower rainfall years.

The comparison of historical and projected rainfall is illustrated in Figure 17 for 2035. The Projected seasonal rainfall from the OzClim models is plotted as dashed lines with square markers. The mean projected value is the best estimate, with the maximum and minimum projected values giving upper and lower bounds. The Projected mean rainfall is compared to the historical Emerald rainfall data, divided into PDO and ENSO phase (hence autumn, which has an undefined ENSO phase, being excluded). The cool PDO phase is denoted by triangle markers and the warm PDO phase by circular markers; the El Niño ENSO phase is denoted by blue colouring, the neutral ENSO phase by green colouring, and the La Niña ENSO phase by red colouring.

In Figure 17 the Projected seasonal average rainfall is seen to generally fall between average rainfall in neutral years and average rainfall in El Niño years, with summer rainfall being most comparable to El Niño years. This is consistent with previous findings that climate change may result in reduced average rainfall in central Queensland (Queensland Government, 2009).




| **Figure 17** | **Site averaged historical and projected 2035 seasonal rainfall** | | |
|---|---|---|---|
| **Location:**<br>Emerald, QLD | **Period:**<br>1890-2012 and 2035 | **Data source:**<br>OzClim and BoM | **Units:**<br>mm |
| **Type:**<br>Plot | | **Prepared by:**<br>Adam Thomas | **Date:**<br>November 2012 |

### 3.4.2 Temperature

The average minimum temperature and average maximum temperature from the summary table in Appendix A may be compared to the historical averaged minimum and maximum temperatures in Table 11.

The average daily minimum temperatures in the Appendix A summary table are higher than the average minimum temperatures in Table 11 for all seasons regardless of ENSO phase or PDO phase. The same is true for average daily maximum temperatures. The predicted average daily temperature minima and maxima are approximately 0.2-2 °C higher than historical values for the various PDO phase, ENSO phase and season combinations.

**Table 11 Summary of historical average minimum and maximum temperature by season, PDO phase and ENSO phase**

| PDO phase | ENSO phase | Season | Minimum daily temperature (°C) | | Maximum daily temperature (°C) | |
|---|---|---|---|---|---|---|
| | | | Minimum | Average | Average | Maximum |
| Cool | El Niño | Winter | -3.9 | 7.2 | 23.6 | 32.8 |
| | | Spring | -2.2 | 15.2 | 31.8 | 43.7 |
| | | Summer | 12.8 | 21.3 | 34.8 | 46.2 |
| | La Niña | Winter | -2.7 | 8.2 | 23.8 | 35.4 |
| | | Spring | 0.4 | 15.8 | 30.4 | 41.7 |
| | | Summer | 7.2 | 20.6 | 33.2 | 42.8 |
| | Neutral | Winter | -3.9 | 7.8 | 23.3 | 32.4 |
| | | Spring | 1.1 | 15.5 | 31.1 | 44.0 |
| | | Summer | 6.7 | 20.6 | 33.6 | 44.5 |
| | Undefined | Autumn | 0.0 | 15.3 | 29.0 | 42.9 |
| Warm | El Niño | Winter | -3.6 | 8.4 | 24.0 | 35.2 |
| | | Spring | 3.4 | 16.2 | 32.0 | 42.9 |
| | | Summer | 10.6 | 21.9 | 34.7 | 45.6 |
| | La Niña | Winter | -1.7 | 9.2 | 23.1 | 33.3 |
| | | Spring | 2.2 | 16.0 | 30.6 | 40.6 |
| | | Summer | 15.6 | 21.2 | 33.0 | 41.9 |
| | Neutral | Winter | -1.7 | 8.7 | 23.6 | 35.0 |
| | | Spring | 1.8 | 16.2 | 31.3 | 44.6 |
| | | Summer | 11.2 | 21.6 | 34.7 | 45.5 |
| | Undefined | Autumn | -0.6 | 16.2 | 29.5 | 42.5 |

### 3.4.3 Relative humidity

The Projected relative humidity for 2035 is given at 9am and 3pm as well as a daily average (Appendix A). In contrast the DPI historical data presented in Table 12 gives the relative humidity measured at the minimum and maximum temperature for each day. Hence a direct comparison of historical and projected data in this case is not possible.

**Table 12 Summary of historical average minimum and maximum relative humidity by season, PDO phase and ENSO phase**

| PDO phase | ENSO phase | Season | Average relative humidity (%) | |
|---|---|---|---|---|
| | | | At minimum temperature | At maximum temperature |
| Cool | El Niño | Winter | 93 | 36 |
| | | Spring | 86 | 33 |
| | | Summer | 87 | 41 |
| | La Niña | Winter | 94 | 39 |
| | | Spring | 90 | 39 |
| | | Summer | 92 | 45 |
| | Neutral | Winter | 95 | 40 |
| | | Spring | 89 | 36 |
| | | Summer | 90 | 44 |
| | Undefined | Autumn | 94 | 44 |
| Warm | El Niño | Winter | 88 | 35 |
| | | Spring | 81 | 32 |
| | | Summer | 85 | 41 |
| | La Niña | Winter | 93 | 42 |
| | | Spring | 88 | 39 |
| | | Summer | 91 | 47 |
| | Neutral | Winter | 91 | 39 |
| | | Spring | 85 | 36 |
| | | Summer | 87 | 42 |
| | Undefined | Autumn | 90 | 42 |

### 3.4.4 Evaporation

The historical average evaporation, divided into PDO phase, ENSO phase and season is presented in Table 13. These values may be compared to the Projected values in Appendix A. The Projected average values are higher than each value obtained from the DPI data set with one exception – the predicted overall average total spring evaporation of 679 mm is slightly lower than the average spring evaporation of 687 mm in El Niño years during a warm PDO phase. The OzClim models indicate there may be an increase in the average evaporation at the site over the medium term to 2035.

**Table 13 Summary of historical average evaporation by season, PDO phase and ENSO phase**

| PDO phase | ENSO phase | Season | Evaporation (mm) |
|---|---|---|---|
| Cool | El Niño | Winter | 351 |
| | | Spring | 637 |
| | | Summer | 693 |
| | La Niña | Winter | 337 |
| | | Spring | 622 |
| | | Summer | 663 |
| | Neutral | Winter | 334 |
| | | Spring | 622 |
| | | Summer | 684 |
| | Undefined | Autumn | 479 |
| Warm | El Niño | Winter | 354 |
| | | Spring | 687 |
| | | Summer | 714 |
| | La Niña | Winter | 318 |
| | | Spring | 577 |
| | | Summer | 624 |
| | Neutral | Winter | 343 |
| | | Spring | 644 |
| | | Summer | 702 |
| | Undefined | Autumn | 483 |

### 3.4.5 Solar radiation

The Projected solar radiation in Appendix A may be compared to the historical averages in Table 14. The Projected average values of solar radiation are similar to those based on the historical DPI data. The 2035 projections for winter, spring and summer are most similar to the values for a neutral ENSO phase during either PDO phase. Therefore the OzClim models do not seem to predict significant differences in solar radiation in 2035 compared to historical values.

**Table 14 Summary of historical average daily solar radiation by season, PDO phase and ENSO phase**

| PDO phase | ENSO phase | Season | Solar radiation (MJ/m2) |
|---|---|---|---|
| Cool | El Niño | Winter | 16.6 |
| | | Spring | 24.5 |
| | | Summer | 23.7 |
| | La Niña | Winter | 16.1 |
| | | Spring | 22.7 |
| | | Summer | 22.6 |
| | Neutral | Winter | 16.2 |
| | | Spring | 23.7 |
| | | Summer | 22.8 |
| | Undefined | Autumn | 18.2 |
| Warm | El Niño | Winter | 16.8 |
| | | Spring | 24.3 |
| | | Summer | 22.9 |
| | La Niña | Winter | 15.6 |
| | | Spring | 22.6 |
| | | Summer | 21.8 |
| | Neutral | Winter | 16.2 |
| | | Spring | 23.5 |
| | | Summer | 23.1 |
| | Undefined | Autumn | 18.1 |

### 3.4.6 Summary of projected versus historical climate findings

The comparison between projected characteristics and historical data in the previous sections has been summarised as follows:

- The models predict that average seasonal rainfall in 2035 will be more similar to historical neutral and El Niño years than La Niña years
- Daily average minimum and maximum temperatures for all seasons are predicted to be higher in 2035 than historical values for any combination of PDO phase and ENSO phase. The Projected averages are approximately 0.2-2°C higher than values for each season for all ENSO and PDO phase combinations
- Evaporation is predicted to generally increase in 2035 relative to historical levels
- Solar radiation is predicted be similar in 2035 to historical levels in terms of seasonal daily average values

# 4. Risk assessment

## 4.1 Method

Mine design takes into account an understanding of local climatic conditions based on historical meteorological records. A suitable design would ensure both the adequate management of environmental aspects and the health and safety of mining personnel. Unanticipated climate conditions may threaten mine design, as a result it is necessary to identify and manage the risk through the implementation of adaptation measures to address climate risks to mining operations.

Climate will affect mining operations at Taroborah over the planned life of mine. The EIS ToR requires as assessment of the Project's vulnerabilities to climate change. This includes:

- A risk assessment of how changing weather patterns may affect the viability and environmental management of the Project
- The preferred and alternative adaptation strategies to be implemented
- A commitment to undertake, where practicable, a cooperative approach with government, other industry and sectors to address adaptation to climate change

This risk assessment has considered climate variability as well as climate change. The attention given to climate change in public debate currently provides the opportunity to understand the implications of climate change in greater detail. Closer investigation of climate provides a better understanding of climate variability as a complement to considering the possible effects of climate change. The climate related risks the mine might experience, result from extreme events or prolonged extreme conditions that effectively could occur with or without climate change. These climate extremes are factored into the risk assessment that follows.

The risk assessment methodology applied to the Project is consistent with AS/NZS ISO31000:2009 Risk management – Principles and Guidelines (Standards Australia, 2009), and draws on Draft Australian Standard DR AS5334 - Climate Change Adaptation for Settlements and Infrastructure (Standards Australia, 2011).

The risk assessment was comprised of the following elements:

- Climate conditions and weather events that could affect the Project
- The likelihood of each climate condition or weather event occurring, informed by data on climate, climate variability and climate change
- Impacts associated with climate effects on the Project
- Consequences relating to each impact; rated according to criteria from DR AS5334
- The risk rating associated with the impact; considering both the likelihood of the climate condition occurring and the consequences of the impact

Possible measures to mitigate the identified risks were canvassed and presented as adaptation strategies, with an indication as to how these strategies may reduce the risk ratings.

The TOR has recognised that predictions of climate change and its effects have inherent uncertainties, and that a balance must be found between the cost of preparing for climate change and the uncertainty of outcomes. The ToR note that proponents should use their best efforts to incorporate adaptation to climate change in their EIS and project design.

The risk assessment has assumed the mine would be developed and operated in the manner described in the pre-feasibility study that guided the preparation of the EIS. The conclusions of the risk assessment could be affected by changes made in design, operation or rehabilitation of the mine.

The study has proceeded using a desktop method; that is, the risk assessment element was completed at arm's length from personnel who may be leading the development or operation of the mine. Closer involvement of proponent personnel concerned with design, operation and rehabilitation of the mine would improve the value of a climate risk analysis.

This risk assessment has not given detailed consideration to possible secondary risks or synergistic effects. Its focus on the EIS study area is also a limitation in that the mine's operations rely on activities beyond the study area that may themselves be affected by extreme weather, potentially interrupting mine activities.

The residual risk that the Project will carry will depend on the implementation of adaptation measures and cannot be ascertained with certainty until specific measures have been selected.

## 4.2 Sources of climate risk and risk criteria

The likelihood factor of the risk calculation has been assessed primarily with reference to the sources of climate risk. Initially a series of local climatic conditions/weather events consistent with dominant weather patterns expected during the mine life have been predicted; these are defined in Table 15. The primary and secondary impacts associated with the changed climatic conditions/weather events were then identified firstly through a desktop approach followed by a collaborative risk assessment workshop (among the EIS team).

Significantly, note that if a warm PDO phase influences the coming decades as anticipated, La Niña conditions are predicted to be more frequent than El Niño conditions (Cai and Rensch, 2012). This would result in the La Niña risks of intense rainfall, cyclones and high winds that are anticipated to be more frequent, which is at odds with the common interpretation of climate change impacts in this area that emphasise high temperature and drought conditions.

**Table 15 Sources of climate risk with potential impact on Taroborah Coal Project operations and breakdown of probabilities**

| Source of climate risk | Parameter | Average | Probability of parameter being exceeded (%) under ENSO phases | | |
|---|---|---|---|---|---|
| | | | Total | El Niño | La Niña |
| Intense rainfall | Number of days per Sep - Feb period (i.e. excluding autumn) with rainfall above 25 mm [a] | 5 days | 50% | 30% | 80% [d] |
| Cyclones | Number of cyclones per cyclone season within 400 km of the Project site [b] | 0.6 cyclones | 40% | 40% | 70% |
| High temperatures | Number of days per Sep - Feb period (i.e. excluding autumn) with maximum temperature above 35 °C [a] | 50 days | 50% | 80% | 10% |
| Drought | Number of months per Sep - Feb period (i.e. excluding autumn) with rainfall at or below the 5th percentile for that month [a] | 0.9 months | 60% | 80% | 30% |
| Strong winds | Number of days per Sep - Feb period (i.e. excluding autumn) when wind speed exceeds 8 m/s [c] | 23 days | 30% | 30% | 70% |
| Damaging winds | Number of days per Sep - Feb period (i.e. excluding autumn) when wind speed exceeds 25 m/s [c] | 0.2 days | 10% | 10% | 10% |

Data sources:
[a] Based on 110 years of data (1902-2012) from Bureau of Meteorology records at Emerald, Qld
[b] Based on 101 years of data (1906- 2007) from Bureau of Meteorology cyclone track data
[c] Based on 50 years of data (1956-1964 and 1972-2012) from the NCDC dataset
[d] Red shading identifies significantly higher probabilities for a particular ENSO phase.

Table 15 shows some significant differences between probabilities for events occurring in El Niño years and La Niña years. The following may be noted:

- In a La Niña year there is an approximately 80% probability that there will be more than the average number of heavy rain days (defined as a day during which more than 25 mm of rain is recorded), compared to only 30% in an El Niño year
- In a La Niña year there is an approximately 70% chance of a cyclone passing within 400 km of the Project site, compared to a roughly 40% chance in El Niño years
- In an El Niño year there is an approximately 80% chance of experiencing more than the average number of very hot days (above 35 C), but only a 10% probability in a La Niña year
- There is an 80% chance in an El Niño year that rainfall in one or months will be lower than the 5$^{th}$ percentile for rainfall for that month. A prolonged period of rainfall below the 5$^{th}$ percentile may correspond to a severe rainfall deficiency. In contrast there is a 30% chance of this occurring in a La Niña year.
- The data indicates that there may be a higher probability of strong winds in a La Niña year than an El Niño year
- The wind speed data gives little information on damaging winds, since records of winds above 25 m/s exist for only 10 days in the data. Since approximately half of the 50 years of wind speed data consists of only 1-3 measurements each day, the data may not cover a representative sample of extreme wind events. The records that

exist do not suggest a difference in damaging wind frequency between El Niño and La Niña years; however this may be inconsistent with the known higher frequency of cyclones in La Niña years.

The probabilistic results from Table 16 were then used to select a likelihood rating for impacts using the likelihood criteria in Table 16 from DR AS5334. (Section 4.3.2 describes the process for this selection in detail.) The selected likelihood was derived from the probability of the climate condition/weather event occurring, as opposed to the probability of the impact occurring. Indirectly this assumes that if the identified climate condition/weather event were to occur then the impact would occur to a level of severity consistent with the consequence rating assigned to the impact.

**Table 16 Qualitative Measures of Likelihood - Taroborah Project**

| Rating | Event Risk | Recurrent risk | Long term risks |
|---|---|---|---|
| Almost Certain | Could occur several times per year | Has happened several times in the past year and in each of the previous 5 years | Greater than 90% chance of occurring in the mine life |
| Likely | May arise about once per year | Has happened at least once in the past year and in each of the previous 5 years | 60-90% chance of occurring in the mine life |
| Possible | May arise a couple of times during mine life | Has happened in the last 5 years but not in every year | 40-60% chance of occurring in the mine life |
| Unlikely | May occur once during mine life | May have occurred in the last 5 years | 10-40% chance of occurring in the mine life |
| Rare | Unlikely to occur during mine life | Has not occurred in the past 5 years | Less than 10% chance of occurring in the mine life |

The consequence level for each impact was considered based on the categories and descriptors detailed in Table 17.

**Table 17 Risk Criteria - Qualitative Measures of Consequences**

| Consequence descriptor | Adaptive capacity* | Infrastructure, service | Social/cultural | Governance | Financial | Environmental | Economy |
|---|---|---|---|---|---|---|---|
| **Insignificant** | No change to the adaptive capacity | No infrastructure damage, little change to service | No adverse human health effects | No changes to management required | Little financial loss or increase in operating expenses | No adverse effects on natural environment | No effects on the broader economy |
| **Minor** | Minor decrease to the adaptive capacity of the asset. Capacity easily restored | Localized infrastructure service disruption. No permanent damage. Some minor restoration work required. | Short-term disruption to employees, customers or neighbours. Slight adverse human health effects or general amenity issues | General concern raised by regulators requiring response action | Additional operational costs. Financial loss small, <10% | Minimal effects on the natural environment | Minor effects on the broader economy due to disruption of service provided by the asset |
| **Moderate** | Some change in adaptive capacity. Renewal or repair may need new design to improve adaptive capacity | Limited infrastructure damage and loss of service. Damage recoverable by maintenance and minor repair. Early renewal of Infrastructure by 20–50%. | Frequent disruptions to employees, customers or neighbours. Adverse human health effects | Investigation by regulators. Changes to management actions required | Moderate financial loss 10-50% | Some damage to the environment, including local ecosystems. Some remedial action may be required | High impact on the local economy, with some effect on the wider economy |
| **Major** | Major loss in adaptive capacity. Renewal or repair would need new design to improve adaptive capacity | Extensive infrastructure damage requiring major repair. Major loss of infrastructure service. Early renewal of Infrastructure by 50–90% | Permanent physical injuries and fatalities may occur. Severe disruptions to employees, customers or neighbours | Notices issued by regulators for corrective actions. Changes required in management. Senior management responsibility questionable | Major financial loss 50–90% | Significant effect on the environment and local ecosystems. Remedial action likely to be required | Serious effect on the local economy spreading to the wider economy |
| **Catastrophic** | Capacity destroyed, redesign required when repairing or renewing asset | Significant permanent damage and/or complete loss of the infrastructure and the infrastructure service. Loss of infrastructure support and translocation of service to other sites. Early renewal of infrastructure by >90% | Severe adverse human health effects, leading to multiple events of total disability or fatalities. Total disruptions to employees, customers or neighbours. Emergency response at a major level | Major policy shifts. Change to legislative requirements. Full change of management control | Extreme financial loss >90% | Very significant loss to the environment. May include localized loss of species, habitats or ecosystems. Extensive remedial action essential to prevent further degradation. Restoration likely to be required | Major effect on the local, regional and state economies |

* Adaptive capacity relates to the ability of the infrastructure element to adapt/change/cope with a specified climate change scenario.

In cases where the impact could be associated with more than one consequence category, the higher level consequence has been selected.

The selected likelihood level (from very unlikely to almost certain) and consequence levels (from insignificant to catastrophic) were then combined using Table 18 to determine the risk rating for each impact and its causal climate condition/weather event.

**Table 18 Risk rating matrix**

| Likelihood | Consequences | | | | |
|---|---|---|---|---|---|
| | Insignificant | Minor | Moderate | Major | Catastrophic |
| Almost certain | LOW | MODERATE | HIGH | EXTREME | EXTREME |
| Likely | LOW | MODERATE | MODERATE | HIGH | EXTREME |
| Possible | LOW | LOW | MODERATE | HIGH | EXTREME |
| Unlikely | LOW | LOW | MODERATE | MODERATE | HIGH |
| Rare | LOW | LOW | LOW | MODERATE | MODERATE |

| | |
|---|---|
| Low Risk | Issue requiring action through routine maintenance of assets |
| Moderate Risk | Issue requiring change to design standards and maintenance of assets |
| High Risk | Issue requiring detailed research and planning at a senior management level |
| Extreme Risk | Requiring immediate action |

## 4.3 Risk evaluation

### 4.3.1 Summary

A summary of risk ratings determined for the potential impacts of envisaged climate conditions on the Project is provided in Table 19.

**Table 19 Risk assessment for the potential impact of climate conditions on the Project**

| Impact Description | Likelihood | Consequence | Risk rating |
|---|---|---|---|
| Disruption of operations due to flooding | Likely | Minor | **MODERATE** |
| Reduced water availability for mine site operations | Possible | Moderate | **MODERATE** |
| Increased equipment outages due to storm activity | Almost certain | Minor | **MODERATE** |
| Infrastructure damage due to cyclones and severe storm events | Likely | Moderate | **MODERATE** |
| Disruption of operations issues due to bushfire | Possible | Minor | **LOW** |
| Increased dust levels causing disruption to operations | Possible | Minor | **LOW** |
| Decreased workforce productivity relating to higher temperatures | Possible | Minor | **LOW** |

| Impact Description | Likelihood | Consequence | Risk rating |
|---|---|---|---|
| Higher instance of spontaneous combustion in stockpiles | Possible | Minor | LOW |
| Increased operations costs relating to energy requirements | Possible | Minor | LOW |
| Power outages due to increased energy demand caused by higher temperatures | Possible | Minor | LOW |

### 4.3.2 Detailed consideration of individual risks

Each climate condition/weather event identified can be associated with one or a number of impacts. Conversely, a number of climate conditions/weather events can result in a comparable impact. To recognise this, a risk rating has been determined for each impact taking into account the range of causal climate conditions.

The likelihood associated with a climate condition/weather event remains consistent while the consequence is related to the impact of the climate condition/weather event on the Project. Based on the parameters identified in Table 16, the likelihood assigned to each climate condition/weather event is detailed. In all instances the likelihood category of 'Long term risks' was identified as the most significant.

As it is anticipated that La Niña conditions will be more frequent than El Niño conditions for the life of the mine, likelihoods associated with El Niño conditions have been adjusted to reflect this. Table 20 summarises the likelihood measures associated with the identified climate conditions; climate conditions have also been assigned an identifier.

**Table 20 Measure of Likelihood for sources of climate risk**

| ID | Source of climate risk | Likelihood |
|---|---|---|
| RR | Intense rainfall | Likely |
| CY | Cyclones | Likely |
| HH | High temperatures | Possible |
| DR | Drought | Possible |
| SW | Strong winds | Likely |
| DW | Damaging winds | Rare |

The impacts on the Project associated with the climate conditions have been identified initially through a desktop exercise and further developed at a risk workshop. Desktop research included published literature (e.g. Hodgkinson et al. 2010) and the information from recent risk assessments of other coal mining proposals that have undergone environmental assessment.

The impacts on mining operations and the associated climate drivers are summarised in Table 21.

**Table 21 Summary of impacts and climate drivers**

| Impact Description | Source of climate risk (Y=Yes, N=No) | | | | | |
|---|---|---|---|---|---|---|
| | RR | CY | HH | DR | SW | DW |
| Disruption of operations due to flooding | Y | Y | N | N | N | N |
| Reduced water availability for mine site operations | N | N | Y | Y | N | N |
| Increased equipment outages due to storm activity | Y | Y | N | N | Y | Y |
| Infrastructure damage due to cyclones and severe storm events | N | Y | N | N | Y | Y |
| Disruption of operations issues due to bushfire | N | N | Y | Y | Y | Y |
| Increased dust levels causing disruption to operations | N | N | Y | Y | Y | Y |
| Decreased workforce productivity relating to higher temperatures | N | N | Y | N | N | N |
| Higher instance of spontaneous combustion in stockpiles | N | N | Y | Y | Y | Y |
| Increased operations costs relating to energy requirements equipment efficiency | N | N | Y | N | N | N |
| Power outages due to increased energy demand caused by higher temperatures | N | N | Y | N | N | N |

The Project site is currently a green-field site and will employ conventional processes and technologies to extract, refine and transport the coal. On this basis the risk ratings have been determined by considering the likely impact of the climate condition/weather event on comparable mining operations in the area.

Characteristics of this project include:

- Nearby water courses
- Relatively close proximity to town of Emerald
- Higher elevation than town of Emerald
- Nearby state forest
- Productive cropping land located over proposed mining area
- Site divided by railway and highway

The risk ratings associated with each envisaged impact have been determined from the likelihood and consequence ratings using the risk rating matrix summarised in Table 18.

#### 4.3.2.1 Disruption of operations due to flooding

In recent years in the central Queensland coalfields region a number of flood events have occurred sometimes resulting in significant disruptions to operations.

The risk rating for this impact has been determined as 'MODERATE', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Likely** | Long term risk | **Minor** | All | **MODERATE** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Site access issues can lead to: mine shutdown due to mine workers being unable to get to site; coal product unable to be transported offsite; supplies including diesel and consumables cannot be delivered to site<br>• Pumping requirements to clear water from inundated areas can be significant both in terms of power and workforce requirements. Larger capacity pumps will limit the time required to return to normal operations, but also have more significant power requirements<br>• Power outages due in part to damage of infrastructure but also due to the sudden spike in electricity demand across the region | • Ensure adequate storage of diesel and consumables onsite on higher ground to cater for likely flood period<br>• Consider onsite accommodation<br>• Ensure adequate pumping capability<br>• Avoid major construction during the wet season<br>• Implement an emergency response plan |

#### 4.3.2.2 Reduced water availability for mine site operations

Water availability for the Project has been assessed as being adequate, based on sourcing water from a local aquifer via dewatering supplemented by rainfall. Conditions of higher temperatures causing increased evaporation and drought conditions may affect water supply.

The risk rating for this impact has been determined as 'MODERATE', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Possible** | Long term risk | **Moderate** | Social/ Financial/ Economy | **MODERATE** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Adequate water supply is essential to the mine site operations for extraction and processing for coal. | • A conservative approach to water use across the Project site is essential. This should consist of ensuring a high standard of water efficiency across operations including the utilisation of recycled water where possible |

#### 4.3.2.3 Increased equipment outages due to storm activity

Some of the climate conditions being considered are associated with storm activity; namely, intense rainfall and strong winds. The climate assessment for this study has projected that storm activity is likely to increase during the coming decades. Equipment outages under consideration would likely be caused directly or indirectly by an increased frequency of lightning strikes and by the general inability to operate equipment during storm events.

Taking historical events into account it is likely that a number of storm events will occur on an annual basis.

The risk rating for this impact has been determined as 'MODERATE', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Almost certain** | Recurrent risk | **Minor** | All | **MODERATE** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Shutdown of individual pieces of equipment due to lightning strike<br>• Power outages caused by local infrastructure damage or substation damage<br>• Storm conditions causing general site shutdown due to safety concerns | • Provide adequate protection of equipment from lightning strike where possible<br>• Localised hourly updated weather forecasting to enable management action in sufficient time to protect personnel and equipment |

#### 4.3.2.4 Infrastructure damage due to cyclones and severe storm events

It is anticipated that severe storms events will be experienced during the Project's life of mine.

The risk rating for this impact has been determined as 'MODERATE', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Likely** | Long term risk | **Moderate** | Infrastructure/ Financial | **MODERATE** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Damage to mine site infrastructure could result in disruptions to operations, to varying extents<br>• Costs relating to maintenance and repair would likely increase | • Design mine layout and equipment configuration to limit the adverse affects of severe storm activity<br>• Implement an emergency response plan |

#### 4.3.2.5 Disruption of operations due to bushfire

The hotter drier conditions associated with El Niño weather pattern and the state forest adjacent to the mine site increase the vulnerability of mine site operations to bushfire events.

The risk rating for this impact has been determined as 'LOW', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Possible** | Long term risk | **Minor** | All | **LOW** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Visibility for conducting mining operations could be compromised causing temporary mine shutdown<br>• Potential employee health and safety issues relating to site access and smoke inhalation<br>• Damage to powerlines | • Ensure adequate fire breaks are maintained<br>• Operational procedures must recognise this risk and manage appropriately |

#### 4.3.2.6 Disruption of operations due increased dust levels

Dust generation on mine sites in the Central Queensland coalfields is predominantly due to vehicle movement on haul roads and to a lesser extent blasting operations. Dust generation can be exacerbated by hot, dry weather conditions as well as higher windspeeds.

The risk rating for this impact has been determined as 'LOW', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Possible** | Long term risk | **Minor** | All | **LOW** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Increased dust levels on site could cause visibility issues leading to temporary closure of haul out roads and pit operations<br>• Health issues relating to dust inhalation both on site and for surrounding dwellings | • Ensure adequate dust management plan is in place<br>• Localised hourly updated weather forecasting to enable management action in sufficient time to protect personnel and equipment |

#### 4.3.2.7 Decreased workforce productivity relating to higher temperatures

Decreased workforce productivity due to future hotter conditions has been cited by CSIRO as potentially a greater limiter to future mine design and operations than equipment and machinery limitations (Moffat, 2009). However, the temperature variation in the coming decades is not expected to be to this extent.

The risk rating for this impact has been determined as 'LOW', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Possible** | Long term risk | **Minor** | Social | **LOW** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Increased operating costs including higher general workforce costs and increased heat load on ventilation systems | • Adequate health and safety management plans and procedures<br>• Cooling of underground ventilation air |

#### 4.3.2.8 Higher instance of spontaneous combustion in stockpiles

Spontaneous combustion in product stockpiles is an existing issue for coal mines in the region. This risk may be exacerbated due to hotter, drier conditions with potentially higher windspeeds.

The risk rating for this impact has been determined as 'LOW', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Possible** | Long term risk | **Minor** | Governance/ Environmental | **LOW** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Increased operational costs as a function of monitoring and responding to stockpile fire events<br>• Loss of product | • Minimise residency time of accumulated coal around coal handling facilities (e.g. application of the first in first out method in association with a residency management system)<br>• Implement scheduled housekeeping procedures including observations.<br>• Keep the stockpile's angle of repose to a minimum, particularly on the prevailing windward side to reduce airflow into and through the Stockpile (NCIG, 2010)<br>• Consider stockpile compaction where coal is classified as reactive (Stracher, 2007) |

#### 4.3.2.9 Increased costs relating to higher energy requirements

In most cases mine site equipment and electrical infrastructure will operate less efficiently in higher temperatures. This is particularly the case with cooling operations associated with ventilation of underground operations.

The risk rating for this impact has been determined as 'LOW', as follows:

| Likelihood | | Consequence | | Risk |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Possible** | Long term risk | **Minor** | Financial | **LOW** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Increased cost due to increased energy requirement<br>• Increased greenhouse gas emissions and related costs | • Design to minimise the effects of higher ambient temperature where possible<br>• Schedule maintenance downtime for hottest part of the day and production for cooler parts of the day |

#### 4.3.2.10 Power outages due to regionally increased energy demands caused by higher temperatures

The increased energy demand relating to equipment and electrical infrastructure operating in higher temperatures creates a greater potential for overloading both on site and regional electrical infrastructure.

The risk rating for this impact has been determined as 'LOW', as follows:

| Likelihood | | Consequence | | Risk rating |
|---|---|---|---|---|
| Measure | Category | Measure | Category | |
| **Possible** | Long term risk | **Minor** | Infrastructure/ Financial | **LOW** |

**Impact and mitigation**

| Impact on mining operations | Mitigation measures |
|---|---|
| • Ongoing temporary disruption to operations<br>• Note that electrical failure may lead to secondary impacts associated with electricity dependent equipment, such as water pumps becoming unavailable and affecting controlled dewatering | • Consider the robustness of electricity supply to site (e.g. substation vulnerability)<br>• Design to minimise the effects of higher ambient temperature where possible<br>• Schedule maintenance downtime for hottest part of the day and production for cooler parts of the day<br>• Incorporate additional standby generation capacity |

## 4.4 Residual risk

The implementation of one or a number of these mitigation measures could reduce individual risk ratings to more acceptable levels. The most appropriate measures to undertake and the affect of the chosen course of action on the risk rating would need to be determined through a more detailed risk management process.

The more detailed risk assessment should incorporate engineering perspectives on the relationship between extreme weather events and failure or sub-optimal performance of structures or equipment. The risk assessment has highlighted the potential effects of intense rainfall and cyclonic activity to water management on-site. Sound engineering responses through design as well as active management involving inspection, maintenance and monitoring of stresses and weather activity could combine to address effectively the highest risks.

# 5. Climate Change Adaptation

## 5.1 Summary of adaptation strategies

The Department of Environment and Heritage Protection has recognised that predictions of climate change and its effects have inherent uncertainties, and that a balance must be found between the costs of preparing for climate change and the uncertainty of outcomes. Proponents must nevertheless use their best efforts to incorporate adaptation to climate change in the EIS and project design (EIS ToR).

The risk mitigation items that have been identified alongside the individual risks above can be combined into an integrated program of climate adaptation for the mine. The following items should be considered as suitable adaptation strategies for the Project:

1. **Next stage of risk assessment –** a next stage of risk assessment should be undertaken prior to completion of design and commencement of works. The risk assessment should involved design engineers and hydrologists, mine managers, corporate risk managers and other internal (and potentially external) stakeholders. It should consider secondary and supply chain risks as well as the inter-relationship between weather events and the performance of equipment and structures. It should also consider the implications of climate change for the long-term rehabilitation of the mine site.

2. **Prioritisation of hydrologic design and water management -** with recognition of the implications of La Niña conditions.

3. **Implementation of a weather intelligence system –** employ a weather system that combines frequent site-specific and tailored forecasting with observations and provides simple and practical management guidance to on-site decision makers. This system can also contribute to better dust management and planning of blasting.

4. **Water conservation -** Given the possibility of drought conditions occurring during the life of the mine, it would be prudent to incorporate water efficiency and water recycling in design and operating procedures.

5. **Incorporate climate risk management in core management systems -** include subjects such as safety, emergency response and training

6. **Periodically update risk assessment and adaptation actions -** review climate information, weather observations, site experiences and technological developments at least every three years to enhance adaptation planning. Note that information about climate and climate change adaptation is developing rapidly.

## 5.2 Cooperative approach to adaptation

It is recognised that there are multiple interested parties to the operation and climate adaptation of the Project, including:

- The workforce
- Local communities such as the Town of Emerald
- Local and state government agencies, particularly in relation to infrastructure and emergency services
- Supply chain participants and stakeholders in the export process
- Environmental regulators and community environmental groups
- Investors and financial regulators
- Industry bodies and neighbouring mines

It is further recognised that successful climate adaptation for the Taroborah Coal Project will depend in part on the maintenance of effective communication among these stakeholders throughout mine development, operation and rehabilitation. Cooperation among stakeholders and with government is particularly important as there is a high community concern regarding climate change and scientific information and adaptation strategies are evolving rapidly.

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# Appendix A Detailed assessment of future climate

**Projected ensemble statistics for 2035**

| Parameter | Season | Average maximum | Average minimum | Average mean | Standard deviation (pooled) |
|---|---|---|---|---|---|
| Relative humidity at 3pm (%) | Winter | 39.2 | 33.2 | 35.4 | 1.5 |
| | Spring | 34.7 | 27.9 | 30.8 | 1.9 |
| | Summer | 43.4 | 36.7 | 39.8 | 1.8 |
| | Autumn | 42.4 | 36.6 | 38.9 | 1.5 |
| Relative humidity at 9am (%) | Winter | 64.0 | 60.9 | 62.1 | 0.8 |
| | Spring | 55.9 | 50.5 | 52.9 | 1.3 |
| | Summer | 63.7 | 59.6 | 61.4 | 1.0 |
| | Autumn | 65.4 | 61.4 | 63.0 | 1.0 |
| Average relative humidity (%) | Annual | 69.9 | 64.6 | 67.4 | 1.4 |
| | Winter | 67.0 | 62.7 | 64.9 | 1.1 |
| | Spring | 56.1 | 47.7 | 51.8 | 2.2 |
| | Summer | 75.5 | 70.3 | 73.0 | 1.3 |
| | Autumn | 81.2 | 77.8 | 79.7 | 1.0 |
| Minimum daily temperature (°C) | Annual | 17.2 | 15.4 | 16.6 | 0.5 |
| | Winter | 10.4 | 8.1 | 9.5 | 0.7 |
| | Spring | 17.6 | 15.8 | 17.1 | 0.5 |
| | Summer | 22.9 | 21.5 | 22.6 | 0.4 |
| | Autumn | 18.0 | 16.1 | 17.4 | 0.5 |
| Average temperature (°C) | Annual | 24.0 | 22.4 | 23.6 | 0.4 |
| | Winter | 17.6 | 15.7 | 17.0 | 0.5 |
| | Spring | 25.1 | 23.5 | 24.7 | 0.4 |
| | Summer | 29.2 | 27.9 | 28.9 | 0.3 |
| | Autumn | 24.3 | 22.7 | 23.9 | 0.4 |
| Maximum daily temperature (°C) | Annual | 31.0 | 29.6 | 30.7 | 0.3 |
| | Winter | 25.0 | 23.3 | 24.6 | 0.4 |
| | Spring | 32.7 | 31.3 | 32.4 | 0.3 |
| | Summer | 35.7 | 34.6 | 35.5 | 0.3 |
| | Autumn | 30.8 | 29.3 | 30.5 | 0.3 |
| Rainfall (mm) | Annual | 609.7 | 511.3 | 544.5 | 24.8 |
| | Winter | 68.0 | 59.0 | 61.7 | 2.4 |
| | Spring | 127.7 | 107.1 | 116.3 | 5.9 |
| | Summer | 271.0 | 220.6 | 241.3 | 14.3 |
| | Autumn | 143.0 | 118.2 | 125.2 | 5.7 |
| Evaporation (mm) | Annual | 2299.1 | 2217.4 | 2265.3 | 25.2 |
| | Winter | 370.3 | 349.8 | 363.4 | 5.2 |
| | Spring | 691.7 | 659.4 | 678.7 | 9.7 |
| | Summer | 734.1 | 691.9 | 716.4 | 10.9 |
| | Autumn | 512.8 | 498.0 | 506.8 | 4.5 |
| Daily solar radiation ($MJ/m^2$) | Annual | 20.4 | 19.8 | 20.1 | 0.2 |
| | Winter | 16.6 | 16.2 | 16.4 | 0.1 |
| | Spring | 23.9 | 23.3 | 23.6 | 0.2 |
| | Summer | 23.4 | 22.4 | 22.9 | 0.3 |
| | Autumn | 17.8 | 17.3 | 17.5 | 0.2 |