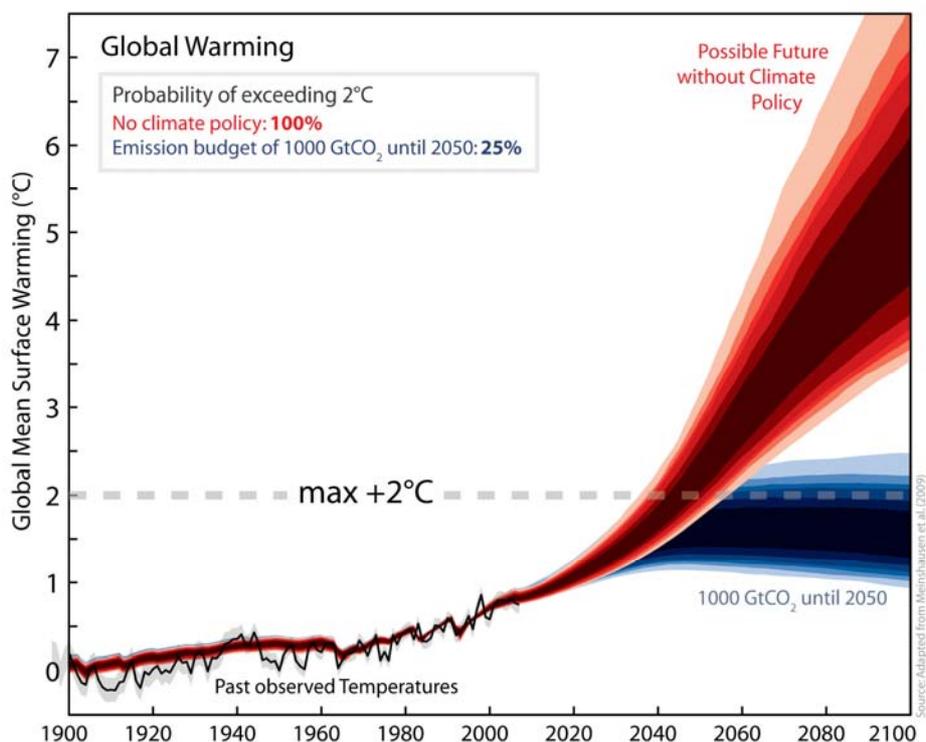


# Contribution of the Wandoan Coal Mine to climate change and ocean acidification



Report prepared for an objections hearing in the Land Court of Queensland  
regarding the proposed Wandoan Coal Mine

Reference numbers:

MRA092-11 & EPA093-11 (MLA 50229)

MRA098-11 & EPA099-11 (MLA 50230)

MRA105-11 & EPA106-11 (MLA 50231)

**Dr Malte Meinshausen**

School of Earth Sciences, University of Melbourne, Australia  
Potsdam Institute for Climate Impact Research, Potsdam, Germany

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## INTRODUCTION

1. I have been asked by the Environmental Defenders Office (EDO) on behalf of Friends of the Earth – Brisbane Co-Op Ltd to provide an expert report on the resilience of the climate to emissions of greenhouse gases from the proposed Wandoan Coal Mine in Queensland, Australia. Other experts, including Professor Ove Hoegh-Guldberg are addressing related issues in separate reports, including ocean acidification. The reports are to assist the Land Court of Queensland in an objections hearing regarding the proposed mine.
2. The Wandoan Coal Mine is an open-cut coal mine proposed to operate for 30 years west of the township of Wandoan, approximately 350 km northwest of Brisbane and 60 km south of Taroom in the Surat Basin, Queensland, Australia (the mine).
3. The thermal coal deposits for the mine are estimated to be in excess of 1.2 billion tonnes, and are located within three Mining Lease Applications (MLAs 50229, 50230 and 50231), which comprise approximately 32,000 hectares. The coal from the mine is proposed to be crushed, processed and blended on site before being transported by rail to port for export or, possibly, for domestic use. The thermal coal produced by the mine is intended to be sold to other companies to be burnt in coal-fired power stations to generate electricity.
4. The Wandoan Coal Project environmental impact statement (Xstrata Coal 2008) and an accompanying technical report on greenhouse gas emissions (Clarke 2008) calculated that the emissions from the mining and use of the coal from the mine would be 1.3 billion tonnes (Gigatonnes) of carbon dioxide equivalents (GtCO<sub>2</sub>eq).

## RELEVANT EXPERTISE

5. I am a senior research fellow at the Potsdam Institute for Climate Impact Research and Honorary Senior visiting researcher at the School of Earth Sciences, University of Melbourne. My expertise is climate change, in particular climate change projections, the carbon cycle, emission inventories under the *United Nations Framework Convention on Climate Change* (UNFCCC), international climate policy and emission implications of climate targets. I hold the following qualifications:
  - (a) Diploma Environmental Sciences (Dipl.) of the Swiss Federal Institute of Technology (ETH Zurich) in Zurich, Switzerland.
  - (b) Master of Environmental Change and Management, University of Oxford, UK.
  - (c) PhD in Climate Science of the Swiss Federal Institute of Technology (ETH Zurich) in Zurich, Switzerland.
6. A copy of my curriculum vitae is set out in Appendix A.

## QUESTIONS ADDRESSED IN THIS REPORT

7. I have been asked by EDO on behalf of Friends of the Earth – Brisbane Co-Op Ltd to provide a statement in regard to following questions:
- (1) In respect of climate change, what is the resilience of the atmosphere to carbon dioxide (CO<sub>2</sub>) emissions? That is, what does paleoclimate evidence and ongoing climate change suggest as the maximum atmospheric CO<sub>2</sub> concentration that can be sustained by the atmosphere while preserving a planet similar to that on which civilization developed and to which life on Earth is adapted? Having regard to:
    - i. observed annual average extent of Arctic sea ice;
    - ii. observed annual average extent of Alpine glaciers;
    - iii. paleoclimate history of sea levels associated with current atmospheric CO<sub>2</sub> concentrations or warming; and
    - iv. any other matter you consider relevant.
  - (2) What are the cumulative human CO<sub>2</sub> emissions which can be released to the atmosphere prior to 2050 before reaching a 20%, 25%, and 50% probability respectively of exceeding 2°C warming above pre-industrial levels during the 21st Century?
  - (3) If the total proven recoverable reserves of the world's coal continued to be produced and consumed at current rates, what would be the resulting atmospheric CO<sub>2</sub> concentration and likely degrees of global warming above pre-industrial averages?
  - (4) Is an atmospheric CO<sub>2</sub> target of 350 parts per million (ppm) achievable by phasing out coal use, except where CO<sub>2</sub> is captured, and adopting agricultural and forestry practices that sequester carbon?
  - (5) To what extent will the emissions from the production, transport and use of coal from the proposed mine increase atmospheric CO<sub>2</sub> concentrations?
  - (6) To what extent will the emissions of the production, transport and use of coal from the proposed mine contribute to global warming, having regard to:
    - i. The likelihood of global warming;
    - ii. The severity of global warming;
    - iii. The longevity of global warming?
  - (7) How long will the emissions from the proposed mine continue to increase atmospheric CO<sub>2</sub> concentrations?
  - (8) Is the increase in atmospheric CO<sub>2</sub> concentrations due to the proposed mine reversible? If so, on what timescales?
  - (9) Are the emissions from the production, transport and use of coal from the proposed mine significant with respect to global warming?
  - (10) Is the calculation of total emissions from the mine in the environmental impact statement (EIS) accurate? If not, what could be alternative emission estimates?
  - (11) What are the expected atmospheric CO<sub>2</sub> and temperature rises based on current international and Australian emission reduction pledges?

## SCIENTIFIC METHODS, FACTS AND ASSUMPTIONS

8. In producing this report, I have relied on a number of scientific methods, facts and assumptions drawn from the cited references. The scientific methods are state-of-the-art approaches in climate science and represent the best-estimates or ranges of uncertainty regarding our current scientific knowledge in regard to radiative forcing, climate system and carbon cycle responses.
9. I have attached for further reference (if required) copies of the main references cited, Hansen et al (2008), Meinshausen et al (2009), Rogelj et al (2010), Archer (2005); Archer and Brovkin (2008); Solomon et al (2009) and Meinshausen et al. (accepted).
10. The assumptions for the presented calculations in this report related to the Wandoan coal project are the following:
  - (a) **Conservative emission estimate:** If not otherwise stated, estimated climate effects assume the reported value of scope 3, “end-use for electricity-production” related emissions of 1.311 Gigatonnes of carbon dioxide (GtCO<sub>2</sub>) (see Table 14-5 of the Xstrata Coal (2008), with stated 43,706,866 tCO<sub>2</sub> of emissions, multiplied by 30 years of operation). Alternative estimates of up to 2.05 GtCO<sub>2</sub> are provided in the answer to Question 10 below and Appendix C.
  - (b) **Conservative attribution approach:** For calculating induced CO<sub>2</sub> concentration increases and temperature implications, I highlight the marginal effects, rather than normalized marginal or other proportional methods (see Trudinger & Enting, 2005, for a discussion). Likewise, a conservative approach is followed (i.e. doubting rather on the side of underestimating than overstating potential climate implications), when attributing the illustrative number of annually flooded people (see Question 8 below) towards carbon dioxide emissions of the Wandoan Coal Mine using a normalized marginal approach (as here, the normalized marginal method yields lower implied impacts than the marginal one).
  - (c) **Standard climate and carbon-cycle assumptions:** In order to quantify the induced increases in atmospheric CO<sub>2</sub> concentrations and temperatures, a couple of assumptions were necessary. Given a decreasing radiative efficiency of CO<sub>2</sub> at higher concentrations in combination with non-linear climatic feedbacks and CO<sub>2</sub> fertilization effects onto the carbon cycle, the background emission scenario has a moderate influence on calculated CO<sub>2</sub> concentrations. Given the current state of international negotiations, I assume a quantification of the low-ambition Copenhagen/Cancun pledges for 2020 and the often envisaged halving of global emissions by 2050. Specifically, I assume here the “Pessimistic with 2050 goal” scenario developed in Rogelj et al. (2010) to estimate the climate effects in terms of CO<sub>2</sub> concentrations and temperatures up to year 2300. For equilibrium considerations (Appendix B), I assume year 2000 CO<sub>2</sub> concentrations as background concentration level in line with Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) global warming potential (GWP) calculations. Carbon cycle and climatic responses were assumed as for the production of the new set of IPCC scenarios, i.e. the RCPs, as described in Meinshausen et al. (accepted).

## OPINION AND FINDINGS

### Question 1: Resilience of the atmosphere

11. In respect of climate change, what is the resilience of the atmosphere to CO<sub>2</sub> emissions? That is, what does paleoclimate evidence and ongoing climate change suggest as the maximum atmospheric CO<sub>2</sub> concentration that can be sustained by the atmosphere while preserving a planet similar to that on which civilization developed and to which life on Earth is adapted? Having regard to:

- (a) Observed annual average extent of Arctic sea ice;
- (b) Observed annual average extent of Alpine glaciers;
- (c) paleoclimate history of sea levels associated with current atmospheric CO<sub>2</sub> concentrations; and
- (d) any other matter you consider relevant.

### Answer:

12. Anthropogenic activities, mainly the burning of fossil fuels, increased atmospheric CO<sub>2</sub> concentrations above levels that were present over at least the last 650,000 years. Atmospheric CO<sub>2</sub> concentrations ranged in between 190 (during the glacial periods) and 280ppm (during the warm inter-glacials). Today's CO<sub>2</sub> concentrations reached 390ppm (NOAA, 2011), unprecedented over that time-frame.
13. Given the warming effect of CO<sub>2</sub>, but as well the effect of CO<sub>2</sub> on ocean acidification, today's concentrations already moved the planetary balance out of the window of conditions that existed over the holocene, i.e. the last 11,700 years of the present interglacial, over which the human civilisation developed. Similarly, today's ecosystems and its fauna and flora are adapted to the climatic zones which existed in the relatively stable climate over the Holocene. Limiting warming to below today's levels of 0.8°C would require reducing CO<sub>2</sub> concentrations to below 350ppm (cf. Table 10.8 in IPCC Working Group I (WG1) 2007, Solomon et al.).

**Table 1** (Reproduced from Table 10.8 from IPCC WGI, 2007). Best guess (i.e. most likely), likely and very likely bounds/ranges of global mean equilibrium surface temperature increase  $\Delta T(^{\circ}\text{C})$  above pre-industrial temperatures for different levels of CO<sub>2</sub> equivalent concentrations (ppm), based on the assessment of climate sensitivity given in Box 10.2 of IPCC WGI (2007).

Equivalent CO <sub>2</sub>	Best Guess	Very Likely Above	Likely in the Range
350	1.0	0.5	0.6–1.4
450	2.1	1.0	1.4–3.1
550	2.9	1.5	1.9–4.4
650	3.6	1.8	2.4–5.5
750	4.3	2.1	2.8–6.4
1,000	5.5	2.8	3.7–8.3
1,200	6.3	3.1	4.2–9.4

14. Recent observations show a steep decline in Arctic sea ice, more pronounced than the IPCC AR4 generation of general circulation models had projected. In 2011, the summer Arctic sea ice extent has so far been the lowest ever observed. The stabilisation of Arctic sea ice at current levels would require restoring the Earth's energy balance, requiring a return to 335-355ppm down from current atmospheric CO<sub>2</sub> concentrations, see Hansen et al. (2008).
15. The recent retreat of mountain glaciers implies that the preservation of seasonal water supplies in downstream areas will only be guaranteed in the long-term, if human-induced forcings were reduced to below current levels, possibly 350 ppm or lower, see Hansen et al. (2008).
16. Observational evidence over the last five glacial cycles and a 25m sea level rise estimate from the Pliocene, i.e. 3 million years ago, imply that equilibrium (millennium time-scale) sea level is closely related to global-mean temperatures. Based on the analysis of Rohling et al. 2009, paleoclimatic evidence suggests that approximately 5 to 10 m of sea level rise can be expected per degree of global warming. With current warming of about 0.8°C, it is hence to be expected that observed sea level rise of 20cm only constitutes a very small fraction of the induced sea level rise in the long-term. Returning to today's sea level would imply the world to return to below 350 ppm in the long-term.

## Question 2: Carbon budget

17. What are the cumulative human CO<sub>2</sub> emissions which can be released to the atmosphere prior to 2050 before reaching a 20%, 25%, and 50% probability respectively of exceeding 2°C warming above pre-industrial levels during the 21<sup>st</sup> Century?

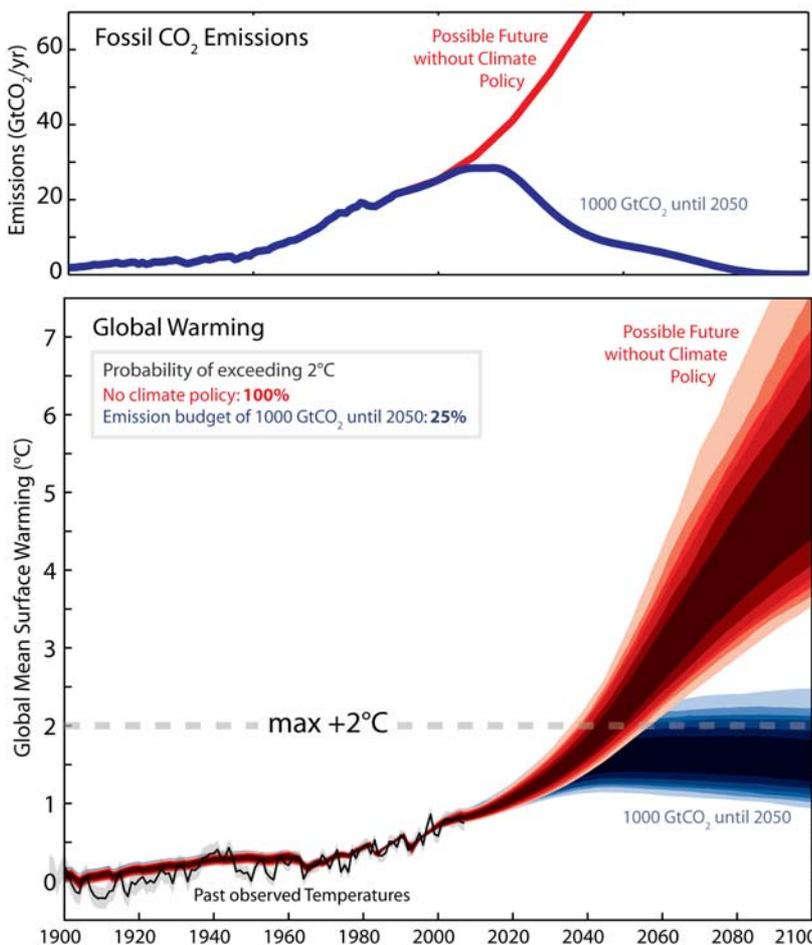
### Answer:

18. Based on a best estimate of climate sensitivity of 3°C warming for a doubling of pre-Industrial atmospheric CO<sub>2</sub> concentrations to 560 ppm, stabilizing mean global temperature rises to 2°C requires stabilizing atmospheric CO<sub>2</sub> and other factors that force the climate to change to below 450 ppm (IPCC 2007, see Table 10.8 therein, reproduced above). Climate sensitivity is not known precisely but probabilities can be assigned to the expected rise in mean global temperatures if atmospheric CO<sub>2</sub> rises to different levels. Table 10.8 from IPCC WGI (2007) given above shows the best estimate/guess and likely range of mean global rise at different levels of atmospheric CO<sub>2</sub> and other factors that force the climate to change.
19. The amount of carbon that we can still afford to emit without causing dangerous climate change (implicitly defined in the Copenhagen/Cancun agreements as exceeding 2°C global-mean temperatures) has become known as the “Global Carbon Budget”. This carbon budget, i.e., the cumulative CO<sub>2</sub> emissions between 2000 and 2050, is 886, 1000, and 1437 GtCO<sub>2</sub> in order to limit the probability of exceeding 2°C to 20%, 25% or 50%, respectively. See Table 2 below. This is equivalent to 32%, 36% and 52% of the estimated fossil carbon reserves of approximately 2800 GtCO<sub>2</sub> (see Meinshausen et al. 2009).
20. Part of this carbon budget is already used due to the emissions since year 2000. Thus, the actual carbon budget remaining until 2050 has already considerably shrunk. Rather than 1000 GtCO<sub>2</sub> for a probability of 25% of staying below 2°C, the remaining carbon budget is only 643 GtCO<sub>2</sub> over the period 2011 to 2050. See second column in Table 2 below. Fossil, cement and landuse-related CO<sub>2</sub> emissions from 2000-2010 amounted to approximately 357GtCO<sub>2</sub> (see Friedlingstein et al. 2010 and Le Quere et al. 2009). Thus, only another 19%, 23%, and 39% (529, 643 or 1080 GtCO<sub>2</sub>) of the available fossil carbon reserves (2800 GtCO<sub>2</sub>) can be burned from 2011-2050, if the probability of exceeding 2°C shall be limited to 20%, 25% or 50%, respectively.

**Table 2:** Carbon Budget to 2050 to achieve less than 2°C warming. (cf. Table 1 of Meinshausen et al. 2009)

Carbon budget 2000-2050 (GtCO <sub>2</sub> )	Carbon budget 2011-2050 (GtCO <sub>2</sub> )	Probability of exceeding 2°C (%)	Probability of remaining beneath 2°C (%)
886	529	20	80
1000	643	25	75
1437	1080	50	50

21. These proven recoverable fossil fuel reserves are only the small fraction of estimated resources that can be accessed with today’s prices and technologies. The overall amount of carbon in the resources, including methane clathrates, unconventional deposits etc. is multiple times higher.



**Figure 1.** Two possible futures: One in which no climate policies are implemented (red), and one with strong action to mitigate emissions (blue). Shown are fossil CO<sub>2</sub> emissions (top panel) and corresponding global warming (bottom panel). The shown mitigation pathway limits fossil and land-use related CO<sub>2</sub> emissions to 1000 billion tonnes CO<sub>2</sub> over the first half of the 21st century with near-zero net emissions thereafter. Greenhouse gas emissions of this pathway in year 2050 are ~70% below 1990 levels. Without climate policies, global warming will cross 2°C by the middle of the century. Strong mitigation actions according to the blue route would limit the risk of exceeding 2°C to 25%. For more details, see Figure 2 in Meinshausen et al., *Nature*, (2009).

### Question 3: Global temperature rises if total global coal burnt

22. If the total proven recoverable reserves of the world's coal continued to be produced and consumed, what would be the resulting atmospheric CO<sub>2</sub> concentration and likely degrees of global warming above pre-industrial averages?

#### Answer:

23. If the total proven recoverable reserves of the world's coal continues to be produced and consumed, by the end of the century, a global-mean temperatures of 3°C (with a 80% uncertainty range of 2.5 to 4.4°C) relative to pre-industrial levels can be expected. Atmospheric CO<sub>2</sub> concentrations would reach around 575 ppm (80% uncertainty range between 530 and 620 ppm).
24. This calculation assumes that fossil CO<sub>2</sub> reserves of 2780 GtCO<sub>2</sub> are emitted along a high-emission-growth trajectory (following the new Representative Concentration Pathway RCP85) until all reserves would be depleted (by approximately 2058). Burning all available *resources* (in contrast to only the reserves) would lead to much higher climate effects over the centuries, possibly up to 8 degree or higher warming. See Figure 1 above and compare Meinshausen et al., accepted.
25. Note that the assumption regarding non-CO<sub>2</sub> gases affect the derived climatic effects. The climate implications are derived based on a representation of current scientific uncertainties as described in Meinshausen et al. 2009. Other gases are assumed to follow the same high scenario RCP85 trajectory as described in Meinshausen, accepted.

### Question 4: Is 350ppm achievable by phasing out coal use?

26. Is an atmospheric CO<sub>2</sub> target of 350 ppm achievable by phasing out coal use, except where CO<sub>2</sub> is captured, and adopting agricultural and forestry practices that sequester carbon?

#### Answer:

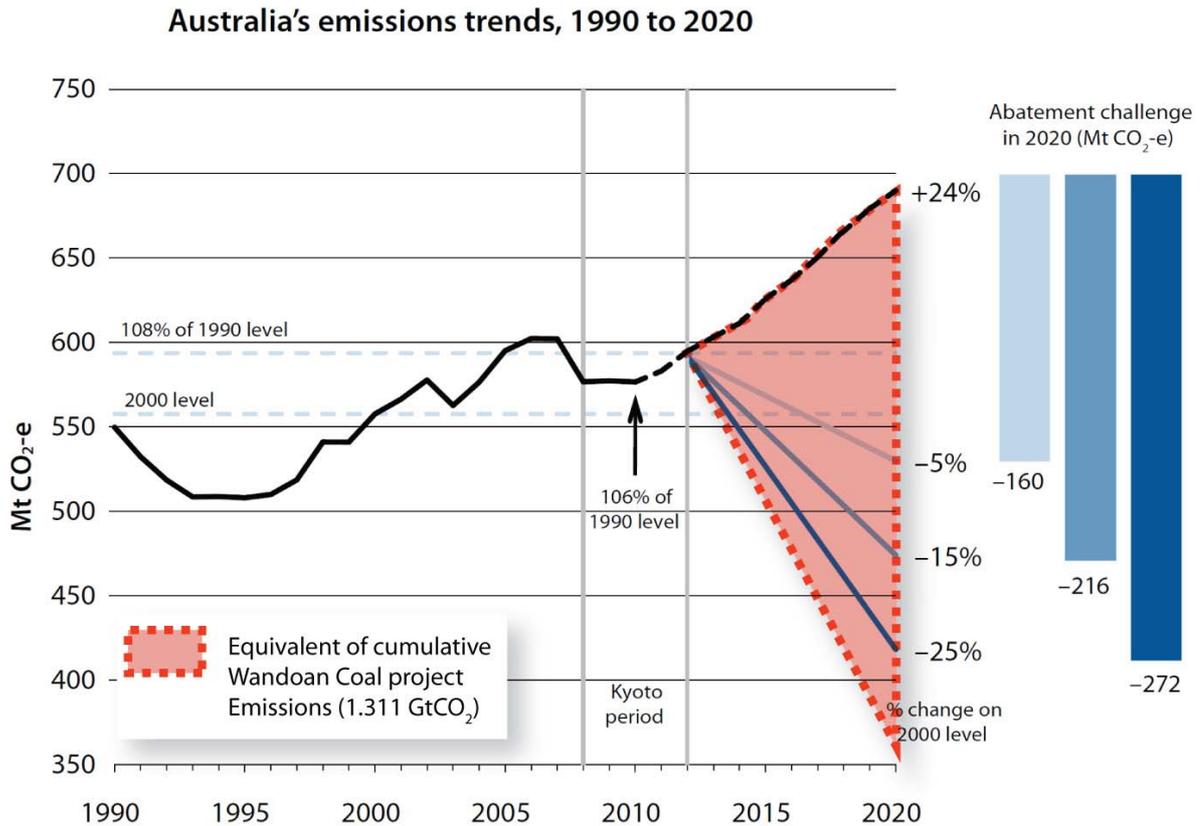
27. In the long-term, say by 2300, yes, it is possible that the atmospheric concentration of CO<sub>2</sub> can be returned to 350ppm or less. But only if emissions are substantially cut in the near-term, e.g. peak by 2015 and reduced to zero or net negative emissions in the second half of the 21<sup>st</sup> century. Given current CO<sub>2</sub> concentrations in 2010 of 390 ppm, a 350ppm target can only be achieved "from above" in the long-term. If agricultural and forestry practices were adopted in combination with biomass burning in combination with carbon sequestration and storage (CCS) and a phase-out of coal, atmospheric CO<sub>2</sub> concentrations could be drawn down – faster than the rather slow natural rate. With approximately 1 GtC net negative CO<sub>2</sub> emissions beyond 2070/2080, the lowest of the new scenarios used for IPCC Fifth Assessment Report (AR5), will indicate a return to 360ppm by 2300. With an enhanced phase out of coal, a 350ppm target could be reached, however only after a peaking around 450ppm CO<sub>2</sub>, possibly not much earlier than 2200.

## Question 5: Contribution of the mine to increased atmospheric CO<sub>2</sub> concentrations

28. To what extent will the emissions from the production, transport and use of coal from the proposed mine increase atmospheric CO<sub>2</sub> concentrations?

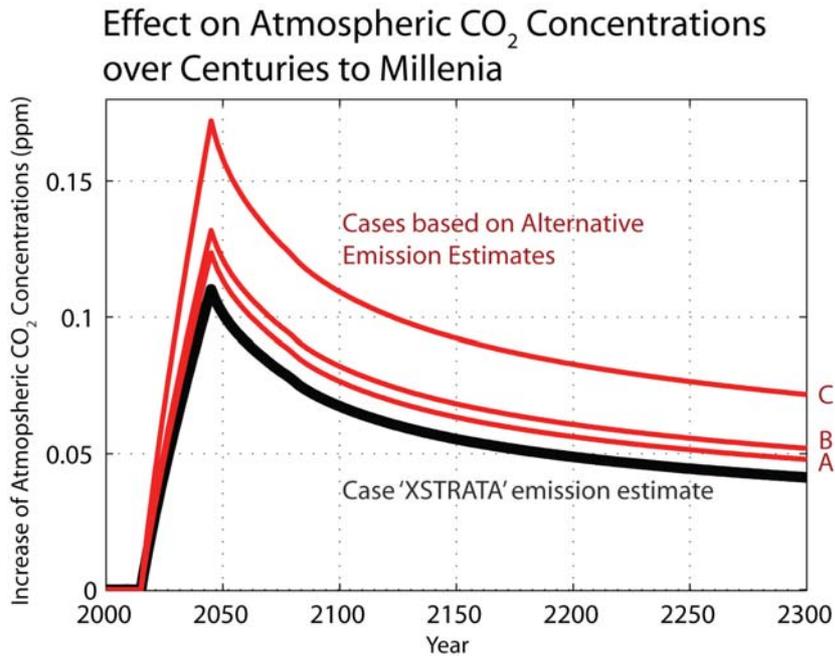
### Answer:

29. The impact on atmospheric CO<sub>2</sub> concentrations will be proportional to its cumulative CO<sub>2</sub> emissions (see Solomon et al, 2009, Allen et al. 2009, Meinshausen et al. 2009). Thus, it is illustrative to compare the CO<sub>2</sub> emissions associated with the Wandoan coal project to the mitigation efforts in Australia or national emissions of other developed countries. It turns out that the cumulative emissions associated with burning the coal from the Wandoan coal project will be equivalent to the mitigation effort necessary to reach a 35% reduction target by 2020 in Australia. In other words, if Australia would put in place policies to reduce its national emissions by -35% below 2000 levels (the current carbon pricing scheme and associated policies envisage to yield approximately a reduction of 5% below 2000 levels), then the cumulative effect of the Wandoan project would offset all Australian mitigation efforts up to then (see Figure 2). Note that because the cumulative emissions of CO<sub>2</sub> are driving climate change (see e.g. Meinshausen et al. 2009), it is legitimate to compare annual emissions, or emissions up to 2020 with cumulative emissions of a single project. In other words, it does not matter over what timeframe CO<sub>2</sub> emissions occur, the cumulative amount is decisive. A comparison to national emissions is provided below (see Question 9 and Figure 4), showing that emissions associated with the Wandoan project are equivalent to 39.2 years of current New Zealand fossil, industrial and agricultural CO<sub>2</sub> emissions,.



**Figure 2** – Comparison of the emissions arising from burning the produced coal in the Wandoan coal project with Australia's abatement ambitions until 2020. The cumulative emissions arising from the Wandoan coal project (1.311 GtCO<sub>2</sub> – end-use electricity production, scope 3) would offset all abatement efforts to reach a -35% target by 2020 for Australia. Currently, the proposed carbon pricing legislation envisages reaching a -5% target by 2020. Source: Graph adapted from Fig 2.3 in Garnaut (2011), itself based on 'Australian Government 2010, Australia's emissions projections 2010, Department of Climate Change and Energy Efficiency, p. 8'.

30. The CO<sub>2</sub> emissions related to burning the coal produced by the Wandoan mine project will have a lasting effect on the atmosphere, for centuries to millennia. Far out in the future, i.e., by 2300, the effect of the Wandoan coal project on atmospheric CO<sub>2</sub> concentrations far out in the future, by 2300, will still be approximately a third of the maximum impact on CO<sub>2</sub> concentrations by the mid 21st century (see Figure 2 below). Using scientific methods as for the next generation of emission scenarios to represent best-estimate projections, the projected increase of atmospheric CO<sub>2</sub> concentrations is 0.11 ppm by mid-century due to burning the produced coal from the Wandoan mine. This implies long lasting effects on both, global warming and ocean acidification.



**Figure 3** - Induced changes in atmospheric CO<sub>2</sub> concentrations due to the burning of the coal from the Wandoan coal project, with an assumed 30-year lifetime from 2015 to 2045. See Table 2 below for a description of the emission cases.

## Question 6: Contribution of the mine to global warming

31. To what extent will the emissions of the production, transport and use of coal from the proposed mine contribute to global warming, having regard to:

(a) The likelihood of global warming

### Answer:

32. Considering the background scenario of implemented Copenhagen/Cancun pledges for 2020, and halved global emissions by 2050 (with zero carbon emissions from 2080 onwards), the emissions from coal stemming from the Wandoan mine can be expected to increase the likelihood of exceeding 2°C by 0.05%.
33. If emissions were not 1.311 GtCO<sub>2</sub> over the 30-year lifetime, but rather 2.05 GtCO<sub>2</sub> (highest alternative emission estimate case C, see Appendixes C), the probability of exceeding 2°C as climatologically mean temperature would increase by 0.08% (with the background scenario roughly implying a 50:50 probability of staying below 2°C).
34. Taken at face value, this additional risk of 0.05% of missing the international goal of staying below 2°C might not seem to be of quantitative importance. Given the climatic risks at stake and the probabilistic nature of future climate change, attributing future climate impacts to these Wandoan coal emissions would nevertheless yield substantial attributable impacts (see paragraph 33 below).

(b) The severity of global warming

**Answer:**

32. Using the same climate/carbon-cycle model and setup as I used for the design of the next generation of IPCC scenarios, the best estimate additional warming is a climatologically mean increase in global-mean temperatures due to the burning of Wandoan coal of about  $0.0006^{\circ}\text{C}$  by 2050. Again, this might not be judged to be much in absolute terms, but is probably unmatched when compared to the climatic impact associated with any other single human project (except for other large oil field and coal mine explorations). Given climatic variability, this temperature contribution can be seen as a small, but non-negligible single contribution towards “loading the dice”, as extreme weather events (droughts, floods, strong cyclones, etc.) might become more frequent or more intense.
33. Furthermore, this small temperature change will induce a small sea level change, here estimated to be 0.23 cm in equilibrium, i.e. after hundreds to thousands of years (see Table 1, Row R, in Appendix B). Again, such sea level rise addition seems small, but given that the overall expected impacts are large, the attributed proportion of the impacts to this Wandoan coal mine are rather significant. Specifically, the Wandoan mine could cause the extra annual flooding of the settlements and houses of 23,000 people worldwide by the 2080s due to attributed increases of sea level rise (IPCC 2007). This assumes that only 5% of the induced equilibrium sea level rise (of 0.23 cm, see Appendix B) will have materialized by the end of the 21<sup>st</sup> century, and assumes constant protection at current levels. Adaptation measures could decrease this amount of affected people to a certain degree.

(c) The longevity of global warming?

**Answer:**

34. The carbon emissions associated with coal from the Wandoan project will increase atmospheric  $\text{CO}_2$  concentrations for the coming hundreds to thousands of years, as there is no finite lifetime for  $\text{CO}_2$  (see Figure 3 above). Basically,  $\text{CO}_2$  is redistributed between the oceans, terrestrial biosphere and the atmosphere, but is not decaying or chemically active like, e.g., methane with a comparatively short methane lifetime around 12 years.
35. The airborne fraction of  $\text{CO}_2$  emissions on millennial timescales is estimated to be in the order of 20%, meaning that carbon emissions associated with the Wandoan project will still lead to an increase of atmospheric  $\text{CO}_2$  concentrations in several hundred to thousand years, by approximately 0.035 ppm (see Row L in Table 1 of Appendix B) (Archer 2005; Archer and Brovkin 2008; Solomon et al 2009). Assuming a conservative best-estimate of climate sensitivity of  $3^{\circ}\text{C}$  (note that on such long timescales, additional feedback effects are likely yielding much higher, so-called Earth System sensitivities, possibly  $6^{\circ}\text{C}$ ), the induced temperature increase over thousands of years could be  $0.00042^{\circ}\text{C}$  under assumed background concentrations of current levels.

## Question 7: Timeframe of impacts from emissions

36. How long will the emissions from the proposed mine continue to increase atmospheric CO<sub>2</sub> concentrations?

### Answer:

37. As aforementioned, CO<sub>2</sub> emissions associated with burning the coal of this Wandoan project would lead to increased CO<sub>2</sub> concentrations over millennia (Archer 2005; Archer and Brovkin 2008; Solomon et al 2009). See Fig 3 above. The strongest increase in CO<sub>2</sub> concentrations could be expected at the end of the project lifetime, around 2050 by approximately 0.11 ppm, decreasing to a long-term millennial contribution of about 0.037ppm.

## Question 8: Are the impacts to the atmosphere from the mine reversible?

38. Is the increase in atmospheric CO<sub>2</sub> concentrations due to the proposed mine reversible? If so, on what timescales?

### Answer:

39. In principle, the answer to this question is, yes. Carbon dioxide concentrations could be drawn down with the equivalent amount of negative emissions. Thus, if a scheme were implemented by which 1.311 GtCO<sub>2</sub>eq would be drawn out of the atmosphere, the atmospheric CO<sub>2</sub> concentration in the longer-term would approximate the levels as if the Wandoan mine had not been going into operation. This however assumes that no amplifying feedbacks were started in the meantime (e.g. permafrost / clathrates), which would imply higher radiative forcing levels in the long-term.

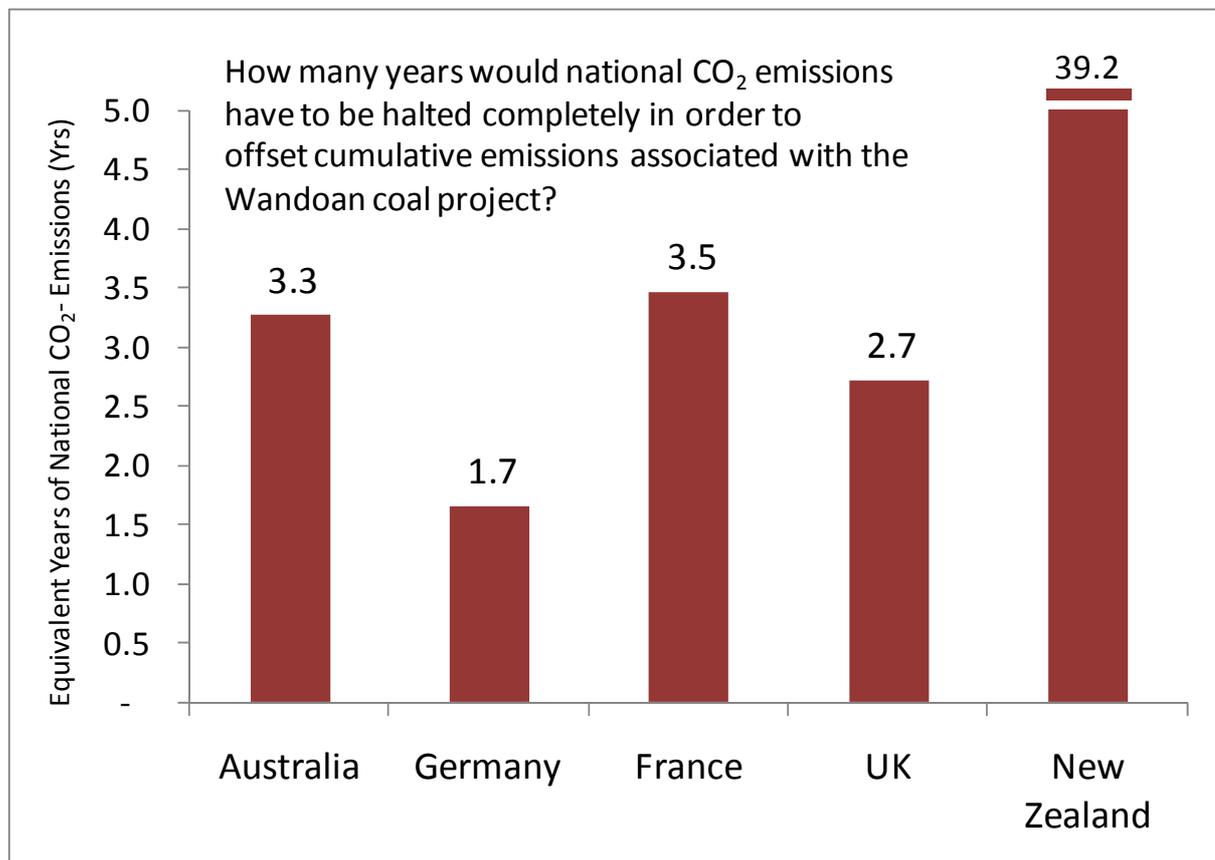
40. Options for drawing CO<sub>2</sub> out of the atmosphere again (net negative emissions) are for example the biomass burning in combination with CCS, air capture and sequestration or mineral sequestration techniques. However, these techniques are likely to be much more expensive than preventing the carbon to be emitted into the atmosphere in the first place. The timescale depends on the implementation rate of these technologies and the rate at which they could draw the 1.311 GtCO<sub>2</sub>eq again out of the atmosphere.

## Question 9: Are the emissions from the mine significant?

41. Are the emissions from the production, transport and use of coal from the proposed mine significant with respect to global warming?

**Answer:**

42. Yes, for the following three reasons, I believe that these mine emission, i.e. the emissions resulting from the burning of the Wandoan coal, can be considered significant with respect to global warming.
43. Firstly, human-induced global warming occurs because of the collective and cumulative emissions across all nations, which is why the international community negotiates emission caps for individual countries for certain years and periods. Thus, it is illustrative to compare these cumulative Wandoan project emissions with annual national emissions. In fact, it turns out that the reported estimate of cumulative emissions from the Wandoan coal project would equate to more than three years of current annual fossil CO<sub>2</sub> Australian emissions (327%, see Figure 4). With the higher-end alternative estimate of 2.05GtCO<sub>2</sub>, emissions attributable to burning the coal from the Wandoan mine would even equal more than 5 years of current annual 2009 fossil, industrial and agricultural CO<sub>2</sub> emissions of Australia. Compared to New Zealand's emissions, the CO<sub>2</sub> emissions associated with the Wandoan coal project are equivalent to 39.2 years of current New Zealand emissions.



**Figure 4** – Comparison of cumulative emissions arising from the burning of the produced coal in the Wandoan coal project (1.311 GtCO<sub>2</sub>) with national CO<sub>2</sub> emissions of major developed countries (2009 emissions, officially reported under UNFCCC for Total CO<sub>2</sub> emissions, excluding LULUCF, see [ghg.unfccc.int](http://ghg.unfccc.int)). The emissions arising from the Wandoan coal project are equivalent to 39.2 years of current New Zealand emissions. Thus, New Zealand would have to halt its fossil, industrial and agricultural CO<sub>2</sub> emissions over 39.2 years completely, in order to offset emissions arising from the Wandoan coal project.

44. Secondly, compared to the remaining carbon budget until 2050 (e.g. 643 GtCO<sub>2</sub>, see Question 2 above), emissions due to the coal from the Wandoan mine would constitute 0.20% of the remaining carbon that can be emitted to still have a likely chance of staying below 2°C (25% risk of exceeding it). Again, for a single project, such a 0.20% share can be considered significant, as it is larger than annual emissions of large developed countries (see point above).

**Table 3:** *The contribution of the Wandoan Coal Mine to the Carbon Budget up to 2050 to achieve less than 2°C warming.*

Carbon budget 2011-2050 (GtCO <sub>2</sub> )	Probability of exceeding 2°C (%)	Probability of remaining below 2°C (%)	Percentage contribution of mine to remaining budget based on 1.311 GtCO <sub>2</sub> of emissions (%)	Fraction mine contributes to budget based on 1.311 GtCO <sub>2</sub> of emissions
529	20	80	0.25	1/403 <sup>rd</sup> part
643	25	75	0.20	1/490 <sup>th</sup> part
1080	50	50	0.12	1/824 <sup>th</sup> part

45. Thirdly, the amount of carbon in coal mines and gas/oil fields that are already under operation, might well be already more than enough to prevent the international community from reaching their common goal, i.e. staying below 2°C. As a new project, the Wandoan mine would hence increase an already large stock of “tapped” carbon reserves in mines under operation – beyond the level that we can actually afford to emit given the internationally recognized 2°C goal.
46. Given that much of the information regarding the carbon content and development status of worldwide oil, gas fields and coal mines is not readily available in the public domain, this conclusion has to be somewhat speculative at this stage, but is supported by the following evidence:
- From the total proven recoverable coal resources listed by the 100 top stock-traded companies (389.19 Gt CO<sub>2</sub>), 85% of the coal sits in mines that are already in operation, in the construction phase or suspended (J. Leaton, pers. Communication, 19 July 2011, main author of the CarbonTracker 2011 report).
  - Assuming a similar development ratio of 85% (i.e., the carbon-weighted ratio of the mines and oil/gas fields being in operation or under construction versus only in the planning or potential future use status), the conclusion can be drawn that the Wandoan

mine would be “tapping” reserves that we cannot afford to emit anyway, if the probability of exceeding 2°C shall be kept between 20% or even up to 50%.

- (c) Even only a 40% overall assumed development ratio would render the additional carbon from the Wandoan mine as being “too much”, as the maximal “permissible” development ratios of the proven recoverable reserves (in the absence of implemented CCS) would be 19%, 23%, and 39% for a 20%, 25% or 50% probability of exceeding 2°C (see Question 2 above), respectively.
- (d) A necessary piece of information, probably available within the industry would hence be the overall amount of carbon that resides in mines and oil fields that are already under operation or in the construction phase.

### Question 10: Are the estimates of emissions in the EIS correct?

47. Is the calculation of total emissions from mine contained in the environmental impact statement (EIS) correct? If not, what could be alternative emission estimates?

#### Answer:

- 48. Unfortunately, I found the presented estimation of the overall emissions in the EIS (Xstrata Coal 2008 and Clarke 2008) not to be very transparent and they seem to be rather low compared to alternative emission estimates sketched below.
- 49. By far the most important share of emissions, 98.1%, is resulting from the burning of the produced coal by the end-user. In Table 14-5 of the EIS, these end-use emissions for electricity production are estimated in average to be 43,70 MtCO<sub>2</sub> per year, which amounts to 1.311 GtCO<sub>2</sub> over the 30 year operational lifetime of the project. The most straightforward way to estimate these CO<sub>2</sub> emissions is to estimate the carbon content of the produced coal, because basically all end-use applications result in the oxygenation of the carbon and release of CO<sub>2</sub>. Thus, the only two parameters necessary for the robust estimation of end-use-related CO<sub>2</sub> emissions due to the use/burning of the produced coal is (a) the mass of the produced coal, and (b) its carbon content on an ‘as is’ basis, i.e., taking into account the ash and moisture weight within the 23 Mt of product coal.
- 50. The carbon content of the product coal varies regionally. The Australian coal association states (on [http://www.australiancoal.com.au/coal-and-its-uses\\_coal-classification.aspx](http://www.australiancoal.com.au/coal-and-its-uses_coal-classification.aspx), accessed 19 July 2011):
 

*“Bituminous coals are dense black solids, frequently containing bands with a brilliant lustre. The carbon content of these coals ranges from 78 to 91 percent and the water content from 1.5 to 7 percent. The major NSW and Queensland deposits are bituminous and many are suited to the production of metallurgical coke. ...”*
- 51. XSTRATA provided an estimate of 77% (76% to 78%) for the carbon content of the product coal on an ash and moisture free basis. Thus, the question arises as to the expected ash and moisture content of the product coal. Table 9-3 of the EIS Geology chapter 9 provides estimates of 9-10% for the ash content and 10% for the moisture

content on an air-dried basis. This is used below, see Appendix C to derive the alternative emission estimates.

52. As the project documents state that the investigated amount of coal production is only related to the initial mining of 0.9 Gt coal, but given that overall, coal “in excess of 1.2 billion tonnes” (Page 15 of EIS Executive Summary in Xstrata Coal (2008)) is expected in that mine, the ultimately induced emissions might be even higher, up to 56% higher compared to the stated 1.311 GtCO<sub>2</sub> (see Case C in Appendix C).
53. If additional investigation should indeed show that those higher emission estimates might be more realistic compared to the 1.311 GtCO<sub>2</sub>eq one, then the climatic effects reported in the points above would be proportionally higher.

### **Question 11: Expected CO<sub>2</sub> and temperature rises based on current international and Australian policies**

54. What are the expected atmospheric CO<sub>2</sub> and temperature rises based on current international and Australian policies?

55. The only legally binding international commitments to reduce greenhouse gas emissions are contained in the *Kyoto Protocol to the United Nations Framework Convention on Climate Change 1997* (Kyoto Protocol). Those commitments end in 2012 and the parties to the UNFCCC have not been able to agree on new commitments.
56. At the 2009 conference of the parties (COP) to the UNFCCC and Kyoto Protocol held in Copenhagen, a majority of the parties, including Australia, agreed on non-binding pledges to emission reductions. This agreement is known as the “Copenhagen Accord”. Articles 1 and 2 of the Copenhagen Accord provided:

*“We underline that climate change is one of the greatest challenges of our time. We emphasise our strong political will to urgently combat climate change in accordance with the principle of common but differentiated responsibilities and respective capabilities. To achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2 degrees Celsius, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change. We recognize the critical impacts of climate change and the potential impacts of response measures on countries particularly vulnerable to its adverse effects and stress the need to establish a comprehensive adaptation programme including international support.*

*We agree that deep cuts in global emissions are required according to science, and as documented by the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below*

*2 degrees Celsius, and take action to meet this objective consistent with science and on the basis of equity. ...”*

57. Rogelj et al (2010) reviewed the emission reduction pledges made by parties to the Copenhagen Accord and found, in summary:
- (a) Global emissions in 2020 could be up to 20% higher than today;
  - (b) Even assuming that nations meet the ambitious end of their stated pledges without using surplus allowances and land-use credits, this it is still far above an emissions pathway that could realistically reach the 2°C target;
  - (c) Current pledges mean a greater than 50% chance that warming will exceed a mean global temperature rise of 3°C by 2100.
58. At the 2010 COP in the Cancun, the Copenhagen Accord pledges were formally brought into the United Nations Framework Convention on Climate Change process by listing the countries’ pledges in the “Cancun Agreement”. Given that the pledges inscribed in the Cancun Agreement are basically identical to those in the Copenhagen Accords, the analysis of Rogelj et al (2010) remains an accurate reflection of the climate implications of current international climate policy reduction pledges.
59. Australia’s unconditional commitment under the Copenhagen Accord of a 5% reduction in national emissions by 2020 is based on stabilizing atmospheric CO<sub>2</sub> around 550 ppm, thereby allowing a 3°C warming (Australian Treasury 2011, Ch 3). The Clean Energy Future legislative package that was recently released by the Commonwealth Government is based on this scenario (Australian Treasury 2011, Ch 3).

## **SUMMARY OF OPINIONS AND FINDINGS**

60. There are more proven fossil fuel reserves hold by private companies alone (cf. CarbonTracker, 2011), with the majority of it being in coal, than can be emitted until 2050 in order to keep global-mean temperatures below 2°C with a likely (75%) chance. For a single project, emissions arising from burning of coal from the Wandoan coal mine (estimated by the Environmental Impact Statement to be 1.311 billion tonnes of CO<sub>2</sub>eq over the course of the mine’s 30-year operation), will constitute a very large source of carbon dioxide emissions: equivalent to 3.3 years of current Australian CO<sub>2</sub> emissions, or 39.2 years of current fossil CO<sub>2</sub> emissions of New Zealand (see Figure 4). Of the remaining carbon budget until 2050, coal from the Wandoan mine would constitute a fraction of approximately 0.2%.
61. The climatic effects of the estimated 1.3 billion tonnes of CO<sub>2</sub> emissions from the mine would be: Peak increase of atmospheric CO<sub>2</sub> concentrations by 0.1 ppm around 2050, with continued increases for hundreds and thousands of years thereafter (0.04 ppm by 2300). This would lead to a peak increase of global-mean temperatures by approximately 0.0006°C. The increase of the probability of exceeding 2°C by approximately 0.05%.

62. The induced long-term (millennium time scale) sea level increase is estimated to be 0.23 cm, based on paleoclimatic evidence. If just 5% of this induced additional sea level rise occurred in 2080s as part of a 1m total sea level rise, the flooding of annually 23 thousand people' homes (out of 200 Million people) could be proportionally attributed to the Wandoan coal mine, if current coastal flooding protection is assumed.
63. These climatic effects would be proportionally higher, if the actual emissions arising from burning the coal of the Wandoan coal mine were higher than 1.311 billion tonnes of CO<sub>2</sub>eq (see Question 9) above. The provided details of the mine, with coal deposits "in excess of 1.2 billion tonnes" could result in an up to 56% higher amount of emissions than the provided emission estimate in the Environmental. Impact Statement. Even under optimistic assumptions for the "initial mining" with 30Mt/yr run of mine coal only, alternative emission estimates are 12% to 20% higher.

### **ADDITIONAL INFORMATION REQUIRED**

64. The actual carbon content on an 'as received' basis of the 23Mt product coal , which is expected to be produced in the Wandoan coal mine annually, would be relevant for estimating the resulting end-use CO<sub>2</sub> emissions more accurately. Alternatively, the expected ash and moisture content of the processed product coal would allow to relate the 23 Mt product coal to its total carbon content in tones.

### **DECLARATION**

65. I confirm the following:

- (a) the factual matters stated in this report are, as far as I know, true;
- (b) I have made all enquiries that I consider appropriate;
- (c) the opinions stated in this report are genuinely held by me;
- (d) the report contains reference to all matters I consider significant; and
- (e) I understand my duty to the court and have complied with the duty.



.....  
Dr Malte Meinshausen

3 August 2011

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## Appendix A – Curriculum vitae for Dr Malte Meinshausen

Dr. Malte Meinshausen  
 Potsdam Institute for Climate Impact Research (PIK)  
 P.O. Box 60 12 03  
 Telegrafenberg A31  
 D-14412 Potsdam, Germany

& as well:  
 School of Earth Sciences  
 McCoy Building, Room 310  
 University of Melbourne  
 Victoria 3010  
 Australia

### Publications

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## Contributing Author to IPCC Fourth Assessment Report

### *Working Group I, Chapter 10:*

Meehl, G. A., T. F. Stocker, W. Collins, P. Friedlingstein, A. Gaye, J. M. Gregory, A. Kitoh, R. Knutti, J. Murphy, A. Noda, S. C. B. Raper, I. Watterson, A. Weaver, Z.-C. Zhao, R. Alley, J. Annan, J. Arblaster, C. Bitz, A. le Brocq, P. Brockmann, V. Brovkin, L. Buja, P. Cadule, G. Clarke, M. Collier, M. Collins, E. Driesschaert, N. A. Diansky, M. Dix, K. Dixon, J.-L. Dufresne, M. Dyrgerov, M. Eby, N. Edwards, S. Emori, P. Forster, R. Furrer, P. Glecker, J. Hansen, G. Harris, G. Hegerl, M. Holland, A. Hu, P. Huybrechts, C. Jones, F. Joos, J. Jungclaus, J. Kettleborough, M. Kimoto, T. Knutson, M. Krynytzky, D. Lawrence, M.-F. Loutre, J. Lowe, D. Matthews, M. Meinshausen, S. Müller, S. Nawrath, J. Oerlemans, M. Oppenheimer, J. Orr, J. Overpeck, T. Palmer, A. Payne, G.-K. Plattner, J. Räisänen, A. Rinke, E. Roeckner, G. L. Russell, D. Salas y Melia, B. Santer, G. Schmidt, A. Schmittner, B. Schneider, A. Shepherd, A. Sokolov, D. Stainforth, P. Stott, R. Stouffer, K. Taylor, C. Tebaldi, H. Teng, L. Terray, D. Vaughan, E. M. Volodin, B. Wang, T. M. L. Wigley, M. Wild, R. van de Wal, J. Yoshimura, Y. Yu and S. Yukimoto (2007). Chapter 10: Global Climate Projections. IPCC Fourth Assessment Report. IPCC. Cambridge, Cambridge University Press.

### *Working Group I, Chapter 8:*

Randall, D., R. A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R. Stouffer, A. Sumi, K. Taylor, K. AchutaRao, R. Allan, A. Berger, H. Blatter, C. Bonfils, A. Boone, C. Bretherton, A. Broccoli, V. Brovkin, W. Cai, M. Claussen, P. Dirmeyer, C. Doutriaux, H. Drange, J. L. Dufresne, P. Forster, A. Frei, A. Ganopolski, P. Gent, P. Glecker, H. Goosse, R. Graham, J. M. Gregory, R. Gudgel, A. Hall, S. Hallegatte, H. Hasumi, A. Henderson-Sellers, H. Hendon, K. Hodges, M. Holland, A. A. M. Holtslag, E. Hunke, P. Huybrechts, W. J. Ingram, F. Joos, B. Kirtman, S. Klein, R. Koster, P. Kushner, J. Lanzante, M. Latif, N.-C. Lau, M. Meinshausen, A. Monahan, J. Murphy, T. J. Osborn, T. Pavlova, V. Petoukhov, T. Phillips, S. Power, S. Rahmstorf, S. C. B. Raper, H. Renssen, D. Rind, M. Roberts, A. Rosati, C. Schär, A. Schmittner, J. F. Scinocca, D. Seidov, A. G. Slater, J. Slingo, D. Smith, B. J. Soden, W. Stern, D. A. Stone, K. Sudo, T. Takemura, G. Tselioudis, M. Webb and M. Wild (2007). Climate Models and Their Evaluation. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning et al. Cambridge, United Kingdom, and New York, NY, USA, Cambridge University Press: 591-662.

### *Working Group II, Chapter 2:*

Carter, T. R., R. N. Jones, X. Lu, S. Bhadwal, C. Conde, L. O. Mearns, B. O'Neill, M. D. A. Rounsevell, M. B. Zurek, J. de Chalaz, S. Hallegatte, M. Kandlikar, M. Meinshausen, R. Nicholls, M. Oppenheimer, A. Patt, S. C. B. Raper, K. Ruosteenoja, C. Tebaldi and D. Van Vuuren (2007). New assessment methods and the characterisation of future conditions. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, O. F. Canziani, J. Palutikof, P. J. Van der Linden and C. E. Hanson. Cambridge, UK, Cambridge University Press: 133-171.

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### **Diploma Thesis**

Meinshausen, M. (2001). Long term chlorine loading prediction: SiMCeL. Institute for Atmosphere and Climate, IACETH. Zurich, ETH Zurich: 91.<http://e-collection.ethbib.ethz.ch/show?type=dipl&nr=22>

### **Academic Education & Employment**

- Since Honorary Senior Research Fellow at School of Earth Sciences, University of Melbourne & Affiliate  
2011 member of PRIMAP Research Group, Potsdam Institute for Climate Impact Research, Germany
- 2008 Team-Leader of Research Group PRIMAP at Potsdam Institute for Climate Impact Research, Potsdam,  
– Germany  
2011
- since Researcher at Potsdam Institute for Climate Impact Research, Potsdam, Germany  
2006
- 2005 - Guest researcher at the National Center for Atmospheric Research, NCAR, Boulder, USA  
2006
- 2002 - Doctoral courses in macroeconomics, microeconomics and econometrics at the Study Center Gerzensee,  
2003 Swiss National Bank
- 2001 - PhD study in the area "International climate policy and economics", Department of Environmental  
2005 Sciences, ETH
- 1995 - Diploma course "Environmental Sciences" at the ETH Zurich. Diploma thesis on "Long-term  
1999 stratospheric chlorine loading prediction" at the Institute for Atmospheric and Climate Science, ETH  
2000 - Zurich  
2001
- 1999 - MSc Environmental Change & Management, University of Oxford, UK. MSc Thesis on "The climatic  
2000 effect of temporary carbon storage under the Clean Development mechanism of the Kyoto Protocol"

### **Other Professional experience**

- Since Freelance consultancy for government bodies and environmental NGOs on climate policy issues  
2000
- 2001 - Assisting and lecturing at the Institute for Atmospheric and Climate Science, ETH Zurich, for the case  
2002 study "Montreal Protocol"
- 1998 - Internship at Ecologic gGmbH, Berlin on the Montreal- and Kyoto Protocol  
1999

## Appendix B – Induced millennium scale sea level rise

**Table B1.** Estimation of Wandoan coal emissions' effect on millennium-scale sea level rise.

Row	Derivation	INPUT	Unit	Value	Source / Description
A		Cumulative CO <sub>2</sub> emissions	GtCO <sub>2</sub>	1.31	Wandoan Coal Project Env. Impact Statement EIS
B	A/44*12	Cumulative CO <sub>2</sub> emissions	GtC	0.36	Divided by the mol weight of CO <sub>2</sub> and multiplied by the mol weight of C
C		Mass per atmospheric concentration	GtC/ppm	2.12	
D		Millenium timescale airborne fraction	Percent	0.22	Bern-CC model, as provided in footnote a to Table 2.14 in IPCC AR4 (Solomon et al., 2007)
E		Forcing at doubled CO <sub>2</sub> concentrations	W/m <sup>2</sup>	3.71	Mhyre et al. 1998
F		Climate Sensitivity at doubled CO <sub>2</sub> concentrations	K	3.00	The IPCC AR4 estimate is 3 (2 - 4.5)°C per doubling of CO <sub>2</sub> concentrations
G		Millenium timescale sea level rise per degree of Antarctic Warming	cm/K	500.00	Based on Rohling et al. 2009, Fig. 2B, could be 1000cm per degree of warming.
H		Antarctic Amplification	K/K	1.10	Frieler et al. 2011, submitted, J.Climate.
I		Background CO <sub>2</sub> concentration	ppm	378.00	Consistent with Bern-CC formula, see above.
J		Pre-industrial CO <sub>2</sub> concentration	ppm	278.00	IPCC AR4 (Solomon et al., 2007)
K		Number of people flooded under constant protection per meter SLR	Million/m	200.00	Fig. 6.8 of IPCC AR4 WG2 (Parry et al., 2007), following Nicholls and Lowe, 2006
Row	DERIVATIVES				
L	B/C*D	Millenium Timescale CO <sub>2</sub> concentration increase	ppm	3.65E-02	
M	E/ln(2)* ln((I+L)/J)	Forcing due to background plus Wandoan mine CO <sub>2</sub> concentration	W/m <sup>2</sup>	1.65	
N	E/ln(2)* ln(I/J)	Extra Forcing due to this atmospheric CO <sub>2</sub> increase	W/m <sup>2</sup>	1.64	
O	M-N	Extra Forcing due to Wandoan Mine	W/m <sup>2</sup>	5.17E-04	
P	O*F/E	Extra equilibrium global-mean warming due to Wandoan Mine	K	4.18E-04	
R	P*G*H	Extra millenium time-scale sea level due to Wandoan Mine	cm	0.23	
S		Proportion of induced sea level rise that materialized by the end of the 21st century. This assumption is rather uncertain.	%	5%	
T	K*S	Approximate number of people flooded, i.e. the share of people that lives in the 2080s in areas prone to be flooded under constant protection, if such an additional sea level would occur in 2080 already as part of a total 1m SLR.	Thousand	23.01	

## Appendix C –Alternative Emission estimates for Scope 3 ‘end-use for electricity production’

**Table D1** - Default full fuel cycle cumulative CO<sub>2</sub> equivalence emissions as provided by the Environmental Impact Statement (see Row A), compared with alternative estimates for the scope 3 end-use CO<sub>2</sub> emissions due to the burning of the coal.

Case	Run of Mine Coal (Mt/yr)	Washing Yield (weight %)	Product Coal (incl. Ash and moisture) Mt/yr	Ash content of product coal (weight %)	Moisture content of product coal (weight %)	Product coal moisture and ash free (Mt/yr)	Carbon content on dry and ash free basis	Carbon of product coal (MtC/yr)	Carbon of product coal (MtCO <sub>2</sub> /yr)	Over 30 years (GtCO <sub>2</sub> )	XSTRATA estimate (GtCO <sub>2</sub> )	Relative to XSTRAT estimate	Total Run of Mine Coal Extraction over 30 yrs (Mt)
	A	B	C	D	E	$F=C*(1-D-E)$	G	$H=F*G$	$I=H*44/12$	$J=I*30/1000$	K	$L=J/K$	$M=A*30$
XSTRATA estimate "Initial Mining"	30	?	23	?	?	?	77%	11.92	43.70	1.31	1.31	100%	900
Case B "Initial Mining; 15% moisture"	30	77%	23	9.5%	15%	17.37	77%	13.37	49.03	1.47	1.31	112%	900
Case B "Initial Mining; 10% moisture"	30	77%	23	9.5%	10%	18.52	77%	14.26	52.27	1.57	1.31	120%	900
Case C "Full Mining"	40	75%	30	9.5%	10%	24.15	77%	18.60	68.18	2.05	1.31	156%	1200

**Notes:**

- 1) Estimated 30Mtpa of ROM material times 30 years of operation, as stated in Terms of reference for an environmental impact statement, page 2. Only initial mining considered. Fourth ROM processing unit optional.
- 2) Source for carbon content of Queensland bituminous coal: From [http://www.australiancoal.com.au/coal-and-its-uses\\_coal-classification.aspx](http://www.australiancoal.com.au/coal-and-its-uses_coal-classification.aspx), accessed 18 July 2011

## Appendix D – Comparison of fossil CO<sub>2</sub> emissions associated with the Wandoan project and developed country annual emissions.

**Table F1** - Comparison of emissions associated with Wandoan Coal Project over its entire lifetime (only scope 3, end-use electricity generation, i.e., 1.311 GtCO<sub>2</sub>) and fossil CO<sub>2</sub> emissions of major developed countries in 2010.

Country	Fossil, industrial and agricultural CO <sub>2</sub> emissions in year 2009 (GtCO <sub>2</sub> /yr)	Wandoan Project Lifetime emissions (1.311 GtCO <sub>2</sub> ) in comparison (%)	How many years would national CO <sub>2</sub> emissions have to be halted completely in order to offset cumulative emissions associated with the Wandoan coal project?
Australia	0.400	327%	> 3 years and 3 months
Germany	0.789	166%	> 1 years and 7 months
France	0.378	347%	> 3 years and 5 months
UK	0.481	273%	> 2 years and 8 months
New Zealand	0.033	3920%	> 39 years and 2 months

Data Source for national emissions: Officially reported 2009 CO<sub>2</sub> emissions for national total excl. LULUCF under UNFCCC, see [ghg.unfccc.int](http://ghg.unfccc.int).

**Appendix E -**

**Hansen et al (2008)**

**Target Atmospheric CO2: Where Should Humanity Aim?**

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**Appendix F -****Meinshausen et al (2009)****Greenhouse-gas emission targets for limiting global warming to 2°C**

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**Appendix G -****Rogelj et al (2010)****Copenhagen Accord pledges are paltry**

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**Appendix H -**

**Archer (2005)**

**The Fate of CO<sub>2</sub> in Geologic Time**

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**Appendix I -**

**Archer and Brovkin (2008)**

**The millennial atmospheric lifetime of anthropogenic CO<sub>2</sub>**

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**Appendix J -**

**Solomon et al (2009)**

**Irreversible climate change due to carbon dioxide emissions**

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**Appendix K –**

**Meinshausen et al (accepted)**

**The RCP Greenhouse Gas Concentrations and their Extension from  
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