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Technical appendix

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Appendix 1

1.0. Approach to modelling damages from climate change as the baseline

To date, most macroeconomic models and economic policy analysis is considered against a ‘baseline’ that assumes economic growth will occur unhindered by rising concentrations of greenhouse gases in the world’s atmosphere.

Models inherently assume that economic growth will continue unhindered alongside rising emissions, and standards of living will continue to rise globally. Deloitte Economics Institute believes that this viewpoint does not hold true in practice – particularly in the long-run – and therefore economic analysis and climate policy is informed through a dated theoretical framework.

Climate change impacts should not be considered as a ‘scenario’ on the baseline – because in the absence of fundamental societal and economic shifts, the impacts of unmitigated climate change are the baseline.

By excluding the economic impacts of climate change from economic baselines, decision making misses a fundamental point. The Network of Central Banks and Supervisors for Greening the Financial System (NGFS), made up of 69 central banks last year released guidance on the need to solve for this exact issue (and many others).

Understanding and accounting for the longer-term effects of climate change on productivity, potential output and economic growth is critical to understanding the likely future growth path of the global economy, as well as the distribution of disruptive climate impacts.

Deloitte Economics Institute has invested in developing an extension of the in-house Regional General Equilibrium Model (DAE-RGEM), giving it the functionality of a fully-fledged Integrated Assessment Model (IAM). Unlike many IAMs, this model has multiple economic damages which vary by sector and region, and unlike many regional CGE models, it has full integration with the global economy through the GTAP database and a complete set of emissions accounts covering CO2 and non-CO2 gases.

This work draws on, and contributes to, a three key streams of research:

- The primary stream is that which has pioneered, refined and expanded CGE models, allowing for modelling of complex and dynamic policies, like those required to affect a transition to a low-carbon environment (see Adams and Parmenter, 2013).[a]
- Another stream has followed the same process of pioneering, refinement and expansion, but for IAMs. The IAM stream, in its initial phases, used a more aggregate representation of the economy which allowed for a stylised climate module (establishing a link between the economic system potential damages associated with climate change to be incorporated to form a an integrated (but simplified) framework for assessing the decisions facing policy makers when it came to emissions reduction targets (see Nordhaus 2013).[b]
- The third and most recent stream is that which seeks to combine the two described above and provide the rich sectoral and policy detail inherent in modern CGE models, alongside climate feedback mechanisms which allow for integrated assessment (see Kompas, 2018).[c]

D.CLIMATE – which has been tested in Australian state jurisdictions – is a modelling methodology and policy analysis technique that seeks to 'correct' the typical business as usual baseline assumed in most modelling.

D.CLIMATE is built on an economic modelling framework that accounts for the economic impacts of climate change and establishes a reference case that can be modelled out to the year 2100 or beyond. The D.CLIMATE process and logic as follows:

1. The modelling produces an economic baseline economic growth path which draws on short to medium term global and regional forecasts in combination with a long-run assumption of contraction and convergence.
2. The baseline economic growth path has an associated emissions growth path – derived from the established link between economic flows and emissions – and this corresponds to an evolution in atmospheric greenhouse gas concentration which rise in line with a Representative Concentrative Pathway (RCP)
3. Rising atmospheric concentrations of greenhouse gases causes global warming above pre-industrial levels.
4. Warming causes shifts in global climate patterns and results in damages to the factors of production and their productivities.
5. Damages to factors of production are distributed across the economy, impacting Gross Domestic Product.
6. These feedbacks are fed back into the model to determine the associated deviation in economic activity associated with a given level of warming (i.e. the damages).

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[a] Philip D. Adams and Brian R. Parmenter. (2013). *Chapter 9 – Computable General Equilibrium Modeling of Environmental Issues in Australia: Economic Impacts of an Emissions Trading Scheme*, Handbook of Computable General Equilibrium Modeling (1) 553-657. https://doi.org/10.1016/B978-0-444-59568-3.00009-2

[b] Nordhaus, William. (2013). *Chapter 16 – Integrated Economic and Climate Modeling.* Handbook of Computable General Equilibrium Modeling (1) 1069-1131. https://doi.org/10.1016/B978-0-444-59568-3.00016-X

[c] Kompas, T., Pham, V. H., & Che, T. N. (2018). The effects of climate change on GDP by country and the global economic gains from complying with the Paris Climate Accord. Earth's Future, 6, 1153– 1173. https://doi.org/10.1029/2018EF000922

Translating this concept into a modelling process involves three models which are linked through three key outputs. Deloitte Economics Institute' approach extends methods adopted by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), the International Panel on Climate Change (IPCC) and other research organisations. The method is extended by necessity for practical public policy purposes and the modelling is regionalised – allowing results and insights to be produced at the regional level (such as countries or regions or more granular geographies such as statistical or local government areas).

The modelling process is summarised below:

1. Deloitte's in-house regional Computable General Equilibrium model (DAE-RGEM) is used to produce a projected path for economic output and emissions that align with a chosen Representative Concentration Pathway (RCP), for example RCP6.0.
2. For each RCP scenario the associated climate data (like annual temperature increases and atmospheric concentrations) are sourced from a synthesis of the models available Coupled Modelling Intercomparison Project (CMIP6).[d]
3. This climate data is then feed into damage functions to inform how shifts in temperature may play out in terms of impacts on the stocks and productivities of factors of production in each sector/region. Unlike most other models, we model a broad range of damages, including capital damages, sea level rise damages to land stock, heat stress damages on labour productivity, human health damages to labour productivity, agricultural damages from changes in crop yields, tourism damages to net inflow of foreign currency and damages to energy demand.

As with all CGE modelling exercises the results presented in this report are deviations – either percentage changes or absolute dollar/employment differences. Unlike most modelling exercises, though, the deviations presented in this report involve a two-step calculation to account for the combined impact of avoided damages alongside transition costs. In a simple example, a region might be expected to lose 10% of output due to the damages associated with less ambitious domestic/global action on climate change. In a scenario where they and the rest of the world take more ambitious action, there might be a smaller loss due to damages, but there will be some cost associated with the policies enacted to reduce emissions. The results presented here show the combination of damages and transition costs, relative to the more severe damages from the baseline scenario.

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[d] Only models that permit an appropriate license for commercial application are used in the modelling process. Swart et al. (2019): CCCma CanESM5 model output prepared for CMIP6 ScenarioMIP. Version 20190429. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.1317

Appendix 2

2.0. Database construction

The core economic data underpinning D.CLIMATE – the social account matrix (SAM) – is sourced from the Global Trade Analysis Project (GTAP) database (Walmsley et. al., 2013). In this instance, that economic data is supplemented with specific data on electricity differentiated by power generation type (i.e. coal, gas, solar, etc.) from the GTAP satellite database GTAP-Power as well as CO2 and non-CO2 emissions data.

The behavioural parameters are also sourced from GTAP for the most part with some exceptions as discussed below.

2.1. Regional Aggregation

D.CLIMATE is a global model and can be tailored to a specified regional concordance in line with the GTAP database.[e] For this project, the Asia Pacific region was isolated in the model with several regional aggregations modelled within this geographical area. The regional concordances for this study are presented in Table A.1 below.

Table A.1 Regional concordance

Abbreviation	Geographies	GTAP regions
ROA	Australia	Australia
NZ	New Zealand	New Zealand
PACIFIC	Pacific Nations	Rest of Oceania
CHINA	Mainland China	China Hong Kong
JAPAN	Japan	Japan
KOREA	South Korea	Republic of Korea
OTHASIA	Other Asia	Mongolia Rest of East Asia Nepal Pakistan Sri Lanka Rest of South Asia
TWN	Taiwan	Taiwan
ASEAN	ASEAN+	Brunei Darussalam Cambodia Indonesia Lao PDR Malaysia Philippines Singapore Thailand Vietnam Rest of Southeast Asia
INDIA	India	India
ROW	Rest of World	All others

Source: Deloitte Economics Institute

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[e] GTAP (2021), 'GTAP Data Bases' – https://www.gtap.agecon.purdue.edu/databases/regions.aspx?version=9.211

2.2. Sectoral Aggregation

D.CLIMATE can also be tailored to a specified sectoral concordance in line with GTAP database. For this project, a relatively high-level sectoral aggregation was chosen given the level of regional detail that was required in the Asia Pacific region.

However, there was a specific effort made to distinguish two non-GTAP sectors (hydrogen and bio-energy) to aid in the representation of the transition to net zero.

The sectoral concordance for this study are presented in Table A.2 below.

Table A.2 Sectoral concordance

Abbreviation	Sector name	GTAP sector(s)
AGRI	Agriculture, forestry & fishing	Paddy rice Wheat Cereal grains nec Vegetables, fruit, nuts Oil seeds Sugar cane, sugar beet Plant-based fibers Crops nec Bovine cattle, sheep and goats, horses Animal products nec Raw milk Wool, silk-worm cocoons Forestry Fishing
COAL	Coal	Coal
OIL	Oil	Oil
GAS	Gas	Gas
OMIN	Other mining	Other Extraction (formerly omn Minerals nec)
FOODMAN	Food manufacturing	Bovine meat products Meat products nec Vegetable oils and fats Dairy products Processed rice Sugar Food products nec Beverages and tobacco products
LIGHTMAN	Light manufacturing	Textiles Wearing apparel Leather products Wood products Paper products, publishing
HYD	Hydrogen	Petroleum, coal products*
BIO	Bio-energy	Petroleum, coal products*
P_C2	Petroleum, coal products	Petroleum, coal products

Abbreviation	Sector name	GTAP sector(s)
HEAVYMAN	Heavy manufacturing	Chemical products Basic pharmaceutical products Rubber and plastic products Mineral products nec Ferrous metals Metals nec Metal products Computer, electronic and optical products Electrical equipment Machinery and equipment nec Motor vehicles and parts Transport equipment nec Manufactures nec
ELYTND	Electricity transmission and distribution	Electricity: Transmission and
ELYDIRTY	Fossil fuels	Coal base load Gas base load Oil base load Other base load Gas peak load Oil peak load
ELYCLEAN	New energy sector	Nuclear base load Wind base load Hydro base load Hydro peak load Solar peak load
GDT	Gas manufacture and distribution	Gas manufacture, distribution
WATER	Water	Water
CONS	Construction	Construction
TRADE	Retail trade & tourism	Trade Accommodation, Food and service activities
TRANS	Transport	Transport nec Water transport Air transport Warehousing and support activities
OSERV	Other services	Communication Financial services nec Insurance (formerly isr) Real estate activities Business services nec Recreational and other services Dwellings
GOVSERV	Government services	Public Administration and defense Education Human health and social work activities

Source: Deloitte Economics Institute

*The Hydrogen and Bio-energy sectors are not identified as individual sectors in the GTAP database but have instead been distinctly separated from the petroleum, coal products sector. An explanation of this process is provided in the following section.

2.3. Commodity Splits

In an effort to provide greater granularity in the representation of the transition to net zero, the Hydrogen and Bio-energy sectors were split from the parent sector: Petroleum, coal products. This process was required as the GTAP database does not specifically identify either of these new energy sectors, individually.

The Petroleum, coal products sector was targeted as the parent sector due to the similarities in its sales structure to that of Hydrogen and Bio-energy. This transformation was informed by information gathered on the current size of the Hydrogen, Bio-energy and Petroleum, coking sectors and the respective cost and sales structures of each individual sector. This research was gathered and the split executed so as to maintain the following high-level facts:

- The size of the Hydrogen sector is approximately $70 billion, representing around 2% of the parent sector (Petroleum, coal products). Its cost structure is different in that it draws more heavily on coal and P_C (i.e. the parent sector itself) although there is sufficient flexibility in it’s production function to allow for a shift toward production using zero emission electricity and primary factors as the main inputs. The sales structure is the same as its parent.
- The size of the Bio-energy sector is approximately $50 billion, representing around 1.4% of the parent sector (Petroleum, coal products). It relies solely on the output of agriculture and waste as inputs to production in conjunction with primary factors. The sales structure is the same as its parent.
- The remaining P_C sector is essentially the same as the original GTAP sector, but slightly smaller.

There is scope for further refinement of this process, drawing on more detailed data to help get a better picture of production, consumption and export, specifically at the detailed regional level.

Appendix 3

3.0. Baseline economic assumptions

In the baseline, a set of assumptions have been applied for macroeconomic growth rates and technological improvements over the period 2015 to 2070. These key variables have been calibrated drawing on historical and forecast timeseries from reputable sources.

3.1. Macroeconomic variables

Macroeconomic variables including GDP (Table A.3), population and labour supply (Table A.4), unemployment rate (Table A.5) are calibrated for each year over the model period, 2015 to 2070.

Growth rates for GDP are calibrated drawing on data from the International Monetary Fund's (IMF) World Economic Outlook Database that provides historical and forecast GDP growth over the period 1980 to 2025.[1] These growth rates are extrapolated using historical growth rates and assuming a degree of convergence over the long-run.

Population growth rates are calibrated using a combination of data from the IMF in the short-term and Medium Forecasts developed by the United Nations over the medium- to long-term.[2,3] Labour supply is calibrated employing a similar approach and is assumed to broadly reflect trends in population growth.

Unemployment rates are calibrated using short-term forecasts developed by the IMF.[4] These are short-term forecasts and are extrapolated using a moving average. This approach implicitly assumes a steady state unemployment rate over the medium- to long-term.

3.2. Emissions, Energy efficiency and Productivity improvements

In the base year, once-off shocks are used to calibrate the energy mix for each region to ensure an accurate reflection of the current state of the energy mix between renewable and traditional sources. These shocks are calibrated drawing on data from Our World in Data.[5]

The emissions trajectory for the baseline is calibrated to align with the RCP6.0 emissions scenario, developed by the Intergovernmental Panel on Climate Change (IPCC). RCP6.0 is chosen as an intermediate baseline scenario as it includes no specific or significant policy effort to mitigate, acting as an appropriate baseline for reference. Emissions are calibrated via uniform shocks to emissions efficiencies for all regions.[6]

In addition to these specific calibrations, a uniform energy productivity shock (0.75% per annum) is applied across all regions reflecting a continuation of the long-run improvement that has been observed to date.

Appendix 4

4.0. Physical climate modelling for D.CLIMATE

The future of climate change is inherently uncertain. The rate at which CO2 and other pollutants accumulate in the earth's atmosphere could follow any number of trajectories, with each leading to a wide range of physical climate effects varying in both scope and scale. What is certain, however, is that the average global temperature has been rising and will likely continue to rise until a sustained and concerted effort is made to decarbonize globally.

In the IPCC's Fifth Assessment Report, four Representative Concentration Pathways (RCPs) were selected as plausible future GHG emissions and atmospheric concentration trajectories extending out to 2100. These emissions pathways are as follows:

- RCP2.6 (assumes stringent decarbonization),
- RCP4.5 and RCP6.0 (two central scenarios), and
- RCP8.5 (a high GHG emission scenario).

Data from the RCP6.0 climate scenario has been integrated in D.CLIMATE, representing the baseline state. RCP6.0 represents an economic future with a high rate of GHG emissions, where several technologies and strategies are implemented to reduce GHG emissions and radiative forcing stabilises after 2100. The economic and emissions profile consistent with RCP6.0 has the potential to result in an increase to global average temperature in excess of 3°C.[g]

Global climate models associated with the IPCC AR5 model thousands of climate variables, few of which are relevant for economic modelling inputs, over multiple temporal frequencies. For this modelling exercise average temperature, precipitation, and relative humidity variables have been used. The data for each variable is the multi-model mean of 17 global climate models (GCMs) for the RCP6.0 future pathway. The GCMs output was downloaded from the Earth System Grid Federation portal and then processed into monthly periods per geography/region across Asia-Pacific from present day to 2100.

Twenty-year averages of the GCM projections are used here to assess the key signals for future climate change across short to long term horizons. Each 20-year averaged period represents the climate of the mid-year. For example, the average temperature projection for the period 2011 to 2030 is assumed to represent the climate in the 2020 horizon.

The physical climate model projections are then translated into likely economic damages of climate change using methodologies summarized in the following section.

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[g] Intergovernmental Panel on Climate Change. (October 2014). *Fifth Assessment Report.*

Appendix 5

5.0. Temperature as the fundamental driver of damages

The fundamental 'driver' of economic damages is rising temperature. As rising temperature induces climate change, economic output (as measured by GDP) is impacted through the physical damages that affect productivity and/or the stock of production factors (Figure A.1).

This study includes six regionalised damages to the Asia Pacific:

1. Heat stress damages to labour productivity
2. Human health damages to labour productivity
3. Sea level rise damages to land and capital stock
4. Capital damages
5. Agricultural damages from changes in crop yields
6. Tourism damages to net inflow of foreign currency.

The following section outlines each damage and how they impact the economy. Appendix 5 provides a technical discussion on the relationship between climate change and economic damages, including the technical methodology underlying the analysis.

5.2. Heat stress damages on labour productivity

A working environment which is "too hot" can negatively affect the health and safety of workers, as well as restrict their ability to perform tasks and limit their productive capacity.[7] For jobs where tasks are performed outdoors, it can be difficult for workers to moderate their heat exposure. The same can be true for indoor jobs where air-conditioning is not readily accessible.

Climate change is expected to see average global temperatures continue to rise, leading to shifts in the distribution of daily peak temperatures and relative humidity. Altogether, this means that heat waves are likely to become more frequent and increasingly extreme for many countries.

When workers exert energy to perform physical tasks, their bodies produce thermal energy and begin to heat up internally. For body temperature to be maintained at a healthy level, thermal energy needs to be transferred to a cooler external environment. If body temperature exceeds 39°C, heatstroke can develop, and temperatures exceeding 40.6°C can be fatal. However, before these serious health effects occur, at lower levels of heat exposure, workers can experience diminished "work capacity", mental task ability, and increased accident risk.

Figure A.1 'Two-stage' economic damages relationship

Source: Deloitte Economics Institute

To continue functioning at elevated body temperatures, workers can take instinctive actions to reduce their work intensity or increase the frequency of short breaks. This "slowing down" of activity (whether it occurs through self-instinct or occupational health management interventions) results in reduced "work capacity" and lower labour productivity.[8]

This analysis estimates the effect of rising temperatures and changing relative humidity levels on labour productivity using wet bulb globe temperature (WBGT) as a measure of heat stress. Analysis is conducted at a geography or regional level. It is assumed that changes in labour productivity (economic concept) are equal to changes in estimated work capacity (physiological concept).

The methodology follows an approach proposed by Kjellstrom et. al. (2017). This approach utilises a series of functions describing the relationship between WBGT and labour productivity across three different work intensities: 200W (equivalent to light manual labour, such as office work), 300W (equivalent to moderate manual labour, such as manufacturing) and 400W (equivalent to high intensity manual labour, such as farming). Relationships have been determined by Kjellstom et al. (2017), based on a review of epidemiological datasets.

Workers in each GTAP sector are assumed to perform tasks at one of the three work intensities specified above. GTAP sectors have been allocated to specific work intensities based internal advice from Deloitte subject matter experts.

Consistent with the approach proposed by Kjellstrom et. al. (2017), it is assumed that a geography or region's WBGT varies over three 4-hour intervals comprising the approximate 12 hours in a working day:

1. Early morning and early evening: 4-hours at WBGT mean (calculated using average monthly temperature)
2. Middle of the day: 4-hours at WBGT max (calculated using average monthly maximum temperature)
3. Hours in between: 4-hours at WBGT half (calculated as the mid-point between WBGT mean and WBGT max).

These three variants of WBGT have been projected at monthly intervals using the simplified WBGT index, sWBGT, based on surface temperature and water vapour pressure (developed by the Australian Bureau of Meteorology).[h] Water vapor pressure was derived using estimates of relative humidity and the corresponding surface temperature.

Labour productivity is then estimated for each geography / region at monthly intervals, across each of the three 4-hour intervals assumed to comprise the working day. The mean of these three estimates is then taken to represent the average labour productivity for workers throughout the working day. Workers are assumed to maintain the same level of productivity for all days contained within each month. Monthly labour productivity estimates are then averaged to give an aggregate measure of labour productivity for each year in the modelling period.

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[h] Bureau of Meteorology (5 February 2020) *Thermal Comfort observations*

5.3. Human health damages to labour productivity

The impacts of climate change on human health are many and complex.[9] Increasing temperatures can increase heat-related health problems, particularly those with pre-established cardiovascular and respiratory disorders.[10] Increasing temperatures can also reduce cold-related health problems, again most prevalent in people with cardiovascular disorders.[11]

Climate change can impact the range, abundance and dispersion of species carrying diseases. Studies generally agree that the prevalence of Malaria increases alongside temperature increases. Other vector-borne diseases may increase or decrease.[12] Climate change would allow diseases to invade immunologically naïve populations with unprepared medical systems and would affect food- and waterborne diseases, with cholera and diarrhoea being potentially most problematic.[13]

As extreme weather events become more severe and frequent, so too does the threat they present to human populations also rise. Climate change can affect air quality, leading to greater incidence of diseases caused by air pollution – the 2020 summer of bushfires in Australia are a stark reminder of this. Climate change may also affect human health indirectly, through changes in food production, water resources, migration and economic development.[14]

Human health is therefore prominent in estimates of future climate change impacts. The welfare costs (or benefits) of health impacts contribute substantially to the total costs of climate change. Many estimates of economic damages rely on direct costs methodologies (i.e. price times quantity). With regards to human health, the price is typically equal to the value of a statistical life, based on estimates of willingness to pay to reduce the risk of death or diseases, or the willingness to accept compensation for increased risk.[15] However, these methods ignore the human health impacts on labour productivity and the demand for health services.

The approach adopted for this analysis is an adaption of work undertaken by Roson & Sartori (2015), which is based on Bosello et al. (2006), by considering some vector-borne diseases (malaria, dengue, schistomiasis), heat and cold related diseases, and diarrhoea. It does not consider other diseases and impacts mentioned in the IPCC AR5 (2014), such as the effects of extreme events, heat exposure effects on labour productivity (separately considered), haemorrhagic fever with renal syndrome, plague, chikungunya fever, Japanese and tick-borne encephalitis, cholera and other (non-diarrhoea) enteric infections, air quality and nutrition related diseases, allergic diseases, and mental health.[16]

The starting point of the analysis presented in Bosello et al. (2006) is a meta-analysis of the epidemiological, medical and interdisciplinary literature to achieve the best estimates for the additional number of extra cases of mortality and morbidity associated with a given increase in average temperature.[17] The information obtained in this research has been combined with data on the structure of the working population, to infer the number of lost working days. The changes in morbidity and mortality are interpreted as changes in labour productivity.

Roson & Sartori (2015) update the work of Bosello et al. (2006) to account for recent literature on health impacts and studies mentioned in IPCC (2014, scaling up or down the variations in labour productivity.

The results of these studies are expressed as changes in average labour productivity for a +1°C increase in temperature (implicitly assuming that the relationship is approximately linear). For the purposes of this analysis, and to understand the relationship between human health impacts, an increase in average temperature and time, we regressed the variables to find an equation with a satisfactory fit for the relationship.

The analysis estimates the higher-order economic effects (or indirect costs) of human health impacts; variations in labour productivity. It is important to note that this methodology excludes induced demand for health care.

5.4. Sea level rise damages to land and capital stock

As average global temperatures continue to rise, land-based glaciers are melting, and water bodies are experiencing thermal expansion. Together, these factors cause the phenomenon of sea level rise (SLR).

SLR can impact a geography's total stock of land (an economic factor of production) through a combination of erosion, inundation and salt intrusion along the coastline. As the global stock of land declines due to SLR, productive activity that would otherwise occur on that land is also foregone.

The extent of land lost to SLR will depend on several geography-specific characteristics, including (i) the composition of the shoreline (cliffs and rocky coasts are less subject to erosion than sandy coasts and wetlands), (ii) the total length of the coastline, (iii) the share of the coast which is suitable for productive purposes (i.e. in agriculture or urban land), and (iv) the vertical land movement (VLM).[i]

This report estimates land area lost due to SLR using a methodology proposed by Roson & Sartori (2016), who estimated the mean SLR (in metres) associated with global mean surface temperature change from a series of regressions based on data within the latest IPCC AR5 Report, while also accounting for vertical land movement.

The proportion of agricultural land lost per metre of SLR is then estimated based on the findings of Roson & Sartori (2016), as well World Bank data describing the extent of Low Elevation Coastal Zones (LECZ) for each geography or region. The proportion of LECZ used for agricultural production in each geography is assumed to be equal to the proportion of total land area used for agriculture in that same geography.

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i. VLM is a general term for all processes affecting the elevation at a given location (tectonic movement, subsidence, ground water extraction), causing the land to move up or down. Local VLM is relevant when looking at local effects of SLR.

This analysis extends the Roson & Sartori (2016) methodology to also capture urban land area lost due SLR, again leveraging World Bank data describing the extent of urban area in LECZ. In low lying and seacoast urban areas, residential and commercial properties may incur physical damages and require significant capital costs to repair. Economic activity that would otherwise occur in these urban areas will also need to transition to other geographies.

The process for estimating both components is as follows:

- The percentage of effective land area lost per meter of SLR is calculated by multiplying the following factors: the percentage loss in coastal wetland (a proxy for loss of land due to SLR, estimated by HadCM3 climate model under the A1b SRES scenario),[j] the LECZ area, the percentage of erodible coast and relevant coastline.
- Considering which proportion of total coast is suitable for agricultural(productive)/urban purposes, the percentage of effective land change is adjusted by agricultural land area/urban land area.
- The percentage change in agricultural and urban land stock is computed by multiplying the percentage of effective land change by meter of SLR and the estimated SLR.

5.5. Capital damages

This study captures climate induced capital damages as a function of increasing global mean average temperature. Capital damages in this context, consider the impact of riverine flooding, forest fires, subsidence, high wind speeds (excluding Cyclone) and extreme heat climate events on physical capital, including dwellings, infrastructure and machinery and equipment.

Accounting for capital damages in this way represents a departure from existing economic impact modelling and integrated assessments of climate change. In some cases, capital damages are included but at a highly aggregated level that limits regional analysis. Often, reports discuss the exposure or risk of geographies to capital damages but do not attempt to monetise an impact.

The methodology used in this report employs data produced by XDI modelling of climate change impacts on Australia's physical capital stock.[18] Global databases monetising climate induced capital damages are uncommon and those that exist are difficult to integrate into an IAM framework. As a result, Australia specific data is used to infer capital damages in other regions through a process of climate matching, controlling for key regional differences such as physical capital density and distribution.

The XDI data provides estimates for total technical insurance premiums at the Local Government Area level – akin to a monetised capital damage by Local Government Area. These Local Government Areas are subsequently categorised by key climatic characteristics including temperature and precipitation to form several sub-groupings. The categorisation of Local Government Areas is largely informed by climate maps produced by the Australian Building Codes Board and are derived from climate data published by the Australian Bureau of Meteorology.

Data on climate characteristics (average temperature, precipitation, etc.) are then gathered for each geography or region within Asia Pacific. Drawing on this data and an updated Köppen-Geiger climate classification map (a concept frequently applied in climate research), each of the geographies within Asia Pacific region are categorised into comparable climate groups based on the Australian Local Government Areas.

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j. Roson, R & Sartori, M (2015), Estimation of climate change damage functions for 140 regions in the GTAP9 database, No 2016:06, Working papers from the Department of Economics, University of Venice "Ca' Foscari"

A log-log model is produced for each geography drawing on data for Australian Local Government Areas with similar climatic characteristics and predicted global mean average temperature increases under an RCP 6.0 emissions pathway. This regression controls for differences in physical capital density across Local Government Areas. The estimated damages produced by this research can be interpreted as a percentage of annual capital investment that is diverted to repair and replace damages assets due to an associated rise in average temperature in a region.

Estimated capital damages are produced at a geography level and are aggregated to focus regions using regional shares of capital stock, proxied by population distribution.

5.6. Agricultural damages from changes in crop yields

Climate change will see rising temperatures, higher concentrations of carbon dioxide (CO2) in the atmosphere and different regional patterns of precipitation.[19] These factors all affect crop yields and agricultural productivity.

The effects of climate change on agricultural productivity are one of the most studied areas of climate change impacts. Yet, despite the many existing studies and the extensive empirical evidence, it is still difficult to identify some sort of “consensus” for the impacts of climate change on agricultural productivity. There are many factors at play, including the role of adaptation behaviour by farmers, firms and organisations, including variety selection, crop rotation, sowing times, the amount of fertilization due to higher CO2 concentration, and the actual level of water available for irrigation, and irrigation techniques.[20]

Modelling the economic consequences of yield changes to understand the consequences of climate change impacts on agriculture is important for two main reasons. Firstly, varying levels of agronomic and economic adaptation exists in the agricultural sector; farmers can adjust how they grow a particular crop, the location and timing of crop growth will shift in response to climate change impacts, trade in agricultural commodities will adjust and consumers are able to substitute goods as prices adjust.[21] Each of these adaptive responses will mediate the impacts of yield changes. Secondly, climate change impacts will vary by crop and by region, changing the comparative advantage of countries, creating winners and losers in global agricultural markets.[22]

The bulk of the scientific literature on yield response to temperature focuses on four major crops, maize, wheat, rice and soybeans, which collectively account for approximately 20% of the value of global agricultural production, 65% of harvested crop area, and just under 50% of calories consumed (FAO, 2016). However, for a Queensland specific context, the output of these crops only surmounts to a small proportion of crop output, and more broadly, total agricultural output. Taking any of these approaches would not provide a realistic indication of agricultural economic damages from climate change.

The approach undertaken in this analysis is one which provides an estimate of productivity changes for the whole agricultural sector across the Queensland regions. The methodology is based on the Mendelsohn and Schlesinger (1999) reduced form Agricultural Response Functions in the formulation proposed by Cline (2007), where the variation in output per hectare is expressed as a function of temperature, precipitation and CO2 concentration.[23]

One disadvantage of this approach is that adaptation is not incorporated within the function. Studies that include an agronomic adaptation do, on average, report higher yields than those that don't; however, recent research has noted that the effects of agronomic, on-farm, within-crop adaptations (principally changes in crop variety and planting date) are found to be small and statistically insignificant.[24] Additional economic adaptations such as crop switching, increasing production intensity, substituting consumption, or adjusting trade relationships are captured within the CGE model.

A further constraint of this approach to note is that the methodology is not as thorough as Agricultural Model Inter-Comparison Project (AgMIP). AgMIP has used both partial and general equilibrium models to examine the economic implications of climate-induced yield shocks determined by a number of process-based crop models (Nelson et al., 2014). Modelling based on AgMIP explicitly accounts for regional variation resulting from soil type, irrigation, baseline temperature, and nutrient limitations.

5.7. Tourism damages to net inflow of foreign currency

Climate induced economic tourism damages are driven by changes in net visitor flows and expenditure. In D.CLIMATE, changes to net visitor flows and expenditure are fundamentally driven by the exposure of each region to climate change. As such, regions with a greater exposure to adverse climate change – in terms of average temperature – experience relatively more severe tourism damages.

To estimate tourism damages in D.CLIMATE, functions that relate visitor arrivals and departures to average temperature are employed. These functions are consistent with those employed by Roson & Satori and are derived from econometric models expressed in terms of land area, average temperature, length of coastline, per capita income and the number of countries with shared land borders.[25] This approach yields global parameters that are assumed consistent with Australia. Forecast average temperatures are used as inputs to these functions to determine a resulting net flow of foreign currency. The forecast net flow of foreign currency is subsequently apportioned to the appropriate industry based on 2018 shares of direct tourism output produced by Tourism Research Australia.

The magnitude and persistence of tourism damages are also a function of the economic structure of each region's economy. Regions whose economy are more diverse in nature are less likely to experience persistent economic damages as industries are less reliant on tourism and more malleable/adaptable.

Appendix 6

6.0. The policy scenario

The transition to a low-carbon economy has been modelled as one in which policy makers set clear and ambitious targets. These are implemented as constraints on the total level of emissions in each region such that global and regional emissions are reduced at a rapid rate over the next 30 years in line with the budget prescribed in the RCP1.9 scenario.

The emissions constraint forms a shadow price on carbon such that processes which have associated emissions – like the combustion of coal to produce electricity – become more expensive. Those processes which don't have associated emissions – like the generation of electricity from renewables – don't face this price increase. Relative price changes such as these lead to changes in behaviour – like the switching from fossil fuel-based electricity generation to renewables. As these changes aren't seamless, the combined effect of them is to impose an aggregate cost on each economy which is known as the shadow price of carbon. This isn't the same as a legislated carbon tax, or a traded emissions price, but it is analogous in that it represents the projected price at which a given reduction in emissions can be achieved.

The process described above is the first of two steps in the policy simulation. The second step involves the introduction on learning rate-based productivity improvements for renewables, hydrogen and bio-energy. It also involves the introduction of gradual reductions in emissions which aren't a function of fuel choice (like fugitive emissions in agriculture). These are deliberately excluded from the first step as they are a function of the shadow price which forms and the switching behaviour it induces.

For example, the case for cost reductions zero emission fuel sources is based on the concept of learning by doing articulated first (and best) by Kenneth Arrow in 1962.[k] The first step of the simulation provides a guide to the potential uptake of each technology which is then used in determining the appropriate rate of productivity induced cost reduction to impose.

There is a significant portion of the global and regional emissions inventory which can't be reduced through the kind of price-based switching described above. Examples include fugitive emissions from mining, industrial process emission from the production of cement and factor-based emissions from livestock farming. These emissions will need to be removed through changes in production process like, for example, the adoption of methane reducing feed additivities for livestock. These changes will not be costless, but there is inherent uncertainty regarding how these processes will be developed and what each will cost. Simulating the policy scenario in two steps allows for the formation of a shadow price at which the adoption of process improvements are projected to become economically viable.

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Appendix 7

7.0. Valuing the future

It is inherently difficult to 'discount' the future, particularly concerning an issue as socially and economically complex as global climate change due to increased global average temperatures.

In considering this issue, it is important to recognize the intergenerational impact of climate change on society and in doing so, account for the tendency of people to preference short term economic flows over longer term-flows. In comparing welfare, utility and costs and benefits across generations, the discount rate needs to be determined for analysis.

In determining the rate, the question becomes what rate is appropriate to embody these preferences in estimating the net present value of impacts to economies and societies from climate change and various climate change policy responses.

Greenhouse gas emissions have a long residence time in the atmosphere, which means that the value of the impacts of today's emissions must be considered for future generations. Equally, the decisions made by society today in relation to policy responses regarding mitigation and adaptation to altered climatic conditions, impact future generations significantly.

In this context:[26]

- The use of a high discount rate implies that society put less weight on future impacts and therefore less emphasis on guarding against such future costs.
- The use of a low discount rate highlights the importance of future generations' wellbeing.[27] Society should act now to protect future generations from climate change impacts.

A discount rate of 2% has been used by Deloitte Economics Institute in this analysis, after considering the differing perspectives within literature, the economic framework adopted for analysis in D.CLIMATE and broader policy actions modelled. This rate reflects a consistent view social discounting in climate change economic analysis. For example, the results of a survey of economists in the American Economic Journal: Economic Policy (the sample contains over 200 academics who are defined as experts on social discounting by virtue of their publications) indicates that most favor a low discount rate: with more than three-quarters comfortable with a median discount rate of 2%.[28]

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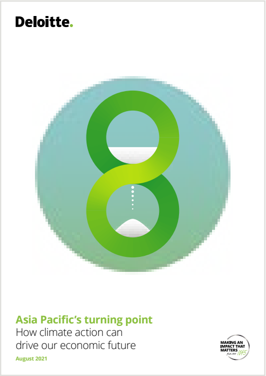

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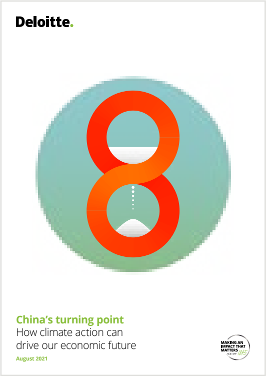

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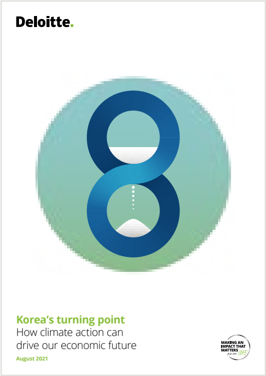

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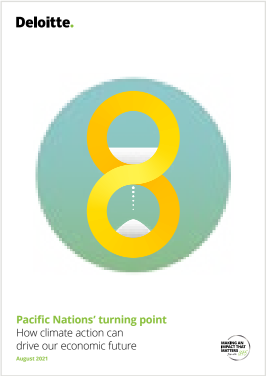

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