Downscaling – Water use and transmission

19 April 2023

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The Net Zero Australia (NZAu) project is a collaborative partnership between the University of Melbourne, The University of Queensland, Princeton University and management consultancy Nous Group. The study examines pathways and detailed infrastructure requirements by which Australia can transition to net zero emissions, and be a major exporter of low emission energy and products.

Net Zero Australia

Downscaling – Water use and transmission

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1 Introduction

The main Net Zero Australia (NZAu) balancing model is a least-cost optimization model, and while it considers water as an input with a cost, it does not explicitly consider water scarcity as part of its optimization. The significant use of water in both the traditional energy industries, and in emerging energy and decarbonization industries, make it a particularly relevant focus for Australia, which is a water-stressed continent [1]. Australia's options for reaching net-zero emissions will, in part, be determined by its ability to source adequate water for clean energy carriers and decarbonization technologies, while ensuring that these additional water demands do not compete with critical water uses elsewhere in the economy (e.g. agriculture). An example of water trade-offs that will be encountered in decarbonization pathways might be a reduction in fresh water demand for coal washing (due to decreasing coal exports and domestic coal power generation [2]), at the same time that desalinated water demand increases to supply electrolysis plants for hydrogen exports [3].

Net zero emissions targets of 2050 for the domestic economy and 2060 for the energy export sector are achieved in NZAu modelling using a range of energy and decarbonization activities [4]. The contribution of each energy and decarbonization activity varies across modelled scenarios, covering reference (REF), high electrification (E+), slow electrification (E–), high electrification with 100% renewables (RE+), high electrification with renewable build constraints but more carbon storage availability (RE–), and a scenario where reduces energy and mineral exports to support strong domestic iron and steel and aluminium industries (ONS). Detailed information on NZAU modelling regions, the energy and decarbonisation activities allowed in each model region, and the formulation of scenarios is provided in the companion *Methods, Assumptions, Scenarios & Sensitivities* (MASS) document [4].

The regional water requirement for each modelled scenario is directly connected to the regional energy activities included in each scenario's energy transition. For example, electrolysis facilities located at export energy hubs in WA, NT and QLD produces over 95% of the hydrogen in all scenarios but the RE– scenario which also uses autothermal reforming with carbon capture in WA, VIC, the NT, QLD and NSW to produce roughly half of its hydrogen. While most of the scenarios assume ammonia as a key energy carrier for export from WA, the NT, and QLD, the E+ONS scenario reduces ammonia export by nearly 75 % while building a new direct reduced iron (DRI) industry in WA.

Within regions, water demand depends on the spatial characteristics of the energy activities. In NZAu modelling, water intensive activities supporting exports such as ammonia and DRI production are in or near export ports to facilitate storage and shipment. In contrast, water demand by electrolysis facilities for export is modelled as occurring in energy dense, but low population energy export areas which are often far from ports and Australia's coastline.

This document aims to account for the water demand (including production) in each NZAu scenario [5, 6] downscaled to regional decarbonization efforts in five-year timesteps from 2020 to 2060. Both fresh and seawater sources are considered, along with the water quality requirements of activities and processes.

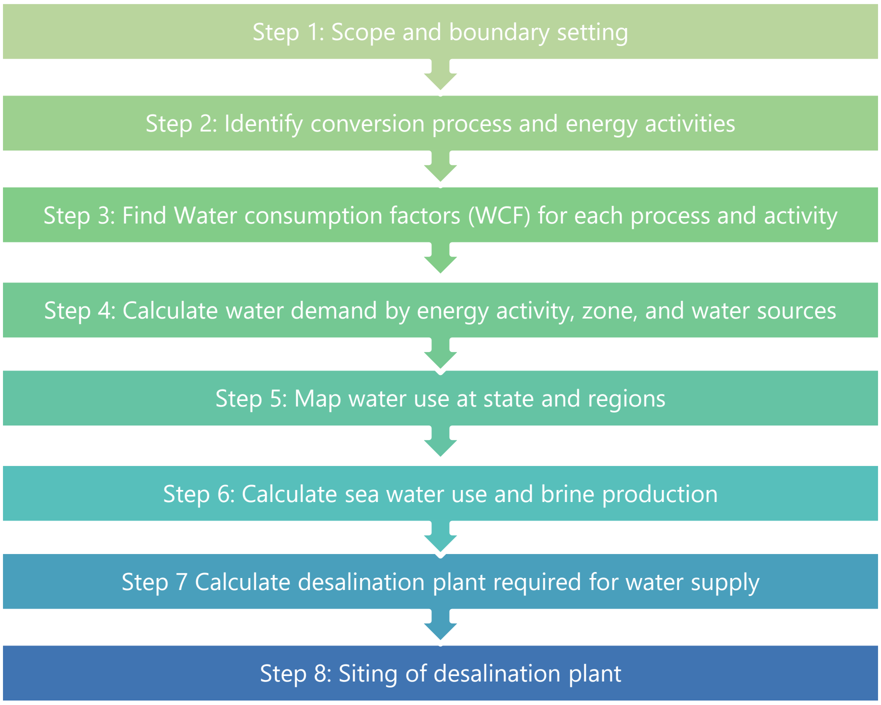
2 Methodology

Energy activities use water for a number of purposes. For example, coal production uses water for washing and removing gases like sulfur during the production stage. Coal power generation requires water for cooling, whilst clean energy technologies such as wind and solar PV use water for cleaning blades and panels. Emergent decarbonization technologies like direct air capture, electrolysis, and autothermal reforming all have significant implications for water production and use. Many of these technologies are consumers of water, either as direct inputs (e.g. electrolysis) or as a byproduct of the process (e.g. provision of cooling in ammonia production via the Haber Bosch process).

It is important to consider that not all the water used in energy activities is consumed (i.e. used and either converted to a product like hydrogen or degraded into waste water). For example, significant quantities of water are used in technologies like hydropower and some cooling activities but in such cases the water is not degraded and returned to its source (e.g. a river, dam or ocean). This NZAu downscaling report on water demand, only focuses on water consumed in energy activities or non-energy conversion process that are substantially different from the REF scenario.

This analysis calculates water demand in NZAu scenarios using the multi-step process shown in Figure 1.

Figure 1 | Process of water demand and supply estimations in NZAu scenarios

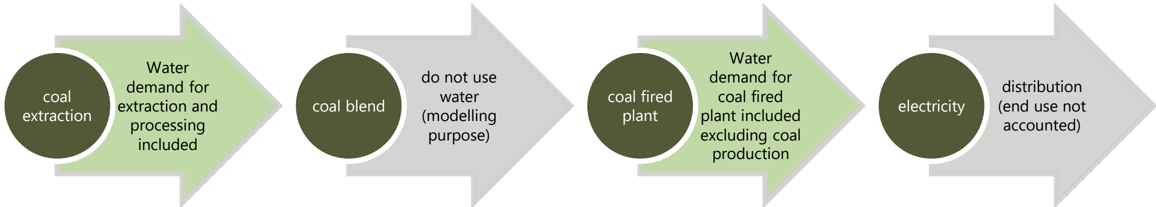


In the process described in Figure 1, water demand is tracked for both energy activities and non-energy conversion processes. For energy activities, water demand is tracked for each step from the sourcing of primary energy to either its end use in Australia or its storage in an Australian port for export. An energy activity may use one or more form of energy as inputs and may produce one or more outputs. For example, the Haber Bosch process uses inputs of electricity and hydrogen and produces ammonia, while also consuming water as a byproduct. For a non-energy conversion process such as direct air capture (DAC) which uses water in the capture of carbon dioxide (CO_2), water consumption is tracked during a single step.

2.1 Scope and boundary of water demand calculation

We set the following boundary to calculate the water demand. We calculate water demand in a step-wise process for energy activities. It was not feasible to apply the lifecycle assessment approach to water modelling as NZAu's integrated energy system modelling allows several energy feedstocks to produce the same output which might be blended into an intermediate product and then fed into a variety of energy activities. Calculating water in a stepwise fashion and reporting for each step in the process rather than as a full lifecycle footprint also reduces the risk of double counting. Figure 2 illustrates the step wise water demand process used in the estimation of both coal extraction (used for export and domestically) and domestic coal fired power generation.

Figure 2 | Example of the water demand estimation process used for coal energy sources in NZAu modelling with the green arrows showing the steps where water demand is calculated



This analysis excludes water consumed in processes outside of Australia. For example, NZAu water estimations do not include the water used in the extraction and production of the refined oil imported by Australia. If crude oil is imported and refined domestically, we only account for water used during the refining process.

We use either the inputs or outputs of an energy activity to calculate water demand – usually dependent on the format of water consumption factor (WCF) identified or estimated by NZAu researchers. For most energy activities, water demand is based on the output of a process. For example, to calculate water demand for hydrogen produced using ATR+CC, we use the quantity of hydrogen produced from ATR+CC. However, in the case of electrolysis, we calculate water demand using the GWh of electricity fed into electrolysis.

Water consumption for primary energy sources is limited to operation, by technology as described in Table 1. For example, the water demand considered in the use of solar PV panels includes panel washing and other operational water use but excludes the water used for the manufacturing of solar panels and the construction of the solar PV farm.

Table 1 | Water consumption boundary for primary sources

Primary sources	Boundary (what is included and/or excluded)
Solar PV	Panel washing and operations. Excludes production of panel and construction of solar farm infrastructure.
Wind	Includes water for blade washing
Coal (black/brown)	Production and processing of coal. The water used in feedstock conversion is calculated in the respective feedstock conversion process
Natural gas (Conventional/Unconventional)	Includes extraction, dehydration, and acid gas removal
Hydropower (including pumped hydro)	Seepage and evaporation

Primary sources	Boundary (what is included and/or excluded)
Biomass	Includes water used in gas production. Water used in feedstock conversion is accounted for in the respective process.
Municipal waste	Includes power plant cooling during conversion
Crude/refined oil	Includes water used in the oil refinery.
Hydrogen	Water used in electrolysis
Haber Bosch	Water accounted for ammonia production using hydrogen as an input.

Water demand for some technologies is location specific. For example, water demand for DAC depends on the humidity and temperature at a DAC facility's location. For technologies that are dependent on aspects of the local environment, we calculate location-specific WCFs. For DAC, a different WCF is used for each of the five potential DAC locations.

Water demand for some technologies is efficiency dependent. In the case where the efficiency of a technology is projected to rise over the course of the modelled transition (e.g. PEM based electrolysis) we calculated a new WCF for each year before estimating water demand.

Transporting energy from one point to another may require water. We assume this water demand to be insignificant when compared to the water demanded by the production and conversion of energy. Water demand from the transport of energy from one point to other is excluded from our analysis.

End-user water demand that is not associated with the net zero transition is excluded from the analysis. For example, water consumption of residential or commercial buildings is not modelled.

The manufacture of the technologies used in the net zero transition requires water. NZAu largely assumes that the manufacture of key technologies such as solar panels, wind turbines, and electrolysers will not occur in Australia – although an argument might be made for their onshoring in some instances. This analysis does not onshore the manufacture of key technologies in any scenario and excludes water consumed overseas before key technologies are imported for deployment in Australia.

For integrated processes, we do not separately account for the water demand of each integrated step. For example, the water demanded by technologies involving carbon capture (like ATR+CC), is treated as arising from an integrated systems rather than two sperate processes (ATR and then carbon capture (herafter CC). We exclude water demand from the storage of hydrogen and ammonia.

Water demand in NZAu scenarios is considered by source — fresh water and seawater — and is compared against water use in 2019/20. We assume that all water supplied to meet demand from water intensive technologies like ATR+CC, electrolysis, DAC, and ammonia facilities will be sourced from coastal desalination of seawater. We assume that freshwater supplies all other uses, as is already the case.

2.2 Identify water intensive conversion process and energy activities

Table 2 lists the water intensive conversion processes and energy activities considered by the analysis. The water requirement for some of these activities is discussed in detail in the MASS [4], while the requirement for other activities is provided in more detail in this document.

Table 2 | Water consuming activities and processes considered in NZAu

Water consuming activities	Use
Electrolysis	Hydrogen production
Gasification of coal and biomass	Hydrogen/synthetic fuels production
Fischer-Tropsch technologies	Liquid hydrocarbons/hydrogen production
Autothermal reforming	Hydrogen/synthetic fuels production
Steam reforming	Hydrogen/synthetic fuels production
Gas power plants	Electricity generation
Coal power plants	Electricity generation
Haber-Bosch technology	Ammonia production
Direct air capture (DAC) of carbon	Carbon capture for use and sequestration (CCUS)
Coal (black/brown) industry	Extraction and processing
Natural and coal gas industries	Extraction
Hydropower (including pumped)	Electricity generation
Biomass/waste industries	Extraction and processing
Crude oil refining (in Australia)	Crude oil refining
Solar PV plants	Electricity generation
Wind power plants	Electricity generation

2.3 Find water consumption factors (WCF)

2.3.1 water consumption factors

WCFs measures the amount of water consumed for each reference unit of a process/activity. Not all water withdrawn and fed into a process is consumed. Water demand can be accounted as water has withdrawn, water consumed, and water returned. Hydropower, for example, uses massive water to run turbines, and part of the water is lost in the process such as evaporation and seepage. Most of the water is returned to the environment. For this analysis, we only include water consumed [7]. For hydropower, we only consider water consumed on seepage and evaporation. Water consumption is described as 'water removed from, but not returned to, the same drainage basin. Water consumption can be because of evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea.' (*ISO 14046 clause* 3.2.1) from Shi, Liao [8]. This analysis only accounts for water consumed in an energy activity (Green colour in Figure 3).

Figure 3 | Different types of water use.

Table 3 provides the summary of the WCFs used in the water demand calculation. Important considerations used to arrive at the WCFs in Table 3 include:

a. We use Grubert and Sanders [7] for water use in coal production and processing because they disaggregate water consumed for different stage of coal production. Note, the WCF for coal production is higher as compared to WCF discussed in Ian [9].
b. NZAu assumes the production of bioenergy is resourced from waste biomass (see the MASS document MASS [4]. We exclude water consumed in the production of biomass.
c. For electricity generation we use plant-specific WCF for coal plants if available and when not available, we use an average WCF for coal-fired plant types based on Ian [9].
d. WCFs for electrolysis varies widely [10]. The basis for the WCF selected for PEM electrolysis is discussed in the MASS [4]. The WCF for electrolysis is updated in every model year to include process efficiency gains.
e. Our WCF for aluminium (onshoring) is based on electricity input and uses Buxmann, Koehler [11] to calculate water consumed per GWh of electricity input.
f. Our WCF for Ammonia production is based on the production process footprint where we calculate the quantity of water consumed in the process per unit of Ammonia production[12].
g. WCF for direct water capture varies by location due to changes in environmental conditions. In addition to Keith, Holmes [13] we also incorporated[14] to calculate a WCF for each potential DAC location as outlined in MASS [4].
h. Hydropower consumes the highest amount of water per GWh. The WCF for hydropower varies substantially across the literature reviewed. For example, Vanham, Medarac [15] report 2,532 m^3 per GWh which is substantially lower than the 15,500 m^3 per GWh estimated by Buxmann, Koehler [11]. In this report, we use the WCF for hydropower from Grubert and Sanders [7] of 9831 m^3/GWh because they provide a WCF for seepage and evaporation.
i. The WCF of electricity production using nuclear also varies substantially [7, 15, 16]. The WCF for Mekonnen, Gerbens-Leenes [16] and Vanham, Medarac [15] are comparable, therefore we use a WCF of 610 m^3/GWh from Mekonnen, Gerbens-Leenes [16].
j. For electricity using coal power plant, we use plant specific WCF if available. For rest of the coal power plant, we use of 1254 based on Ian [9].

Table 3 | Selected water consumption factors used in water demand estimation

Sources	WCF (M3 per GWh)	Source
Primary energy production		
Black coal (production/ processing)	342	[7]
Brown coal (production/ processing)	407	[7]
Coal seam gas (extraction)	83	[7]
Conventional gas (extraction)	13	[7]
Municipal waste (extraction)	6.72	[7]
Wind power	11	[17]
Solar PV power	23	[17]
Hydro and pumped hydro power	9531	[7]
Nuclear power plant	610	[16]
Processing		

Sources	WCF (M3 per GWh)	Source
Oil refining	50	[7]
Waste methane to pipeline gas	7	[7]
Aluminum (Onshoring)	728	[11]
biomass gasification (methane)	597	[17]
Power Production		
Black coal power (w and w/o CC)	1254	[9]
Black coal from mine to electricity (IGCC)	1455	[17]
NGCC Power plant	955	[17]
Municipal waste gas to power	433	[18]
Waste/biomass to power (w/o CC)	2773	[17]
Hydrogen, FTL and Ammonia production		
Hydrogen (ATR + CC)	421	[19-21]
Hydrogen production (Electrolysis)	Variable	[19, 20]
Hydrogen production (biomass gasification)	597	[17]
Hydrogen (Coal gasification)	1042	[17]
Hydrogen production (SMR +CC)	553	[20, 21]
Ammonia (Haber Bosch)	162	
FT liquid (mixed)	958	[17]
Other		
DAC (CO2 captured)	Variable	[13, 14]
Power plant specific (Electricity) WCF	**Variable**	
Power plant (plant specific)	Variable	[9]

2.3.2 WCF for electrolysis

The most used hydrogen production technology in NZAu scenarios is electrolysis. As discussed in the MASS[4], RIO chooses PEM electrolysis as being the most cost-effective option from 2025 and the most efficient option from 2035. PEM electrolysis is considered environmentally friendly and sustainable due to its technological features [22]— in part because NZAu assumed that the PEM electrolysis facilities built in NZAu scenarios use air cooling rather than wet cooling to reduce the WCF [23].

The NZAu WCF assumed for PEM electrolysis is based on the quantity of electricity used by the process. The WCF is recalculated for each model year to account for the expected increase in efficiency of PEM electrolysis from 65% to 74% between 2020 and 2050. As listed in Table 4 and described in the MASS[4], NZAu estimates that in 2020, PEM electrolysis was able to produce 0.65 GWh of H_2 from 1 GWh of electricity and 164.8 m^3 of treated water (See Table 4). This includes 10% water loss factor during the PEM process.

Table 4 | Water consumption factor (WCF) for hydrogen production through electrolysis

Year	PEM efficiency	Treated water (m^3 water per GWh electricity input)
2020	0.650	164.8
2025	0.665	168.6
2030	0.680	172.4
2035	0.695	176.2
2040	0.710	180.0
2045	0.725	183.8
2050	0.740	187.6
2055	0.740	187.6
2060	0.740	187.6

2.3.3 WCF for direct air capture

Rosa, Sanchez [24] identify a WCF range of between 2 to 6.83 m^3 per ton of CO_2, and then estimate a WCF for DAC of 4.01 m^3 per ton of CO_2. Keith, Holmes [13] determine a WCF of 3.1 m^3 per tonne of CO_2. However, the WCF of DAC is influenced by environmental conditions at the location of the DAC facility and method of capturing the CO_2. NZAu chose to estimate a WCF for a continuous process using an aqueous potassium hydroxide sorbent coupled to a calcium caustic recovery loop MASS [4].

Temperature and humidity are two key locational variables that influence the WCF of DAC [25]. The molality of the solution in sorbent-based DAC also influences the WCF. Increasing the molality of the solution to 5 M reduces the WCF value but increases cost and energy parameters. This analysis estimates its WCF based on a 2 M solution and calculates the WCF for DAC as per the MASS [4].

The WCF for DAC at different basins in Australia is provided in Table 5. The WCF calculation uses an average value of relative humidity at 9 am and 3 pm and the average temperature at each potential DAC location.

Table 5 | Water loss (m^3) per ton of CO2 captured in DAC process by basin

Basin	Average Annual Temperature (°C)	Relative humidity (%)			WCF (m^3 treated water /t CO_2
		9 am	3 pm	Average	
Port Hedland	26	45	35	40	10.6
Darwin	27	65	45	55	7.8
Cooper	23	45	25	35	10.8
Surat	18	70	45	58	6.9
Gippsland	15	75	60	68	4.4

2.4 Calculate water demand by energy activity, zone and water sources

2.4.1 Calculate water demand for each activity and total water demand

We start with a simple water demand analysis using WCF based on Hoekstra [26]

$$WD_{nsy} = energy_{nsy} * WCF_n \text{ ----------Equation 1}$$

Where water demand (WD) for ‘n’ energy activity in ‘s’ scenario in ‘y’ year is the amount of energy (GWh) multiplied by WCF_n. The unit of WCF in our analysis is cubic meters (m^3) per gigawatt hour (m^3/GWh) except for DAC. WCF for DAC is measured as cubic meters of water consumed per kt of CO_2 captured.

Total water demand (TWD) in ‘y’ year for ‘s’ scenario is the sum of water demand for all energy activity (Equation 2)

$$TWD_{sy} = \sum waterdemand_{nsy}$$

2.4.2 Water demand by geographic regions

NZAu has 15 regions, 10 ports and 10 export zones. Export zones aggregate renewable energy and are the location of PEM electrolysis facilities producing hydrogen for export. Export ports receive hydrogen from export zones (and regional electrolysis facilities in Victoria and Tasmania) and from autothermal reforming facilities also in the export zones to produce Ammonia for export. There are three export zones connected to three ports in Western Australia (WA). There are three export zones connected to three ports in Queensland (QLD). There are two export zones connected to Port Darwin in the Northern Territory (NT), with one of these export zones spanning the NT/WA border. South Australia (SA) and New South Wales (NSW) each have a single export port connected to a single export zone. Victoria (VIC) contains an export port but has no explicitly demarcated export zone to which it is connected. Tasmania (TAS) has neither an export port nor zone but does serve implicitly as an export zone in at least one NZAu scenario (RE–). The selection of export zones is discussed in the MASS [4], but is largely arbitrary while being informed by distance from key export ports and population densities.

As export zones and ports often span or sit on the borders of regions, the following conventions were followed when allocating the water demand connected to energy exports to regions or to state/territories:

a) Two-thirds of the water demand connected to export-related electrolysis in WA occurs in WA-central and one-third occurs in WA-north.
b) All of the water demand connected to the electrolysis facilities serving exports from the NT are allocated to the NT.
c) All water demand for electrolysis connected to energy exports from QLD occurs in the QLD-outback.
d) All water demand connected to the production of Ammonia for export from QLD ports occurs in QLD-north.

Water is aggregated to the selected geographic zone (e.g. region or state/territory) first by summing the water demand for each individual activities/process within the selected region, and then aggregating all water use to a total water demand for the entire selected region.

Water can be supplied through a number of water supply sources [27]. For simplicity, we categorise water as fresh water and seawater. We assume that the water demanded by the Haber-Bosch process, electrolysis, autothermal reforming, and DAC will be supplied using seawater. Sea water needs desalination before it is fed to a process and produces brine as a waste or by-product. In later sections of this report, we account for new desalinisation plants, the total demand for seawater to meet each zones estimated process water demand, and the quantity of brine that is returned to the sea from each desalinisation plant.

To fulfill the remaining water demand in NZAu scenarios, fresh water is needed. Fresh water can be sourced from a natural systems like rainfall or mechanically withdrawn from groundwater sources. We also considered the potential for supplying fresh water to electrolysis in the export zone located closest to the Ord River (See Section 4). We assume that freshwater resources do not need desalination but are treated.

Water demand for each selected zone considers the following metrics:

- Total process water demand
- Sea water supplied through a coastal desalination plant
- Brine production
- Fresh water demand

2.5 Mapping water demand for NZAu Scenarios by zone and state

Mapping water demand to specific locations in Australia requires the use of conventions to bridge a gap between downscaling efforts. While this gap does not impact on the state or regional results presented in this document, it does have implications for water results presented at specific locations.

The following conventions were adopted in the estimation of demand as specific export locations in NZAu scenarios. If there is more than one export port in the same NZAu zone (relevant for QLD and WA), we assume that water intensive energy activities are shared equally among these ports. For example, in water downscaling, each export port in QLD is allocated one-third of the state's total energy export and the in-port ATR+CC and the Haber Bosch process are split evenly between the ports.

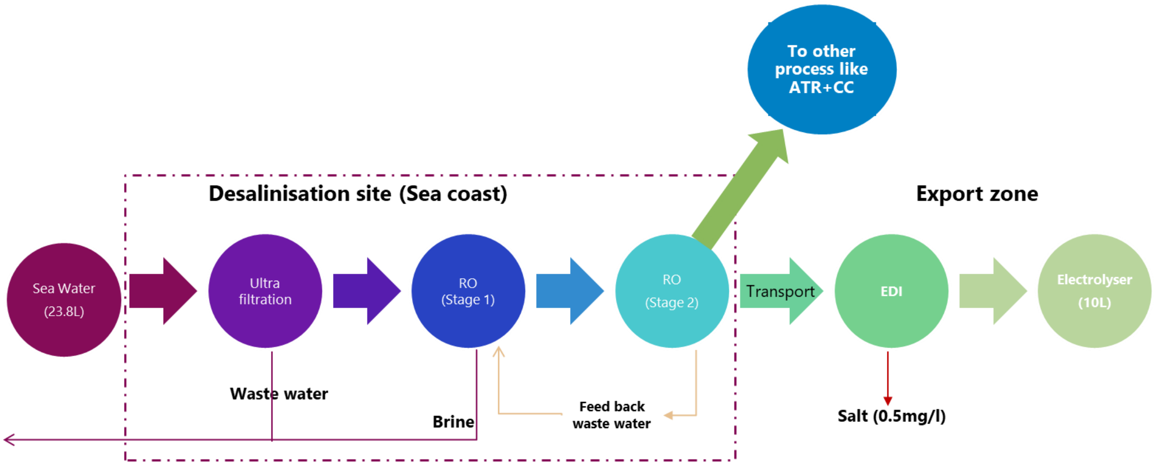
2.6 Calculation of sea water use and brine production

Desalination of seawater [28] is the process selected by NZAu to supply water to new water-intensive industrial processes in Australia – covering demand from ATR+CC, electrolysis, Haber-Bosch, and DAC facilities. The quantity of brine produced during desalination is directly connected to the quantity of sea water used.

2.6.1 Desalination

We assume a chemical-free desalination process that uses state-of-art technologies. The efficiency of a desalination plant depends on the desalination process used and characteristics of the water entering the plant [29]. For NZAu, we assume that desalination of sea water will use a two-step reverse osmosis process [30, 31] with an efficiency of 0.42 as per Jones, Qadir [29], that is, an NZAu desalination plant uses one litre of seawater to produce 0.42 litre of desalinised water. The NZAu desalination process along with additional pre-processing and post-processing steps and likely locations of those steps and facilities supplying water for electrolysis is presented in Figure 4.

Figure 4 | Desalination process of sea water



The desalination process shown in Figure 4 starts with ultra-filtration that removes biotic and abiotic materials back into the ocean. The filtered water then enters the first reverse osmosis (RO) stage, during which salt and other unwanted contaminants are removed from the sea water and a brine containing all contaminants and some portion of the input water is ejected as brine back into the ocean along with wastewater from ultra-filtration. For this first stage of RO we use a water-use efficiency of 42 % Jones, Qadir [29].

After leaving RO stage one, the desalinized water enters the second stage RO process to further purify the water. The wastewater from the second stage RO is fed back into the first stage RO and is expected to be fully recovered in reprocessing — we therefore assume no water loss from the second stage RO.

The desalinated water leaving the second RO stage can either directly used in an ATR+CC, DAC or Haber Bosch process. However, if the water from the second RO stage is to be used in electrolysis, it requires deionizing. In this situation, the water would be first transported from the desalination site to the electrolysis site using a polymer pipe, and then fed into an electro-deionizer (EDI) on arrival. The use of a polymer pipe rather than a metal pipe is to avoid corrosion caused by desalinated water to metal pipes. We assume the EDI unit produces roughly one litre of deionized water (no significant loss of water) and 5 grams of salt from one litre of desalinated water. After leaving the EDI unit, water can be used for electrolysis. Salt leaving the EDI process is not included in brine calculations in the next step. However, to avoid the dispersing of salt exiting the EDI process at inland electrolysis sites, the salt from EDI should be transported back to sea.

2.6.2 Brine production

We have modelled brine production from a desalination plant (covering filtration and RO stages) at 0.58 litre of brine for every 1 litre of seawater entering the system.

2.6.3 Calculation of seawater use and brine production for water intensive NZAu activities/ processes

Figure 5 describes the sea water demand, brine production and water demand for green (left) and blue (right) hydrogen production using electrolysis and ATR+CC, respectively.

Figure 5 | WCF for hydrogen production using electrolysis (left) and ATR+CC (right)

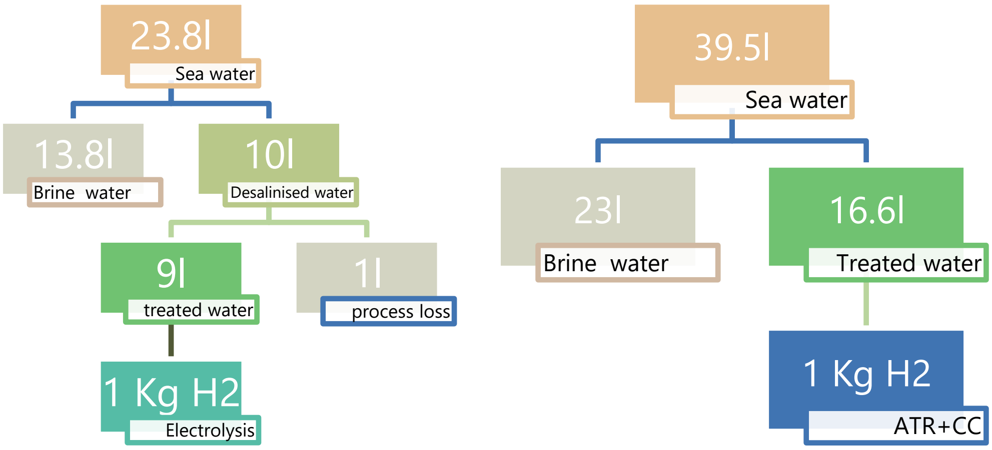


Figure 5 indicates that producing one kg of green hydrogen requires 23.8 L of sea water which generates 10 L of desalinated water and returns 13.8 L as brine back to sea. Similarly, to produce one kg of hydrogen using ATR+CC, we feed 39.5 L of sea water to the desalination plant, which produces 23L of brine and supplies 16.6 L of treated water to ATR+CC. Table 6 presents the quantity of water needed in cubic meters to produce a GWh equivalent of hydrogen and ammonia, and also lists the water demand, seawater use, and brine production arising from DAC in the capture of 1 t CO_2. Note that the water demand and brine production for DAC listed in Table 6 represents the averages across the values estimated at the five DAC sites, each of which have a location specific WCF (see the companion *Downscaling – CO_2 capture, transmission, use and storage* document for discussion about DAC site selection).

Table 6 | Water demand for process using sea water in m^3/GWh for all technologies but DAC which is shown in m^3 per tonne CO_2 captured

Process	Treated water	Brine	Sea Water
Haber-Bosch	162	207	493
Electrolysis	208	287	963
ATR+CC	421	581	1002
DAC	8.08	11.16	19.26

2.7 Estimate of the desalination plant required

Desalination is a mature technology widely used to supply treated water in water-stressed areas. Australia has 270 desalination plants of varying capacity [32]. According to Orr and Kay [33] Australia's 6 reverse osmosis desalination plants are spread across 6 states/territories and have a maximum cumulative capacity of 1.5 GL of desalinated water per day. Australia's largest desalination facility uses reverse osmosis and has a capacity of 444,000 m^3/day of desalinated water [34]. Based on discussion with experts, NZAu has assumed that a desalination plant with a capacity of 1GL litres per day (1000MLD) is feasible, also see Campos, Vieira [35] for largest desalination plant in world. To determine a simple measure of the number of desalination plants required by each NZAu scenario, the total water demand from electrolysis, ATR+CC, Haber Bosch, and DAC facilities is divided by 328.5GL per year (90% efficiency).

2.7.1 Desalination plant land footprint

The site density of the three Australian seawater desalination plants listed in Table 7 were considered in estimating per facility and total land footprints for the NZAu desalination requirements. The three plants considered in Table 7 are the Victorian Desalination Plant, the Cape Riche Desalination Plant in WA and the southern Seawater Desalination Plant, also in WA.

Table 7 | Desalination plant with capacity and footprint

Plant	Capacity (MLD)	Footprint		Reference
		ha	ha/MLD	
Victorian Desalination Plant	550	40	0.073	[36]
Cape Riche Desalination Plant	32.88	8.5	0.259	[37]
Southern Seawater Desalination Plant	274	20	0.073	[38]

Table 7 indicates that both the Victorian and Southern Seawater desalination plants have similar footprints of ~0.073 ha/MLD, despite the Victorian plant having double the capacity of the Southern Seawater plant. The Cape Riche plant has a much larger normalized footprint of 0.26 ha/MLD – presumably owing to its low capacity. NZAu expects that desalination plants built in the future will allow for the greater site densities observed in the Victorian and Southern Seawater plants and uses a figure of 0.073 ha/MLD (7.3×10^{-4} km^2/MLD) to determine the land footprints connected with NZAu sited facilities. Use of this number results in a 0.7 km^2 footprint for a 1,000 MLD plant and 0.48 km^2 footprint for a 600 MLD plant.

2.8 Selecting desalination plant locations

NZAu attempts to minimize the transportation of seawater and desalinized water by locating desalination plants close to electrolysis, ATR+CC, Haber Bosch, and DAC end-use locations. However, the desalination processes results in 58% of seawater returning to the sea as concentrated brine. Brine released from desalination plant will have different physicochemical properties (e.g. temperature and salinity) to the surrounding seawater and requires careful dispersal to avoid being a marine pollutant [39, 40]. Injecting GL of brine per day into the sea at a single point has the potential to harm local marine ecology through increased salinity in discharged areas [40, 41]. NZAu desalination plant siting considers two main criteria to minimizing both the cost of transporting water and the potential for environmental impacts on sensitive local marine ecology.

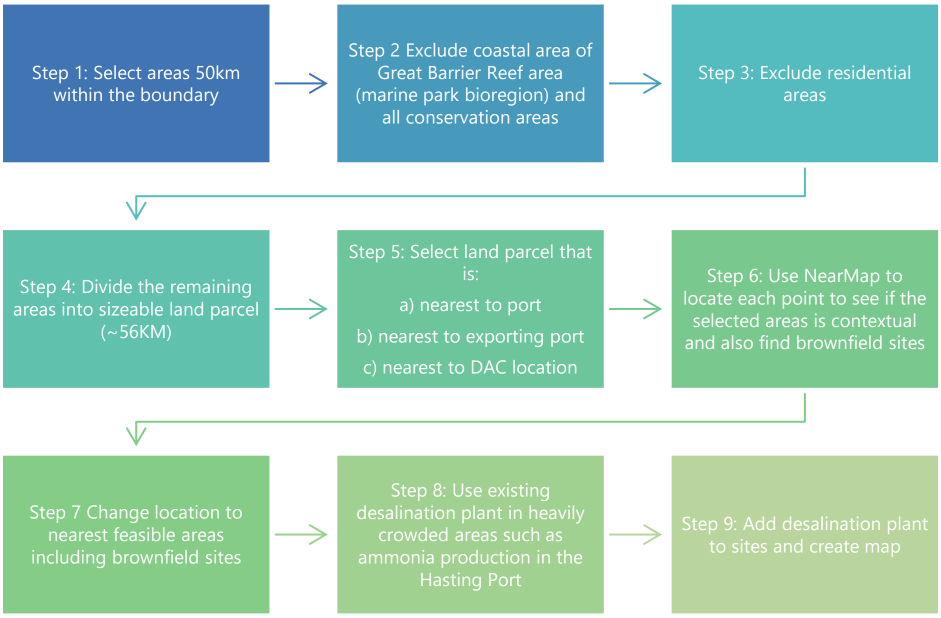
We use the following key criteria to select desalination plant sites.

a. Desalination plants are sited near to the coast to minimize the cost of water transport from the sea to the desalination plant and the cost of transporting brine back to the sea.
b. Do not site desalination plants on terrestrial conservation areas or with an expected discharge point near to marine conservation areas. This required some additional considerations in QLD due to the Great Barrier Reef.
c. Separate desalination plants by location and activity to reduce the quantity of brine discharge in a single location and reduce the water transport distance.
d. ATR+CC and Haber-Bosch facilities are generally sited close to export ports
e. Co-location of desalination and Haber-Bosch facilities is preferred
f. Electrolysis is generally sited far from export ports in inland locations

g. DAC is generally close to a storage location, or the main pipeline carrying CO_2 to the storage location
h. Do not allow plants in residential areas. Use existing desalination plants to supply treated water in areas where finding sites for desalination is difficult. This analysis assumes that existing desalination plants can be expanded by 50% to meet future needs – except for where those plants would expand into residential areas or into conservation areas.

Figure 6 shows the step-by-step process used for the siting of desalination plants.

Figure 6 | Process used to site desalination plants



The steps listed in Figure 6 are:

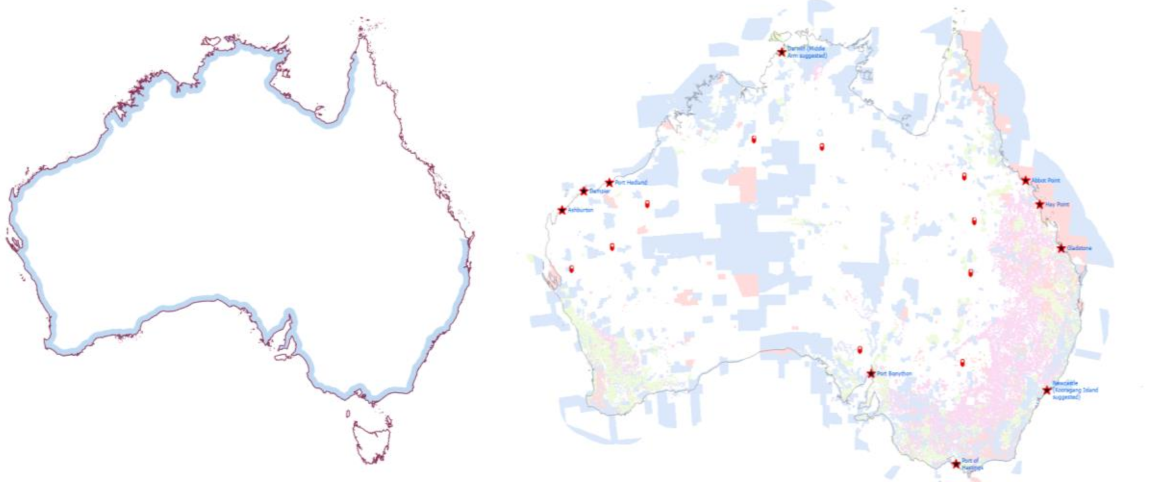
Step 1: Limit water and brine transportation distances and costs. Candidate desalination locations are limited to sites that are a maximum of 50 km from the sea.

Step 2: Exclude conservation areas from consideration as potential desalination sites. We exclude terrestrial areas of:

- National reserves [42]
- Sites in the Collaborative Australian Protected Area Database (CAPAD) [43],
- Ecological Communities of National Environmental Significance [44],
- Species of National Environmental Significance [45],
- Coastal areas of Great Barrier Reef Marine Park Authority [46], with 10km buffer

Figure 7 illustrates areas considered in the siting of desalination plants (left) and areas excluded from consideration (right). All potential NZAu export port locations are shown as stars on the right map in Figure 7.

Figure 7 | Map showing areas included the area near the coast (left) and areas excluded areas (right)



Step 3: Exclude residential areas from consideration by removed class 5 from the land use map provided by the Department of Agriculture, Fisheries and Forestry [47]. The land use map uses the Australian Land Use and Management (ALUM) Classification system.

Step 4: Divide land remaining under consideration for desalination sites into ~56 km^2 blocks. The use of 56sqkm block is based on rough calculation of land required for Candidate Energy Export Facility discussed in the *Downscaling – Energy export system* report. All candidate desalination blocks are sized to allow for the co-location of new ammonia production sites with new desalination plant.

Step 5: Identify separate desalination sites for ATR+CC, DAC, electrolysis, and Haber Bosch using the following guidelines:

a) Nearest to the port for energy export-related water supply (ATR+CC and Haber-Bosch)
b) Nearest to export zone to supply water for electrolysis
c) Nearest to DAC sites to supply water for DAC

Step 6: Consider desalination sites for local appropriateness using online tool that allows high resolution areal visualization [48], and an existing desalination plant layer [49]. This is especially important around sites in SA, VIC, and QLD in high population areas. The same approach was used to identify potential brownfield locations for siting of new desalination plants. We assume expansion of existing desalination sites is possible if siting of a new plant is considered infeasible due to population and exclusion considerations.

Step 7: Select final locations and map desalination locations.

2.8.1 Special consideration for desalination around the Great Barrier Reef

The Great Barrier Reef stretches most of the coastal areas of Northern Queensland. Siting desalination plants in the coastal areas of Southern Queensland is challenging for two reasons. Firstly, the areas are heavily used either for residential purposes or have conservation areas including an island. Secondly, moving to the south means the water must be transported to the port and export zone in Northern QLD increasing the cost and environmental impact of tunnelling water through the coast. Therefore, sites for a coastal desalination plant in the coastal area of QLD to supply water to three export zone and three ports of Queensland is challenging. To address the potential environmental impact on reef areas, this analysis uses a two-step strategy.

We separate the water demand for ammonia, ATR, DAC and hydrogen production. Then, we calculated the water supply required for energy export at the port and hydrogen and DAC in the mainland. Energy activities in the port include Haber Bosch and ATR+CC. So, the water demand at QLD port is known.

This analysis assumes the desalination plant is co-located with the Haber Bosch plant. So, the water needed for ammonia is divided into three ports. We divided the total water demand by three (assuming all port equally shares the energy export) to calculate the demand for a desalination plant for each port of the QLD. Decentralizing the desalination plant decentralizes the discharge of brine and reduces the environmental impact of brine discharge and avoids the environmental damage of tunnelling desalinated water from south Queensland or the northern Gulf areas of North Queensland across the port located in the coastal area of the Great Barrier Reef.

To site the desalination plant, we looked for brownfield sites or to be brownfield sites in NZAu scenarios. This allows the reuse of brownfield sites and reduces the environmental impact of new infrastructure in coastal areas of GBR.

To resource water for DAC and hydrogen production in the export zone, we site a desalination plant away from GBR coastal areas. Desalinated water for hydrogen production in three export zone of Queensland was feasible from the Gulf areas of Northern Queensland.

3 Results

3.1 Total national water demand

Figure 8 shows the total national water demand for the six NZAu scenarios.

Figure 8 | Total national water demand (GL) in NZAu scenarios

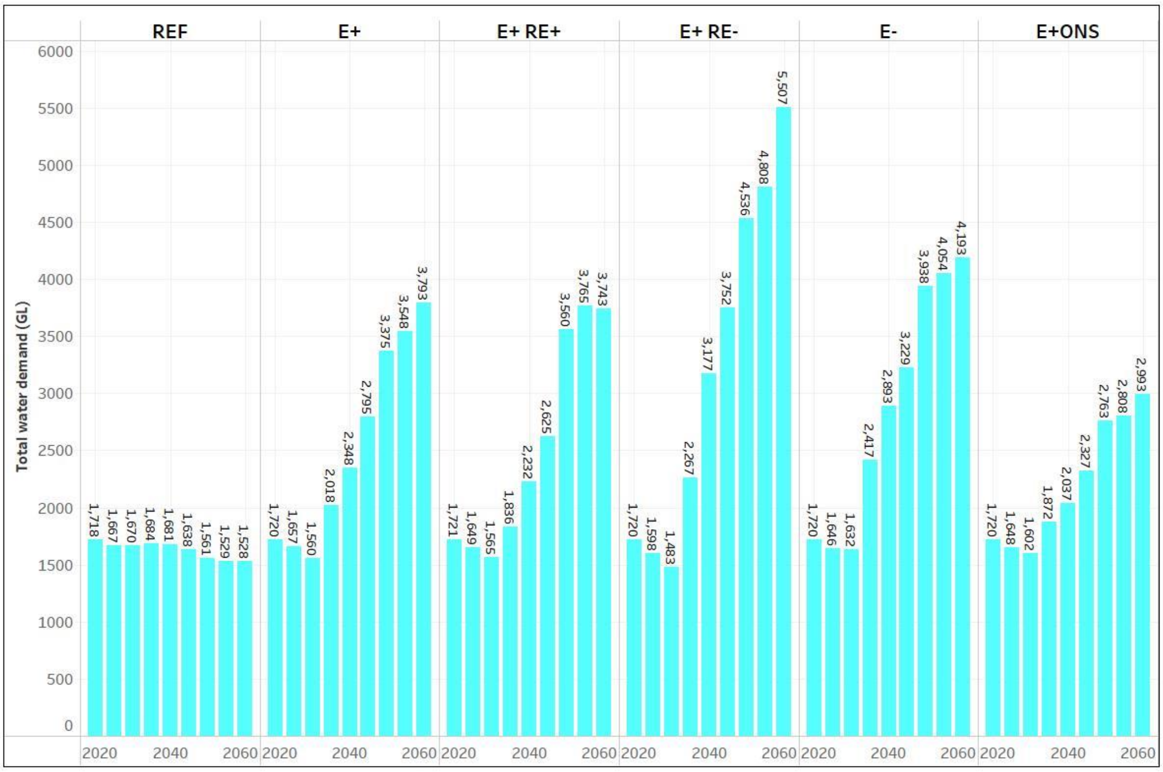


Figure 8 shows water demand increasing over time in all NZAu scenarios but the REF scenario. Water demand by 2060 is highest in the RE– scenario and lowest in ONS scenario. Initially water demand falls slightly in all scenarios, for instance in E+, water demand decreases from 1721 in 2020 to 1560 in 2030. After 2030, water demand increases. Change in water demand between model years varies by scenario. For example, in the RE+ scenario the total water demand increases by 1060GL between 2030 and 2045, and then from 2045 to 2050 by 935GL whereas in the same period in RE–scenarios, water demand increases by 2269GL and 784GL, respectively.

3.1.1 Total national water consumption by NZAu transition activity/ process

Figure 9 shows total national water demand by NZAu transition activity/ process.

Figure 9 | Water demand by energy activities

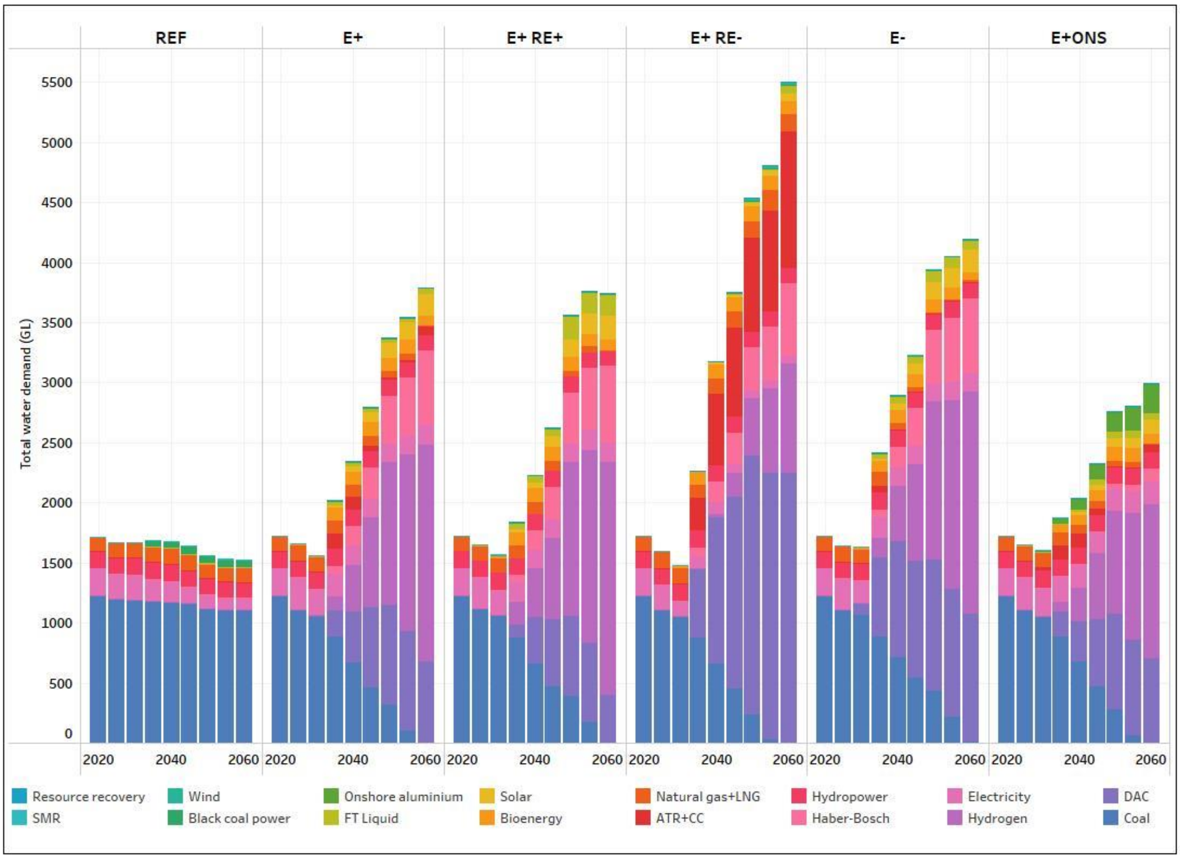


Figure 9 indicates that in all core scenarios, water demand from coal focused industries will be replaced by demand from industries connected to the production of clean energy exports and the capture of CO_2 from the air. Water demand is dominated by electrolysis in the E+, RE+, and E– scenarios whereas DAC and ATR+CC dominate water demand in the RE– scenario. Water demand from DAC is the least significant in the E+RE+ scenario but plays a much larger role in all other scenarios. Water for cooling in Haber-Bosch facilities also plays a significant role in water demand for all but the ONS scenario which sees relatively minor water demand connected to the export of ammonia. Water demand for onshored industries is also fairly minor in the ONS when compared against demand from DAC and electrolysis in that scenario.

3.1.2 Total national water consumption by water source

Figure 10 shows national water consumed by water source. In Figure 10, desalinated refers to the quantity of treated water sourced from the coastal desalination plant, rather than the total seawater demand.

Figure 10 | Total national water demand by source

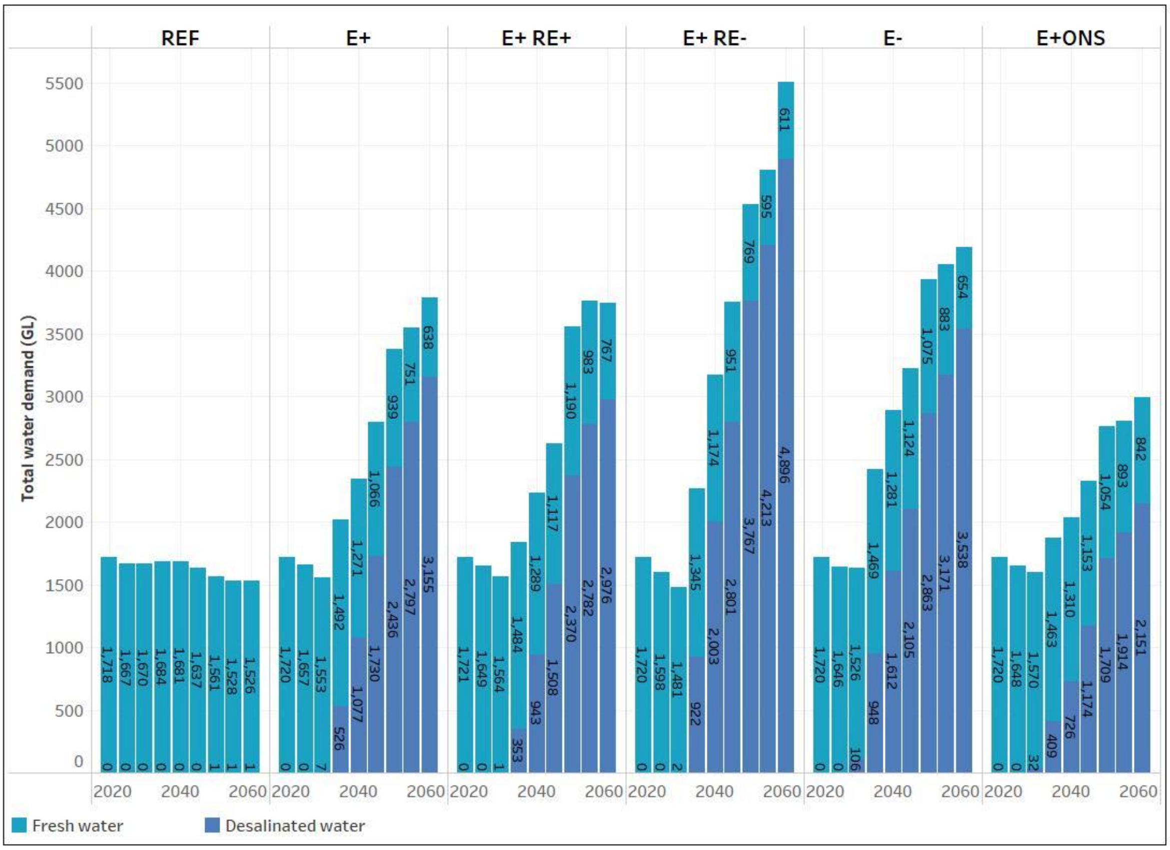


Figure 10 shows that freshwater consumption decreases over time from 2020, whereas desalinated water consumption increases in all scenarios. While water consumption shifts from freshwater sources to desalinated water in all scenarios, the pace of shift varies by scenario. The share of water supplied by desalinated water varies by scenario. In E+RE- scenario, 11.1% of water is sourced from fresh water in 2060 whereas the share of fresh water in E+ONS scenario is 28.1% and 20.4 in E+RE+ in same year.

3.1.3 Total national water consumption by water source and activity/ process

Figure 11 provides a more granular look into water demand by cross-tabulating water source with activities/processes. Note, the range of y-axis for fresh water and desalinated water is different.

Figure 11 | Water consumption by water source and energy activities

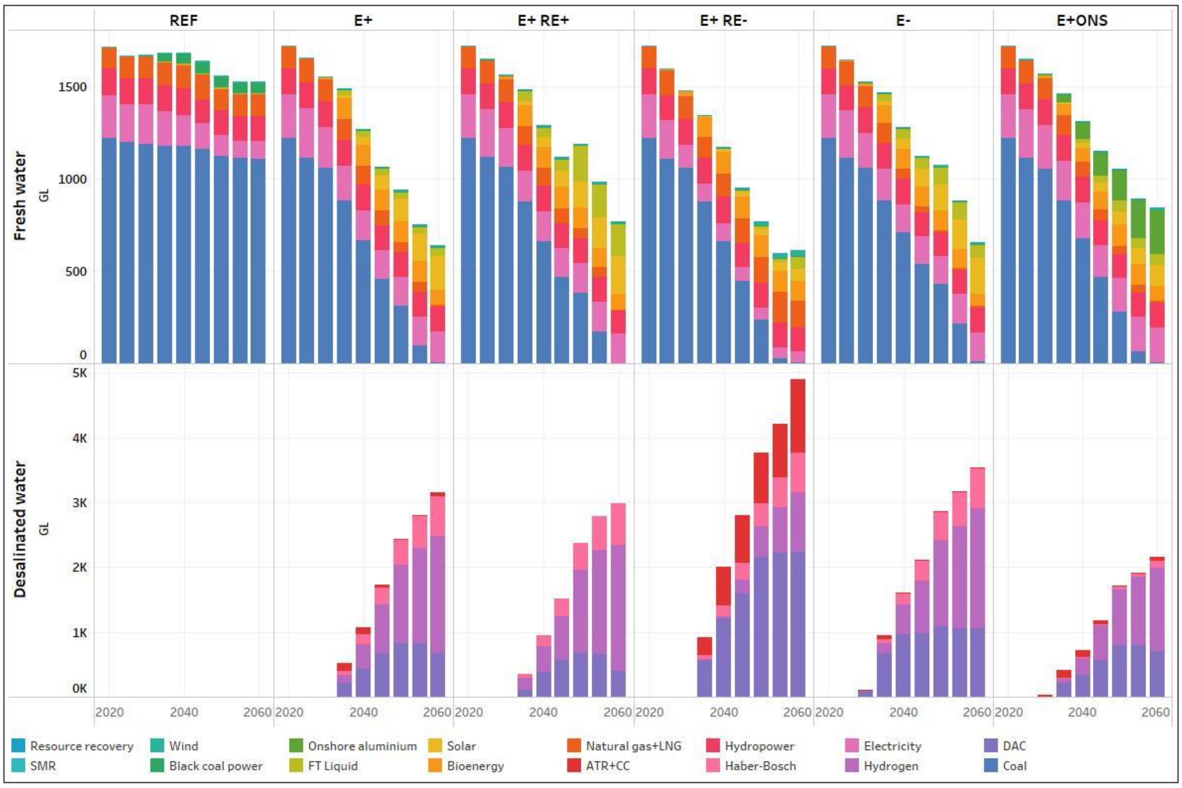


Figure 11 shows fresh water demand decreasing as fossil fuel-related activities reduce over time. The increased demand for desalinated water is connected directly to the increased production of hydrogen and ammonia, and the capture and storage of CO_2. Freshwater demand in the ONS scenario decreases between 2020 and 2060, but not as much as other scenarios as the increased water demand from greater domestic aluminium production is met with fresh instead of desalinated water.

3.1.4 Total national water demand as compared to 2019/20 Australian water use

To give a sense of future water demand for NZAu scenario, we compare NZAu water demand with water supplied in 2019-20 to industries. According to statistics released by Water Account, Australia on 20/10/2021, total water consumption for Australia in 2019-20 was 11,231 GL, with 1,801 GL supplied to household [50]. Figure 12 is a line graph showing water demand for different NZAu scenarios as a percentage of 2019-20 water supplied to industries by Water supply, Sewerage and drainage services. Because NZAu energy activity is a mix of mining and energy production, we use industry water supply in 2019-20 for comparison noting this comparison does not account for future changes to the water supply.

Figure 12 | Water consumption as a percentage of the total water consumed in 2019/20

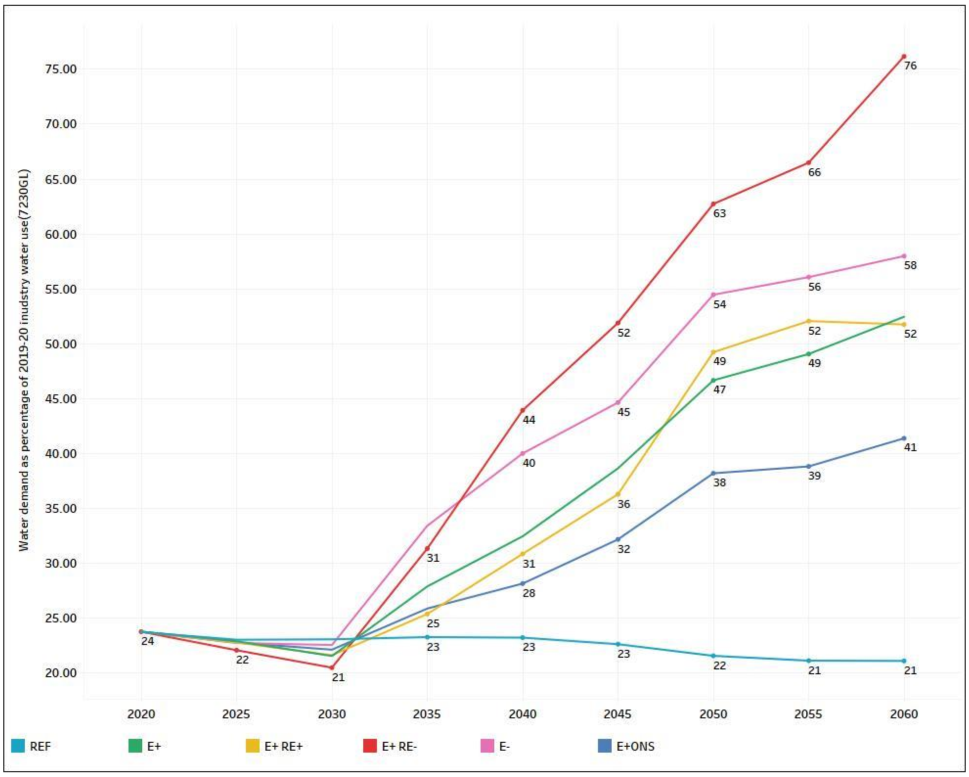


Figure 12 indicates that even RE–, the NZAu scenario with the highest water demand in 2060, uses 49.5% of Australia's 2019/2020 total water use in the final year of the transition. NZAu water demand is the lowest overall in ONS (41%) leading to a total water savings from 2019/2020 of 76%.

3.2 Water demand by state/ territory

Figure 13 shows water demand in GL by state/territory and NZAu scenario in 2020, 2040, and 2060.

Figure 13 | Water demand in GL by state/territory and NZAu scenario in 2020, 2040, and 2060

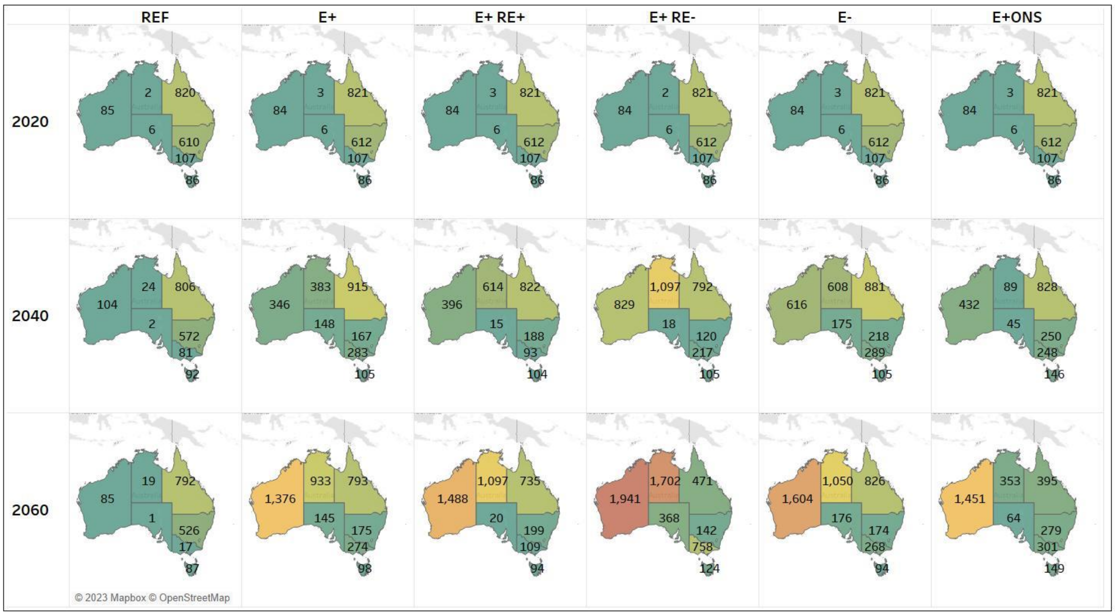
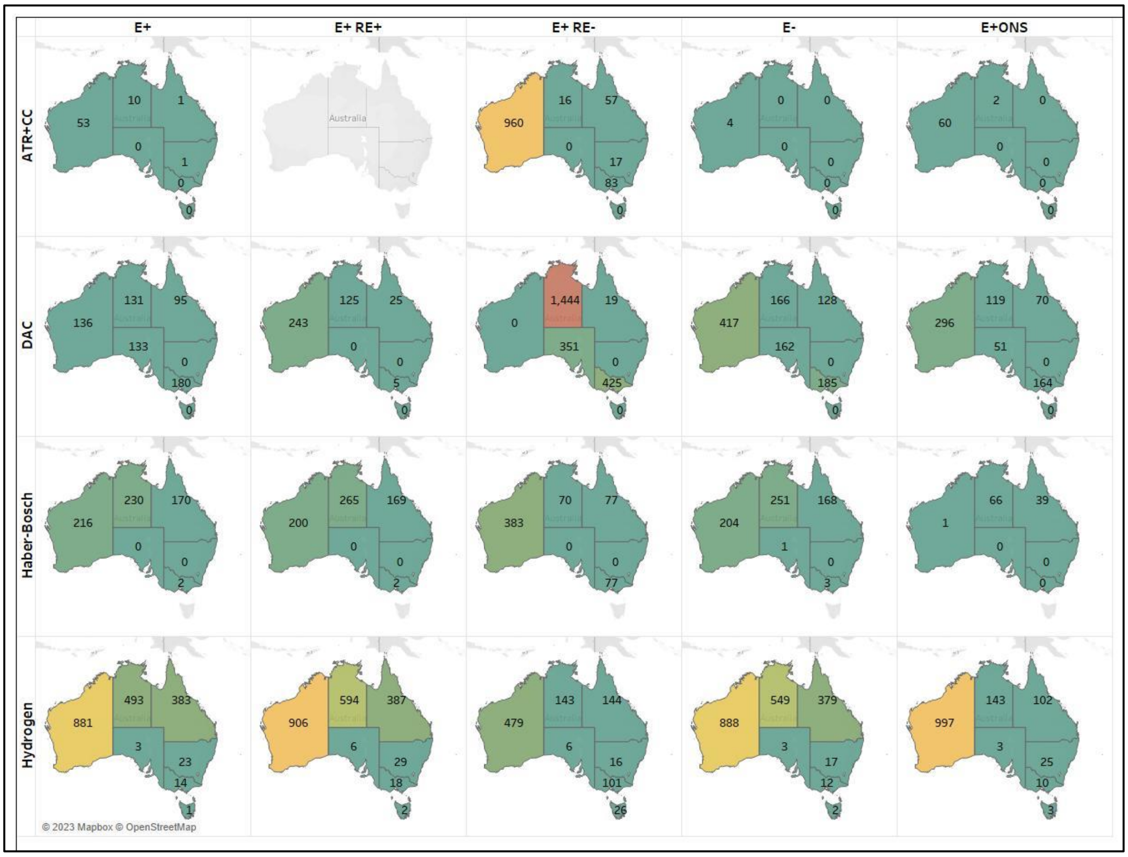


Figure 13 shows the largest changes in water demand at a state/territory level occurring in the exporting regions of WA, the NT and QLD in all scenarios, and in VIC as well in the RE– scenario. The largest single-state water demand change occurs in WA in the RE+ scenario which sees an increase in demand of over 1,800 GL between 2020 and 2060. State-level demand is aggregated from the water demand of regions. We have provided an example of region demand for the E+ scenario in Appendix B.

3.2.1 State/ Territory water consumption by NZAu transition activity/ process

Figure 14 reports water consumption by electrolysis, ATR+CC, Haber-Bosch and DAC for each state/territory for each NZAu scenario in 2060.

Figure 14 | Water consumption by electrolysis, ATR+CC, Haber-Bosch and DAC for each state/territory for each NZAu scenario in 2060



Depending on the intensity of energy activities, water demand for these four-water intensive energy activity varies by scenarios. Water demand for ATR+CC is highest in E+RE- scenario in which 960GL of water is required for ATR+CC in WA. ATR+CC consumes 83GL of water in VIC in E+RE- in 2060. Water demand for ATR+CC in E- scenario is less than 1GL in all regions except WA. In E+RE-, DAC consumes 1444GL of water in NT, highest as compared to state wise water use in all scenarios. DAC water consumption is more evenly spread in E- scenario where DAC in WA, VIC, NT, SA and QLD uses water between 417 to 128GL. State wise water demand for Haber Bosch(HB) is highest in WA in E+RE- (383GL) whereas in E+ONS, HB water demand is concentrated in NT(66GL) and QLD(39GL). Water demand for hydrogen is lowest (479GL) in E+RE- scenario and highest (997GL) in E+ONS scenario.

3.2.2 State/ Territory water consumption by source

Figure 15 shows freshwater demand in GL by state/territory and NZAu scenario in 2020, 2040, and 2060.

Figure 15 | Freshwater demand in GL by state/territory and NZAu scenario in 2020, 2040, and 2060

Fresh water demand in two states decreases in two state and increases in three states in all core scenarios. Figure 15 shows demand for freshwater reducing in QLD and NSW in all core scenarios when water for four water intensive energy activities is supplied from desalination plant. The highest fall in freshwater demand is observed in QLD due to reduced fossil fuel extraction, especially coal. In E+ scenario, freshwater demand in QLD reduces by 678GL between 2020 to 2060 whereas in WA water demand slightly increases from 84GL in 2020 to 91GL in 2060. Fresh water in SA, NT and WA increases in all scenarios. Fresh water demand in VIC reduces in all core scenario except E+ONS. Consumption of desalinated water by the state is reported in Figure 16.

Figure 16 | Desalinated water demand in GL by state/territory and NZAu scenario in 2020, 2040, and 2060

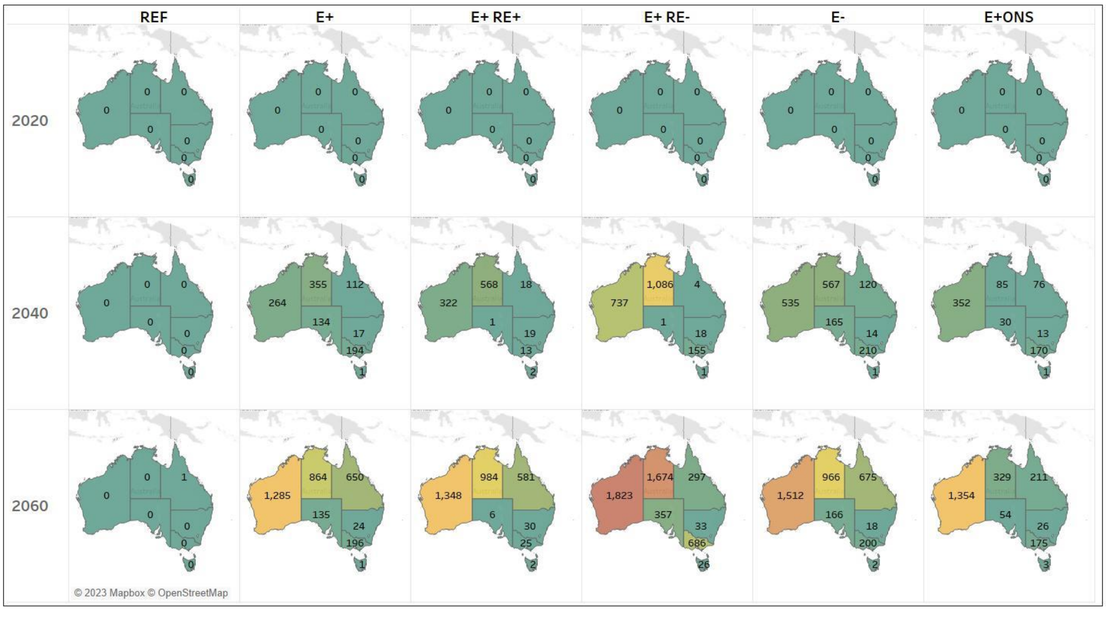


Figure 16 shows that desalinated water demand changes by state and scenario. However, the largest amount of desalinated water will be consumed in WA. In the E+ and RE– scenarios, WA consumed 1,285 GL and 1,823 GL of desalinated water. The NT demands the second largest amount of desalinated water in all scenarios, with the NT consuming 864 GL and 1,674 GL of water in 2060 in the E+ and RE– scenarios respectively. Queensland consumes the third largest amount of desalinated water in all scenarios but the RE– scenario, with QLD consuming 650 GL and 297 GL of water in 2060 in the E+ and RE– scenarios respectively. Water consumption in VIC is small relatively to WA, the NT, and QLD in all scenarios but RE–, in which its water demand rises to claim the third largest demand at 686 GL.

3.2.3 Desalination plant state/ territory distribution

The distribution of desalination plants – each with an output capacity of 1,000 ML per day – is shown by state and scenario in 2020, 2040, and 2060 in Figure 17.

Figure 17 | Desalination plants required to supply treated water, by scenario and state/territory in 2020, 2040, and 2060

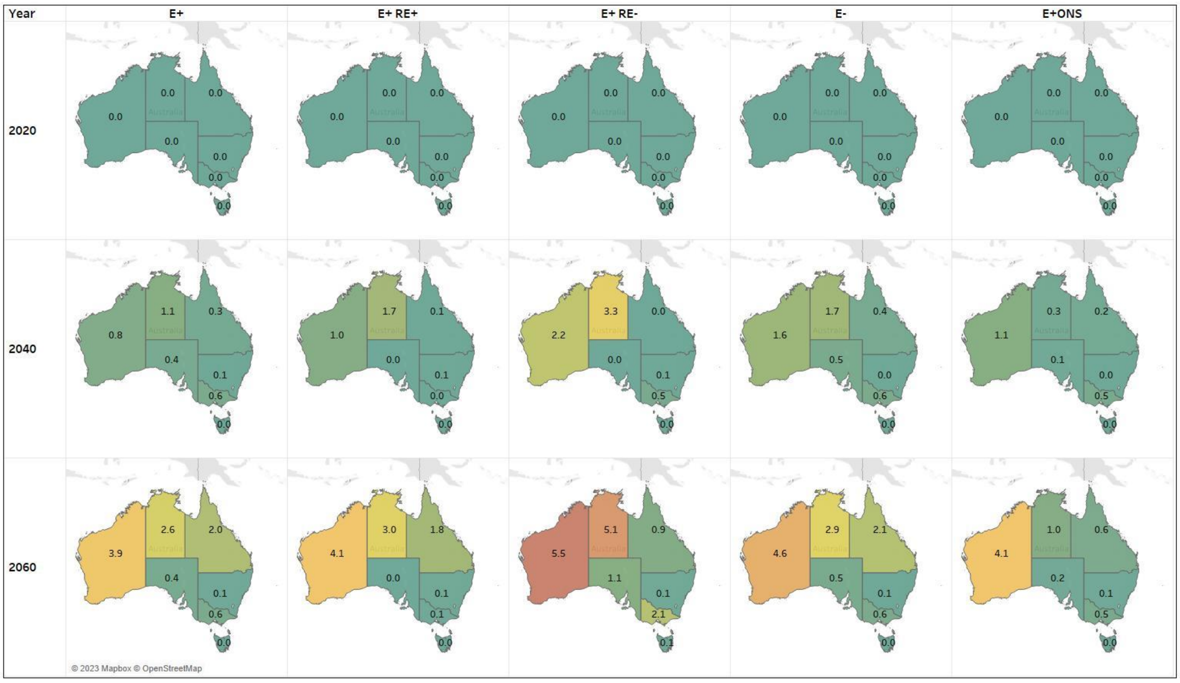


Figure 17 indicates that at a minimum 7 desalination plants are built to meet desalinated water requirements in the E+ONS scenario and a maximum of 15 desalination plants are built to meet desalinated water requirements in the E+RE- scenario. The number of desalination plant built at states varies by scenario, for instance, WA, NT and VIC will have 5.5, 5.1 and 2.1[1] desalination plant (capacity of 1GL per day at 90% efficiency) in 2060 in E+RE- scenario whereas in E+, 4, 3 and 2 desalination plant are built in WA, NT and QLD, respectively. State wise distribution of desalination. Further insight into activities/processes that regional desalination plants are supplying is provided in Figure 18.

[1] Desalination plant fractions (e.g. 5.5 plants in WA) are provided for precision. Practically, desalination plants would be sized according to more precise geographic demand rather than the single 'one size fits all' approach used in NZAu. Hence the 5.5 x 1000 MLD plants in WA may become 5 x 1100 MLD plants.

Figure 18 | Desalinisation plant by energy activities and NZAu zones

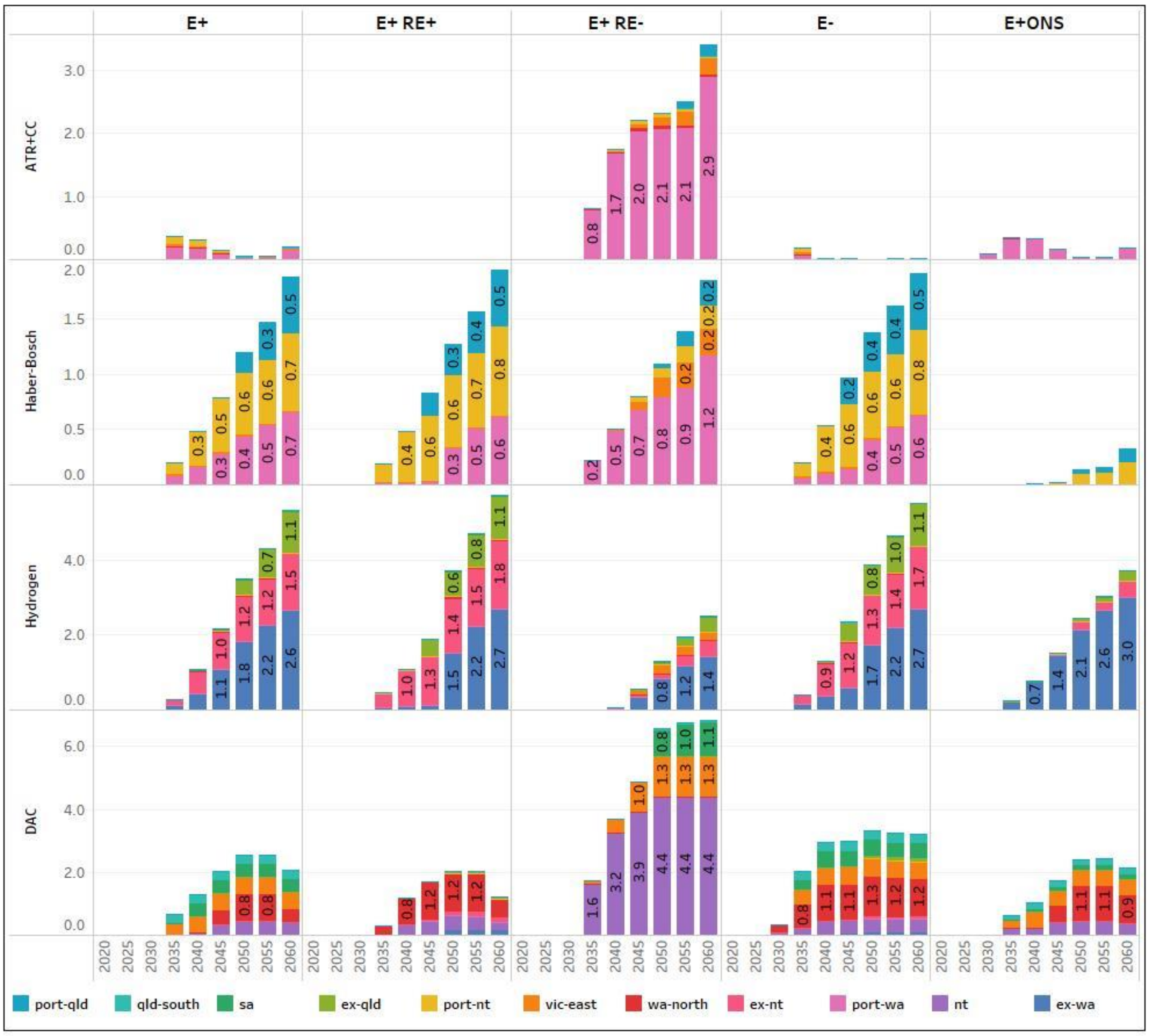


Figure 18 indicates that in the E+, E+RE+, E- and E+ONS scenarios, desalination plant for ATR+CC is fraction of desalinated plant capacity. For example, in 2035, desalination plant of one third of 1GL capacity is built in E+ONS, whereas ATR+CC water demand falls in 2040. 3 desalinated plant is built in WA in E+RE- to supply ATR+CC. Desalination plant for HB is built in port of WA, QLD and NT in all core scenarios. Desalinated plant with 20% capacity of 1GL plant is built in VIC for HB in E+RE- scenario in 2050. Desalination plants for hydrogen are built in WA, NT and QLD. In 2060, 2.7, 1.8 and 1.1 desalination plant is built in WA, NT and QLD to supply water for electrolysis in E+RE- whereas 3 desalination plant are built in WA to supply water for hydrogen production. 4.4, 1.3 and 1.1 desalination plant supplying water for DAC in E+RE- scenario is built in NT, VIC and SA respectively whereas in E+RE+ 1.2 desalination plant is built in WA.

3.3 Sea water withdrawal and brine production

Table 8 shows the total seawater pumped into the desalination plant and brine production in each NZAu scenario.

Table 8 | Sea water withdrawal, water to demand, and brine by scenarios in 2060 (GL)

Scenarios	Seawater withdrawal	Water to demand	Brine released
REF	3	1	2
E+	7,512	3,155	4,357
E+ RE+	7,085	2,976	4,109
E+ RE-	11,500	4,831	6,670
E-	8,425	3,538	4,886
E+ONS	5,121	2,151	2,970

Table 8 shows the largest withdrawal of seawater occurring in the RE– scenario at 11,500GL of seawater, with 6,670 GL being sent to the sea as concentrated brine. The distribution of sea water withdrawn and brine released is reported at a state/territory level in Figure 19 and Figure 20, respectively.

Figure 19 | Sea water withdrawal in NZAu scenarios.

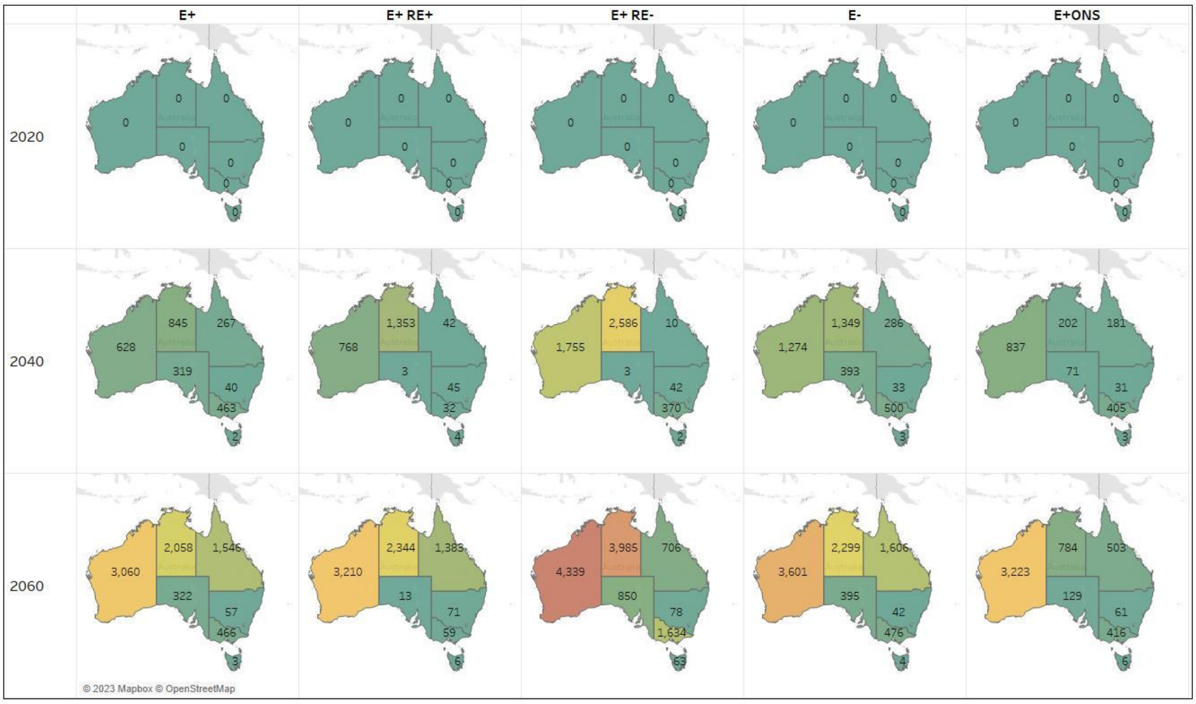
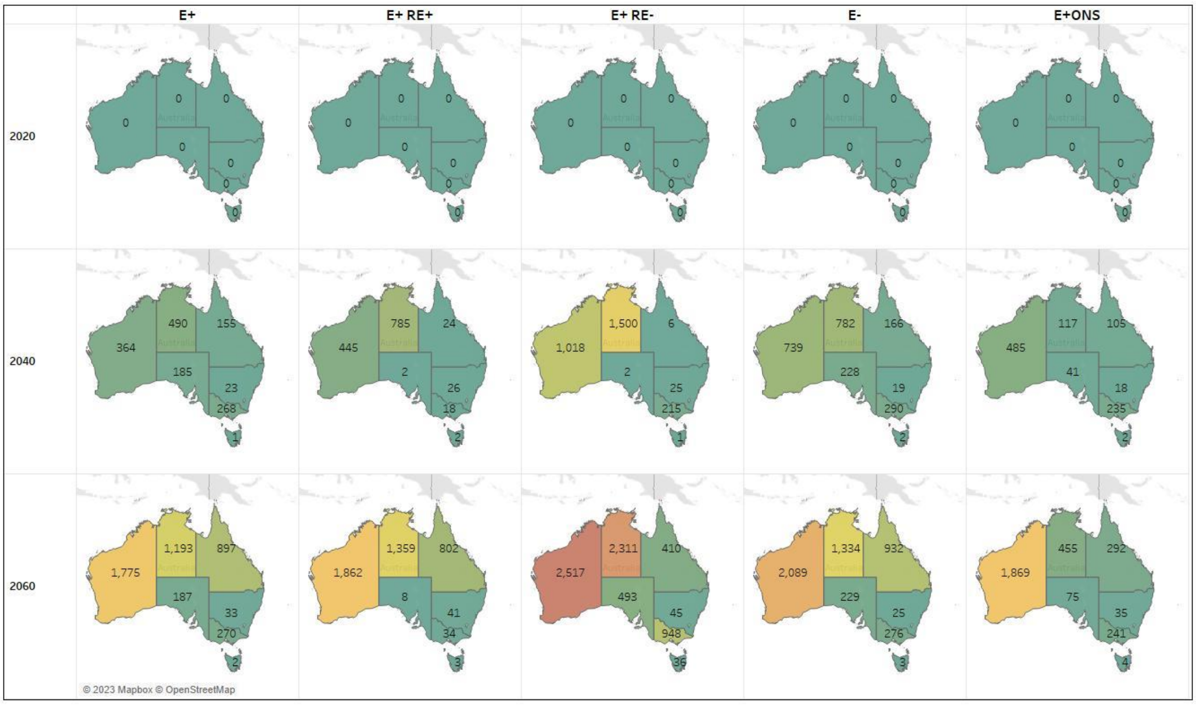


Figure 20 | Quantity of brine produced from the desalination plant by state.

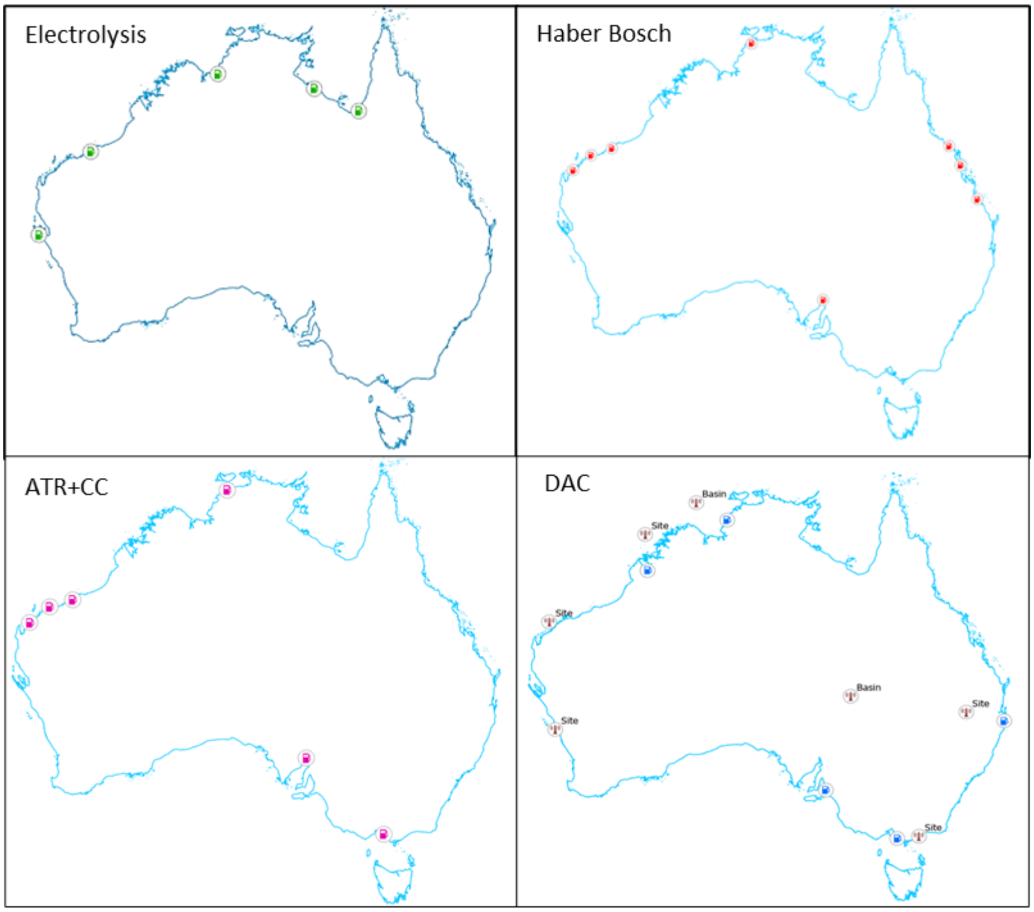


We further explore the siting of desalination plant and brine release in north Queensland in Appendix B.

3.4 Final mapping of desalination plant locations

Figure 21 maps the 19 candidate desalination plant locations considered by the NZAu team for supply to ATR+CC, electrolysis, DAC, and Haber-Bosch facilities.

Figure 21 | Desalination plant sites



Of the 19 candidate desalination sites shown in Figure 21, five of the sites are selected to only supply desalinated water to electrolysis. Water for electrolysis in QLD can be supplied from a single site in the gulf area in northern QLD as one moves towards the NT border. The desalinated water for electrolysis in NT can be supplied from two sites, one located on the gulf coast in the east of the NT and the other located on the northwestern coast of Australia near the NT/WA border. The desalinated water for electrolysis in WA can also be sourced from two sites, one located on the west coast near Inggarda and the other located in the north-west coastal area above Port Hedland.

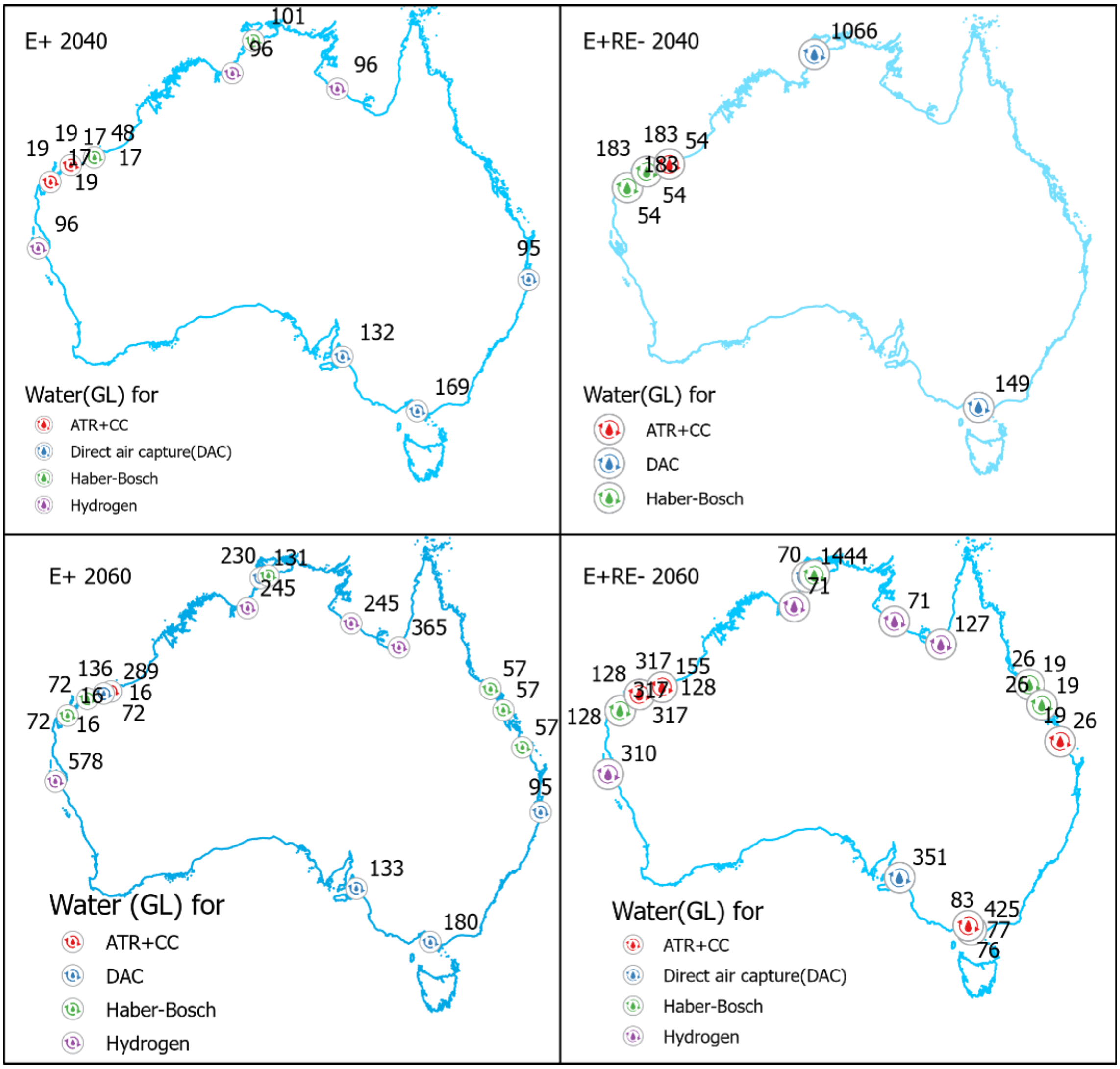
The remaining 14 candidate desalination sites are located to be able to supply desalinated water to ATR+CC, DAC, and Haber-Bosch facilities across Australia. 10 of the candidate desalination sites are co-located with Haber-Bosch plants at each state's Candidate Energy Export Facility (CEEF) to supply water to both ATR+CC and Haber-Bosch facilities in/around the CEEF. Five of the candidate desalination sites serve water to DAC facilities. Two of the candidate desalination sites in WA and the NT involve new desalination plant construction and are located close to the large pipelines transporting CO_2 to the regional offshore storage location. The final three candidate desalination sites are located at existing desalination plants in QLD, VIC, and SA which, we assume will be expanded to supply water to DAC sites near the Surat, Gippsland, and Cooper storage locations respectively.

The final selection of which of the 19 candidate desalination sites are constructed in each NZAu scenario corresponds to the final layout of water-intensive industry. The final selection and mapping of locations for electrolysis facilities are discussed in the *Downscaling – Solar, wind and electricity transmission siting* document. The final selection and mapping of locations for Haber-Bosch facilities in each NZAu scenario are discussed in the *Downscaling – Energy export systems* document. The final selection and mapping of locations for ATR+CC facilities in each NZAu scenario are discussed in the *Downscaling – Hydrogen and synthetic fuel production, transmission and storage* document. The final selection and mapping of locations for DAC sites in each NZAu scenario are discussed in the *Downscaling – CO2 capture, transmission, use and storage* document. The complexity of tying together all of these activities across different downscaling streams and teams led to the formulation of a few expedient conventions for the siting of desalination plants.

3.4.1 Desalination plant by mapped location and scenario in E+ and RE- Scenarios

The desalination plants required to supply water to activities/processes varies by year and scenario. Figure 22 presents the capacity of the desalination plants required in the E+ and RE– scenarios in 2040 and 2060.

Figure 22 | Mapped desalination location and water demand for E+ and RE– in 2040 and 2060



The details of the water demand and the number of desalination plants at each of the desalination sites shown in Figure 22 for the E+ and RE– scenarios are provided in the Appendices including water demand and the number of desalination plants at all desalination sites for each year of all NZAu scenarios. We provide notional water transport pipeline schema, connecting desalination plant to energy activities in Appendix C.

Further, we also explored the possibility of supplying water using freshwater demand, for one export zone, in Appendix E.

Appendices

Appendix A: WCF for Direct Air Capture

DAC WCF depends on temperature and humidity. The average WCF for capturing 1 kt of CO_2 in each NZAu model zone is provided in Table .

Table A1 | Average WCF for capturing 1 kt of CO_2 in each NZAu zone

Basin	NZAu Zone	WCF - Treated water (m^3)	Brine (m^3)	Sea Water (m^3)
Cooper	ex-NSW	10,825	14,949	25,774
Darwin	ex-NT	7,771	10,732	18,503
Surat	ex-QLD	6,889	9,513	16,402
Cooper	ex-SA	10,825	14,949	25,774
Port Hedland	ex-WA	10,578	14,608	25,186
Port Hedland	export	10,578	14,608	25,186
Cooper	NSW-central	10,825	14,949	25,774
Cooper	NSW-north	10,825	14,949	25,774
Cooper	NSW-outback	10,825	14,949	25,774
Cooper	NSW-south	10,825	14,949	25,774
Darwin	NT	7,771	10,732	18,503
Surat	port-NSW	6,889	9,513	16,402
Darwin	port-NT	7,771	10,732	18,503
Surat	port-QLD	6,889	9,513	16,402
Cooper	port-SA	10,825	14,949	25,774
Port Hedland	port-WA	10,578	14,608	25,186
Surat	QLD-north	6,889	9,513	16,402
Surat	QLD-outback	6,889	9,513	16,402
Surat	QLD-south	6,889	9,513	16,402
Cooper	SA	10,825	14,949	25,774
Gippsland	TAS	4,379	6,047	10,426
Gippsland	VIC-east	4,379	6,047	10,426
Gippsland	VIC-west	4,379	6,047	10,426
Port Hedland	WA-central	10,578	14,608	25,186
Port Hedland	WA-north	10,578	14,608	25,186
Port Hedland	WA-south	10,578	14,608	25,186

Appendix B: Water demand by region

Figure B1 and Figure B2 map the fresh and desalinated water demand by NZAu scenario in the E+ scenario, respectively. Fresh water demand is currently concentrated in WA-north which gradually reduces over the course of the transition. Desalinated water demand sharply increases in WA-north, WA-central, the NT and QLD-outback due to hydrogen and ammonia production. The desalinated water demand in VIC-East, QLD-south, and VIC is mainly influenced by water demands from DAC.

Figure B1 | Fresh water demand by NZAu zones in the E+ scenario

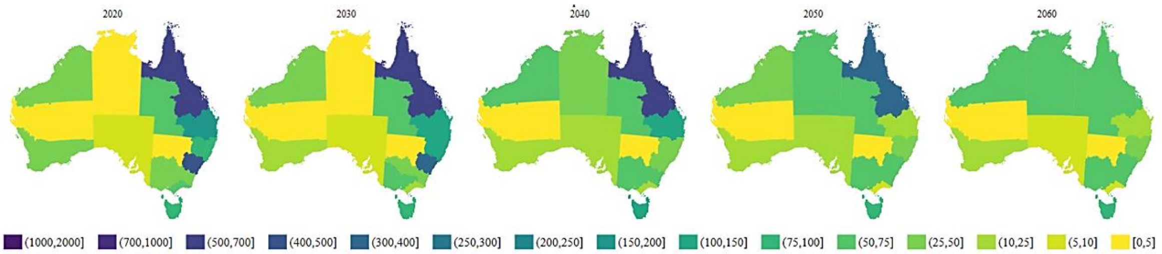
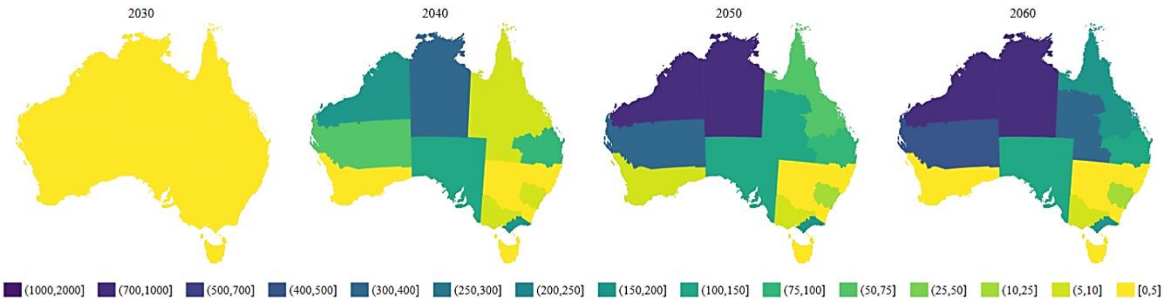


Figure B2 | Desalinated water demand by NZAu scenario for E+ scenario



Appendix C: Desalination sites in the coastal area of Queensland

Three ports from Queensland: Gladstone, Hay Point and Abbot point use hydrogen supplied from central Queensland to produce Ammonia at the port. NZAu assumes the Haber Bosch plant is installed near the port to facilitate the export of ammonia. The ports in Queensland are located in the Great Barrier Reef marine park. Therefore, we separately analyse the desalinated water demand and quantity of brine released.

Table C1 presents the total amount of water required for the Haber Bosch process in Queensland in different scenarios. Three scenarios, E-, E+ and E+RE+ only require a desalination plant for Haber Bosch and ATR+CC at the port. The rest of the scenarios have substantially low water demand in QLD. In the E+ scenario, demand for desalinated water is roughly 171GL per year, the highest as compared to other scenarios. To produce this 171GL of desalinated water, 407GL of sea water has to be fed into a desalination plant with an RO efficiency of 0.42 is required [29]. 236GL of brine is produced in 2060 in E+RE+ scenarios.

Table C1 | Water demand for Haber Bosch and ATR+CC in Queensland in 2060 by scenarios

Scenario	Desalinated water demand (GL)	Sea water (GL)	Brine (GL)
REF	0.0	0.0	0.0
E+	171.1	407.4	236.3
E+ RE+	168.7	401.7	233.0
E+ RE-	134.0	319.1	185.1
E-	168.1	400.2	232.1
E+ONS	39.0	92.8	53.8

NZAu has selected three ports in Queensland as the potential for ammonia export. This analysis assumes each of these ports will have an equal share of ammonia production. Hence, the desalinated water demand at a port is one-third of the total demand. In E+, desalinated water demand for the Haber Bosch process and ATR+CC in Gladstone, Hay Point and Abbot point requires a Desalination plant of capacity 173MLD and 90% utilisation can supply the required water. This plant capacity is roughly 58% of Adelaide's Desalination plant (300MLD per day) and one-third of the extended capacity of the Victorian desalination plant. The maximum amount of brine discharged by the desalination plant in QLD port is around 239 MLD.

Table C2 | Desalination plant in three ports of Queensland in 2060

Scenario	Desalinated water demand (GL/year)	Sea water (GL/Year)	Brine (GL/Year)	Plant capacity (MLD)	Brine per plant (MLD)
E+	57.03	135.80	78.76	173.4	239.4
E+ RE+	56.24	133.90	77.66	170.9	236.1
E+ RE-	44.68	106.37	61.69	135.8	187.6
E-	56.02	133.39	77.37	170.3	235.2
E+ONS	12.99	30.93	17.94	39.5	54.5

Appendix D: Water transport

Figure D1 shows a notional sketch (mapped using a method like the one used to map electricity, H_2 and CO_2 networks) of all candidate water transport pipelines that supply water from desalination sites to water-intensive activities/processes.

Figure D1 | Water transport pipelines

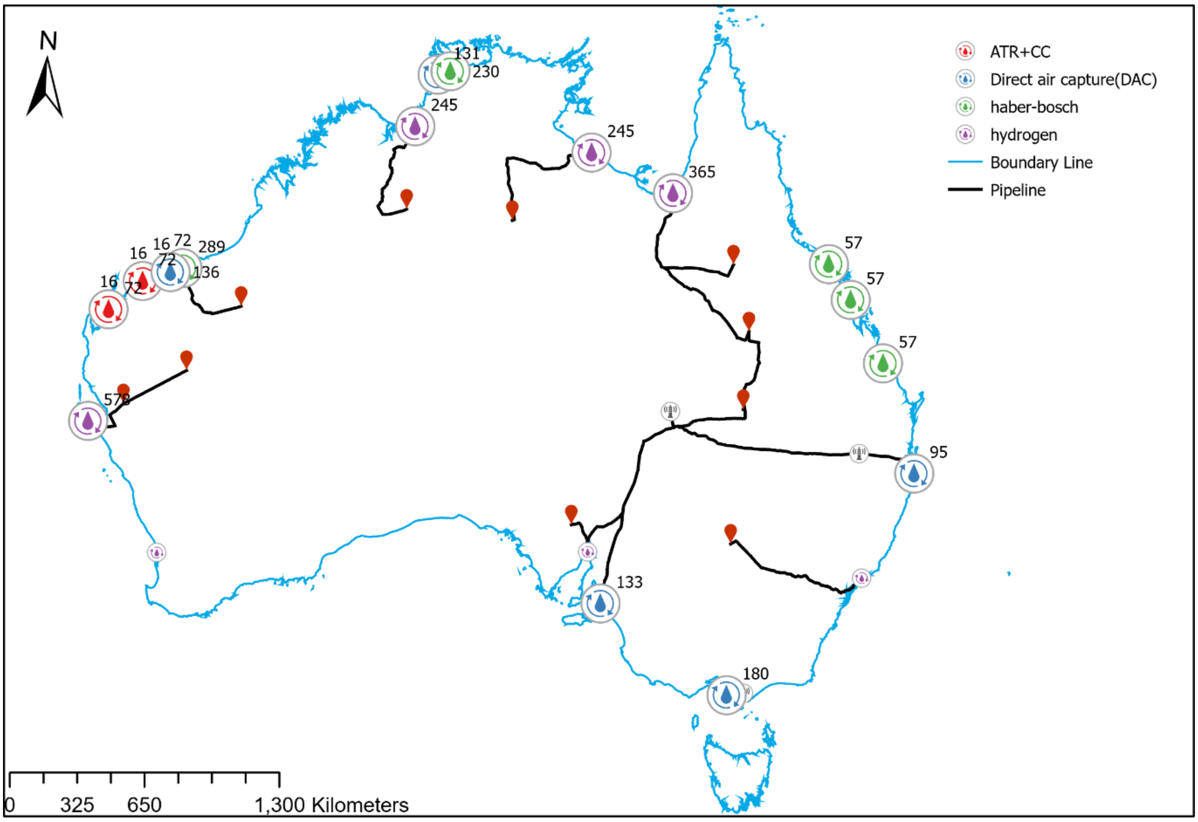


Figure D1 shows candidate pipelines in QLD supplying water from the gulf area of northern QLD to electrolysers in the three export zones in the outback of QLD (red dots), as well as provide a back-up water supply for DAC located near the Eromanga/Cooper storage location (and points onward in the east coast pipeline network). The candidate pipeline running east-west from the SE coast of QLD supplies water to DAC located near the Surat CO_2 storage site, as well as providing a backup water supply for the Eromanga/Cooper DAC site which is supplied from candidate pipelines connecting to the two desalination sites in SA. Water for electrolysis at the two more southern export nodes in WA is supplied via a candidate pipeline connected to a desalination plant on the west coast. Individual candidate pipelines connect the three remaining inland electrolysis sites with coastal desalination sites in WA and the NT. Although it is hard to see on the map, a candidate water pipeline links the desalination plant in the Port of Melbourne with the DAC site near the Gippsland storage site. Final selection of candidate pipelines depends on the final selection of activities/processes in each NZAu scenario and year, and the intentions of infrastructure builders around providing water supply resilience to key NZAu transition infrastructure (and possibly other uses along pipeline routes like agriculture).

Figure D2 shows the pipeline connecting the desalination plant and energy activity location for electrolysis and DAC. Note, the DAC site in the northern part of WA and VIC are very close to the desalination site, therefore the pipeline is not visible.

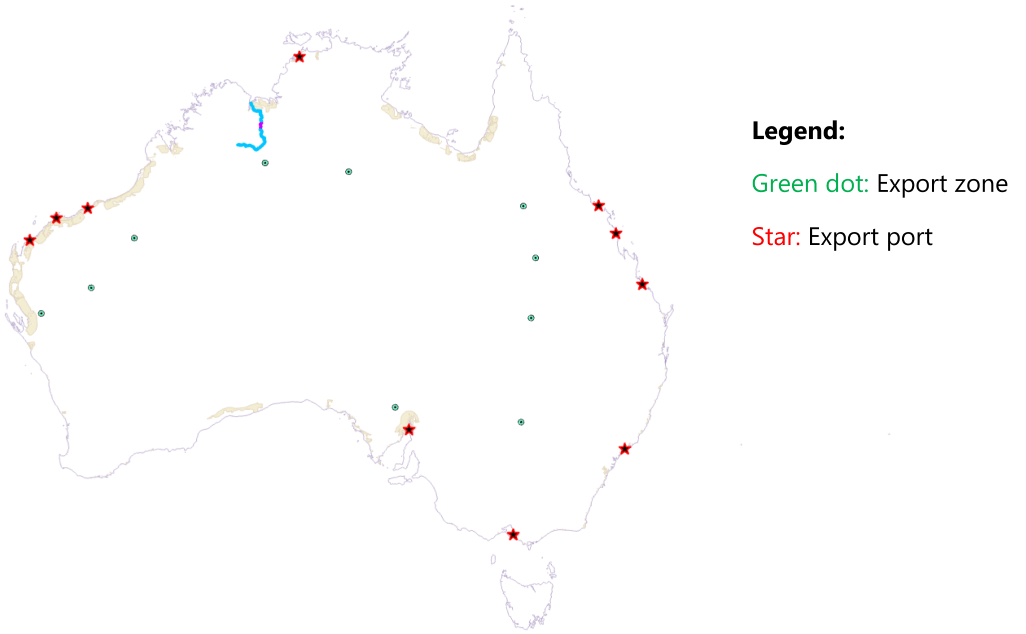
Figure D2 Pipeline to desalination plant from electrolysis (top) and DAC (bottom)

Appendix E: ORD River as a water supply in NT export zone for electrolysis

Ord River:

On average Ord River discharge 6462 GL water per year. Ord river flows from the northern part of WA toward the southwest[51]. The location of Ord River is near to export zone located in the boundary line dividing NT and WA (See Figure 30).

Figure E1 | Map showing exporting zone and port with Ord River and Candidate Desal project areas.



Data, calculation, and assumptions

Table E1 presents the energy activity and water consumption for three water-intensive processes. The water for Autothermal and hydrogen production happens in the export node on the mainland whereas water for the Haber-Bosch process happens in exporting port.

Table E1 | Energy activities in three water-intensive processes in the E+ scenario in 2060 at NT

Process	Energy (GWH)	Water (GL)
Autothermal reforming w/CC	23,876.5	10.05
Haber Bosch	1,417,898	229.81
Hydrogen (Electrolysis)	2,630,086	493.43
Total	**3,937,546**	**746.89**

We calculate water demand on Ord River (as a percentage of Ord River discharge) with three key sensitivities:

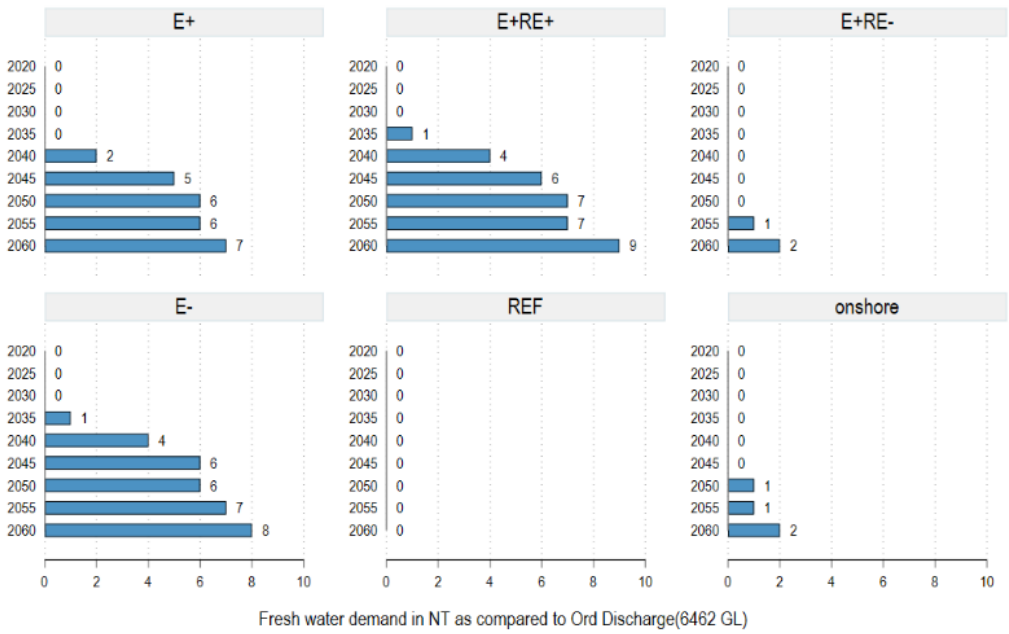
1. All treated water for electrolysis in NT comes from the Ord River
2. All land water for electrolysis in NT is supplied from the Ord River. The treated water to fresh water ratio is 1:1.42[4]. 14.2L of river water gives 10L of treated water to produce 1 KG of hydrogen. Similarly for ATR+CC, 23.6L of river water produces 16.6L of water to produce 1 KG of blue hydrogen.
3. Water for half of the hydrogen (using electrolysis) in NT is sourced from the export zone near Ord River.

Result:

The following four figures show water demand as compared to Ord discharge for the three sensitivities mentioned above. The water demand only includes hydrogen production from Autothermal and Electrolysis. We base water calculation based on Electrolysis.

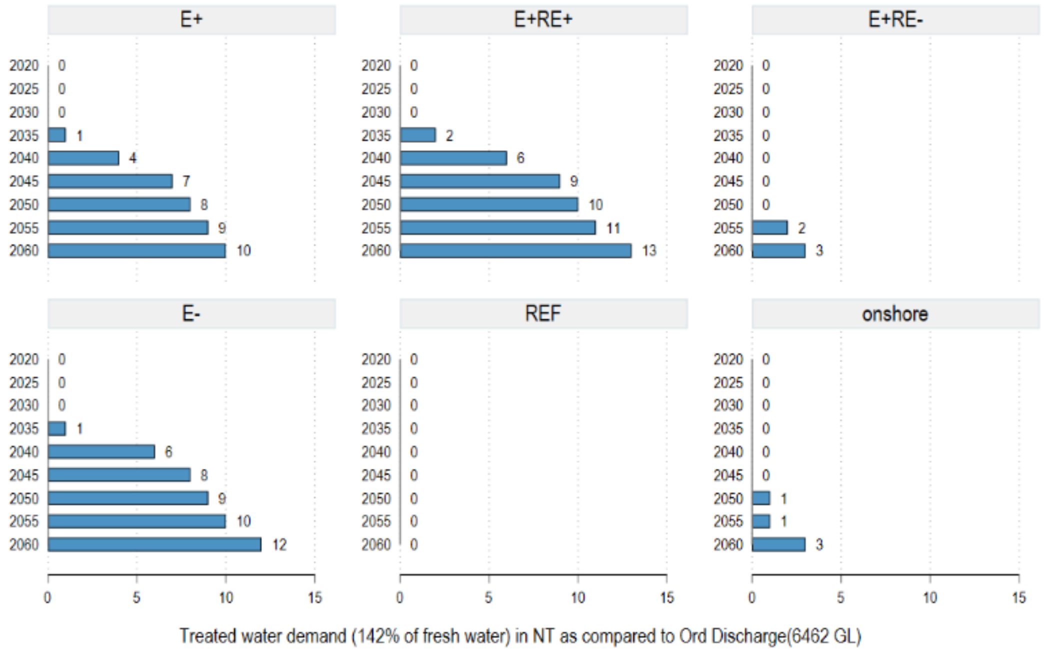
a. It needs roughly 7% of Ord water to meet water demand for NT hydrogen demand in 2060. As shown in Figure , the water demand varies by scenario. For example, water demand in the Onshore scenario is roughly 2% and that in E+RE+ is ~9% of Ord River.

Figure E2 | Treated water demand as compared to Ord River discharge for NT hydrogen production



b. As shown in Figure E3, 10% of Ord water is used when we account for the land water demand (see assumption 2).

Figure E3 | Fresh water consumption as compared to Ord River discharge for NT hydrogen production



c. There is two export zone that feeds hydrogen to exporting port. When we assume only 50% of hydrogen production happens in exporting zone near Ord River and therefore account for 50% of the total Land water demand from Ord River, the water demand for Ord River reduces to 10% in the 2060 E+ and E+RE scenario/

Figure E4 | Treated water demand for half of NT hydrogen production

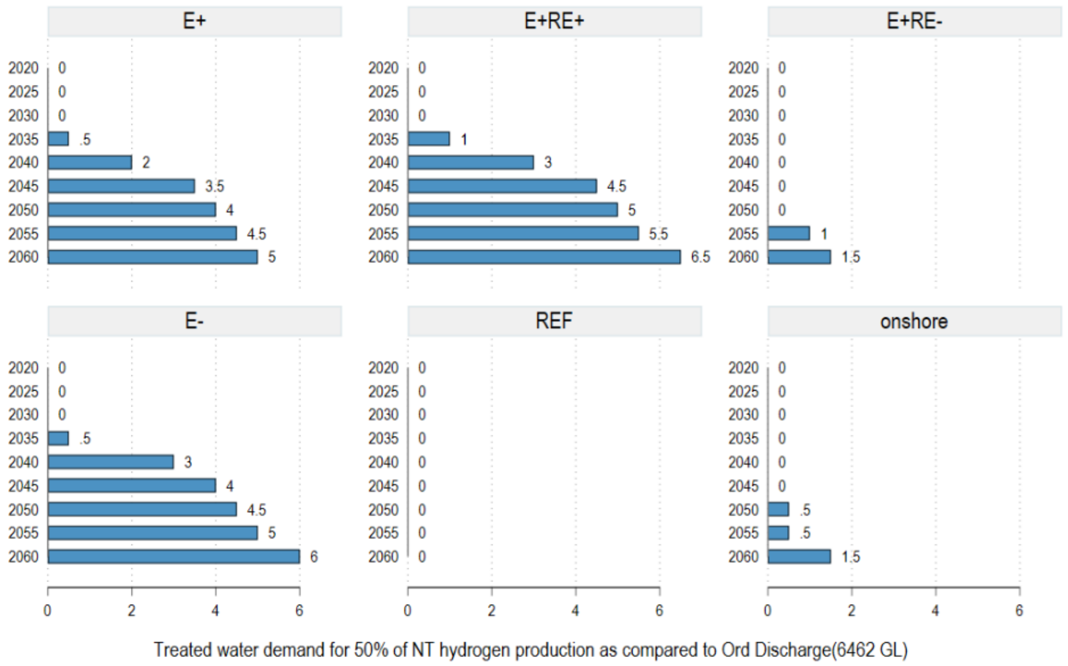
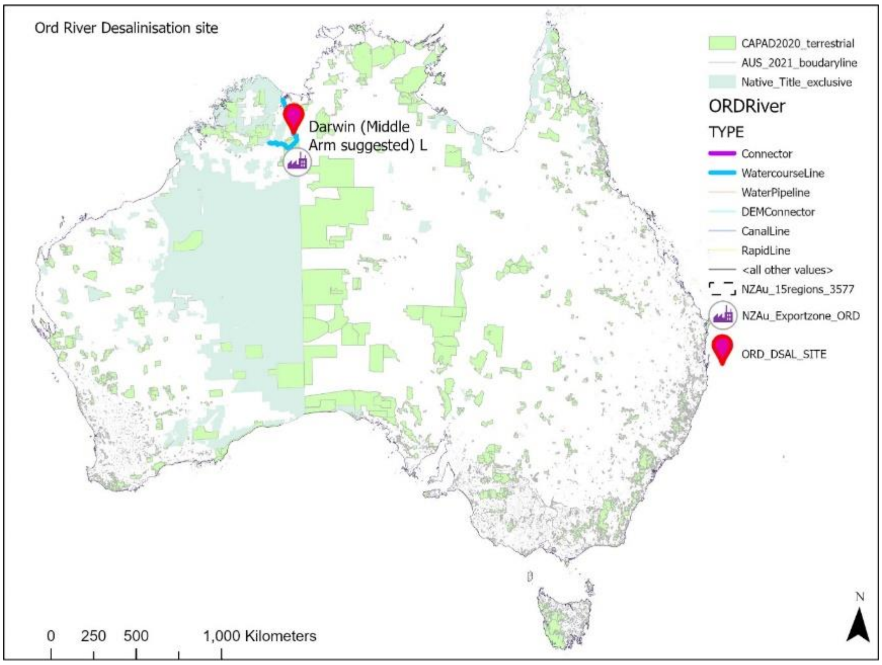


Figure E5 presents the Ord River desalinisation site. The site excludes the conservation area around the Ord River and is located within 5km of the Ord Riverbank.

Figure E5 | Ord River desalination site



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