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Prospective hydrogen production regions of Australia

A. Feitz, E. Tenthorey and R. Coghlan

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Contents

List of figures

Executive summary

There is significant interest in Australia, both federally and at the state level, to develop a hydrogen production industry. In August 2018, Australia's Chief Scientist, Dr Alan Finkel, prepared a briefing paper for the COAG Energy Council outlining a road map for hydrogen. It identifies hydrogen has the potential to be a significant source of export revenue for Australia in future years, assist with decarbonising Australia's economy and could establish Australia as a leader in low emission fuel production.

As part of ongoing investigations into the hydrogen production potential of Australia, Geoscience Australia has been engaged by the Department of Industry, Innovation and Science to develop maps that show areas with high potential for future hydrogen production. The study is technology agnostic, but considers only low carbon production processes. It includes hydrogen production via electrolysis using renewable energy sources (referred to as renewable hydrogen), as well as fossil fuel-derived hydrogen coupled with carbon capture and storage (CCS) (referred to as CCS hydrogen). The maps presented in this work are synthesized from the key individual national-scale datasets that are relevant for hydrogen production. In the case of hydrogen from electrolysis, renewable energy potential (from wind, solar and hydro resources) and the availability of water are the most important factors, while various infrastructure considerations also play a role. In the case of CCS hydrogen, proximity to gas and coal resources, water and availability of carbon storage sites are the important parameters that control the spatial distribution of potential hydrogen production.

In this report we present five different scenarios that reflect key differences in technologies for hydrogen production and the requirements of those technologies. Using geospatial analysis, each scenario is translated into a heat map that shows regional trends in potential for hydrogen production, based on access to underpinning resources and existing infrastructure.

Three scenarios explore the future potential for renewable hydrogen produced by electrolysis. These demonstrate a high potential for hydrogen production in the future near many Australian coastal areas, which is even larger if infrastructure is available to transport renewable power generated from inland areas to the coast. Results also show significant future potential for hydrogen production in inland areas where water is available. The final two scenarios focus on the future potential for CCS hydrogen: a 2030 scenario and a 2050 scenario. A key factor in future CCS hydrogen potential is related to the timeframes for the availability of geological storage resources for CO_2.

Table 1 gives a sense of the scale of the opportunity for future renewable hydrogen production, showing the mapped land comprising the top 20 percent of prospectivity ratings for the different renewable hydrogen scenarios in this report. While this provides a broad national perspective and so may not capture all of Australia's renewable energy opportunities, it shows there are large areas of Australia which may be suitable to develop renewable hydrogen production, where this is commercially viable.

Renewable hydrogen production requires access to land. In comparison, CCS hydrogen production occupies less space above ground as only a small amount of land is needed for production. CCS does have specific requirements for deep geological storage of CO_2 and storage sites can be onshore or offshore. Results from the CCS hydrogen scenarios indicate that there are large regions where future hydrogen production could potentially occur within the vicinity of suitable geological storage sites.

Table 1. Summary of renewable hydrogen mapping scenarios and land area associated with the top fifth of hydrogen prospectivity ratings.

Scenario number	Scenario Name	Land area of top fifth of hydrogen prospectivity ratings (km^2)
Scenario 1	Renewable resource potential, without infrastructure constraints	872 760
Scenario 2	Coastal production and constrained by existing infrastructure	261 755
Scenario 3	Coastal or inland generation, hydrogen transported via pipeline, and constrained by existing infrastructure	350 287

The report shows the importance of additional infrastructure and technology development to unlock Australia's hydrogen resource potential. Many areas may only become suitable if additional infrastructure investments can improve connection between the coast and inland areas that possess efficient renewable energy potential. The development of further geological storage sites and the CCS industry in general will be required to enable the rapid acceleration of CCS hydrogen production.

When reviewing this work, it is important to keep in mind that economic considerations around whether and when renewable and CCS hydrogen may become commercially viable have not been considered in this analysis. Cost factors will have a significant influence on the timeframes over which large-scale markets for Australian hydrogen production emerge.

Finally, mapping has been produced at a national scale which tends to camouflage some site specific factors. Further work is underway that will enable assessment at a finer scale which should be of particular benefit to investors and will allow identification of regions, such as heavy industrial zones, that will be suitable for hydrogen production based on access to infrastructure and end-demand.

Key report findings are listed below:

- Australia has vast physical resources that could support a large-scale hydrogen industry.
- Using a geospatial analysis approach, this report considers that there are extensive regions with the base elements and infrastructure to support both large-scale renewable hydrogen and CCS hydrogen.
- Most coastal areas have elevated potential for hydrogen production from electrolysis. The unlimited supply of desalinated seawater and the availability of electrical and port infrastructure make these favourable areas for hydrogen production.
- Australia has extensive fresh water resources which means inland hydrogen production from electrolysis is possible. However, water availability is not equally distributed across the country. This presents a challenge for inland production in some regions, particularly where relying on access to groundwater. It is possible that harvesting water from industrial water production or urban wastewater might be a "game changer" in such locations.
- Additional infrastructure and technology development is important to unlock Australia's hydrogen resource potential. For example, many areas may only become suitable if additional infrastructure investments can improve connection between the coast and inland areas that possess renewable energy potential.
- Australia has extensive fossil fuel resources that can be used with CCS to produce hydrogen with low carbon emissions. The potential increases significantly when additional CCS sites, which are expected to become available over time, are incorporated into the analysis.
- For inland CCS hydrogen, access to groundwater or competition for reservoir pore space may be a limiting factor. It is recommended to take a holistic view of hydrogen generation in these regions

and explore mutually beneficial arrangements for the oil and gas industry, agricultural water users, town water supplies and hydrogen generation.

- There are regions of Australia (marked in grey on the maps) which are of known environmental, cultural or historical significance or which otherwise have known competing uses. While these may not necessarily be a barrier to project development, close examination will be needed of the suitability of land for projects proposed in these regions.
- Further pre-competitive characterisation work is required to determine the geological potential for transient hydrogen storage and permanent geological storage for CO_2 in Australia. Studies since the 2009 National Carbon Taskforce mapping exercise have generally found less CO_2 storage potential than indicated in the earlier high level basin wide studies. There still, however, remains large unexplored onshore regions of Australia, which may contain good storage for hydrogen and CO_2 (e.g. the Canning Basin in WA). The discovery of good localised CO_2 storage potential in the deep troughs of the Darling Basin in NSW (previously rated marginal in the National Carbon Taskforce) gives cause for optimism that additional geological storage resources are present.
- The methodology employed in this study can be readily implemented for delivery through a dynamic tool. This would allow efficient updates to the hydrogen production prospectivity maps, but also interactive interrogation by stakeholders to support a range of applications and use cases. This could be extended further by incorporating a cost function to enable a comprehensive economic analysis that quantifies viability of particular locations based on the development and transport costs.
- There are a number of national scale datasets that currently do not exist but would benefit future studies:
  - A national scale land value dataset – requires integration of data from state and territory Valuer General Offices. This data would enable optimisation of the location of large-scale renewable installations with existing or planned supporting infrastructure (e.g. electricity networks and sub-stations).
  - A national scale groundwater use and quality dataset – groundwater management units are not necessarily tied to the most productive and utilised aquifers and can extend over vast areas with little groundwater productivity.
  - It would be also useful to develop a national dataset that quantifies volumes of groundwater extracted from mining and petroleum activities that are not necessarily covered by the Water Act (i.e. those covered by state mining and petroleum acts).
  - Development of a national scale hydropower potential development data layer.
  - Development of an improved national scale wind energy prospectivity layer.

1 Introduction

Hydrogen has been identified as a clean fuel source for the future in Australia and internationally. Unlike hydrocarbon based fuels, the only output of hydrogen combustion is water vapour and there are no CO_2 emissions associated with its use. Countries that are highly dependent on imported fossil fuels, such as Japan and South Korea, are developing roadmaps to transition to hydrogen intensive economies in the coming decades.

It is envisaged that Australia can play an important role in this transition by potentially developing a hydrogen export industry and supporting domestic hydrogen use in the future. There have been several important roadmap documents discussing a “hydrogen future” for Australia in recent years, including the briefing paper to the COAG Energy Council, chaired by Australia’s Chief Scientist, Alan Finkel (Commonwealth of Australia, 2018) and CSIRO’s National Hydrogen Roadmap (Bruce et al, 2018). Following this work, in December 2018 the COAG Energy Council committed to develop a National Hydrogen Strategy (the Strategy) by December 2019. This work has been commissioned to inform the Strategy. Some states have also developed strategy papers or documentation designed to advance the hydrogen industry in the individual states (Government of South Australia, 2017; Government of Queensland, 2019).

The purpose of this study is to develop a geospatial understanding of regions within Australia with high potential for future hydrogen production. This work is being conducted in consultation with the states and territories, in order to ensure that all important information and considerations are taken into account. It is unlikely that hydrogen production and use will be ‘one size fits all’ across Australia and future planning at the state/territory level is likely to have a strong influence on hydrogen growth potential. Therefore, the project team engaged with state/territory representatives familiar with their local hydrogen landscape. As a result of this engagement, the project has drawn on this input, which was incorporated into the project design and methodology.

The main deliverable associated with this study are heat maps that show the national potential for ‘clean’ hydrogen production in Australia, based on geospatial analysis of the key parameters for hydrogen production, transport and export. For the purposes of this study, ‘clean’ is hydrogen production with low carbon emissions and considers production via electrolysis using renewable energy sources (referred to as renewable hydrogen), as well as fossil fuel-derived hydrogen coupled with carbon capture and storage (CCS) (referred to as CCS hydrogen).

A number of different components come into play depending on how and where the hydrogen is produced. For example, regional potential for hydrogen produced from renewable resources will look very different from that for hydrogen produced using fossil fuels with CCS. Furthermore, the production potential will differ greatly depending on technology used and its requirements for nearby infrastructure, hydropower firming or electric grid connectivity. All options and assumptions considered in this study result in complex spatial variability, which would be nearly impossible to represent meaningfully as a single map.

In this report we present five scenarios that cover two broad methods for hydrogen production. The first scenario maps wind, solar and hydropower resource potential, without infrastructure constraints. This map strictly shows the areas of renewable energy resource, and does not take into account any infrastructure considerations required for future hydrogen production. It highlights regions where the highest potential wind and solar coexist or where renewable resources could be firmed by hydropower. The next two scenarios consider renewable power and hydrogen production via electrolysis of water, using renewable energy as the energy source. The final two scenarios map hydrogen produced from fossil fuel sources, coupled with CCS to ensure hydrogen production has low carbon emissions. The CCS hydrogen approach integrates both hydrogen from coal gasification and steam methane reforming (see Box 1).

Box 1. Methods for Hydrogen Production

There are three primary methods that are expected to be used to produce hydrogen with low carbon emissions over the timeframes considered for the National Hydrogen Strategy:

1. Electrolysis of water using renewable energy sources
   - The electrolysis option involves using renewable energy to split water, producing O_2 and H_2 gas (hereafter referred to as 'hydrogen'). The hydrogen is collected and likely compressed and stored or transported from site. The reaction occurs in an electrolyser, possessing and anode and cathode, separated by an electrolyte. When an electrical potential is applied between the anode and cathode, oxygen and hydrogen form at each electrode, respectively. Currently most electrolysis uses alkaline electrolysers, as they are the most mature and lower cost option. However, it is envisaged that PEM electrolysers will become competitive with alkaline technologies in the near future.
2. Coal gasification coupled with carbon capture and storage (CCS)
   - Coal gasification produces hydrogen by reacting pulverised coal with steam at high temperatures. The first stage of the reaction process produces carbon monoxide and hydrogen. After the impurities are removed, the carbon monoxide is further reacted with steam to produce further hydrogen and CO_2. There are future plans to use Victoria's brown coal deposits to generate hydrogen coupled with CCS.
3. Steam methane reforming with CCS
   - In this process, methane (CH_4) is reacted with steam at high temperatures (700-1000°C), producing hydrogen, carbon monoxide and a small amount of CO_2. In a subsequent reaction called the water-gas shift, carbon monoxide and steam are further reacted in the presence of a catalyst to produce more hydrogen and CO_2. Both the Quest (Canada) and Port Arthur (USA) projects couple hydrogen production from steam methane reforming with CCS.

There are a number of other methods in the development stage or being considered for application to hydrogen production. Other methods include biomass gasification, biomass fermentation and renewable liquid fuels, which can be used to produce hydrogen near the point of use (USDOE, 2019). Techniques in the development stage are high-temperature water splitting, and photobiological or photoelectrochemical water splitting. While these techniques may turn out to be important in the future, none of these techniques are considered for the heat maps presented in this study.

For each production method, the analysis assesses the presence or absence of the physical resources required (e.g. land, water, coal or gas, suitable geological storage reservoirs) and reflects proximity to key infrastructure. The analysis models potential for large scale centralised production facilities, which require substantial additional resources, and does not reflect potential for small-scale production.

The analyses and heat maps presented in this report are indicative of relative hydrogen production potential on a regional scale, and should not be interpreted as an accurate reflection of the potential at individual locations. The analysis does not consider any costs associated with hydrogen production. Analysis is based on proximity to existing infrastructure and does not reflect any planned changes to this infrastructure over time.

Chapter 2 in this report discusses the scenarios and how they are modelled in the analysis, and shows the results in the form of heat maps. Chapter 3 discusses the key inputs into hydrogen production and provides additional contextual information regarding these inputs. Chapter 4 further highlights the most prospective regions in Australia for future renewable and CCS hydrogen. Chapter 5 provides key findings from the work. Detailed datasets are provided in the Appendix.

2 Hydrogen production scenarios

This report uses five different scenarios to identify areas with high potential for large scale hydrogen production in Australia. An underpinning assumption is that the hydrogen production has low carbon emissions, i.e. either based on renewable energy or involving CCS if based on fossil fuel sources. There are regions of Australia (marked in grey on the maps) which are of known environmental, cultural or historical significance or which otherwise have known competing uses. They include residential areas and government, indigenous and privately protected areas of Australia. Close examination will be needed of the suitability of land for projects proposed in these regions to see if these factors are a barrier to project development.

Three renewables-based scenarios for future hydrogen production are considered:

- Scenario 1: *Renewable wind, solar and hydropower resource potential, without infrastructure constraints* assumes that hydrogen is produced in the future by electrolysis at the coast (i.e. not constrained by water availability) using renewable energy from anywhere in the country. Hydropower is considered to add a firming capacity to electricity production from solar and wind. This scenario ignores the importance of well-developed electrical connectivity, and reflects Australia's renewable resource potential.
- Scenario 2: *Coastal production and constrained by existing infrastructure* requires that renewable power sources for future hydrogen production are located close to a connected grid, which can power hydrogen production at the coast. Water availability is not considered a constraint provided hydrogen production is in proximity to the coast.
- Scenario 3: *Coastal or inland generation, hydrogen transported via pipeline, and constrained by existing infrastructure* assumes that future hydrogen production can occur inland (as well as on the coast). Hydrogen produced inland transported via pipeline to the coast for export, and has dependencies on current infrastructure, such as gas pipeline easements. Inland water availability is an important consideration in this scenario.

In addition to the above renewable based scenarios, two scenarios map the potential for hydrogen produced from fossil fuel sources to be coupled with CCS to ensure the hydrogen has low carbon emissions. This integrates both hydrogen from coal gasification and steam methane reforming methods (see Box 1). The difference between the two CCS hydrogen production scenarios reflects the maturity of available carbon storage sites, in a '2030' and a '2050' hydrogen potential analysis.

- Scenarios 4 and 5 (named *Advanced development* and *Greenfields areas*, respectively): The two scenarios are the same except for the availability of storage space for CO_2. Scenario 5 is a longer term 2050 scenario in which more storage space is available for use.

Each section briefly discusses the scenario. A flow diagram depicts how elements of the model were incorporated into the analysis. The heat map shows the results for the analysis.

2.1 Scenario 1: Renewable wind, solar and hydropower resource potential, without infrastructure constraints

Hydrogen production from electrolysis requires significant energy and water as primary resources. In this scenario, renewable electricity is generated at optimum wind and solar locations and exported to coastal locations where it is processed into renewable hydrogen. Offshore wind potential and capacity for hydropower firming is also included. Coastal locations can be assumed to have unlimited water availability through desalination whereas inland water availability is more constrained as described in Section 3.1. Existing infrastructure is displayed but not included in the analysis. Exclusion areas include protected areas (e.g. national parks or indigenous protected areas), residential areas and inland water bodies. Land cost is not considered.

Figure 1 shows that large portions of inland Australia are prospective sites to generate renewable energy, but would need connection to the electrical grid to support hydrogen production in regions with access to suitable water supplies. The most suitable areas are central and western regions which generally have high solar potential in combination with high wind potential. There are also regions to the south and south east of Australia, particularly along the coast lines, with strong wind potential and also with proximity to hydropower resources. Nearby hydropower can substantially increase the renewable energy resource potential. The CSIRO's National Hydrogen Roadmap indicates "Tasmania is a somewhat unique locality as it offers the potential to combine a high grade wind resource with hydro-electric generation which would lead to a high capacity factor." Tasmania's existing hydro capacity could already provide these high capacity factor benefits as the existing system is not capacity constrained. Augmentation of Tasmania's hydro capacity, and the addition of pumped storage capacity, as outlined in Hydro Tasmania's Battery of the Nation initiative (Hydro Tasmania, 2018), could enhance these benefits.

2.1.1 Map

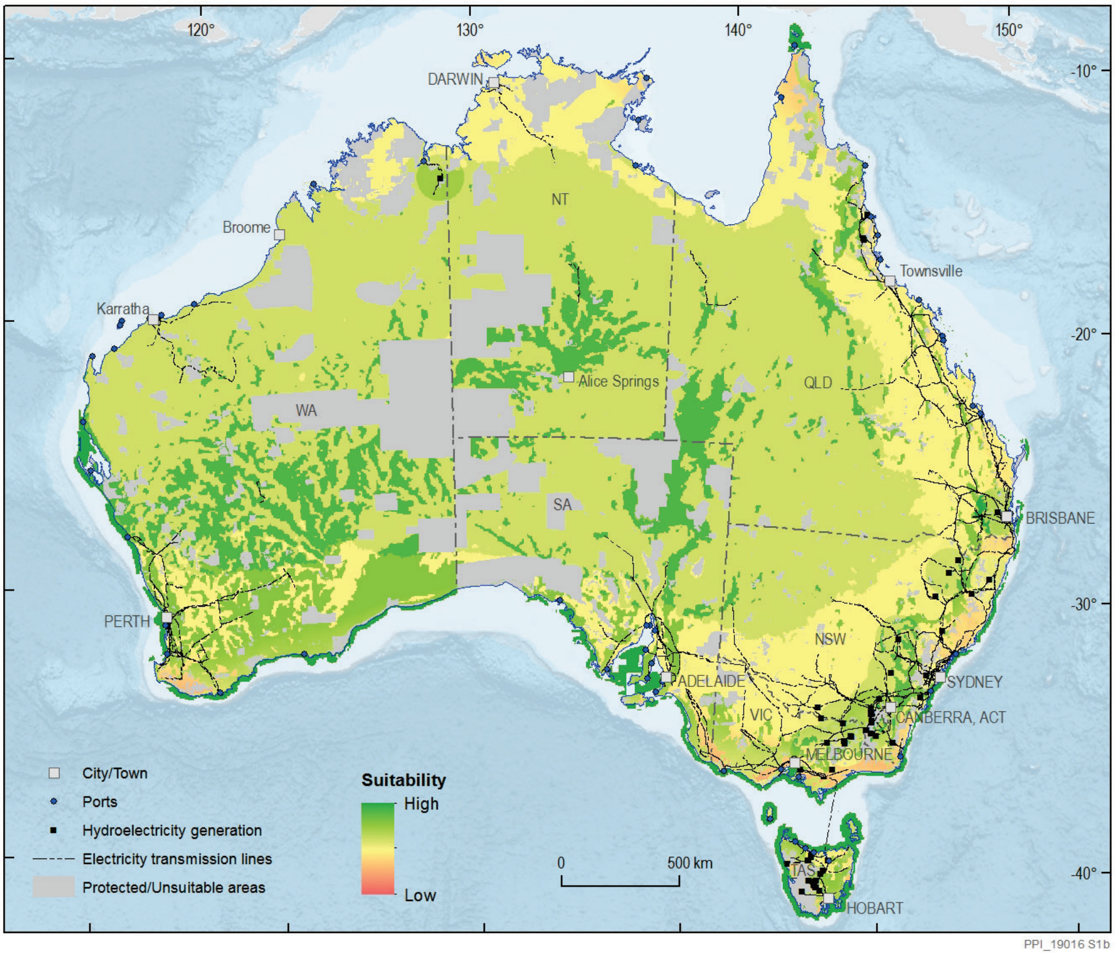
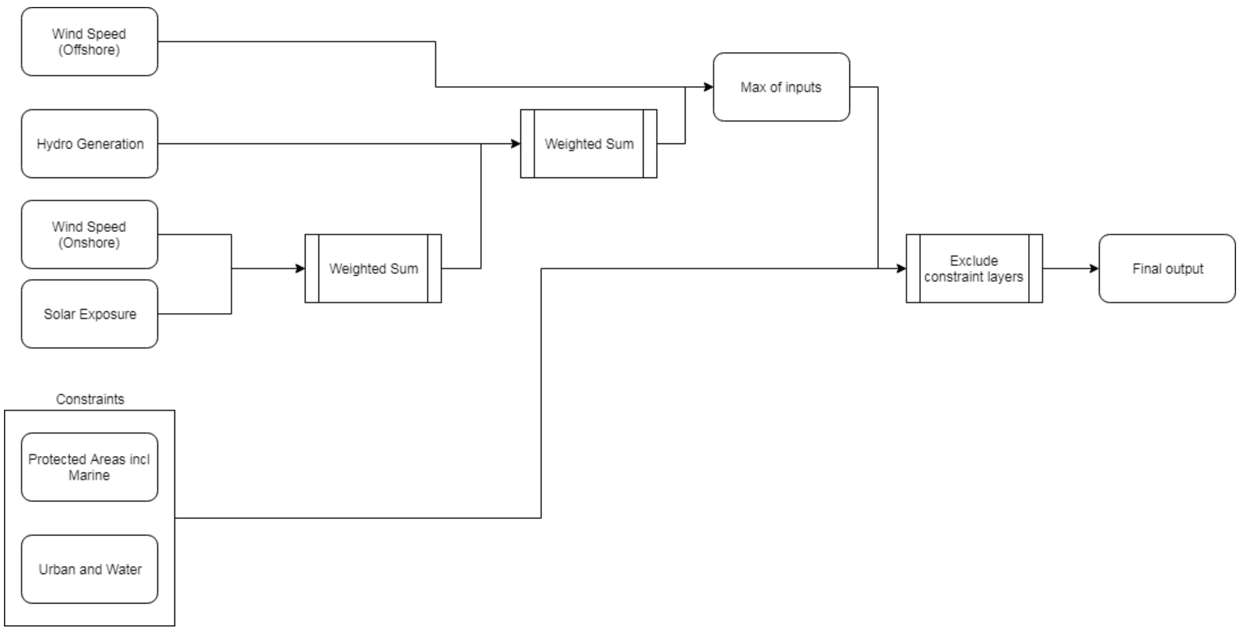


Figure 1. Scenario 1: Renewable wind, solar and hydropower resource potential, without infrastructure constraints. Darkest areas of green for inland Australia show where highest potential wind and solar coexist or where renewable resources could be firmed by hydropower. This map strictly shows the best areas for ramping up renewable energy generation, and does not take into account any infrastructure considerations that will be critical for future hydrogen production.

2.1.2 Spatial analysis workflow



Layers displayed but not included in workflow

- Existing electricity network
- Existing ports
- Existing population centres

2.2 Scenario 2: Renewable hydrogen – Coastal production and constrained by existing infrastructure

In this scenario, future renewable hydrogen production builds on existing infrastructure. The model reflects that hydrogen potential benefits from proximity to existing ports, electricity networks and existing industrial estates. As in Scenario 1, the model assumes unlimited water availability through desalination as inland water availability is more constrained (described in Section 3.1). Land cost is not considered. When constraining additional renewable energy capacity to existing infrastructure, this limits hydrogen production prospectivity largely to proximity to electricity networks along the coastal zone. Figure 2 shows likely zones of coastal hydrogen production based on proximity to existing infrastructure. The map illustrates that some of the good co-located wind and solar resources in Scenario 1 are isolated from good hydrogen prospectivity without additional infrastructure, e.g. southern WA, central NT, northern SA and western Queensland.

2.2.1 Map

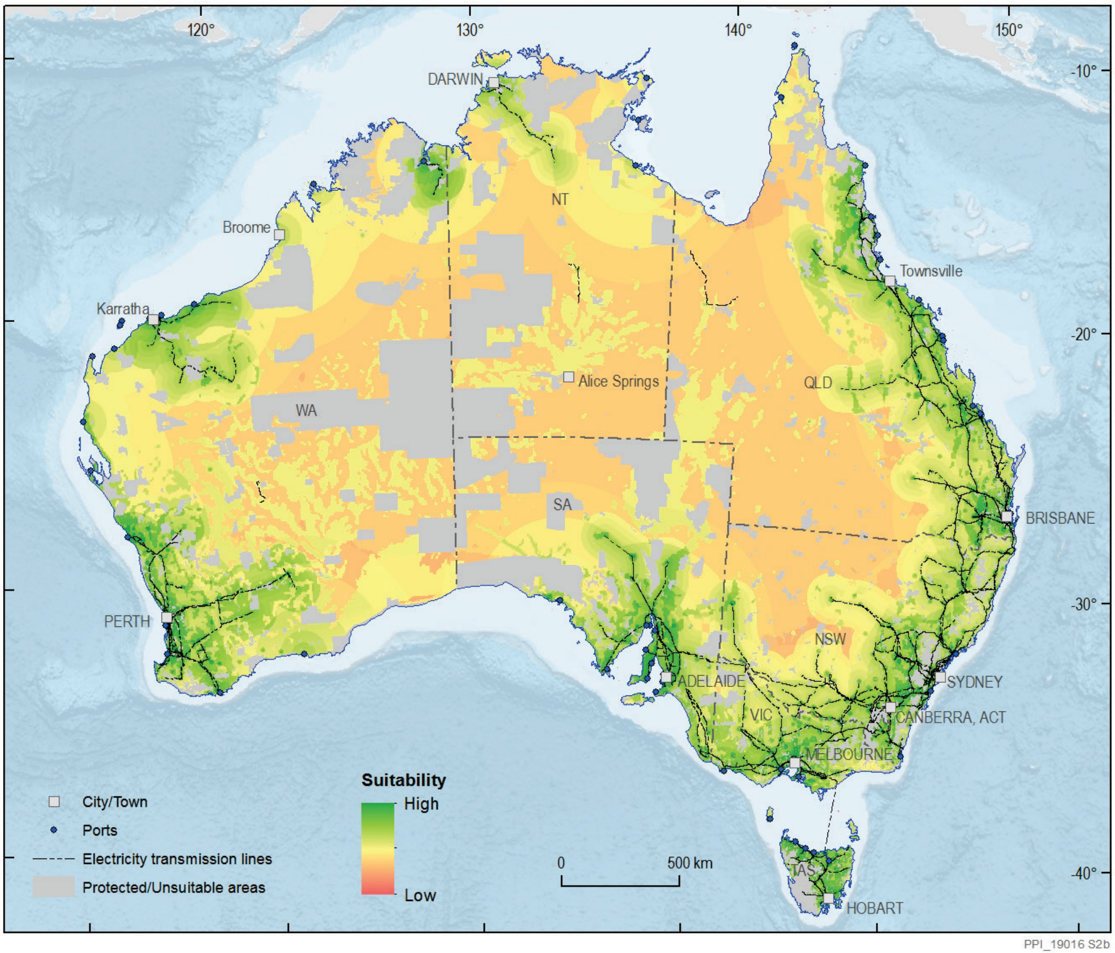
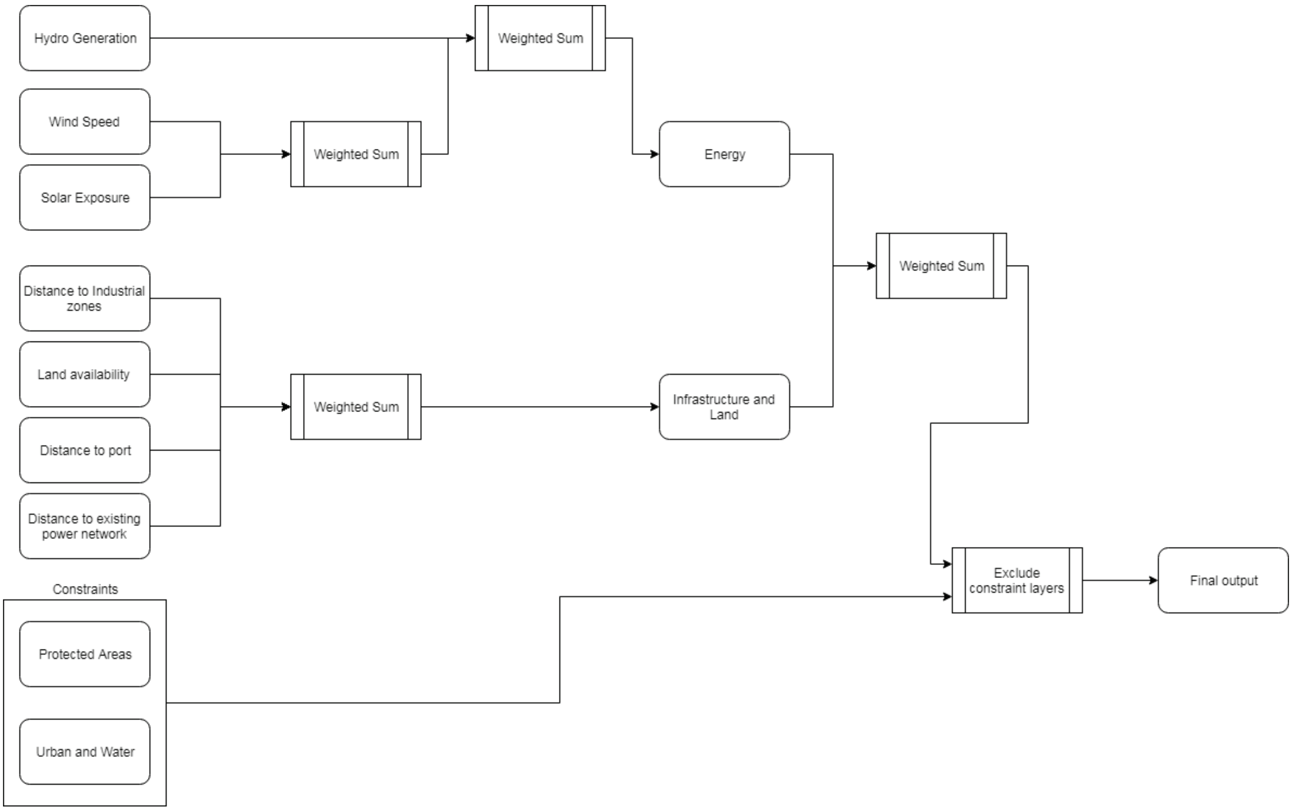


Figure 2. National hydrogen prospectivity heat map based on Scenario 2: Renewable hydrogen – Future coastal production and constrained by existing infrastructure. This map identifies high potential areas for hydrogen production by assessing the availability of renewable power which can be transported through the existing electrical grid for use in coastal areas. This scenario assumes that most future hydrogen production will use desalinated seawater.

2.2.2 Spatial analysis workflow



Layers displayed but not included in workflow

- Existing population centres

2.3 Scenario 3: Renewable hydrogen – Coastal or inland generation, hydrogen transported via pipeline, and constrained by existing infrastructure

In this scenario, the model of future renewable hydrogen production is quite different to the preceding ones. The model considers the potential for renewable hydrogen production across the country using inland and coastal water supplies. Proximity to the coast for seawater desalination or access to available groundwater and surface water storage is critical. Proximity to existing ports, existing gas pipeline easements and electricity power networks is also considered. Figure 3 shows how inland production potential is dependent on high productivity groundwater resources and favoured near existing pipelines and electricity networks, especially in Queensland and the Northern Territory. Most coastal areas continue to have high production potential.

2.3.1 Map

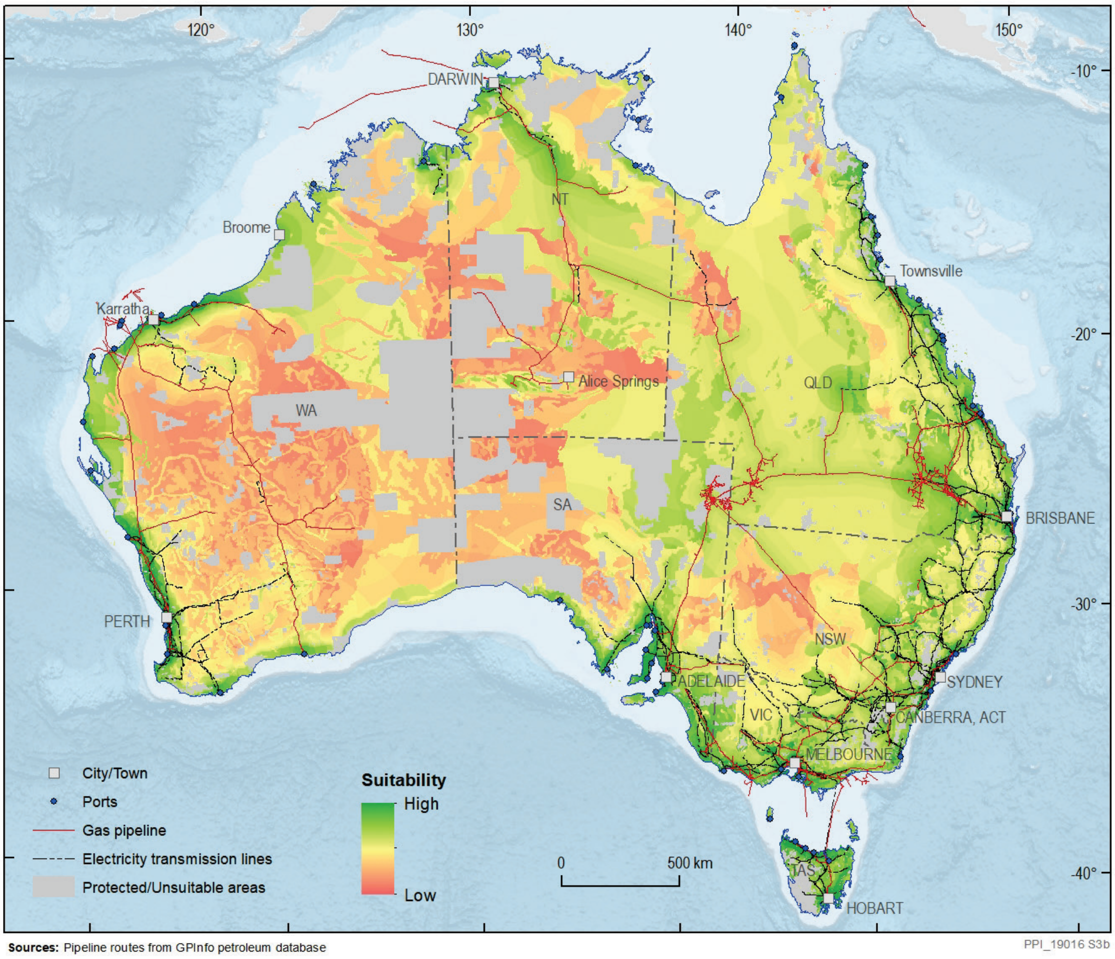
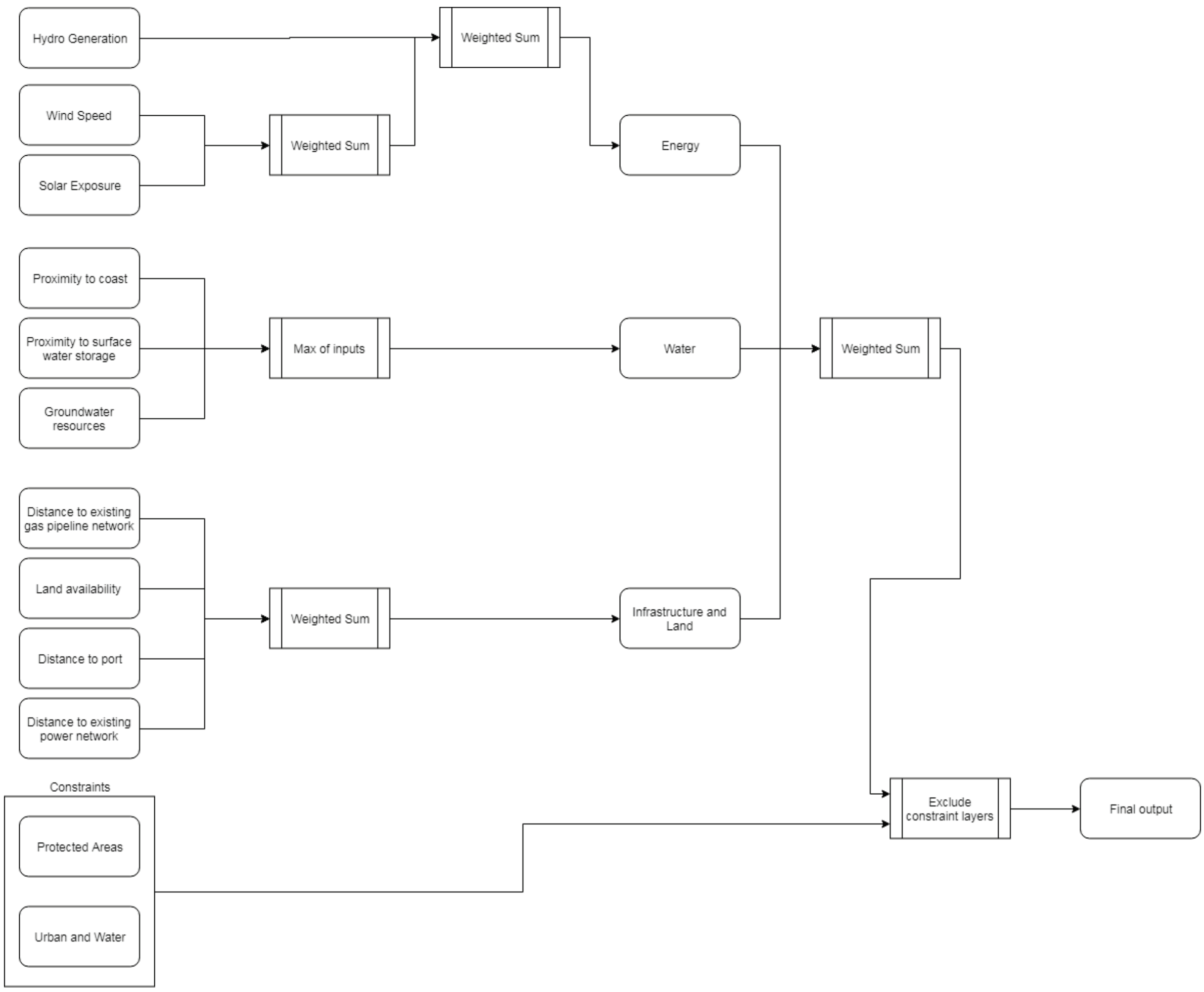


Figure 3. National Hydrogen prospectivity heat map based on Scenario 3: Renewable hydrogen – Coastal or inland production, hydrogen transported via pipeline, and constrained by existing infrastructure.

2.3.2 Spatial analysis workflow



Layers displayed but not included in workflow

- Existing population centres

2.4 Scenario 4: CCS hydrogen –Advanced development

In this scenario, hydrogen is produced in the future through steam methane reforming or coal gasification processes. This scenario reflects that production needs to occur near natural gas or coal sources and also be within an economically viable distance to a subsurface storage site for the CO_2 (produced as a by-product of hydrogen generation). Availability of water, whether it is seawater, surface water or groundwater, is considered essential for production. Figure 4 identifies areas that are at a relatively advanced stage in terms of hydrocarbon production, with suitable CCS sites that have been identified and that could realistically be brought on line in the next decade. Existing pipeline infrastructure is displayed and is also included in the analysis (i.e. easements), as these are likely to be important for any future hydrogen development. The map shows high potential in southern Victoria due to proximity to the offshore Gippsland Basin and high potential in WA due to proximity to the offshore Carnarvon Basin. Onshore storage is limited to regions near the Cooper Basin (QLD/SA) and Surat Basin (QLD) and access to gas pipeline easements.

2.4.1 Map

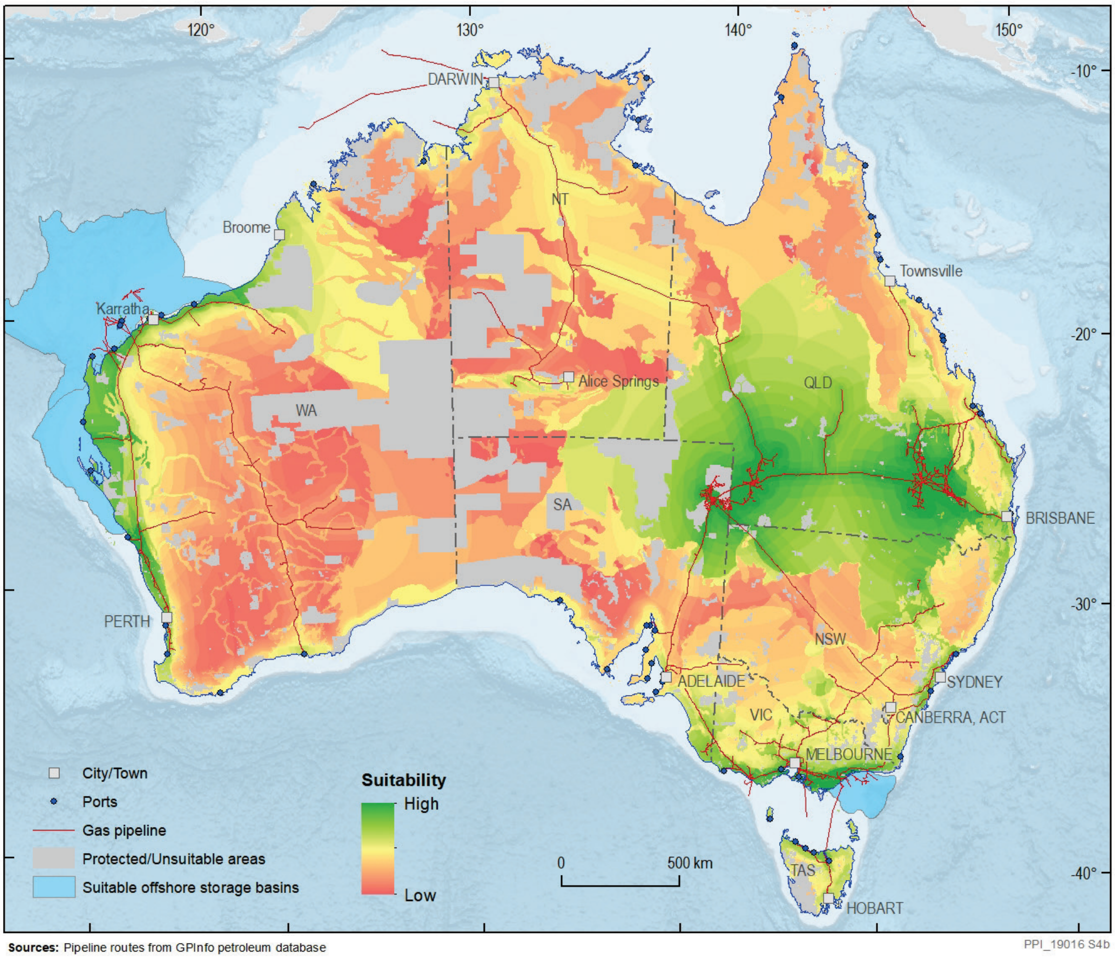
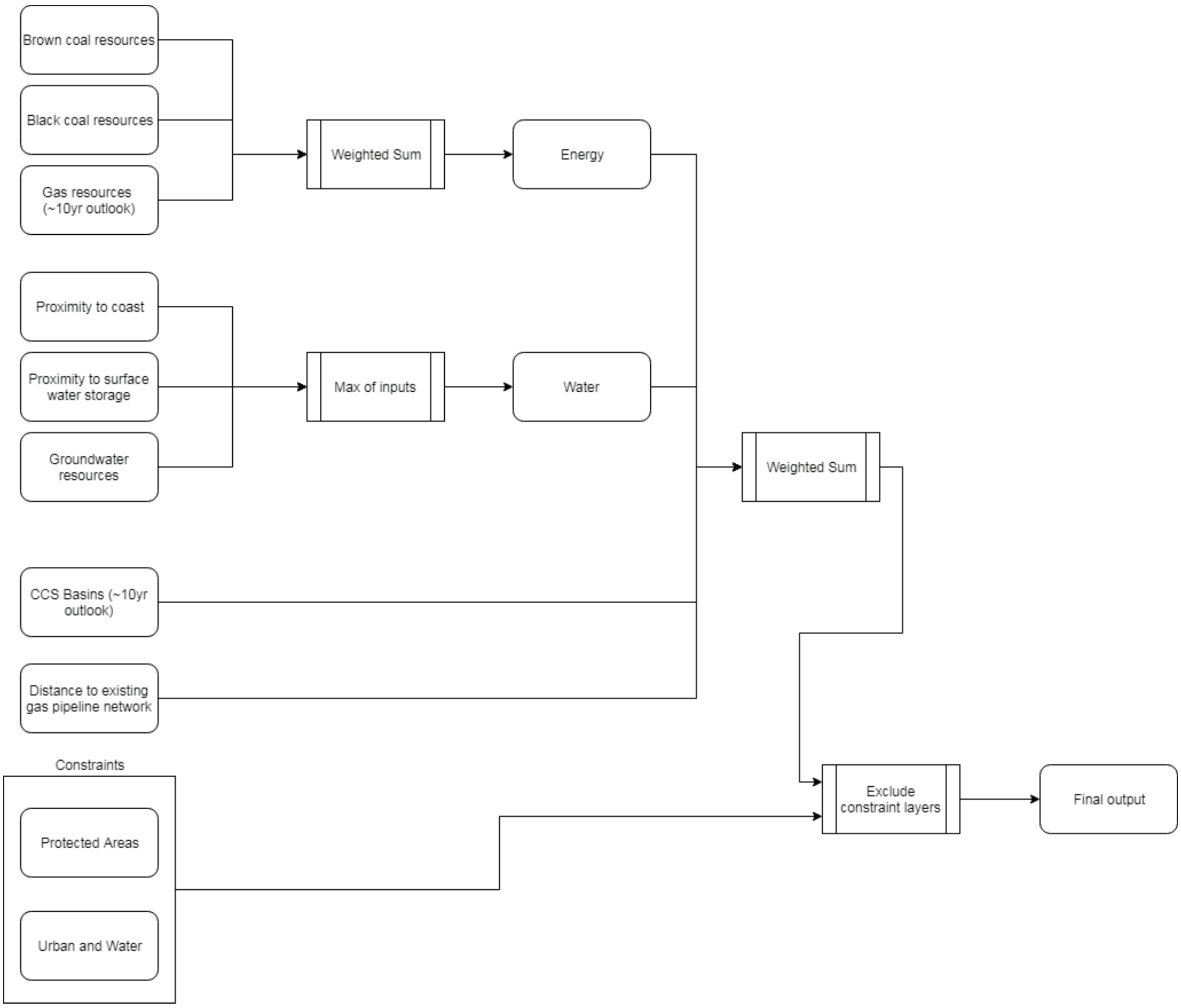


Figure 4. National Hydrogen prospectivity heat map based on Scenario 4: CCS hydrogen – Advanced development. This map represents sites for CCS hydrogen production that can potentially proceed in the nearer term. Note the lateral extent of the most suitable reservoirs for CO_2 storage within the Carnarvon Basin in WA is uncertain.

2.4.2 Spatial analysis workflow



Layers displayed but not included in workflow

- Existing ports
- Existing population centres

2.5 Scenario 5: CCS hydrogen –Greenfield areas

In this scenario, there are an increased number of sites suitable for CCS storage for future hydrogen production. This scenario reflects that Australia has significant potential for CO_2 geological storage, but requires time to develop that industry, including the infrastructure to support it. Hydrogen is produced through steam reforming or coal gasification processes. The modelling in this scenario assumes that hydrogen production occurs near natural gas or coal sources, and also within an economically viable distance to a subsurface storage site for the CO_2 that is produced as a by-product of hydrogen generation. Availability of water, whether it be seawater, inland water, or wastewater from mining operations are considered essential for production. This map does not constrain potential to developed gas, coal and CCS prospects, as is the case in Scenario 4. Instead, the Carbon Storage Taskforce (2009) basin ranking is used to identify potential site for CO_2 disposal for offshore areas and state geological storage assessments for onshore areas. Existing pipeline infrastructure is displayed but is not included in the analysis, as required supporting infrastructure is likely developed within the timeframe relevant for this scenario.

2.5.1 Map

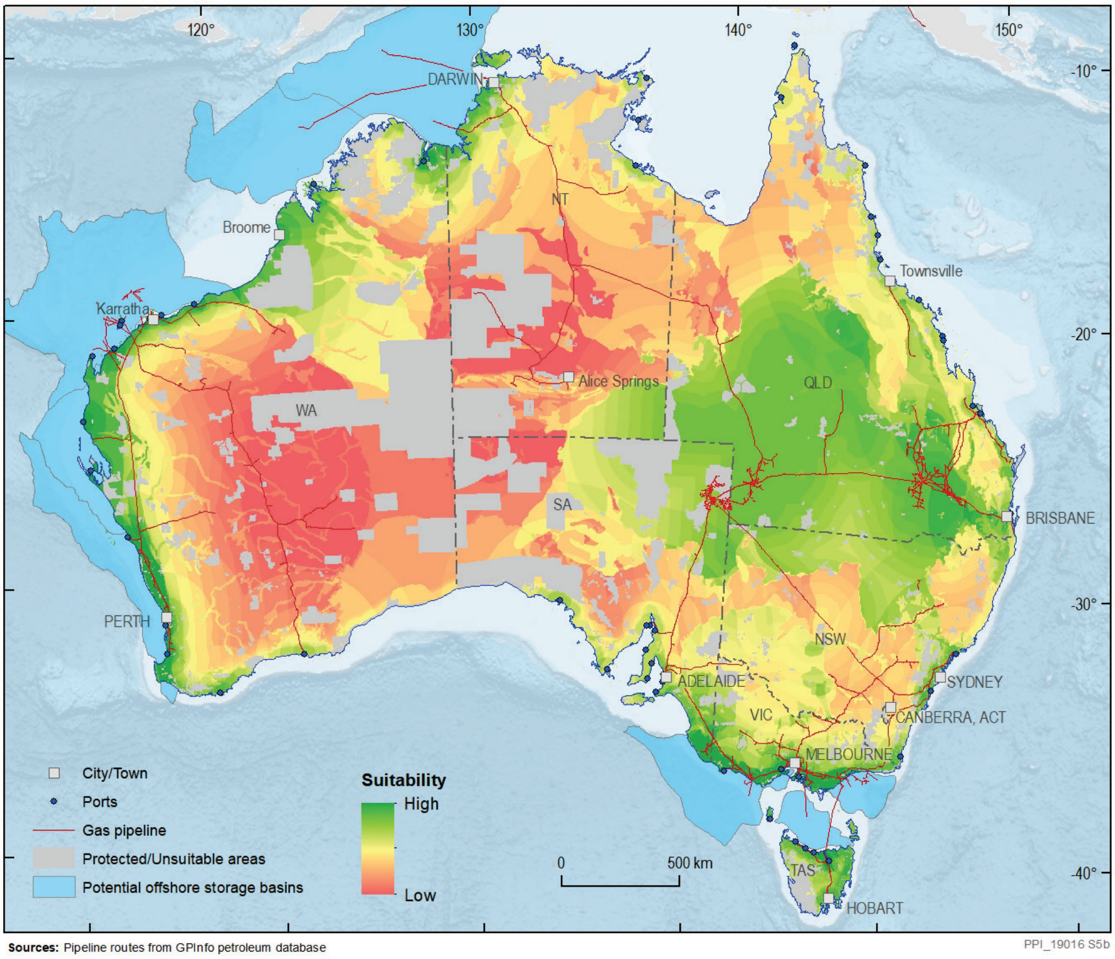
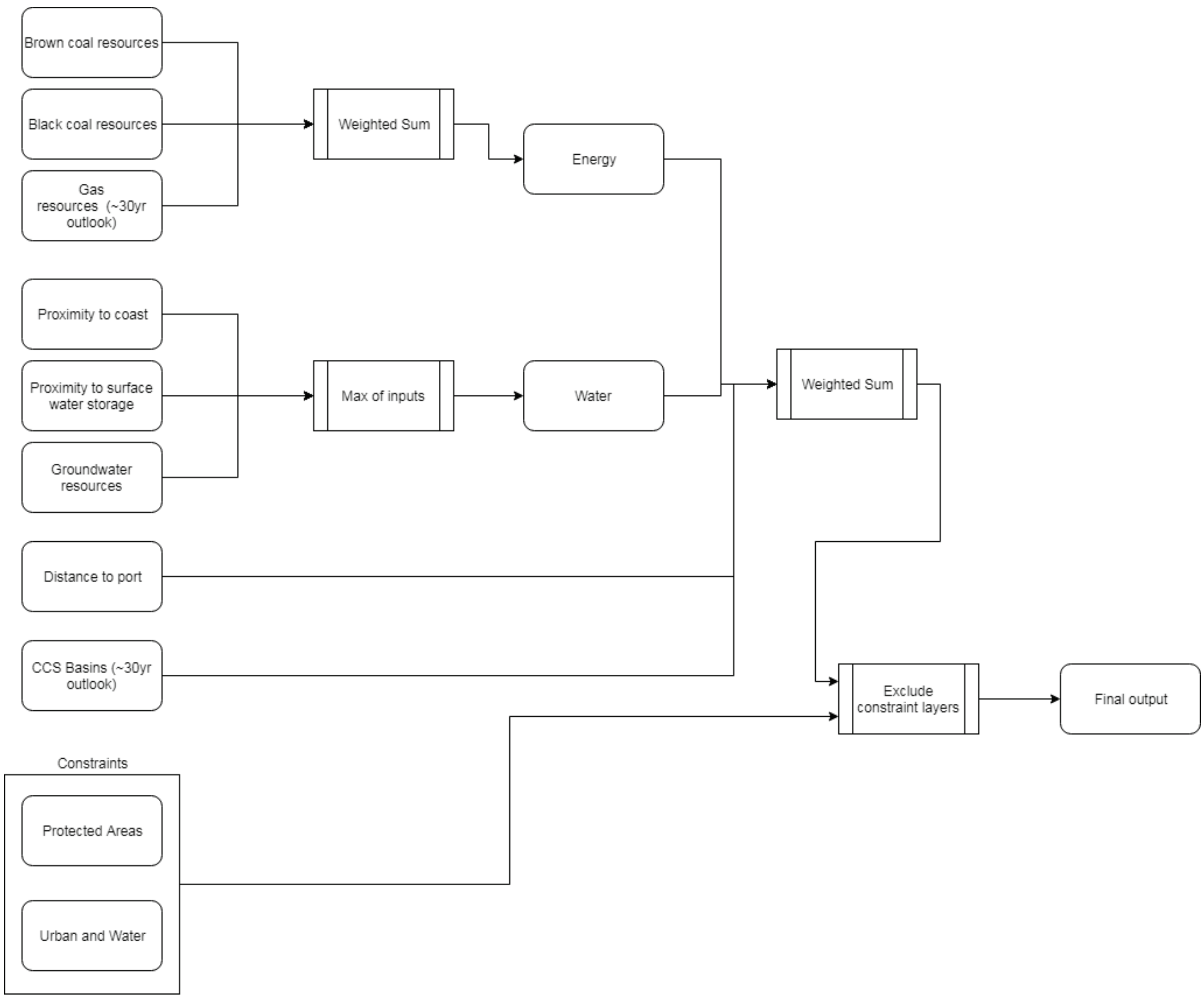


Figure 5. National Hydrogen prospectivity heat map based on Scenario 5: CCS hydrogen – Greenfield areas. This map expands the possible CCS sites that can be co-located with CCS hydrogen production, thereby expanding the suitable areas for production.

2.5.2 Spatial analysis workflow



Layers displayed but not included in workflow

- Existing pipeline infrastructure
- Existing population centres

3 Primary resource inputs

3.1 Water

3.1.1 National water resource and use

Water is an essential input for hydrogen production, with water use figures ranging from 2.9 to over 300 litres per kilogram of hydrogen depending on the hydrogen production method employed (Mehmeti et al., 2018). A typical water consumption figure for hydrogen production using alkaline electrolysis is 9 litres per kilogram of hydrogen.

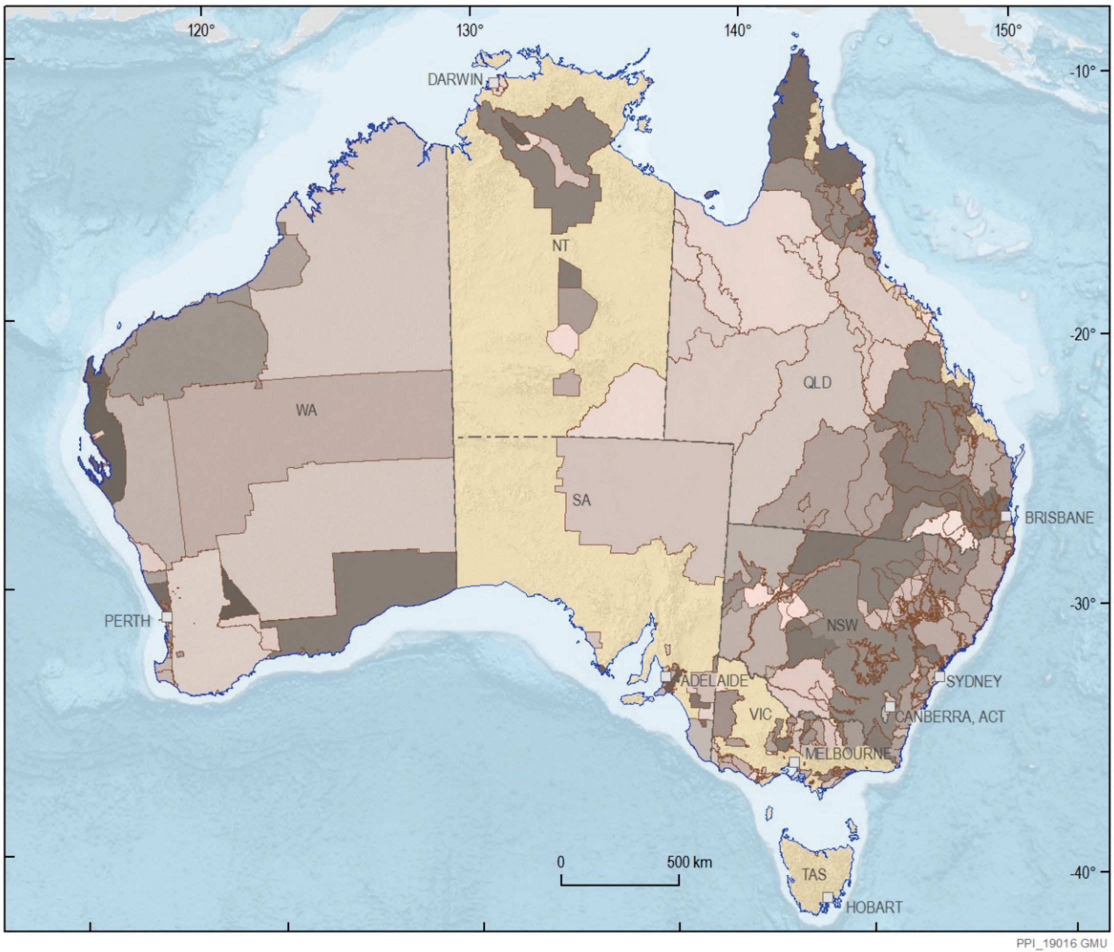


Figure 6. Groundwater management units (GMUs) across Australia. The buff colour indicates the absence of GMUs. Shading is for illustration purposes only and highlights different or overlapping GMUs.

Australia has extensive surface water and groundwater resources, but the distribution across Australia is uneven, making some parts of the country more prospective for supporting hydrogen production than others. This is particularly important for supporting inland-produced CCS hydrogen, which requires co-location of water, coal or gas in proximity of a suitable geological storage site. For renewable hydrogen, electricity can be generated inland and exported to the coast for production and use surface water, recycled water, groundwater or desalinated seawater if necessary.

Nationally, Australia has over 80 000 GL of surface water storage capacity (46.7% full as of 8/7/19; BOM, 2019a) with current groundwater entitlements of 8659 GL per year (BOM, 2019b). The amount of groundwater extracted in 2017 was 5251 GL (BOM, 2019b). This volume of extracted groundwater is limited to data collected from groundwater management units (Figure 6) and does not include domestic and stock volumes or groundwater produced from mining for some states. Australia's total consumptive use of water in 2016-17 was 16 558 GL of which households consumed 1909 GL, agriculture 1679 GL and mining consumed 693 GL (Australian Bureau of Statistics, 2019). The Hydrogen Strategy Group has estimated that replacing the equivalent of Australia's 2019 total LNG exports with hydrogen using renewable hydrogen alone would require 279 GL of water per year, which is less than half of what the total Australian mining industry currently consumes.

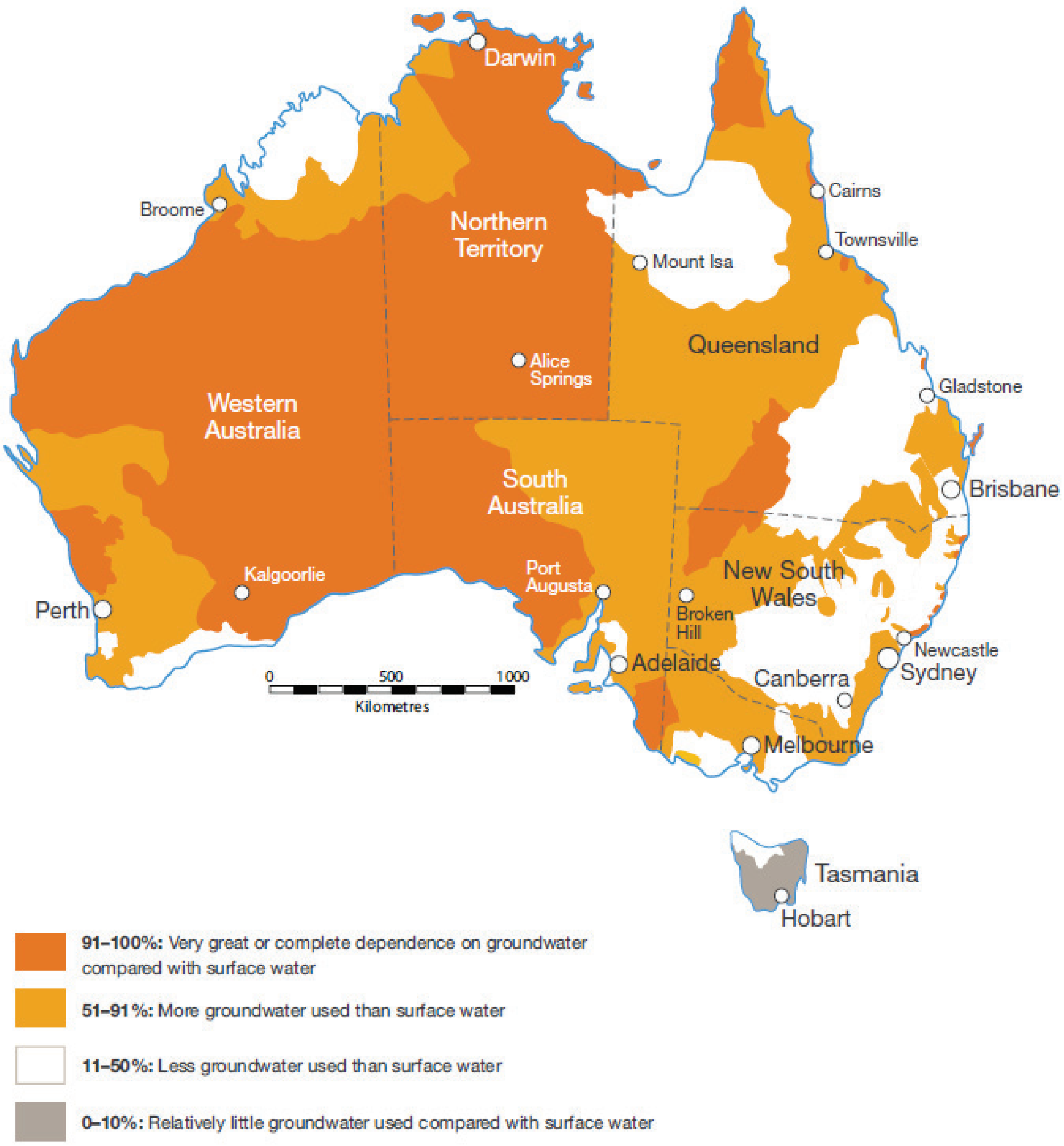


Figure 7. Groundwater use in Australia as a percentage of total water consumption (Harrington and Cook, 2014).

Groundwater use in Australia as a percentage of total water use is illustrated in Figure 7 (Harrington and Cook, 2014). Large regions of WA, SA and the NT have almost complete dependency on groundwater (91-100%) with the water used as a drinking water supply for rural communities and used to support irrigation, industry and mining. Groundwater offers significant water security when surface water is not available and underpins various types of agricultural, mining and industrial production throughout Australia.

In this report we have assumed that there is an unlimited supply of water (through desalination) if a hydrogen production facility is located proximal to the coastline. Hydrogen production from water splitting (i.e. the renewable hydrogen scenarios considered in this document) is an energy intensive process but it is estimated that seawater desalination would only contribute 2% to the overall cost of hydrogen production (Bruce et al., 2018). One promising emerging technique is hydrogen production directly from seawater without the need for desalination (Rau et al., 2018). Such an approach may reduce the overall energy consumption of the hydrogen production process.

3.1.2 Surface water storage

Figure 8 provides an overview of urban and rural surface water storage locations, storage capacity and current percentage storage across Australia as of 8/7/19. Immediately apparent is the large difference in surface water storage for Tasmania and the east coast of Australia compared to the rest of the country. Besides the east coast facilities and the Ord River Reservoir in northern WA, there are no large surface water storage facilities across the remainder of the Australian mainland due to varying aridity across the country but also less development and infrastructure in Northern Australia.

The impact of the current drought in NSW can be observed with the majority of water storage percentages less than 20% in north-western NSW. Also included in the figure are the outlines of prospective storage geological reservoirs, the Toolachee formation in the Cooper Basin and the deeper portion of the Precipice Sandstone in the Surat Basin. It is clear that any hydrogen production associated with these basins will most likely require groundwater as the primary water source.

On the national scale maps presented in this document it is not possible to differentiate urban water recycling activities from surface water storage. However, it is useful to consider that much of the annual surface water taken from urban storage reservoirs is transformed into domestic wastewater and is either recycled, irrigated or ultimately discharged to rivers or the ocean. The amount of water consumed by large cites greatly exceeds many industries. Sydney for example, produces approximately 593 GL/yr of drinking water and collects approximately 463 GL/yr of wastewater (treated to varying standards) (Sydney Water, 2018). Less than 10% of the collected wastewater is recycled. Increased harvesting of water from wastewater for hydrogen production could be an option for urban centres where there is often an excess of treated wastewater due to restrictions with disposal (e.g. depending on the receiving body, there may be no or limited river disposal options due to elevated nutrient levels in the treated wastewater).

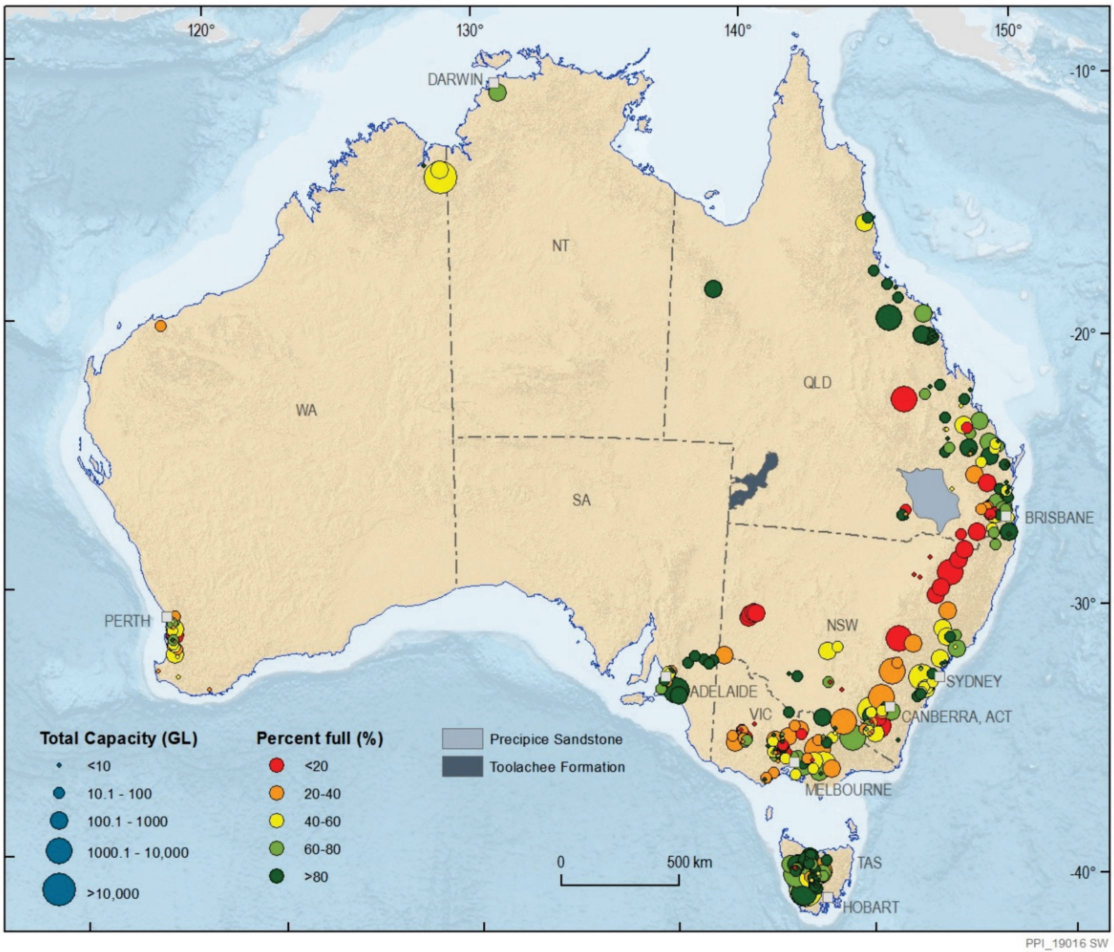


Figure 8. Australian surface water storage (as of 9/7/19) and outlines of onshore CO_2 geological storage reservoirs prospective for near term use.

3.1.3 Groundwater

Groundwater is present across virtually all of Australia but the best yielding aquifers are the high productivity sandstones (e.g. Great Artesian Basin, Canning Basin and aquifers along the southern to central western coast of WA) or the high productivity fractured rocks largely present in the NT (Figure 9). The productivity of an aquifer is a measure of the rate of groundwater that can be extracted in a specific location and in Figure 9 the dark blue and green regions represent aquifers that have a bore yield of more than 5 litres per second and cover a large area. It is worth noting that both of the most prospective near-term onshore geological storage basins fall within the bounds of the Great Artesian Basin (GAB). The Surat Basin forms part of the GAB and the Cooper Basin lies beneath the GAB.

Groundwater from the GAB in QLD is fully assigned and allocations for hydrogen production would require acquisition via water trading mechanisms. Excess water from coal seam gas (CSG), petroleum production and mining could offer an additional source of water for hydrogen production. This water is regarded as unallocated and statistics compiled by the Queensland Government indicate that some 47 GL of production water was produced from CSG fields in Queensland (mostly from the Surat Basin) during 2018 with another 10 GL from conventional petroleum wells. If not utilising by-product water from existing industries, the abstraction of groundwater for hydrogen production will add to the cumulative impact on water resources in addition to other industries. Mine dewatering is another potential source of groundwater in some regions. In the Pilbara region of WA for example, there is presently 140 GL/yr of mostly fresh groundwater available from iron ore mine dewatering activities (Government of Western Australia, 2014). If this water was harvested for hydrogen using renewable energy for example, this water source alone could produce approximately 14 Mt/yr of hydrogen.

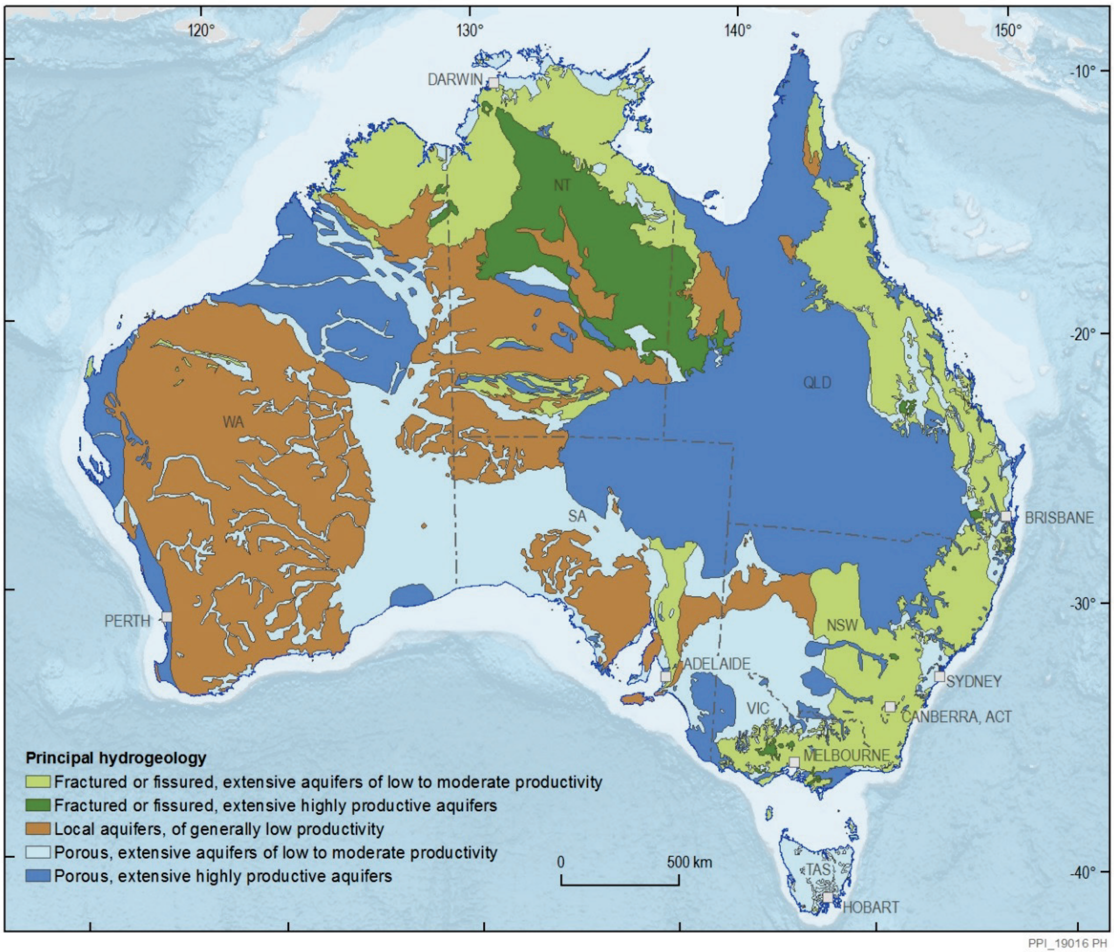


Figure 9. Hydrogeology of Australia.

3.2 Land

The total area for the Australian landmass is 7.692 million square kilometres and in Table 2 the proportion of different land uses is given. Approximately 77% is primary producing land, 8% is national parks, 0.4% is residential land and 0.045% industrial land. Included within primary producing land is some 3 407 630 square kilometres of land used for grazing (Australian Bureau of Statistics, 2018), some of which may be suitable for large-scale solar and wind installations (Figure 10).

Table 2. Percentage area occupied by different land use in Australia based on ABS Mesh Blocks (ABS, 2016).

Land use category	Percentage use of Australia land mass (%)	Land area (km^2)
Commercial	0.015	1129
Education	0.008	604
Hospital/medical	0.001	65
Industrial	0.045	3471
Other	14.035	1 079 572
Parkland	8.402	646 293
Primary production	76.540	5 887 431
Residential	0.405	31 118
Transport	0.003	248
Water	0.0547	42 067
Total	100.00%	7 692 000

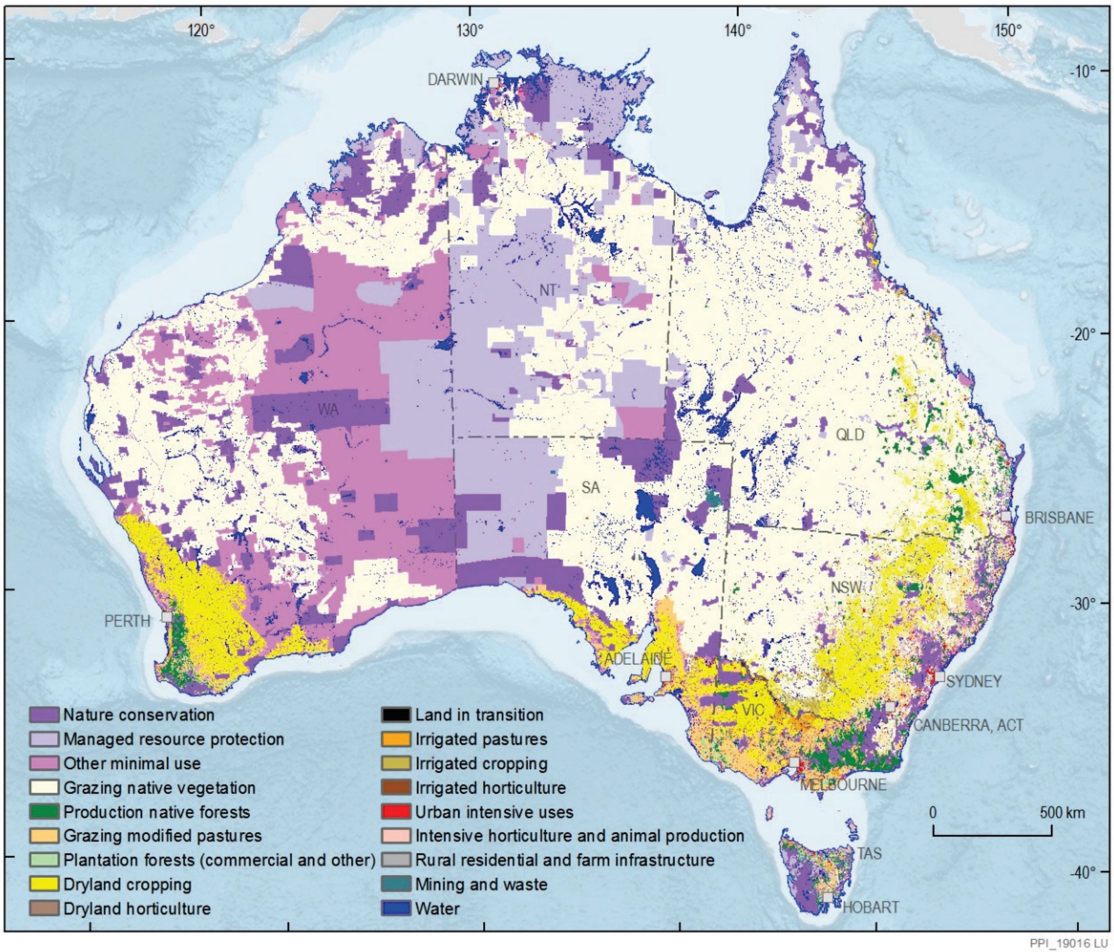


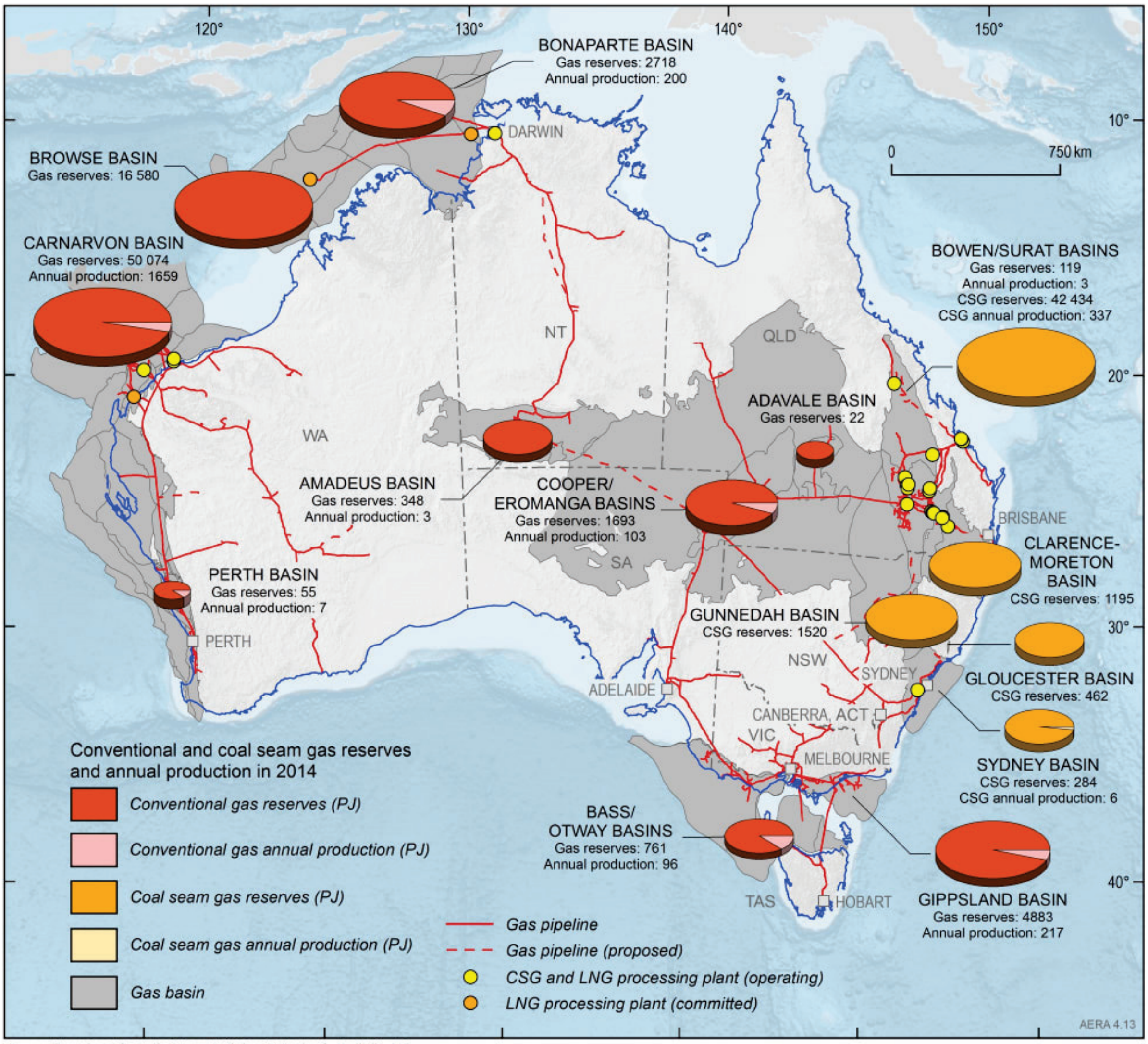
Figure 10. Land use in Australia.

3.3 Fossil fuels (coal and gas)

Australia has abundant fossil reserves. It is one of the world's largest natural gas exporters at 2864 PJ (around 52 Mt) in 2016/2017 and third largest coal exporter at 10 702 PJ (around 370 Mt) in 2016/2017 (Department of Environment and Energy, 2018). Domestic consumption in 2016/2017 was 1937 PJ of coal and 1515 PJ of gas. Even at these production and use levels, there is many decades worth of accessible reserves for gas (123 187 PJ; Figure 11) and in situ Economic Demonstrated Resources (EDR) of black and brown coal, 86 261 million tonnes (Mt) and 92 887 Mt, respectively (Figure 12) (Australian Energy Resources Assessment, 2019). Vast prospective gas reserves have also been estimated (Table 3; Figure 13).

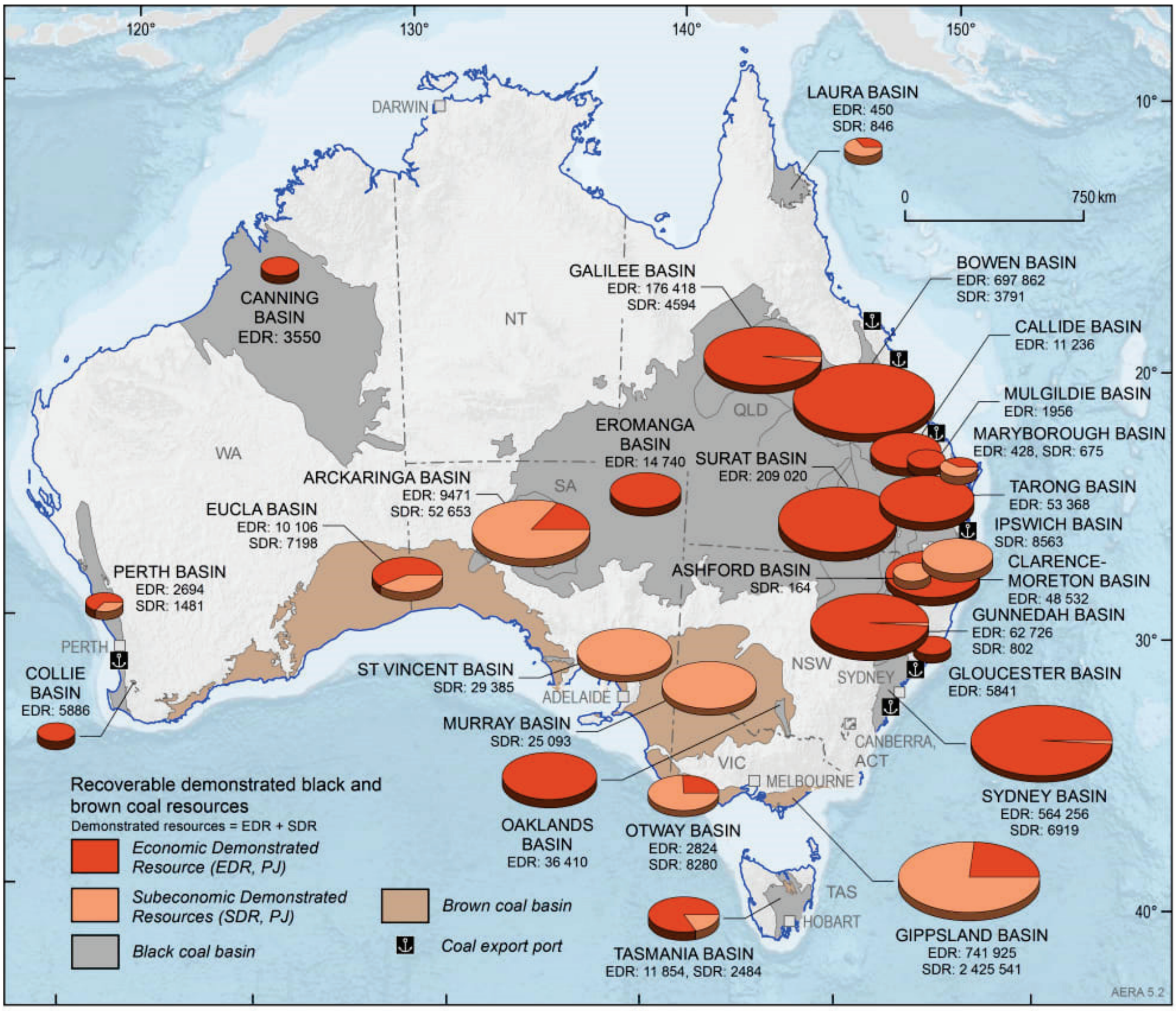
Table 3. Australia's total identified and prospective gas resources as of 2014 (PJ) (AERA, 2019).

Resource category	Conventional gas (PJ)	Coal seam gas (PJ)	Tight gas (PJ)	Shale gas (PJ)	Total gas (PJ)
Reserves	77 253	45 895	39	0	123 187
Contingent resources	108 982	33 555	1709	12 252	156 498
All identified resources	186 235	79 450	1748	12 252	279 685
Prospective resources	235 913	6890	2 650 622	9 577 353	12 470 778



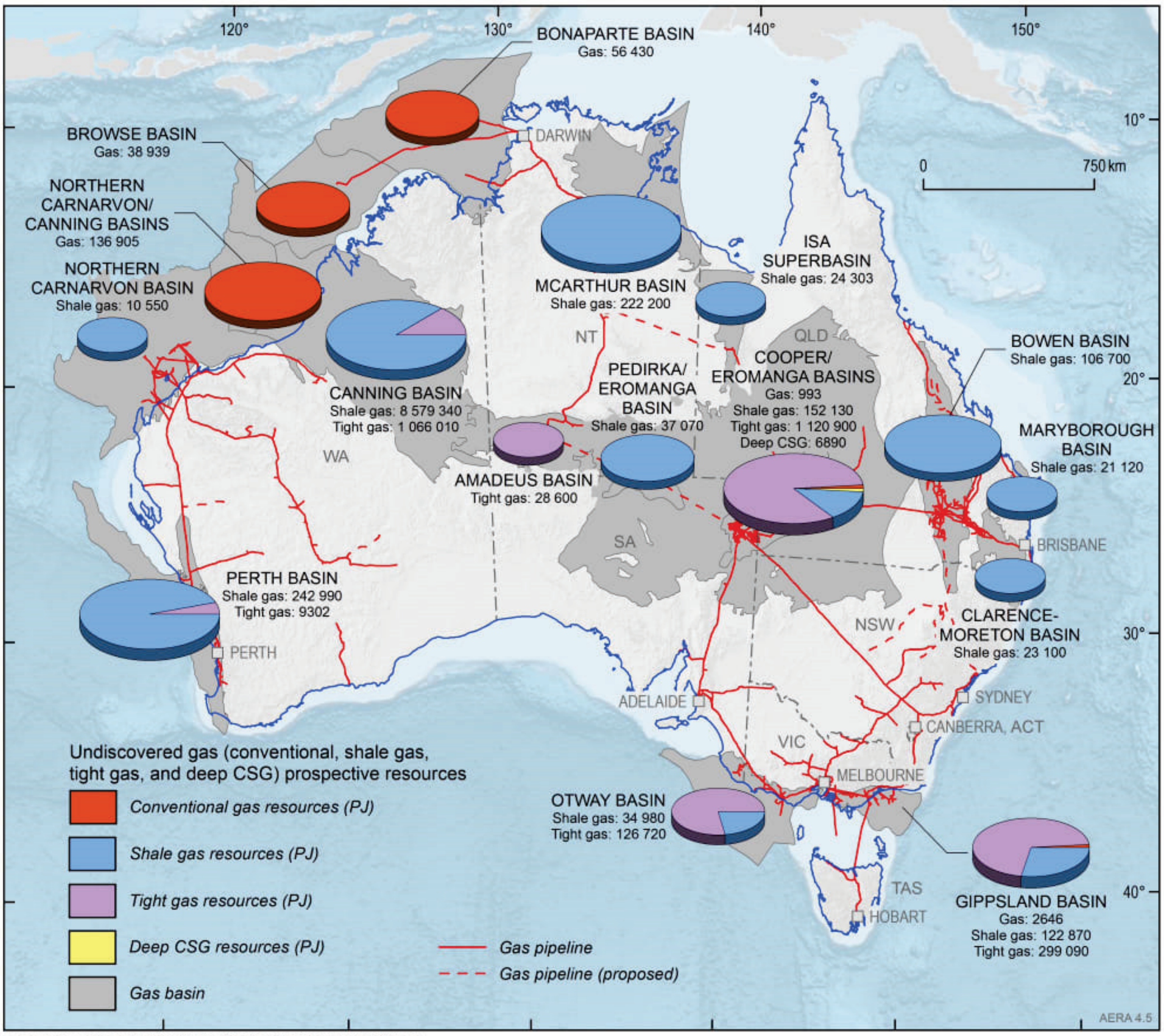
Source: Geoscience Australia, Encom GPinfo, a Datamine Australia Pty Ltd.
Whilst all care is taken in the compilation of the petroleum pipelines by Datamine, no warranty is provided re the accuracy or completeness of the information, and it is the responsibility of the Customer to ensure, by independent means, that those parts of the information used by it are correct before any reliance is placed on them. Accurate at August 2017.

Figure 11. Conventional and coal seam gas reserves and annual production in 2014 (PJ).



Source: Geoscience Australia

Figure 12. Recoverable demonstrated black and brown coal reserves (PJ).



Sources: Geoscience Australia; Encom Gpinfo, a Datamine Australia Pty Ltd
Whilst all care is taken in the compilation of the petroleum pipelines by Datamine, no warranty is provided re the accuracy or completeness of the information, and it is the responsibility of the Customer to ensure, by independent means, that those parts of the information used by it are correct before any reliance is placed on them. Accurate at August 2017.

Figure 13. Undiscovered gas (conventional, shale gas, tights and deep CSG) prospective resources (PJ).

3.4 Geological storage resources

One enabling technology that is critical to developing a clean fossil fuel hydrogen industry is carbon capture and storage (CCS). CCS involves capture of CO_2 emissions and then transportation via pipeline, truck or ship to suitable locations where it is injected deep underground into geological formations, where the CO_2 remains permanently trapped.

In nearly all cases, for carbon storage to be conducted successfully, a high porosity reservoir rock is needed as the storage formation, accompanied by an overlying low permeability rock that prevents leakage of CO_2 towards the surface. Depleted oil and gas fields that previously held significant accumulations of hydrocarbons are well suited candidates for CCS as they possess the required properties for storage and have been proven to be secure storage complexes for millions of years. Saline aquifers can also be used as potential areas to store carbon, although in most cases the sealing integrity of caprock and faults is likely to be less certain than with depleted hydrocarbon fields.

One key requirement for CCS is that the CO_2 is injected at depths greater than about 800 m, as this is the depth where CO_2 naturally transitions from a gas state to a supercritical fluid, which increases its density substantially, making the process more efficient and minimizing buoyancy forces.

Fortunately, Australia possesses the appropriate rock types and configuration for geological storage in many parts of the country and therefore has the potential to store large amounts of CO_2. In 1998-2002, the first national assessment of Australia's geological storage resources was conducted through the GEODISC project (Bradshaw and Rigg, 2001). This concluded there is excellent potential to sequester CO_2 in the major sedimentary basins of Australia.

A more comprehensive National Carbon Mapping and Infrastructure Plan was released in 2009 (Carbon Storage Taskforce, 2009). This identified potential storage basins, indicative storage capacities and matched these with stationary energy emission hubs. The report suggested eastern Australia has storage capacity for 70-450 years for 200 Mtpa CO_2 emissions and 260-1120 years for 100 Mtpa for Western Australia. State governments (WA, NSW, VIC and QLD) released their own geological storage 'Atlases' and specific state-based geological storage regulations shortly after release of the national plan. These provided a more detailed assessment of on-shore storage capacity and ranked the suitability of specific sandstone sequences in each of the storage basins.

Since then, a number of CCS flagship programs have been established by the Australian federal government. These include the South West Hub project in WA and CarbonNet project in Victoria, which were scoped as potential carbon storage hubs for use by CO_2 intensive industries.

In terms of incorporating potential carbon storage sites into the geospatial analysis, we have divided storage areas into those that are at an advanced stage of development and those that have significant potential but are unlikely to be ready for development by around 2030. The areas considered to be at an advanced stage and therefore incorporated into Scenario 4 are parts of the Cooper Basin in central Australia, a portion of the Surat Basin (QLD) and the offshore Gippsland Basin, where the CarbonNet Project (VIC) is currently at an advanced stage of development (Figure 14). We have also considered the offshore Carnarvon Basin (WA), where the Gorgon CO_2 Injection Project is occurring on Barrow Island, although the lateral extent of the most suitable reservoirs within this basin is uncertain and will be smaller than that displayed in Figure 14.

The oil and gas fields of Australia's northwest shelf also host significant storage capacity and already possess significant onshore and offshore infrastructure. The longer term storage potential is shown in Figure 15 and is used in Scenario 5. In this scenario, storage volumes open up in central Australia and the Surat Basin, together with some new storage opportunities in the Darling Basin of New South Wales. The areas for CO_2 storage are also expanded on the northwest shelf.

Although somewhat speculative, it is possible that CO_2 storage associated hydrogen production may provide a way to generate further water for use in hydrogen production. It is often the case that large scale CO_2 storage operations require pressure relief wells, which produce water, to prevent mechanical damage to the host formations. This type of CO_2 Enhanced Water Recovery (CO_2 EWR) can be used for beneficial use and could be a potential water source of hydrogen production. If the water is brackish or saline and requires desalination, salt disposal would need to be considered as part of the production process.

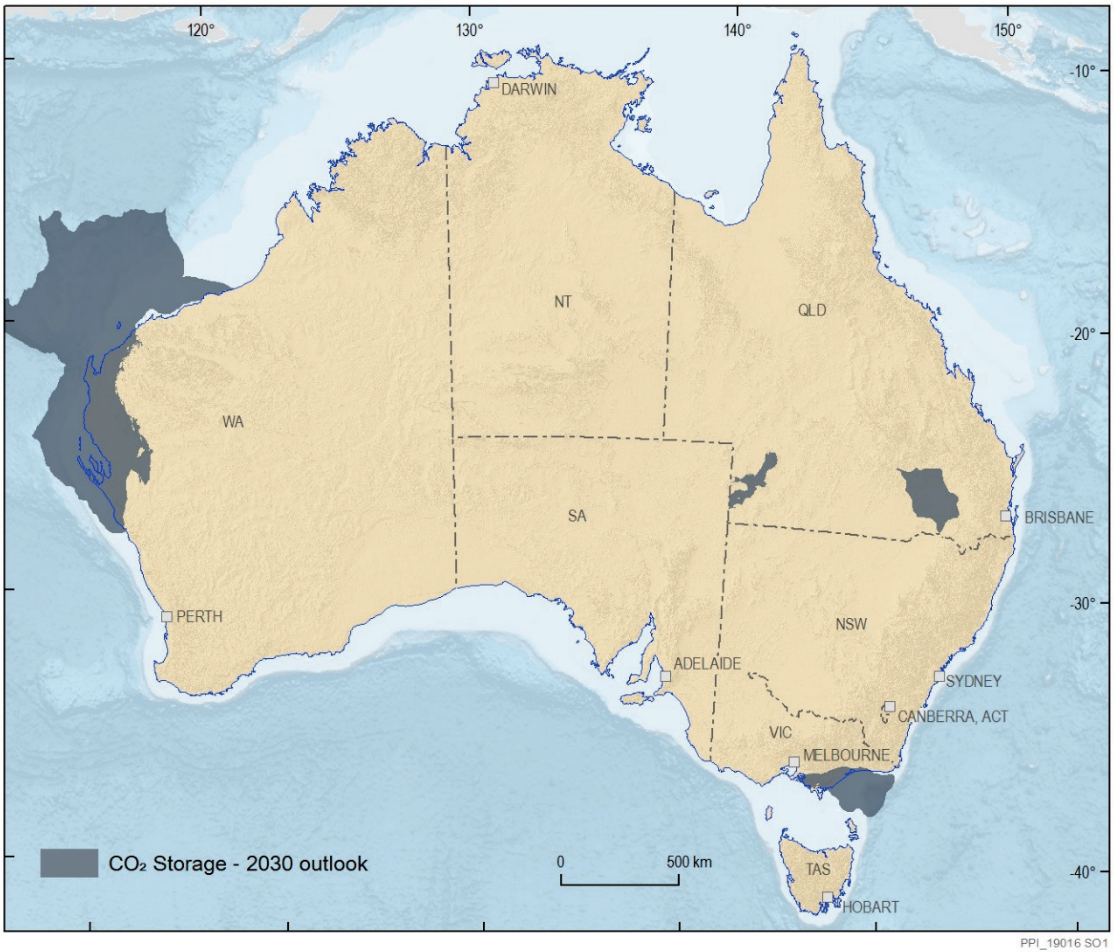


Figure 14. Potential CO_2 storage sites that are at an advanced stage of characterisation and/or development. Note the lateral extent of the most suitable reservoirs for CO_2 storage within the Carnarvon Basin in WA is uncertain.

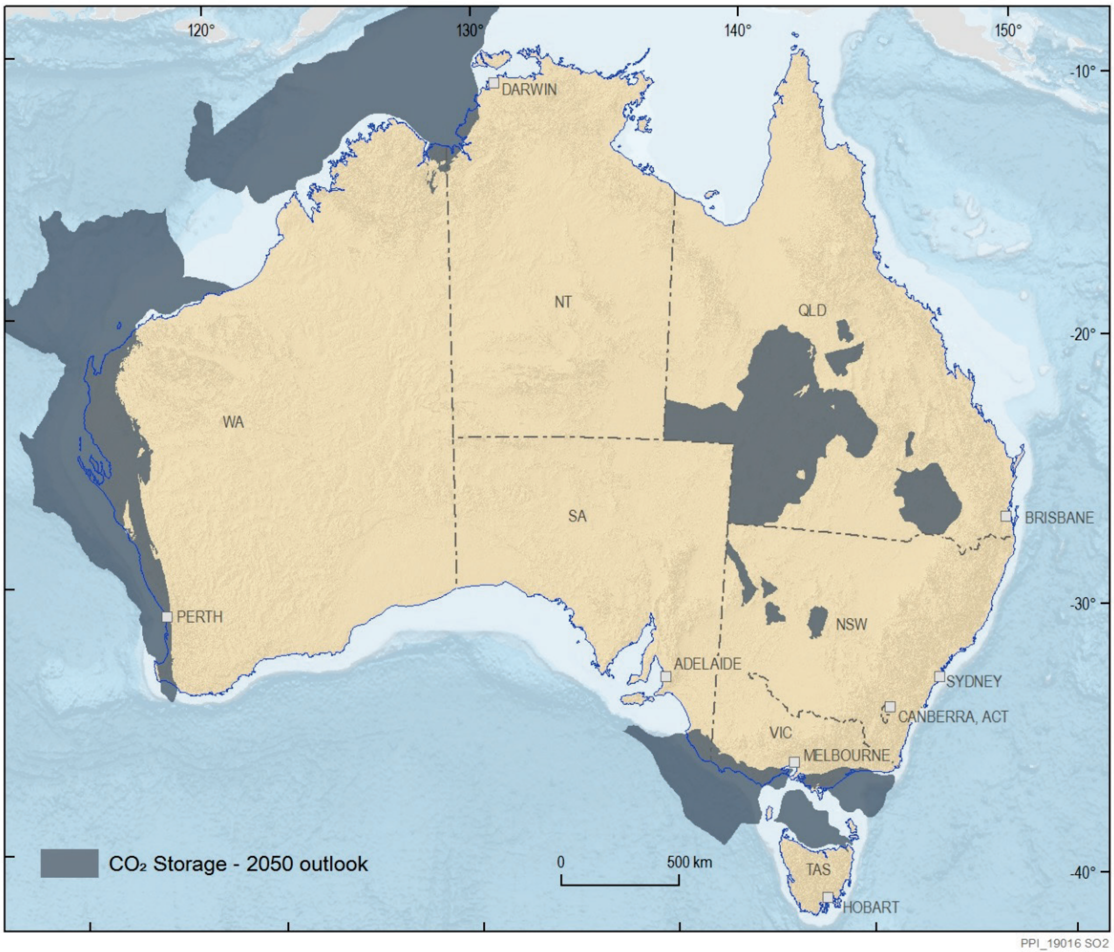


Figure 15. Longer term outlook for CO_2 storage sites in Australia. There is highly likely to be storage potential in South Australia in the Cooper Basin (e.g. Moomba) but it has not been recently mapped.

4 Hydrogen resource estimates

Analysis of the amount of land comprising the top 20 percent of hydrogen prospectivity ratings developed for this report indicates that there are vast areas of land within Australia with good potential for future renewable hydrogen production. In this analysis, the top and bottom 1% of data according to suitability were initially removed from consideration, as these data were outliers that skew the distributions unrealistically and only represented a very small part of the map. The top 20% or ratings were then taken from the remaining 98% of the data. Figures are listed in Table 4 below. While the amounts of land in Table 4 are very large, the area occupied is a small fraction of the total area across the continent (e.g. Figure 16 to Figure 18).

Table 4: Summary of renewable hydrogen mapping scenarios and land area of top fifth of scenario range.

Scenario number	Scenario Name	Land area of top fifth of prospectivity ratings (km^2)
Scenario 1	Renewable resource potential, without infrastructure constraints	872 760
Scenario 2	Coastal production and constrained by existing infrastructure	261 755
Scenario 3	Coastal or inland generation, hydrogen transported via pipeline, and constrained by existing infrastructure	350 287

In contrast to renewable hydrogen, CCS hydrogen production occupies less space above ground as only a small amount of land is needed for production. CCS does have specific requirements for deep CO_2 storage underground and storage sites can be onshore or offshore. Results from the CCS hydrogen scenarios indicate that there are large regions in Australia where future hydrogen production could potentially occur within the vicinity of suitable CO_2 storage sites. Australia has large fossil fuel reserves that could potentially support a CCS hydrogen industry.

CCS hydrogen is highly prospective in Victoria using brown coal or gas due to the co-location of abundant fossil fuels, an excellent storage reservoir, access to water and good infrastructure (ports, pipeline easements, electricity networks). Brown coal is well suited to hydrogen production due to its higher moisture content. Geological storage capacity for the Gippsland Basin is very large and is estimated to be over 30 000 Mt of CO_2 (Carbon Storage Taskforce, 2009). The Hydrogen Energy Supply Chain (HESC) project in Victoria plan to use brown coal for hydrogen production and store in excess of 4 Mt per year of CO_2 in the Gippsland Basin during the 2030s (Kawasaki Heavy Industries, 2012). Very large scale geological storage in a single basin has yet to be deployed internationally (>10 Mtpa) and therefore large-scale demonstrations of geological storage are required to provide confidence in the scalability of CCS hydrogen production with its corresponding geological storage requirements.

Future CCS hydrogen, if produced near the most prospective inland storage reservoirs, would be constrained by groundwater availability and, in some locations, competition with other resource users. Groundwater in the Surat Basin, for example, has many different users including irrigators, the grazing industry, intensive agriculture, CSG industry, and town water supplies. An example of the competition for subsurface space is APLNG's CSG production water disposal program. Approximately 15.5 GL of highly purified CSG production water has been reinjected into the Precipice Sandstone (Surat Basin) for disposal by APLNG. The total volume of water injected since operational injection commenced is estimated to be equivalent to approximately 90% of all water extracted from the Precipice Sandstone under authorised allocations (Office of Groundwater Impact Assessment, 2016), over the equivalent time (i.e. non-CSG related water use by landholders and industry) (Origin, 2018). This aquifer is the same geological formation with high prospectivity for carbon storage, although optimal locations for CO_2 storage are in deeper parts of the formation. It highlights the challenges of managing competing use for reservoir pore space.

While not considered during the geospatial analysis of this study, for a large scale hydrogen industry to develop in Australia, hydrogen storage is key. In addition to depleted oil and gas reservoirs, it has been proposed that hydrogen gas could be injected and compressed in underground salt caverns to enable seasonal storage (Bruce et al., 2018). Figure 19 shows onshore halite deposits that may be suitable for gas storage in salt caverns. These include thick sections of halite in the Adavale Basin (Etonvale Formation; Boree Salt member), Amadeus Basin (Chandler Formation) and Canning Basin (Carribuddy Group; Mallowa Salt and Minjoo Salt members) (Wells, 1980; Haines, 2010; Hashimoto et al., 2018). The Mallowa Salt member in the Canning Basin is the most extensive halite unit in Australia with thicknesses up to 700-800 m.

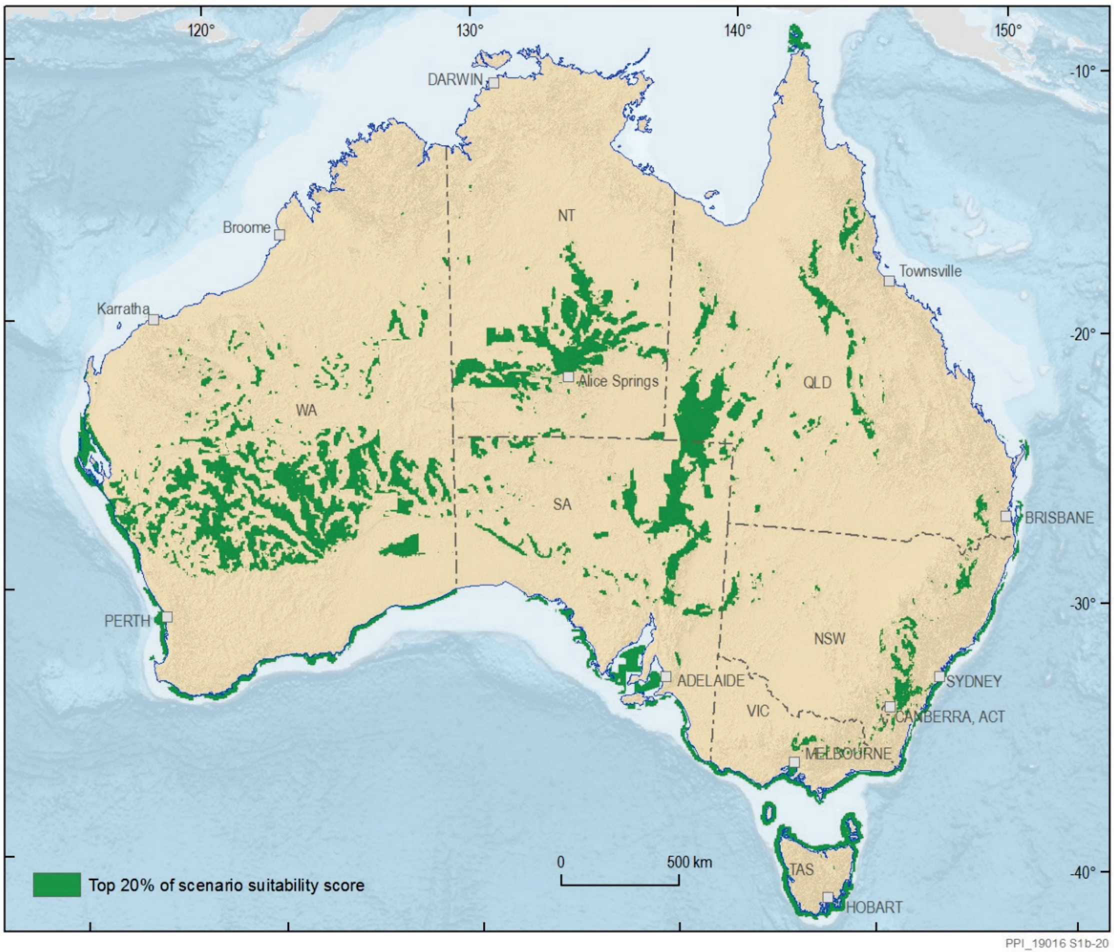


Figure 16. Top 20 percent of the most prospective renewable areas for Scenario 1 (Renewable resource potential - unconstrained). The areas highlighted in green cover a total area of 872 760 km².

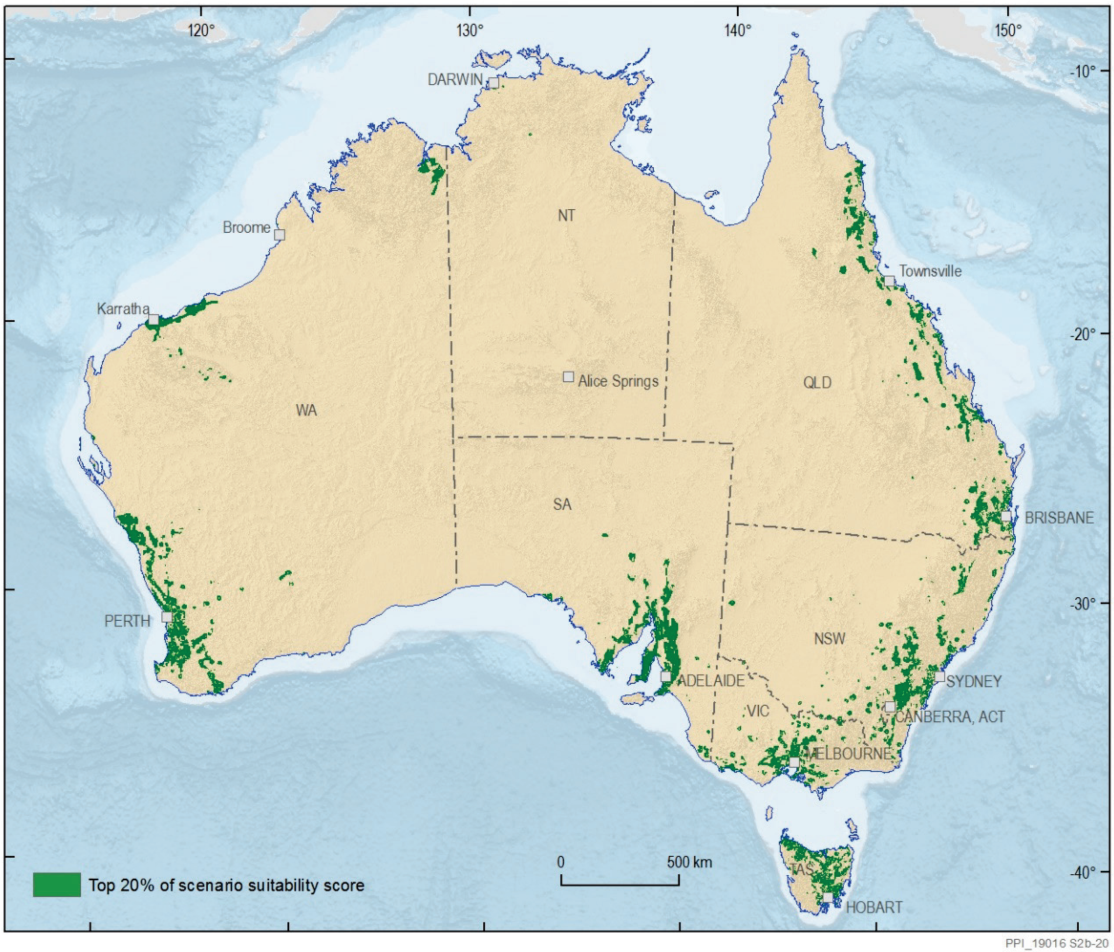


Figure 17. Top 20 percent of the most prospective areas for Scenario 2 (Renewable Hydrogen; coastal production and constrained by existing infrastructure). The areas highlighted in green cover a total area of 261 755 km^2.

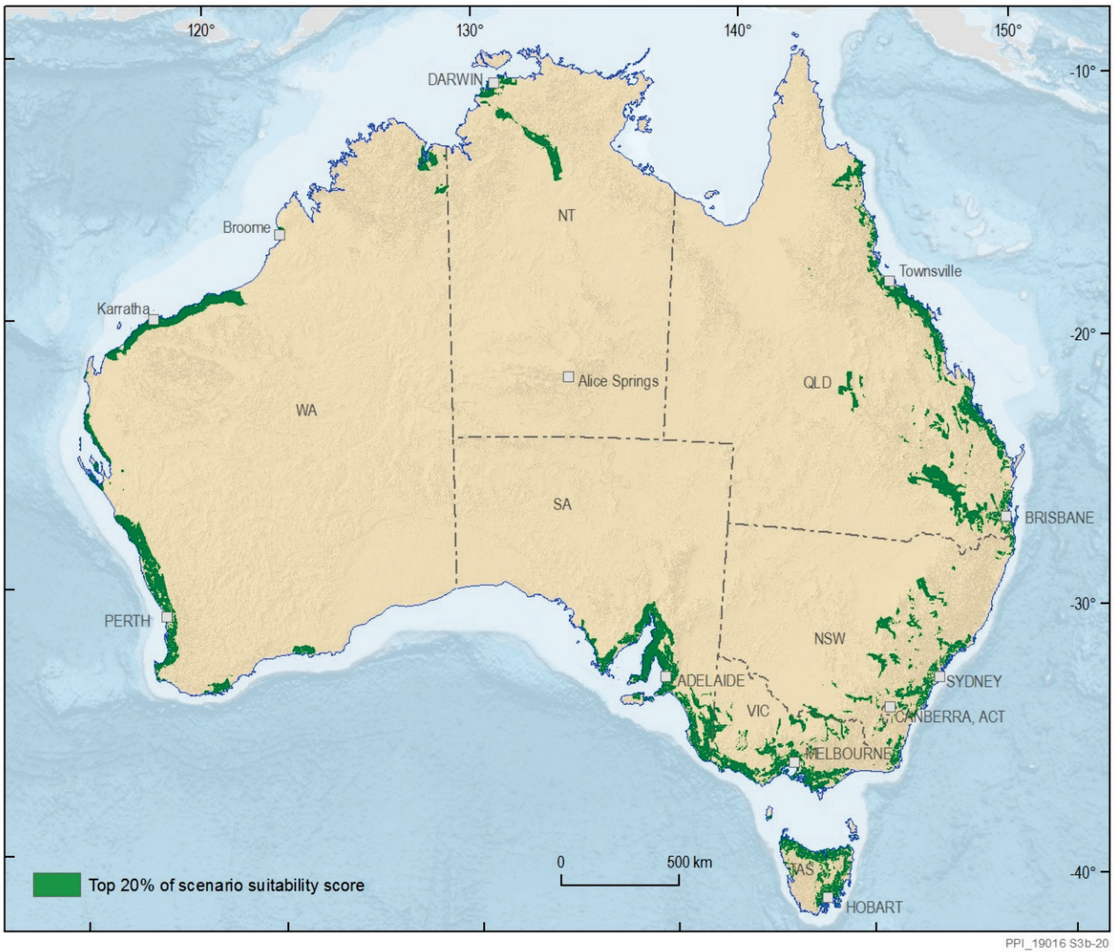


Figure 18. Top 20 percent of the most prospective areas for Scenario 3 (Renewable Hydrogen; coastal or inland production, pipeline transport and constrained by existing infrastructure). The areas highlighted in green cover a total area of 350 287 km^2.

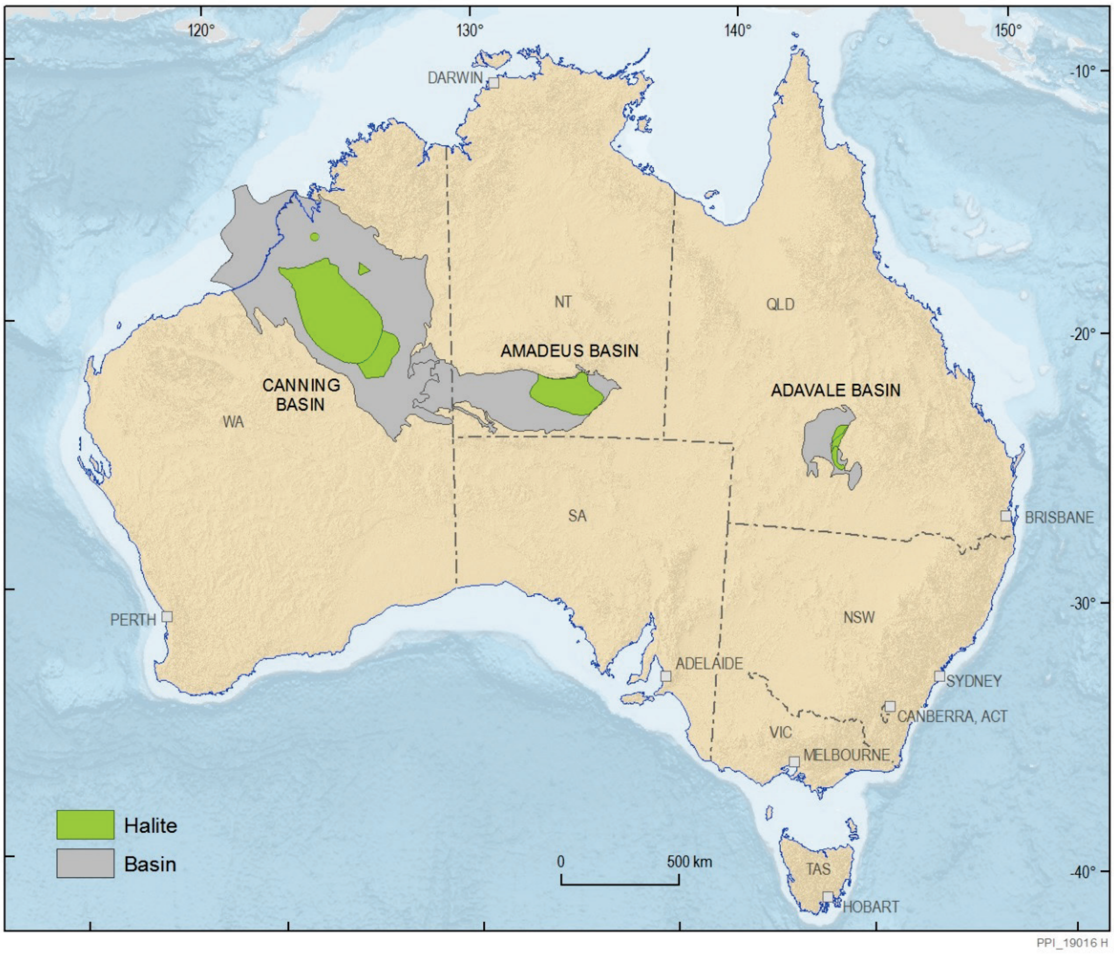


Figure 19. Thick onshore halite units that may be suitable for gas storage in salt caverns. Depths to the salt units are typically greater than 800 m but can be kilometres underground.

5 Key findings

- Australia has vast physical resources that could support a large-scale hydrogen industry.
- Using a geospatial analysis approach, this report considers that there are extensive regions with the base elements and infrastructure to support both large-scale renewable hydrogen and CCS hydrogen.
- Most coastal areas have elevated potential for hydrogen production from electrolysis. The unlimited supply of desalinated seawater and the availability of electrical and port infrastructure make these favourable areas for hydrogen production.
- Australia has extensive fresh water resources which means inland hydrogen production from electrolysis is possible. However, water availability is not equally distributed across the country. This presents a challenge for inland production in some regions, particularly where relying on access to groundwater. It is possible that harvesting water from industrial water production or urban wastewater might be a "game changer" in such locations.
- Additional infrastructure and technology development is important to unlock Australia's hydrogen resource potential. For example, many areas may only become suitable if additional infrastructure investments can improve connection between the coast and inland areas that possess renewable energy potential.
- Australia has extensive fossil fuel resources that can be used with CCS to produce hydrogen with low carbon emissions. The potential increases significantly when additional CCS sites, which are expected to become available over time, are incorporated into the analysis.
- For inland CCS hydrogen, access to groundwater or competition for reservoir pore space may be a limiting factor. It is recommended to take a holistic view of hydrogen generation in these regions and explore mutually beneficial arrangements for the oil and gas industry, agricultural water users, town water supplies and hydrogen generation.
- There are regions of Australia (marked in grey on the maps) which are of known environmental, cultural or historical significance or which otherwise have known competing uses. While these may not necessarily be a barrier to project development, close examination will be needed of the suitability of land for projects proposed in these regions.
- Further pre-competitive characterisation work is required to determine the geological potential for transient hydrogen storage and permanent geological storage for CO_2 in Australia. Studies since the 2009 National Carbon Taskforce mapping exercise have generally found less CO_2 storage potential than indicated in the high level basin wide studies. There still, however, remains large unexplored onshore regions of Australia, which may contain good storage for hydrogen and CO_2 (e.g. the Canning Basin in WA). The discovery of good localised CO_2 storage potential in the deep troughs of the Darling Basin in NSW (previously rated marginal in the National Carbon Taskforce) gives cause for optimism that additional geological storage resources are present.
- The methodology employed in this study can be readily implemented for delivery through a dynamic tool. This would allow efficient updates to the hydrogen production prospectivity maps, but also interactive interrogation by stakeholders to support a range of applications and use cases. This could be extended further by incorporating a cost function to enable a comprehensive economic analysis that quantifies viability of particular locations based on the development and transport costs.

- There are a number of national scale datasets that currently do not exist but would benefit future studies:
  - A national scale land value dataset – requires integration of data from state and territory Valuer General Offices. This data would enable optimisation of the location of large-scale renewable installations with existing or planned supporting infrastructure (e.g. electricity networks and sub-stations)
  - A national scale groundwater use and quality dataset – groundwater management units are not necessarily tied to the most productive and utilised aquifers and can extend over vast areas with little groundwater productivity
  - It would be also useful to develop a national dataset that quantifies volumes of groundwater extracted from mining and petroleum activities that are not necessarily covered by the Water Act (i.e. those covered by state mining and petroleum acts)
  - Development of a national scale hydropower potential development data layer
  - Development of an improved national scale wind energy prospectivity layer.

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8 Appendix: Input datasets and pre-processing steps

The Appendix provides a summary of the datasets used in this study.

Datasets used in the analysis and each scenario output are available as data downloads and web services. They can be accessed through the Geoscience Australia Data and Publications Search tool (http://pid.geoscience.gov.au/dataset/ga/130930).

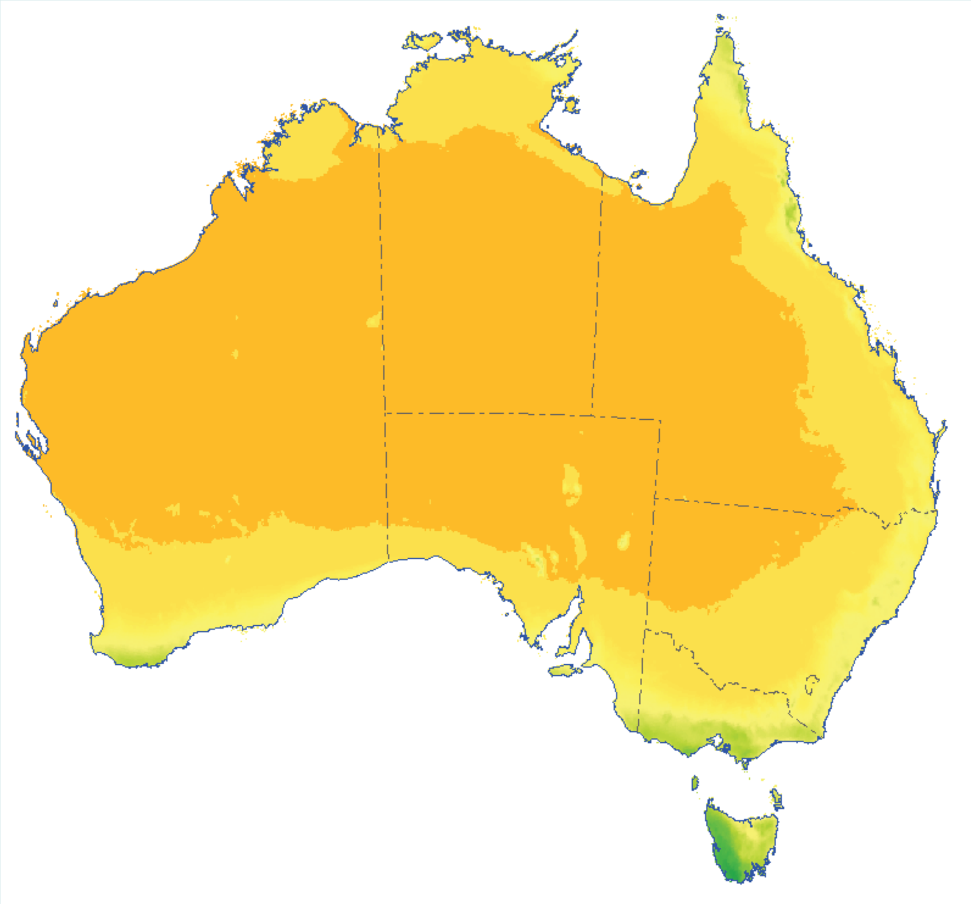
Table A-1: Input dataset - Windspeed at 100m (E001).

Metric	Wind speed at 100m (E001)
Dataset/s	Wind speed
Data source	DNV GL Wind speed at 100m, AREMI National Map portal © 2015, Garrad Hassan Pacific Pty Ltd (registered in Australia) (DNV GL)
Method	• Download dataset • Reclassify input raster as per table below • Reprojected to GDA 1994 Australia Albers • Snapped to snap raster • Onshore areas masked to coastline and extracted to become onshore layer • Offshore areas extracted into separate layer
Map	

Scoring: Wind speed in m/s.

Score	Indicator
0	<7.31m/s
10	≥7.31m/s

Table A-2: Input dataset - Solar exposure (E002).

Metric	Solar exposure (E002)
Dataset/s	Direct Normal Exposure (DNI)
Data source	Bureau of Meteorology © Bureau of Meteorology
Method	• Reclassify input raster as per table below • Reprojected to GDA 1994 Australia Albers • Snapped and masked to snap raster
Map	

Scoring: Solar exposure in MJ/m^2.

Score	Indicator
2-8	Continuous scale for values through to 20.5
8	20.5 – 23.5
10	>23.5

Table A-3: Input dataset – Black coal resources (E003).

Metric	Black coal resources (E003)
Dataset/s	Geological Provinces
Data source	Geoscience Australia
Method	• Selection of black coal basins as per AERA 5.4 figure • Polygons scored as per table below • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster
Map	

Scoring: Presence of black coal resources.

Score	Indicator
0	All remaining areas
10	Black coal basin

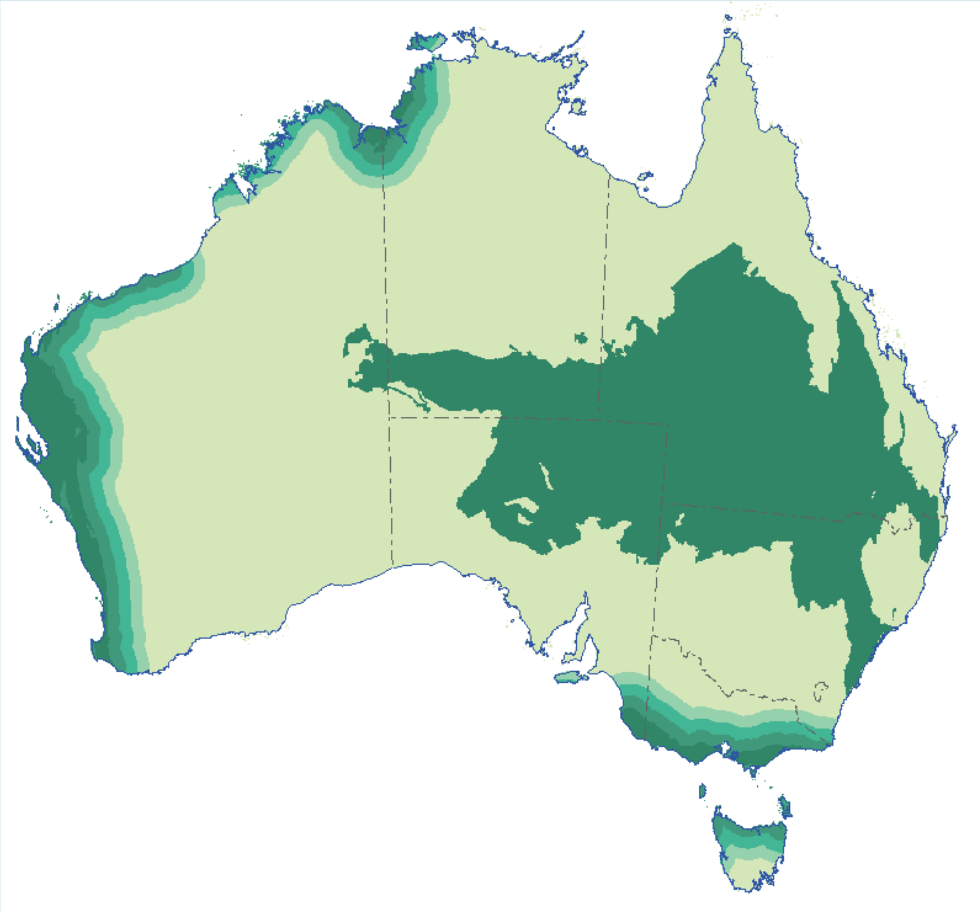
Table A-4: Input dataset – Brown coal resources (E004).

Metric	Brown coal resources (E004)
Dataset/s	Geological Provinces
Data source	Geoscience Australia
Method	• Selection of brown coal basins as per AERA 5.4 figure • Polygons scored as per table below • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster
Map	

Scoring: Presence of brown coal basin.

Score	Indicator
0	All remaining areas
10	Brown coal basin

Table A-5: Gas resources 2030 (E005).

Metric	Gas resources 2030 (E005)
Dataset/s	Geoscience Australia
Data source	Geoscience Australia
Method	• Selection of gas basins as per AERA 4.13 figure • Offshore basins buffered by 50, 100 and 150km • Polygons scored as per table below • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster
Map	

Scoring: Presence of gas resource.

Score	Indicator
0	All remaining areas
2	100-150km to offshore gas basin
5	50-100km to offshore gas basin
8	<50km to offshore gas basin
10	Gas Basin

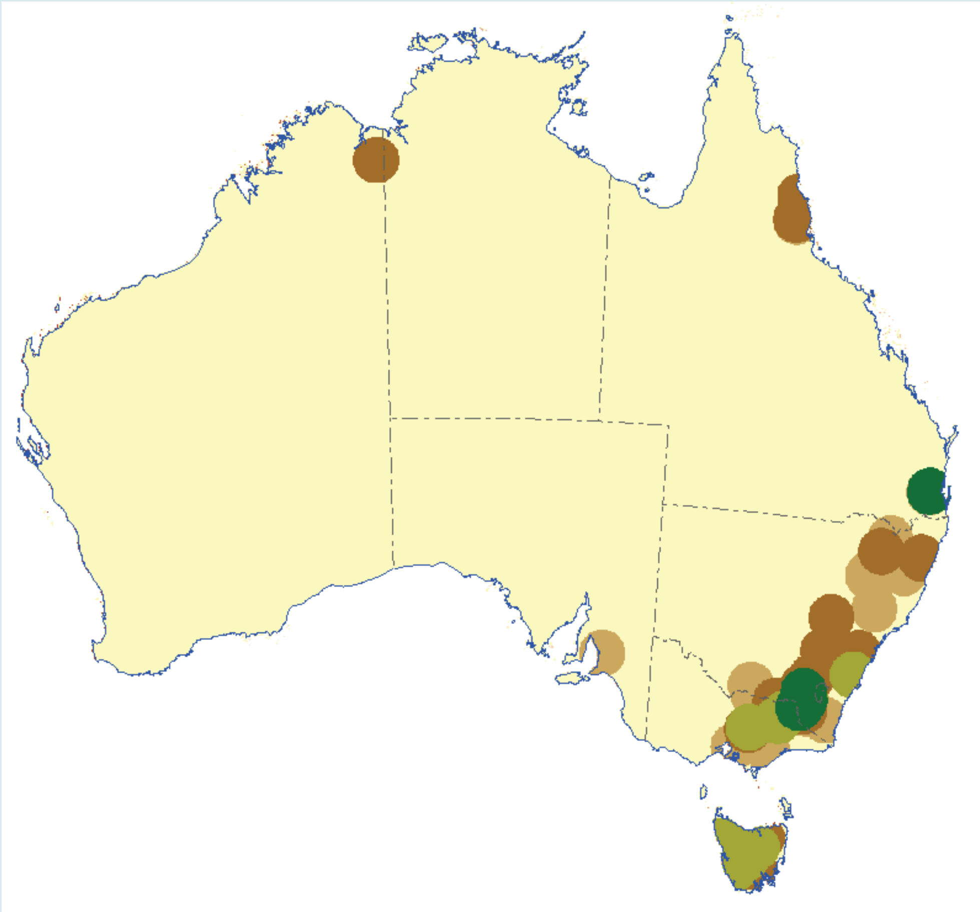
Table A-6: Input dataset - Gas resources 2050 (E006).

Metric	Gas resources 2050 (E006)
Dataset/s	Geological Provinces
Data source	Geoscience Australia
Method	• Selection of gas basins as per AERA 4.13 and AERA 4.5 figures • Offshore basins buffered by 50, 100 and 150km • Polygons scored as per table below • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster
Map	

Scoring: Presence of gas resource.

Score	Indicator
0	All remaining areas
2	100-150km to offshore gas basin
5	50-100km to offshore gas basin
8	<50km to offshore gas basin
10	Gas Basin

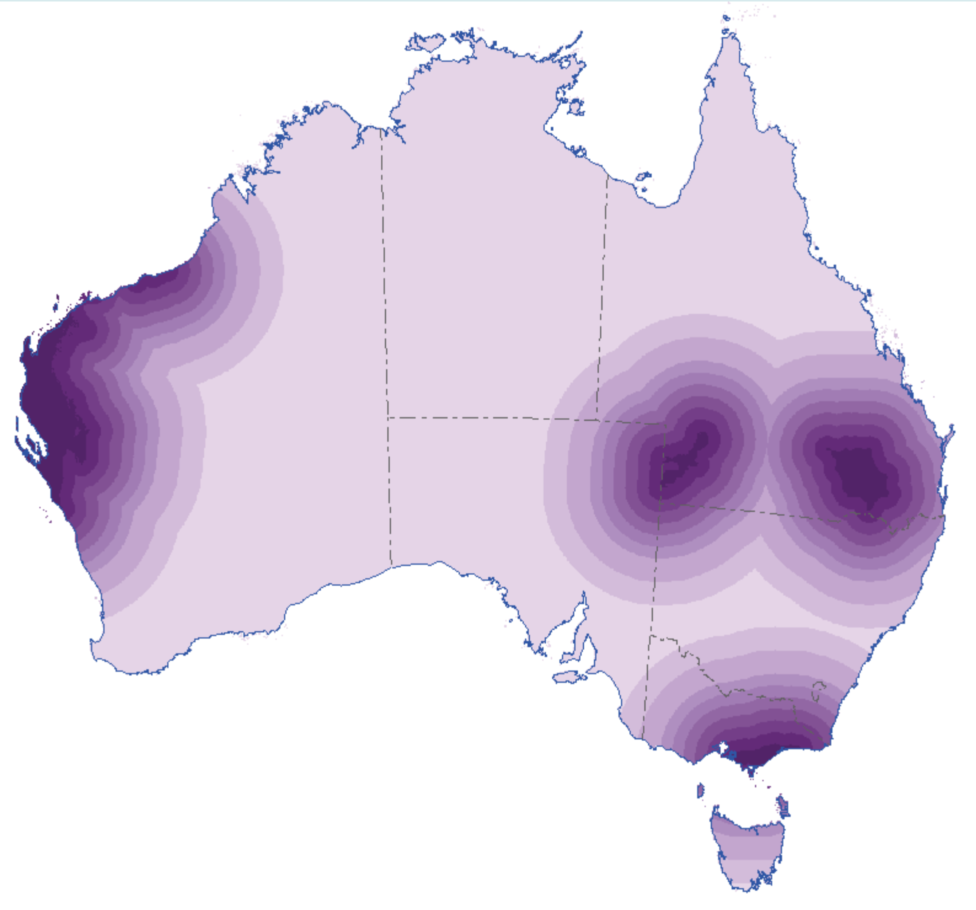
Table A-7: Input dataset - Hydroelectricity Generation (E007).

Metric	Hydroelectricity Generation (E007)
Dataset/s	Power Stations
Data source	Geoscience Australia
Method	• Selection of hydro power stations from input dataset • Features buffered by 100km • Features scored as per table below • Union of buffered features with highest score having priority • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster •
Map	

Scoring: Hydropower capacity (MW).

Score	Indicator
0	All remaining areas
1	<10
5	10-100
7	100-500
10	>500

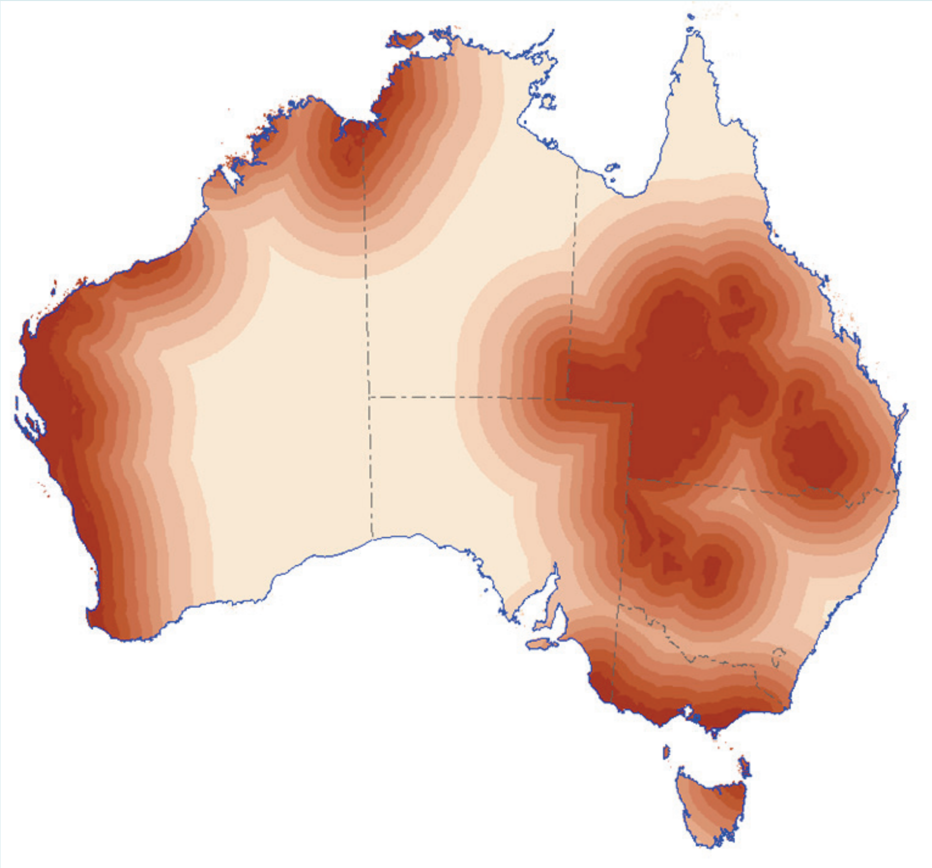
Table A-8: Input dataset - Storage 2030 outlook (S001).

Metric	Storage 2030 outlook (S001)
Dataset/s	Geological Provinces, Precipice Sandstone, Toolachee Formation
Data source	• Geoscience Australia • Carbon Storage Taskforce (2009) National Carbon Mapping and Infrastructure Plan-Australia: Full Report, Department of Resources Energy and Tourism, Canberra • Bradshaw, B.E., Spencer, L.K., Lahtinen, A.C., Khider, K., Ryan, D.J., Colwell, J.B., Chirinos, A., Bradshaw, J. (2009), Queensland Carbon Dioxide Geological Storage Atlas, Queensland Department of Employment, Economic Development and Innovation: Brisbane
Method	• Selection of basins/features as per table below from inputs datasets • Reprojected to GDA 1994 Australia Albers • Calculated Euclidean distance • Reclassify input raster as per table below • Snapped and masked to snap raster
Map	

Scoring: Distance to storage basin.

Score	Indicator
1	>500 km
2	400-500 km
3	300-400 km
4	250-300 km
5	200-250 km
6	150-200 km
7	100-150 km
8	50-100 km
9	<50 km
10	Gippsland, Carnarvon, Precipice Sandstone outline (>800m), Toolachee Formation (>800m)

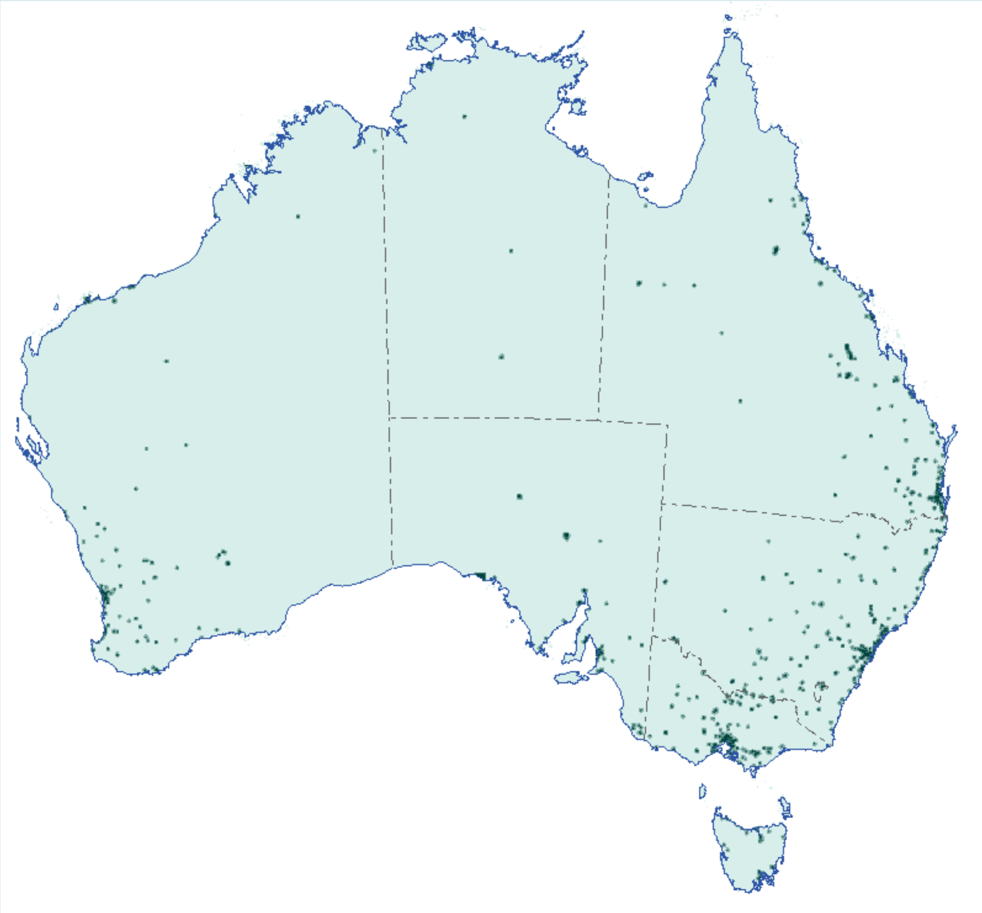
Table A-9: Input dataset - Storage 2050 outlook (S002).

Metric	Storage 2050 outlook (S002)
Dataset/s	Australian Basin Ranking Map dataset QLD-Atlas_Potential_areas_high_prospectivity Pondie_Range_GDANSWLamberts Bancannia_NSW_lamberts Blantyre_NSW_lamberts Yathong_NSW_lamberts
Data source	• Geoscience Australia • NSW Department of Planning, Industry and Environment • Carbon Storage Taskforce (2009) National Carbon Mapping and Infrastructure Plan-Australia: Full Report, Department of Resources Energy and Tourism, Canberra • Bradshaw, B.E., Spencer, L.K., Lahtinen, A.C., Khider, K., Ryan, D.J., Colwell, J.B., Chirinos, A., Bradshaw, J. (2009), Queensland Carbon Dioxide Geological Storage Atlas, Queensland Department of Employment, Economic Development and Innovation: Brisbane
Method	• Selection of basins as per Australian Basin Ranking Map and state supplied data. • Reprojected to GDA 1994 Australia Albers • Calculated Euclidean distance • Reclassify input raster as per table below • Snapped and masked to snap raster
Map	

Scoring: Distance to storage basin.

Score	Indicator
1	>500 km
2	400-500 km
3	300-400 km
4	250-300 km
5	200-250 km
6	150-200 km
7	100-150 km
8	50-100 km
9	<50 km
10	Offshore basins as per Australian Basin Ranking Map Areas supplied by NSW and QLD (see datasets listing)

Table A-10: Input dataset - Distance to industrial estate (I001).

Metric	Distance to industrial estate (I001)
Dataset/s	ABS Mesh Block 2016
Data source	PSMA Australia Incorporates or developed using Administrative Boundaries ©PSMA Australia Limited licensed by the Commonwealth of Australia under Creative Commons Attribution 4.0 International license (CC BY 4.0).
Method	• Download dataset • Industrial classified Mesh blocks extracted from input data • Polygons buffered as per table below • Polygons scored as per table below • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster
Map	

Scoring: Distance to industrial estate (km).

Score	Indicator
1	> 10
6	5-10
8	2-5
10	<2km

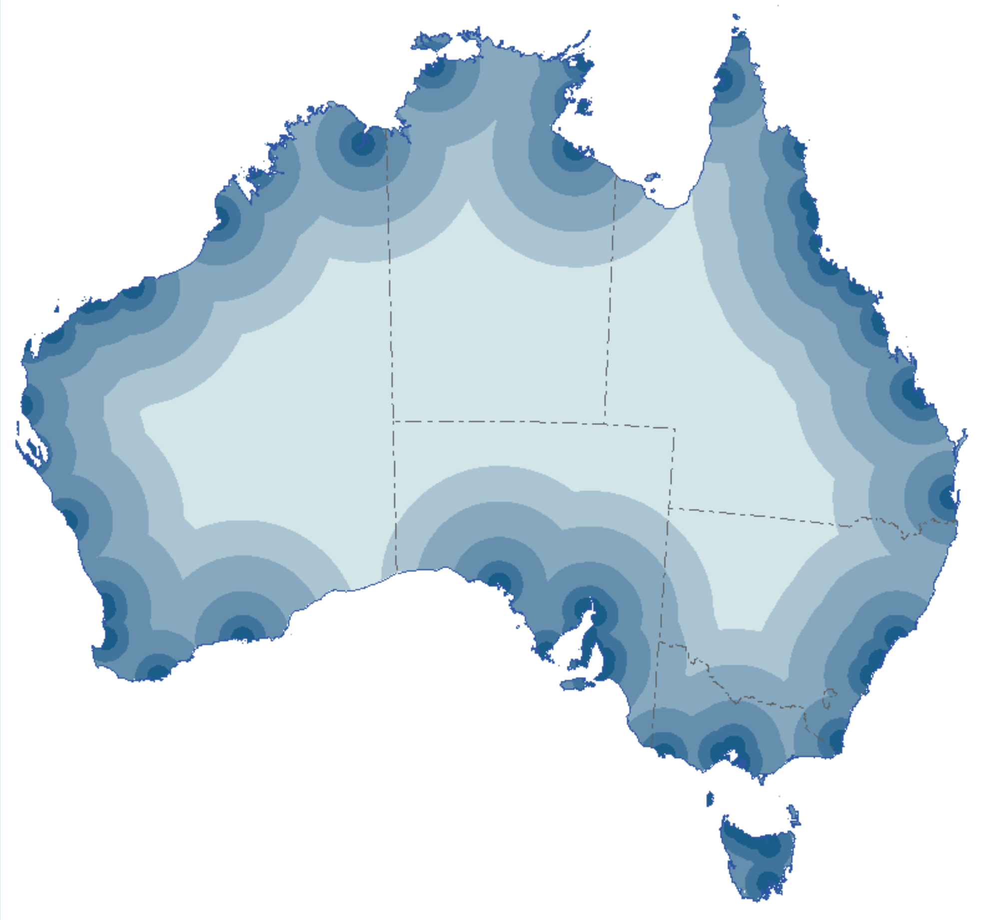
Table A-11: Input dataset - ABS Mesh Block 2016.

Metric	Land availability (I002)
Dataset/s	ABS Mesh Block 2016
Data source	PSMA Australia Incorporates or developed using Administrative Boundaries ©PSMA Australia Limited licensed by the Commonwealth of Australia under Creative Commons Attribution 4.0 International license (CC BY 4.0).
Method	• Download dataset • Industrial, Other, Parkland and Primary Production classified Mesh blocks extracted from input data • Polygons scored as per table below • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster
Map	

Scoring: Presence of available land.

Score	Indicator
0	All remaining classifications
10	Industrial, Other, Parkland and Primary Production classified mesh block

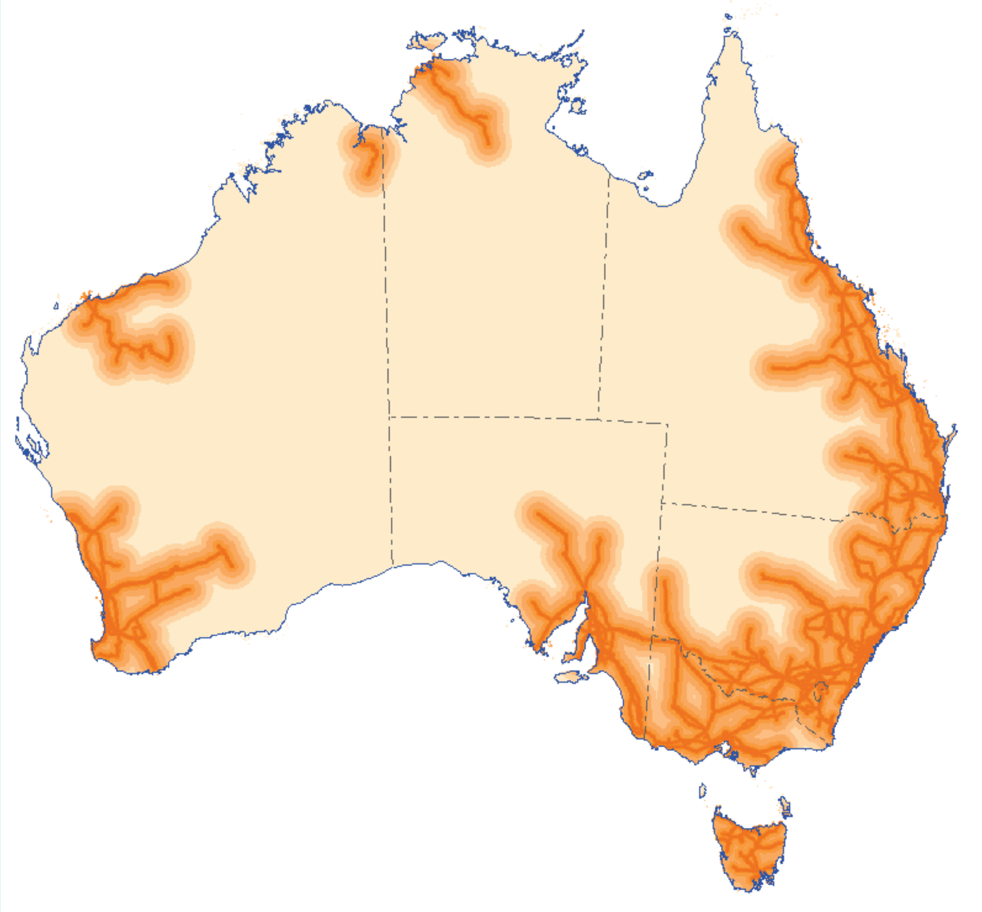
Table A-12: Input dataset - Proximity to major ports (I003).

Metric	Proximity to major ports (I003)
Dataset/s	Major Ports
Data source	Geoscience Australia
Method	• Reprojected to GDA 1994 Australia Albers • Calculated Euclidean distance • Reclassify input raster as per table below • Snapped and masked to snap raster
Map	

Scoring: Distance to port.

Score	Indicator
1	>500km
2	350-500km
4	200-350km
6	100-200km
8	50-100km
10	<50km

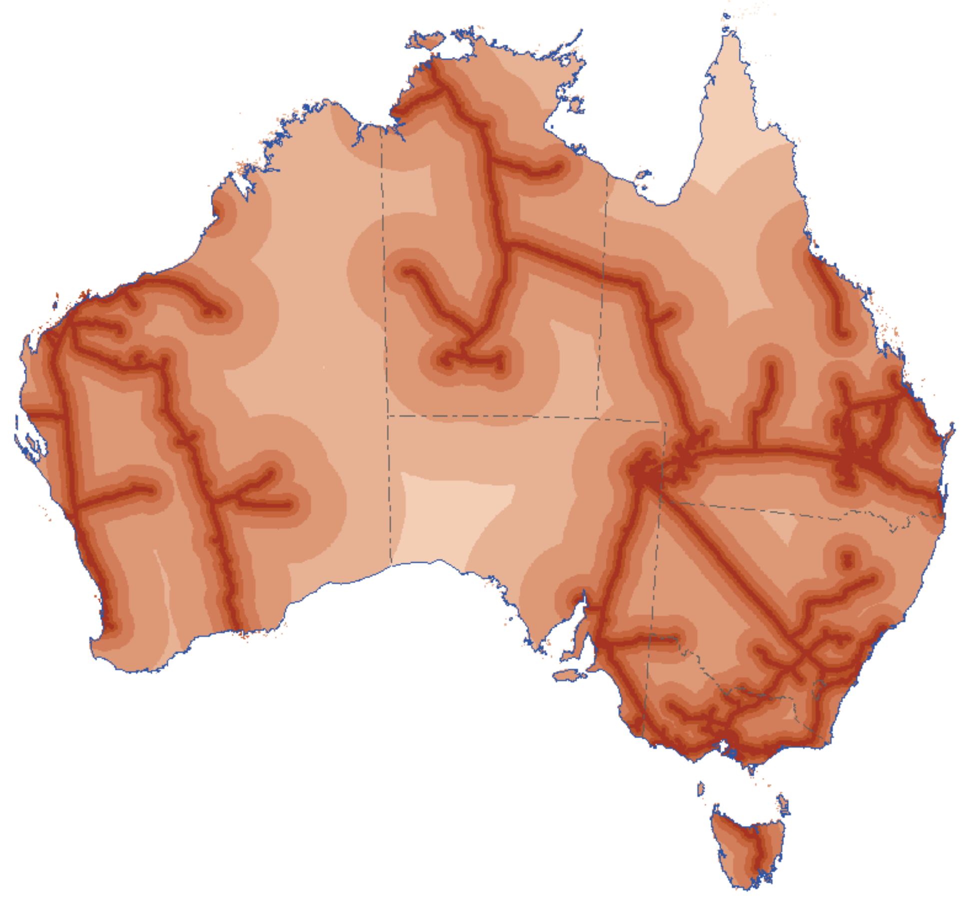
Table A-13: Input dataset - Distance to existing power grid (I004).

Metric	Distance to existing power grid (I004)
Dataset/s	Transmission line and substations
Data source	Geoscience Australia
Method	• Transmission lines with a connection to the coastline selected from input dataset. • Substations coinciding with selected transmissions lines selected. • Buffered transmission lines and substations by 500m • Merged two datasets • Reprojected to GDA 1994 Australia Albers • Calculated Euclidean distance • Reclassify input raster as per table below • Snapped and masked to snap raster
Map	

Scoring: Distance to electricity grid.

Score	Indicator
1	> 100km
5	75-100km
6	50-75km
7	25 to 50km
8	10-25km
9	5-10km
10	<5km

Table A-14: Input dataset - Pipelines (I005).

Metric	Pipelines (I005)
Dataset/s	Petroleum Pipelines
Data source	GPinfo, a Vela Software Inc product
Method	• Operational Gas pipeline features extracted from pipelines dataset • Reprojected to GDA 1994 Australia Albers • Calculated Euclidean distance • Reclassify input raster as per table below • Snapped and masked to snap raster
Map	

Scoring: Distance to gas pipeline.

Score	Indicator
1	> 5000km
2	2000-5000km
3	1000-2000km
4	500-1000km
5	250-500km
6	100-250km
7	50-100km
8	25-50km
9	10-25km
10	<10km

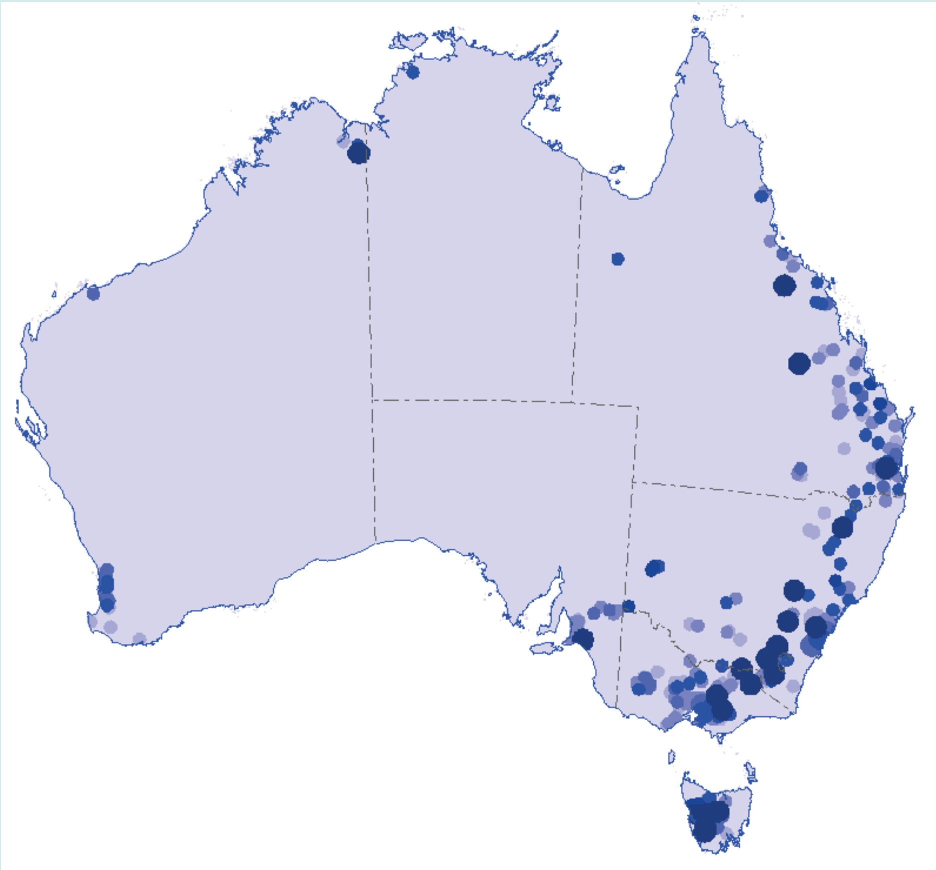
Table A-15: Input dataset - Coastal water (W001).

Metric	Coastal water (W001)
Dataset/s	Australian Coastline
Data source	Geoscience Australia
Method	• Convert coastline to polylines • Reprojected to GDA 1994 Australia Albers • Calculated Euclidean distance • Reclassify input raster as per table below • Snapped and masked to snap raster
Map	

Scoring: Distance to coast.

Score	Indicator
0	Not within 100km of coastline
1-5	Continuous score for distances 50-100km from coastline
5-8	Continuous score for distances 30-50km from coastline
10	Within 30km of coastline

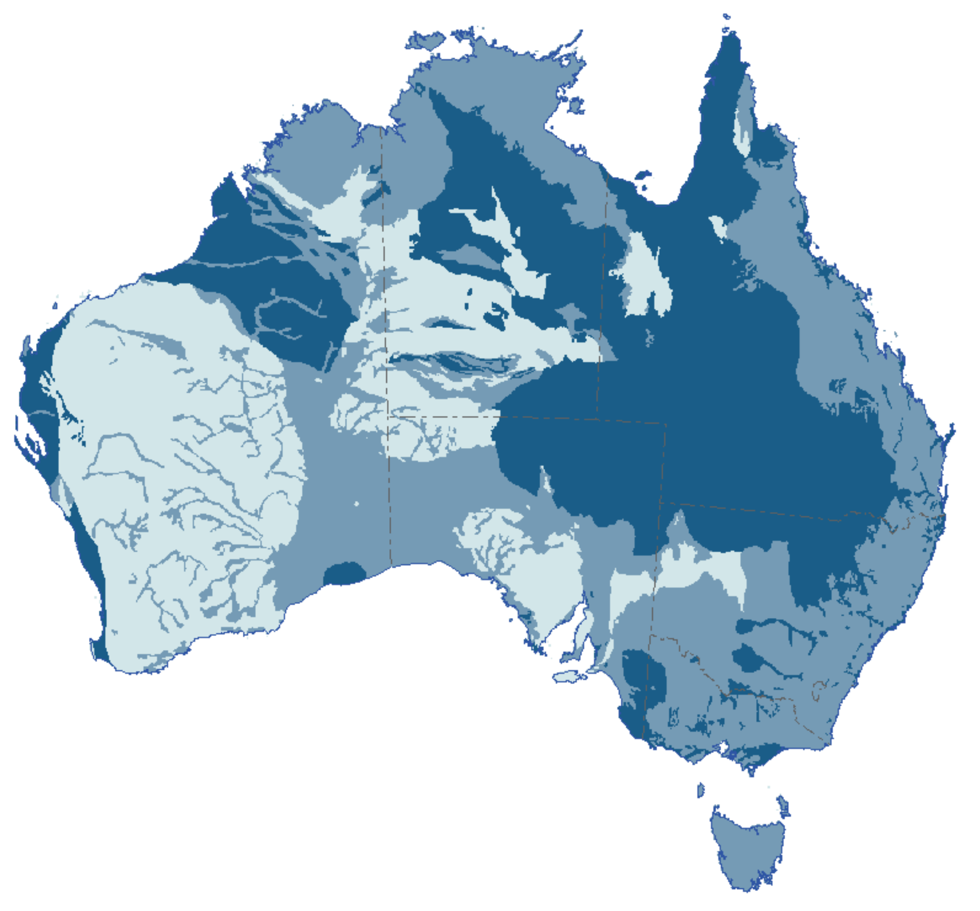
Table A- 16: Input dataset - Surface water (W002).

Metric	Surface water (W002)
Dataset/s	Water storage summary (BoM)
Data source	Bureau of Meteorology © Bureau of Meteorology
Method	• Buffer waterbodies by 50km for those >1000GL and in the Sydney and Melbourne classified region. Remaining features buffered by 30km • Reprojected to GDA 1994 Australia Albers • Reclassify buffered input data as per table below • Convert to raster • Snapped and masked to snap raster
Map	

Scoring: Surface water storage capacity (GL).

Score	Indicator
0	No data
1	<10GL
2	10-50GL
3	50-100GL
4	100-500GL
5	500-1000GL
6	>1000GL

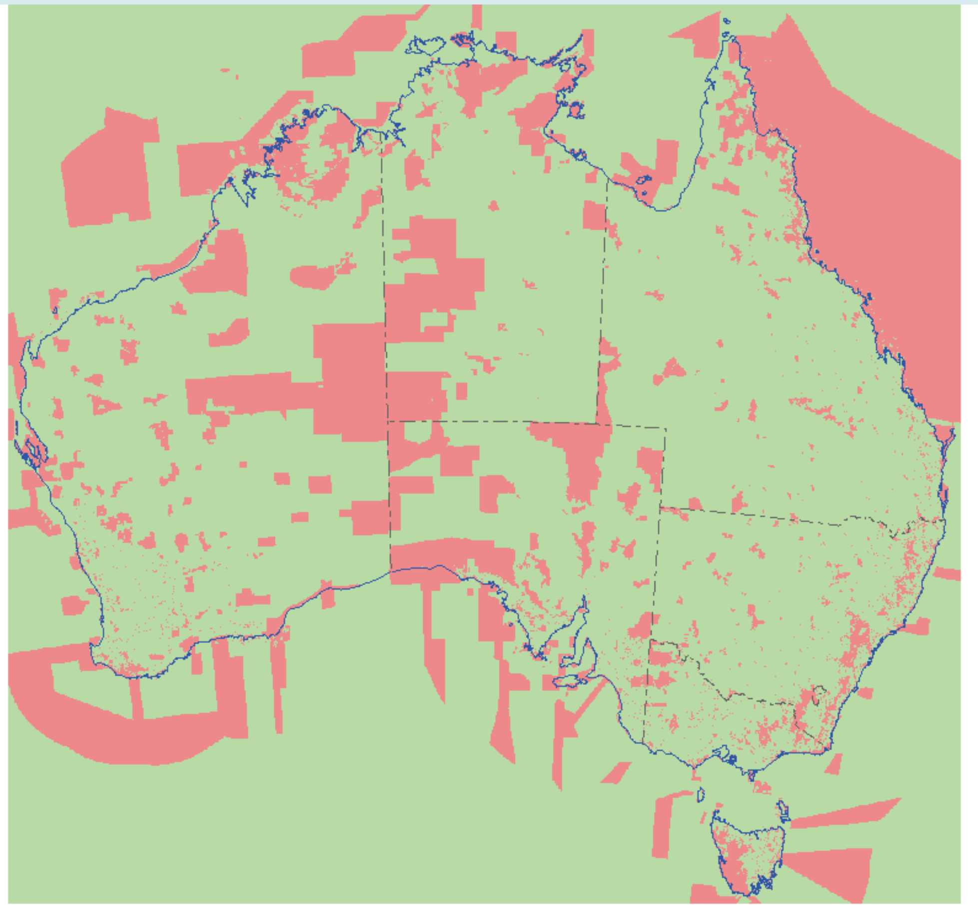
Table A-17: Input dataset - Groundwater (W003).

Metric	Groundwater (W003)
Dataset/s	Hydrogeology of Australia 1987
Data source	National Groundwater Information System © Bureau of Meteorology
Method	• Reclassify input dataset as per table below • Reprojected to GDA 1994 Australia Albers • Convert to raster • Snapped and masked to snap raster
Map	

Scoring: Presence of groundwater feature.

Score	Indicator
1	Local aquifers, of generally low productivity
5	Porous, extensive aquifers of low to moderate productivity Fractured or fissured, extensive aquifers of low to moderate productivity
10	Fractured or fissured, extensive highly productive aquifers Porous, extensive highly productive aquifers

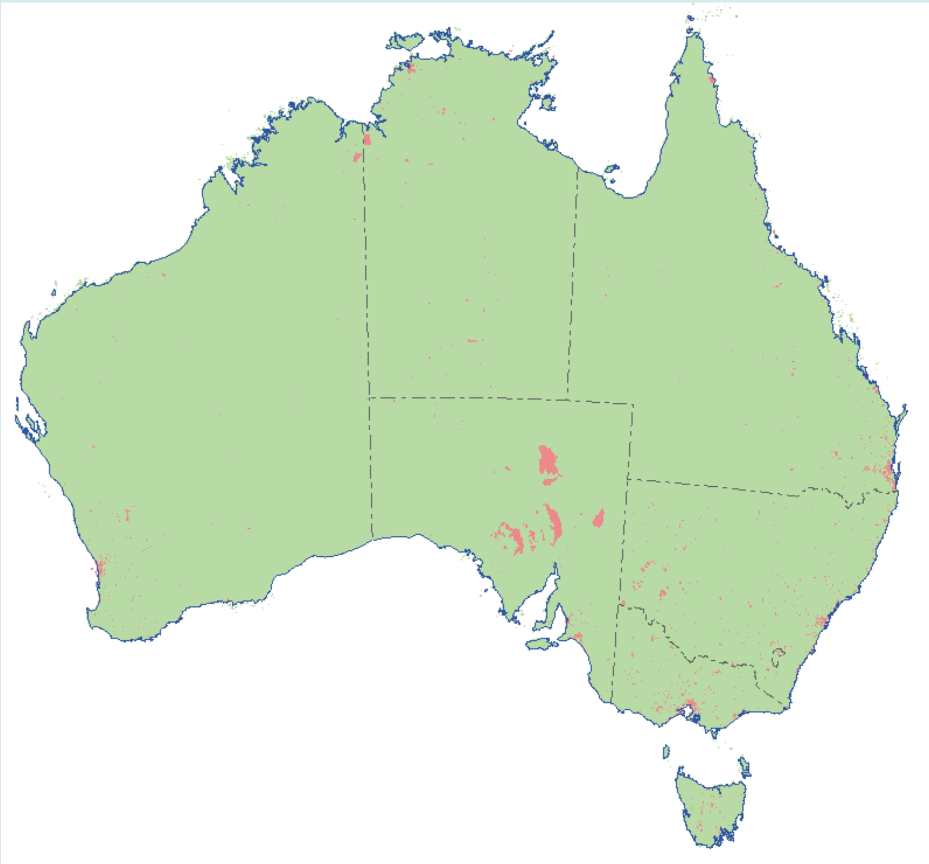
Table A-18: Input dataset - CAPAD feature (C001).

Metric	CAPAD feature (C001)
Dataset/s	Collaborative Australian Protected Areas Database 2016
Data source	Department of the Environment and Energy
Method	• Reclassify input data as per table below • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster • Note: Constraint layers are only scored between 0 and 1 as they are used as a mask for the final output.
Map	

Scoring: Presence of CAPAD feature.

Score	Indicator
0	No CAPAD feature
1	CAPAD features

Table A-19: Input dataset - Urban and Water (C002).

Metric	Urban and Water (C002)
Dataset/s	ABS Mesh Block 2016
Data source	PSMA Australia Incorporates or developed using Administrative Boundaries ©PSMA Australia Limited licensed by the Commonwealth of Australia under Creative Commons Attribution 4.0 International license (CC BY 4.0).
Method	• Residential, commercial, education, hospital/medical, transport and water classified Mesh blocks extracted from input data • Reclassify input data as per table below • Reprojected to GDA 1994 Australia Albers • Converted to raster • Snapped and masked to snap raster • Note: Constraint layers are only scored between 0 and 1 as they are used as a mask for the final output.
Map	

Scoring: Presence of feature.

Score	Indicator
0	All remaining classifications
1	Residential, commercial, education, hospital/medical, transport and water classifications