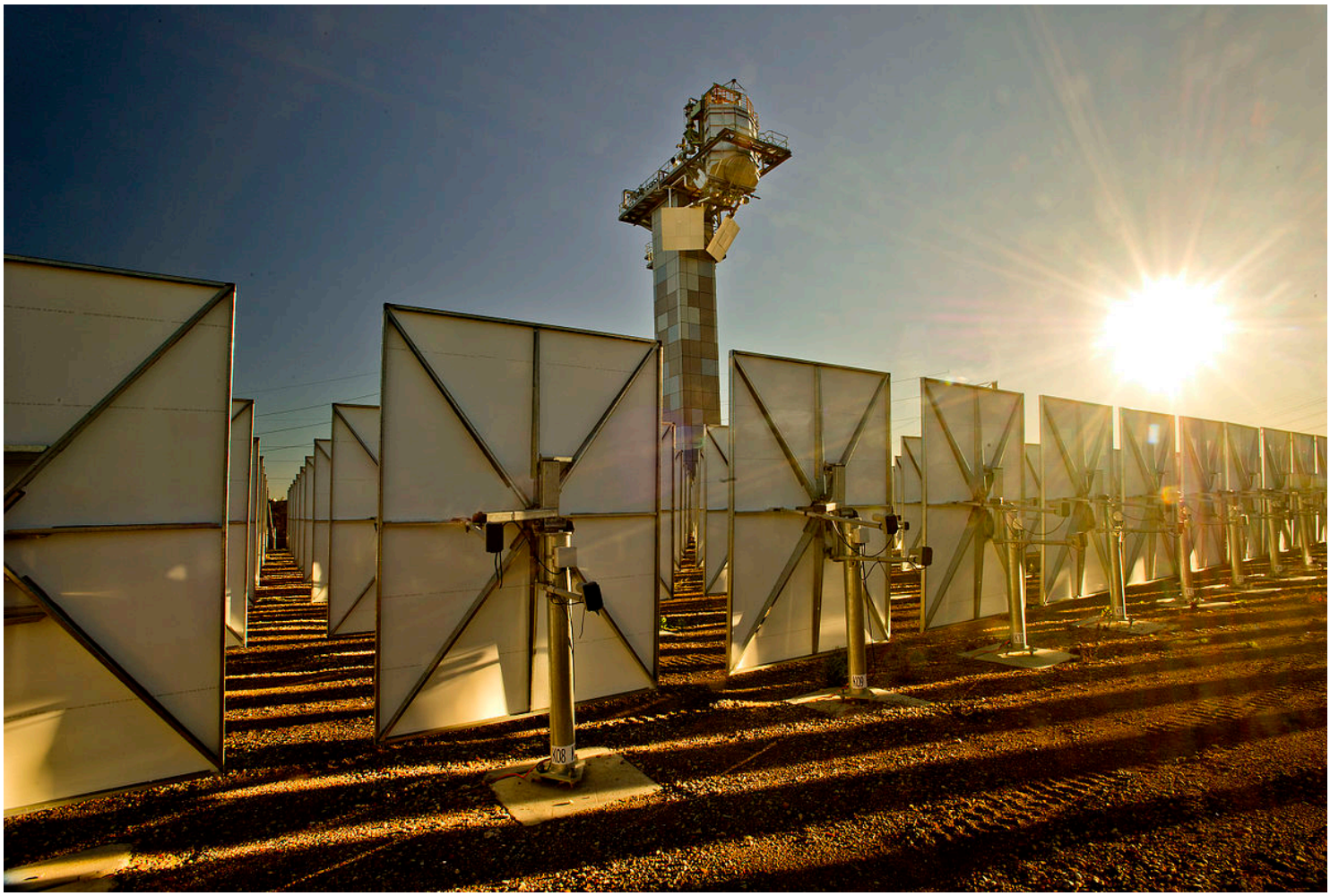

100% RENEWABLE ENERGY FOR AUSTRALIA

Decarbonising Australia's Energy Sector Within One Generation

Prepared for: GetUp! and Solar Citizens

UTS:ISF
INSTITUTE FOR SUSTAINABLE FUTURES

2016

ABOUT THE AUTHORS

The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human well-being and social equity. We seek to adopt an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

For further information visit: **www.isf.uts.edu.au**

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1 INTRODUCTION

The Institute of Sustainable Futures (ISF) at the University of Technology Sydney has produced an economic and technical scenario model for a transition towards a renewable energy system. The model describes Australia's future energy system, including an assessment of technology pathways and cost implications of three future energy scenarios. The model used by ISF was created by the German Aerospace Agency in cooperation with Greenpeace International and has previously been used to inform the German government's 'Energiewende' and climate mitigation scenarios for the Intergovernmental Panel on Climate Change (IPCC). This research was commissioned by GetUp! and Solar Citizens to provide the technical basis for the Homegrown Power Plan. The key results of the modelling are presented in Section 2, followed by methodology and assumptions in Section 3 and detailed results and cost analysis in Section 4.

1.1 GLOBAL CONTEXT

Global energy markets are rapidly changing. Renewable energy technologies now constitute more than half of the new power plants built worldwide each year[1]. In 2014, growth rates for coal use stalled globally for the first time, including in China. This trend continued through 2015[2]. Currently, oil and coal prices are at record lows, which has halted the development of most new coal and oil mining projects.

While electric vehicles still have a negligible share of global car transport this is likely to change as most international car manufacturers prepare for a massive shift toward electric vehicles. It is possible that the market for electric vehicles could follow the same exponential development pathways as the solar photovoltaic (PV) market. Between 2010 and 2015 solar technology suddenly took off, with increasing market shares and a significant drop in investment costs. Solar photovoltaic at the household level is now cheaper than retail electricity prices (tariffs) in most industrialised countries. As such, it is now cost-effective for many households to produce their own power.

Wind power is now the cheapest technology worldwide for new power plants. This led to a huge global market for wind with 63,000MW of capacity added during 2015 – equivalent to installing a new turbine every 10 minutes[3].

These global developments are already having an impact on Australia's energy market, and this impact can only increase in the coming years.

1.2 THE AUSTRALIAN CONTEXT

The fundamental shifts in the energy system globally, represent a huge opportunity for innovative energy interventions both in technologies and business models. This is happening at a time when the Australian Government has put science and innovation on the national agenda, investing in technologies and concepts to start an "ideas boom".

[1] REN21 (2015) *Renewables 2015 Global Status Report*, Paris, REN21 Secretariat. Available at: www.ren21.net/status-of-renewables/global-status-report/

[2] Li Junfeng, Director General at the National Climate Change Strategy Research and International Cooperation Centre: *The Guardian Interview*, 20th January 2016. Available at: www.theguardian.com/environment/2016/jan/19/chinas-coal-burning-in-significant-decline-figures-show

[3] Global Wind Energy Council (GWEC), February 2016: www.gwec.net/global-figures/wind-energy-global-status/

While most renewable power generation technologies are mature and ready for large-scale market deployment, there is still a need for system-supporting technologies that ensure Australia has a resilient power supply system into the future. Australia is very well positioned to tap into the new large-scale global renewable market with a well-known tendency to be an "early adopter" of technologies – especially information technologies.

The need to transform Australia's energy system is further strengthened by the ageing coal power plant fleet. Indeed, the age of the fleet necessitates an almost complete replacement within the next two decades. This opens up a historic window of opportunity to restructure Australia's power sector, moving from our current reliance on fossil fuels to a resilient and carbon-free renewable power system. Innovation is needed to develop new business models for future renewable power supply. At the same time, we can redefine the role of energy as a service rather than a commodity and to evolve the role of network companies and retailers as energy service organisations. International examples of power markets with a high share of renewable energy such as Germany, Denmark, Spain and USA states such as Texas have paved the way to 100% renewable energy is technically feasible, and our research indicates that Australia is in a good position to do likewise.

1.3 THE ROLE OF SCENARIOS IN ENERGY POLICIES

Scenarios are necessary to describe possible future development paths, giving decision-makers a broad overview outlining the implications of various options. A scenario is by no means a prognosis of what will happen, but an "if-then" analysis. The scenarios provide decision-makers with an indication of how they can shape the future energy system.

Three scenarios have been developed to show possible pathways for Australia's future energy supply system**:**

- **Reference scenario** based on Australian government forecasts and reflecting a continuation of the status quo.[4]
- **Renewable scenario** focused on renewable energy in the stationary power sector by 2030 while the transport and industry sectors remain dependent on fossil fuels.
- **Advanced Renewable scenario** for a fully decarbonised power sector by 2030 and a fully renewable energy supply system – including transport, and industry – by 2050.

Changes to energy markets require long term decision-making, because of the potential for changes in infrastructure to be required. They are not dependent on short-term market developments. Without long term planning for infrastructure, the power market cannot function optimally. Grid modifications and the roll-out of smart metering infrastructure, for example, require several years to implement. These technologies build the basis for the energy market and enable for energy trading.

It should be noted that long term energy scenarios have a different role to 'grid and dispatch' scenarios and simulate the energy system in annual or 5-year rather than 15-minute steps. Energy scenarios develop the 'big picture' for a country, while a grid or dispatch model develops the details on how to implement such a concept. This project uses one of the main models that underpinned Germany's "Energiewende", in which the German Government has a target of 80% renewable electricity by 2050.

This report specifically looks at energy generation. An important parallel stream of research is the analysis of organisations like CSIRO and others, for example through the Future Grid Research Program to better understand the role of and needs of Australian electricity grids in a future powered by increasing levels of renewable energy. The Institute for Sustainable Futures has developed its own grid investment model and has significant knowhow in grid modelling, with a number of other specialised power grid simulation models, however this analysis was not within the scope of this project.

[4] We note that some of the assumptions embodied in these forecasts, such as the replacement of existing coal power plants with additional coal power plants, are increasingly unlikely to be realised given the very factors covered in this report.

2 KEY RESULTS

2.1 KEY RESULTS FOR THE ADVANCED RENEWABLES SCENARIO

The transition to a 100% renewable energy system by 2050 is both technically possible and economically viable in the long term. This report presents two scenarios for transitioning towards a decarbonised energy system and a reference case based on current policies. The **Advanced Renewables** scenario is the focus of this report as it is the most ambitious scenario, resulting in a renewable electricity system by 2030 (for stationary energy) and a fully renewable energy system by 2050. The key results of the **Advanced Renewables** scenario are presented below, and discussed in detail in report alongside the **Renewables** and **Reference** scenarios.

Power Sector

- The supply of electricity is 100% renewable by 2030 for stationary power.
- By 2035 97% of total electricity demand (including electrified transport) is supplied by renewables.
- Energy productivity doubles by 2030.
- All coal power plants shut down by 2030.
- Firm capacity remains at today's level of approximately 75% throughout the entire scenario period.

Transport Sector

- The supply of energy is 41% renewable by 2035, 64% by 2040 and 100% by 2050.
- Australia is independent from oil imports within one generation.

Industry Sector

- The supply of energy is 50% renewable by 2035 and 100% by 2050.
- Electricity use doubles by 2050 to replace direct fuel consumption.

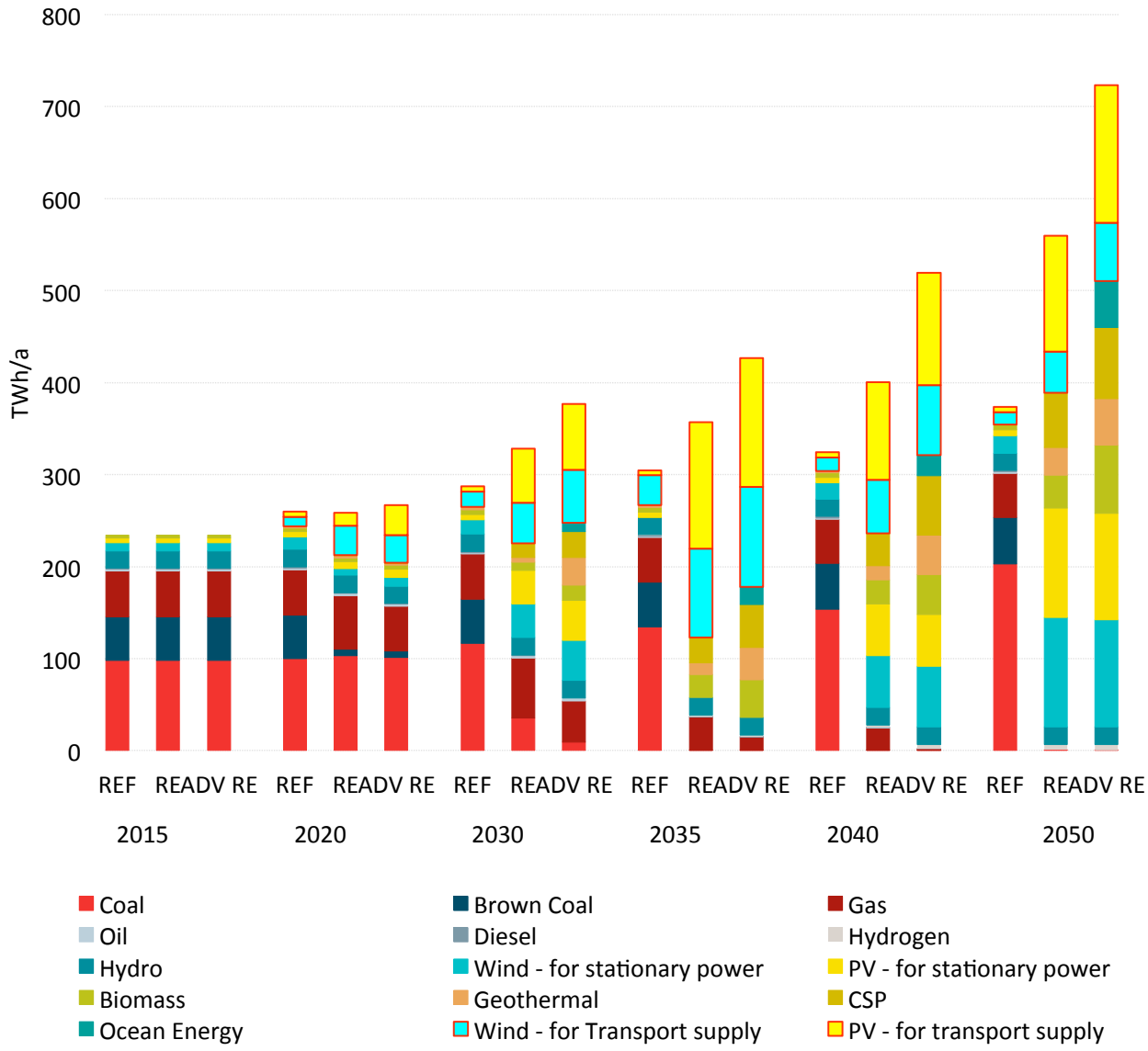
Primary Energy

- 41% of energy use across all sectors is renewable by 2030, 59% by 2035, 75% by 2040 and 96% by 2050.

Cost Analysis

- New capital investment in the power sector would almost entirely (99%) be directed to renewables and cogeneration until 2050.
- This results in higher investment costs of $800 billion out to 2050, compared to $150 billion in the Reference scenario. A large part of the additional investment in renewable power generation capacity goes towards meeting increased demand from the transport and heating sectors (as those sectors switch over to electricity), and towards generating synthetic fuels for use in those sectors.
- Because renewable technologies have no ongoing fuel costs, power sector fuel savings of $340 billion and transport fuel savings of $400 billion more than compensate for the higher investment costs, a net saving of $90 billion.
- The combined power and transport fuel cost savings would cover around 110% of the capital investment cost. New renewable power generation needed for a 100% renewable energy system can therefore be financed by fuel cost savings before 2050.

Figure 1: Breakdown of electricity generation by technology



3 METHODOLOGY AND ASSUMPTIONS

3.1 MODELLING OVERVIEW

The modelling approach used in this research is the development of target-orientated scenarios. In this approach a target is set and technical scenarios are developed to meet this target and then compared to a reference case. The scenarios are based on detailed input data sets, which take into account defined targets, renewable and fossil fuel energy potential and specific parameters for power, heat and fuel generation in the energy systems. The data sets are then fed into a model developed by DLR that uses MESAP/PlaNet software, an accounting framework for the calculation of the complete energy system balance to 2050.

The simulation model PlaNet that includes MESAP, an energy and environmental planning package (MESAP, 2008), was created to assist long-term strategic planning at a national, regional, or local level. PlaNet consists of two independent modules:

1. A flow calculation module, balancing energy supply and demand annually; and
2. A cost calculation module for the calculation of the corresponding generation and fuel costs.

The PlaNet flow calculation uses a set of linear equations, which can be solved sequentially. Note that this is not a dispatch model (such as UNSW CEEM's NEM simulation model), a cost optimisation model, DigSilent technical grid simulation model or a geo-spatial grid model (Such as the [R]E 24/7 model developed by Dr Teske). Rather, it is a bottom-up integrated energy balance model. Different modelling approaches each have their benefits and drawbacks. This model is particularly good at helping policy makers and analysts understand the relationships between different energy demand types in an economy.

Historically, heating, electricity and mobility have been quite separate in terms of their energy sources, requiring different infrastructure and therefore planning – electricity for stationary power, petrol and diesel for mobility and onsite heat for buildings and industrial processes. However, things are changing, with electricity projected to be used increasingly for heating and mobility (via electric vehicles). Thus, it is important to take an integrated approach across heat, mobility and electricity/stationary power when developing future energy system scenarios, as this model does.

In a simulation model, the user specifies the drivers of energy consumption, including forecast population growth, GDP and energy intensities.

Specific energy intensities are assumed for:

- Electricity consumption per person,
- The industrial heat demand to GDP ratio,
- Demand for energy services, such as useful heat, and
- Different transport modes.

For heat as well as electricity production, the model distinguishes between different technologies, characterised by their primary energy source, their efficiency and their costs. Examples include biomass or gas burners, heat pumps, solar thermal and geothermal technologies and several power generation technologies (PV, wind, biomass, gas, coal, nuclear, combined heat and power).

For each technology, the market share with respect to total heat or electricity production is specified according to a range of assumptions including targets, potentials, costs and societal, structural and economic barriers.

The main outputs of the model are:

- Final and primary energy demand, broken down by fuel, technology and sectors of the economy as defined by the International Energy Agency (IEA) – industry, power generation, transport and other (buildings, forestry and fisheries)[5],

[5] Note these industry sectors correspond to IEA energy statistics that are input to the model.

- Results broken down by the three main types of energy demand – electricity, heating and mobility (transport) – specifically, the energy required, technology deployment and investment costs for each of these types of energy demand.
- Total energy budget – the total cost of energy for the whole energy system, and
- Energy-related greenhouse gas emissions over the projection period.

3.2 OVERVIEW OF THE SCENARIOS

The average age of a power plant in Australia is 36 years[6] meaning most are reaching their optimal lifespan. For this reason, Australia needs to renew its power plant fleet over the coming decades. Building new power plants – no matter what technology – will increase production costs for generated electricity and increase wholesale market prices, because most coal power plants are fully paid off, so they are operating on marginal costs with no capital costs. The need to build new plants means that an increase in the cost of generation is therefore unavoidable.

With the decrease in the price of solar photovoltaic and onshore wind in recent years renewables have become an economic alternative to building new coal and gas power plants. As a result, renewables achieved a global market share of over 50% of all new build power plants in 2014 and 2015. Australia is blessed with some of the best solar and wind resources world-wide and renewables generation costs are generally lower than in other parts of the world. However constantly shifting policy frameworks have lead to high investment risks and therefore higher project development and installation costs for solar and wind projects relative to countries with more stable policy.

The scenario-building process for all scenarios includes assumptions on policy stability, the role of future energy utilities, nuclear power generation and carbon capture and storage (CCS), population and GDP, firm capacity and future costs.

- **Policy stability:** This research assumes that Australia will establish a secure and stable framework for the deployment of renewable power generation. In essence, financing a coal power plant or a wind farm is quite similar. In both cases a power purchase agreement, which ensures a relatively stable price for a specific quantity of electricity, is required to finance the project. Daily spot market prices for electricity and/or renewable energy or carbon are not sufficient for long-term investment decisions for power plants with technical lifetimes of 20 years or longer.
- **Strengthened energy efficiency policies:** Existing policy settings, namely those outlined in the National Energy Productivity Plan, will need to be strengthened in order to deliver on Australia's well-demonstrated potential to double energy productivity by 2030.[7]
- **Role of future energy utilities:** With 'grid parity' of rooftop solar PV under most current retail tariffs, this modelling assumes that the energy utilities of the future take up the challenge of increased local generation and develop new business models which focus on energy services rather than only selling kilowatt-hours.
- **Nuclear power generation and carbon capture and storage (CCS):** As they are not classified as renewable energy resources, the scenarios do not include these options in the modelled future energy mix as they fall outside the 100% renewable energy scenario definition. In the case of nuclear, high costs, uncertainties over social license to operate, and very long construction times (an average of 12 years based on all currently operating nuclear power plants worldwide[8]) would likely exclude this option from featuring in a rapid energy system transition. Uncertainties surrounding the technical and economic case for carbon capture and storage may also preclude that technology from featuring within a rapid energy system transition scenario.[9]

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[6] Climate Council (2014) *Australia's Electricity Sector: Ageing, Inefficient and Unprepared*, available at: http://www.climatecouncil.org.au/uploads/f9ba30356f697f238d0ae54e913b3faf.pdf

[7] ClimateWorks (2015) 'Australia's Energy Productivity Potential', ClimateWorks Australia, Melbourne, Victoria

[8] Mycle Schneider, Antony Froggatt et al. *World Nuclear Industry Status Report 2015*

[9] See, for example, Steffen, W (2015), 'Unburnable Carbon: why we need to leave fossil fuels in the ground', and Stock, A (2014), 'Australia's Electricity Sector: Ageing, Inefficient and Unprepared' Climate Council of Australia

- **Population and GDP:** The three scenarios are based on the same population and GDP assumptions. Projections of population growth are taken from the Australian Bureau of Statistics (ABS) while the GDP projection assumes long-term average growth of around 2.0% per year over the scenario period, as documented in Section 3.3.1.
- **Firm Capacity:** The scale of each technology deployed and the combinations of technologies in each of the three scenarios target a firm capacity in line with the current Australian energy system's firm capacity (75%). Firm capacity is the "proportion of the maximum possible power that can reliably contribute towards meeting peak power demand when needed."[10] Firm capacity is important to ensure a reliable and secure energy system. Note that fluctuating or variable renewables still have a firm capacity rating and the combination of technology options increases the firm capacity of the portfolio of options (see also 'security of energy supply' point in the RE scenarios).
- **Cost assumptions:** The same cost assumptions are used across the three scenarios. As technology costs decline with deployment scale rather than time, the renewable energy cost reduction potentials in both renewable cases may even be larger than in the reference case because market sizes are bigger. The reverse is true for the fuel cost assumptions as all three scenarios are based on low fossil fuel price projections, while both renewable scenarios have a significant drop in demand; the reference case assumes increased demand that might lead to higher fuel costs. As such, the costs should be considered to be conservative. The cost assumptions are documented in section 3.3.3.

3.2.1 The Reference Scenario

The **Reference scenario (REF)** reflects a continuation of current policies and is based on Australian Government forecasts. Energy statistics are taken from the International Energy Agency's "Energy Balances of OECD Countries 2016"[11] as well as "Australian Energy Update 2015" published by the Commonwealth Department of Industry, Innovation and Science[12]. The Australian energy demand projections use a combination of recent regulatory reporting forecasts where available, and the Australian Bureau of Resources and Energy Economics (BREE) Australian Energy Projections published November 2014[13]. Official market forecast sources include the Australian Energy Market Operator (AEMO) national electricity and gas forecasts[14] and the IMO 2015 Gas forecast for Western Australia[15]. This results in a forecast incorporating the most recent outlook from official sources where available.

[10] http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf
[11] International Energy Agency, 2015, *Energy Balances of OECD Countries.* Available at: https://www.iea.org/statistics/relateddatabases/energybalancesofoecdcountries/
[12] Department of Industry and Science. 2015. *2015 Australian energy update* Available at: http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aes/2015-australian-energy-statistics.pdf
[13] Commonwealth of Australia Bureau of Resources and Energy Economics. 2014. *Australian Energy Projections to 2049-50*. Available at: http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aep/aep-2014-v2.pdf
[14] Australian Energy Market Operator (AEMO). 2015. *National Electricity and Gas Forecasting.* [ONLINE]. Available at: http://forecasting.aemo.com.au/Electricity/AnnualConsumption/Operational
[15] Independent Market Operator (IMO). 2015. *Gas Statement of Opportunities*. Available at: http://wa.aemo.com.au/docs/default-source/Reserve-Capacity/november-2015-gas-statement-of-opportunities_v28968963f29c46dc8b2c9ff0000bd36b5.pdf?sfvrsn=0

3.2.2 Assumptions for both renewable scenarios

Both the **Renewables (RE)** and **Advanced Renewables (ADV RE)** scenarios are built on a framework of targets and assumptions that strongly influences the development of individual technological and structural pathways for each sector. The main assumptions considered for this scenario-building process are detailed below:

- **Emissions reductions:** Strong improvements in energy efficiency and the dynamic expansion of renewable energy across all sectors are the main measures to meet CO_2 emission reductions targets.
- **Renewables industry growth:** A dynamic growth in new capacities for renewable heat and power generation is assumed based on current knowledge about potentials (see energy potentials discussed in Section 3.3.5), costs and recent trends in renewable energy deployment.
- **Fossil fuel phase out:** The operational lifetime for coal power plants is conservatively estimated to be 40 years. In both scenarios brown coal power plants are phased out early on, followed by hard coal power plants and finally gas power plants.
- **Future power supply:** The capacity of large hydropower remains flat in Australia over the entire scenario period,[16] while the quantities of bioenergy grow within the potential for sustainable biomass for Australia (see dot point on sustainable biomass levels below). Wind power and solar power, both photovoltaic and concentrating solar power (CSP), are expected to be the main pillars of future power supply, complemented by smaller contributions from bioenergy, geothermal (hydrothermal and Enhanced Geothermal Systems [EGS]), and the future expansion of small and medium sized ocean energy. Note that solar PV figures combine both rooftop and greenfield development.
- **Annual renewable energy installation market:** In the process of defining the input assumptions for this modelling, ISF contacted the Clean Energy Council (CEC) to identify Australia's current and future potential renewable industry capacity in regards to installations (MW) per year for solar PV, concentrated solar power, wind, bioenergy and different forms of geothermal energy technologies. The annual installation numbers modelled between 2015 and 2020 for the Advanced Renewables scenario are in line with the capacities identified by the CEC.
- **Security of energy supply:** The scenarios limit the share of fluctuating or variable power generation and maintain a sufficient share of controllable, secured capacity. Power generation from biomass and CSP, as well as a share of gas-fired back-up capacities and storage, are considered important for the security of supply in a future energy system, related to the output of firm capacity discussed above.
- **Sustainable biomass levels:** The sustainable level of biomass use for Australia is assumed to be limited to 1500 PJ, based on background studies on sustainable biomass potentials[17]**.** Low-tech biomass use, for example inefficient household wood-burners, are largely replaced in the renewable scenarios by state-of-the-art technologies, primarily highly efficient cogeneration plants.
- **CSP technology:** CSP implementation after 2030 was assumed to have a solar multiple of three[18], which then enables thermal energy storage to provide energy for 12 hours per day of full-load operation of the turbine.

[16] Increased droughts due to climate change pose risks to large-scale hydro's potential to continue generating at the same level as it has in the past, a risk which may be partly addressed through efficiency upgrades to existing installations and the addition of run-of-river, mini and micro hydro schemes. Geoscience Australia and ABARE (2010), 'Hydro Energy', chapter 8, *Australian Energy Resource Assessment,* Canberra

[17] Global Biomass Potentials: Investigation and assessment of data Country-specific energy crop potentials, Remote sensing in biomass potential research, Global Biomass Potentials -Investigation and assessment of data, Country-specific energy crop potentials, Remote sensing in biomass potential research; Thilo Seidenberger et. al. (2008) German Biomass Research Centre

[18] Oversizing the heliostat field by three times, to ensure both peak output and overnight thermal storage.

- **Electrification of transport:** Efficiency savings in the transport sector are a result of fleet penetration with new highly efficient vehicles, such as electric vehicles, but also assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The scenarios assume a limited use of biofuels for transportation as the supply of sustainable biofuels is limited.
- **Hydrogen and synfuels:** Hydrogen and synfuels generated by electrolysis using renewable electricity is introduced as a third renewable fuel in the transportation sector, complementary to biofuels, the direct use of renewable electricity and battery storage. Hydrogen generation can have high energy losses; however the limited potentials of biofuels and mostly likely also battery storage for electric mobility mean it is necessary to have a third renewable option in the transport sector. Alternatively, this renewable hydrogen could be converted into synthetic methane and liquid fuels depending on economic benefits (storage costs vs. additional losses) as well as technology and market development in the transport sector (combustion engines vs. fuel cells).

3.2.3 The Renewables scenario

The **Renewables scenario (RE)** is designed to meet targets of halving Australia's energy related carbon dioxide emissions by 2035 and reducing them by 70% by 2050 compared to 1990 levels. These targets are in line with those that underpin ClimateWorks' Deep Decarbonisation Pathways modelling and are focused mainly on stationary power generation. Further to these targets are the objectives of phasing out all coal power plants by 2035, doubling energy productivity by 2030 and tripling it by 2050.

The energy efficiency projections for each sector are taken from research by ClimateWorks, ANU and CSIRO in "Pathways to deep decarbonisation in 2050"[19]. The renewable energy trajectories for the first decades are taken from the ClimateWorks projections with solar photovoltaic figures updated with market figures from the Australian PV Institute for 2015. Renewable energy markets are projected to grow at a rate equal to the renewable energy markets of OECD countries with consistent reliable energy policies over the past decade and into the next decade. In addition, pathways for the deployment of renewable energy and efficiency measures reflect the technology trends of the last few years and market estimations of the solar photovoltaic, wind industry and other innovative technologies.

This scenario includes significant efforts to fully exploit the large potential for energy efficiency, available through current best-practice technology. At the same time, various proven renewable energy sources are integrated, to a large extent for electricity generation and also to a lesser extent for the production of synthetic fuels and hydrogen for heating (domestic, commercial and industrial) and transport.

3.2.4 The Advanced Renewables scenario

The **Advanced Renewables scenario (ADV RE)** takes a more ambitious approach to transforming Australia's entire energy system towards 100% renewable energy supply. The consumption pathways remain almost the same as in the **Renewables scenario**, however under this scenario a much faster introduction of new technologies leads to a complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry) and transportation. The latter requires a strong role for storage technologies such as batteries, synthetic fuels and hydrogen.

The resulting final energy demand for transportation is lower compared to the **Renewables scenario** based on the assumptions that:

- Future vehicles and particularly electric vehicles will be more efficient and
- There will be greater changes in the transport mode-shift i.e. a greater use of public transport

[19] ClimateWorks Australia, ANU, CSIRO and CoPS, 2014, *Pathways to Deep Decarbonisation in 2050: How Australia can prosper in a low carbon world: Technical report*. Available at: http://www.climateworksaustralia.org/sites/default/files/documents/publications/climateworks_pdd2050_technicalreport_20140923.pdf

The Advanced Renewables scenario increases the share of electric and fuel cell vehicles. This scenario also relies on a greater production of synthetic fuels from renewable electricity for use in the transport and industry sectors. Renewable hydrogen is converted into synthetic hydrocarbons, which replace the remaining fossil fuels, especially for heavy duty vehicles and air transportation, albeit with low overall efficiency of the synfuel system. Note that since renewable synfuels would use the current gas infrastructure, they could, with investment, become an export industry for Australia, in addition to what is modelled in these scenarios. To compensate for the high energy losses associated with the production of synthetic fuels, this scenario requires more fundamental changes in mobility patterns, behaviour and infrastructure.

In the heating sector (mainly heat for industry) electricity and hydrogen play a larger role in substituting for remaining fossil fuels. In the power sector, natural gas is also replaced by hydrogen. Therefore, electricity generation increases significantly in this scenario, assuming power from renewable energy sources to be the main "primary energy" of the future.

The **Advanced Renewables** scenario also models a shift in the heat sector towards an increase in the direct use of electricity, because of the enormous and diverse potential for renewable power and the limited availability of renewable fuels for high-temperature process heat in industry. A rapid expansion in the use of district heating and geothermal heat pumps is assumed, leading to an increase in electricity demand, which partly offsets the efficiency savings in these sectors. A rapid expansion of solar and geothermal heating systems is also assumed.

The increasing shares of variable renewable power generation, principally by wind farms and photovoltaics, will require the implementation of smart grids and a fast expansion of transmission grids, storage, and other load balancing capacities. Other infrastructure needs will also result, for example from the increasing role of on-site renewable process heat generation for industries and mining and the generation and distribution of synthetic fuels. The **Advanced Renewables** scenario therefore assumes that such infrastructure projects will be implemented in all parts of Australia without serious societal, financial or political barriers.

Scenarios by no means claim to predict the future; they provide a useful tool to describe and compare potential development pathways out of the broad range of possible 'futures'. The **Advanced Renewables** scenario was designed to indicate the efforts and actions required to achieve the ambitious objective of a 100% renewable energy system and to illustrate the options available to change our energy supply system into one that is truly sustainable. They may serve as a reliable basis for further analyses of possible concepts and actions needed to implement pathways for an energy transition.

3.3 SCENARIO ASSUMPTIONS

3.3.1 Population and economic development

Future population and economic growth are important factors in energy scenario building because they affect the size and composition of energy demand, directly and through its impact on economic growth and development. For population the Australian Bureau of Statistics projections[20] are used (see Table 1) while GDP growth is assumed to converge with the long-term OECD average at 2.0% per annum over the next 35 years.[21]

Table 1: Australia's population projection

Year	2015	2020	2030	2040	2050
Population	22,000,000	24,000,000	28,000,000	32,000,000	40,000,000

[20] Australian Bureau of Statistics *3222.0 - Population Projections, Australia, 2012 (base) to 2101 - Series A* http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/3222.0main+features52012%20(base)%20to%202101

[21] OECD *Shifting Gear: Policy Challenges for the next 50 Years*, Economics Department Policy Notes, 24 July 2014.

3.3.2 Fuel price projections

Global oil prices have fluctuated dramatically over recent years and this has been considered in the price projections for this modelling. In the IEA's World Energy Outlook 2014 oil price projections by 2040 range from $100 per barrel in the '450-ppm scenario' up to $155 per barrel in the 'Current Policies scenario' (in 2013 USD). At the time of this analysis (January 2016), the oil price was at a historic low of only $30 per barrel with gas prices also showing significant fluctuation. The international coal price fell significantly and reached a low of $50 dollar per ton in early 2016.

To account for these fluctuations the IEA projections from 2014 have been adjusted to the fuel prices of January 2016, which were less than half the price originally projected for this year. While there are coal price projections for export coal[22], there are no long term price projections for domestic thermal coal. Furthermore Australian coal power plants do not pay the full international export price, a factor which can in many cases be classified as an effective subsidy.

The oil price assumption for all futures is taken from IEA World Energy Outlook 2014 '450-ppm scenario'.

Given the very high uncertainties of fossil fuel price projections, this research has taken into account the following cost projections for the power generation sector (coal and gas):

- The IEA WEO High Coal and Gas Price Scenario (WEO 2014)
- A continuing low coal price (as of January 2016) with the price staying at this current low price through to 2050.
- A low coal price (as of January 2016) with the price recovering (escalating) in line with the IEA's trajectory
- A low gas price (as of January 2016) with the price recovering (escalating) in line with the IEA's trajectory
- The average coal price of the past 5 years and prices increasing according to the IEA's trajectory.

Table 2: Development projections for fossil fuel and biomass prices in AUS$/GJ (Source IEA WEO 2014, DLR/GPI - Energy [R]evolution 2015)

in AUS$/GJ		2015	2020	2025	2030	2035	2040	2045	2050
Hard coal	IEA WEO High Price	5.9	6.5	7.5	8.0	8.4	8.9	9.3	9.6
	Historic low price	2.0	2.2	2.5	2.7	2.8	3.0	3.1	3.2
	Average price	2.9	3.2	3.8	4.0	4.2	4.5	4.6	4.8
	Current and continuing low price	2.9	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Natural gas	IEA WEO High Price	20.5	24.2	26.1	28.0	29.9	31.8	34.7	37.6
	Historic low price	6.8	8.1	8.7	9.3	10.0	10.6	11.6	12.5
	High price	9.8	11.5	12.4	13.3	14.2	15.1	16.5	17.9
	Current and continuing low price	9.8	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Crude oil	IEA WEO	23.2	27.2	29.3	31.4	31.4	31.4	31.4	31.4
Biomass and waste	DLR	4.5	4.9	5.2	5.5	5.8	6.0	6.4	6.7
	Biomass and waste	2.1	2.3	2.5	2.6	2.7	2.9	3.0	3.2

[22] Bullen, J., Kouparitsas, M. and Krolikowski, M; *Long-Run Forecasts of Australia's Terms of Trade*; Treasury Working Paper 2, 2014–01 http://www.treasury.gov.au/~/media/Treasury/Publications%20and%20Media/Publications/2014/Long%20run%20forecasts%20of%20Australias%20terms%20of%20trade/Documents/PDF/long_run_tot.ashx

These coal and gas fuel cost projections are combined into the following three possible fuel cost futures and in two cases a relatively low carbon price which the three scenarios are tested against:

1. A current and continuing low coal price, with a low gas price and no carbon price
2. A low coal price, a low gas price and a carbon price of $20/tonne in 2020 rising to $30/tonne in 2030 and staying stable at this price until 2050
3. The average coal price, high gas price (from IEA WEO) and a carbon price as in 2.

It should be noted that the impact of the carbon price is only relevant to the resulting costs of electricity generation as outlined in Section 4.2.2. In this model a carbon price is not applied to the investment cost or the fuel costs, and is therefore not assumed in the calculation of the fuel cost savings delivered by either renewable scenario.

3.3.3 Cost projections for investment, operation and maintenance costs

The assumptions for the specific investment and operation costs of coal, gas, brown coal and oil power plants have been made according to the World Energy Outlook (WEO) 2014 Special Report on Investments[23]. Because these technologies are at an advanced stage of technology and market development, the potential for cost reductions is limited.

The different renewable energy technologies available today all have different costs, levels of technical maturity and development potential. While hydropower has been widely used for decades, other technologies, such as the gasification of biomass or ocean energy, have yet to find their way to market maturity. Other types of renewable technologies being employed today are at a relatively early stage of market development, while others already developed mature markets. It is expected, however that large cost reductions can come from technical advances, manufacturing improvements and large-scale production, unlike conventional technologies. The dynamic trend of cost developments over time plays a crucial role in identifying economically sensible expansion strategies for scenarios spanning several decades.

Some renewable sources by their very nature, including wind and solar power, provide a variable supply, requiring a revised coordination with the grid network. But although in many cases renewable energy technologies are 'distributed' - their output being generated and delivered locally to the consumer – they also have large-scale applications like offshore wind parks, photovoltaic power plants or concentrating solar power stations.

To identify long-term cost developments, learning curves have been applied to the model calculations to reflect how the cost of a particular technology changes in relation to the cumulative production volumes. For many technologies, the learning factor (or progress ratio) sits between 0.75 for less mature systems to and 0.95 and higher for well-established technologies. A learning factor of 0.9 means that costs are expected to fall by 10% every time the cumulative output from the technology doubles. Empirical data shows, for example, that the learning factor for PV solar modules has been fairly constant at 0.8 over 30 years whilst that for wind energy varies from 0.75 in the UK to 0.94 in the German market.

The ISF research partners, the German Aerospace Centre (DLR) Institute for Technical Thermodynamics, Technology and System-Analysis, developed cost projections for renewable energy technologies. Assumptions on future costs for renewable electricity technologies were derived from a review of learning curve studies of Lena Neij[24], the analysis of technology foresight and road mapping studies, including the European Commission funded NEEDS project (New Energy Externalities Developments for Sustainability)[25], the IEA Energy Technology Perspectives 2008, projections by the

[23] IEA 2014: *Power Generation in the New Policies and 450 Scenarios - Assumed investment costs, operation and maintenance costs and efficiencies in the IEA World Energy Investment Outlook 2014*, data file download: http://www.worldenergyoutlook.org/investment/

[24] Neij, L, 'Cost development of future technologies for power generation - a study based on experience curves and complementary bottom-up assessments', *Energy Policy* 36 (2008), 2200-2211

[25] www.needs-project.org

European Renewable Energy Council published in April 2010 ("Re-Thinking 2050") and discussions with experts from different sectors of the renewable energy industry.

In 2014 and 2015 DLR updated and revised those cost projection for the Greenpeace International Energy [R]evolution research[26]. Due to significant cost decreases between 2014 and 2016, recent market developments have been taken into account, leading to further reduction of cost assumptions – especially for photovoltaics and solar thermal power plants (including heat storage). However, to increase consistency in the modelling, cost assumptions from WEO 2014 are adopted for biomass power plants, hydro, wind power and ocean energy.

These cost assumptions – especially for the base years – have been adapted to current Australian costs on the basis of the Australian Power Generation Technology Report[27]. Future cost projections have been compared with several other projections, including the International Renewable Energy Agency (IRENA), Renewable Power Generation Costs in 2014.[28]

It should be noted that all the publications referred to above are within the same cost estimation range. These cost assumptions (investment, operation and maintenance costs) are detailed in Appendix A. It should be noted that the solar PV costs listed in Appendix A assume an average between rooftop and utility scale solar PV, as it is assumed that Australia will see both.

3.3.4 Assumptions for hydrogen and synfuel production from renewable electricity

In the **Advanced Renewables** scenarios hydrogen and sustainable synthetic fuels (synfuels) are introduced as a substitute for natural gas, and make up a significant share of transport fuels after 2030. Hydrogen is assumed to be produced via electrolysis, resulting in an additional electricity demand supplied by extra renewable power production capacity mainly from wind, PV and CSP.[29] Renewable hydrogen and synthetic fuels are essential for a variety of sectors:

- For the industry sector, hydrogen serves as an additional renewable fuel option for high-temperature applications, supplementing biomass in industrial processes, whenever direct use of renewable electricity is not applicable.
- The transport sector also increasingly relies on hydrogen as a renewable fuel, where battery supported electric vehicles reach their limitations and where limited biomass potentials restrict the extension of biofuel use. However, future application of hydrogen might not suffice to replace all fossil fuel demand, especially in aviation, heavy-duty vehicles and navigation. The **Advanced Renewables** study introduces synthetic hydrocarbons from renewable hydrogen, electricity and biogenic/atmospheric CO_2. These synfuels are introduced after 2030 and provide for the remaining fossil fuel demand that cannot be supplied by biofuels due to limited potentials**.**

3.3.5 Renewable Energy Potential

The renewable energy potential is taken from AEMO's 100% Renewables Study – Modelling Outcomes Report[30]. The energy potential figures are used to make sure each energy technology in the scenarios is within the maximum installable generation capacity (GW) and maximum recoverable electricity (TWh/year). AEMO's figures (see Table 3) estimate the energy resource available for each technology based on historical weather and spatial data, giving consideration to competing land uses, topography and population density. The Australian Energy Resource Assessments[31] (ABARE 2010 and 2014) were also reviewed but AEMO data was used as it is more conservative and comparable across technologies.

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[26] This research has been undertaken for more than 10 years and resulted in more than 100 country analyses
[27] CO2CRC Limited, 2015, *Australian Power Generation Technology Report*:, Australia, www.co2crc.com.au
[28] IRENA, *Renewable Power Generation Costs in 2014*, January 2014, Abu Dhabi, www.IRENA.org
[29] Note this is also good for balancing the energy system – on very windy and sunny days, where generation exceeds supply, the excess generation can be used to create syn-fuels.
[30] AEMO (2013) *100 per cent Renewables Study – Modelling Outcomes Report*. Retrieved from https://www.environment.gov.au/climate-change/publications/aemo-modelling-outcomes
[31] ABARE (2010, 2014) *Australian Energy Resource Assessments*. Retrieved from http://www.ga.gov.au/scientific-topics/energy/resources/australian-energy-resource-assessment

Table 3: Renewable Energy Potential (AEMO 2013)

Resource	Maximum installable generation capacity (GW)	Maximum recoverable electricity (TWh/year)
Wind – onshore (greater than 35% capacity factor)	880	3100
Wind – offshore (greater than 50% capacity factor)	660	3100
Solar – CST/PV	18,500 / 24,100	41,600 / 71,700
Geothermal (EGS)	5,140	36,040
Geothermal (HSA)	360	2,530
Biomass	16	108
Wave	133	275
Hydro	8	12
Total	25,700 / 31,300	86,800 / 116,900

Table 4 shows the required areas for three types of renewable energy technologies.

Table 4: Required area for Solar PV and Wind

Technology		Unit	2015	2020	2030	2040	2050
PV	Total installed capacity	GW	3	28	72	111	166
	Specific nominal capacity (per m2)	kW/m^2	0.14	0.15	0.16	0.17	0.17
	Area	km^2	22.3	174.2	449.2	654.4	976.5
Wind onshore	Total installed capacity	GW	4	13	29	37	47
	Average capacity	MW	2.0	3.0	3.5	4.0	4.3
	Number of plants	#	2,087	4,354	7,143	9,138	10,960
Wind offshore	Total installed capacity	GW	0	0	6	7	9
	Average capacity	MW	5.4	6.2	7.5	8.5	9.0
	Number of plants	#	0	0	797	1,011	1,022

4 RESULTS

In this section, we outline the key results across a range of areas, both in terms of the impacts and the costs of the different scenarios. First, we consider stationary energy, focusing on electricity generation, capacity and breakdown by technology. We then examine energy supply for heating, focusing on industrial heat supply. This is followed by a section considering the impacts and costs of the different scenarios on transport and on the development of CO2 emissions. The section ends with an examination of the final costs, outlining the required energy budget.

4.1 ELECTRICITY CONSUMPTION/DEMAND

To understand the results, it is first necessary to clarify the metrics used. Two of the main metrics used in the energy industry to analyse energy are primary energy consumption and final energy demand.

Final energy demand "is a measure of the energy that is delivered to energy end users in the economy to undertake activities as diverse as manufacturing, movement of people and goods, essential services and other day-to-day energy requirements of living."[32]

Primary energy consumption is defined as the "direct energy use at the source, or supply to users without transformation, of crude energy; that is, energy that has not been subjected to any conversion or transformation process."[33] Primary energy statistics often make the renewables share appear lower than other forms of energy. For example, IEA 2010 statistics listed the global primary energy share for nuclear energy as 6% and hydropower at 2%, however both technologies produced the same amount of power generation in Terawatt hours. This is due to the fact that nuclear power is a thermal process with an average efficiency of around 30% - thus the input of uranium (the primary energy resource) is therefore three times higher, than the final energy (3:1), while hydropower which does not involve a thermal process is calculated as final energy equals primary energy (1:1).

4.1.1 Final Energy Demand

Total final energy demand

Combining the population development GDP growth and energy intensity projections results in future development pathways for Australia's final energy demand under all three scenarios (Figure 2).

Under the Reference scenario, the total final energy demand increases by 54% from 3900 PJ/a in 2015 to 6000 PJ/a in 2050. In the basic **Renewables** scenario, final energy demand decreases by 8% compared to current consumption, equating to 3600 PJ/a of energy in 2050. The **Advanced Renewables** scenario results in further reductions due to a higher share of electric cars.

[32] http://www.seai.ie/Energy-Data-Portal/Frequently-Asked-Questions/Energy_Use_FAQ/
[33] https://stats.oecd.org/glossary/detail.asp?ID=2112

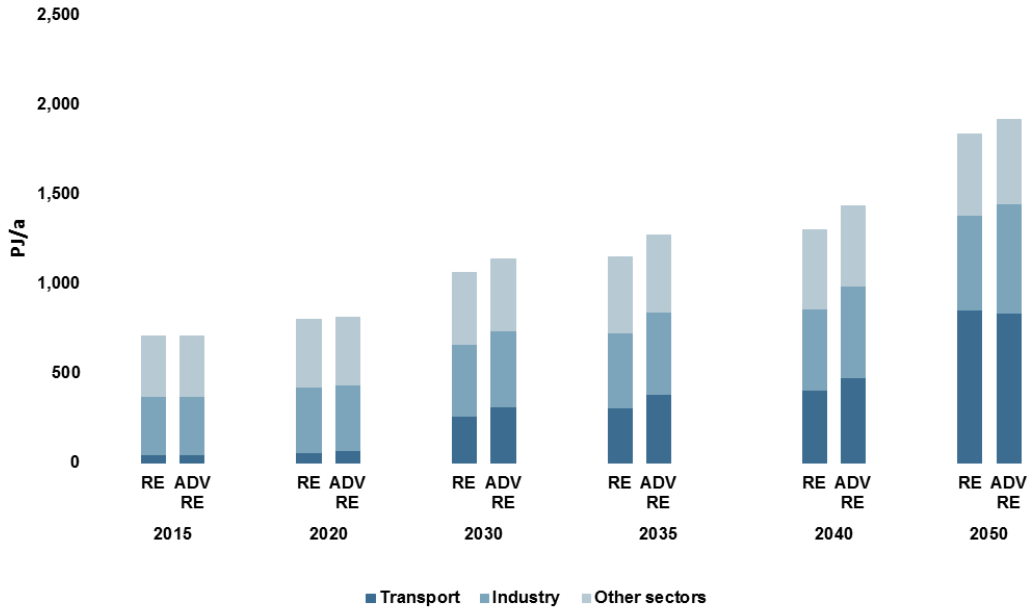
Figure 2: Projection of total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)

Final energy demand for electricity

Figure 3 shows the breakdown by sector of final energy demand drawn from electricity, excluding gas and oil used directly for transport, heating and industry. Under both renewable scenarios, overall electricity demand is expected to increase despite efficiency gains.

This reduction can be achieved in particular by introducing highly efficient electronic devices using the best available technology in all demand sectors. The transformation to a carbon free energy system in the **Advanced Renewables** scenario will further increase the electricity demand in 2050 up to 500 TWh/a. Electricity will become the major renewable 'primary' energy, not only for direct use for various purposes but also for the generation of synthetic fuels to substitute for fossil fuels. Around 230 TWh are used in 2050 for electric vehicles and rail transport in 2050 in the 100% scenario, around 50 TWh for hydrogen and 40 TWh for synthetic liquid fuel generation for the transport sector (excluding bunkers).

Figure 3: Development of electricity demand by sector in both renewable scenarios



Total electricity demand rises from 700PJ/a to approximately 1830PJ/a by 2050 in the basic **Renewables** scenario. This is due to economic growth, increasing living standards and electrification of the transport sector. However, compared to the Reference scenario, efficiency measures in the industry, residential and service sectors avoid the generation of approximately 80TWh/a (or 288 PJ/a). This reduction can be achieved in particular by introducing highly efficient electronic appliances using the best available technology in all demand sectors.

The transformation to a carbon free energy system in the **Advanced Renewables** scenario results in a greater increase in electricity demand by 2050 of 1900PJ/a. Under this scenario, electricity becomes the major renewable 'primary' energy, not only for direct use for various purposes (stationary electricity, electric vehicles, etc.) but also for the generation of synthetic fuels for fossil fuel substitution. In 2050 under the **Advanced Renewables** scenario, approximately:

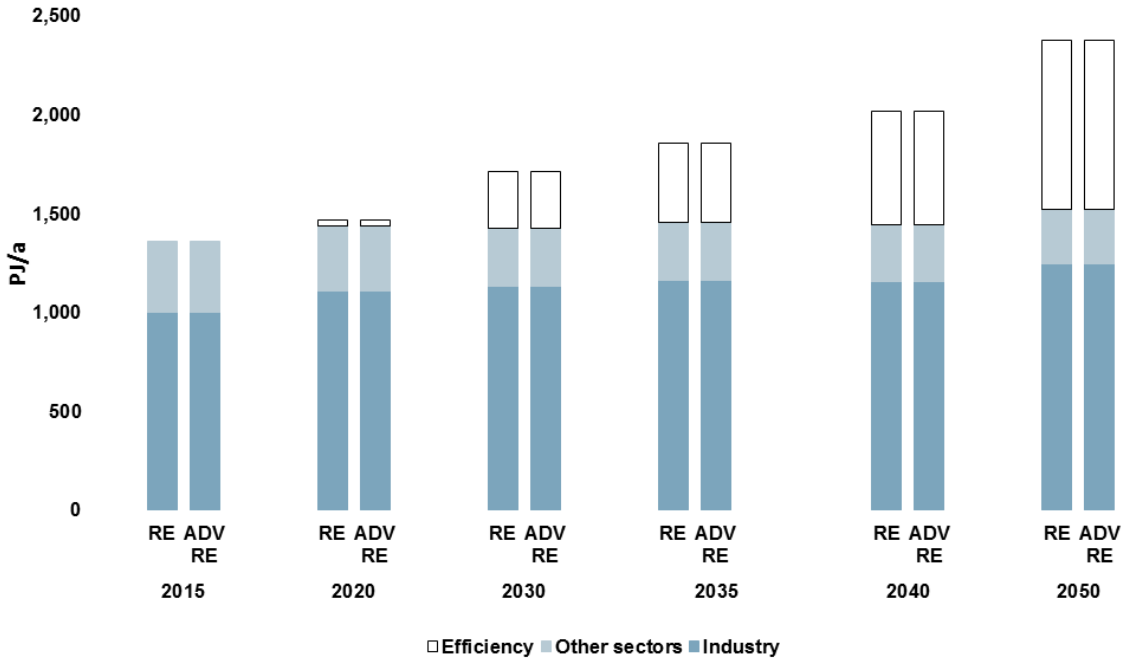
- 830PJ of electricity is used for electric vehicles and rail transport
- 180PJ of electricity is used for hydrogen production, and
- 145PJ of electricity is used for synthetic liquid fuel generation for the transport sector (excluding bunkers[34]).

Final energy demand for heat

Under both renewable scenarios, heat related final energy consumption equivalent to about 900 PJ/a by 2050 is avoided through efficiency gains compared to the Reference scenario (see Figure 4). These gains can be driven by energy-related innovation in industry and renovation of the existing stock of residential buildings, for example the introduction of low energy standards and 'passive climatisation' for new buildings, as well as highly efficient air conditioning systems. In this way the same level of comfort and other energy services is delivered by lower future energy demand. The efficiency gains in process heating - mainly in industry - are even larger than in the electricity sector.

[34] Bunker fuels: Fuels for international aviation and shipping

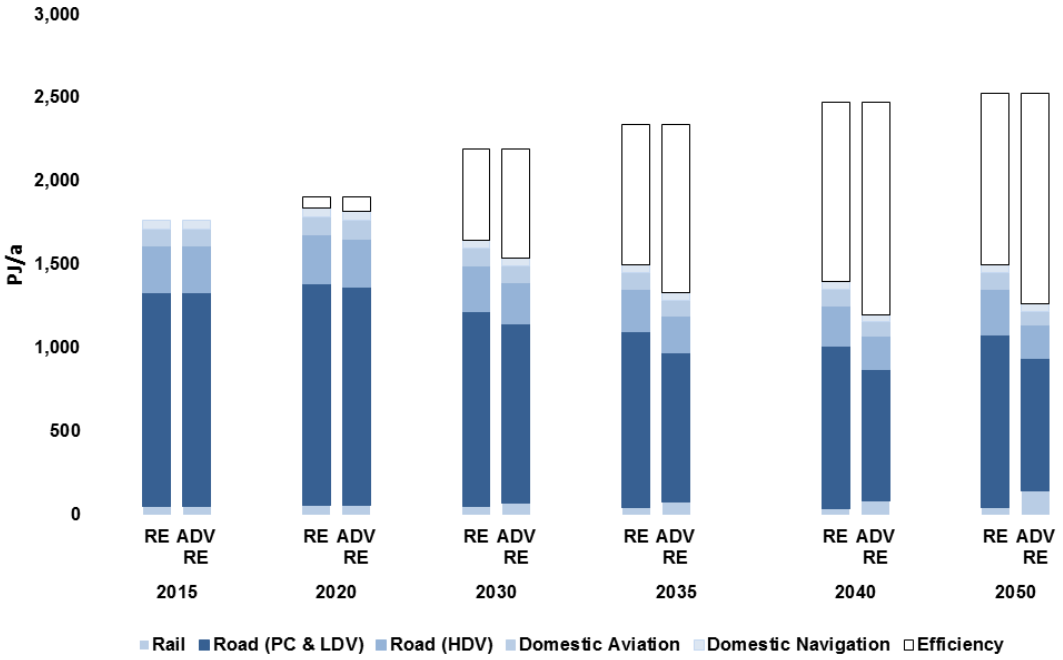
Figure 4: Development of heat demand by sector in the renewable scenarios



Final energy demand for transport

Figure 5 shows increased efficiency in transport energy demand, despite population and GDP growth in both renewables scenarios. In particular, there is a reduction of final energy demand for road transport due to electrification of vehicles (electrified vehicles are more efficient than combustion engines). There is a slight increase in final energy demand for rail due to mode shifting (i.e. increased public transport use) but this is relatively minor. In both renewables scenarios domestic aviation remains stable despite population growth, but goes up significantly in the Reference scenario.

Figure 5: Development of the final energy demand for transport by sector in the renewable scenarios



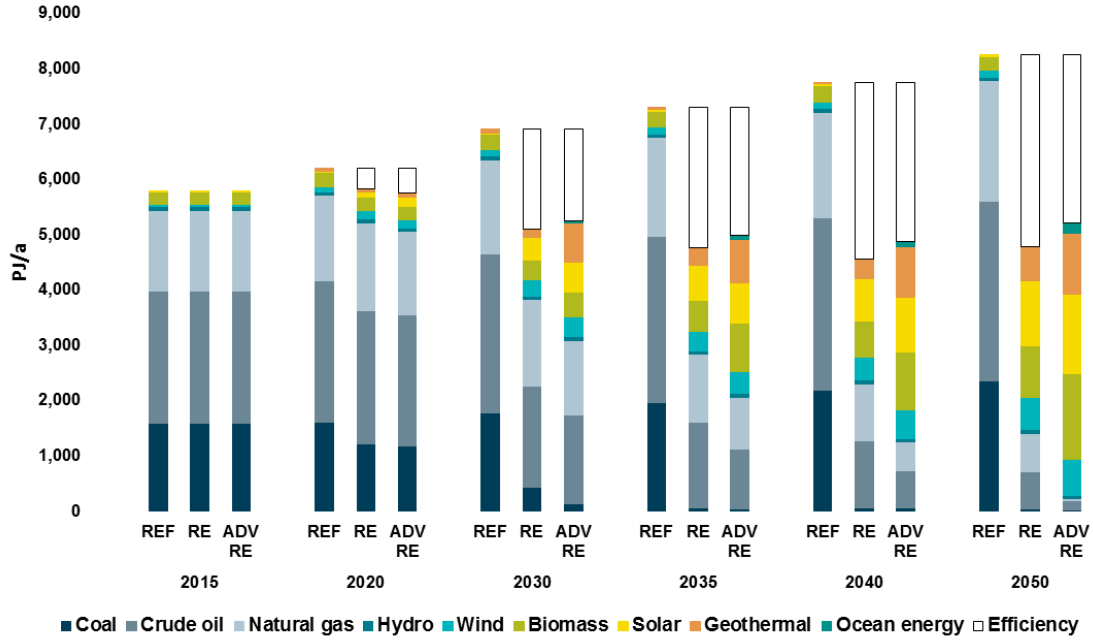
4.1.2 Primary energy consumption

The primary energy consumption under the three scenarios is shown in Figure 6, based on the modelling assumptions discussed in Sections 3.2 and 3.3. Under the basic **Renewables** scenario, primary energy demand decreases by 18% from today's 5800PJ/a to 4750 PJ/a in 2050. In the **Advanced Renewables** scenario the reduction is slightly less – 11% from today's level to 5200 PJ in 2050. Demand is lower under both renewables scenarios in comparison to the Reference scenario where primary energy demand is around 8000PJ in 2050. Overall primary energy demand is 42% lower in 2050 under the **Renewables** scenario and 36% lower in the **Advanced Renewables** scenario.

The **Advanced Renewable** scenario aims to phase out fossil fuels as fast as possible by expanding renewable energy and a rapid introduction of very efficient vehicles in the transport sector to replace oil based combustion engines. This leads to an overall renewable primary energy share of 59% in 2035 and more than 96% in 2050 – this includes non-energy consumption[35]. In the basic **Renewables** scenario the overall renewable primary energy share is slightly lower at 40% in 2030 and 70% in 2050 – this represents a 100% renewable *electricity* system, but with fossil fuels still providing energy for industry and transport needs. In contrast to the Reference scenario, no new coal power plants will be built in Australia in both renewable scenarios.

[35] "Non-energy use covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel." IEA - https://www.iea.org/statistics/resources/balancedefinitions/#nonenergyuse

Figure 6: Projection of total primary energy demand by energy carrier (incl. electricity import balance)



4.2 ELECTRICITY GENERATION

4.2.1 Electricity generation, capacity and breakdown by technology

The development of the electricity supply sector is characterised by a dynamic and growing renewable energy market and an increasing share of renewable electricity. This trend will more than compensate for the phasing out of brown and hard coal power production and continuously reducing the number of fossil fuel-fired power plants.

In the **Renewables** scenario:

- By 2050 97% of the electricity produced in Australia will come from renewable energy sources, with the remaining 3% from gas. 'New' renewables – mainly wind, PV and geothermal energy – will contribute 82% to the total electricity generation.
- The share of electricity production from renewable sources will be 33% by 2020, 68% by 2030 and 90% by 2035.
- The installed generation capacity of renewables will reach about 151 GW in 2035 and 260 GW in 2050.

In the **Advanced Renewables** scenario:

- By 2050 100% electricity supply will come from renewable energy sources, with 96.5% by 2035. If transport electrification is excluded, 100% of electricity supply for stationary power will come from renewable energy sources by 2030.
- The installed generation capacity of renewables will reach around 174 GW in 2035, and 310 GW in 2050
- Secure (firm) capacity remains at around 75% for the entire period, shifting from 74% in 2015 to 80% in 2035.

Figure 7: Breakdown of electricity generation by technology

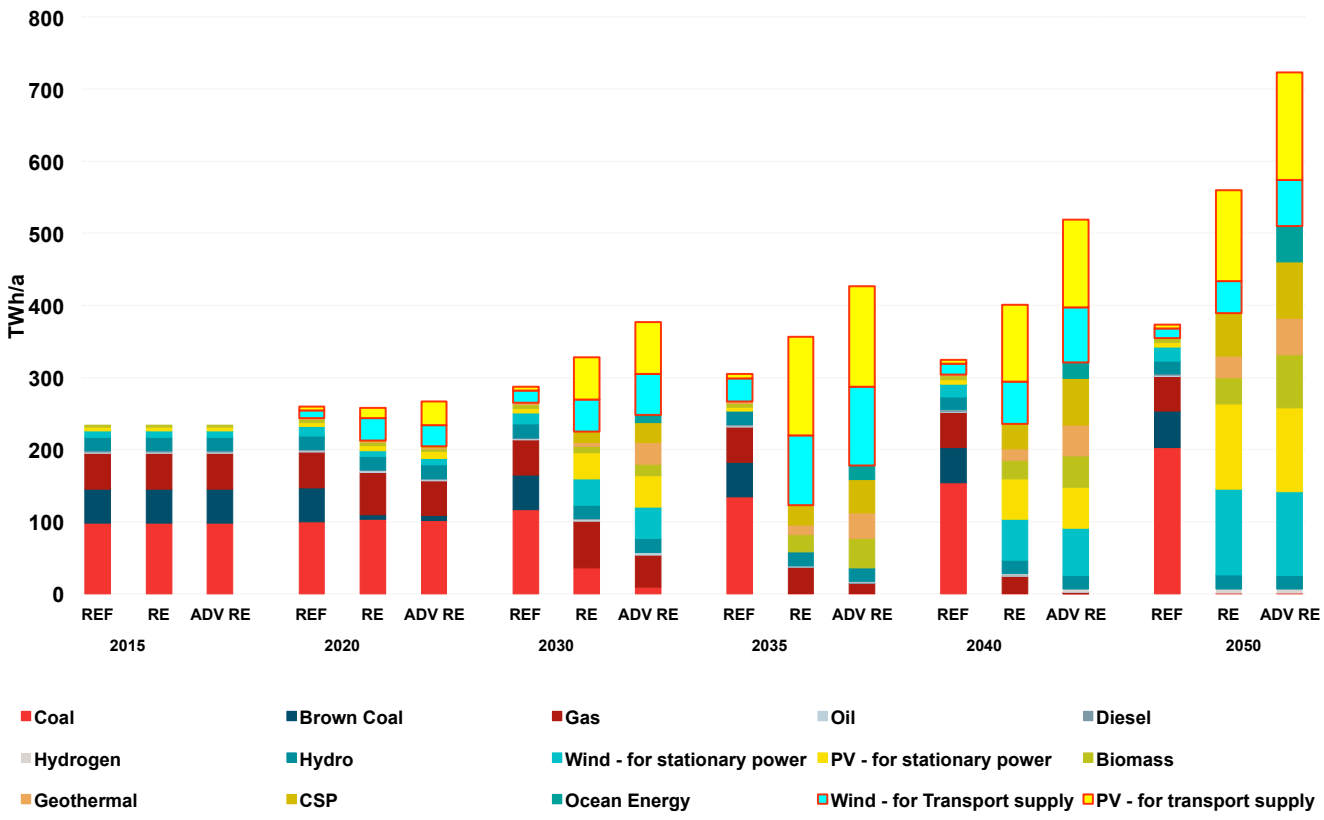


Figure 7 shows the structure of power generation by technology type. The supply for stationary power will reach 100% in 2030 under the **Advanced Renewables scenario,** with electricity generation for transport excluded. By 2020 there will already be solar PV and wind capacity dedicated to supply electricity for the transport sector, either for electrified public transport or individual transport vehicles.[36] Battery technologies as well as the production of synfuels for heavy duty vehicles, mining and shipping, will also be required for the transport sector where it is not connected to the grid. Geothermal and Concentrated Solar Power (CSP) plants will also be vital for providing additional dispatchable capacity while storage technologies will be expanded significantly after 2020 particularly in providing electricity for transport (see Section 4.4).

Table 5: Projection of renewable electricity generation capacity

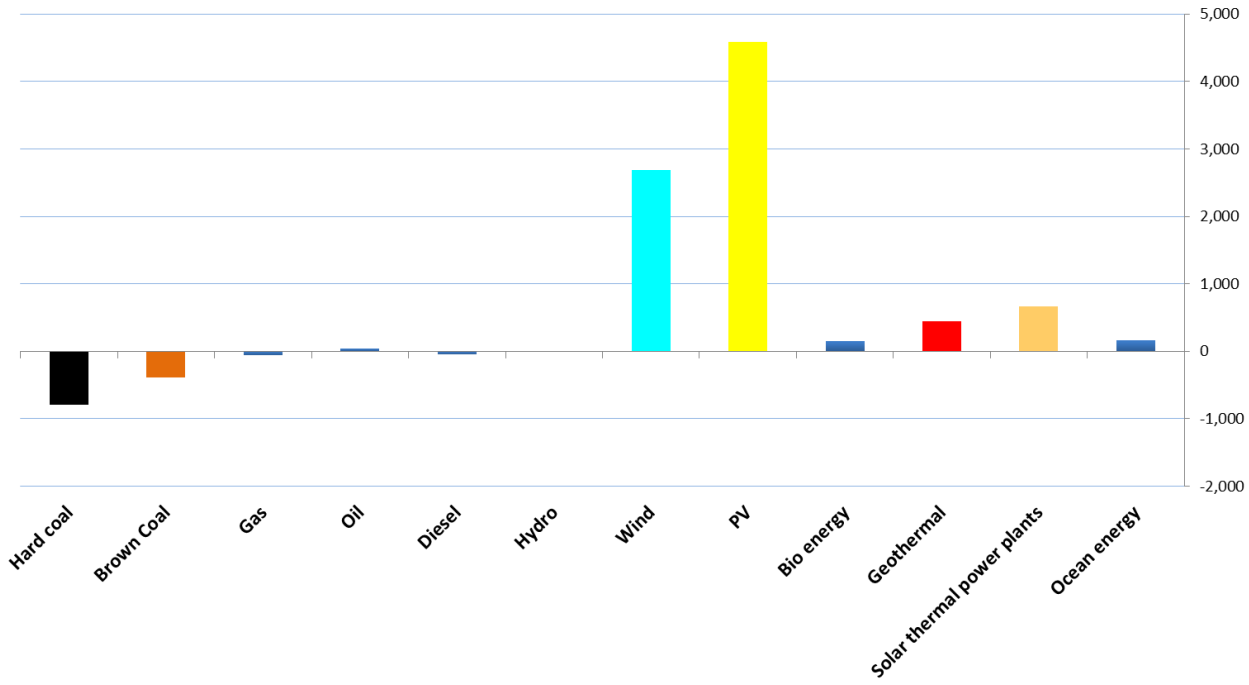
In GW		2015	2020	2030	2040	2050
Hydro	REF	8	8	7	7	7
	RE	8	8	8	8	8
	ADV	8	8	8	8	8
Biomass	REF	0	1	1	1	1
	RE	0	1	2	5	9
	ADV	0	1	3	8	20
Wind	REF	4	11	15	15	15
	RE	4	18	37	52	72
	ADV	4	18	45	63	80
Geothermal	REF	0	0	1	0	0
	RE	0	0	1	3	7
	ADV	0	0	7	9	10
PV	REF	3	3	4	4	4
	RE	3	14	59	102	153
	ADV	3	26	72	111	166
CSP	REF	0	0	0	0	0
	RE	0	0	6	7	12
	ADV	0	0	10	13	16
Ocean	REF	0	0	0	0	0
	RE	0	0	0	0	0
	ADV	0	0	3	6	13
Total	REF	15	23	28	27	27
	RE	15	41	113	176	260
	ADV	15	54	146	217	311

[36] Note this is already starting to happen with the NSW Government putting out a request for tender for renewable electricity to supply a new train line in Sydney. http://reneweconomy.com.au/2016/nsw-seeks-renewable-energy-to-power-north-west-rail-line-63247

Table 5 shows the comparative evolution of the different renewable technologies in Australia over time. By 2020 wind and solar PV overtake hydropower, which is currently the main renewable power source. After 2020, wind and solar PV will continue to grow, complemented by electricity from solar thermal, geothermal and ocean energy. Both renewable scenarios will lead to a high share of variable power generation sources (PV and onshore-wind) of 54% and 60% by 2030 and 79% and 83% by 2050, which underscores the importance of robust generation forecasts. Smart grids, demand side management (DSM), energy storage capacities and other options need to be expanded in order to increase the flexibility of the power system for grid integration, load balancing and a secure supply of electricity.

Figure 8 shows the average annual capacity changes in the Advanced Renewable scenario by electricity generating technology.

Figure 8: Average annual capacity change by technology in the Advanced Renewables case



The average annual installations for solar PV between 2015 and 2030 are at around 4,500 MW, only four times more than the PV market size of 2011, 2012 and 2015. The wind turbine installations will need to remain at 2,600 MW a year for the coming 15 years. This is equal to the development in the German wind power market between 1999 and 2014, a country smaller in area than New South Wales. There are neither space nor wind resource constraints to building the wind and solar capacities projected in the Advanced Renewables case until 2050 or exceeding this market size.

The renewable energy capacity will be built up in moderate annual steps, based on the experiences of other OECD countries of the past 15 years. Existing coal power plants will be retired step-by-step at a rate of approximately 750 MW per year, equal to one or two average coal power plant blocks.

4.3 ENERGY SUPPLY FOR HEATING

4.3.1 Industrial heat supply and breakdown by energy carrier

Renewables already supply around 10% of Australia's energy demand for heating, mainly in the commercial buildings and industrial sectors. This is mainly supplied from the use of biomass. Dedicated support instruments are required to ensure the development needed for renewable heating technologies for buildings and process heat production.

In the basic **Renewables** scenario, renewables provide 21% of Australia's total heat demand in 2030 and 49% in 2050. In the **Advanced Renewables** scenario renewables also supply approximately 25% of heat demand by 2030 and reach 100% by 2050.

Figure 9: Projection of heat supply by energy carrier

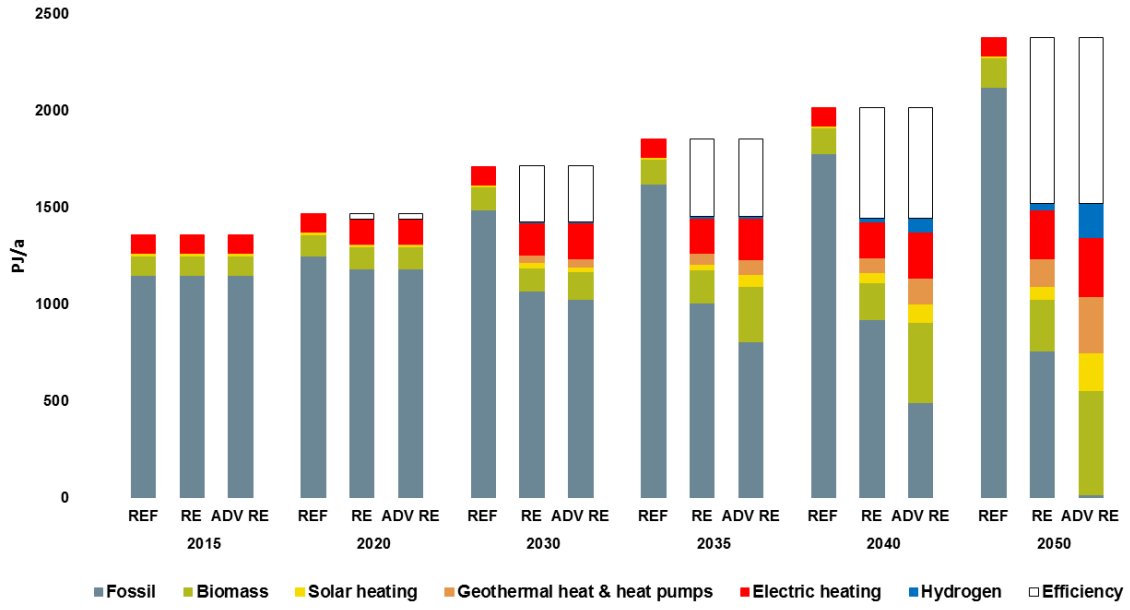


Figure 9 shows the projection of heat supply by energy carrier in Australia over time. In spite of improving living standards and economic growth, energy efficiency measures help to reduce the growing energy demand for heating by 36% between now and 2050 in both renewable scenarios (relative to the reference scenario). Biomass remains the main renewable energy source for heating, with increasing investments in highly efficient modern biomass technology. After 2030, a massive growth of solar collectors and a growing share of geothermal (including geothermal heat pumps) as well as heat from renewable hydrogen can further reduce the demand for fossil fuel based heating systems. A shift from coal and oil to natural gas in the remaining conventional applications leads to a further reduction of CO_2 emissions. The **Advanced Renewable** scenario results in a complete substitution of the remaining gas consumption by hydrogen generated from renewable electricity.

Table 6 shows the development of different renewable technologies for heating in Australia over time in terms of energy and Table 7 shows the installed capacity for each technology.

Table 6: Projection of renewable heat supply

in PJ/a		2015	2020	2030	2040	2050
Biomass	REF	105	110	118	132	149
	RE	105	111	120	190	264
	ADV RE	105	111	144	414	536
Solar heating	REF	11	11	11	11	11
	RE	11	10	26	52	68
	ADV RE	11	10	26	98	197
Geothermal heat & heat pumps	REF	0	0	0	0	0
	RE	0	7	39	76	145
	ADV RE	0	7	41	133	292
Hydrogen	REF	0	0	0	0	0
	RE	0	0	2	17	37
	ADV RE	0	0	2	72	177
Total	REF	116	121	129	143	160
	RE	116	128	187	334	514
	ADV RE	116	128	212	716	1,202

Table 7: Installed capacities for renewable heat generation

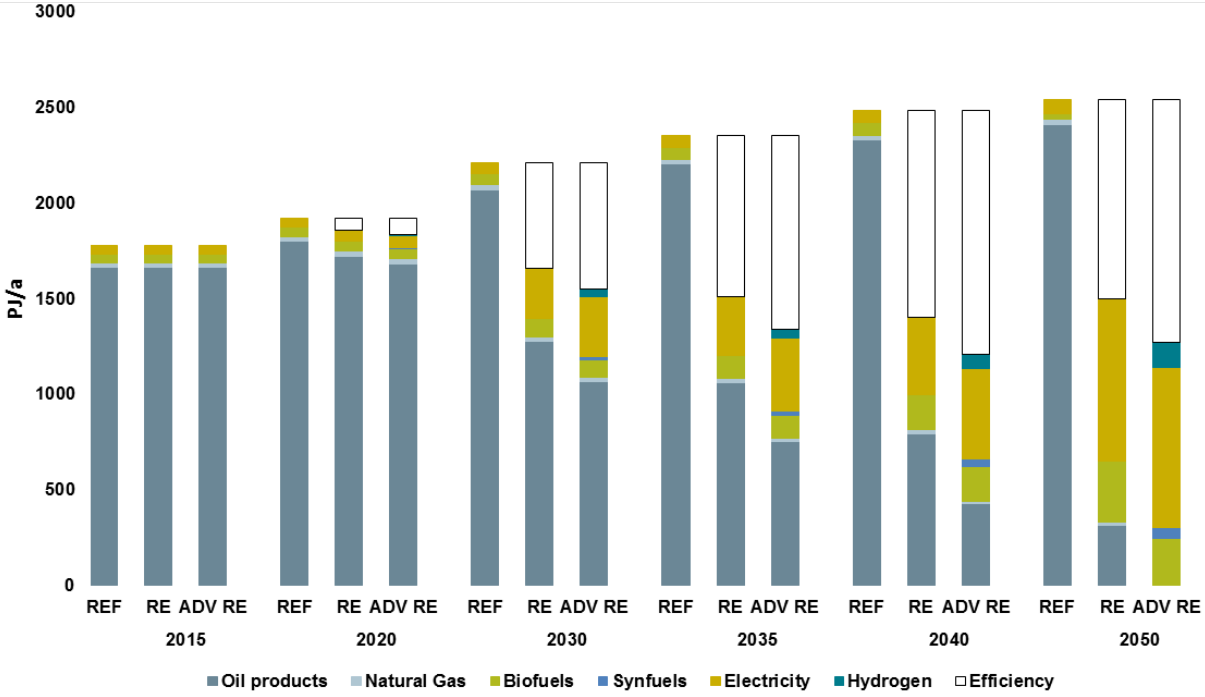
in GW		2020	2030	2040	2050
Biomass	REF	17	17	18	18
	RE	15	14	12	11
	ADV RE	15	15	30	43
Geothermal	REF	0	0	0	0
	RE	0	2	4	6
	ADV RE	0	2	5	9
Solar heating	REF	3	3	3	3
	RE	3	8	16	21
	ADV RE	3	8	31	61
Heat pumps	REF	0	0	0	0
	RE	1	5	8	15
	ADV RE	1	5	11	28
Total	REF	20	21	21	22
	RE	20	29	40	52
	ADV RE	20	30	77	140

4.4 TRANSPORT

To decarbonise the transport sector in Australia a key requirement is the introduction of incentives for people to drive more efficient vehicles. It is also vital to develop infrastructure to shift transport use to more efficient modes like rail, light rail and buses, especially in the expanding large metropolitan areas. These requirements, along with rising prices for fossil fuels, reduce the projected growth in car sales in both renewables scenarios in comparison to the projections in the Reference scenario.

Due to population increase, GDP growth and higher living standards, energy demand from the transport sector is expected to increase in the Reference scenario by around 40% to 2540 PJ/a in 2050. However in the **Renewables** scenario, efficiency measures and modal shifts will save 41% (1040 PJ/a) in 2050 in comparison to the Reference scenario. Greater modal shifts and technology switching will lead to even higher energy savings in the **Advanced Renewable** scenario of 50% (1270 PJ/a) in 2050 compared to the Reference scenario.

Figure 10: Final energy consumption transport under the scenarios



Highly efficient propulsion technology with hybrid, plug-in hybrid and battery-electric power cars and trains will bring about large efficiency gains. Table 8 shows the projection of transport energy demand by different modes in the **Renewables** scenario. Figure 10 shows the projection of transport energy supply by energy carrier in Australia over time. Specifically, it shows that electricity will provide 16% of the transport sector's total energy demand by 2030, while in 2050 the share will be 57%. In the **Advanced Renewables** scenario electricity would provide 66% of total energy demand by 2050. The remaining transport energy supply (up to 130 PJ/a or around 5%) will be delivered by biofuels, hydrogen and other synthetic fuels generated using renewable electricity.

Table 8: Projection of transport energy demand by mode

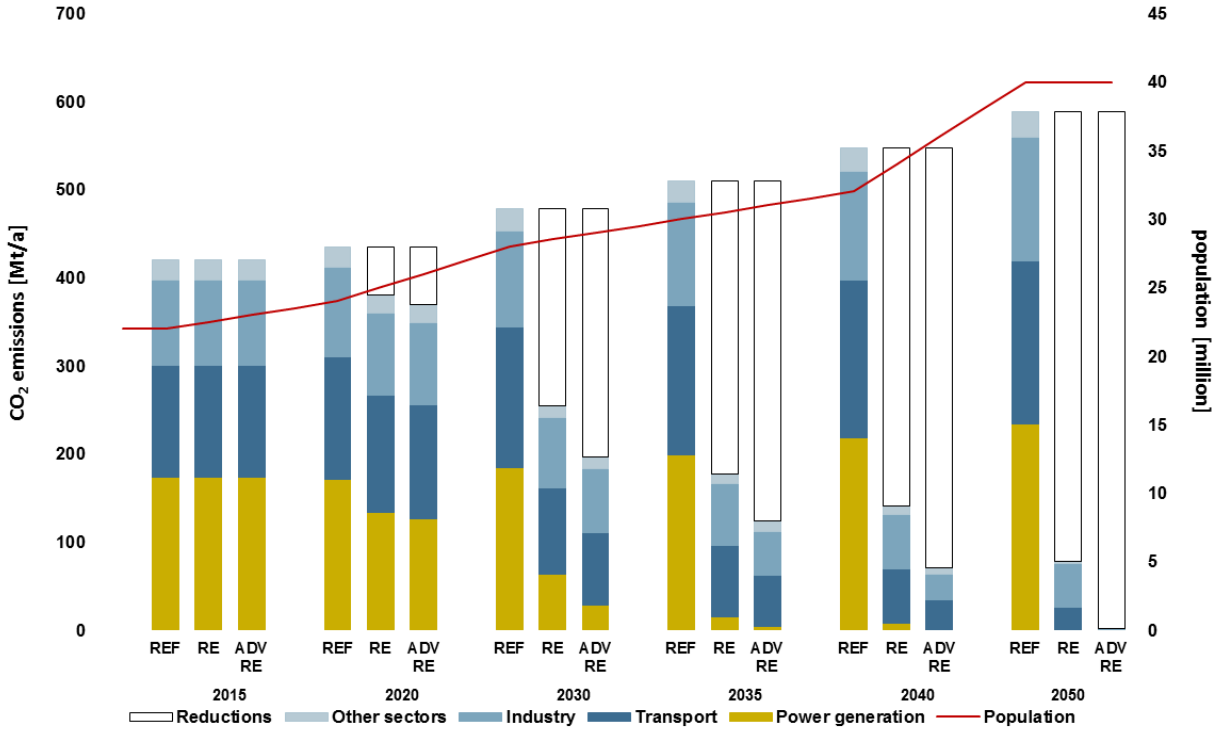
in PJ/a		2015	2020	2030	2040	2050
Rail	REF	52	56	64	72	80
	RE	52	56	50	42	45
	ADV RE	52	60	73	85	143
Road	REF	1,558	1,681	1,930	2,176	2,232
	RE	1,558	1,621	1,445	1,209	1,307
	ADV RE	1,558	1,596	1,320	987	998
Domestic aviation	REF	101	113	134	148	132
	RE	101	110	105	104	103
	ADV RE	101	109	99	88	80
Domestic navigation	REF	53	57	65	73	81
	RE	53	56	50	42	45
	ADV RE	53	56	50	42	45
Total	REF	1,764	1,907	2,194	2,470	2,526
	RE	1,764	1,843	1,649	1,397	1,500
	ADV RE	1,764	1,821	1,542	1,202	1,266

4.5 CO_2 EMISSIONS TRAJECTORIES

Figure 11 sets out Australia's energy greenhouse gas emissions resulting from modelling the three scenarios. In the **Advanced Renewables** scenario Australia's energy sector is completely decarbonised by 2050. By 2030 total energy sector emissions decrease to 206 million tonnes a year, with per capita emissions down to 7.0 tonnes from 19.1 tonnes. By 2035 emissions decrease to 120 million tonnes and annual per capita energy emissions from 19.1 to 4.0 tonnes. Comparatively, in the Reference scenario Australia's greenhouse gas emissions from energy increase by 40% between 2015 and 2050.

Under the **Renewables** scenario energy emissions decrease from 450 million tonnes in 2015 to 178 million tonnes in 2035. By 2050 emissions will decrease to 80 million tonnes and annual energy per capita emissions will drop from 19.1 tonnes at present to 2.0 tonnes by 2050. In spite of increasing power demand, energy greenhouse emissions will decrease in the electricity sector. In the long run efficiency gains and the increased use of renewable electricity in vehicles strongly reduce emissions in the transport sector as well. In the basic **Renewables** scenario, the Industry sector will be the largest source of emissions from energy, accounting for 62% in 2035 and 48% in 2050, with the remainder coming from the transport sector. In the Reference scenario power generation remains the largest source of emissions from energy.

Figure 11: Development of energy-related CO2 emissions by sector ('Reductions' = emissions reduction compared to the Reference scenario)



4.6 COST ANALYSIS

The previous sections have outlined the technical results of the modelling, and the following section outlines the results of the cost analysis. Specifically, the report sets out the following for the three scenarios:

- Capital investment costs to meet Australia's power (electricity) and heating needs,
- Fuel costs (and savings) to meet Australia's power, heating and transport needs,
- Impact of these capital and fuel costs on the electricity generation prices, and
- Combined energy budget for Australia including capital investment, operations and fuel costs.

As set out in the assumptions, it should be noted that there are costs and savings that are outside the scope of this research:

- Grid infrastructure costs, including the costs of smart meters and greater integration with communications technologies,
- Transport capital investment such as the cost of new cars or charging infrastructure, and
- Demand management and energy storage costs.

It should also be noted that these costs are Australia wide and are not an analysis of how consumer electricity bills will be impacted, as this involves a highly complex set of factors including the extent to which consumers own some of the generation infrastructure, price, volume and tariff structures, grid charges, as well as local network credits for decentralized generation.

4.5.1 Capital investment

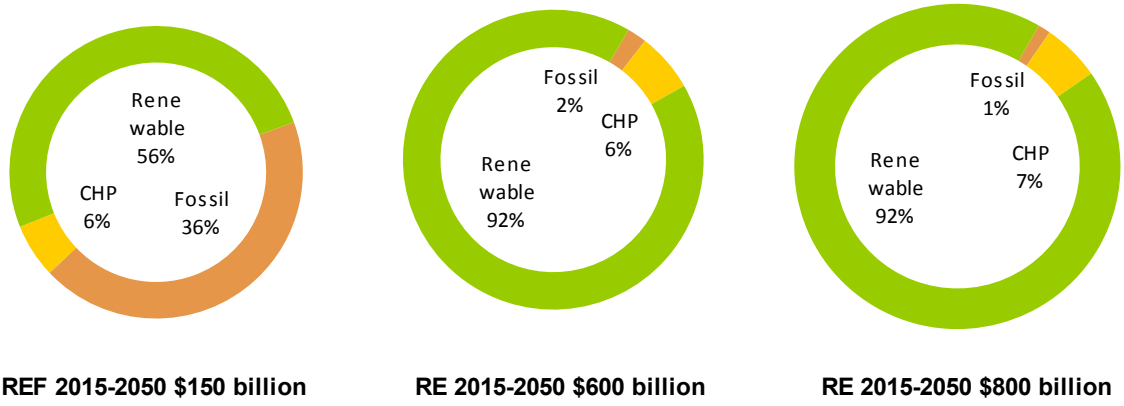
Electricity

Under the **Renewables** and **Advanced Renewables** scenarios Australia would shift almost 98% and 99% respectively of new power sector capital investment towards renewables and cogeneration between now and 2050 (see Figure 12). This will result in higher investment costs than the reference scenario, in significant part due to the fact that electricity becomes the 'primary' fuel to meet an increased proportion of Australia's heating and transport energy needs. We assume, as in almost every other country worldwide, that this will be private sector investment. As such, the power sector investment costs should not be considered in isolation from transport and heating costs – particularly operational/fuel cost savings (see Section 4.5.4 for the combined energy budget for Australia).

Around $600 billion will be required in investment in the power sector over the period to 2050 for the basic **Renewables** scenario, approximately $13.8 billion per year between 2015 and 2030 and on average $17 billion per year over the entire period until 2050. Investments for the **Advanced Renewable** scenario are around $800 billion until 2050, on average $22 billion per year between 2015 and 2030 and on average $23 billion per year over the whole time span. This includes investments for replacement after the economic lifetime of the current power plants. The costs increase slightly over time as the level of more expensive dispatchable renewables required grows. However, this also means there is time to bring these technologies down the cost curve to a greater extent than projected, and as such these investment projections should be considered to be conservative (i.e. on the high side of the likely costs).

In the **Reference** scenario the total investment would be around $150 billion. This includes the assumption that 4000 MW of new coal power plant capacity will be installed, replacing power stations to be closed by 2050 (we note however that this is unlikely to eventuate given current cost projections). Under the **Reference** scenario, conventional power plants account for approximately 43% of total power sector investment, while the remaining 57% would be invested in renewable energy and cogeneration technology.

Figure 12: Share of investment between renewable, fossil and CHP technologies by scenario



REF 2015-2050 $150 billion **RE 2015-2050 $600 billion** **RE 2015-2050 $800 billion**

Heating

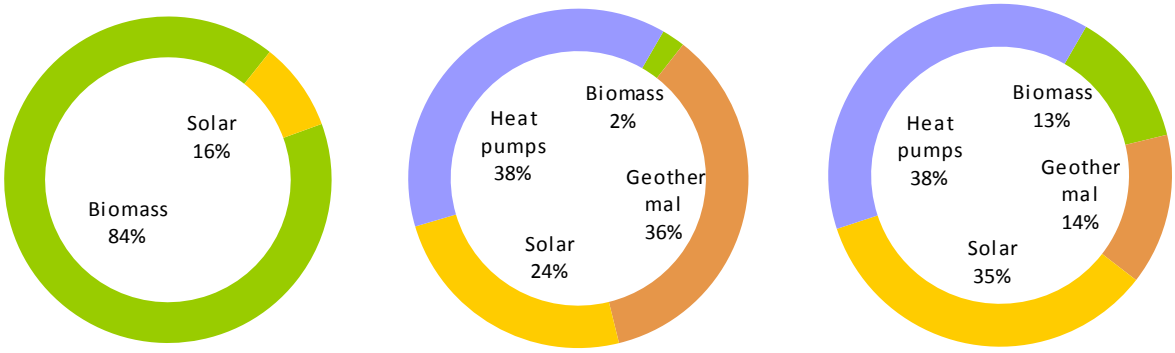
In the heating sector both renewable scenarios would require a major revision of current investment strategies in heating technologies. In particular, solar thermal, geothermal and heat pump technologies need an enormous increase in installations if their potential is to be tapped for the heating sector.

It should be noted that in Australia and around the world the costs associated with heating in the residential, commercial and industrial sectors are not well documented, particularly compared to the costs for electricity generation. Further, renewable heating technologies are extremely variable, from low-tech biomass generators or unglazed flat panel solar collectors to very sophisticated enhanced geothermal and solar systems. As such these results should only be considered an indicative estimate.

The modelling results estimate that the **Renewables** scenario in total requires around $90 billion to be invested in renewable heating technologies through to 2050 (including investments for the replacement of heating infrastructure after it reaches the end of its economic life). This equates to approximately $2 billion per year (see Figure 13).

The **Advanced Renewables** scenario assumes a more ambitious expansion of renewable technologies resulting in an average investment of around $4 billion per year. It should be noted that this analysis does not include the capital cost of increased electricity generation for direct heating needs and to generate synthetic fuels to substitute for the remaining fossil fuel heating. Instead these costs are factored into the electricity capex analysis above.

Figure 13: Share of investment for renewable heat generation technologies

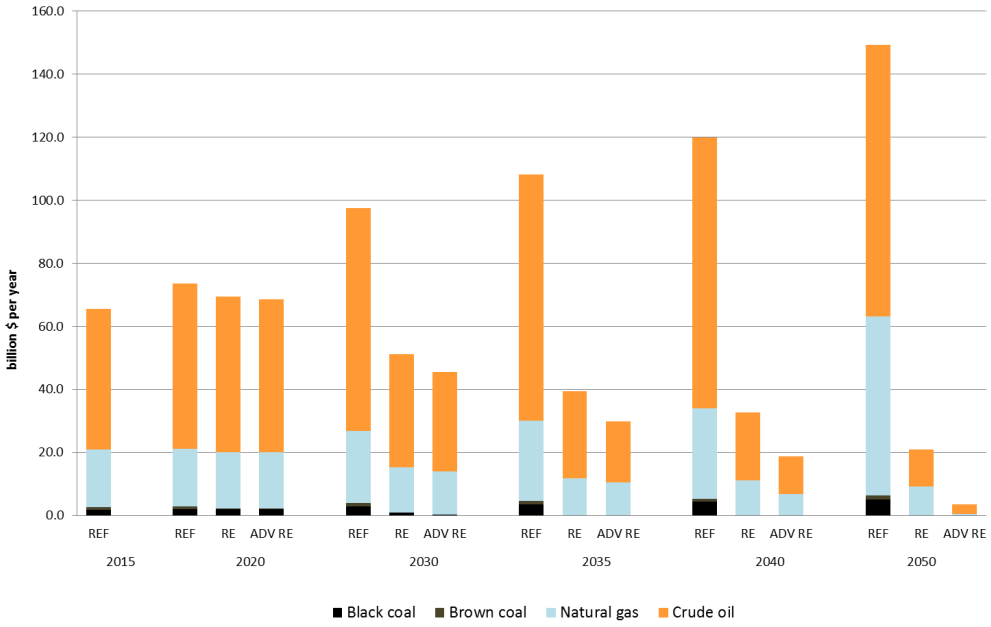


REF 2012-2050 $16.6 billion **RE 2012-2050 $92.6 billion** **ADV RE 2012-2050 $150 billion**

4.5.2 Fuel Costs and Savings

Figure 14 shows the annual fuel costs for each three scenarios. This in turn illustrates that under both renewables scenarios fuel costs decline significantly from 2030. Further, the biggest costs in the **Reference** scenario and thus the biggest savings are from avoiding the use of oil (which is primarily used for transport), although savings from the avoided use of natural gas are also significant.

Figure 14: Fuel costs by scenario (assumed low coal and gas prices)



The primary reason for this is that most renewable energy technologies have no ongoing fuel costs after construction. As such, in the **Renewables** scenario the power sector fuel cost savings reach a cumulative total of between $230 and $270 billion by 2050 (depending on fuel price projections). This is approximately $7 to $8 billion per year. The total fuel cost savings over the period 2015-2020 for the power sector would therefore cover between 50% and 60% of the additional capital investments in renewables compared to the **Reference** scenario.

Power sector fuel cost savings in the **Advanced Renewables** scenario are even greater, around $300 to $340 billion cumulative to 2050, or $8 to $9 billion per year. This would compensate for 46% to 52% of the additional capital investment in renewable energy in this scenario.

If fuel cost savings from the transport sector are included (primarily from avoiding oil use) this leads to further fuel cost savings, even accounting for the electrification of the road transport increasing the overall electricity demand significantly. The cumulative fuel cost savings from transport to 2050 in the **Renewables** scenario would be around $300 billion and $400 billion in the **Advanced Renewables** scenario. This would compensate for 70% and 60% of the electricity sector capital investment costs respectively on top of the 50-60% savings from avoided fuel use in the power sector.

It should be noted that fuel input costs (Figure 14) are independent of any carbon pricing assumptions. Carbon pricing only affects electricity generation prices (see Section 4.5.3 below)

4.5.3 Future Electricity Generation Prices

Due to the ageing electricity generation fleet in Australia, replacement of generation capacity cannot be avoided under all three scenarios. It then becomes only a matter of timing. When the generation fleet will be replaced, and the replacement technology to be used, becomes a matter of sustainable and prudent investment. As such, all scenarios (including the **Reference** case) show an increase of the average generation cost of 1-2c/kWh until 2030 or between 12-30% (see Figure 15). The one exception to this is the **Reference** case under a fuel price projection of current very low coal prices continuing to 2050, low gas prices and no carbon price (see Figure 16).

Figure 15: Average electricity generation costs for each scenario (low coal and low gas price)

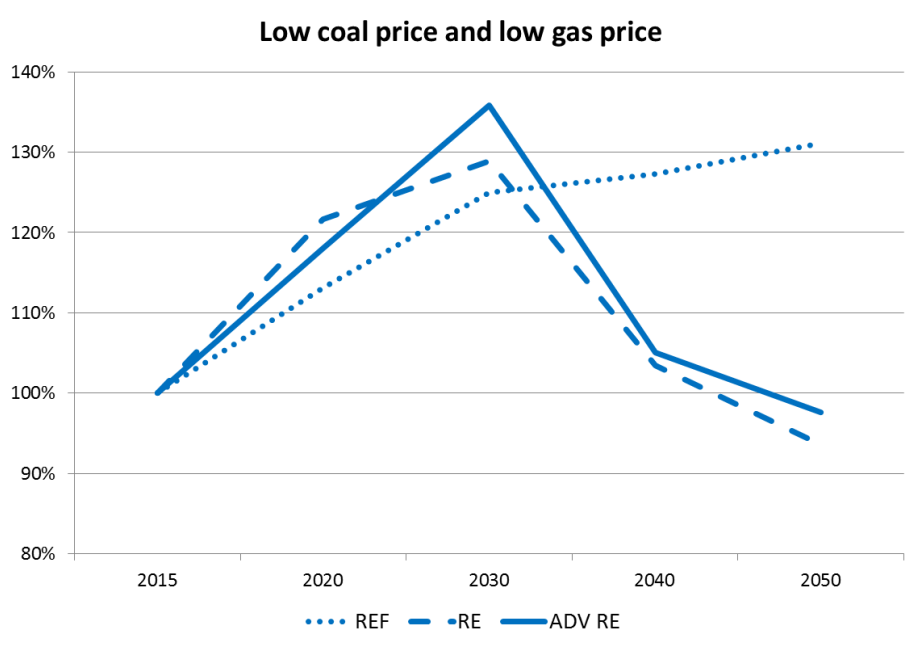
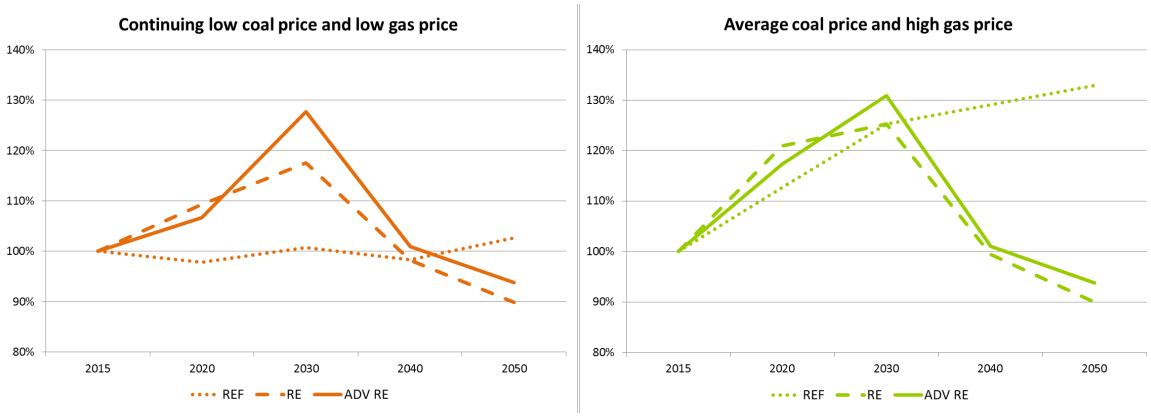


Figure 15 and Figure 16 show that under both renewable energy scenarios and all coal and gas price projections generation costs will be lower than the reference scenario in the long-term. By 2050, the generation costs of the **Advanced Renewable** scenario will be between 1.1c/kWh and 3.7c/kWh below those in the **Reference** case under a high fuel cost future and low fuel cost future respectively. This is because renewable power generation with the exception of biomass do not include fuel costs, while conventional power plants have ongoing fuel costs. This also means that for renewables generation costs are stable and predictable over the entire technical lifetime, unlike conventional power generation that is subject to fuel cost fluctuations.

Figure 16: Average electricity generation costs for each scenario under two fuel cost assumptions



While both renewables scenarios ultimately end up cheaper under all fuel price assumptions, they become cheaper at different dates depending on the scenario and the fuel price projections as shown in Figures 15 and 16. For example at one extreme, which assumes the current low coal prices will remain low over the next 35 years to 2050, low gas prices and no carbon price, renewable scenarios become cheaper in 2040. At the other extreme under an average coal, high gas and a small future carbon price, renewable energy scenarios become cheaper as soon as 2025.

In 2030, the difference in full cost of generation compared to the **Reference** case under the low fuel price projection will between 0.8-1.9c/kWh in the **Renewable** scenario and 0.6 – 1.6c/kWh in the **Advanced Renewables** scenario.

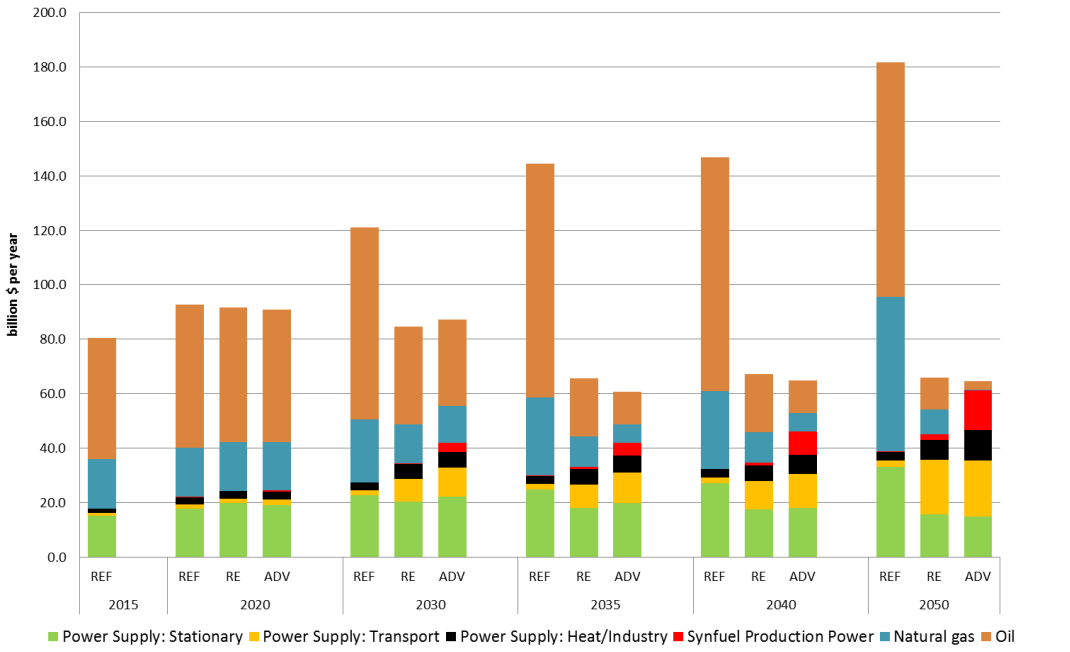
4.5.4 Combined Energy Budget

Figure 17 shows the total energy costs including operational and capital power supply costs and fuel costs for heating and transport for all three scenarios in $billion per year. Both renewable scenarios replace fossil fuels with renewable electricity, either directly or indirect via synfuels and/or hydrogen. However the **Advanced Renewables** scenario is more ambitious and as Figure 17 shows, leads to the lowest annual combined costs for Australia's total energy budget between 2035 and 2050.

This graph also shows that currently over a half of Australia's combined energy budget is spent on oil and as such the biggest cost savings to be had from avoided oil and natural gas (for heating and transport) fuel costs. It should also be noted that:

- Electricity for synfuel production becomes significant in the Advanced Renewables scenario by 2050
- Electricity for transport starts to make a cost impact by 2030 in both renewables scenarios
- The annual cost of electricity for stationary power is similar across all three scenarios in 2020 and 2030 and starts to be measurably cheaper by 2035.

Figure 17: Annual electricity and fuel costs by sector and scenario (assumed low coal and gas prices)



By 2030, the economic advantage of the Renewables Scenarios compared to the Reference case starts to be significant, with overall annual savings of almost $40 billion. By 2050, Australia's total energy costs are approximately one third of what they would otherwise be under the Reference Case: ~$65 billion/year as opposed to $180 billion/year.

Depending on fuel cost projections, the combined transport and power sector fuel cost savings cover 120% to130% of the renewable energy infrastructure investment required to deliver the **Renewable** scenario. For the **Advanced Renewables** case, fuel savings cover around 110% (106% to 112%) of all capital investments in renewables.

To conclude, the total investment in new power generation under both Renewable cases can be financed by fuel cost savings before 2050, while simultaneously delivering a reliable carbon and fossil fuel free electricity system for Australia post-2050. This suggests that a 100% renewable energy system is beneficial for Australia's economy, and planning for this transition now is an investment in Australia's future.

5 CONCLUSIONS & IMPLICATIONS

The transition towards 100% renewable energy supply is technically and economically viable for Australia. The abundant local renewable energy potentials of solar, wind, geothermal and sustainable bioenergy production exceed the current and future energy demand by an order of magnitude.

Renewable energy technologies are mature, available, and significant recent price reductions – especially for solar PV and wind power – offer an economic alternative to the current coal based electricity sector for future power generation in Australia.

Under every fossil fuel price projection, the renewables scenarios are the least cost alternative for future generations. Depending on fuel cost developments and whether or not a carbon price is implemented, the timing of when overall generation cost in the renewable scenarios fall below the Reference scenario ranges from 8 to 20 years from now.

When power generation moves closer to the consumer, an increase of actual power generation costs do not necessarily lead to higher power bills, as the cost structure changes for end-use customers. While current rooftop solar generation costs are more than twice as high as the current wholesale electricity price, it is already significantly cheaper than the average end-consumer price for power.

Required technologies for a 100% renewable energy supply for Australia are available and mature. However, the integration of large shares of variable power generation requires a “systems-thinking” approach, to adapt to new infrastructure needs and operational strategy, and change business models for energy retailers as well as power and gas grid operators.

Baseload power generation is not a technical concept, but a business concept supported by the traditional power sector over the past decades in order to maximise the quantum and value of electricity supplied by an individual conventional power plant.[37] With high shares of variable renewable power generation operating in a wholesale market with no fuel cost, this approach to maintaining ‘baseload’ generation is no longer feasible. The focus for the energy sector will have to shift towards the management of wind and solar photovoltaic which will represent the ‘base-generation’, and reactive dispatch power plants such as hydro, concentrated solar power with storage, geothermal, bio energy plants and a cascade of storage technologies combined with demand side management. The future value chain for the power sector will replace fuel production with power system management – a field that requires more research and is not within the scope of this analysis.

A transition towards a 100% renewable energy supply for Australia can spark a series of innovations that represent huge potential for societal value, while the transition away from fossil fuels must be organised with sound social policies so no worker will be left behind. This will lead to a greater acceptance of renewable energy, which is required as power generation moves closer to the consumer and will be increasingly visible in daily life.

Long-term stable energy policies are required as the transition will take one generation. International experiences such as in Denmark, Germany, China, as well as parts of the USA and Latin America, show that an energy transition is possible and is well under way in many countries.

This 100% renewable energy system analysis has been developed by applying global technology development trends into Australia’s energy sector. While there is still significant research needed towards a full renewable energy supply by 2050, there are no technical barriers to starting the transition process immediately.

[37] Hansen, L. and Lovins, A. (2010) ‘Keeping the Lights on While Transforming Electric Utilities’, Rocky Mountain Institute

APPENDIX A: TECHNOLOGY COST ASSUMPTIONS

The following tables set out the costs for power generation for the range of technologies used in the modelling. These are based on up to date data and current market developments, as described in section 3.3.3. The specific investment costs in $/kW are given in Table 9 and ongoing operation and maintenance costs in $/kW/year given in Table 10.

Table 9: Specific investment costs for power generation

in $/kW		2015	2020	2030	2040	2050
Power plants	Biomass and waste power plant	3,145	2,969	2,867	2,750	2,691
	Coal power plant	1,411	1,390	1,356	1,321	1,287
	Diesel generator	907	907	907	907	907
	Gas power plant	769	751	715	679	644
	Geothermal power plant	12,579	9,507	6,509	5,409	4,652
	Hydro large	3,466	3,573	3,734	3,869	3,987
	Hydro small	3,466	3,573	3,734	3,869	3,987
	Lignite power plant	1,645	1,609	1,575	1,540	1,507
	Nuclear power plant	6,615	6,615	6,615	6,615	6,615
	Ocean energy power plant	4,710	3,364	2,340	1,943	1,730
	Oil power plant	967	948	910	872	834
	PV power plant	1,817	1,682	1,305	1,059	1,079
	Solar thermal power plant	5,787	4,705	3,799	3,595	3,479
	Wind turbine offshore	5,631	3,876	3,072	2,775	2,386
	Wind turbine onshore	1,519	1,316	1,305	1,312	1,371
Hydrogen production	Electrolysis	893	844	746	746	746
CHP for Power Generation and Industry	CHP Biomass and waste	5,150	4,505	3,934	3,626	3,445
	CHP Coal	1,950	1,919	1,872	1,824	1,777
	CHP Fuel cell	1,726	1,346	1,214	1,155	1,141
	CHP Gas	1,038	995	974	954	933
	CHP Geothermal	13,456	11,409	9,068	7,606	6,582
	CHP Lignite	1,950	1,919	1,872	1,824	1,777
	CHP Oil	1,340	1,312	1,259	1,205	1,153
Buildings / Other Small Scale	CHP Biomass and waste	2,545	2,486	2,443	2,418	2,391
	CHP Coal	1,949	1,919	1,872	1,824	1,777
	CHP Fuel cell	1,726	1,346	1,214	1,155	1,141
	CHP Gas	965	911	804	790	775
	CHP Geothermal	13,456	11,409	9,068	7,606	6,582
	CHP Lignite	1,950	1,919	1,872	1,824	1,777
	CHP Oil	1,339	1,312	1,259	1,205	1,153

Table 10: Operation and maintenance cost for power generation technologies

in $/kW/a		2015	2020	2030	2040	2050
Power plants	Biomass and waste power plant	189.1	178.3	172.0	165.5	162.2
	Coal power plant	30.8	29.7	29.7	29.7	29.7
	Diesel generator	112.6	112.6	112.6	112.6	112.6
	Gas power plant	23.7	22.1	20.6	18.6	17.8
	Geothermal power plant	548.6	426.6	324.4	302.9	286.7
	Hydro large	139.0	143.3	149.2	155.0	159.4
	Hydro small	139.0	143.3	149.2	155.0	159.4
	Lignite power plant	27.1	26.5	25.9	25.4	24.9
	Nuclear power plant	162.0	162.0	162.0	162.0	162.0
	Ocean energy power plant	188.7	134.7	93.0	78.2	69.0
	Oil power plant	22.4	21.7	20.3	18.8	17.4
	PV power plant	38.7	21.9	15.4	14.7	15.4
	Solar thermal power plant	350.9	270.0	233.8	215.0	196.4
	Wind turbine offshore	209.5	164.5	133.6	126.6	108.9
	Wind turbine onshore	56.5	55.9	56.8	59.8	62.6
Hydrogen production	Electrolysis	17.9	16.8	14.6	14.6	14.6
CHP for Power Generation	CHP Biomass and waste	361.3	315.9	275.0	254.5	241.3
	CHP Coal	68.7	67.3	65.8	64.4	62.9
	CHP Gas	42.4	39.5	39.5	38.0	38.0
	CHP Geothermal	487.1	409.5	342.3	298.4	272.1
	CHP Lignite	81.9	80.4	77.5	76.1	73.1
	CHP Oil	48.3	46.8	43.9	42.4	41.0
CHP for Industry	CHP Biomass and waste	93.6	83.4	74.6	68.7	62.9
	CHP Coal	68.7	67.3	65.8	64.4	62.9
	CHP Fuel cell	86.3	67.3	61.4	58.5	57.0
	CHP Gas	42.4	39.5	39.5	38.0	38.0
	CHP Geothermal	239.9	231.1	222.3	220.9	219.4
	CHP Lignite	81.9	80.4	77.5	76.1	73.1
	CHP Oil	48.3	46.8	43.9	42.4	41.0
CHP for Buildings / Other Small Scale	CHP Biomass and waste	101.7	99.5	98.0	96.5	95.1
	CHP Coal	68.0	67.3	65.8	64.4	62.9
	CHP Fuel cell	86.3	67.3	61.4	58.5	57.0
	CHP Gas	38.8	36.6	32.2	32.2	30.7
	CHP Geothermal	239.9	231.1	222.3	220.9	219.4
	CHP Lignite	81.9	80.4	77.5	76.1	73.1

APPENDIX B: INVESTMENT COSTS

In the following tables the difference between the investment costs in the power sector for the renewable scenarios compared to the reference is shown. This is split by investment costs for electricity generation and fuel cost savings, with investment costs for heat generation shown separately. The results of the **Renewable** Scenario compared to the Reference are shown in Table 11 and 12 and the **Advanced Renewable** Scenario in Tables 13 and 14. Positive values reflect a net saving from the reference scenario and negative values reflect a cost.

Table 11: Accumulated investment costs for electricity generation and fuel cost savings under the Renewable scenario compared to the Reference scenario

in billion $	2015-2020	2021-2030	2031-2040	2041-2050	2015-2050	Average 2015-50	Average 2015-30	Average 2030-50
ACCUMULATED INVESTMENT COSTS (difference REF minus RE)								
Conventional (fossil)	0.5	13.8	20.8	17.7	52.8	1.5		
Renewables (incl. CHP)	-30.6	-121.1	-127.2	-224.0	-503.0	-14.4		
Total	-30.2	-107.3	-106.4	-206.4	-450.2	-12.5	-9.2	-16.5
ACCUMULATED FUEL COST SAVINGS (savings cumulative RE versus REF)								
Fuel oil (power)	-0.4	-1.3	1.8	2.7	2.8	0.1		
Fuel oil (road transport - electrification credit)	0.0	15.2	78.4	206.4	300.0	8.6		
Gas	-4.3	-12.2	36.6	92.0	112.1	3.2		
Hard coal	-0.2	9.7	32.0	42.1	83.7	2.4		
Brown coal	2.0	8.0	8.8	10.0	28.7	0.8		
Total power sector	-2.9	4.1	79.2	146.9	227.3	6.5	0.1	11.9
Total power + transport sector	-2.9	19.3	157.6	353.3	527.3	15.1	1.1	26.9

Table 12: Accumulated investment costs for heat generation under the Renewable scenario compared to the Reference scenario

in billion $	2015-2020	2021-2030	2031-2040	2041-2050	2015-2050	Average 2015-50	Average 2015-30	Average 2030-50
ACCUMULATED INVESTMENT COSTS (difference REF minus RE)								
Renewables	16.1	11.4	14.8	33.8	76.0	2.2	1.8	2.6

Table 13: Accumulated investment costs for electricity generation and fuel cost savings under the Advanced Renewable scenario compared to the Reference scenario

in billion $	2015-2020	2021-2030	2031-2040	2041-2050	2015-2050	Average 2015-50	Average 2015-30	Average 2030-50
ACCUMULATED INVESTMENT COSTS (difference REF minus RE)								
Conventional (fossil)	3.3	13.7	19.8	18.8	55.6	1.6		
Renewables (incl. CHP)	-57.0	-220.5	-160.4	-266.7	-704.6	-20.1		
Total	-53.7	-206.8	-140.5	-247.9	-649.0	-18.5	-17.4	-20.4
ACCUMULATED FUEL COST SAVINGS (savings cumulative RE versus REF)								
Fuel oil (power)	-0.4	-1.9	1.5	2.7	1.9	0.1		
Fuel oil (road transport - electrification credit)	0.1	19.4	112.5	264.1	396.0	11.3		
Gas	0.6	7.3	65.3	105.3	178.6	5.1		
Hard coal	-0.1	11.0	33.3	42.2	86.4	2.5		
Brown coal	2.0	8.0	8.8	10.0	28.7	0.8		
Total power sector	2.2	24.4	108.8	160.2	295.6	8.4	1.8	14.2
Total power + transport sector	2.2	43.8	221.3	424.3	691.6	19.8	3.1	34.0

Table 14: Accumulated investment costs for heat generation under the Advanced Renewable scenario compared to the Reference scenario

in billion $	2015-2020	2021-2030	2031-2040	2041-2050	2015-2050	Average 2015-50	Average 2015-30	Average 2030-50
ACCUMULATED INVESTMENT COSTS (difference REF minus RE)								
Renewables	-0.6	12.4	43.8	77.9	133.4	3.8	0.8	6.4

Electricity generation in TWh/a
Scenario: Australia Reference (2015)

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Power plants	236	217	237	249	263	278	297	321	344
- Hard coal (& non-renewable waste)	138	98	100	102	117	134	153	178	202
- Brown Coal	31	47	47	47	48	49	49	50	51
- Gas	42	38	37	36	35	33	33	32	31
of which from H2	0	0	0	0	0	0	0	0	0
- Oil	1	0	0	0	0	0	0	0	0
- Diesel	2	1	1	2	1	2	2	2	2
- Biomass (& renewable waste)	1	0	1	2	2	2	2	2	2
- Hydro	14	19	19	19	19	19	18	18	18
- Wind	6	9	24	32	32	32	33	33	33
of which wind offshore	0	0	0	1	1	2	3	3	4
- PV	1	5	6	6	6	6	6	6	6
- Geothermal	0	0	2	4	3	2	2	1	0
- Solar thermal power plants	0	0	0	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0	0	0	0
Combined heat and power plants	13	17	17	18	19	21	22	22	23
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0
- Brown Coal	2	0	0	0	0	0	0	0	0
- Gas	8	12	12	13	13	15	16	16	17
of which from H2	0	0	0	0	0	0	0	0	0
- Oil	1	2	2	2	2	1	1	1	1
- Biomass (& renewable waste)	2	3	3	3	3	4	4	4	4
- Geothermal	0	0	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0	0	0
CHP by producer	0	0	0	0	0	0	0	0	0
- Main activity producers	5	5	5	5	5	5	5	5	5
- Autoproducers	8	12	12	13	14	16	17	17	18
Total generation	249	234	254	267	282	299	319	343	368
- Fossil	225	198	200	201	216	234	255	280	305
- Hard coal (& non-renewable waste)	138	98	100	102	117	134	154	178	203
- Brown Coal	33	47	47	47	48	49	49	50	51
- Gas	50	50	50	49	49	49	48	48	48
- Oil	2	2	2	2	2	2	1	1	1
- Diesel	2	1	1	2	1	2	2	2	2
- Hydrogen	0	0	0	0	0	0	0	0	0
- of which renewable H2	0	0	0	0	0	0	0	0	0
- Renewables (w/o renewable hydrogen)	**24**	**36**	**54**	**66**	**65**	**65**	**64**	**63**	**63**
- Hydro	14	19	19	19	19	19	18	18	18
- Wind	6	9	24	32	32	32	33	33	33
- PV	1	5	6	6	6	6	6	6	6
- Biomass (& renewable waste)	2	3	4	5	5	5	6	6	6
- Geothermal	0	0	2	4	3	2	2	1	0
- Solar thermal power plants	0	0	0	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0	0	0	0
Import	0	0	0	0	0	0	0	0	0
- Import RES	0	0	0	0	0	0	0	0	0
Export	0	0	0	0	0	0	0	0	0
Distribution losses	13	12	13	14	15	16	17	18	20
Own consumption electricity	27	27	25	25	24	23	21	21	21
Electricity for hydrogen production	0.0	0.0	0.5	0.5	0.5	0.6	0.6	0.6	0.7
Electricity for synfuel production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Final energy consumption (electricity)	209.4	195.6	215.4	227.7	242.8	260.2	279.9	303.1	326.0
Fluctuating RES (PV, Wind, Ocean)	8	14	30	38	38	38	38	39	39
Share of fluctuating RES	3%	6%	12%	14%	13%	13%	12%	11%	11%
RES share (domestic generation)	10%	15%	21%	25%	23%	22%	20%	18%	17%

Heat supply and air conditioning in PJ/a
Scenario: Australia Reference (2015)

	2012	2015	2020	2025	2030	2035	2040	2045	2050
District heating plants	1	1	1	1	1	1	1	1	1
- Fossil fuels	1	1	1	1	1	1	1	1	1
- Biomass	0	0	0	0	0	0	0	0	0
- Solar collectors	0	0	0	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0	0	0	0
Heat from CHP 1)	43	62	65	68	71	83	86	88	94
- Fossil fuels	30	42	43	45	47	55	57	58	61
- Biomass	13	20	21	22	23	27	28	29	32
- Geothermal	0	0	0	0	0	0	0	0	0
- Hydrogen	0	0	1	1	1	1	1	1	1
Direct heating	931	1,295	1,401	1,517	1,641	1,771	1,929	2,100	2,283
- Fossil fuels	738	1,103	1,205	1,318	1,439	1,566	1,718	1,883	2,059
- Biomass	124	84	89	92	95	98	104	111	117
- Solar collectors	11	11	11	11	11	11	11	11	11
- Geothermal	0	0	0	0	0	0	0	0	0
- Heat pumps 2)	0	0	0	0	0	0	0	0	0
- Electric direct heating	57	96	96	96	96	96	96	96	96
- Hydrogen	0	0	0	0	0	0	0	0	0
Total heat supply3)	975	1,357	1,467	1,585	1,713	1,855	2,016	2,189	2,378
- Fossil fuels	770	1,146	1,249	1,364	1,487	1,621	1,775	1,941	2,121
- Biomass	137	105	110	114	118	125	132	140	149
- Solar collectors	11	11	11	11	11	11	11	11	11
- Geothermal	0	0	0	0	0	0	0	0	0
- Heat pumps 2)	0	0	0	0	0	0	0	0	0
- Electric direct heating	57	96	96	96	96	96	96	96	96
- Hydrogen	0	0	1	1	1	1	1	1	1
RES share (including RES electricity)	16%	10%	10%	9%	9%	8%	8%	8%	7%
electricity consumption heat pumps (TWh/a)	0%	0%	0%	0%	0%	0%	0%	0%	0%

1) public CHP and CHP autoproduction 2) heat from ambient energy and electricity use 3) incl. process heat, cooking

Final energy consumption transport in PJ/a
Scenario: Australia Reference (2015)

	2012	2015	2020	2025	2030	2035	2040	2045	2050
road	1,092	1,558	1,681	1,806	1,930	2,067	2,176	2,212	2,232
- fossil fuels	1,076	1,507	1,626	1,746	1,865	1,997	2,101	2,172	2,191
- biofuels	14	47	50	54	58	62	66	29	29
- synfuels	0	0	0	0	0	0	0	0	0
- natural gas	2	4	5	6	7	8	10	11	12
- hydrogen	0	0	0	0	0	0	0	0	0
- electricity	0	0	0	0	0	0	1	1	1
Electrification share:	0%	0%	0%	0%	0%	0%	0%	0%	0%
rail	57	52	56	60	64	68	72	76	80
- fossil fuels	42	7	7	8	8	9	9	10	10
- biofuels	0	0	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0	0	0
- electricity	15	45	49	52	56	60	63	66	70
navigation	29	53	57	61	65	70	73	77	81
- fossil fuels	29	53	57	61	65	70	73	77	81
- biofuels	0	0	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0	0	0
aviation	111	101	113	123	134	132	148	132	132
- fossil fuels	111	101	113	123	134	132	148	132	132
- biofuels	0	0	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0	0	0
total (incl. pipelines)	1,304	1,780	1,924	2,067	2,211	2,354	2,487	2,515	2,542
- fossil fuels	1,258	1,668	1,803	1,938	2,073	2,208	2,332	2,392	2,415
- biofuels (incl. biogas)	14	47	50	54	58	62	66	29	29
- synfuels	0	0	0	0	0	0	0	0	0
- natural gas	19	20	21	22	23	24	26	27	28
- hydrogen	0	0	0	0	0	0	0	0	0
- electricity	15	45	49	53	56	60	64	67	71
total RES	15	54	61	67	71	75	78	41	41
RES share	1%	3%	3%	3%	3%	3%	3%	2%	2%

Installed capacity in GW
Scenario: Australia Reference (2015)

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total generation	43	44	52	57	59	61	64	64	66
- Fossil	33	29	29	29	31	34	36	36	39
- Hard coal (& non-renewable waste)	18	13	13	14	16	18	21	21	24
- Brown Coal	4	6	6	6	6	6	6	6	6
- Gas (w/o H2)	8	8	8	8	8	8	8	8	8
- Oil	1	1	1	1	1	1	1	1	1
- Diesel	1	1	1	1	1	1	1	1	1
- Hydrogen (fuel cells, gas power plants, g	0	0	0	0	0	0	0	0	0
- Renewables	**10**	**15**	**23**	**28**	**28**	**27**	**27**	**27**	**27**
- Hydro	6	8	8	8	7	7	7	7	7
- Wind	3	4	11	15	15	15	15	15	15
of which wind offshore	0	0	0	0	0	1	1	1	1
- PV	1	3	3	4	4	4	4	4	4
- Biomass (& renewable waste)	0	0	1	1	1	1	1	1	1
- Geothermal	0	0	0	1	1	1	0	0	0
- Solar thermal power plants	0	0	0	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0	0	0	0
Fluctuating RES (PV, Wind, Ocean)	4	7	15	18	19	19	19	19	19
Share of fluctuating RES	9%	17%	28%	32%	31%	30%	29%	29%	28%
RES share (domestic generation)	23%	35%	44%	49%	47%	45%	43%	43%	41%

Final energy demand in PJ/a 1)
Scenario: Australia Reference (2015)

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy use)	3,333	4,133	4,458	4,755	5,069	5,392	5,736	6,005	6,281
Total energy use 1)	3,132	3,897	4,216	4,513	4,826	5,150	5,494	5,763	6,039
Transport	1,304	1,780	1,924	2,067	2,211	2,354	2,487	2,515	2,542
- Oil products	1,258	1,668	1,803	1,938	2,073	2,208	2,332	2,392	2,415
- Natural gas	19	20	21	22	23	24	26	27	28
- Biofuels	14	47	50	54	58	62	66	29	29
- Synfuels	0	0	0	0	0	0	0	0	0
- Electricity	15	45	49	53	56	60	64	67	71
RES electricity	1	7	10	13	13	13	13	12	12
- Hydrogen	0	0	0	0	0	0	0	0	0
RES share Transport	1%	3%	3%	3%	3%	3%	3%	2%	2%
Industry	1,002	1,365	1,514	1,637	1,763	1,892	2,049	2,232	2,417
- Electricity	288	327	370	385	405	427	458	498	534
RES electricity	28	50	79	95	94	92	92	92	92
- Public district heat	11	12	12	12	12	12	13	13	13
RES district heat	0	1	1	1	1	1	1	1	1
- Hard coal & Brown Coal	111	80	86	92	98	103	107	108	105
- Oil products	168	196	210	224	238	252	261	271	281
- Gas	316	695	779	861	944	1,028	1,137	1,265	1,404
- Solar	0	0	0	0	0	0	0	0	0
- Biomass	108	55	58	62	66	70	73	76	80
- Geothermal	0	0	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0	0	0
RES share Industry	14%	8%	9%	10%	9%	9%	8%	8%	7%
Other Sectors	825	753	778	809	853	903	958	1,016	1,079
- Electricity	451	332	357	382	413	449	486	526	569
RES electricity	43	51	76	94	96	97	98	97	97
- Public district heat	0	0	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0	0	0
- Hard coal & Brown Coal	1	0	0	0	0	0	0	0	0
- Oil products	124	141	140	146	151	157	161	165	169
- Gas	180	211	210	210	217	226	240	255	271
- Solar	11	11	11	11	11	11	11	11	11
- Biomass	58	58	60	60	60	60	60	60	60
- Geothermal	0	0	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0	0	0
RES share Other Sectors	14%	16%	19%	20%	20%	19%	18%	17%	16%
Total RES	263	279	347	390	398	406	413	378	382
RES share	8%	7%	8%	9%	8%	8%	8%	7%	6%

CO2 emissions in Mill t/a
Scenario: Australia Reference (2015)

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	195	169	168	168	181	197	216	212	231
- Hard coal (& non-renewable waste)	132	93	95	96	111	127	146	141	161
- Brown Coal	37	55	52	51	50	50	51	52	53
- Gas	23	21	20	19	19	18	18	17	17
- Oil	1	0	0	0	0	0	0	0	0
- Diesel	2	1	1	1	1	1	1	1	1
Combined heat and power plants	8	8	8	8	8	9	9	9	9
- Hard coal (& non-renewable waste)	0	0	0	0	0	1	1	0	0
- Brown Coal	3	0	0	0	0	0	0	0	0
- Gas	5	7	7	7	7	8	8	8	8
- Oil	1	1	1	1	1	1	1	1	1
CO2 emissions power and CHP plants	203	178	176	176	190	206	225	221	241
- Hard coal (& non-renewable waste)	132	93	95	97	111	128	146	142	161
- Brown Coal	39	55	52	51	50	50	51	52	53
- Gas	28	28	27	27	26	26	26	25	25
- Oil & diesel	3	2	2	2	2	2	2	2	2
CO2 intensity (g/kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
without credit for CHP heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CO2 intensity fossil electr. generation	902	897	883	877	876	878	883	790	791
- CO2 intensity total electr. generation	815	759	694	661	674	688	705	644	655
CO2 emissions by sector	374	420	435	450	478	510	547	557	589
- % of 1990 emissions (276 Mill t)	136%	152%	158%	163%	173%	185%	198%	202%	213%
- Industry 1)	45	67	74	80	87	94	102	110	119
- Other sectors 1)	20	23	23	24	24	25	26	28	29
- Transport	96	128	138	149	159	169	179	184	185
- Power generation 2)	200	173	172	171	185	200	219	215	234
- Other conversion 3)	13	29	29	26	23	22	21	21	22

1) incl. CHP autoproducers
2) incl. CHP public
3) district heating, refineries, coal transformation, gas transport

Primary energy demand in PJ/a
Scenario: Australia Reference (2015)

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total	5,147	5,800	6,207	6,535	6,915	7,310	7,757	7,855	8,249
- Fossil	4,836	5,442	5,711	5,957	6,354	6,759	7,218	7,380	7,783
- Hard coal (& non-renewable waste)	1,538	1,072	1,114	1,136	1,298	1,485	1,694	1,648	1,855
- Brown Coal	387	521	497	486	483	482	489	497	504
- Natural gas	1,036	1,468	1,535	1,614	1,698	1,783	1,902	2,025	2,176
- Crude oil	1,874	2,380	2,565	2,721	2,874	3,009	3,133	3,211	3,248
- Renewables	**311**	**359**	**496**	**578**	**561**	**550**	**540**	**475**	**466**
- Hydro	50	68	68	68	68	67	66	66	65
- Wind	22	32	86	115	116	117	117	118	119
- Solar	17	29	31	31	32	32	32	32	33
- Biomass (& renewable waste)	222	229	254	266	273	285	292	244	249
- Geothermal	0	0	56	97	72	51	32	15	0
- Ocean energy	0	0	0	0	0	0	0	0	0
Total incl. net elec. & synfuel import	5,147	5,800	6,207	6,535	6,915	7,310	7,757	7,855	8,249
- of which non-energy use	202	235	242	242	242	242	242	242	242
Total RES incl. electr. & synfuel import	311.271	358.668	496.03	577.898	560.628	550.497	539.689	474.9	465.574
RES share	0.06047	0.06184	0.07992	0.08843	0.08108	0.07531	0.06957	0.06046	0.05644

Electricity generation in TWh/a
Scenario: Australia RENEWABLE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Power plants	236	217	238	272	302	325	363	449	519
- Hard coal (& non-renewable waste)	138	98	103	62	36	0	0	0	0
- Brown Coal	31	47	7	0	0	0	0	0	0
- Gas	42	38	44	49	47	21	8	2	0
of which from H2	0	0	0	0	0	0	0	0	0
- Oil	1	0	0	0	0	0	0	0	0
- Diesel	2	1	1	1	0	0	0	0	0
- Biomass (& renewable waste)	1	0	0	2	3	11	9	10	6
- Hydro	14	19	19	19	19	19	19	19	19
- Wind	6	9	39	57	81	97	115	134	163
of which wind offshore	0	0	0	2	6	10	20	31	40
- PV	1	5	22	72	95	137	163	215	245
- Geothermal	0	0	2	4	5	13	14	22	26
- Solar thermal power plants	0	0	1	5	15	27	35	48	60
- Ocean energy	0	0	0	0	0	0	0	0	0
Combined heat and power plants	13	17	20	23	26	32	38	35	40
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0
- Brown Coal	2	0	0	0	0	0	0	0	0
- Gas	8	12	14	16	18	15	16	11	0
of which from H2	0	0	0	0	0	0	0	0	0
- Oil	1	2	2	2	3	0	0	0	0
- Biomass (& renewable waste)	2	3	4	5	6	13	17	18	30
- Geothermal	0	0	0	0	0	1	1	2	4
- Hydrogen	0	0	0	0	0	2	3	4	6
CHP by producer	0	0	0	0	0	0	0	0	0
- Main activity producers	5	5	5	5	5	5	5	5	5
- Autoproducers	8	12	15	18	21	27	33	30	35
Total generation	249	234	258	295	328	357	401	485	560
- Fossil	225	198	171	131	104	37	25	13	1
- Hard coal (& non-renewable waste)	138	98	103	63	36	0	1	0	1
- Brown Coal	33	47	7	0	0	0	0	0	0
- Gas	50	50	58	65	65	36	24	13	0
- Oil	2	2	2	3	3	0	0	0	0
- Diesel	2	1	1	1	0	0	0	0	0
- Hydrogen	0	0	0	0	0	2	3	4	6
- of which renewable H2	0	0	0	0	0	2	3	4	6
- Renewables (w/o renewable hydrogen)	**24**	**36**	**87**	**164**	**224**	**318**	**373**	**467**	**553**
- Hydro	14	19	19	19	19	19	19	19	19
- Wind	6	9	39	57	81	97	115	134	163
- PV	1	5	22	72	95	137	163	215	245
- Biomass (& renewable waste)	2	3	4	7	9	25	26	28	36
- Geothermal	0	0	2	4	5	13	16	25	30
- Solar thermal power plants	0	0	1	5	15	27	35	48	60
- Ocean energy	0	0	0	0	0	0	0	0	0
Import	0	0	0	0	0	0	0	0	0
- Import RES	0	0	0	0	0	0	0	0	0
Export	0	0	0	0	0	0	0	0	0
Distribution losses	13	12	12	12	13	13	13	13	13
Own consumption electricity	27	27	24	22	19	17	16	14	13
Electricity for hydrogen production	0.0	0.0	0.2	0.1	1.7	8.0	11.6	16.8	24.8
Electricity for synfuel production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Final energy consumption (electricity)	209.4	195.6	222.3	261.0	294.7	318.5	360.4	440.8	509.1
Fluctuating RES (PV, Wind, Ocean)	8	14	61	129	176	234	278	348	408
Share of fluctuating RES	3%	6%	24%	44%	54%	66%	69%	72%	73%
RES share (domestic generation)	10%	15%	34%	56%	68%	90%	94%	97%	100%

Heat supply and air conditioning in PJ/a
Scenario: Australia RENEWABLE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
District heating plants	1	1	2	2	2	2	2	2	2
- Fossil fuels	1	1	2	2	2	2	2	2	2
- Biomass	0	0	0	0	0	0	0	0	0
- Solar collectors	0	0	0	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0	0	0	0
Heat from CHP 1)	43	62	75	92	110	165	206	210	270
- Fossil fuels	30	42	49	58	65	52	55	38	2
- Biomass	13	20	26	33	42	96	121	127	198
- Geothermal	0	0	0	0	0	6	13	20	33
- Hydrogen	0	0	0	0	2	11	17	24	37
Direct heating	931	1,295	1,359	1,371	1,312	1,286	1,235	1,340	1,249
- Fossil fuels	738	1,103	1,131	1,106	1,000	950	863	873	755
- Biomass	124	84	85	83	77	73	69	72	66
- Solar collectors	11	11	10	14	26	33	52	59	68
- Geothermal	0	0	0	0	11	15	21	26	33
- Heat pumps 2)	0	0	7	15	29	35	42	69	79
- Electric direct heating	57	96	126	152	169	179	189	242	248
- Hydrogen	0	0	0	0	0	0	0	0	0
Total heat supply3)	975	1,357	1,437	1,465	1,424	1,454	1,443	1,552	1,521
- Fossil fuels	770	1,146	1,182	1,167	1,068	1,005	920	914	759
- Biomass	137	105	111	117	120	170	190	198	264
- Solar collectors	11	11	10	14	26	33	52	59	68
- Geothermal	0	0	0	0	11	21	34	47	66
- Heat pumps 2)	0	0	7	15	29	35	42	69	79
- Electric direct heating 2)	57	96	126	152	169	179	189	242	248
- Hydrogen	0	0	0	0	2	11	17	24	37
RES share (including RES electricity)	16%	10%	12%	16%	21%	30%	35%	41%	50%
electricity consumption heat pumps (TWh/a)	0%	0%	55%	124%	227%	269%	309%	492%	546%

1) public CHP and CHP autoproduction 2) heat from ambient energy and electricity use 3) incl. process heat, cooking

Final energy consumption transport in PJ/a
Scenario: Australia RENEWABLE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
road	1,092	1,558	1,621	1,580	1,445	1,305	1,209	1,226	1,307
- fossil fuels	1,076	1,507	1,552	1,390	1,145	939	696	467	287
- biofuels	14	47	50	57	69	89	132	143	189
- synfuels	0	0	0	0	0	0	0	0	0
- natural gas	2	4	12	13	12	13	13	15	17
- hydrogen	0	0	0	0	0	0	0	0	0
- electricity	0	0	7	121	218	264	368	601	814
Electrification share:	0%	0%	0%	8%	15%	20%	30%	49%	62%
rail	57	52	56	54	50	45	42	43	45
- fossil fuels	42	7	7	6	6	5	4	4	4
- biofuels	0	0	0	1	1	1	2	2	2
- synfuels	0	0	0	0	0	0	0	0	0
- electricity	15	45	48	47	43	39	37	37	39
navigation	29	53	56	54	50	45	42	43	45
- fossil fuels	29	53	54	52	44	36	28	23	14
- biofuels	0	0	2	3	6	10	14	19	32
- synfuels	0	0	0	0	0	0	0	0	0
aviation	111	101	110	107	105	105	104	104	103
- fossil fuels	111	101	110	100	86	84	67	41	10
- biofuels	0	0	0	8	18	21	36	62	93
- synfuels	0	0	0	0	0	0	0	0	0
total (incl. pipelines)	1,304	1,780	1,857	1,810	1,660	1,509	1,405	1,421	1,503
- fossil fuels	1,258	1,668	1,723	1,548	1,280	1,063	795	536	315
- biofuels (incl. biogas)	14	47	52	68	95	120	184	226	316
- synfuels	0	0	0	0	0	0	0	0	0
- natural gas	19	20	27	25	23	21	19	19	19
- hydrogen	0	0	0	0	0	0	0	0	0
- electricity	15	45	55	168	262	304	407	640	854
total RES	15	54	70	162	274	393	565	849	1,169
RES share	1%	3%	4%	9%	16%	26%	40%	60%	78%

Installed capacity in GW
Scenario: Australia RENEWABLE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total generation	43	44	67	104	130	157	181	225	262
- Fossil	33	29	26	21	17	6	4	2	0
- Hard coal (& non-renewable waste)	18	13	14	8	5	0	0	0	0
- Brown Coal	4	6	1	0	0	0	0	0	0
- Gas (w/o H2)	8	8	10	11	11	6	4	2	0
- Oil	1	1	1	1	1	0	0	0	0
- Diesel	1	1	0	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants, g	0	0	0	0	0	1	1	1	2
- Renewables	**10**	**15**	**41**	**83**	**113**	**151**	**176**	**221**	**260**
- Hydro	6	8	8	8	8	8	8	8	8
- Wind	3	4	18	26	37	44	52	59	72
of which wind offshore	0	0	0	1	2	4	7	11	14
- PV	1	3	14	45	59	86	102	134	153
- Biomass (& renewable waste)	0	0	1	1	2	4	5	6	9
- Geothermal	0	0	0	1	1	3	3	5	7
- Solar thermal power plants	0	0	0	2	6	6	7	10	12
- Ocean energy	0	0	0	0	0	0	0	0	0
Fluctuating RES (PV, Wind, Ocean)	4	7	32	72	97	130	153	193	225
Share of fluctuating RES	9%	17%	48%	69%	74%	83%	85%	86%	86%
RES share (domestic generation)	23%	35%	61%	80%	87%	96%	97%	99%	99%

Final energy demand in PJ/a 1)
Scenario: Australia RENEWABLE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy use)	3,333	4,133	4,283	4,221	3,983	3,815	3,665	3,773	3,761
Total energy use 1)	3,132	3,897	4,079	4,018	3,779	3,611	3,461	3,569	3,557
Transport	1,304	1,780	1,857	1,810	1,660	1,509	1,405	1,421	1,503
- Oil products	1,258	1,668	1,723	1,548	1,280	1,063	795	536	315
- Natural gas	19	20	27	25	23	21	19	19	19
- Biofuels	14	47	52	68	95	120	184	226	316
- Synfuels	0	0	0	0	0	0	0	0	0
- Electricity	15	45	55	168	262	304	407	640	854
RES electricity	1	7	18	94	179	273	381	623	853
- Hydrogen	0	0	0	0	0	0	0	0	0
RES share Transport	1%	3%	4%	9%	16%	26%	40%	60%	78%
Industry	1,002	1,365	1,462	1,469	1,405	1,379	1,329	1,421	1,349
- Electricity	288	327	366	381	401	423	454	493	529
RES electricity	28	50	123	213	274	379	425	480	528
- Public district heat	11	12	12	13	15	16	16	18	18
RES district heat	0	1	1	1	1	1	1	1	13
- Hard coal & Brown Coal	111	80	63	60	56	52	46	51	28
- Oil products	168	196	213	213	198	189	175	184	161
- Gas	316	695	748	742	680	646	591	624	569
- Solar	0	0	0	0	0	0	0	0	0
- Biomass	108	55	60	60	56	53	47	50	44
- Geothermal	0	0	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0	0	0
RES share Industry	14%	8%	13%	19%	24%	31%	36%	37%	43%
Other Sectors	825	753	760	739	714	723	727	727	705
- Electricity	451	332	379	390	398	419	437	453	449
RES electricity	43	51	128	217	272	376	410	440	449
- Public district heat	0	0	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0	0	0
- Hard coal & Brown Coal	1	0	0	0	0	0	0	0	0
- Oil products	124	141	107	85	37	34	15	8	1
- Gas	180	211	205	188	175	151	131	92	60
- Solar	11	11	10	14	26	33	52	59	68
- Biomass	58	58	53	51	47	45	41	38	35
- Geothermal	0	0	5	11	31	41	51	77	92
- Hydrogen	0	0	0	0	0	0	0	0	0
RES share Other Sectors	14%	16%	26%	40%	53%	68%	76%	84%	91%
Total RES	263	279	450	729	981	1,320	1,592	1,994	2,398
RES share	8%	7%	11%	18%	26%	37%	46%	56%	67%

CO2 emissions in Mill t/a
Scenario: Australia RENEWABLE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	195	169	130	86	60	12	5	1	0
- Hard coal (& non-renewable waste)	132	93	98	59	34	0	0	0	0
- Brown Coal	37	55	8	0	0	0	0	0	0
- Gas	23	21	24	26	26	11	4	1	0
- Oil	1	0	0	0	0	0	0	0	0
- Diesel	2	1	0	0	0	0	0	0	0
Combined heat and power plants	8	8	9	10	11	8	8	6	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0
- Brown Coal	3	0	0	0	0	0	0	0	0
- Gas	5	7	8	9	9	8	8	6	0
- Oil	1	1	1	1	1	0	0	0	0
CO2 emissions power and CHP plants	203	178	139	96	71	20	13	7	1
- Hard coal (& non-renewable waste)	132	93	98	59	34	0	1	0	1
- Brown Coal	39	55	8	0	0	0	0	0	0
- Gas	28	28	32	35	35	19	13	7	0
- Oil & diesel	3	2	2	2	2	0	0	0	0
CO2 intensity (g/kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
without credit for CHP heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CO2 intensity fossil electr. generation	902	897	813	739	682	539	530	504	967
- CO2 intensity total electr. generation	815	759	540	327	215	56	33	14	1
CO2 emissions by sector	374	420	381	315	254	178	140	113	79
- % of 1990 emissions (276 Mill t)	136%	152%	138%	114%	92%	64%	51%	41%	28%
- Industry 1)	45	67	71	71	67	62	57	58	48
- Other sectors 1)	20	23	20	18	13	12	9	6	3
- Transport	96	128	133	119	99	82	62	42	25
- Power generation 2)	200	173	134	90	63	15	8	4	1
- Other conversion 3)	13	29	23	18	12	8	5	3	2

1) incl. CHP autoproducers
2) incl. CHP public
3) district heating, refineries, coal transformation, gas transport

Primary energy demand in PJ/a
Scenario: Australia RENEWABLE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total	5,147	5,800	5,837	5,525	5,103	4,760	4,559	4,711	4,777
- Fossil	4,836	5,442	5,222	4,550	3,825	2,836	2,300	1,903	1,411
- Hard coal (& non-renewable waste)	1,538	1,072	1,104	677	399	29	29	28	26
- Brown Coal	387	521	110	39	34	30	26	27	11
- Natural gas	1,036	1,468	1,595	1,644	1,567	1,232	1,031	907	697
- Crude oil	1,874	2,380	2,413	2,190	1,826	1,544	1,215	941	677
- Renewables	**311**	**359**	**616**	**975**	**1,278**	**1,925**	**2,259**	**2,808**	**3,366**
- Hydro	50	68	68	68	68	68	68	68	70
- Wind	22	32	141	205	292	349	413	481	587
- Solar	17	29	93	293	422	623	765	1,005	1,164
- Biomass (& renewable waste)	222	229	253	300	352	567	656	723	928
- Geothermal	0	0	61	108	144	316	357	531	618
- Ocean energy	0	0	0	0	0	0	0	0	0
Total incl. net elec. & synfuel import	5,147	5,800	5,837	5,525	5,103	4,760	4,559	4,711	4,777
- of which non-energy use	202	235	204	204	204	204	204	204	204
Total RES incl. electr. & synfuel import	311	359	616	975	1,278	1,925	2,259	2,808	3,366
RES share	0.06047	0.06184	0.1055	0.17648	0.25044	0.40428	0.49544	0.59601	0.70463

Electricity generation in TWh/a
Scenario: Australia Advanced RE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Power plants	236	217	247	292	350	395	481	624	683
- Hard coal (& non-renewable waste)	138	98	101	68	9	0	0	0	0
- Brown Coal	31	47	7	0	0	0	0	0	0
- Gas	42	38	34	39	29	4	2	0	0
of which from H2	0	0	0	0	0	0	0	0	0
- Oil	1	0	0	0	2	0	0	0	0
- Diesel	2	1	1	1	0	0	0	0	0
- Biomass (& renewable waste)	1	0	0	2	7	22	13	27	43
- Hydro	14	19	19	19	19	19	19	19	19
- Wind	6	9	39	57	101	109	142	164	180
of which wind offshore	0	0	0	2	26	22	32	39	40
- PV	1	5	42	82	115	140	178	241	266
- Geothermal	0	0	2	14	30	34	40	47	47
- Solar thermal power plants	0	0	1	5	28	47	65	79	78
- Ocean energy	0	0	0	5	10	19	23	48	50
Combined heat and power plants	13	17	20	23	26	32	38	35	40
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0
- Brown Coal	2	0	0	0	0	0	0	0	0
- Gas	8	12	14	16	16	11	0	0	0
of which from H2	0	0	0	0	0	0	0	0	0
- Oil	1	2	2	2	1	0	0	0	0
- Biomass (& renewable waste)	2	3	4	5	9	18	30	28	30
- Geothermal	0	0	0	0	0	1	3	3	4
- Hydrogen	0	0	0	0	0	2	4	4	6
CHP by producer	0	0	0	0	0	0	0	0	0
- Main activity producers	5	5	5	5	5	5	5	5	5
- Autoproducers	8	12	15	18	21	27	33	30	35
Total generation	249	234	267	315	377	427	519	659	723
- Fossil	225	198	160	126	57	15	2	0	0
- Hard coal (& non-renewable waste)	138	98	101	68	9	0	0	0	0
- Brown Coal	33	47	7	0	0	0	0	0	0
- Gas	50	50	48	55	45	14	2	0	0
- Oil	2	2	2	3	3	0	0	0	0
- Diesel	2	1	1	1	0	0	0	0	0
- Hydrogen	0	0	0	0	0	2	5	4	6
- of which renewable H2	0	0	0	0	0	2	5	4	6
- Renewables (w/o renewable hydrogen)	**24**	**36**	**107**	**189**	**319**	**410**	**512**	**655**	**717**
- Hydro	14	19	19	19	19	19	19	19	19
- Wind	6	9	39	57	101	109	142	164	180
- PV	1	5	42	82	115	140	178	241	266
- Biomass (& renewable waste)	2	3	4	7	16	41	44	55	74
- Geothermal	0	0	2	14	30	35	43	50	51
- Solar thermal power plants	0	0	1	5	28	47	65	79	78
- Ocean energy	0	0	0	5	10	19	23	48	50
Import	0	0	0	0	0	0	0	0	0
- Import RES	0	0	0	0	0	0	0	0	0
Export	0	0	0	0	0	0	0	0	0
Distribution losses	13	12	12	12	13	13	13	13	13
Own consumption electricity	27	27	24	22	19	17	16	14	13
Electricity for hydrogen production	0.0	0.0	1.3	5.6	17.3	26.9	65.5	119.3	127.9
Electricity for synfuel production	0.0	0.0	3.9	8.9	11.7	17.4	26.9	34.5	37.2
Final energy consumption (electricity)	209.4	195.6	225.6	267.1	315.8	352.4	398.1	478.3	532.5
Fluctuating RES (PV, Wind, Ocean)	8	14	81	144	226	268	343	452	495
Share of fluctuating RES	3%	6%	30%	46%	60%	63%	66%	69%	68%
RES share (domestic generation)	10%	15%	40%	60%	85%	96%	100%	100%	100%

Heat supply and air conditioning in PJ/a
Scenario: Australia Advanced RE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
District heating plants	1	1	2	2	2	1	2	2	2
- Fossil fuels	1	1	2	2	2	1	2	1	0
- Biomass	0	0	0	0	0	0	0	0	1
- Solar collectors	0	0	0	0	0	0	0	0	1
- Geothermal	0	0	0	0	0	0	0	0	1
Heat from CHP 1)	43	62	76	92	117	174	248	233	270
- Fossil fuels	30	42	50	57	57	36	0	1	1
- Biomass	13	20	27	34	56	120	197	184	198
- Geothermal	0	0	0	0	1	7	24	24	33
- Hydrogen	0	0	0	0	2	12	27	25	38
Direct heating	931	1,295	1,359	1,371	1,305	1,278	1,193	1,317	1,249
- Fossil fuels	738	1,103	1,131	1,106	964	767	488	204	15
- Biomass	124	84	85	83	87	169	216	296	337
- Solar collectors	11	11	10	14	26	58	98	154	197
- Geothermal	0	0	0	0	11	15	30	44	58
- Heat pumps 2)	0	0	7	15	29	55	79	148	200
- Electric direct heating	57	96	126	152	189	214	237	316	304
- Hydrogen	0	0	0	0	0	0	45	155	139
Total heat supply3)	975	1,357	1,437	1,465	1,424	1,454	1,443	1,552	1,521
- Fossil fuels	770	1,146	1,182	1,166	1,023	804	490	205	16
- Biomass	137	105	111	118	144	289	414	480	536
- Solar collectors	11	11	10	14	26	58	98	154	197
- Geothermal	0	0	0	0	12	22	54	69	92
- Heat pumps 2)	0	0	7	15	29	55	79	148	200
- Electric direct heating	57	96	126	152	189	214	237	316	304
- Hydrogen	0	0	0	0	2	12	72	180	177
RES share (including RES electricity)	16%	10%	13%	16%	26%	44%	66%	87%	99%
electricity consumption heat pumps (TWh/a)	0%	0%	55%	124%	226%	422%	583%	1059%	1390%

1) public CHP and CHP autoproduction 2) heat from ambient energy and electricity use 3) incl. process heat, cooking

Final energy consumption transport in PJ/a
Scenario: Australia Advanced RE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
road	1,092	1,558	1,591	1,522	1,307	1,094	956	916	966
- fossil fuels	1,076	1,507	1,513	1,306	943	645	344	103	0
- biofuels	14	47	50	58	71	94	146	156	141
- synfuels	0	0	5	10	13	19	31	35	32
- natural gas	2	4	12	11	8	5	3	0	0
- hydrogen	0	0	3	14	40	47	73	103	130
- electricity	0	0	14	133	246	303	390	553	695
Electrification share:	0%	0%	1%	9%	19%	28%	41%	60%	72%
rail	57	52	60	63	73	79	85	114	143
- fossil fuels	42	7	6	5	4	3	3	1	0
- biofuels	0	0	0	1	1	1	1	2	2
- synfuels	0	0	0	0	0	0	0	0	1
- electricity	15	45	53	57	68	75	82	111	140
navigation	29	53	56	54	50	45	42	43	45
- fossil fuels	29	53	54	52	43	35	27	15	0
- biofuels	0	0	2	2	6	8	12	23	37
- synfuels	0	0	0	0	1	2	3	5	8
aviation	111	101	109	106	99	92	88	86	80
- fossil fuels	111	101	109	98	79	72	57	30	0
- biofuels	0	0	0	6	17	17	25	46	65
- synfuels	0	0	0	1	3	3	5	10	15
total (incl. pipelines)	1,304	1,780	1,836	1,769	1,553	1,341	1,211	1,201	1,270
- fossil fuels	1,258	1,668	1,682	1,461	1,069	755	431	149	0
- biofuels (incl. biogas)	14	47	52	68	95	120	184	226	246
- synfuels	0	0	5	12	17	25	39	51	56
- natural gas	19	20	26	24	19	14	10	5	2
- hydrogen	0	0	3	14	40	47	73	103	130
- electricity	15	45	67	190	314	379	473	666	836
total RES	15	54	82	197	409	555	767	1,046	1,268
RES share	1%	3%	4%	11%	26%	41%	63%	87%	100%

Installed capacity in GW
Scenario: Australia Advanced RE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total generation	43	44	78	113	156	178	219	280	313
- Fossil	33	29	24	20	10	4	1	0	0
- Hard coal (& non-renewable waste)	18	13	14	9	1	0	0	0	0
- Brown Coal	4	6	1	0	0	0	0	0	0
- Gas (w/o H2)	8	8	8	9	8	3	1	0	0
- Oil	1	1	1	1	1	0	0	0	0
- Diesel	1	1	0	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants, g	0	0	0	0	0	1	1	1	2
- Renewables	**10**	**15**	**54**	**93**	**146**	**174**	**217**	**279**	**311**
- Hydro	6	8	8	8	8	8	8	8	8
- Wind	3	4	18	26	45	49	63	73	80
of which wind offshore	0	0	0	1	9	8	12	14	14
- PV	1	3	26	51	72	88	111	150	166
- Biomass (& renewable waste)	0	0	1	1	3	7	8	11	20
- Geothermal	0	0	0	3	7	8	9	9	10
- Solar thermal power plants	0	0	0	2	10	10	13	16	16
- Ocean energy	0	0	0	1	3	5	6	12	13
Fluctuating RES (PV, Wind, Ocean)	4	7	44	79	119	141	180	235	258
Share of fluctuating RES	9%	17%	57%	70%	76%	79%	82%	84%	83%
RES share (domestic generation)	23%	35%	69%	82%	93%	98%	99%	100%	99%

Final energy demand in PJ/a 1)
Scenario: Australia Advanced RE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy use)	3,333	4,133	4,261	4,181	3,871	3,645	3,437	3,538	3,542
Total energy use 1)	3,132	3,897	4,057	3,977	3,668	3,441	3,234	3,335	3,338
Transport	1,304	1,780	1,836	1,769	1,553	1,341	1,211	1,201	1,270
- Oil products	1,258	1,668	1,682	1,461	1,069	755	431	149	0
- Natural gas/biogas	19	20	26	24	19	14	10	5	2
- Biofuels	14	47	52	68	95	120	184	226	246
- Synfuels	0	0	5	12	17	25	39	51	56
- Electricity	15	45	67	190	314	379	473	666	836
RES electricity	1	7	27	114	266	365	471	666	836
- Hydrogen	0	0	3	14	40	47	73	103	130
RES share Transport	1%	3%	4%	11%	26%	41%	63%	87%	100%
Industry	1,002	1,365	1,462	1,469	1,398	1,374	1,288	1,397	1,350
- Electricity	288	327	366	381	421	463	512	589	610
RES electricity	28	50	147	229	357	447	510	589	610
- Public district heat	11	12	12	14	15	17	16	17	18
RES district heat	0	1	1	2	6	11	14	15	17
- Hard coal & Brown Coal	111	80	63	59	43	33	60	29	18
- Oil products	168	196	213	213	197	66	29	23	0
- Gas	316	695	748	742	652	575	328	136	0
- Solar	0	0	0	0	0	25	47	80	116
- Biomass	108	55	60	60	69	181	223	310	343
- Geothermal	0	0	0	0	0	15	37	78	100
- Hydrogen	0	0	0	0	0	0	36	136	146
RES share Industry	14%	8%	14%	20%	31%	49%	67%	86%	99%
Other Sectors	825	753	760	739	717	726	735	737	718
- Electricity	451	332	379	390	403	427	448	466	471
RES electricity	43	51	152	234	341	411	446	466	471
- Public district heat	0	0	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0	0	0
- Hard coal & Brown Coal	1	0	0	0	0	0	0	0	0
- Oil products	124	141	107	85	36	33	14	7	0
- Gas	180	211	205	188	174	149	107	30	0
- Solar	11	11	10	14	26	33	51	74	81
- Biomass	58	58	53	51	47	44	52	55	58
- Geothermal	0	0	5	11	31	41	51	77	108
- Hydrogen	0	0	0	0	0	0	12	29	0
RES share Other Sectors	14%	16%	29%	42%	62%	73%	83%	95%	100%
Total RES	263	279	509	799	1,287	1,763	2,247	2,954	3,317
RES share	8%	7%	13%	20%	35%	51%	69%	89%	99%

Australia Advanced RE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	195	169	123	86	26	3	1	0	0
- Hard coal (& non-renewable waste)	132	93	96	65	9	0	0	0	0
- Brown Coal	37	55	8	0	0	0	0	0	0
- Gas	23	21	19	21	16	2	1	0	0
- Oil	1	0	0	0	2	0	0	0	0
- Diesel	2	1	0	0	0	0	0	0	0
Combined heat and power plants	8	8	9	10	9	5	0	0	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0
- Brown Coal	3	0	0	0	0	0	0	0	0
- Gas	5	7	8	9	8	5	0	0	0
- Oil	1	1	1	1	1	0	0	0	0
CO2 emissions power and CHP plants	203	178	133	96	35	8	1	0	0
- Hard coal (& non-renewable waste)	132	93	96	65	9	0	0	0	0
- Brown Coal	39	55	8	0	0	0	0	0	0
- Gas	28	28	26	30	24	7	1	0	0
- Oil & diesel	3	2	2	2	2	0	0	0	0
CO2 intensity (g/kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
without credit for CHP heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CO2 intensity fossil electr. generation	902	897	829	763	611	538	567	1,068	0
- CO2 intensity total electr. generation	815	759	497	305	93	19	2	0	0
CO2 emissions by sector	374	420	369	308	196	123	71	27	2
- % of 1990 emissions (276 Mill t)	136%	152%	134%	111%	71%	45%	26%	10%	1%
- Industry 1)	45	67	71	71	63	46	27	13	2
- Other sectors 1)	20	23	20	18	13	11	7	2	0
- Transport	96	128	129	112	82	58	33	11	0
- Power generation 2)	200	173	127	89	28	4	1	0	0
- Other conversion 3)	13	29	22	17	10	5	2	1	0

'Efficiency' savings (compared to Ref.)

1) incl. CHP autoproducers
2) incl. CHP public
3) district heating, refineries, coal transformation, gas transport

Primary energy demand in PJ/a
Scenario: Australia Advanced RE

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Total	5,147	5,800	5,746	5,681	5,249	4,993	4,870	5,112	5,209
- Fossil	4,836	5,442	5,059	4,409	3,088	2,058	1,248	600	226
- Hard coal (& non-renewable waste)	1,538	1,072	1,077	722	110	9	37	5	7
- Brown Coal	387	521	110	39	34	30	25	26	12
- Natural gas	1,036	1,468	1,503	1,552	1,341	933	512	205	32
- Crude oil	1,874	2,380	2,368	2,097	1,603	1,086	675	364	175
- Renewables	**311**	**359**	**688**	**1,273**	**2,162**	**2,935**	**3,621**	**4,512**	**4,984**
- Hydro	50	68	68	68	68	68	68	68	70
- Wind	22	32	141	205	364	392	511	591	647
- Solar	17	29	165	329	541	730	972	1,308	1,433
- Biomass (& renewable waste)	222	229	253	300	448	880	1,061	1,294	1,544
- Geothermal	0	0	61	352	705	796	928	1,081	1,110
- Ocean energy	0	0	0	18	36	69	81	171	180
Total incl. net elec. & synfuel import	5,147	5,800	5,746	5,681	5,249	4,993	4,870	5,112	5,209
- of which non-energy use	202	235	204	204	204	204	204	204	204
Total RES incl. electr. & synfuel import	311	359	688	1,273	2,162	2,935	3,621	4,512	4,984
RES share	0.06047	0.06184	0.1197	0.224	0.41183	0.58787	0.74364	0.88265	0.9567

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