

100% RENEWABLE ENERGY FOR AUSTRALIA

Decarbonising Australia's Energy Sector Within One Generation

Prepared for: GetUp! and Solar Citizens



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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.

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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 year¹. In 2014, growth rates for coal use stalled globally for the first time, including in China. This trend continued through 2015². 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 minutes³.

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: <u>www.ren21.net/status-of-renewables/global-status-report/</u>

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: <u>www.gwec.net/global-figures/wind-energy-global-status/</u>



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.



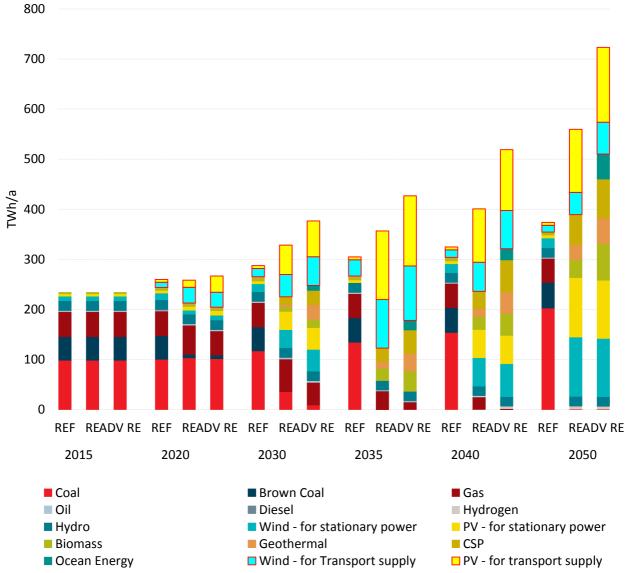


Figure 1: Breakdown of electricity generation by technology



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,
- 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 years⁶ 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

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

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



(an average of 12 years based on all currently operating nuclear power plants worldwide⁸) 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

- **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 Science¹². 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 2014¹³. Official market forecast sources include the Australian Energy Market Operator (AEMO) national electricity and gas forecasts¹⁴ and the IMO 2015 Gas forecast for Western Australia¹⁵. This results in a forecast incorporating the most recent outlook from official sources where available.

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
 ¹⁰ <u>http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf</u>

¹¹ International Energy Agency, 2015, *Energy Balances of OECD Countries.* Available at: <u>https://www.iea.org/statistics/relateddatabases/energybalancesofoecdcountries/</u>

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-energystatistics.pdf

¹³ Commonwealth of Australia Bureau of Resources and Energy Economics. 2014. *Australian Energy Projections to 2049-*50. Available at: <u>http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aep/aep-2014-v2.pdf</u>

¹⁴ Australian Energy Market Operator (AEMO). 2015. *National Electricity and Gas Forecasting*. [ONLINE]. Available at: <u>http://forecasting.aemo.com.au/Electricity/AnnualConsumption/Operational</u>

¹⁵ Independent Market Operator (IMO). 2015. Gas Statement of Opportunities. Available at: <u>http://wa.aemo.com.au/docs/default-source/Reserve-Capacity/november-2015-gas-statement-of-opportunities_v28968963f29c46dc8b2c9ff0000bd36b5.pdf?sfvrsn=0</u>



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 CO₂ 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 potentials¹⁷. Lowtech 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 three¹⁸, which then enables thermal energy storage to provide energy for 12 hours per day of fullload 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: <u>http://www.climateworksaustralia.org/sites/default/</u> <u>files/documents/publications/climateworks_pdd2050_technicalreport_20140923.pdf</u>



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 projections²⁰ 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	
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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 coal²², 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	IEA WEO High Price	20.5	24.2	26.1	28.0	29.9	31.8	34.7	37.6
gas	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	DLR	4.5	4.9	5.2	5.5	5.8	6.0	6.4	6.7
and waste	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 <u>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</u>



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 <u>only</u> relevant to the resulting costs of electricity generation as outlined in Section 4.2.2. In this model a carbon price is <u>not</u> 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 Investments²³. 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 Neij²⁴, 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: <u>http://www.worldenergyoutlook.org/investment/</u>

 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 research²⁶. 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 Report²⁷. 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 hightemperature 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 CO₂. 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 Report³⁰. 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 Assessments³¹ (ABARE 2010 and 2014) were also reviewed but AEMO data was used as it is more conservative and comparable across technologies.

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, <u>www.co2crc.com.au</u>

²⁸ IRENA, *Renewable Power Generation Costs in 2014*, January 2014, Abu Dhabi, <u>www.IRENA.org</u>

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 <u>https://www.environment.gov.au/climate-change/publications/aemo-modelling-outcomes</u>

³¹ ABARE (2010, 2014) *Australian Energy Resource Assessments*. Retrieved from <u>http://www.ga.gov.au/scientific-topics/energy/resources/australian-energy-resource-assessment</u>



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: Req	uired area for	Solar PV	and Wind
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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
Unanore	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



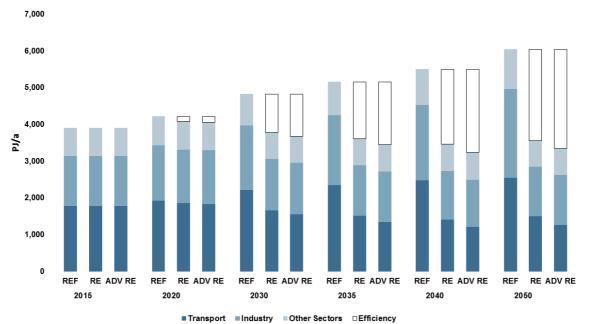


Figure 2: Projection of total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)

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).



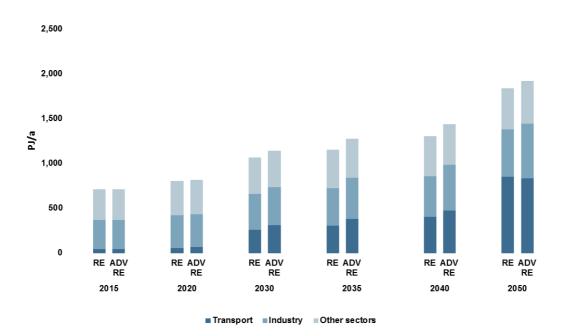


Figure 3: Development of electricity demand by sector in both renewable scenarios

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 bunkers³⁴).

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



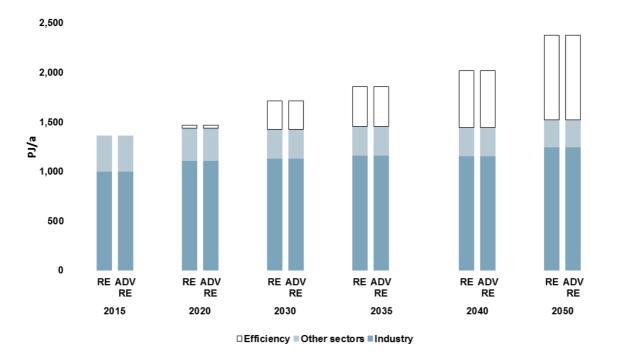


Figure 4: Development of heat demand by sector in the renewable scenarios

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.



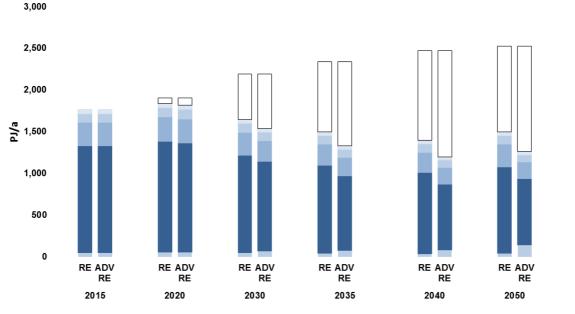


Figure 5: Development of the final energy demand for transport by sector in the renewable scenarios

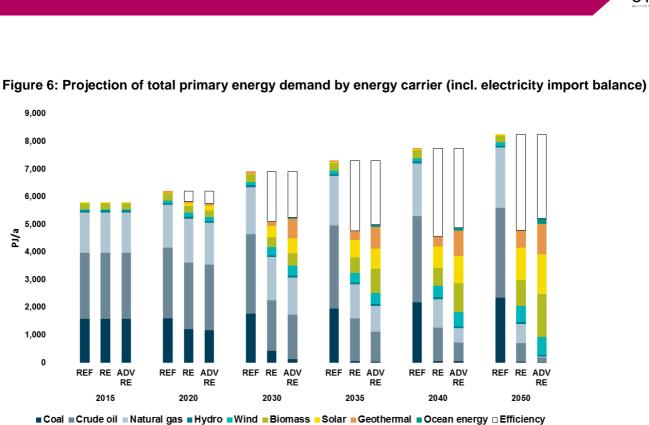


4.1.2 Primary energy consumption

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 consumption³⁵. 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 - <u>https://www.iea.org/statistics/resources/balancedefinitions/#nonenergyuse</u>



100% RENEWABLE ENERGY FOR AUSTRALIA

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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.

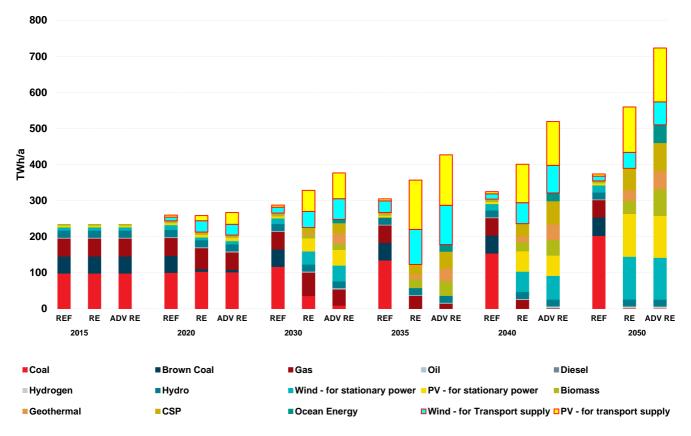
In the Renewables scenario:

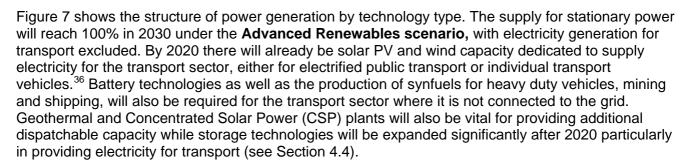
- By 2050 97% of the electricity produced in Australia will come from renewable energy sources, with the remaining 3% from gas. 'New' renewables mainly wind, PV and geothermal energy will contribute 82% to the total electricity generation.
- The share of electricity production from renewable sources 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





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

Table 5: Projection of renewable electricity generation capacity

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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. <u>http://reneweconomy.com.au/2016/nsw-seeks-renewable-energy-to-power-north-west-rail-line-63247</u>



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.

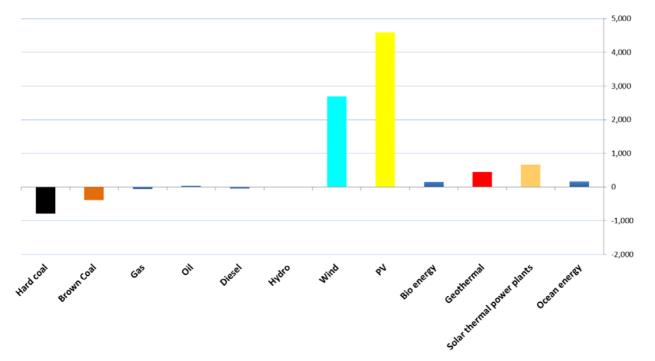


Figure 8: Average annual capacity change by technology in the Advanced Renewables case

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.

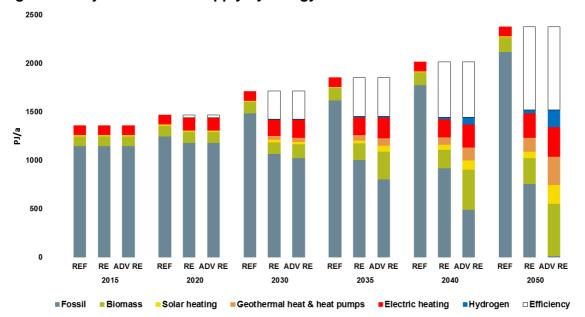


Figure 9: Projection of heat supply by energy carrier

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 CO₂ 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
	REF	105	110	118	132	149
Biomass	RE	105	111	120	190	264
	ADV RE	105	111	144	414	536
	REF	11	11	11	11	11
Solar heating	RE	11	10	26	52	68
	ADV RE	11	10	26	98	197
	REF	0	0	0	0	0
Geothermal heat & heat pumps	RE	0	7	39	76	145
	ADV RE	0	7	41	133	292
	REF	0	0	0	0	0
Hydrogen	RE	0	0	2	17	37
	ADV RE	0	0	2	72	177
	REF	116	121	129	143	160
Total	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
	REF	17	17	18	18
Biomass	RE	15	14	12	11
	ADV RE	15	15	30	43
	REF	0	0	0	0
Geothermal	RE	0	2	4	6
	ADV RE	0	2	5	9
	REF	3	3	3	3
Solar heating	RE	3	8	16	21
	ADV RE	3	8	31	61
	REF	0	0	0	0
Heat pumps	RE	1	5	8	15
	ADV RE	1	5	11	28
	REF	20	21	21	22
Total	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.

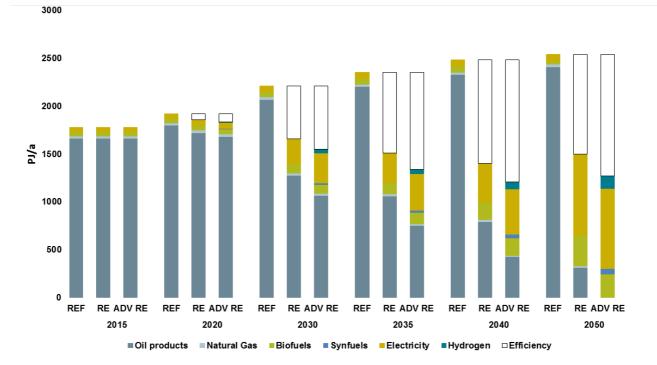


Figure 10: Final energy consumption transport under the scenarios

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

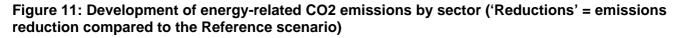
in PJ/a		2015	2020	2030	2040	2050
Rail	REF	52	56	64	72	80
	RE	52	56	50	42	45
	ADV RE	52	60	73	85	143
Road	REF	1,558	1,681	1,930	2,176	2,232
	RE	1,558	1,621	1,445	1,209	1,307
	ADV RE	1,558	1,596	1,320	987	998
Domestic aviation	REF	101	113	134	148	132
aviation	RE	101	110	105	104	103
	ADV RE	101	109	99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

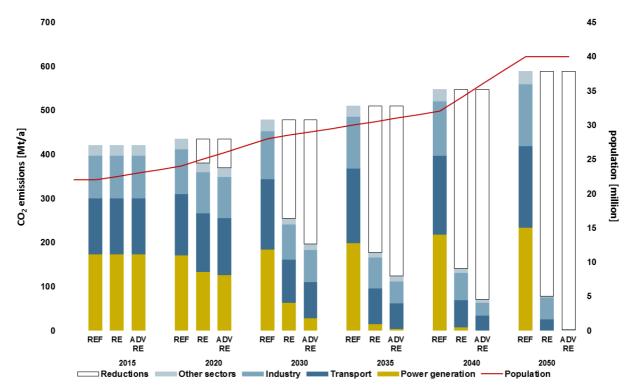


4.5 CO₂ EMISSIONS TRAJECTORIES

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.







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

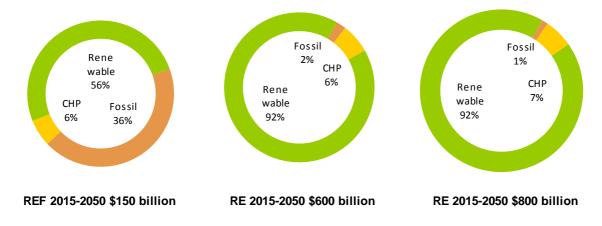
Under the **Renewables** and **Advanced Renewables** scenarios Australia would shift almost 98% and 99% respectively of new power sector capital investment towards renewables and cogeneration between now and 2050 (see Figure 12). This will result in higher investment costs than the reference scenario, 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



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.

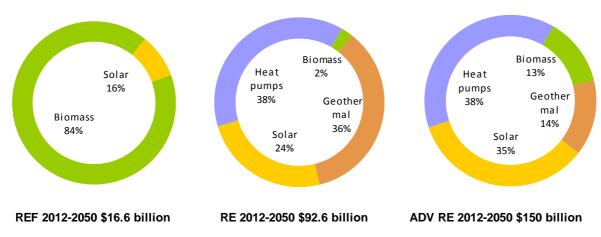


Figure 13: Share of investment for renewable heat generation technologies

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.

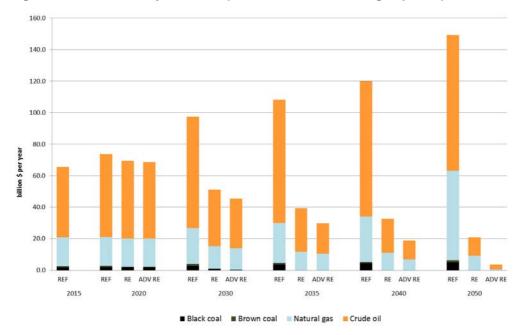


Figure 14: Fuel costs by scenario (assumed low coal and gas prices)

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).

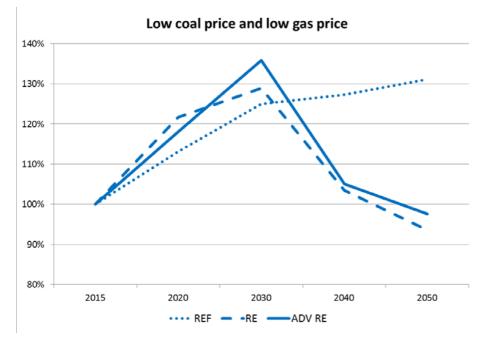
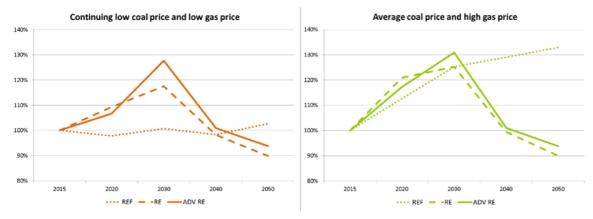


Figure 15: Average electricity generation costs for each scenario (low coal and low gas price)

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.





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.

UTS:



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.

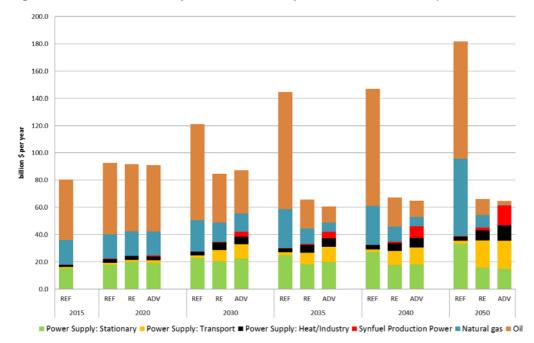


Figure 17: Annual electricity and fuel costs by sector and scenario (assumed low coal and gas prices)

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	t costs for	power	generation
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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	CHP Biomass and waste	5,150	4,505	3,934	3,626	3,445
Generation and Industry	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 /	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
Other Small Scale	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

Coal power plant 30.8 29.7 29.7 29.7 29.7 Diesel generator 112.6 <th>in \$/kW/a</th> <th></th> <th>2015</th> <th>2020</th> <th>2030</th> <th>2040</th> <th>2050</th>	in \$/kW/a		2015	2020	2030	2040	2050
Diesel generator 112.6 136.0 136.0 136.0 136.0 136.0 136.0 136.0 136.0 136.0 136.0 143.3 149.2 155.0 156.9 156.0 156.9 156.0 156.9 156.0 156.9 156.0 156.9 156.0 156.9 156.0 156.9 156.0 156.9 156.0 156.9 156.0 156.9 156.0 156.0 156.9 156.0 156.9 156.0 156.9 156.8 156.9 156.8 156.9 156.8 156.9 156.8 156.9 156.9 156.9 156.9 156.9 156.9 156.9 156.9 156.9	Power plants	Biomass and waste power plant	189.1	178.3	172.0	165.5	162.2
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 139.0 143.3 149.2 155.0 159.9 Hydro small 139.0 143.3 149.2 155.0 159.9 Lignite power plant 27.1 26.5 25.9 25.4 24.9 Nuclear power plant 162.0 <td></td> <td>Coal power plant</td> <td>30.8</td> <td>29.7</td> <td>29.7</td> <td>29.7</td> <td>29.7</td>		Coal power plant	30.8	29.7	29.7	29.7	29.7
Geothermal power plant 548.6 426.6 324.4 302.9 286.7 Hydro large 139.0 143.3 149.2 155.0 159.9 Hydro small 139.0 143.3 149.2 155.0 159.9 Lignite power plant 27.1 26.5 25.9 25.4 24.9 Nuclear power plant 162.0 163.0 14.0 14.0 14.0 14.0 14.0 14.0 14.0 162.0 163.0 163.0 17.0 163.0		Diesel generator	112.6	112.6	112.6	112.6	112.6
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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 1		Geothermal power plant	548.6	426.6	324.4	302.9	286.7
Lignite power plant 27.1 26.5 25.9 25.4 24.9 Nuclear power plant 162.0 162		Hydro large	139.0	143.3	149.2	155.0	159.4
Nuclear power plant 162.0 <td></td> <td>Hydro small</td> <td>139.0</td> <td>143.3</td> <td>149.2</td> <td>155.0</td> <td>159.4</td>		Hydro small	139.0	143.3	149.2	155.0	159.4
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 209.5 164.5 133.6 126.6 108.8 Hydrogen production Electrolysis 17.9 16.8 14.6 14.6 14.6 CHP for Power Generation CHP Coal 68.7 67.3 65.8 64.4 62.9 CHP Gas 42.4 39.5 38.0 38.0 38.0 CHP Gas 42.4 39.5 342.3 298.4 272.2 CHP Golthermal 487.1 409.5 342.3 298.4 272.2 CHP Coal 68.7 67.3 65.8 64.4 62.9 CHP Coal 487.1 409.5 342.3 298.4 272.2		Lignite power plant	27.1	26.5	25.9	25.4	24.9
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 209.5 164.5 133.6 126.6 108.3 Wind turbine offshore 56.5 55.9 56.8 59.8 62.6 Hydrogen production Electrolysis 17.9 16.8 14.6 14.6 CHP for Power Generation CHP Coal 68.7 67.3 65.8 64.4 62.9 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 Gas 42.4 39.5 39.5 38.0 38.0 CHP Goal 68.7 67.3 65.8 64.4 62.9 CHP Goal 487.1 409.5 342.3 298.4 272.5 CHP Dil 48.3 <td></td> <td>Nuclear power plant</td> <td>162.0</td> <td>162.0</td> <td>162.0</td> <td>162.0</td> <td>162.0</td>		Nuclear power plant	162.0	162.0	162.0	162.0	162.0
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 209.5 164.5 133.6 126.6 108.3 Wind turbine offshore 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 Gas 42.4 39.5 39.5 38.0 38.0 CHP Coal 68.7 67.3 65.8 64.4 62.9 CHP Coal 68.7 67.3 38.0 38.0 38.0 CHP Coal 81.9 80.4 77.5 76.1 73.4 CHP Coal 68.7 67.3 65.8 64.4 62.9 CHP Coal 81.9 80.4 77.5 76.1 73.4 CHP		Ocean energy power plant	188.7	134.7	93.0	78.2	69.0
Note Note <th< td=""><td></td><td>Oil power plant</td><td>22.4</td><td>21.7</td><td>20.3</td><td>18.8</td><td>17.4</td></th<>		Oil power plant	22.4	21.7	20.3	18.8	17.4
Wind turbine offshore 209.5 164.5 133.6 126.6 108.7 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 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 38.0 38.0 38.0 CHP Coal 487.1 409.5 342.3 298.4 272.4 CHP Dignite 81.9 80.4 77.5 76.1 73.1 CHP For CHP Oil 48.3 46.8 43.9 42.4 41.0 Industry CHP Coal 68.7 67.3 65.8 64.4 62.9 CHP for CHP Coal 68.7 67.3 65.8 64.4 62.9 CHP For CHP Coal 68.7 67.3		PV power plant	38.7	21.9	15.4	14.7	15.4
Wind turbine onshore56.555.956.859.862.6Hydrogen productionElectrolysis17.916.814.614.614.614.6CHP for Power GenerationCHP Biomass and waste361.3315.9275.0254.5241.3CHP Coal68.767.365.864.462.9CHP Geothermal487.1409.5342.3298.4272.3CHP Lignite81.980.477.576.173.1CHP Oil48.346.843.942.441.0CHP Coal68.767.365.864.462.9CHP Coal68.767.365.864.462.9CHP Coal68.767.365.864.462.9CHP Coal68.767.365.864.462.9CHP Coal68.767.365.864.462.9CHP Coal68.767.365.864.462.9CHP Coal68.767.365.864.462.9CHP Coal68.767.365.864.462.9CHP Gas42.439.539.538.038.0CHP Geothermal86.367.365.864.462.9CHP Gas42.439.539.538.038.0CHP Geothermal239.9231.1222.320.921.9		Solar thermal power plant	350.9	270.0	233.8	215.0	196.4
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 Lignite 487.1 409.5 342.3 298.4 272.4 CHP Dil 48.3 46.8 43.9 42.4 41.0 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 Coal 487.1 409.5 342.3 298.4 272.4 CHP Dignite 81.9 80.4 77.5 76.1 73.1 Industry CHP Biomass and waste 93.6 83.4 74.6 68.7 62.9 CHP Coal 68.3 67.3 61.4 58.5 57.0 CHP Gas <td></td> <td>Wind turbine offshore</td> <td>209.5</td> <td>164.5</td> <td>133.6</td> <td>126.6</td> <td>108.9</td>		Wind turbine offshore	209.5	164.5	133.6	126.6	108.9
production Electrolysis 17.9 16.8 14.6 16.7 16.7 16.7 <td></td> <td>Wind turbine onshore</td> <td>56.5</td> <td>55.9</td> <td>56.8</td> <td>59.8</td> <td>62.6</td>		Wind turbine onshore	56.5	55.9	56.8	59.8	62.6
Generation CHP Coal 68.7 67.3 65.8 64.4 62.9 CHP Gas 42.4 39.5 39.5 38.0		Electrolysis	17.9	16.8	14.6	14.6	14.6
CHP Coal 68.7 67.3 65.8 64.4 62.9 CHP Gas 42.4 39.5 39.5 38.0		CHP Biomass and waste	361.3	315.9	275.0	254.5	241.3
CHP Geothermal 487.1 409.5 342.3 298.4 272.5 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 Gas 42.4 39.5 39.5 38.0 38.0 CHP Gas 42.4 39.5 39.5 38.0 38.0	Generation	CHP Coal	68.7	67.3	65.8	64.4	62.9
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 38.0		CHP Gas	42.4	39.5	39.5	38.0	38.0
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 38.0		CHP Geothermal	487.1	409.5	342.3	298.4	272.1
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 38.0		CHP Lignite	81.9	80.4	77.5	76.1	73.1
Industry 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 38.0 CHP Geothermal 239.9 231.1 222.3 220.9 219.4		CHP Oil	48.3	46.8	43.9	42.4	41.0
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 Biomass and waste	93.6	83.4	74.6	68.7	62.9
CHP Gas 42.4 39.5 39.5 38.0 38.0 CHP Geothermal 239.9 231.1 222.3 220.9 219.4	Industry	CHP Coal	68.7	67.3	65.8	64.4	62.9
CHP Geothermal 239.9 231.1 222.3 220.9 219.4		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 Lignite 81.9 80.4 77.5 76.1 73.1		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 Oil	48.3	46.8	43.9	42.4	41.0
		CHP Biomass and waste	101.7	99.5	98.0	96.5	95.1
	Other Small	CHP Coal	68.0	67.3	65.8	64.4	62.9
Scale CHP Fuel cell 86.3 67.3 61.4 58.5 57.0	Scale	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 Gas	38.8	36.6	32.2	32.2	30.7
CHP Geothermal 239.9 231.1 222.3 220.9 219.4		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 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 INVES		STS (differe	nce REF mi	nus 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 SAVI	NGS (saving	gs cumulati	ve RE versı	ıs 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 INVES	TMENT CO	STS (differe	nce REF mi	inus 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 INVES		STS (differe	nce REF mi	inus 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 SAVI	NGS (savin	gs cumulati	ve RE versı	ıs 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 INVES	TMENT CO	STS (differe	nce REF mi	nus RE)				
Renewables	-0.6	12.4	43.8	77.9	133.4	3.8	0.8	6.4



APPENDIX C: RESULTS SUMMARIES

Electricity generation in TWh/a Scenario:	Australia F	Reference	(2015)							Installed capacity in GW Scenario: Australia Reference (2015)
and a second PDA	2012	2015	2020	2025	2030	2035	2040	2045	2050	2012 2015 2020 2025 2030 2035 2040 2045 205
Power plants - Hard coal (& non-renewable waste) - Brown Coal - Gas of which from H2 - Oil	236 138 31 42 0	217 98 47 38 0 0	237 100 47 37 0	249 102 47 36 0	263 117 48 35 0	278 134 49 33 0	297 153 49 33 0	321 178 50 32 0	344 202 51 31 0	Total generation 43 44 52 57 56 61 64 64 66 - Fossil coal (d non-renewable waste) 13 29 29 31 34 36 36 35 - Brown Coas (wid N2) 16 16 16 16 21 <
 Diesel Biomass (& renewable waste) 	1 2 1	1 0	0 1 1	0 2 2	0 1 2	0 2 2	0 2 2	0 2 2	0 2 2	- Diesel 1 1 1 1 1 1 1 1 1 1 - Hydrogen (fuel cells, gas power plants, gas 0 0 0 0 0 0 0 0 0 0 0
- Hydro - Wind of which wind offshore	14 6 0	19 9 0	19 24 0	19 32 1	19 32 1	19 32 2	18 33 3	18 33 3	18 33 4	- Renewables 10 15 23 28 27
- PV - Geothermal	1 0	5 0	6 2	6 4	6 3	6 2	6 2	6 1	6 0	of which wind offshore 0 0 0 0 0 0 1 1 1 1 1 - PV 1 3 3 4 4 4 4 4 4
 Solar thermal power plants Ocean energy 	0	0	0	0	0	0	0	0	0	- Biomass (& renewable waste) 0 0 1 <th1< td=""></th1<>
Combined heat and power plants - Hard coal (& non-renewable waste)	13 0	17 0	17 0	18 0	19 0	21 0	22 0	22 0	23 0	- Ocean energy 0 0 0 0 0 0 0 0 0
- Brown Coal - Gas of which from H2	2 8 0	0 12 0	0 12 0	0 13 0	0 13 0	0 15 0	0 16 0	0 16 0	0 17 0	Fluctuating RES (PV, Wind, Ocean) 4 7 15 18 19 19 19 19 15 Share of fluctuating RES 9% 17% 28% 32% 31% 30% 29% 29% 28%
- Oil - Biomass (& renewable waste)	1 2	2	2	2	2	1 4	1 4	1 4	1 4	RES share (domestic generation) 23% 35% 44% 49% 47% 45% 43% 43% 41*
- Geothermal - Hydrogen	0	0	0	0	0	0	0	0	0	Final energy demand in PJ/a 1)
CHP by producer - Main activity producers - Autoproducers	0 5 8	0 5 12	0 5 12	0 5 13	0 5 14	0 5 16	0 5 17	0 5 17	0 5 18	Stenario: Australia Reference (2015) 2012 2015 2020 2025 2030 2035 2040 2045 204 Total (incl. non-energy use) 3.333 4.133 4.458 4.755 5.069 5.392 5.736 6.005 6.2 Total energy use 1) 3.132 3.897 4.216 4.513 4.826 5.150 5.494 5.733 6.0 Tansport 1.304 1.760 1.924 2.067 2.211 2.347 2.475 7.251 2.55
Total generation - Fossil	249 225	234 198	254 200	267 201	282 216	299 234	319 255	343 280	368 305	- Oil products 1,258 1,668 1,803 1,938 2,073 2,208 2,332 2,392 2,4 - Natural gas 19 20 21 22 23 24 26 27 26
 Hard coal (& non-renewable waste) Brown Coal Gas 	138 33 50	98 47 50	100 47 50	102 47 49	117 48 49	134 49 49	154 49 48	178 50 48	203 51 48	- Biofuels 14 47 50 54 58 62 66 29 25 - Synfuels 0
- Oil - Diesel	2	2	2 1	2	2	2	1	1 2	1 2	RES electricity 1 7 10 13 13 13 12 12 - Hydrogen 0 <td< td=""></td<>
- Hydrogen - of which renewable H2 - Renewables (w/o renewable hydrogen)	0 0 24	0 0 36	0 0 54	0 0 66	0 0 65	0 0 65	0 0 64	0 0 63	0 0 63	RÉS share Transport 1% 3% 3% 3% 3% 3% 2% 2% Industry 1,002 1,365 1,514 1,637 1,632 2,049 2,232 2,4'
- Hydro - Wind	24 14 6	36 19 9	19 24	19 32	19 32	19 32	18 33	18 33	18 33	- Electricity 288 327 370 385 405 427 458 498 53 RES electricity 28 50 79 95 94 92 92 92 92
 - PV - Biomass (& renewable waste) - Geothermal 	1 2 0	5 3 0	6 4 2	6 5 4	6 5 3	6 5 2	6 6 2	6 6 1	6 6 0	- Public district heat 11 12 12 12 12 13 13 13 RES district heat 0 1<
- Solar thermal power plants - Ocean energy	0 0	0	0	0	0	0	0	0 0	0 0	- Oil products 168 196 210 224 238 252 261 271 28 - Gas 316 695 779 861 944 1,028 1,137 1,265 1,44
Import - Import RES	0	0	0	0	0	0	0	0	0	- Solar 0 </td
Export Distribution losses	0 13	0 12	0 13	0 14	0 15	0 16	0 17	0 18	0 20	- Geometrinal 0 <
Own consumption electricity Electricity for hydrogen production Electricity for synfuel production	27 0.0 0.0	27 0.0 0.0	25 0.5 0.0	25 0.5 0.0	24 0.5 0.0	23 0.6 0.0	21 0.6 0.0	21 0.6 0.0	21 0.7 0.0	Other Sectors 825 753 778 809 853 903 958 1,016 1,07 Electricity 451 332 357 382 413 449 486 526 56
Final energy consumption (electricity)	209.4	195.6	215.4	227.7	242.8	260.2	279.9	303.1	326.0	RES electricity 43 51 76 94 96 97 98 97 97 - Public district heat 0 </td
Fluctuating RES (PV, Wind, Ocean) Share of fluctuating RES RES share (domestic generation)	8 3% 10%	14 6% 15%	30 12% 21%	38 14% 25%	38 13% 23%	38 13% 22%	38 12% 20%	39 11% 18%	39 11% 17%	RES district heat 0
Heat supply and air conditioning in PJ/a										- Gas 180 211 210 210 217 226 240 255 27 - Solar 11 11 11 11 11 11 11 11
Scenario:	Australia I 2012	Reference 2015	(2015) 2020	2025	2030	2035	2040	2045	2050	Biomass 58 58 60 <t< td=""></t<>
District heating plants	1	1	1	1	1	1	1	1	1	RES share Other Sectors 14% 16% 19% 20% 20% 19% 18% 17% 16%
Fossil fuels Biomass Solar collectors	1 0 0	1 0 0	1 0 0	1 0 0	1 0 0	1 0 0	1 0 0	1 0 0	1 0 0	Total RES 263 279 347 390 398 406 413 378 38 RES share 8% 7% 8% 9% 8% 8% 7% 69
- Geothermal	0	Ō	0	0	0 71	0	0 86	0	0 94	CO2 emissions in Mill Va Scenario: Australia Reference (2015)
Heat from CHP 1) - Fossil fuels - Biomass	30 13	62 42 20	43 21	68 45 22	47 23	55 27	57 28	58 29	61 32	2012 2015 2020 2025 2030 2035 2040 2045 206 Condensation power plants 195 169 168 181 197 216 212 23
- Geothermal - Hydrogen	0	0	0	0	0	0	0	0	0	- Hard coal (& non-renewable waste) 132 93 95 96 111 127 146 141 16 - Brown Coal 37 55 52 51 50 50 51 52 55 - Gas 23 21 20 19 19 18 18 17 17
Direct heating - Fossil fuels	931 738	1,295 1,103	1,401 1,205	1,517 1,318	1,641 1,439	1,771 1,566	1,929 1,718	2,100 1,883	2,283 2,059	- Gas 23 21 20 19 19 18 18 1/ 1/ - Oli 1 0 0 0 0 0 0 0 0 - Diesel 2 1 1 1 1 1 1 1 1
- Biomass - Solar collectors - Geothermal	124 11 0	84 11 0	89 11 0	92 11 0	95 11 0	98 11 0	104 11 0	111 11 0	117 11 0	Combined heat and power plants 8 8 8 8 9 9 9 9 - Hard coal (& non-renewable waste) 0 0 0 0 1 1 0
 Heat pumps 2) Electric direct heating 	0 57	0 96	0 96	0 96	0 96	0 96	0 96	0 96	0 96	-Brown Coal 3 0 0 0 0 0 0 0 0 -Gas 5 7 7 7 7 8 8 8 8
- Hydrogen Total heat supply3)	0 975	0	0	0	0	0	0	0 2,189	0	- Oil 1 1 1 1 1 1 1 1 1 1 CO2 emissions power and CHP plants 203 178 176 176 190 206 225 221 24
- Fossil fuels - Biomass	770 137	1,146 105	1,249 110	1,364 114	1,487 118	1,621 125	1,775 132	1,941 140	2,121 149	- Hard coal (& non-renewable waste) 132 93 95 97 111 128 146 142 16 - Brown Coal 39 55 52 51 50 51 52 53
Solar collectors Geothermal Heat pumps 2)	11 0 0	11 0 0	11 0 0	11 0 0	11 0 0	11 0 0	11 0 0	11 0 0	11 0 0	- Gas 28 28 27 27 26 26 26 25 25 - Oil & diesel 3 2<
- Heat pumps 2) - Electric direct heating - Hydrogen	57 0	96 0	96 1	CO2 intensity (g/kWh) 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.						
RES share (including RES electricity) electricity consumption heat pumps (TWh/a)	16% 0%	10% 0%	10% 0%	9% 0%	9% 0%	8% 0%	8% 0%	8% 0%	7% 0%	- CO2 intensity fossil electr. generation 902 897 883 877 876 878 883 790 79 - CO2 intensity total electr. generation 815 759 694 661 674 688 705 644 65
1) public CHP and CHP autoproduction			rgy and electr				ess heat, cool		0 /0	CO2 emissions by sector 374 420 435 450 478 510 547 557 58 - % of 1990 emissions (276 Mill t) 136% 152% 158% 163% 173% 185% 198% 202% 21
Final energy consumption transport in PJ/a Scenario: road	Australia F 2012 1,092	Reference 2015 1,558	(2015) 2020 1,681	2025 1,806	2030 1,930	2035 2,067	2040	2045	2050	- Industry 1) 45 67 74 80 87 94 102 110 111 - Other sectors 1) 20 23 24 24 25 26 28 25 - Transport 96 128 138 149 159 169 179 184 18 - Power generation 2) 200 173 172 171 185 200 219 215 23
- fossil fuels - biofuels	1,076 14	1,507 47	1,626 50	1,746 54	1,865 58	1,997 62	2,101 66	2,172 29	2,191 29	- Other conversion 3) 13 29 29 26 23 22 21 21 22
- synfuels - natural gas	0 2	0 4 0	0 5 0	0 6	0 7 0	0 8	0 10	0 11	0 12	1) incl. CHP autoproducers 2) incl. CHP public 3) district beating refineers chal transformation, gas transport
- hydrogen - electricity Electrification share:	0 0 0%	0 0 0%	0 0 0%	0 0 0%	0 0 0%	0 0 0%	0 1 0%	0 1 0%	0 1 0%	 district heating, refineries, coal transformation, gas transport
rail - fossil fuels	57 42	52 7	56 7	60 8	64 8	68 9	72	76 10	80 10	
- tossil tuels - biofuels - synfuels	0	0	0	8 0 0	8 0 0	9 0 0	0	10 0 0	10 0 0	Primary energy demand in PJ/a
- electricity	15	45	49 57	52	56 65	60	63	66	70 81	Scenario: Australia Reference (2015) 2012 2015 2020 2025 2030 2035 2040 2045 205
navigation - fossil fuels - biofuels	29 29 0	53 53 0	57 0	61 61 0	65 0	70 70 0	73 73 0	77 77 0	81 0	Total 5,147 5,800 6,207 6,535 6,915 7,310 7,757 7,855 8,27 - Fossil 4,836 5,442 5,711 5,957 6,354 6,759 7,218 7,380 7,71
- synfuels	0	Ō	0	0	0	0	0	0	0	- Hard coal (& non-renewable waste) 1,538 1,072 1,114 1,136 1,298 1,485 1,694 1,648 1,88 - Brown Coal 387 521 497 486 483 482 489 497 50
aviation - fossil fuels - biofuels	111 111 0	101 101 0	113 113 0	123 123 0	134 134 0	132 132 0	148 148 0	132 132 0	132 132 0	- Natural gas 1,036 1,468 1,535 1,614 1,698 1,783 1,902 2,202 2,11 - Crude oil 1,874 2,380 2,565 2,721 2,874 3,009 3,133 3,211 3,29 - Renewables 311 359 496 578 561 550 540 475 46
- synfuels	0	0	0	0	0	0	0	0	0	- Hydro 50 68 68 68 68 67 66 66 65 - Wind 22 32 86 115 116 117 117 118 11
total (incl. pipelines) - fossil fuels - biofuels (incl. biogas)	1,304 1,258 14	1,780 1,668 47	1,924 1,803 50	2,067 1,938 54	2,211 2,073 58	2,354 2,208 62	2,487 2,332 66	2,515 2,392 29	2,542 2,415 29	- Solar 17 29 31 31 32 32 32 33 - Biomass (& renewable waste) 222 229 254 266 273 285 292 244 24 - Geothermal 0 0 56 97 72 51 32 15 0
- synfuels - natural gas	0 19	0 20	0 21	0 22	0 23	0 24	0 26	0 27	0 28	- Ocean energy 0 0 0 0 0 0 0 0 0 0
- hydrogen - electricity	0 15	0 45	0 49	0 53	0 56	0 60	0 64	0 67	0 71	Total incl. net elec. & synfuel import 5,147 5,800 6,207 6,535 6,915 7,310 7,757 7,855 8,24 - of which non-energy use 202 235 242 <t< td=""></t<>
total RES RES share	15 1%	54 3%	61 3%	67 3%	71 3%	75 3%	78 3%	41 2%	41 2%	Total RES incl. electr. & synfuel import 311.271 358.668 496.03 577.898 560.628 550.497 539.689 474.9 465.1 RES share 0.06047 0.06184 0.07992 0.08433 0.08108 0.07531 0.06957 0.06046 0.056
			-					-		



Electricity generation in TWh/a Scenario:	Australia I	RENEWAE	BLE							Installed capacity in GW Scenario:	Australia	RENEWA	BLE						
	2012	2015	2020	2025	2030	2035	2040	2045	2050		2012	2015	2020	2025	2030	2035	2040	2045	2050
Power plants - Hard coal (& non-renewable waste) - Brown Coal - Gas of which from H2	236 138 31 42 0	217 98 47 38 0	238 103 7 44 0	272 62 0 49 0	302 36 0 47 0	325 0 21 0	363 0 0 8 0	449 0 2 0	519 0 0 0	Total generation - Fossil - Hard coal (& non-renewable waste) - Brown Coal - Gas (w/o H2)	43 33 18 4 8	44 29 13 6 8	67 26 14 1 10	104 21 8 0 11	130 17 5 0 11	157 6 0 0 6	181 4 0 0 4	225 2 0 0 2	262 0 0 0 0
- Oil - Diesel - Biomass (& renewable waste) - Hydro	1 2 1 14	0 1 0 19	0 1 0 19	0 1 2 19	0 0 3 19	0 0 11 19	0 0 9 19	0 0 10 19	0 0 6 19	Oil Diesel Hydrogen (fuel cells, gas power plants Renewables	10	1 0 15	1 0 0 41	1 0 0 83	1 0 0 113	0 0 1 151	0 0 1 176	0 0 1 221	0 2 260
- Wind of which wind offshore - PV	6 0 1	9 0 5	39 0 22	57 2 72	81 6 95	97 10 137	115 20 163	134 31 215	163 40 245	 Hydro Wind of which wind offshore 	6 3 0	8 4 0	8 18 0	8 26 1	8 37 2	8 44 4	8 52 7	8 59 11	8 72 14
- Geothermal - Solar thermal power plants - Ocean energy	0 0 0	0 0 0	2 1 0	4 5 0	5 15 0	13 27 0	14 35 0	22 48 0	26 60 0	- PV - Biomass (& renewable waste) - Geothermal - Solar thermal power plants	1 0 0	3 0 0 0	14 1 0 0	45 1 1 2	59 2 1 6	86 4 3 6	102 5 3 7	134 6 5 10	153 9 7 12
Combined heat and power plants - Hard coal (& non-renewable waste)	13 0	17 0	20 0	23 0	26 0	32 0	38 0	35 0	40 0	- Ocean energy	0	0	0	0	0	0	Ó	0	0
- Brown Coal - Gas of which from H2	2 8 0	0 12 0	0 14 0	0 16 0	0 18 0	0 15 0	0 16 0	0 11 0	0 0 0	Fluctuating RES (PV, Wind, Ocean) Share of fluctuating RES	4 9%	7 17%	32 48%	72 69%	97 74%	130 83%	153 85%	193 86%	225 86%
 Oil Biomass (& renewable waste) 	1 2	2 3	2 4	2 5	3 6	0 13	0 17	0 18	0 30	RES share (domestic generation)	23%	35%	61%	80%	87%	96%	97%	99%	99%
- Geothermal - Hydrogen	0	0	0	0	0	1 2	1 3	2 4	4 6	Final energy demand in PJ/a 1) Scenario:	Auetralia	RENEWA	DIE						
CHP by producer - Main activity producers - Autoproducers	0 5 8	0 5 12	0 5 15	0 5 18	0 5 21	0 5 27	0 5 33	0 5 30	0 5 35	Total (incl. non-energy use) Total energy use 1)	2012 3,333 3,132	2015 4,133 3,897 1.780	2020 4,283 4,079 1.857	2025 4,221 4,018	2030 3,983 3,779 1.660	2035 3,815 3,611	2040 3,665 3,461	2045 3,773 3,569 1.421	2050 3,761 3,557 1,503
Total generation - Fossil	249 225	234 198	258 171	295 131	328 104	357 37	401 25	485 13	560 1	Transport - Oil products - Natural gas	1,304 1,258 19	1,668 20	1,723 27	1,810 1,548 25	1,280 23	1,509 1,063 21	1,405 795 19	536 19	315 19
 Hard coal (& non-renewable waste) Brown Coal Gas 	138 33 50	98 47 50	103 7 58	63 0 65	36 0 65	0 0 36	1 0 24	0 0 13	1 0 0	- Biofuels - Synfuels - Electricity	14 0 15	47 0 45	52 0 55	68 0 168	95 0 262	120 0 304	184 0 407	226 0 640	316 0 854
- Oil - Diesel	2 2	2 1	2 1	3 1	3 0	0	0	0	0	RES electricity - Hydrogen	1 0	7 0	18 0	94 0	179 0	273 0	381 0	623 0	853 0
- Hydrogen - of which renewable H2 - Renewables (w/o renewable hydrogen)	0 0 24	0 0 36	0 0 87	0 0 164	0 0 224	2 2 318	3 3 373	4 4 467	6 6 553	RES share Transport	1% 1,002	3% 1,365	4% 1,462	9% 1,469	16% 1,405	26% 1,379	40% 1,329	60% 1,421	78% 1,349
- Hydro - Wind	24 14 6	36 19 9	19 39	19 57	19 81	19 97	19 115	19 134	19 163	- Electricity RES electricity	288 28	327 50	366 123	381 213	401 274	423 379	454 425	493 480	529 528
- PV - Biomass (& renewable waste) - Geothermal	1 2 0	5 3 0	22 4 2	72 7 4	95 9 5	137 25 13	163 26 16	215 28 25	245 36 30	Public district heat RES district heat Hard coal & Brown Coal	11 0 111	12 1 80	12 1 63	13 1 60	15 1 56	16 1 52	16 1 46	18 1 51	18 13 28
- Geothermal - Solar thermal power plants - Ocean energy	0	0	2 1 0	4 5 0	5 15 0	13 27 0	35 0	25 48 0	60 0	- Oil products - Gas	168 316	196 695	213 748	213 742	198 680	189 646	175 591	184 624	161 569
Import - Import RES	0	0	0	0	0	0	0	0	0	- Solar - Biomass - Geothermal	0 108 0	0 55 0	0 60 0	0 60 0	0 56 0	0 53 0	0 47 0	0 50 0	0 44 0
Export Distribution losses	0 13	0 12	0 12	0 12	0 13	0 13	0 13	0 13	0 13	- Hydrogen RES share Industry	0 14%	0 8%	0 13%	0 19%	0 24%	0 31%	0 36%	0 37%	0 43%
Own consumption electricity Electricity for hydrogen production Electricity for synfuel production	27 0.0 0.0	27 0.0 0.0	24 0.2 0.0	22 0.1 0.0	19 1.7 0.0	17 8.0 0.0	16 11.6 0.0	14 16.8 0.0	13 24.8 0.0	Other Sectors - Electricity	825 451	753 332	760 379	739 390	714 398	723 419	727 437	727 453	705 449
Final energy consumption (electricity)	209.4	195.6	222.3	261.0	294.7	318.5	360.4	440.8	509.1	RES electricity - Public district heat	43 0	51 0	128 0	217 0	272 0	376 0	410 0	440 0	449 0
Fluctuating RES (PV, Wind, Ocean) Share of fluctuating RES RES share (domestic generation)	8 3% 10%	14 6% 15%	61 24% 34%	129 44% 56%	176 54% 68%	234 66% 90%	278 69% 94%	348 72% 97%	408 73% 100%	RES district heat - Hard coal & Brown Coal - Oil products	0 1 124	0 0 141	0 0 107	0 0 85	0 0 37	0 0 34	0 0 15	0 0 8	0 0 1
Heat supply and air conditioning in PJ/a				5010	5070	5070	5-470	01.10		- Gas - Solar	180 11	211 11	205 10	188 14	175 26	151 33	131 52	92 59	60 68
Scenario:	Australia	2015	3LE 2020	2025	2030	2035	2040	2045	2050	 Biomass Geothermal Hydrogen 	58 0 0	58 0 0	53 5 0	51 11 0	47 31 0	45 41 0	41 51 0	38 77 0	35 92 0
District heating plants	1	1	2	2	2	2	2	2	2	RES share Other Sectors	14%	16% 279	26% 450	40% 729	53% 981	68%	76% 1.592	84%	91% 2.398
 Fossil fuels Biomass Solar collectors 	1 0 0	1 0 0	2 0 0	2 0 0	2 0 0	2 0 0	2 0 0	2 0 0	2 0 0	RES share	263 8%	279 7%	450 11%	729 18%	981 26%	1,320 37%	1,592 46%	1,994 56%	2,398 67%
- Geothermal Heat from CHP 1)	0	0	0	0 92	0	0	0 206	0 210	0 270	CO2 emissions in Mill t/a Scenario:	Australia 2012	RENEWA 2015	BLE 2020	2025	2030	2035	2040	2045	2050
- Fossil fuels - Biomass	30 13	42 20	49 26	58 33	65 42	52 96	55 121	38 127	2 198	Condensation power plants	195	169	130	86	60	12	5	1	0
- Geothermal - Hydrogen	0	0 0	0	0	0 2	6 11	13 17	20 24	33 37	 Hard coal (& non-renewable waste) Brown Coal Gas 	132 37 23	93 55 21	98 8 24	59 0 26	34 0 26	0 0 11	0 0 4	0 0 1	0 0 0
Direct heating - Fossil fuels	931 738	1,295 1,103	1,359 1,131	1,371 1,106	1,312	1,286 950	1,235 863	1,340 873	1,249 755	- Oil - Diesel	23 1 2	0	0 0	0	0	0	0 0	0	0
- Biomass - Solar collectors - Geothermal	124 11 0	84 11 0	85 10 0	83 14 0	77 26 11	73 33 15	69 52 21	72 59 26	66 68 33	Combined heat and power plants - Hard coal (& non-renewable waste)	8 0	8 0	9 0	10 0	11 0	8 0	8 0	6 0	0
- Heat pumps 2) - Electric direct heating - Hydrogen	0 57 0	0 96 0	7 126 0	15 152 0	29 169 0	35 179 0	42 189 0	69 242 0	79 248 0	- Brown Coal - Gas - Oil	3 5 1	0 7 1	0 8 1	0 9 1	0 9 1	0 8 0	0 8 0	0 6 0	0 0 0
Total heat supply3) - Fossil fuels	975 770	1,357 1,146	1,437 1,182	1,465 1,167	1,424	1,454 1,005	1,443 920	1,552 914	1,521 759	CO2 emissions power and CHP plants - Hard coal (& non-renewable waste)	203 132	178 93	139 98	96 59	71 34	20 0	13 1	7	1
- Biomass - Solar collectors - Geothermal	137 11 0	105 11 0	111 10 0	117 14 0	120 26 11	170 33 21	190 52 34	198 59 47	264 68 66	- Brown Coal - Gas - Oil & diesel	39 28 3	55 28 2	8 32 2	0 35 2	0 35 2	0 19 0	0 13 0	0 7 0	0 0 0
 Heat pumps 2) Electric direct heating 2) 	0 57	0 96	7 126	15 152	29 169	35 179	42 189	69 242	79 248	CO2 intensity (g/kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- Hydrogen RES share (including RES electricity) electricity consumption heat pumps (TWh/a)	0 16% 0%	0 10% 0%	0 12% 55%	0 16% 124%	2 21% 227%	11 30% 269%	17 35% 309%	24 41% 492%	37 50% 546%	without credit for CHP heat - CO2 intensity fossil electr. generation - CO2 intensity total electr. generation	0.00 902 815	0.00 897 759	0.00 813 540	0.00 739 327	0.00 682 215	0.00 539 56	0.00 530 33	0.00 504 14	0.00 967 1
1) public CHP and CHP autoproduction Final energy consumption transport in PJ/a		2) heat from	ambient ener	gy and electr	icity use	incl. proce	ess heat, cook	ing		CO2 emissions by sector - % of 1990 emissions (276 Mill t)	374 136%	420 152%	381 138%	315 114%	254 92%	178 64%	140 51%	113 41%	79 28%
Scenario:	Australia I 2012	RENEWAE 2015	3LE 2020	2025	2030	2035	2040	2045	2050	- Industry 1) - Other sectors 1)	45 20	67 23	71 20	71 18	67 13	62 12	57 9	58 6	48 3
road - fossil fuels	1,092 1,076	1,558 1,507	1,621 1,552	1,580 1,390	1,445 1,145	1,305 939	1,209 696	1,226 467	1,307 287	Transport Power generation 2) Other conversion 3)	96 200 13	128 173 29	133 134 23	119 90 18	99 63 12	82 15 8	62 8 5	42 4 3	25 1 2
- biofuels - synfuels	14 0	47 0	50 0	57 0	69 0	89 0	132 0	143 0	189 0	r						-	-	-	
 natural gas hydrogen electricity 	2 0 0	4 0 0	12 0 7	13 0 121	12 0 218	13 0 264	13 0 368	15 0 601	17 0 814	1) incl. CHP autoproducers 2) incl. CHP public									
Electrification share:	0%	0%	0%	8%	15%	20%	30%	49%	62%	 district heating, refineries, coal transfo 	rmation, gas	s transpor	t						
rail - fossil fuels - biofuels	57 42 0	52 7 0	56 7 0	54 6 1	50 6 1	45 5 1	42 4 2	43 4 2	45 4 2										
- synfuels - electricity	0 15	0 45	0 48	0 47	0 43	0 39	0 37	0 37	0 39	Primary energy demand in PJ/a Scenario:	Australia	RENEWA	BLE	200-	2020	2007	2017	20.15	2055
navigation - fossil fuels	29 29	53 53	56 54	54 52	50 44	45 36	42 28	43 23	45 14	Total	2012 5,147	2015 5,800	2020 5,837	2025 5,525	2030 5,103	2035 4,760	2040 4,559	2045 4,711	2050 4,777
- biofuels - synfuels	0	0	2	3 0	6 0	10 0	14 0	19 0	32 0	- Fossil - Hard coal (& non-renewable waste)	4,836 1,538	5,442 1,072	5,222 1,104	4,550 677	3,825 399	2,836 29	2,300 29	1,903 28	1,411 26
1 · · · · · · · · · · · · · · · · · · ·	111	101	110 110	107 100	105 86	105 84	104 67	104 41	103 10	- Brown Coal - Natural gas - Crude oil	387 1,036 1,874	521 1,468 2,380	110 1,595 2,413	39 1,644 2,190	34 1,567 1.826	30 1,232 1,544	26 1,031 1,215	27 907 941	11 697 677
aviation - fossil fuels		101			18	21	36	62	93 0	- Renewables	311	359	616	975	1,020	1.925	2.259	2,808	3,366
aviation - fossil fuels - biofuels - synfuels	111 0 0	101 0 0	0	8 0	0	0	0	0	· ·	- Hydro	50	68	68	68	68	68	68	68	70
 fossil fuels biofuels synfuels total (incl. pipelines) 	111 0 0 1,304	0 0 1,780	0 0 1,857	0 1,810	0	1,509	1,405	1,421	1,503	- Wind - Solar	22 17	32 29	141 93	205 293	292 422	349 623	68 413 765	481 1,005	587 1,164
- fossil fuels - biofuels - synfuels total (incl. pipelines) - fossil fuels - biofuels (incl. biogas) - synfuels	111 0 0 1,304 1,258 14 0	0 0 1,780 1,668 47 0	0 0 1,857 1,723 52 0	0 1,810 1,548 68 0	0 1,660 1,280 95 0	1,509 1,063 120 0	1,405 795 184 0	1,421 536 226 0	1,503 315 316 0	- Wind	22	32	141	205	292	349	68 413	481	587
- fossif fuels - biofuels - synfuels total (incl: pipelines) - fossif fuels - biofuels (incl. biogas) - synfuels - natural gas - hydrogen	111 0 0 1,304 1,258 14 0 19 0	0 0 1,780 1,668 47 0 20 0	0 0 1,857 1,723 52 0 27 0	0 1,810 1,548 68 0 25 0	0 1,660 1,280 95 0 23 0	1,509 1,063 120 0 21 0	1,405 795 184 0 19 0	1,421 536 226 0 19 0	1,503 315 316 0 19 0	- Wind - Solar - Biomass (& renewable waste) - Geothermal - Ocean energy Total incl. net elec. & synfuel import	22 17 222 0 0 5,147	32 29 229 0 0 5,800	141 93 253 61 0 5,837	205 293 300 108 0 5,525	292 422 352 144 0 5,103	349 623 567 316 0 4,760	68 413 765 656 357 0 4,559	481 1,005 723 531 0 4,711	587 1,164 928 618 0 4,777
- fossif fuels - biofuels - synfuels total (incl. pipelines) - fossif fuels - biofuels (incl. biogas) - synfuels - natural gas	111 0 1,304 1,258 14 0 19	0 0 1,780 1,668 47 0 20	0 0 1,857 1,723 52 0 27	0 1,810 1,548 68 0 25	0 1,660 1,280 95 0 23	1,509 1,063 120 0 21	1,405 795 184 0 19	1,421 536 226 0 19	1,503 315 316 0 19	- Wind - Solar - Biomass (& renewable waste) - Geothermal - Ocean energy	22 17 222 0 0 5,147 202 311	32 29 229 0 5,800 235 359	141 93 253 61 0	205 293 300 108 0 5,525 204 975	292 422 352 144 0 5,103 204 1,278	349 623 567 316 0 4,760 204 1,925	68 413 765 656 357 0 4,559 204 2,259	481 1,005 723 531 0 4,711 204 2,808	587 1,164 928 618 0 4,777 204 3,366



Electricity generation in TWh/a	A		25							Installed capacity in GW			105						
Scenario:	Australia /	Advanced 2015	2020	2025	2030	2035	2040	2045	2050	Scenario:	Australia 2012	Advanced 2015	d RE 2020	2025	2030	2035	2040	2045	2050
Power plants	236	217	247	292	350	395	481	624	683	Total generation	43	44	78	113	156	178	219	280	313
- Hard coal (& non-renewable waste) - Brown Coal	138 31	98 47	101 7	68 0	9 0	0	0	0	0	Fossil Hard coal (& non-renewable waste)	33 18	29 13	24 14	20 9	10 1	4	1	0	0
- Gas of which from H2 - Oil	42 0 1	38 0 0	34 0 0	39 0 0	29 0 2	4 0 0	2 0 0	0 0	0 0	- Brown Coal - Gas (w/o H2) - Oil	4 8 1	6 8 1	1 8 1	0 9 1	0 8 1	0 3 0	0 1 0	0 0 0	0 0 0
- Diesel - Biomass (& renewable waste)	2	1	1	1 2	0 7	0 22	0 13	0 27	0 43	- Diesel - Hydrogen (fuel cells, gas power plants,	1 . gas 0	1	0	0	0	0	0	0	0
- Hydro - Wind	14 6	19 9	19 39	19 57	19 101	19 109	19 142	19 164	19 180	- Renewables - Hydro	10 6	15 8	54 8	93 8	146 8	174 8	217 8	279 8	311 8
of which wind offshore - PV	0	0 5	0 42	2 82	26 115	22 140	32 178	39 241	40 266	- Wind of which wind offshore	3	4	18 0	26 1	45 9	49 8	63 12	73 14	80 14
Geothermal Solar thermal power plants	0	0	2	14 5 5	30 28	34 47	40 65	47 79	47 78	 - PV - Biomass (& renewable waste) - Geothermal 	1	3 0 0	26 1	51 1 3	72	88 7 8	111 8 9	150 11 9	166 20
- Ocean energy Combined heat and power plants	0 13	0 17	0 20	23	10 26	19 32	23 38	48 35	50 40	 Geotnermal Solar thermal power plants Ocean energy 	0	0	0 0 0	2	10 3	8 10 5	9 13 6	9 16 12	10 16 13
- Hard coal (& non-renewable waste) - Brown Coal	0	0	0	0	0	0	0	0	0	Fluctuating RES (PV, Wind, Ocean)	4	7	44	79	119	141	180	235	258
- Gas of which from H2	8 0	12 0	14 0	16 0	16 0	11 0	0	0	0	Share of fluctuating RES	9%	17%	57%	70%	76%	79%	82%	84%	83%
 Oil Biomass (& renewable waste) 	1 2	2 3	2 4	2 5	1 9	0 18	0 30	0 28	0 30	RES share (domestic generation)	23%	35%	69%	82%	93%	98%	99%	100%	99%
- Geothermal - Hydrogen	0	0	0	0	0	1 2	3 4	3 4	4 6	Final energy demand in PJ/a 1)									
CHP by producer - Main activity producers	0	0	0 5	0 5	0	0	0	0	0	Scenario:	Australia 2012	Advanced 2015	d RE 2020	2025	2030	2035	2040	2045	2050
- Autoproducers	8	12	15	18	21	27	33	30	35	Total (incl. non-energy use) Total energy use 1)	3,333 3,132	4,133 3,897	4,261 4,057	4,181 3,977	3,871 3,668	3,645 3,441	3,437 3,234	3,538 3,335	3,542 3,338
Total generation	249	234	267	315	377	427	519	659	723	Transport - Oil products	1,304 1,258	1,780 1,668	1,836 1,682	1,769 1,461	1,553 1,069	1,341 755	1,211 431	1,201 149	1,270 0
 Fossil Hard coal (& non-renewable waste) 	225 138	198 98	160 101	126 68	57 9	15 0	2 0	0	0	 Natural gas/biogas Biofuels 	19 14	20 47	26 52	24 68	19 95	14 120	10 184	5 226	2 246
- Brown Coal - Gas	33 50	47 50	7 48	0 55	0 45	0 14	0 2	0	0	- Synfuels - Electricity	0 15	0 45	5 67	12 190	17 314	25 379	39 473	51 666	56 836
- Oil - Diesel - Hydrogen	2 2 0	2 1 0	2 1 0	3 1 0	3 0 0	0 0 2	0 0 5	0 0 4	0 0 6	RES electricity - Hydrogen RES share Transport	1 0 1%	7 0 3%	27 3 4%	114 14 11%	266 40 26%	365 47 41%	471 73 63%	666 103 87%	836 130 100%
- Hydrogen - of which renewable H2 - Renewables (w/o renewable hydrogen)	0 0 24	0 36	0 107	0 189	0 0 319	2 2 410	5 5 512	4 4 655	6 6 717	RES share Transport	1%	3% 1.365	4% 1.462	11%	26%	41% 1.374	63% 1.288	87%	1.350
- Hydro - Wind	14 6	19 9	19 39	19 57	19 101	19 109	19 142	19 164	19 180	- Electricity RES electricity	288 28	327 50	366 147	381 229	421 357	463 447	512 510	589 589	610 610
- PV - Biomass (& renewable waste)	1	5 3	42 4	82 7	115 16	140 41	178 44	241 55	266 74	- Public district heat RES district heat	11 0	12 1	12 1	14 2	15 6	17 11	16 14	17 15	18 17
 Geothermal Solar thermal power plants 	0	0	2	14 5	30 28	35 47	43 65	50 79	51 78	- Hard coal & Brown Coal - Oil products	111 168	80 196	63 213	59 213	43 197	33 66	60 29	29 23	18 0
- Ocean energy	0	0	0	5	10 0	19 0	23 0	48 0	50 0	- Gas - Solar - Biomass	316 0 108	695 0 55	748 0 60	742 0 60	652 0 69	575 25 181	328 47 223	136 80 310	0 116 343
Import - Import RES Export	0	0	0	0	0	0	0	0	0	- Biomass - Geothermal - Hydrogen	108 0 0	55 0 0	60 0	60 0 0	0 0	181 15 0	223 37 36	310 78 136	343 100 146
Distribution losses Own consumption electricity	13 27	12 27	12 24	12 22	13 19	13 17	13 16	13 14	13 13	RES share Industry	14%	8%	14%	20%	31%	49%	67%	86%	99%
Electricity for hydrogen production Electricity for synfuel production	0.0 0.0	0.0 0.0	1.3 3.9	5.6 8.9	17.3 11.7	26.9 17.4	65.5 26.9	119.3 34.5	127.9 37.2	Other Sectors - Electricity	825 451	753 332	760 379	739 390	717 403	726 427	735 448	737 466	718 471
Final energy consumption (electricity)	209.4	195.6	225.6	267.1	315.8	352.4	398.1	478.3	532.5	RES electricity - Public district heat	43 0	51 0	152 0	234 0	341 0	411 0	446 0	466 0	471 0
Fluctuating RES (PV, Wind, Ocean) Share of fluctuating RES RES share (domestic generation)	8 3% 10%	14 6% 15%	81 30% 40%	144 46% 60%	226 60% 85%	268 63% 96%	343 66% 100%	452 69% 100%	495 68% 100%	RES district heat - Hard coal & Brown Coal - Oil products	0 1 124	0 0 141	0 0 107	0 0 85	0 0 36	0 0 33	0 0 14	0 0 7	0 0
Heat supply and air conditioning in PJ/a	10 %	13%	40%	60%	63%	90%	100%	100%	100%	- Gas - Solar	180	211	205 10	188 14	174 26	149 33	107 51	30 74	0 81
Scenario:	Australia	Advanced								- Biomass - Geothermal	58 0	58 0	53 5	51 11	47 31	44 41	52 51	55 77	58 108
	2012	2015	2020	2025	2030	2035	2040	2045	2050	- Hydrogen RES share Other Sectors	0 14%	0 16%	0 29%	0 42%	0 62%	0 73%	12 83%	29 95%	0 100%
District heating plants - Fossil fuels	1	1	2	2	2	1	2	2	2	Total RES	263	279	509	799	1,287	1,763	2,247	2,954	3,317
- Biomass - Solar collectors	0	0	0	0	0	0	0	0	1	RES share	8%	7%	13%	20%	35%	51%	69%	89%	99%
- Geothermal Heat from CHP 1)	0 43	0 62	0 76	0 92	0 117	0 174	0 248	0 233	1 270	Australia Advanced RE	2012	2015	2020	2025	2030	2035	2040	2045	2050
- Fossil fuels - Biomass	30 13	42 20	50 27	57 34	57 56	36 120	0	1 184	1 198	Condensation power plants	195	169	123	86	26	3	1	0	0
- Geothermal - Hydrogen	0	0	0 0	0	1 2	7 12	24 27	24 25	33 38	 Hard coal (& non-renewable waste) Brown Coal 	132 37	93 55	96 8	65 0	9 0	0	0 0	0	0
Direct heating	931	1,295	1,359	1,371	1,305	1,278	1,193	1,317	1,249	- Gas - Oil	23 1	21 0	19 0	21 0	16 2	2	1	0	0
Fossil fuels Biomass Solar collectors	738 124 11	1,103 84 11	1,131 85 10	1,106 83 14	964 87 26	767 169 58	488 216 98	204 296 154	15 337 197	- Diesel Combined heat and power plants	2	1	0	0 10	0 9	0 5	0	0	0
- Geothermal - Heat pumps 2)	0	0	0	0	11 29	15 55	30 79	44	58 200	- Hard coal (& non-renewable waste) - Brown Coal	0	0	0	0	0	0	0	0	0
 Electric direct heating Hydrogen 	57 0	96 0	126 0	152 0	189 0	214 0	237 45	316 155	304 139	- Gas - Oil	5	7	8	9 1	8	5 0	0	0	0
Total heat supply3)	975	1,357	1,437	1,465	1,424	1,454	1,443	1,552	1,521	CO2 emissions power and CHP plants	203	178	133	96	35	8	1	0	0
- Fossil fuels - Biomass	770 137	1,146 105	1,182 111	1,166 118	1,023 144	804 289	490 414	205 480	16 536	- Hard coal (& non-renewable waste) - Brown Coal	132 39	93 55	96 8	65 0	9 0	0	0	0	0
Solar collectors Geothermal Heat pumps 2)	11 0 0	11 0 0	10 0 7	14 0 15	26 12 29	58 22 55	98 54 79	154 69 148	197 92 200	- Gas - Oil & diesel	28 3	28 2	26 2	30 2	24 2	7 0	1 0	0	0
 Heat pumps 2) Electric direct heating Hydrogen 	0 57 0	96 0	126 0	15 152 0	29 189 2	55 214 12	79 237 72	148 316 180	200 304 177	CO2 intensity (g/kWh) without credit for CHP heat	0.00	0.00 0.00	0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00
RES share (including RES electricity)	16%	10%	13%	16%	26%	44%	66%	87%	99%	- CO2 intensity fossil electr. generation - CO2 intensity total electr. generation	902 815	897 759	829 497	763 305	611 93	538 19	567 2	1,068 0	0
electricity consumption heat pumps (TWh/a) 1) public CHP and CHP autoproduction	0% 2) heat from	0% ambient ener	55% gy and electri	124% city use	226%	422% 3) incl. proce	583% ss heat, cook	1059% ing	1390%	CO2 emissions by sector	374	420	369	308	196	123	71	27	2
Final energy consumption transport in PJ/a	Aug. 11	A	DE							- % of 1990 emissions (276 Mill t)	136%	152%	134%	111%	71%	45%	26%	10%	1%
Scenario:	Australia / 2012	Advanced 2015	2020	2025	2030	2035	2040	2045	2050	Industry 1) Other sectors 1) Transport	45 20 96	67 23 128	71 20 129	71 18 112	63 13 82	46 11 58	27 7 33	13 2 11	2 0 0
road - fossil fuels	1,092 1,076	1,558 1,507	1,591 1,513	1,522 1,306	1,307 943	1,094 645	956 344	916 103	966 0	 Transport Power generation 2) Other conversion 3) 	200 13	128 173 29	129 127 22	89 17	82 28 10	5 5	33 1 2	0	0
- biofuels - synfuels	14 0	47 0	50 5	58 10	545 71 13	94 19	146 31	156 35	141 32	'Efficiency' savings (compared to Ref.)	.0					J	-		v
- natural gas - hydrogen	2 0	4 0	12 3	11 14	8 40	5 47	3 73	0 103	0 130	1) incl. CHP autoproducers									
- electricity Electrification share:	0 0%	0 0%	14 1%	133 9%	246 19%	303 28%	390 41%	553 60%	695 72%	 incl. CHP public district heating, refineries, coal transfo 	rmation, ga	s transpor	rt						
rail - fossil fuels	57 42	52 7	60 6	63 5	73 4	79 3	85 3	114 1	143 0										
- tossil tuels - biofuels - synfuels	42 0 0	0	6 0 0	5 1 0	4 1 0	3 1 0	3 1 0	1 2 0	2	Primary energy demand in PJ/a									
- electricity	15	45	53	57	68	75	82	111	140	Scenario:	Australia 2012	Advanced 2015	d RE 2020	2025	2030	2035	2040	2045	2050
navigation - fossil fuels	29 29	53 53	56 54	54 52	50 43	45 35	42 27	43 15	45 0	Total	5,147	5,800	5,746	5,681	5,249	4,993	4,870	5,112	5,209
- biofuels - synfuels	0	0	2	2	6	8	12 3	23 5	37 8	 Fossil Hard coal (& non-renewable waste) 	4,836 1,538	5,442 1,072	5,059 1,077	4,409 722	3,088 110	2,058 9	1,248 37	600 5	226 7
aviation	111	101	109	106	99	92	88	86	80	- Brown Coal - Natural gas	387 1,036	521 1,468	110 1,503	39 1,552	34 1,341	30 933	25 512	26 205	12 32
- fossil fuels - biofuels	111 0	101 0	109 0	98 6	79 17	72 17	57 25	30 46	0 65	- Crude oil - Renewables	1,874 311	2,380 359	2,368 688	2,097 1,273	1,603 2,162	1,086 2,935	675 3,621	364 4,512	175 4,984
- synfuels	0	0	0	1	3	3	5	10	15	- Hydro - Wind Solar	50 22 17	68 32 20	68 141 165	68 205 320	68 364	68 392 730	68 511 972	68 591	70 647 1.433
total (incl. pipelines) - fossil fuels - biofuels (incl. biogas)	1,304 1,258 14	1,780 1,668 47	1,836 1,682 52	1,769 1,461 68	1,553 1,069 95	1,341 755 120	1,211 431 184	1,201 149 226	1,270 0 246	 Solar Biomass (& renewable waste) Geothermal 	17 222 0	29 229 0	165 253 61	329 300 352	541 448 705	730 880 796	972 1,061 928	1,306 1,294 1,081	1,433 1,544 1,110
- synfuels - natural gas	14 0 19	47 0 20	5 26	12 24	95 17 19	25 14	39 10	226 51 5	246 56 2	- Ocean energy	0	0	0	18	36	69	928 81	171	1,110
	0	0	3	14	40 314	47 379	73 473	103 666	130 836	Total incl. net elec. & synfuel import	5,147	5,800 235	5,746 204	5,681 204	5,249 204	4,993 204	4,870 204	5,112 204	5,209 204
- hydrogen - electricity	15	45	67	190	314	0.0	-110	000	630	 of which non-energy use 	202	235	204	204	204	204	204	204	204
	15 15 1%	45 54 3%	67 82 4%	190 197 11%	409 26%	555 41%	767 63%	1,046 87%	1,268 100%	Total RES incl. electr. & synfuel import RES share	311	359 0.06184	688	1,273	2,162 0.41183	2,935	3,621	4,512	4,984



