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REVIEW ARTICLE

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# A comprehensive review of renewable energy resources for electricity generation in Australia



**Abstract** Recently, renewable energy resources and their impacts have sparked a heated debate to resolve the Australian energy crisis. There are many projects launched throughout the country to improve network security and reliability. This paper aims to review the current status of different renewable energy resources along with their impacts on society and the environment. Besides, it provides for the first time the statistics of the documents published in the field of renewable energy in Australia. The statistics include information such as the rate of papers published, possible journals for finding relative paper, types of documents published, top authors, and the most prevalent keywords in the field of renewable energy in Australia. It will focus on solar, wind, biomass, geothermal and hydropower technologies and will investigate the social and environmental impacts of these technologies.

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## 1 Introduction

Renewable energy resources have a rich diversity in Australia ranging from solar, wind, hydro, geothermal, and bioenergy to tidal and wave. Since 2010, the use of solar and wind energy resources has started to increase and is continuing rapidly. Among energy resources, hydro energy is largely developed and thanks to this development, there was a sharp increase in renewable energy generation in 2016 [1]. In 2019, 17.3% (approximately 17500 GWh) of Australia's electricity were supplied by renewable sectors which was adequate to power around 8 million average customers. This was a halfway toward achieving renewable energy target (RET) set at 33000 GWh by 2020 [2]. Note that the RET is an industry development policy with two major parts, namely large-scale renewable energy target (LRET) and small-scale renewable energy scheme (SRES) which plays the role of accelerating renewable energy projects in Australia. The contribution of different types of renewable generation technologies, such as hydro, wind, and photovoltaic (PV), is presented in Table 1.

Australia has six states, namely New South Wales (NSW), Queensland (QLD), South Australia (SA), Tasmania (TAS), Victoria (VIC), and Western Australia (WA), and two major mainland territories, the Australian Capital Territory (ACT) and the Northern Territory (NT) [3]. In Table 2, the information about the contribution of renewable generations to supply customers in each state is listed in detail [1].

As can be seen, TAS is the leader for using renewable energy with apenetration level of more than 85%, mostly thanks to the hydro power. In SA, due to shutting down of Northern coal-fired power station, renewable energies provide 50% of the state's electricity largely thanks to wind and hydro power [4]. As Table 2 represents, NSW

**Table 1** Renewable energy generation

| Technology | Generation/GWh | Percentage of renewable generation/% | Percentage of total generation/% | Equivalent number of households powered over course of the year |
|---|---|---|---|---|
| Hydro | 17747 | 42.3 | 7.32 | 3380371 |
| Wind | 12903 | 30.8 | 5.32 | 2457723 |
| Small-scale solar PV | 6701 | 16.0 | 2.76 | 1276305 |
| Bioenergy | 3608 | 8.6 | 1.49 | 687238 |
| Large-scale solar PV | 456 | 1.1 | 0.19 | 86766 |
| Medium-scale solar PV | 502 | 1.2 | 0.21 | 95598 |
| Solar thermal | 27 | 0.1 | 0.01 | 5143 |
| Geothermal | 0.50 | 0.0 | 0.00 | 95 |
| Total | 41944 | 100 | 17.29 | 7989239 |

**Table 2** Penetration of renewable generation by state

| State | Generation/GWh | Fossil fuel generation/GWh | Total renewable generation/GWh | Penetration of renewables/% |
|---|---|---|---|---|
| TAS | 11103 | 817 | 10286 | 93 |
| SA | 11364 | 5856 | 5508 | 48 |
| VIC | 55221 | 46619 | 8602 | 16 |
| WA | 19609 | 17001 | 2608 | 13 |
| NSW | 64339 | 56879 | 7460 | 12 |
| QLD | 60782 | 57932 | 2850 | 5 |
| National | 222418 | 185104 | 37314 | 17 |

has the largest total power generation; QLD has the largest fossil-fuel power generation, while TAS has the largest total renewable power generation and renewable penetration. Due to this fact, the penetration level of renewables is much lower in these states compared to that of the otherstates. The VIC government aimed to generate 40% of electric power from the renewable energy resources by 2020 while QLD announced a target of generating 50% by 2030. The proportional percentage of the dominant renewable-based technologies in each state in 2018 is summarized in Table 3 [2–4]. Besides, the total share of each state in renewable production of national renewable generation in 2018 is listed in Table 3 [2].

**Table 3** Proportional share of different renewable generation technologies by state

| State | Hydro/% | PV/% | Wind/% | Bioenergy/% | National/% |
|---|---|---|---|---|---|
| TAS | 85.4 | 6.9 | 6.8 | 0.9 | 95.9 |
| SA | 51.5 | 10.3 | 35.2 | 3.1 | 53.1 |
| VIC | 34.9 | 17.3 | 28.0 | 19.8 | 20.6 |
| WA | 63.5 | 22.7 | 9.9 | 3.9 | 16.2 |
| NSW | 35.3 | 13.9 | 19.3 | 31.5 | 15.0 |
| QLD | 29.6 | 28.8 | 0.9 | 40.7 | 9.5 |

According to Bloomberg New Energy Finance (BNEF) [5], the renewable generation technologies can be the cheapest form of new energy generation in Australia. In this regard, the cost of renewable energy generation can be competitive compared to the gas cost. The levelized cost of energy (LCOE) for different technologies is estimated by BNEF as follows [6]:

Wind generation at A$ 61–118/MWh

Solar generation at A$ 78–140/MWh

Combined-cycle gas generation at A$ 74–90/MWh

Ultra-supercritical coal fired generation at A$ 134–203/MWh

Note that, the LCOE for new coal-fired power station using carbon capture and storage would be approximately $352/MWh if considering the carbon reduction targets [7].

There are many organizations and agencies in renewable energy sector with different responsibilities in Australia. Some of them are presented here. The Australian Energy Regulator (AER) has the responsibility to make decision that promotes the efficient investment, efficient operation, and use of energy services for the long-term interests of energy consumer [8]. The Australian Renewable Energy Agency (ARENA) has the responsibility to fund innovations and distribute knowledge regarding renewable generations [9]. The Clean Energy Council (CEC) is a private renewable energy organization which plays a key role in developing effective policies to promote deployment of all clean energy technologies [1]. The Australian

Photovoltaic Institute (APVI) aims to increase the use of PV and develop research and policies by compromising agencies, companies, academics, and individuals [10].

Over the last decade, great attention has been paid to the Australian renewable energy resources in the technical literatures. However, to date, no attempt has been made to compile all these works into a comprehensive review article. Therefore, the aim of this paper is to review and discuss the different renewable energy generation technologies in Australia by focusing on solar, wind, biomass, geothermal and hydropower technologies, and to investigate the social and environmental impact of these technologies.

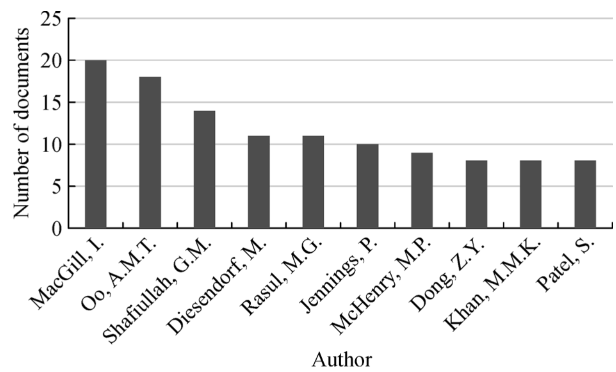


**Fig. 2** Documents by author.

## 2 Methodology

Over the last few decades, the analysis of bibliometric networks, such as co-authorship, bibliographic coupling, and co-citation networks, has taken into attention in the scientific documents [11,12]. This section presents statistics for the documents published in the field of renewable energy in Australia while the Scopus database is used which has resulted in 1137 documents. These statistics give the researchers the information on the rate of papers published, the possible journals for finding relative documents, the types of documents published, the subject area of documents, the top authors, and the most prevalent keywords in the field of renewable energy in Australia. Researchers can use the information as a guide for their future research.

Figure 1 shows the number of documents from 1974 to September 2017. It is clearly observed that the number of documents is increasing over the period, indicating that the topic is worth further investigation.

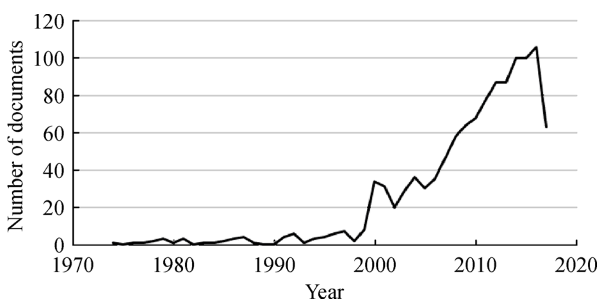


**Fig. 1** Number of documents by year.

Figure 2 illustrates the number of documents by the author. Iain F. MacGill published 20 documents in the field of renewable energy in Australia which is the highest number of documents. It is possible to find researchers with the highest number of publications in the field by using Fig. 2.

To find the most prevalent keywords and the most cited documents, the VOS viewer software has been used in this paper.

Figure 3 demonstrates the visualization of the most prevalent keywords in documents. The red part shows the most common keywords while the blue part the less common ones. Table 4 lists the ten most prevalent keywords in this area of research.

It can be noticed in Table 4 that researchers are interested in renewable energy resources, particularly wind power and solar energy, and they want to use renewable energy resources to tackle the problem of climate change. Table 5 tabulates the top 10 documents with the highest number of citations, ranging from 247 citations for Ref. [13] to 108 citations for Ref. [22].

## 3 Main sources of renewable energy resources in Australia

### 3.1 Solar

Harvesting sunlight and converting it into energy is done by PV systems. In this technology, the sunlight is converted directly into electricity,which is totally different from other types of solar technologies such as solar thermal for heating and cooling and concentrated solar power (CSP). Generally, a PV system consists of cells (often called solar cells), photovoltaic module, mounting structure for the module or array, inverter, battery storage system, and charge controller [23].

There are various applications for PV systems ranging from small systems of few watts to large scale PV systems of hundreds of MW [2].

Recently, there have been significant developments in small PV systems such as combining charge controller and battery system with efficient lights (mostly LEDs). Thanks to even a small PV panel with a few watts, the necessary services such as phone charging, lighting and powering a small computer can be provided. These small PV systems can be expanded to be able to supply extra loads later [4].

Off-grid systems include domestic and non-domestic

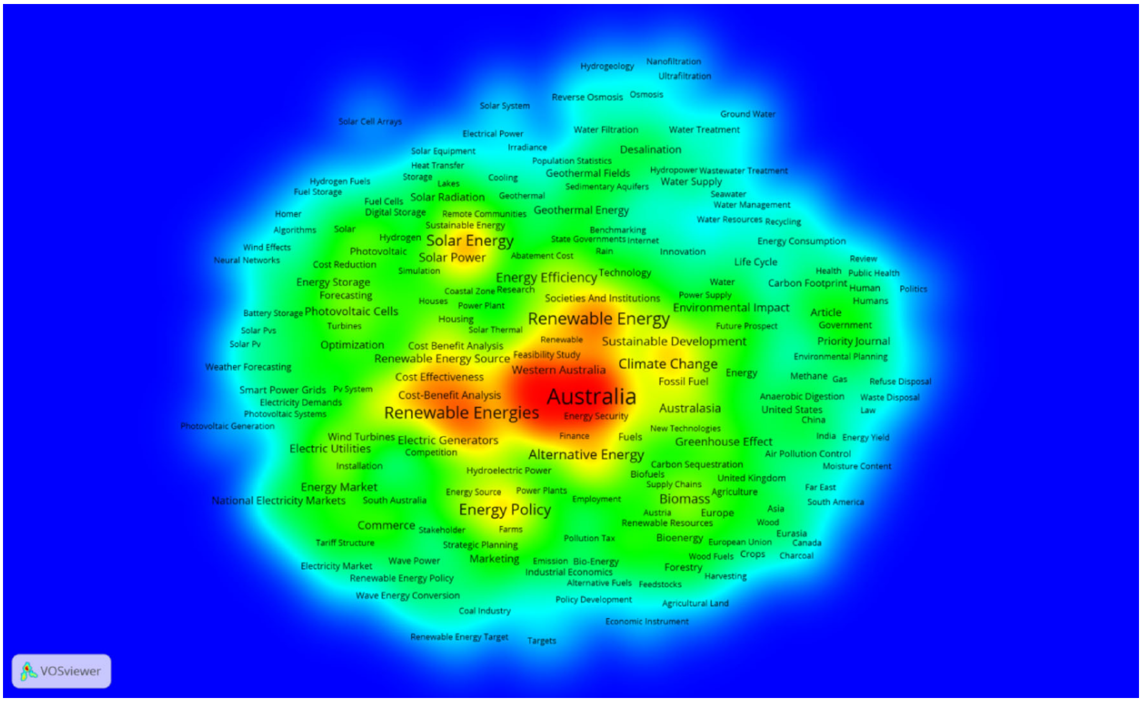


**Fig. 3** Most prevalent keywords.

**Table 4** 10 most prevalent used keywords

| Id | Keywords | Occurrences | Total link strength |
|---|---|---|---|
| 1 | Australia | 478 | 990 |
| 2 | Renewable resource | 226 | 633 |
| 3 | Renewable energies | 212 | 556 |
| 4 | Renewable energy resources | 324 | 516 |
| 5 | Renewable energy | 214 | 490 |
| 6 | Energy policy | 147 | 422 |
| 7 | Wind power | 156 | 357 |
| 8 | Alternative energy | 98 | 311 |
| 9 | Solar energy | 143 | 292 |
| 10 | Climate change | 108 | 235 |

systems providing electricity to remote areas that are not connected to the electricity grid. The applications of such systems might be for lighting and supplying low power loads, which are often the most appropriate options to meet the energy demands of remote area communities. The size of off-grid domestic systems can be considered up to 5 kW which is an economical alternative compared to expanding the electricity distribution network for the areas with more than 1 or 2 km distance from the main grid. Generally, by introducing the concept of mini and micro grids, defining the off-grid domestic system poses a great challenge.

Non-domestic systems can be interpreted as the commercial application for PV systems such as water pumping, telecommunications, navigation systems, etc. For such applications, generation by PVs is commercially cost-competitive compared to other small generating sources [14].

PV systems can be combined with diesel generator as a hybrid system which can hedge against the fuel cost increases, offer operating cost reductions, and deliver higher service quality in comparison with traditional diesel systems. The hybrid systems ranging from micro to large-scale systems can be used to supply large consumers powered by diesel generators [23].

Grid-connected PV systems either distributed or centralized are installed to provide power directly to the main grid or to a grid-connected system. The size of such systems is not a determining feature and they are often located on the demand side of the electricity meter. In Australia, most of the PV systems are roof top residential and there is a slight increase in the small-scale commercial installation. In addition, there are many large-scale PV power stations with a capacity of 100 kW or more. The Clean Energy Regulator is responsible to publish small-scale renewable energy installation data files. The data consist of new installations, stand-alone (off-grid) systems and upgrades to existing systems. The PV systems with a valid certificate are considered to be reported. The installation numbers of small-scale PV system for different state/territory are presented in Table 6 [24].

There are more than 1.746 million PV installations in Australia, with a combined capacity of over 6.5 GW as shown in Fig. 4. The installed PV generation capacities for each state/territory is presented in Fig. 5.

**Table 5** Top 10 cited published documents in the field

| ID | Ref. | Document title | Journal/Conference | Citations |
|---|---|---|---|---|
| 1 | [13] | Renewable methane from anaerobic digestion of biomass | *Renewable Energy* | 247 |
| 2 | [14] | Design of commercial solar updraft tower systems—utilization of solar induced convective flows for power generation | *Journal of Solar Energy Engineering* | 226 |
| 3 | [15] | An overview of biofuel policies across the world | *Energy Policy* | 211 |
| 4 | [16] | Fast pyrolysis of oil mallee woody biomass: effect of temperature on the yield and quality of pyrolysis products | *Industrial & Engineering Chemistry Research* | 173 |
| 5 | [17] | Recent advances with UNSW vanadium-based redox flow batteries | *International Journal of Energy Research* | 155 |
| 6 | [18] | Feasibility analysis of stand-alone renewable energy supply options for a large hote | *Renewable Energy* | 154 |
| 7 | [19] | Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles | *Atmospheric Environment* | 122 |
| 8 | [20] | Integrating private transport into renewable energy policy: the strategy of creating intelligent recharging grids for electric vehicles | *Energy Policy* | 113 |
| 9 | [21] | Feasibility analysis of renewable energy supply options for a grid-connected large hotel | *Renewable Energy* | 109 |
| 10 | [22] | Emergy evaluation of three cropping systems in south-western Australia | *Ecological Modeling* | 108 |

**Table 6** Small-scale PV system

| | ACT | NSW | NT | QLD | SA | TAS | VIC | WA | Total |
|---|---|---|---|---|---|---|---|---|---|
| 2001 | – | 12 | 6 | 33 | 41 | – | 15 | 11 | 118 |
| 2002 | – | 23 | 8 | 71 | 107 | 1 | 19 | 22 | 251 |
| 2003 | 3 | 134 | 10 | 150 | 246 | 9 | 98 | 14 | 664 |
| 2004 | 2 | 235 | 22 | 328 | 300 | 17 | 152 | 33 | 1089 |
| 2005 | 4 | 291 | 35 | 339 | 380 | 13 | 254 | 90 | 1406 |
| 2006 | 10 | 216 | 23 | 195 | 413 | 4 | 200 | 54 | 1115 |
| 2007 | 48 | 779 | 26 | 475 | 1037 | 25 | 828 | 262 | 3480 |
| 2008 | 278 | 2890 | 88 | 3087 | 3456 | 161 | 2036 | 2068 | 14064 |
| 2009 | 803 | 14008 | 215 | 18283 | 8569 | 1452 | 8429 | 11157 | 62916 |
| 2010 | 2323 | 69988 | 637 | 48697 | 16705 | 1889 | 35676 | 22293 | 198208 |
| 2011 | 6860 | 80272 | 401 | 95303 | 63553 | 2475 | 60214 | 51667 | 360745 |
| 2012 | 1522 | 53961 | 513 | 130252 | 41851 | 6364 | 66204 | 42653 | 343320 |
| 2013 | 2411 | 33998 | 1024 | 71197 | 29187 | 7658 | 33332 | 21600 | 200407 |
| 2014 | 1225 | 37210 | 1026 | 57748 | 15166 | 4207 | 40061 | 23496 | 180139 |
| 2015 | 1066 | 33477 | 1197 | 39507 | 12081 | 2020 | 31343 | 20797 | 141488 |
| 2016 | 999 | 29441 | 1745 | 34389 | 12594 | 2486 | 26697 | 24185 | 132536 |
| 2017 | 1340 | 32871 | 1532 | 37467 | 11926 | 1849 | 23452 | 26304 | 136741 |
| Total | 18894 | 389806 | 8508 | 537521 | 217612 | 30630 | 329010 | 246076 | 1778687 |

Furthermore, the installation numbers of PV systems with concurrent battery system are presented in Table 7. Note that the data in Table 7 are based on voluntarily disclosed data commenced in 2014 [5].

PV market development for more than 20 years has resulted in a cumulative PV capacity of more than 228 GW all over the world which is mostly grid-connected [23].

The Australian market for PV installations had a huge increase in 2011 and continued to increase in 2012, but it had a slight decrease in 2013 and 2014. In 2015, the installation rate increased to almost 1 GW. The market in 2016 fell around 16% below the capacity installed in 2015 due to the absence of utility-scale project commissioning.

Residential rooftop PV systems with an average penetration of 19% play a significant role in grid-connected systems. In many parts of cities across Australia, the penetration of residential PV peaks up to 40% [10].

The off-grid market is highly affected by the rapid

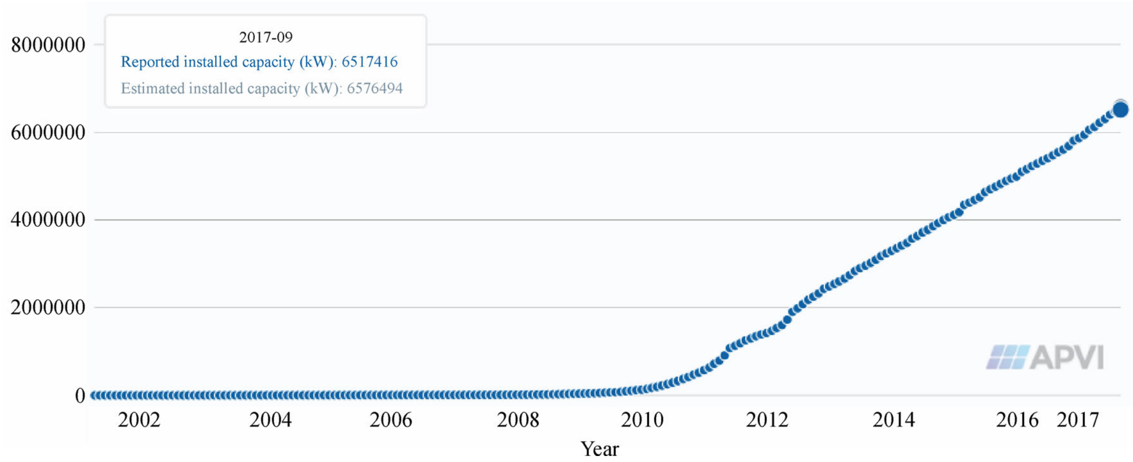


**Fig. 4** Australian PV installation and total capacity (kW).

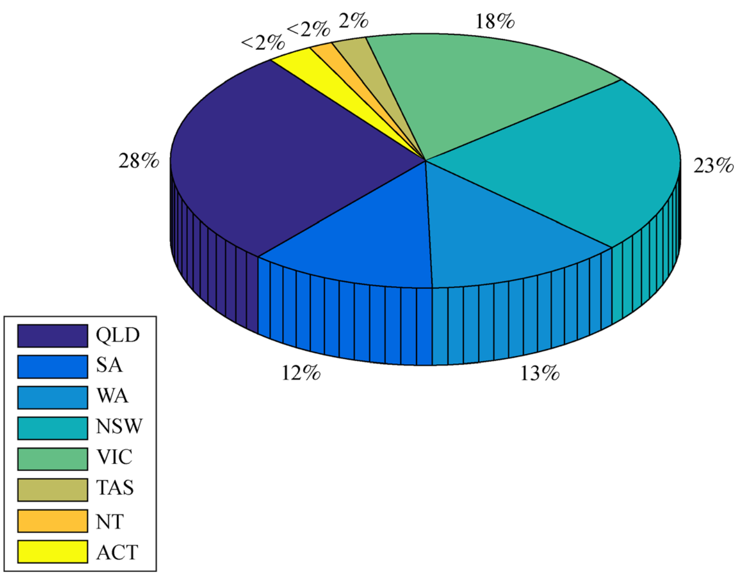


**Fig. 5** Installed PV generation capacity by state/territory.

**Table 7** PV systems with concurrent battery storage

| | ACT | NSW | NT | QLD | SA | TAS | VIC | WA | Total |
|---|---|---|---|---|---|---|---|---|---|
| 2014 | 8 | 208 | 3 | 129 | 34 | 5 | 137 | 169 | 693 |
| 2015 | 3 | 133 | 1 | 186 | 21 | 6 | 163 | 24 | 537 |
| 2016 | 105 | 665 | 6 | 329 | 130 | 18 | 240 | 70 | 1563 |
| 2017 | 144 | 1377 | 9 | 537 | 371 | 66 | 479 | 164 | 3147 |
| Total | 260 | 2383 | 19 | 1181 | 556 | 95 | 1019 | 427 | 5940 |

deployment of grid-connected PV systems as depicted in Fig. 6.

Similarly, in Australia, the off-grid system is dominated by the grid-connected system and just 25 MW of off-grid systems were installed in 2015.

Recently, the Australian government has provided a good support for the programs that significantly impact the PV market. One of the programs is the 45000 GWh RET including two parts: LRET and SRES. In 2015, the government made a decision to decrease the generation target under LRET to 33000 GWh by 2030 owing to a forecasted reduction in electricity demand. It is necessary

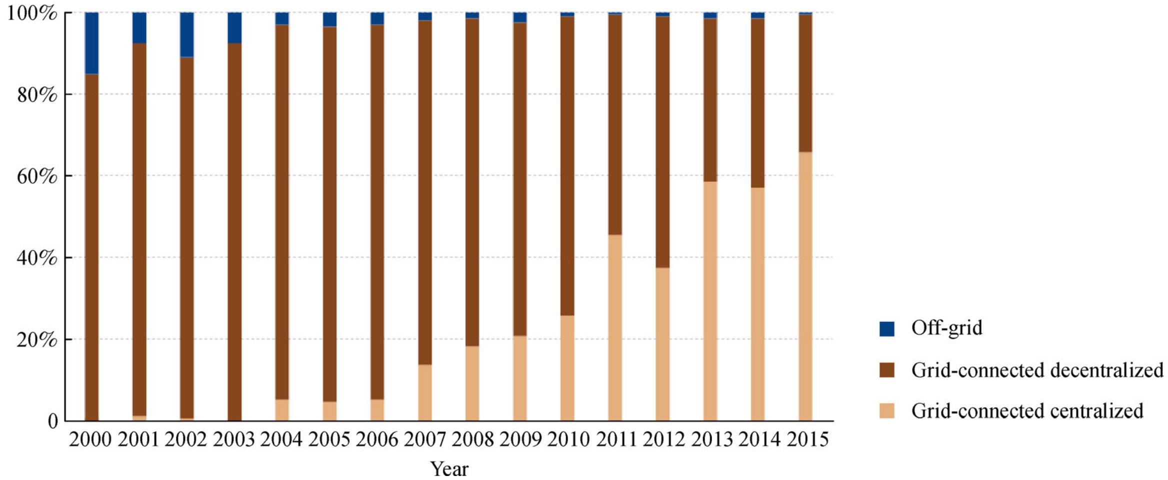


**Fig. 6** Share of grid-connected and off-grid installations globally.

for liable entities to meet obligations under both the LRET and SRES schemes. This can be done by obtaining and surrendering renewable energy certificates that are created from both small and large-scale renewable energy technologies in which PV is one of them.

One of the programs that provides benefits for large-scale PV was the ACT auction program set up in 2012 for up to 40 MW. Generally, incentives for PV, including Feed-in-Tariff (FiT) programs, have been removed by the state governments and reduced by the federal government. For example, in NSW, customers that have been receiving 60 c/kWh FiT now receive an amount set by their electricity retailer ranging from 6 c/kWh to 12 c/kWh [25]. The city of Adelaide provides the storage incentive up to 50% of the battery cost up to \$5000, plus up to a further \$5000 for 20% of the price of a PV system [26]. The Northern Territory government offers a \$2000 subsidy for the rooftop and storage systems under the Home Improvement Scheme. The Act government offers a subsidy of \$900 per sustained kW peak output for residential and commercial customers under the Next Generation Storage Program scheme. With a high penetration of PV, the demand for battery storage systems would increase. However, the battery storage systems are still expensive and without subsidies; therefore, the market is less competitive compared to the PV market.

In Australia, the booming PV industry has raised concerns for utilities regarding their future business model. The country introduced around 0.9 GW in 2016, which in total reached 5.44 GW [27]. There is a possibility for generators to lose the market share, particularly during the daytime peak load periods where the electricity prices are quite high. However, big retailers have entered into the PV business to have a significant impact on the market share.

## 3.2 Wind

Wind energy refers to flow of air in wind turbines to generate electricity for the power system [28]. Wind turbines are key instruments in wind-powered generators as they convert the kinetic energy of the wind into electrical energy using an aerodynamic rotor. The use of a gearbox in wind turbine may cause an increase in rotational speed of rotors. However, modern gearless technology can also be used to change the rotational speed from a low-speed rotor into the fast speed electrical generator. Both two blades and three blades rotating on a horizontal axis can be applied for turbines. Even though the blades, tower, and rotor have become bigger and smarter all over the world, wind turbines superficially have not changed much for decades.

Over the last two decades, there has been an increasing interest in wind farm development in Australia both onshore (land-based wind) and offshore (wind turbines installed in the sea) wind resources [29]. Generally, Australian wind farms are predominantly located onshore around the southern part of the continent, where wind energy density is high [29]. It should be noted here that onshore wind-powered generators in Australia require more scale in case of capacity than those in Europe, so that the electricity generated be cost-effective as electricity prices are low and coal resources are abundant in Australia [30].

Wind-power generations are one of the most widely used groups of renewable energy resources in Australia. In this regard, the installed wind power capacity experienced a 35% growth from 2006 to 2011 in Australia, and it is predicted to account for over 12% of the Australia's electricity generation in 2030 [31]. In 2012, Australia had 1386 operating wind turbines across 61 wind farms with a total installed capacity of 2564.3 MW [32–35]. The number of wind farms in Australia increased to 73 totally incorporating 2022 turbines with a generation capacity of approximately 4135 MW as of August 2015 [33]. By 2017, there were 79 wind farms and 2106 turbines with the electricity production capacity of approximately 4327 MW to meet 4% of Australia's total electricity demand [32–35]. All the wind farms in Australia by the end of 2016 are shown in Table 8 [32–35]. As can be seen, the Macarthur wind farm in Victoria, which was opened in January 2013, with a capacity of 420 MW, is the largest wind farm in Australia. The ten largest wind farms in Australia are also given in Table 9 [32–35].

**Table 8** Installed wind power capacity in Australia

| # | State/Territory | Installed capacity | | |
|---|---|---|---|---|
| | | Projects | Turbines | Total MW |
| 1 | SA | 19 | 689 | 1595 |
| 2 | VIC | 18 | 602 | 1250 |
| 3 | NSW | 12 | 361 | 668 |
| 4 | WA | 21 | 308 | 491 |
| 5 | TAS | 7 | 124 | 310 |
| 6 | QLD | 2 | 22 | 13 |
| 7 | Australian Antarctic Territory | 1 | 2 | 1 |
| 8 | NT | 0 | 0 | 0 |
| 9 | ACT | 0 | 0 | 0 |
| Sum | Australia | 80 | 2108 | 4328 |

**Table 9** Ten largest wind farms in Australia

| Project | State | Capacity/MW |
|---|---|---|
| Macarthur Wind Farm | VIC | 420 |
| Snowtown Wind Farm | SA | 369 |
| Hallett Wind Farm | SA | 351 |
| Lake Bonney Wind Farm | SA | 240 |
| Ararat Wind Farm | VIC | 240 |
| Collgar Wind Farm | WA | 206 |
| Portland Wind Farm | VIC | 195 |
| Waubra Wind Farm | VIC | 192 |
| Musselroe Wind Farm | TAS | 168 |
| Gullen Range Wind Farm | NSW | 165.5 |

The wind resource availability in Australia with different operating wind farms can be found in Ref. [36]. As can be seen, the wind resource is available mostly in western and southern Australia, while the wind resource is almost unavailable in the south-eastern Australia [37]. Some of the best wind resources in the world are located in Australia. Australia's wind energy resources are located mainly on the southern parts of the continent and reach the maximum around Bass Strait [36]. Large-scale topography such as the Great Dividing Range in eastern Australia exerts significant steering effects on the winds, channelling them through major valleys or deflecting or blocking them from other areas. Deflection of weaker fronts from frontal refraction around the ranges of the Divide in south-eastern Australia creates winds with a southerly component along the east coast.

Seasonal and diurnal variations in wind speed are among the major factors influencing wind resources along with the refractions by topography and heat flows over northern Australia. The strength of wind is at the highest level during winter and spring in western and southern Australia; however, the monthly behavior differs from region to region. Variations in the average monthly wind speed of up to 15%–20% over the long-term annual average are common. There may be similar daily variations at individual locations, with increased wind speeds in the afternoon.

Figure 7 also exhibtes the percentage of the national wind farm capacity by states. As can be observed in Fig. 7, most of wind power resources are located in SA, VIC and WA. Considering the potential wind power resource and different state renewable energy policies creating additional incentives, Australiais expected to reach a high level of wind energy generation over the next few decades. However, grid constraints such as the lack of capacity or availability may limit the growth of wind energy in some areas that have good wind resources. In such areas, the upgrade and integration of the wind power systems to the current grid may be needed to accommodate further wind energy development. Many wind farms are under construction or on the way to be constructed 2018. Table 10 shows six large wind farms under construction and committed during the first half of 2018 [32].

### 3.3 Bioenergy

Bio-energy can generally refer to chemically organic and bio-degradable material potentially capable of generating energy primary sources. Bio-energy is treated as a potential source to procure needs associated with the electricity, heat and transport in all domestic, commercial and industrial energy consumption sectors. These materials can be classified mainly into food wastes, industrial waste water, energy crops, agricultural residues, and virgin wood [38–41].

Environmental motivations and sustained autonomous electrification of remote or rural areas are the two most encouraging factors that cause the countries to be motivated in more utilizing biomass-based power plants. Gasification and combustion conversion are the two main processes implemented in the biomass power-plants to generate both heat and electricity [38–41]. The main processes in which electric power is generated through gasification/combustion is schematically depicted in Fig. 8.

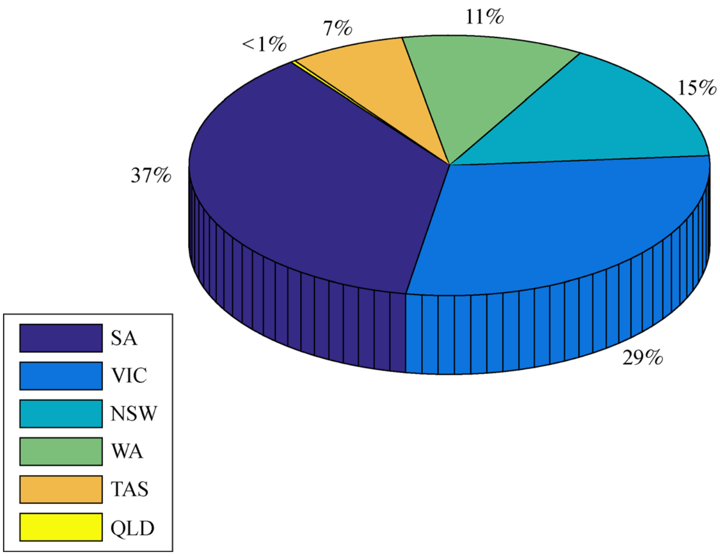


**Fig. 7** Percentage of the national wind farm capacity by state.

**Table 10** Large wind farms under construction and committed during the first half of 2018

| Wind farm | Installed capacity/MW | Developer | State | Expected completion |
|---|---|---|---|---|
| Mount Emerald Wind Farm | 180.5 | Ratch Australia | QLD | Sept 2018 |
| Mount Gellibrand Wind Farm | 132 | Acciona | VIC | Mid-2018 |
| Sapphire Wind Farm | 270 | CWP Renewables | NSW | July 2018 |
| White Rock Wind Farm (Stage I) | 175 | Goldwind Australia | NSW | 2018 |
| Lincoln Gap Wind Farm | 212 | Nexif Energy Australia | SA | 2018 |
| Willogoleche Wind Farm | 119 | Engie | SA | 2018 |

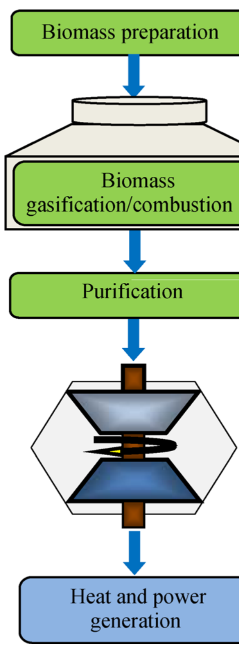


**Fig. 8** Process of heat and power generation in biomass power-plants.

Direct burning is the heart of the combustion conversion processes through which the thermal energy can be extracted. The exhausted heat is employed in a steam/gas turbine to operate as acombined heat and power (CHP) unit. On the contrary, gasification is targeted to breakdown the biomass resources into biogas or liquid bio-fuels. The output of gasification process can be used for transport or it can be employed to supply electricity requirement. Nowadays, the biomass conversion technologies are based on the combination of both thermal and chemical processes [40,41].

Agricultural residues and occasionally urban waste, are the main items for biomass power-plants. Besides, resources like sugar, grain, and vegetable oil crops are more useful for transport-based bio-fuels like bio-ethanol and bio-diesel [42,43]. According to International Energy Agency (IEA) planning, it is the project to procure 6.2% to 6.3% of the world electricity using bio-energy. In 2010, only 1.5% of the world electricity generation was supplied by biomass power-plants. This share for bio-fuels was about 1.9% [44,45].

Biomass-based CHP requirements in Australia are dominantly supplied from sugar-canresidue (bagasse), wood wastes, and gas captured from sewage and landfill facilities. Besides, the ethanol obtained from cooking oil, tallow, and oilseeds are used to produce bio-diesels. Other potential biomass resources in Australia can be derived from forest-based wood residues, waste streams, and non-edible sources [45]. The process of bio-energy utilization from source to end-user consumers is depicted schematically in Fig. 9. It is projected to expand the bio-energy based electricity generation to 3 TWh by 2030. To this end, the bio-energy electricity generation should be grown with a rate of 2.3% per year. In 2008, about 2 TWh of Australia's electricity demand is procured by bio-energy power-plants [44]. The geographically distribution of the bio-energy based electricity facilities and bio-fuel plants in Australia can be found in Ref. [42]. Furthermore, the average price of electricity per kWh for bio-energy power-plants was about 12 USD-cents in 2011 [45].

The share of electricity generation from bioenergy in Australia's different states in 2011 was 53% for Queensland, 25% for New South Wales, 13% for Victoria, 4% for Southern Australia, 4% for Western Australia, 1% for Tasmania, and 1% for Northern Territory [43–45].

### 3.4 Geothermal energy

In the deep earth below the Earth's crust, there is a great potential to produce a huge amount of energy where there is a layer of hot and molten rock named magna. The amount of this energy in the 10 km depth of the earth is 50000 times greater than the total oil and natural gas existing in the world. In this regard, geothermal energy refers to the heat from the earth that can be utilized for different affairs. Electricity generation and heating residential complex are of two examples.

The associated heat energy would be available in many locations such as deep wells in Indonesia to volcanic regions in New Zealand and Iceland. However, this type of energy is new to Australia and it has a great potential to be widely used. In this regard, the geothermal energy has been already started to be a key energy in many countries to more and more mitigate the environmental impacts of fossil fuels [46]. Approximately, 11700 MW geothermal energy has been already operated up until 2013 and another 11700 MW is planned to be installed.

The importance of geothermal energy in some countries is more highlighted such as Iceland (25%), El Salvador (22%), Kenya, the Philippines (17% each), and Costa Rica (13%). Geothermal energy is also used through direct-use applications in 78 countries. These applications include geothermal heat-pumps for heating and cooling, water-heating in pools and spas (26%) as well as space-heating (15%) [47]. It is noteworthy that USA has the largest installed capacity of geothermal energy with more than 3300 MW. In between, there is the possibility to use the geothermal energy in Iceland and New Zealand by utilizing the hot water with high pressure. The high pressure water is available in below the surface because of the volcanos in such countries.

In contrary, in Australia the Enhanced or Engineered geothermal system must be employed. This is done by pumping water from the surface to the depth of the ground to get the heat by circulating the water injected. There are two different types of geothermal technology known as a vapor-dominated and a liquid-dominated forms.The superheated steam with 240°C–300°C can be derived from vapor-dominated ones. However, there are different applications for geothermal energies, particularly the ones with shallower depth. Table 11 includes the geothermal direct-use applications for different temperature levels [48]. Temperatures 30°C–120°C refer to the hot water obtained from the geothermal unit. Moreover, temperatures 110°C and above refer to the saturated steam obtained from the unit.

However, geothermal energy is a novel type of energy which has the potential to increasingly contribute to electricity generation. In this respect, there are several ongoing projects around Australia, particularly in the Northern regions. Although important resources have been explored and some companies are working to explore new regions, no commercial energy has been produced. It is predicted that the whole power demand in Australia can be supplied by only deploying 1% of the geothermal energy. This geothermal energy can be derived from the depth of five kilometers or shallower with the temperature above 150°C [48].

Australia has been involved with geothermal energy for a long time regarding the direct use of the energy, e.g., to warm up swimming pools. On the contrary, producing electricity from geothermal energy has been done only in a capacity of 80 kW. The energy in this scale is used to supply the load demand in the town of Birdsville located in Queensland. This power plant has employed a low-temperature hydrothermal-type geothermal resource at 98°C groundwater. The water is available from the depth of 1230 m in Great Artesian Basin [49]. Except the geothermal energy generation at Birdsville, the Australian government has taken into consideration the geothermal energy subeconomic. Moreover, the large-scale energy generation has not been proved to be commercially justified in the country [50]. In this regard, the geothermal energy generation in 2015 and 2016 was reported to be zero [51].

The schematic representation of the geothermal energy generation technologies used in Australia and interpreted temperature at 5 km depth is available in Refs. [48,52]. In this regard, there are many wells drilled and prepared around Australia [52]. Table 12 presents the data of the 20 wells with the highest temperature. Besides, the map with different basins along with the distribution of energy resources in Australia excluding the hydro and bioenergy can be found in Ref. [50]. In addition, Table 12 represents active companies in different states of Australia.


**Fig. 9** Bio-energy utilization: from main resources to end-users.

**Table 11** Different direct-use applications of geothermal energy

| Temperature/°C | Application |
|---|---|
| 30 | Warm water to be used in mining in cold climates, de-icing, fish farming throughout the year |
| 40 | Soil warming, heating swimming pools, biodegradation, fermentations |
| 50 | Mushroom growing, balneology/therapeutic hot springs |
| 60 | Animal husbandry, greenhouses by combined space |
| 70 | Refrigeration (lower temperature limit) |
| 80 | Space heating, both residential and greenhouses |
| 90 | Drying of stock fish, intense de-icing operations |
| 100 | Drying of organic materials |
| 110 | Drying and curing of light aggregate cement slabs |
| 120 | Concentration of saline solution, refrigeration (medium temperature) |
| 130 | Evaporation in sugar refining, extraction of salts by evaporation and crystallization, fresh water by distillation |
| 140 | Drying farm products, food canning |
| 150 | Alumina via the Bayer process |
| 160 | Drying of fish meal and timber |
| 170 | Heavy water via hydrogen sulfide process, drying of diatomaceous earth |
| 180 | Digestion in paper pulp, evaporation of highly concentrated solutions, refrigeration by ammonia absorption |

**Table 12** Data of the 40 wells with the highest temperature drilled in Australia

| Project | Well name | Basin | Depth/m | Temperature/°C | Status |
|---|---|---|---|---|---|
| SA0126 | Burley 2 | Cooper/Eromanga | 3705.758 | 253 | Abandoned |
| WA0576 | Leo 1 | Canning | 2411.3 | 242 | Plugged & abandoned |
| SA0514 | McLeod 1 | Cooper/Eromanga | 3806.34 | 229.44 | Suspended |
| WA0576 | Leo 1 | Canning | 2411.3 | 228 | Plugged & abandoned |
| SA0078 | Big Lake 41 | Cooper/Eromanga | 3005.328 | 227 | Suspended |
| SA1157 | Bulyeroo 1 | Cooper/Eromanga | 3553.663 | 222.22 | Suspended |
| SA1523 | Habanero 1 | Cooper/Eromanga | 4420.819 | 220.56 | Abandoned |
| SA1157 | Bulyeroo 1 | Cooper/Eromanga | 3553.663 | 220 | Suspended |
| WA0576 | Leo 1 | Canning | 2411.3 | 220 | Plugged & abandoned |
| SA0622 | Moomba 55 | Cooper/Eromanga | 3107.131 | 211.11 | Suspended |
| SA0514 | McLeod 1 | Cooper/Eromanga | 3806.34 | 211 | Suspended |
| SA0066 | Big Lake 29 | Cooper/Eromanga | 3029.102 | 210 | Suspended |
| SA0078 | Big Lake 41 | Cooper/Eromanga | 3005.328 | 210 | Suspended |
| SA1131 | Big Lake 46 | Cooper/Eromanga | 3075.432 | 206.11 | Suspended |
| SA0630 | Moomba North 1 | Cooper/Eromanga | 3101.645 | 205.55 | Suspended |
| SA1523 | Habanero 1 | Cooper/Eromanga | 4420.819 | 202.78 | Suspended |
| SA1524 | Habanero 2 | Cooper/Eromanga | 4357.726 | 202.78 | Suspended |
| SA1133 | Big Lake 50 | Cooper/Eromanga | 3255.264 | 201.11 | Suspended |
| SA1348 | Moomba 79 | Cooper/Eromanga | 3111.398 | 201.11 | Abandoned |
| SA1351 | Moomba 82 | Cooper/Eromanga | 3200.4 | 199.44 | Suspended |

The geothermal energy hit the summit in 2010 while by 2014, the total investment was approximately $900 million. After that and in spite of the promising power plant test in central Australia, the investment rate has significantly reduced. It is such that the merely continuing project in this area is being carried out by the South Australian Centre for Geothermal Energy Research. This center is located at the University of Adelaide and the project is partially funded by the ARENA. However, Australia has a tremendous potential for geothermal energy.

As it can be observed from Table 13, almost all projects relating to the geothermal energy have been suspended [48]. It is due to several reasons than can be stated as economic, technical, geographic, financial, and policy-connected problems. However, the fast evolution in other types of renewable energy has put the stress on the geothermal energy in case of its profitability compared to others. A detailed analysis of these factors can be found in Ref. [53].

There is a significant potential to employ geothermal energy in Australia for both hot rocks and hot sedimentary aquifer geothermal applications [54]. According to estimation, Australia will utilize geothermal energy in 2050 by 8% of the total electrical power generation [54]. The energy will provide Australia with the opportunity to be more exposed to geothermal energy. One key point in developing such a type of generating technology is the issue of social acceptance that is well discussed in Refs. [54,55]. This issue is vital to any new emerging technologies so that the benefits and risks would be identified for all people.

### 3.5 Hydropower

Hydropower is the most mature type of renewable energy. It plays an important role in providing electricity in more than 160 countries all over the world [56–59]. Falling water from reservoirs or flowing water from streams and rivers can be employed to turn the blades of a water turbine. The prominent advantage of hydroelectricity is that it can be used at both base and peak load electricity generation. It is reliable and beneficials from the fast start-up which makes it a suitable source of renewable energy for peak load generation. According to the data from the International Renewable Energy Agency (IRENA) for 2017, the total amount of power produced by hydroelectric plants all over the world is 1153.911 GW, which is 53% of the total power generated from renewable resources [60,61]. Hydroelectricity is the major source of renewable energy with the share of 8% of the total energy generated in Australia as shown in Fig. 10.

Australia is known as the driest inhabited continent worldwide. The annual average rainfall for around 80% of the country area is less than 600 mm per year. Moreover, 50% of the landmass is reported to receive an annual average rainfall of less than 300 mm per year [60,62]. Only around 60 TWh is reported to be technically feasible of Australia’s gross theoretical hydro energy resource of 265 TWh per year [60–63]. Furthermore, the estimated economically feasible capacity of Australia is reported to be 30 TWh per year of which more than 60% has already been harnessed [60,63]. In Australia, the total installed capacity of more than 120 hydroelectric power plants in

**Table 13** Active companies in geothermal energy

| Project | State | Location | Company | Inferred resource (Petajoules) |
|---|---|---|---|---|
| Parachilina Geothermal Play | SA | 150 km north of Port Augusta | Torrens energy | 780000 |
| Olympic Dam Geothermal Energy Project | SA | Olympic Dam, SA | Green Rock Energy | 116770 |
| The Cooper Basin Projecs | SA | Innamincka | Geodynamics | 230000 |
| Anglesea Geothermal Play | VIC | Geelong | Greenearth Energy | 220000 |
| Paralana Geothermal Play | SA | Flinders Range | Petratherm | 230000 |
| Wombat Geothermal Play | VIC | Gippsland | Greenearth Energy | 3600 |
| Limestone Coast Project: Rendelsham Geothermal Play | SA | Mt Gambier | Panax | 17000 |
| Limestone Coast Project: Rivoli-St Clair Geothermal Play | SA | Beachport | Panax | 53000 |
| Limestone Coast Project: Penola Geothermal Play | SA | 40 km north Mt Gambier | Panax | 89000 |
| Limestone Coast Project: Tantanoola Geothermal Play | SA | North-west Mt Gambier | Panax | 130000 |
| Roxby Geothermal Project | SA | 40 km north Port Augusta | Southern old | 260000 |
| Tirrawarra Geothermal Project | SA | Moomba | Panax | 34500 |
| Frome Project | SA | Frome Basin | Geothermal Resources | 84000 |
| Lemont Geothermal Play | TAS | Midlands Area | KUTh Energy | 260000 |
| Perth Permit | WA | Metropolitan Perth | Green Rock Energy | 29960 |
| Geelong Geothermal Power Project | VIC | Geelong | Green Rock Energy | 17000 |
| Nicholas-Fingal Geothermal Play | TAS | Fingal Valley | KUTh Energy | 101000 |
| Port Augusta Project Area | SA | Port Augusta | Torrens Energy | 70.000 |

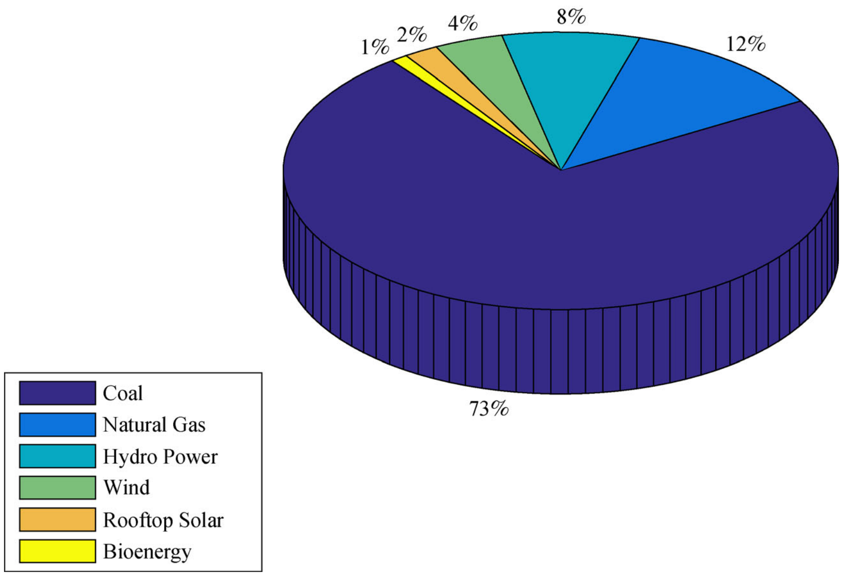


**Fig. 10** Electricity generation in Australia's national electricity market.

operation is reported to be around 20 GWh [64,65]. Approximately, all hydroelectricity generation comes from hydroelectric power plants at reservoir storages of dams in major river valleys [60,66]. In many of these plants,water is pumped back to the higher storage locations to be reused during peak times.

The eastern states of Australia mainly receive the highest annual average rainfall in which the highest hydroelectricity is generated. In this sense, 56.9% of the total electricity generation in 2007 and 2008 was generated in Tasmania, 21.9% in New South Wales, 13.1% in Victoria, and 7.7% in Queensland as shown in Fig. 11. Besides, the data and the map of the major Australian hydro power plants in operation with a capacity greater than 10 MW can be found in Ref. [60].

There are several hydroelectricity schemes around Australia including north-east Victoria, Western Australia, Queensland, Tasmania, and South Australia. Among all, the snowy mountains hydroelectricity scheme accounts for nearly 50% of the total hydroelectricity generation in Australia with a capacity of 3800 MW. This project also provides approximately 70% of all renewable energy available to the eastern mainland grid of Australia [64,65]. It consists of 28 power plants, several lakes, and more than 50 long dams. Hydro Tasmania, the owner of these facilities, provides electricity at both base and peak load periods to Tasmania and Australian network. This is done through Basslink which is an under sea interconnector that runs under Bass Strait. As it has been previously mentioned before, hydroelectricity is the major source of renewable energy with a share of 8% of the total energy generated; however, this will be reduced to 3.5% in 2029 and 2030, which means hydroelectric energy is becoming less significant compared to the total electricity generation in Australia. Hydropower is expected to be outpaced by wind energy during the outlook period [60].

Most of the large scale hydro energy potential has been already developed in Australia. However, upgrading and

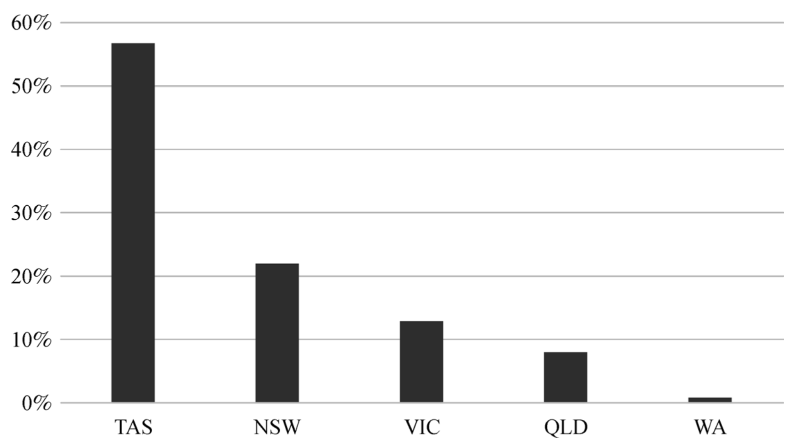


**Fig. 11** Hydro energy consumption in Australia in 2007 and 2008.

refurbishment of existing hydroelectric power plants will improve the efficiency. In addition, small scale hydro units will play a key role in the future growth of hydroelectric power generation while some limitations such as the water availability, variations of the rainfall, temperature, evaporation rate, and environmental factors are key constraints on future growth of hydroelectricity generation.

### 3.6 Offshore energies

Considering that the use of petroleum products to produce electricity is limited day by day, electricity companies have been seeking alternative sources of renewable energy [67]. Of renewable energy resources, offshore energy is one of the most important sources of energy which electric utilities and companies that are active in the field of renewable energy are paying special attention to it [68]. Ocean/offshore renewable energy is divided into four main types, as depicted in Fig. 12.

Australia is one of the leading countries in the field of renewable energy over the last decades. This is due to the fact that Australia is a vast island and it has a big potential to use offshore energy resources for electricity production [69,70]. Recently, the Australian government has showed a noteworthy interest in pre-business wave energy improvements on the Australian coast [70] in acknowledgment of the potential commitment of wave energy to Australia's future low carbon energy mix. This investment supports the incipient wave energy industry [71].

Considering the dramatic developments in other renewable energy sources in Australia, less research has been conducted in the fields of ocean thermal energy and osmotic power. However, regarding the tidal energy and wave energy, many studies and projects have been done regarding electricity generation [71].

Tidal systems require beach front geomorphic settings as they are intended to harvest the potential energy of the tides. Because of their site-particular prerequisites and the unpredictable reaction of the tides in extremely shallow water, it is not pragmatic to attempt a detailed national scale appraisal of the tidal potential energy. The tidal energy systems generally require a full tide on a scale more

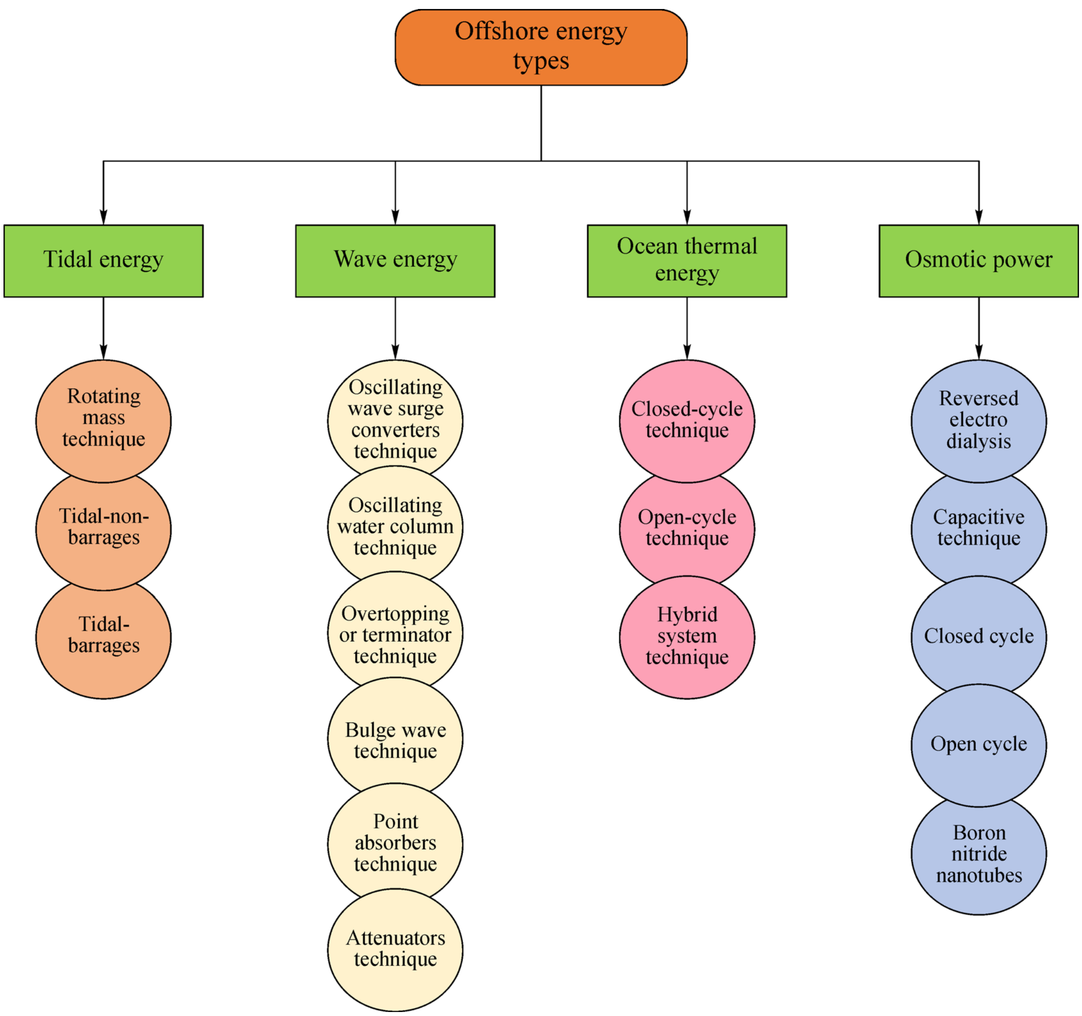


**Fig. 12** Offshore renewable energy techniques.

than 4 m, which are limited from Port Hedland northwards to Darwin and the southern end of the Great Barrier Reef in Australia. Tidal turbines are suitable for establishment on the mainland shelf and they do not really require exceptionally particular coastal designs. In other words, tidal turbines can be transmitted in areas where nearby beach configurations result in expanded tidal streams [72].

The total tidal energy delivered annually to the continent of Australia has been represented in Table 14 [72]. As indicated in Table 14, there are six main areas in Australia which have enough potential to use tidal energy to produce electricity. The best tidal energy area with an average tidal power in depths less than or equal to 50 m is totally over 195 $GJ/m^2$ in Western Australia [72].

Recent studies regarding Australia's wave energy resources have concentrated mostly on the south-western, southern and south-eastern margins of the continent. However, there has been no past comprehensive national evaluation of Australia's wave energy resources. Previous studies have surveyed Australia's potential wave energy at a few lands utilizing wave potential records [73] and wave models [74] while the results suggest significant wave energy resources. To achieve proper measures of the nearshore wave energy resource for determining the efficiency of wave energy converters, it is required to consider the construction of the wave energy over the mainland shelf [75].

Among the accessible wave energy resource evaluations performed in Australia, investigation performed by Hughes and Heap [76] gives descriptions of the nearshore wave energy resource for water profundities of 650 m. These evaluations are highly valuable and represent most of the currently accessible data regarding Australia's nearshore resources. Besides, pre-evaluation of nearshore wave energy resources are required by the wave energy harnessing industry for tuning the existing wave energy converters and arranging future wave energy convertors arrangements. This will enable scientists to survey more precisely the capability of wave energy converters for Australian coastal areas. The best areas of wave energy in Australia are Victoria and Tasmania, South Australia, and Western Australia, as listed in Table 15 [72].

## 4 Social and environmental impacts

The technical issues of renewable energies have been the subject of numerous studies and literatures. However, few studies have addressed the social and environmental aspects of renewable energies. In Australia, coal as a main export commodity is extracted from the strategic coal mines such as one of the largest coal sources in the Hunter Valley of NSW [77]. A transformation of a traditional coal-based energy to a clean and renewable energy can adversely impact the economic and social conditions of the region. These transformation issues could decrease the role of coal as a dominant energy source [77]. However, this transformation is unavoidable due to the environmental and social impacts of the massive coal industry on water resources, climate change, biodiversity, and human health. The significant drivers to change the strategy and policy regarding a low carbon future are public awareness and supports. The energy concerns and climate change have increasingly reinforced the importance of renewable energies in Australia. Reference [78] evaluated the impact of psychological factors and the provision of factual

**Table 14** Total tidal energy which delivered annually on the continent of Australia

| Continental | Power/($W\cdot m^{-2}$) | | | | Energy/($GJ\cdot m^{-2}$) |
|---|---|---|---|---|---|
| | Mean | 10th percentile | 50th percentile | 90th percentile | |
| Northern Territory | 2069.50 | 18.07 | 1029.68 | 5979.38 | 65.45 |
| Queensland | 4153.19 | 33.97 | 2316.85 | 10679.20 | 131.35 |
| New South Wales | 0.36 | 0.024 | 0.19 | 0.96 | 0.0011 |
| Victoria and Tasmania | 488.93 | 6.03 | 378.06 | 1193.56 | 15.46 |
| South Australia | 317.16 | 0.43 | 78.86 | 1014.65 | 10.03 |
| Western Australia | 6179.39 | 249.42 | 7529.65 | 10679.20 | 195.43 |

**Table 15** Total wave energy which delivered annually on the continental of Australia

| Continental | Power/($W\cdot m^{-1}$) | | | | Energy |
|---|---|---|---|---|---|
| | Mean | 10th percentile | 50th percentile | 90th percentile | Mean |
| Northern Territory | 5.32 | 0.33 | 2.68 | 13.09 | 167.90 |
| Queensland | 14.72 | 3.52 | 9.03 | 29.82 | 442.80 |
| New South Wales | 13.61 | 2.77 | 7.31 | 27.19 | 391.04 |
| Victoria and Tasmania | 34.87 | 4.88 | 18.22 | 70.66 | 1100.80 |
| South Australia | 25.51 | 4.28 | 15.35 | 54.96 | 885.13 |
| Western Australia | 26.38 | 4.65 | 15.05 | 56.86 | 901.44 |

information on public support for using renewable technologies in Australia. The results of an online survey from 1907 Australians show that people are interested in renewable energies due to two main reasons as fossil-fuel costs and subjective norms [78].

Another approach to gain public supports regarding renewable energies in a society can be an appropriate educational programin schools to show how the climate change because of the greenhouse gas (GHG) impacts environmental and human sources. The Australian Cooperative Research Centre (CRC) for Renewable Energy (ACRE) has successfully run a program to teach students about renewable energies solutions and the GHG effects [79]. Moreover, a postgraduate multidisciplinary program regarding renewable technologies, including economic, policy, environmental, and social aspects is developed in Australian universities [80].

Another approach to enhance the penetration level of renewable energies into the energy market is the government intervention and policy making. The carbon tax policy was introduced by the Australian government in July 2012 to make companies focus on reducing emission. The carbon tax policy can impact the electricity market, generation companies, and prices. The simulation results in Ref. [81]. indicated that the retailer prices rise by 25%. The coal-based generating companies decrease their power generations, which, in turn, substantially reduces their payoff. Hence, the carbon tax can lead the Australian electricity market to low carbon sources in the long-term [81].

Employment is another significant impact of renewable investment on the Australian society. The renewable industry can create more local jobs than coal industry [82]. According to the clean energy Australia report [83], that 3725 new jobs would be created in renewable energy projects that are under construction or start in 2017 in Australia. However, employment in the coal industry has been dropping in the job market in Australia [82].

Australia is able to supply 15% of the electricity generations by lignocellulosic sources [84]. The social, economic, and environmental impacts of biofuels as an alternative fuel have been investigated in Ref. [85]. The results indicated that lignocellulosic biofuel production will have a high potential for creating jobs and improving the economic growth through the investment in the industry.

Australia has been actively developing wind energy. At the end of 2016, wind power supplied 5.3% of the total electricity generation and 30.8% of total renewable generation in Australia [83]. However, wind power has been associated with some concerns regarding the impacts of wind developments on birds populations, noise pollution, landscape, and heritage values [86,87]. The negative impacts of wind development on biodiversity are fairly minor compared to the advantages in Australia. The noise pollution and bird collisions because of turbines depend on the wind farm locations and can be decreased by technological improvements [85]. The main concerns can be landscape and heritage issues for wind development. Nonetheless, the consequences are minimal in comparison with environmental effects of coal industry and could be managed through well-planned measures [86]. Table 16

**Table 16** Social and environmental impacts of renewable technology in Australia

| Year | Remarks | Ref. |
|---|---|---|
| 2019 | Job creation and investment: The clean energy Australia reported the renewable investments, projects, and job creation in each year since 2009 | [83] |
| 2016 | Biofuel development impacts: This paper investigated the social, economic, and environmental impacts of lignocellulosic biofuel production | [85] |
| 2014 | Carbon tax policy: This paper investigated the impact of carbon tax on the electricity market, generator companies, and prices. The carbon tax increases the cost of conventional power plants, and the payoff of clean power plants | [81] |
| 2013 | The psychological and information factors: This paper investigated the impact of psychological factors and the provision of factual information on public support for the renewable technologies in Australia | [78] |
| 2008 | Australian coal industry: This paper investigated the social and environmental impacts of a transformation of a traditional coal-based energy to a clean and renewable energy on the local coal industry | [77] |
| 2006 | Wind Development impacts: This report investigated the wind energy development impacts on cost, fire risk, efficiency, reliability, noise, birds, biodiversity, landscape, and heritage | [86] |
| 2001 | Educational program: This paper investigated the contributions of the Australian Cooperative Research Centre for Renewable Energy to the provision of factual information about renewable energies to the public and to school students | [79] |
| 2000 | A postgraduate program: This paper focused on a postgraduate multidisciplinary program regarding renewable energy technologies, including economic, policy, environmental, and social aspects | [80] |

shows social and environmental impacts of renewable technology in Australia.

## 5 Conclusions and policy implications

This paper presented a comprehensive review of the status of renewable energy resources in Australia for the first time, including different technologies along with national policies. In addition, to have in depth knowledge about the status of academic progress in the field of renewable energy in Australia, it also reviewed a variety of statistics. Moreover, it analyzed the possible social and environmental impacts of renewable energy technologies in Australia.

## Notations

| | |
|---|---|
| ACT | Australian Capital Territory |
| AER | Australian Energy Regulator |
| APVI | Australian Photovoltaic Institute |
| ARENA | Australian Renewable Energy Agency |
| BNEF | Bloomberg New Energy Finance |
| CEC | Clean Energy Council |
| CHP | Combined Heat and Power |
| CRC | Cooperative Research Centre |
| CSP | Concentrated solar power |
| FiT | Feed-in-Tariff |
| GHG | Greenhouse gas |
| IEA | International Energy Agency |
| LCOE | Levelized cost of energy |
| LRET | Large-scale Renewable Energy Target |
| NSW | New South Wales |
| NT | Northern Territory |
| PV | Photovoltaic |
| QLD | Queensland |
| RET | Renewable energy target |
| SA | South Australia |
| SRES | Small-scale Renewable Energy Scheme |
| TAS | Tasmania |
| VIC | Victoria |
| WA | Western Australia |

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