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Non-Hydro Renewable Energy in South Australia: Policies, Challenges, and Opportunities

By

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ABSTRACT

This thesis examines the factors contributing to South Australia's high penetration of non-hydro renewable energy (NHRE) in its power grid. It investigates the political framework, policies and investments that have facilitated this transition and highlights the associated challenges and opportunities. The findings reveal that South Australia's success is rooted in supportive policy frameworks, significant investments, geographical conditions and community engagement. Despite notable achievements, challenges such as NHRE variability, energy storage, and rising costs remain. The thesis underscores the importance of stable political frameworks, robust policy implementation, and proactive strategies to sustain and expand NHRE adoption. By learning from South Australia's experience, other regions can contribute to global efforts in mitigating climate change and promoting sustainable development.

DECLARATION

I certify that this thesis:

1. does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university

2. and the research within will not be submitted for any other future degree or diploma without the permission of Flinders University; and

3. to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text[1].

Signed...

Date...

[1] I acknowledge the use of ChatGPT in this thesis for grammar checking and improving sentence clarity. After completing each chapter, I used ChatGPT to enhance the grammar and clarity of several paragraphs.

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LIST OF ACRONYMS

ARENA	Australian Renewable Energy Agency
AEMO	Australian Energy Market Operator
ACCC	Australian Competition and Consumer Commission
AOFM	Australian Office of Financial Management
BESS	Battery storage power station
CO2	Carbon dioxide
DPA	Statewide Wind Farm Development Plan Amendment
EV	Electric Vehicles
FiT	feed-in tariff
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
NEM	National Electricity Market
NHRE	non-hydro renewable energy
PHES	Pumped Hydro Energy Storage
PPAs	Power Purchase Agreements
PV	Photovoltaics
RAA	Royal Automobile Association
REC	Renewable Energy Certificate
RET	Renewable Energy Target
REZ	Renewable Energy Zones
RPS	Renewable Portfolio Standard system

CHAPTER 1: INTRODUCTION

Background and Context

Climate change induced by the massive release of greenhouse gases into the atmosphere by humans is causing global warming, which will have irreversible consequences for the earth's ecosystems and human life. In response, the international community signed the Paris Agreement, setting the goal of limiting global warming to below 2°C, and ideally to 1.5°C. The energy sector plays a crucial role in greenhouse gas emissions, primarily because many power generation facilities still rely on fossil fuels. Therefore, to achieve the ambitions of the Paris Agreement and safeguard the future of human society, transitioning the energy sector towards renewables and decarbonization is imperative.

In recent years, most countries, including Australia, have been actively experimenting with and deploying renewable energy technologies, particularly those related to wind and solar energy, categorized as non-hydro renewable energy (NHRE). Significant progress has been made in some regions. The deployment of these technologies is essential for reducing the carbon footprint of the energy sector and meeting international climate goals.

As one of eight states and territories in the Australian federation, South Australia's energy landscape has undergone significant transformation over the past few decades. Historically, the state relied heavily on coal and natural gas for electricity generation. However, starting in the early 2000s, South Australia began investing in renewable energy, driven by state policies and public support. After two decades of relentless efforts, South Australia has achieved remarkable success in energy transition and has emerged as a regional leader. By 2023, renewables energy penetration reached over 74% of the state's grid in South Australia.

Research question and aim

The primary research question of this thesis is: "How has the South Australian grid achieved such a high penetration of NHRE?" This question aims to understand the factors that have enabled South Australia to significantly increase its renewable energy penetration, along with the associated opportunities and challenges. By examining the political background, policy frameworks, economic incentives, and current barriers, this study seeks to uncover the key drivers behind South Australia's successful energy transition. Understanding these elements can provide valuable insights for other regions aiming to enhance their renewable energy capacity and contribute to global sustainable development goals.

Methodology

This thesis adopts desk-based analysis of policy and other documents in the public realm to investigate why South Australia has achieved a high penetration of NHRE. Data for this study is primarily quantitative, sources include government reports, industry publications, other grey literature, existing articles, and energy output records, ensuring a robust and reliable dataset.

Firstly, this paper conducts a review of relevant academic literature to understand the concept of NHRE. It introduces the specificity and necessity of NHRE, distinguishing it from hydro energy, and examines the factors influencing NHRE.

The data regarding NHRE situations and policies globally, in Australia, and specifically in South Australia, are mainly sourced from grey literature, including reports from international agencies, government documents, and relevant regulators such as the Australian Energy Market Operator (AEMO). A small portion of secondary data is also drawn from journal articles. This information from various sources is pulled together to build a comprehensive picture of NHRE transition in South Australia.

For data on South Australia's future strategies and the economic impacts of NHRE, government documents serve as the primary sources. In studying the challenges and opportunities related to NHRE in South Australia, historical price data is sourced from AEMO and the National Electricity Market (NEM). Data on battery prices are taken from secondary sources by other authors, while electricity cost data come from reports by the Australian Competition and Consumer Commission (ACCC) and other studies. Research data on Renewable Energy Zones (REZ) policies are mainly derived from federal and state government documents. After data gathering, the thesis analyses the data to support the argument.

Scope of the Thesis

This thesis focuses on understanding the high penetration of non-hydro renewable energy (NHRE) in South Australia's power grid. The research is geographically limited to South

Australia, a region known for its progressive renewable energy policies and significant achievements in NHRE integration. While the primary focus is on South Australia, brief comparisons with other Australian jurisdictions are made to highlight unique drivers and challenges. This comparative analysis helps contextualize South Australia's experience within the broader global efforts towards renewable energy transition.

Temporally, the study spans from the early 2000s, when significant renewable energy policies began to take shape, to the present, 2024. This period allows for a comprehensive analysis of policy impacts and technological advancements over time.

Thematically, the research is organized around key areas: literature review of NHRE, the impact of government policies, South Australia current NHRE situation and economic incentives, and the challenges and opportunity of South Australian NHRE transition. Each chapter addresses one of these themes, providing a structured approach to exploring the factors contributing to South Australia's NHRE achievement.

By defining these scopes, the thesis maintains a targeted and manageable approach, aimed at producing insightful conclusions about the factors driving South Australia's achievement and challenge in NHRE deployment and integration.

Structure of the thesis

This thesis is organized into four main chapters and will step by step examine the factors contributing to South Australia's high penetration of NHRE in its power grid.

Chapter Two establishes the context of NHRE through a literature review. This chapter begins by introducing the concept of NHRE, followed by an overview of the development background of NHRE globally and in Australia. Finally, it explores the factors affecting NHRE deployment worldwide.

Chapter Three analyses how federal and state-level policies have impacted on South Australia's NHRE penetration. First, this chapter discusses the federal political background, the attitudes of different political parties toward energy transition, and how these attitudes shape federal energy policies. It then explains how the federal government uses Renewable Energy Certificates (RECs) to achieve the Renewable Energy Target (RET) and describes the political landscape in South Australia how to impact the energy transition. Following this, the chapter examines how Feed-in Tariff (FiT) policies have facilitated the rapid deployment of small-scale solar panels in both Australia and South Australia, discussing the resulting impacts. Finally, it explores South Australia's wind energy policies and how they have positioned the state as a leader in wind energy investment.

Chapter Four describes the current state of NHRE in South Australia. This chapter first highlights South Australia's achievements in energy transition and decarbonization. It then discusses the economic impacts of this transition on the state and the potential opportunities for off-grid communities. Finally, the chapter examines the South Australian government's near-future energy transition strategies, with a focus on hydrogen energy and electric vehicles (EVs)

Chapter Five discusses the challenges and opportunities of South Australia's energy transition. The first section examines how the variability and intermittency of NHRE affect the grid and the necessity for energy storage technologies. It also explores the issues and opportunities related to the broadly deployment of Battery Energy Storage Stations (BESS) and Pumped Hydro Energy Storage (PHES) in South Australia. The second section addresses the issue of high electricity prices in South Australia. It analyses the trends in electricity prices in the state, compares the different electricity department cost with other jurisdictions, and provides a detailed analysis. The third section discusses Renewable Energy Zones (REZ) policy, which other jurisdictions are using to facilitate NHRE projects deployment. In contrast, South Australia has shown relative indifference to this policy, with related developments primarily led by private companies. The potential impacts of the South Australian government's different attitude to REZ compared to other state governments will also be discussed.

Chapter Six is the conclusion of the thesis. It summarises the findings, implication, and challenge and opportunity for South Australian energy transition.

CHAPTER 2: NON-HYDRO RENEWABLE ENERGY

In recent decades, human society has realized that it is facing a long-term challenge: climate change. The atmosphere, ocean, cryosphere, and biosphere are changing rapidly and affecting people's lives. According to the 2023 report of the Sixth Assessment Report (IPCC, 2023), hard and soft limitations have been reached in some ecosystems, and influences have already occurred in some sectors and regions. How global warming impacts different generations can be seen in Figure 1. The primary cause of climate change is greenhouse gas emissions from human activities (IPCC, 2023). To meet the target of mitigating climate change, the Paris Agreement emphasizes international cooperation to limit the temperature rise below 2 degrees Celsius, with efforts to restrict the increase to 1.5 degrees to minimize damage to ecosystems (UNFCCC, 2016).

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Figure 1: How the different generations might be impacted by climate change in different scenarios (IPCC, 2023)

According to the findings of the International Energy Agency's (IEA) report (IEA, 2023a), the largest sector of emissions is energy (see Figure 2). Emissions from this sector continue to rise, with a 1.8% increase in 2022 due to the electricity demand rising by 2.7 %. Fortunately, in this sector, the carbon intensity (the ratio of carbon dioxide per unit of energy, commonly used to compare environmental impact between different types of energies) showed a decline, which means that there are fewer emissions in the electricity generation process for the same amount. This is due to the rapidly growing deployment of renewable generators in most global regions (IEA, 2023a). Thus, increasing the amount of renewable energy is a vital pathway to reducing emissions and achieving energy sustainability.

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Figure 2: Global emissions from different sectors, 2019 to 2022 (IEA, 2023b)

"Renewable energy is derived from natural sources that are replenished at a rate higher than they are consumed" (UN, n.d.). In most scenarios, generation via renewable energy creates far lower greenhouse gas emissions than non-renewable energy sources. The most commonly seen renewable energy sources are wind and solar energy; hydropower, geothermal energy, ocean energy and bioenergy are also significant renewable sources. Renewable energy also has some additional social and economic benefits, including reducing air pollution, increasing energy accessibility and, arguably, improving energy security (IPCC, 2011, Owen, 2006). For some specific reasons, there is a sub-concept under renewable energy was gradually mentioned which is non-hydro renewable energy (NHRE).

2.1 The concept of non-hydro renewable energy

This section discusses the differences between NHRE and hydropower and why this concept is frequently mentioned in discussions of pathways to sustainability. Scholars differ in their definition of NHRE but commonly agree that hydropower is a separate category (Lin and Omoju, 2017, Nguyen et al., 2019, Luz et al., 2018, Seriño, 2021), and some argue that bioenergy should also be excluded from NHRE because it might lead to rises food prices and food insecurity if agricultural production switches to energy generation (Pfeiffer and Mulder, 2013).

There are various reasons for distinguishing hydro energy from NHRE. Firstly, hydropower strongly depends on the geographical location and its environmental properties; the region without water flow will have limited capacity to use the power of water. Another factor is that according to some articles, more frequent extreme events like drought due to climate change might affect the generation capacity (Nguyen et al., 2019, Luz et al., 2018). In 2022, the Spanish region of Galicia reduced water generation by 40% due to this reason (Eléctrica, 2023). Secondly, hydro energy projects might have more negative effects on society compared to NHRE projects. A dam's construction leads to land submerging, especially in large projects, which means local communities residing on these lands have to be relocated, and this has been found to affect their welfare (Sayektiningsih and Hayati, 2021). Furthermore, hydro projects also might increase social damage when facing natural disasters (Aureli et al., 2021). For example, in 1975, the Banqiao Dam and 61 other dams collapsed due to heavy rain from Typhoon Nina in Henan province, China, resulting in a significant loss of lives and millions of people losing their homes. Thirdly, hydro projects deeply impact the environment and may pose risks to ecosystems. The hydro generation project will significantly change the hydrological regime (Cejka et al., 2019, Wang et al., 2013, Xie et al., 2015). For example, research showed that the Gabčíkovo hydroelectric power barrier on the Danube River damaged or affected more than 230 KM^2 wetlands and the local original ecosystem. Moreover, hydro projects also might lead to other problems, such as decreasing water level downstream (Xie et al., 2015), increasing upstream temperature, increasing greenhouse gas emissions and reducing water quality (Wang et al., 2013). Finally, hydro projects have competing economic impacts. On the one hand, Hydropower provides low cost and sustainable energy to society. On the other hand, hydro projects need a dam to be built and filled with water to produce energy. It means that hydro projects require higher investment costs (and potential costs, such as social compensation and maintenance expenses) and longer construction phases compared with solar or wind farms (Nguyen et al., 2019).

There are some scholars who do not support NHRE deployment as a primary global strategy. One point they raise is that the cost of the process of global NHRE deployment is unacceptable as this amount of money could help human society solve more significant and urgent problems. As Lomborg argues (Lomborg and Robinson, 2019, Lomborg, 2018), climate change is a problem that can be solved with the advent of technological breakthroughs. Therefore, he suggests that funds would be better invested in other fields with greater needs, such as education and health. Additionally, Lomborg contends that the negative impacts of global warming have been exaggerated (Lomborg, 2007).

However, Howard Friel disputes Lomborg's arguments (Howard, 2010). He found Lomborg has used unverified data to persuade the public that the consequences of climate change are not serious. Research indicates that policy initiatives, like the international low carbon framework (Intended Nationally Determined Contributions framework of the Paris Agreement), can stimulate technological and innovation improvements (Anbumozhi, 2017). This is because green technology is more likely to improve more quickly with political encouragement, rather than just through market forces. Other scholars recommend that the sustainable policy should balance social and environmental considerations in the energy transition process (Delafield et al., 2021). They claim that it is necessary to establish a framework to balance attention between net zero CO2 emissions and other social problems. Another viewpoint is that the concept of renewable energy is not clear yet and that energies should be conceptualized not only by carbon emission but also by the amount of carbon emission in their generation to avoid misleading policymakers (Harjanne and Korhonen, 2019).

There are also researchers and agencies that support the deployment of NHRE for a number of reasons. The most basic advantage is reducing the carbon intensity of the electric sector. NHRE is considered the most efficient way to reduce emissions and meet the increasing demand (GEA, 2013). The decreasing of NHRE price due to technological improvement might also help reduce the cost of energy to consumers. Except for some regions (like Japan and Russia, Figure 3), in most of the regions, the NHRE price is more competitive than fossil fuel based energy (IEA, 2020), especially onshore wind and solar PV. At the same time, the NHRE could improve energy accessibility for the regional or remote settlements (IPCC, 2011). For example, villages or settlements out of the range of conventional energy electric transmission could access power through photovoltaic (PV) solar panels or wind generation. Furthermore, the diversion of energy generation could improve the power network stability. The conventional energy market fluctuates due to many complex factors, which sometimes reduces the affordability of energy. In contrast, the NHRE generation only depends on relevant resources (mostly water or sunshine) which could help reduce the energy market effects by policy, finance or other reasons (Seriño, 2021).

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Figure 3: The levelized cost of energy generation for different power technologies in different regions (IEA, 2020b)

2.2 Current situation and potential of NHRE

This chapter introduces the recent condition and trend of NHRE worldwide and in Australia. Recent policy changes and issues of international energy security led to NHRE rapid deployment. A significant factor increasing NHRE is the war in Ukraine due to Russia's invasion. It led to disruptions of fossil fuel lines that not only led to the price of international crude oil and natural gases rising sharply but also brought attention to energy security. For example, the European Commission released the REPowerEU plan two months after the invasion of Ukraine, aiming to replace Russia's fossil fuel dependence with NHRE by 2027 (IEA, 2023d). Thus, international conflict has accelerated the NHRE development in recently years.

According to the findings of IEA's sustainable energy report 2022 (IEA, 2023d), NHRE deployment will grow significantly. The report indicates that wind electricity capacity is forecast to double in 2027 compared to 2018 (see Figure 4). The solar PV installed power capacity is also forecast to double by 2027, surpassing coal as largest energy resource. Furthermore, the report pointed out that India, China and the United States have all announced that they will double sustainable energy capability over the next 5 years. Producing hydrogen and biofuel (from waste and rubbish) also has opportunities to grow in this period. However, a problem mentioned in this report is that the growth of renewable energy penetration is not fast enough to meet energy demand, and this leads to fossil fuel usage increase.

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Figure 4: Share of cumulative power capacity by technology, 2010-2027 (IEA, 2023c)

Fossil fuel is still the primary source of Australian energy consumption, and coal remains the main source of generation. The Australian government announced that it plans to reduce 43% of Carbon dioxide (CO2) emissions by 2030 and reach net zero by 2050, citing the Climate Change Bill passed in 2022 (Australian Government, 2023f). The rate of coal consumption is decreasing, and renewable energy, gas and oil shows an increasing trend in Australian energy consumption (Australian Government, 2023c). According to the IEA report, the amount of energy consumption by the energy supply sector also increased before the pandemic (see Figure 5). The report of the Australian Office of Financial Management (AOFM) identifies the energy sector also as the largest emission source, contributing 32.8% of Australian emissions from 2021 to 2022 (AOFM, 2022). This report also mentions that the emissions from fossil fuels in Australia are higher than the world average level, but this number will decline as renewable energy penetration rises.

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Figure 5: Australian energy consumption, by fuel type (IEA, 2022)

NHRE penetration has been rapidly increasing in the recent decade. According to the findings of the Australian government's 2023 energy update, renewable energy contributed 35% to total generation in 2022, increasing by 4% compared to 2021. This contribution is planned to climb to 43% by 2030 (Australian Government, 2023c). Another finding highlighted in this report is that wind and solar energy satisfied 100% of demand in South Australia for more than 10 consecutive days and met 85% of demand in the month of December 2022, a world first for a state region level grid.

According to Figure 6, the conventional energy penetration rate in the National Electricity Market decreased from more than 90% in 2011 to 65% in 2022. In the same decade, NHRE penetration increased. Rooftop solar PV was less than 1% in 2011 and rose to nearly 10% in 2022. Utility solar PV development started in 2017, and grew fast in the past 5 years, boosting total solar energy to 13% of electricity generation (Australian Government, 2023c). Wind power rose from less than 5% to more than 10% in this period. As the report mentioned above, the Australian bioenergy generation source mainly is bagasse, the pulpy fibrous waste material from the sugar industry, but the rate is declining.

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Figure 6: Renewables generation share in the National Electricity Market 2011 to 2022 (Australian Government, 2023f)

Although the national energy demand is predicted to rise by 8% in 2030, the Australian government projects that the renewable rate will increase to 83% (Australian Government, 2023f). The Australian Energy Market Operator (AEMO) has the ambitious plan to deploy all NHREs investment and development projects plan in REZs that aim to fill the gap after coal-fired power stations retire (AEMO, 2021a). According to the AEMO report in 2021, there were 35 REZs and 4 Offshore Wind Zone on the candidates list (Figure 7), and which together would increase electricity generation seven-fold (see Figure 8).

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Figure 7: REZs candidates (AEMO, 2021a)

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Figure 8: Projected utility-scale VRE in REZ for the NEM, the transmission network capacity to facilitate (AEMO, 2021a).

Solar energy is the least costly option to most countries for new energy (IEA, 2023c), and it plays a vital role in mitigating global warming. Solar energy is commonly classified into two scales: large scale and small scale. The definition of scale varies by country. In Australia, small-scale solar is defined as solar generator systems with a capacity of less than 100 kW (Australian government, 2023d). The majority of small-scale solar installations consist of rooftop PV solar panels on residential buildings. The solar farm is the most common large scale solar project with PV technology. According to Figure 8, solar energy will be rising worldwide, the IEA predicts that solar energy, with its increasing installed power capacity, will become the world's largest energy source meeting the requirements for net-zero emissions. (IEA, 2023c). Australia has more than 3.5 million dwellings with roof Solar PV panel installed which is one-third of all dwellings (Australian Government, 2023e). South Australia reached a world first when in October 2020, it met its entire electricity demand for one hour through only solar energy (AEMO, 2020a).

However, although solar PV as a new technology has reached outstanding achievements, some problems have been raised. One study showed that the building environment might pose limits for roof solar instalment (Poruschi and Ambrey, 2019). For example, people who live in apartments or units and people who live in houses shadowed by a tall building might not reap the benefit from a roof solar panel. The potential costs of solar energy, including

Battery or other storage solutions must also be taken into account, as they can increase overall costs. Additionally, the lifespan of solar panels can affect potential costs, particularly in extreme environments like deserts where they may need replacement approximately every 25 years.

Wind energy is another key resource in combating emissions and addressing climate change. Onshore wind power is a mature technology capable of generating clean and affordable electricity. According to Figure 8, Australia's wind power installation capacity has continued to grow over the past decades. This is partly due to Australia having one of the best wind resources in the southern hemisphere (Australian Government, 2023g). The cost of offshore wind power generation is higher than some other energy sources, which has led to slower deployment of offshore wind projects. However, it remains a promising industry due to the presence of many strong wind locations near the coast. Wind power accounted for 11% of electricity generation in Australia during 2021-2022, with South Australia being the most wind-dependent state at 44% (Australian Government, 2023b). Every additional gigawatt of wind capacity connected to the Australian National Electricity Market (NEM) is expected to reduce wholesale power prices by 11 AUD per megawatt-hour (Csereklyei et al., 2019). However, wind power faces several challenges. The intermittency and variability of wind power may affect grid stability (Hallgren et al., 2014a). Additionally, wind turbines can have adverse effects on wildlife and generate noise (Saidur et al., 2011).

2.3 Factors affect the deployment of NHRE

Numerous factors can influence NHRE deployment and may vary between developing and developed countries. Research indicates that in developing countries, factors such as economic conditions, high income per capita, policies, and education positively affect NHRE development (Pfeiffer and Mulder, 2013; Seriño, 2021). Additionally, foreign direct investment plays a role in promoting NHRE development (Ma et al., 2022). Ma and colleagues' research suggests that stock markets and bank intermediaries have a positive impact on NHRE diffusion in both developing and developed countries. Conversely, factors such as oil prices and the share of hydropower electricity generation primarily influence NHRE diffusion (Lin and Omoju, 2017, Seriño, 2021). As an example, the Vietnamese government faced challenges in supporting NHRE development due to financial constraints, which significantly impeded the growth of NHRE in the presence of low-cost hydropower electricity (Nguyen et al., 2019).

The factors that have accelerated NHRE growth in Australia in recent years include investments, policies, and the decreasing costs of NHRE. With increasing public awareness, Australia began the process of retiring fossil fuel-based power generation in the last decade, and this trend is expected to continue in the coming decades, as reported by the Reserve Bank of Australia (Atholia, 2020). This shift is contributing significantly to the growth of both large and small-scale NHRE. The findings in this report reveal that between 2016 and 2019, large-scale NHRE investments accounted for approximately 5% of total Australian non-mining business investments, with the private sector playing a substantial role. The primary large-scale NHRE investments have been evenly distributed between wind and solar farm projects. Government policy also propelled the investment into the NHRE industry. The federal policy announced the Renewable Energy Target (RET) which encourages electricity retailers to improve renewable energy penetration through large-scale generation certificates (LGCs). LGCs can be sold and transfer to other companies which increases the profit for the companies that have higher renewable rates. States and territory governments also have specific policies to increase NHRE penetration, such as their own RET and reverse auctions (NHRE project bid for power supply contracts with the state government). The main driver of small-scale NHRE investment are households, with about one-third of Australian households having installed roof solar panels (Mercer, 2022). Government policy has accelerated this increase, including small-scale technology certificate scheme and state-based Feed-in-Tariffs (FiTs). As fossil fuel-based energy prices increase and NHRE costs decrease, NHRE has become more competitive over the past decade and is expected to remain so in the future, as illustrated in Figure 9.

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Figure 9: Electricity generation levelized cost projections ($ per MWh) (Upham and García Pérez, 2015)

2.4 Conclusion

Global society needs to reduce greenhouse emissions to protect the future for ourselves and the next generation. Promoting sustainability in the energy sector is a significant pathway to achieve a low-carbon emissions scenario. The concept of NHRE was introduced due to the high project costs, potential risks, environmental impacts, and regional characteristics of hydropower. While a few scholars disagree with the deployment of NHRE as the primary policy, it is widely agreed that developing NHRE is an effective way to reduce emissions and meet the increasing electricity demand, as recognized by academia and the international community. The global trend of NHRE has shown significant growth over the past decade, particularly in solar and wind power, with rapid deployment also occurring in Australia. Conversely, the use of fossil fuels is gradually decreasing. Solar and wind energy are two main components of NHRE, both of which play a vital role in reducing emissions. Solar energy can be categorized into large-scale and small-scale installations. One of the most common small-scale methods is rooftop solar PV, which promotes decentralized energy generation and improved household-based energy production (decentralized). In most countries, NHRE energy can offer lower-cost alternatives to fossil fuels, and as technology advances, costs are expected to become more competitive. The diffusion of NHRE is influenced by many factors. The lack of funds is one of the barriers to NHRE deployment in developing countries. The low-cost other energy due to regional abundant fossil fuel energy and hydropower also might impact NHRE industry development. In Australia, the low cost is one of the main reasons attracting investment into the NHRE industry, and government policies are also contributing to increased project deployment.

CHAPTER 3. NHRE POLICY SETTING AT FEDERAL AND STATE LEVEL

3.1 Federal and State Policies on Renewable Energy

Australia is one of the first countries to use the Renewable Portfolio Standard system (RPS) to regulate the energy mix. The RPS system is a policy that requires electric utilities to obtain a certain percentage of their electricity from renewable energy sources by a specified date. In Australia, the Federal government uses the Renewable Energy Target (RET) as an Australian-specific RPS scheme to design the renewable target of the nation, aiming to reduce emissions and increase the penetration of renewable energy. The first RET was set in 2001 to at least 20% renewable penetration in the energy sector by 2020. According to the most recent update in 2022, the RET is set to 82% by 2030 (DCCEEW, 2022). Furthermore, carbon dioxide emissions are targeted to reduce by 43% by 2030 and reach net zero by 2050 (Australia Government, 2024c).

Renewable Energy Certificates (RECs) are the primary policy instrument used to achieve the RET. The Federal Government uses RECs to regulate the rate of renewable energy penetration in the National energy market (NEM) through a series of regulatory systems. In Australia, the REC is a means to achieve the renewable penetration requirement of RET in NEM. This policy was announced in 2001 with RET. A REC is created for each megawatt-hour of renewable energy produced or saved and the renewable generator and saver received it. These certificates are tradable, allowing the environmental benefits of renewable energy to be bought and sold in the market. Generators are required to provide RECs to meet their renewable energy obligations. These obligations mandate that generators surrender a certain number of RECs, proportional to their electricity consumption during the year (Clean Energy Regulator, 2015). If liable entities fail to meet the required number of RECs, they will be charged AUD 65 for each missing certificate. Thus, the fossil fuel generators must buy the RECs from the market or other renewable generators each year. As a result of the policy, fossil fuel power generators face increased production costs, while renewable energy generators receive more income from each unit of energy production. Thus, due to the cost increase, the fossil fuel energy investor might turn to the renewable energy industry, but the fossil fuel generator also might increase production to cover the cost (Currier, 2015).

The REC policy successfully helped stimulate Australia's renewable energy installed capacity. This is especially true for bioenergy and wind energy because they are relatively mature technologies with lower generation costs. In contrast, the solar energy industry did not benefit due to higher energy prices compared to other renewable energy sources before the technology matured (Buckman and Diesendorf, 2010). However, some factors might influence the effectiveness of this policy to reduce carbon intensity. For example, the Waste Coal Mine Gas power stations, a kind of power plant that consumes the gas that captured from the coal mining process, are eligible to apply for large-scale REC certification due to it believed reduce the greenhouse gas emission to the atmosphere (Byrnes et al., 2013). It is unusual for a power plant like Waste Coal Mine Gas, which is typically not considered renewable because burning methane releases carbon dioxide, to receive RECs and be included in the RET for renewable energy penetration rate. According to the 2021 Coal mine waste gas variation, this kind of power station is eligible to receive the RECs at least until 2026 (Clean Energy Regulator, 2023). Liam et al. (2013) suggested that creating specific certificates for different types of renewable technologies based on their maturity could help emerging technologies enter the market and improve policy effectiveness.

The relationship between the federal and state governments in Australia regarding energy policy involves a combination of shared responsibilities, individual initiatives, and occasional conflicts (Cheung and Davies, 2017). The federal government provides national policies, incentives, and funding for large-scale renewable energy projects. The federal regulator sets the RET for the energy sector, allowing state governments to adjust their specific resources, capabilities, and set their own targets. For example, the South Australian RET is further advanced than the national target. Moreover, the federal government typically supports research and development in renewable energy technologies, benefiting states by providing access to new technologies and expertise. The Hornsdale Power Reserve which was mentioned before received funding from both levels of government.

However, conflicts can arise between the two levels of government due to several factors. Conflicts may occur when policies are not aligned. For example the federal government criticized South Australia's aggressive renewable energy policies, arguing that they led to state-level blackouts in 2017, as discussed later. Additionally, economic interests, such as the presence of traditional energy industries (Byrnes et al., 2013), and political ideologies between the Labor party and the Coalition might lead to different approaches to renewable energy between federal and state governments. For example, the carbon tax was introduced in 2012 and ended only 2 years later. Furthermore, the federal policy uncertainty may limit sustainable energy transition (Warren et al., 2016).

Numerous scholars broadly agree that there is a barrier to energy transition at the national level (Byrnes et al., 2013, Meya et al., 2016, Cheung and Davies, 2017, McGreevy et al., 2021, Kallies, 2021, Nelson et al., 2022). Grace Cheung and Peter J. Davies argue (2017) that the political group based on the economics of the low-price fossil fuel industry continually shaped Australian policies to mitigate climate change in both major political parties in the past two decades. They also evaluated recent prime ministers (PM), finding that the PMs from the liberal party were considered more conservative on the issue of climate change. For example, Coalition PM Howard refused to ratify the Kyoto Protocol and Coalition PM Abbott withdrew the carbon price policy after Labor PM Gillard announced it two years later. However, there were still differences between the two Coalition PMs. PM Howard did not engage in international cooperative efforts to address climate change, but he contributed to national-level actions such as establishing NEM, announcing RET and REC schemes, funding renewable energy projects and technologies, and encouraging private renewable energy investors. Coalition PM Abbott, a self-confessed climate change sceptic and pro-coal advocate, refused to join international climate action and reduced the funds to climate research and wind farm projects. In contrast, the Labor Party is more progressive on the issue of climate change. PM Rudd and PM Gillard pushed Australia to join international cooperation, updated RET, passed the Clean Energy Act 2011, established an energy secure fund to replace fossil fuel, and announced several policies for energy transition, such as Solar panel rebates, Green Loans, FiT, and carbon tax. After breaking the ice, Australia signed the Paris Agreement in 2015, under Turnbull government, committing to reduce its greenhouse gas emissions by 26-28% below 2005 levels by 2030. Subsequently, at COP26 in Glasgow, the Australian government committed to updating its Nationally Determined Contribution to achieve net-zero emissions by 2050. Nevertheless, Liam et al (2013) concluded that political conflicts diminished the effectiveness of existing policies.

In this context, South Australia achieved remarkable milestones despite national climate policy being stalled (McGreevy and Baum, 2021a). As public environmental awareness rose, the Labor Party took power after the 2002 state election and stayed in government until 2018. In 2002, the South Australian Labor government set a target for 26% renewables generation by 2020. After long-term stable policy implementation, the penetration rate of None-hydro renewable energy (NHRE) in South Australia's electricity grid reached 52%

(AEMO, 2020b) by 2018. Moreover, when the Labor government lost office to the Liberal party, the transition was well advanced, and the new Liberal government embraced the renewables transition, setting a target for 100% renewable electricity by 2030. The Federal and state party ruling terms and the policy announced are summarized in Table 1. In contrast, the Labor Party government has shown more positive on environmental issues, enacting more policies, whereas the Coalition tends to be more conservative.

Australian Federal Government		
Election year	**Federal ruling party**	**Policy**
2001	Coalition	RET and RECs (2001)
2004		
2007	Labor	carbon tax (planning: 2007 released:2012)
2010		
2013	Coalition	withdraw carbon tax (2014)
2016		
2019		
2022	Labor	Update RET to 82 % by 2030 (2023)

South Australian State Government		
Election year	**State ruling party**	**Policy**
2002	Labor	State RET (2002) State FiTs (2008)
2006		
2010		
2014		
2018	Coalition	
2022	Labor	REZ state plan by AEMO (2022)

Table 1: Political party ruling terms and the energy transition policy announcements at Federal and South Australia.

The renewable energy transition in South Australia's energy sector was not without critics. The majority of criticism center on the blackout in 2016 (Byrnes et al., 2013) and high electricity prices between 2014 and 2018 (McGreevy and Baum, 2021b). Six months after a blackout in South Australia, then federal treasurer Scott Morrison brought a lump of coal into parliament and criticized South Australia's transition to renewable energy. He accused the SA government for being overly aggressive in its pursuit of renewable energy and causing instability in the electricity grid. This, he said, was causing economic problems and hardship: "Switching off jobs, switching off lights, and switching off air conditioners, and forcing Australian families to boil in the dark as a result of their Dark Ages policies" (Parliament of Australia, 2017). Michael McGreevy and Fran Baum suggest that in response to these criticisms, the South Australian Government published a new energy plan and new wind farm security standards (South Australian Government, 2017). This report posited that South Australia would reduce reliance of its grid on imported energy from NEM and increase the grid stability through such as establishing large battery capacity, attracting more renewable energy investors, and establishing new power plants.

3.2 FiTs policy in South Australia

Capitalizing on Australia's rich solar energy reserves, as depicted in Figure 10, solar power generation is on track to become a pillar of Australia's NHRE. Accordingly, the feed-in tariff (FiT) policy, designed to promote small-scale solar projects, is gaining widespread implementation across various jurisdictions.

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Figure 10: Australia Solar Power Density Map (The World Bank, 2020)

FiTs are a subnational policy in Australia. As the Federal government does not have national-level FiT rates and policies, the rates and applicability are decided by state or territorial governments. First South Australia and then Queensland started implementing FiT policies in 2008, South Australia started preparing this policy in 2006. The Australian Capital Territory, Victoria followed suit in 2009 adopting similar programs. Western Australia commenced in August 2010. New South Wales introduced a Solar Bonus Scheme, a type of FiT, in 2010. Although the Northern Territory has not established a FiT policy, it designated Alice Springs as a Solar City in 2006 and has progressively introduced policies for selling energy similar to FiTs in additional regions. As a result of Australia's federal structure, there is variation in the policy across different regions. Since the policy began, the tariffs have ranged from 8 cents to 60 cents per kilowatt-hour in different Australian states and territories (Byrnes et al., 2013). These incentives were initially aimed at small systems but have generally been reduced or phased out, with exceptions in remote areas. The FiTs policy has significantly boosted the adoption of small-scale solar Photovoltaics (PV) systems. According to Figure 11, after the FiTs policy, the small-scale solar PV installations increased from less than 50,000 to more than 350,000 in 2021. In 2021, South Australia had around 45% of households equipped with rooftop solar panels, in the leading position compared with the other states and territories (IEEFA, 2021).

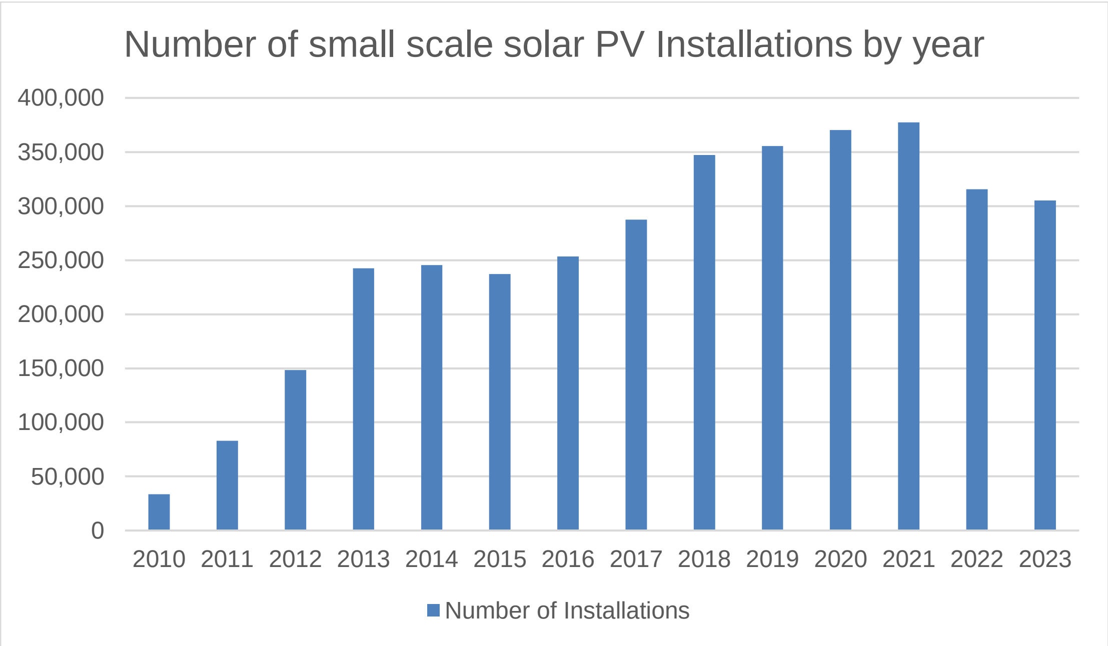

Figure 11: Number of small-scale solar PV Installations by year in Australia (data source: Clean Energy Regulator)

The FiTs policy enables small-scale renewable energy generators, such as solar PV or wind power systems, to connect to the NEM and sell any excess electricity generated. The amount of electricity fed back into the grid is typically measured using a special meter capable of recording both the inflow and outflow of electricity (Australia Government, 2024a).

According to Table 2, the South Australia FiTs policy is divided into 4 periods. After entering Group 4 period, the FiTs no longer receive funds from the state government. Instead, the FiTs rate is determined by the retail companies. Consumers who generate excess electricity and feed it back into the grid receive credit from energy retail companies. These credits are applied to their electricity account to offset their electricity bills.

FiTs Group	**Contract Period**	**Rate paid**	**Program duration**
Group 1	1 July 2008 to 31 August 2010	44c per kWh and retailer feed-in tariff	until 30 June 2028
Group 2	1 September 2010 to 30 September 2011	44c per kWh (Maximum 45 KW) and retailer feed-in tariff	until 30 June 2028
Group 3	1 October 2011 to 30 September 2013	16c per kWh and retailer feed-in tariff	ended on 30 September 2016
Group 4	After 1 October 2013	Same as the retailer feed-in tariff	N/A

Table 2: South Australia's FiTs groups and rates (South Australian Government, 2023b)

The FiTs policy has faced criticism for creating issues related to equity, network stability, and efficiency, primarily because it only focuses on small-scale generators which is unfair to owners of larger-scale solar projects (Byrnes et al., 2013). Additionally, the policy has been criticized for social justice concerns. Research on the effective tax of FITs has shown that low-income households end up paying three times more than wealthier households, because they are unable to afford the roof solar system installation (Nelson et al., 2011). To address these concerns, Liam Byrnes et al. (2013) suggest that the FITs policy should be extended to cover larger-scale projects, such as commercial-scale solar farms. Adjustments could be made based on the maturity of the technology, which could foster a more equitable and efficient development of renewable energy. This approach could also provide more investment certainty for larger projects and facilitate better integration into the grid, potentially addressing issues of network stability.

While criticisms regarding the fairness and justice of the FiTs policy exist, its impact on cost distribution and benefits within the South Australian energy network deserves discussion. In South Australia, the costs associated with FiTs are distributed across the entire grid, with the government providing subsidies for households installing rooftop solar photovoltaic (PV) systems. Some argue that the policy is unfair because the costs of FiTs are evenly distributed across all consumers' electricity bills. However, the widespread deployment of these decentralized generation networks enhances the overall reliability of the power grid. Additionally, during sunny periods, rooftop solar PV systems contribute significantly to the electricity supply, effectively reducing daytime electricity prices to very low levels. This price reduction benefits all users, making electricity more affordable. Consequently, the extensive adoption of rooftop solar PV systems, driven by FITs, has made electricity more accessible and affordable for consumers.

3.3 Wind power policy in South Australia

Wind power is a major energy source in South Australia (Department for Energy and Mining, 2023). Before large-scale solar technology in South Australia became more cost-effective than wind power in 2022 (Li et al., 2020), wind farms were the mainstream of renewable energy investments. Several factors contribute to South Australia's leadership in wind power generation deployment. The first is the abundant wind resource. Figure 12 shows that South Australia possesses exceptional wind resources, especially around the coastline and inland areas, making it a world-class location for both onshore and offshore wind power generation (Shafiullah et al., 2012).

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Figure 12: Australia Wind Power Density Map (Technical University of Denmark, 2021)

The second reason is the low population coastline. South Australia is known for its long and sparsely populated coastline, stretching over 3,800 kilometres, which offers prime locations for the deployment of wind farms. Notably, regions such as the Eyre Peninsula and the Yorke Peninsula are considered highly suitable for the establishment of wind energy projects. The state is already host to numerous operational wind farms, wind energy predicted meso-scale wind speeds above 7.3 meters per second and wind farm locations shown in Figure 13, while the size of location circles represents the wind farm's generation capacity (South Australian government, 2022e).

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Figure 13: Wind energy and wind farm locations in South Australia (South Australian government, 2022e)

The third reason for South Australia's rapid progress in the deployment of wind farms is public awareness. The growing environmental awareness among local communities was driving the state government to respond in terms of policy and political measures. South Australia's energy policy heavily incorporates public consultation. For instance, while shaping the energy transition Green Paper for the next 30 years, the South Australian government sought input from all South Australian (South Australian Government, 2023c).

In 2012, the state government released the Statewide Wind Farm Development Plan Amendment (DPA) (South Australian Government, 2022f), which sets standards for wind farm deployment. The DPA outlines criteria for wind farm placement, including setback distances from dwellings, uniform turbine appearance, and vegetated buffers around ancillary structures. Wind farms are encouraged in rural zones but must manage visual impact and minimize effects on nearby properties and wildlife. This series of policies facilitates local communities' understanding of the impact of wind farms on their lives and environment while also reducing unnecessary potential conflicts for investors.

Moreover, after amending the Pastoral Land Management and Conservation Act 1989 to include Division 4 — Wind Farms in September 2015, NHRE investors gained sponsorship eligibility on crown land and could negotiate directly with pastoral lessees for wind farm deployments (South Australian Government, 2022b). Furthermore, the state government encourages corporations to purchase renewable energy directly from NHRE generators through Power Purchase Agreements (PPAs). For example, For example, BHP signed a PPA with Neoen in 2002, under which Neoen will supply half of BHP's Olympic Dam mine's electricity needs from its wind farms by 2026. In return, BHP will support the construction of the Goyder South Stage 1b wind farm, which is part of the Goyder REZ, for Neoen. South Australian local governments have also purchased renewable energy through PPAs (IGA, 2019) These series of policies have contributed to the increase in NHRE investment in the state.

Another reason why SA promoted wind energy. High electricity prices have prompted South Australia to explore alternative pathways to reduce its reliance on fossil fuel generation. According to Figure 14, South Australian power prices were generally higher than some other Australian states before the renewable energy transition. Especially in the late 1990s and early 2000s. Thus, the state government had the motivation to explore a new source of low-cost energy to replace the traditional generation system.

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Figure 14: The spot electricity price from 1999 to 2004 by states (data source: AEMO)

3.4 Conclusion

This chapter has examined the energy policies and political contexts of both Australia and South Australia. At the federal level, Australia primarily implements the RET policy, enforced through RECs. This policy mandates that non-sustainable energy producers promote the sustainable transformation of the energy sector by purchasing certificates from sustainable energy producers. This mechanism ensures compliance with the RET and fosters a shift towards more environmentally friendly and sustainable energy practices across the nation. However, inconsistencies in the attitudes towards energy transition between the Labor party and the Coalition have led to ambiguity in federal energy transition policies. Political disagreements between the major parties have hindered the federal government's ability to enact consistent policies over the past two decades, impeding further decarbonization of the energy sector. This political turbulence has even impacted the ability of state governments to implement their own energy transition plans effectively. The lack of a clear and stable federal directive complicates efforts at the state level, as state governments may struggle to align their initiatives with the shifting priorities and policies at the national level.

In South Australia, the prolonged dominance of the Labor party enabled a relatively cohesive approach to transitioning to renewable energy Beginning with FITs, which were later adopted by other state governments, the proportion of Australian households installing rooftop solar systems increased rapidly in South Australia and across the country. Additionally, the South Australian government implemented measures such as sponsoring Crown Land agreements and PPAs to attract wind energy investments and also issued DPAs and guidelines to regulate the development of wind farms. These initiatives have contributed to South Australia's remarkable success in increasing wind energy penetration. The following chapter will detail the achievements, current status, economic impacts, and future strategies of South Australia's transition to NHRE.

CHAPTER 4. SOUTH AUSTRALIA'S CURRENT NHRE SITUATION

4.1 The achievement and current situation of NHRE

South Australia is leading the way in Australia's non-hydro renewable energy (NHRE) transition. According to Figure 15, the electricity generation mix varies significantly across states. Compared to the other states and territories that highly rely on fossil fuel, South Australia and Tasmania's power is majority from renewable energy penetration. Unlike Tasmania, whose energy sector is heavily dependent on hydropower, South Australia has the highest share of NHRE generation in 2022, at 71% which is the highest. Thus, the experience of this state's remarkable shift to NHRE sources is valuable for other regions undergoing energy transition.

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Figure 15: Electricity generation mix in Australian states and territories in 2022. (Australian Government, 2023a)

NHRE contributes significantly to South Australian energy generation. According to the South Australian Electricity Report 2023 (AEMO, 2023), wind power is the largest energy source which contributed 46.9% in 2022 equal to 6,651 gigawatt hours (GWh) up from 44.6% in 2021. Solar power majority occupied the second largest electricity generation source, large-scale solar contributed 8.8% of the total generation mix, increasing by 9,125 MW in 2022. In addition, rooftop solar Photovoltaics (PV) accounted for another 17.7%

combined which rose from 16.5% compared with last year. Natural gas is the third highest energy source contributing 25.4% of electricity generation in 2022 which decreased from 29.5% in 2021. In 2022, this state already owns five large-scale solar farms, 23 wind farms and five large battery systems (South Australian Government, 2022c). The information above and Figure 16 indicate that in South Australia fossil fuel generation units are being replaced by NHRE generators step by step, and this process is speeding up.

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Figure 16: South Australian electricity generation by fuel type, 2016-17 to 2022-23
(South Australian Government, 2022c)

There have been other notable achievements in the NHRE transition process. According to the aforementioned report, due to the rooftop PV penetration rate of South Australia increasing and it is the highest of all states (it is 45% of all dwellings, representing over 362,000 installations), the minimum grid demand is continuously decreasing recent years, it records only 96 MW on Sunday, October 16, 2022. Furthermore, according to the Department of Energy and Mining (South Australian Government, 2022c), the state's electricity demand was met 100% by NHRE for 180 days in 2021, which is roughly half a year. Wind power also played a remarkable role in the state's NHRE generation portfolio, it boasts the highest share among all states and territories and supplies nearly half the energy demand for the state's grid. This all adds up to an impressive achievement: the increase in NHRE penetration from 1% to over 70% in the past 20 years (South Australian Government, 2022c). Meanwhile, the carbon intensity of the South Australian energy sector is continually declining (Figure 17), and the carbon intensity of the electricity sector in South Australia was almost three times lower in 2022-2023 compared to 2015-2016. Furthermore, there was a 14% reduction in carbon intensity in 2022-2023 compared to 2021-2022. These data indicate that the electricity sector in South Australia has made significant progress in reducing carbon emissions.

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Figure 17: South Australian energy generation emissions and emissions intensity (South Australian Government, 2022c)

4.2 Economic and off-grid community impact of NHRE

The transition of the South Australian energy sector also reshapes the economic landscape in this state. The state government has named their energy industry page titled "Leading the green economy" (South Australian Government, 2022c). As mentioned, this region has a high installation rate of a decentralized energy system which could reduce energy bills for households (Best. et al., 2019). Authorities estimate average annual savings of hundreds of dollars per household (South Australian Government, 2022d). Households with solar panels can also sell excess power back to the grid to receive benefits through the feed-in tariffs (FITs) policy. South Australia's Virtual Power Plant is a project to establish a network (organized by the state government, Tesla and retail corporations) to smart control around 40000 decentralized power system in the local dwellings as one to smart trade the power with NEM. This is expected to improve grid affordability and reliability, while also generating profits for its owners. There are two examples of how the virtual power plant increased grid reliability, especially during emergencies. One example is the virtual power plant that supplied power to Port Lincoln when the region faced serious fire conditions in November 2019. In another instance, the network released power to enhance the stability of the state's grid during peak periods when the South Australian network was disconnected from the NEM in November 2019, January 2020, and November 2022.

Relevant industries also receive economic benefits from the transition. Firstly, the Australian government supports renewable energy technologies, including photovoltaics, electricity storage, concentrating solar power, small wind turbines, and energy efficiency products (Godfrey, 2008). These industries have gradually become competitive in the international market, with South Australia emerging as a leader in NHRE. The state government believes that the solar energy, wind energy, and battery industries in this region are well-established. Secondly, although South Australian electricity prices have been high in recent years, the situation is expected to change after more NHRE projects are completed as part of the planned Renewable Energy Zone (REZ). According to the report from The South Australian Productivity Commission, this will lead to a significant decrease in power prices around 2025 (Havyatt. et al., 2022), as shown in Figure 18, and cheap solar and wind energy can help industries reduce their energy costs. Furthermore, the energy transition also helps to promote the growth of various NHRE-relative industries and create jobs in sectors including manufacturing, construction, installation, and maintenance. Recently, the South Australian government released a hydrogen action plan (South Australian Government, 2019). The state government expects that a series of government-led hydrogen projects will not only help create jobs and provide low-cost power for the local community but also boost the regional economy in the future (South Australian Government, 2022c). For example, the South Australian government has announced that in their "Hydrogen Jobs Plan" they will invest in the construction of a world-leading hydrogen power station in Whyalla City, creating thousands of job opportunities.

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Figure 18: Historic South Australian wholesale power price and ISP forecast (Havyatt. et al., 2022)

Finally, according to the hydrogen superpower scenario, planned by the state government (South Australian Government, 2019), NHRE generation will be five times greater than state demand. Thus, interstate or even international renewable energy export will be a significant economic growth pathway for South Australia.

Electricity systems or users that are not connected to the main grid are known as "off-grid." These are usually found in isolated or remote areas where electricity is expensive. This high cost is partly due to the expense of fuel for local generators, which is typically diesel or natural gas. Additionally, the cost is driven up by the need to transport fuel to these locations by truck or ship. Although only 2% of Australia's population resides in off-grid locations, these regional and remote areas account for over 6% of the country's electricity consumption (Australia Government, 2024b). South Australian Government believes that off-grid energy systems offer a significant opportunity for self-sufficient generation, storage, and consumption of renewable energy, especially in remote areas (South Australian Government, 2021). In South Australia, off-grid energy is predominantly generated using diesel, which is costly. This makes the substitution of solar and wind energy attractive due to their lower costs. The state government has several off-grid projects. One of the major projects is the Coober Pedy Renewable Hybrid Power Project, which combines wind power, solar energy, and a battery system to help reduce the power demand from existing diesel power stations. Another project deployed at the Heathgate Resources’ Beverley Uranium Mine, included a modular and relocatable solar PV block and an energy storage system. Moreover, the Remote Area Energy Supply scheme provides electricity to around 3,400 customers across 25 remote townships and Aboriginal Communities.

4.3 South Australia’s future strategy for NHRE

4.3.1 Clean hydrogen energy

The South Australian government intends to promote hydrogen energy as the next-generation energy industry and integrate it with the existing NHRE. NHRE will provide green energy for hydrogen production, while hydrogen energy can provide stable power generation.

Hydrogen can indeed play a significant role in a sustainable energy future. When produced using renewable energy sources, hydrogen can be a clean and versatile fuel. It can be used in fuel cells to generate electricity, as a fuel for transport, and as a raw material in various industrial processes, all without emitting greenhouse gases. This makes hydrogen a promising option for reducing greenhouse gas emissions and adapting to climate change.

Hydrogen's role in the global energy landscape is expanding, driven by its potential to contribute to decarbonization efforts across sectors. As technology advances and costs decrease, hydrogen is poised to become a cornerstone of the future clean energy economy. In its Hydrogen Action Plan the South Australian government set out a strategy for the consumption and exportation of hydrogen as part of the state's energy transition efforts (South Australian Government, 2022a).

In February 2021, South Australia introduced natural hydrogen exploration licenses, showing its commitment to developing green hydrogen produced using renewable energy without emissions (Zgonnik, 2022). In its 2021 Inputs, Assumptions and Scenarios Report, Australian Energy Market Operator (AEMO) outlined five future energy scenarios, including the Hydrogen Superpower scenario (AEMO, 2022). This scenario requires deploying more wind or solar energy and integrating hydrogen into South Australia's energy and economic structure (Guo and Yuan, 2023), bringing benefits such as income and jobs from hydrogen exports, reducing carbon intensity to net zero, and enhancing grid stability by diversifying energy sources. To realize this scenario, it is necessary to reduce hydrogen production costs and deploy the required infrastructure.

4.3.2 Electric Vehicles and decentralised generation systems

The South Australian government is investing in the Electric Vehicles (EV) relative facilities, with the aim of accelerating the adoption of EVs in the future and establishing a statewide EV charging network. Concurrently, smart charging trials are also in progress (South Australian Government, 2023a). EVs help reduce emissions, air pollution and noise to improve resident's lifestyles and the environment. The statewide charging network, which includes 140 electric vehicle charging stations in more than 50 rural areas (see Figure 19), is being constructed with an allocation of $12.35 million to Royal Automobile Association (RAA). This project was initiated in the latter part of 2022 and will be completed by early 2024.

The integration of EVs into the grid through smart chargers represents a significant advancement in enhancing grid stability and efficiency, as well as promoting the reduction of carbon emissions. Smart chargers can enable bidirectional flow of electricity between the grid and EV batteries through vehicle-to-grid (V2G) technology. This not only allows the charger to draw energy from the grid but also enables discharging energy back to the grid when needed, ensuring a balanced and harmonious interaction that minimizes power flow losses and increases grid quality and reliability (Gallardo-Lozano et al., 2012). Smart charging introduces a real-time algorithm that reduces charging costs and enhances grid reliability by managing the discharge during peak times and charging during off-peak times. This approach optimizes the use of electricity and supports a more stable and efficient energy system (Zhang et al., 2018). Additionally, if households use rooftop solar PV to charge EVs, it is essentially free for those more than 40% of South Australian dwellings that have solar panels, saving them a significant amount on energy costs each month compared to fuel-powered vehicles. For these families, their quality of life has improved.

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Figure 19: the statewide EV charging network points (South Australian Government, 2023d)

4.4 Conclusion

This chapter explored the achievements of South Australia in its past energy transitions and the current state of its industry. It argued that SA has accomplished remarkable success in terms of NHRE penetration within the grid, with a significant reduction in natural gas consumption, replaced largely by wind and solar power contributing the majority of electricity to the grid. The energy transition has had profound economic and social impacts on South Australia. The NHRE industry has brought economic benefits to the state, and residents have been able to reduce their electricity bills through the installation of rooftop solar systems. Additionally, off-grid communities in South Australia are upgrading to NHRE systems to make their community grids more cost-effective and lower in carbon emissions.

South Australia's early energy transition has yielded multiple benefits, including mitigating global warming and generating economic advantages. This 20-year state government program has spurred job creation in renewable energy sectors such as wind and solar power, and related industries. Additionally, South Australia’s accumulated expertise in non-hydro renewable energy (NHRE) projects positions it to export this knowledge, aiding other countries in decarbonization and enhancing its international reputation.

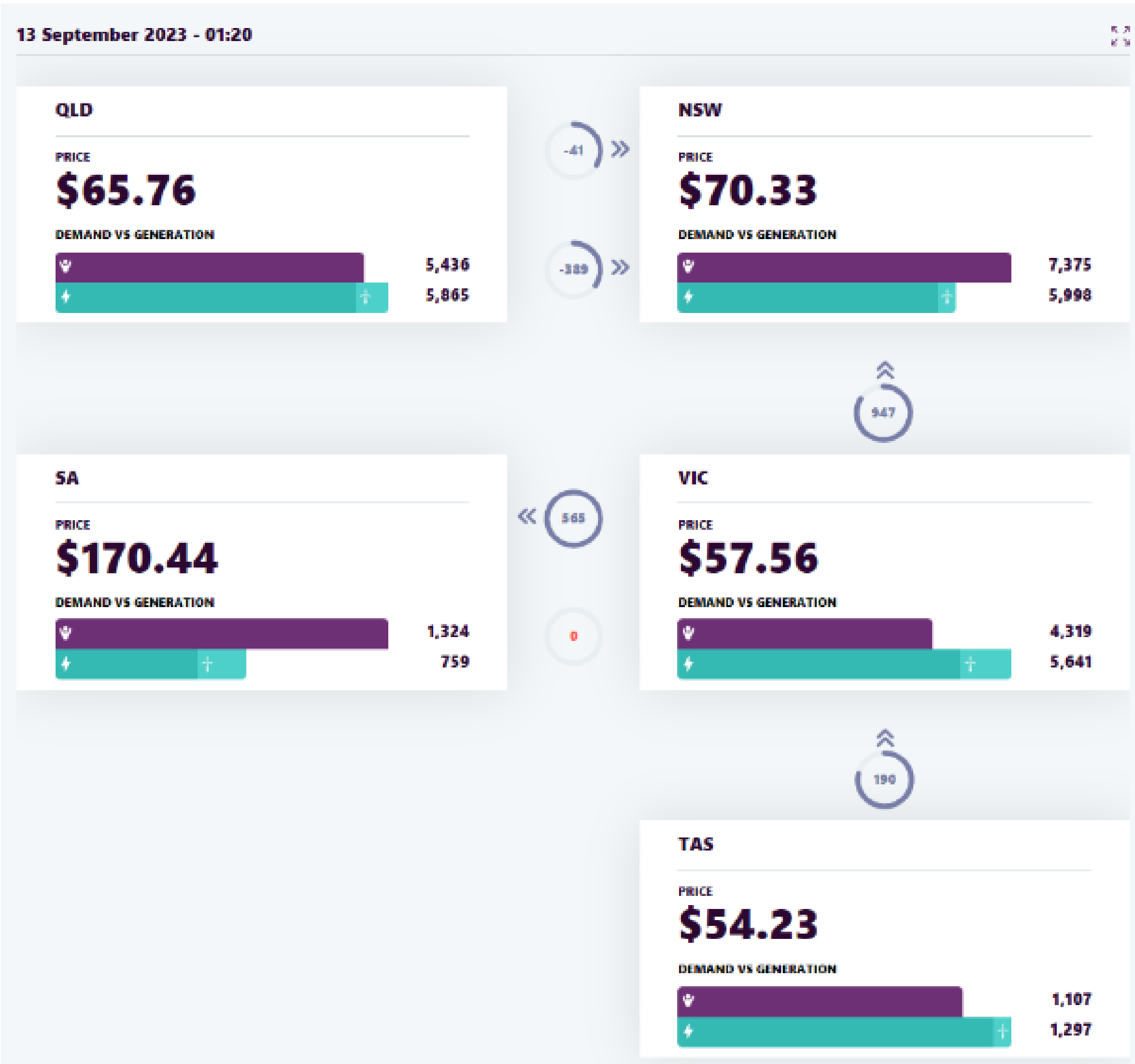
The transition has also significantly changed lifestyles, with a shift from fossil fuels to renewable electricity. The widespread adoption of home solar panels has led to electric appliances replacing traditional gas and coal-based ones. This includes the use of induction cooktops, solar water heaters, and EVs, supported by home solar and battery systems. Innovations like smart charge trials for EV batteries and community virtual power grids are further stabilizing the energy supply and enabling energy trading, profoundly impacting South Australia's economic landscape.

The following chapter will discuss the challenges and opportunities within South Australia's energy transition, exploring how these initiatives align with broader goals for sustainability and how they address the pressing needs of energy security, high electricity price and Renewable Energy Zone (REZ) policy in the region.

CHAPTER 5. THE CHALLENGES AND OPPORTUNITIES OF SOUTH AUSTRALIAN NHRE

5.1 The resources intermittency and energy storage

South Australia is one of the regions with the highest penetration of variable renewable energy sources, such as wind and solar energy (Rai and Nunn, 2020). These variable energy sources can lead to fluctuations in prices within the NEM and may even cause extreme price events. Energy generation is influenced by resource intermittency, and the daily cycle of weather conditions contributes to this intermittency. Variable power generation significantly impacts supply and demand dynamics, which in turn can change electricity prices. For example, according to data from Figure 20, at 01:20 AM on September 13, 2023, South Australia experienced an extreme high price event. This was due to the energy supply meeting only approximately half of the demand, necessitating the importation of electricity from Victoria. The primary cause of this supply shortfall was the intermittency of wind power.



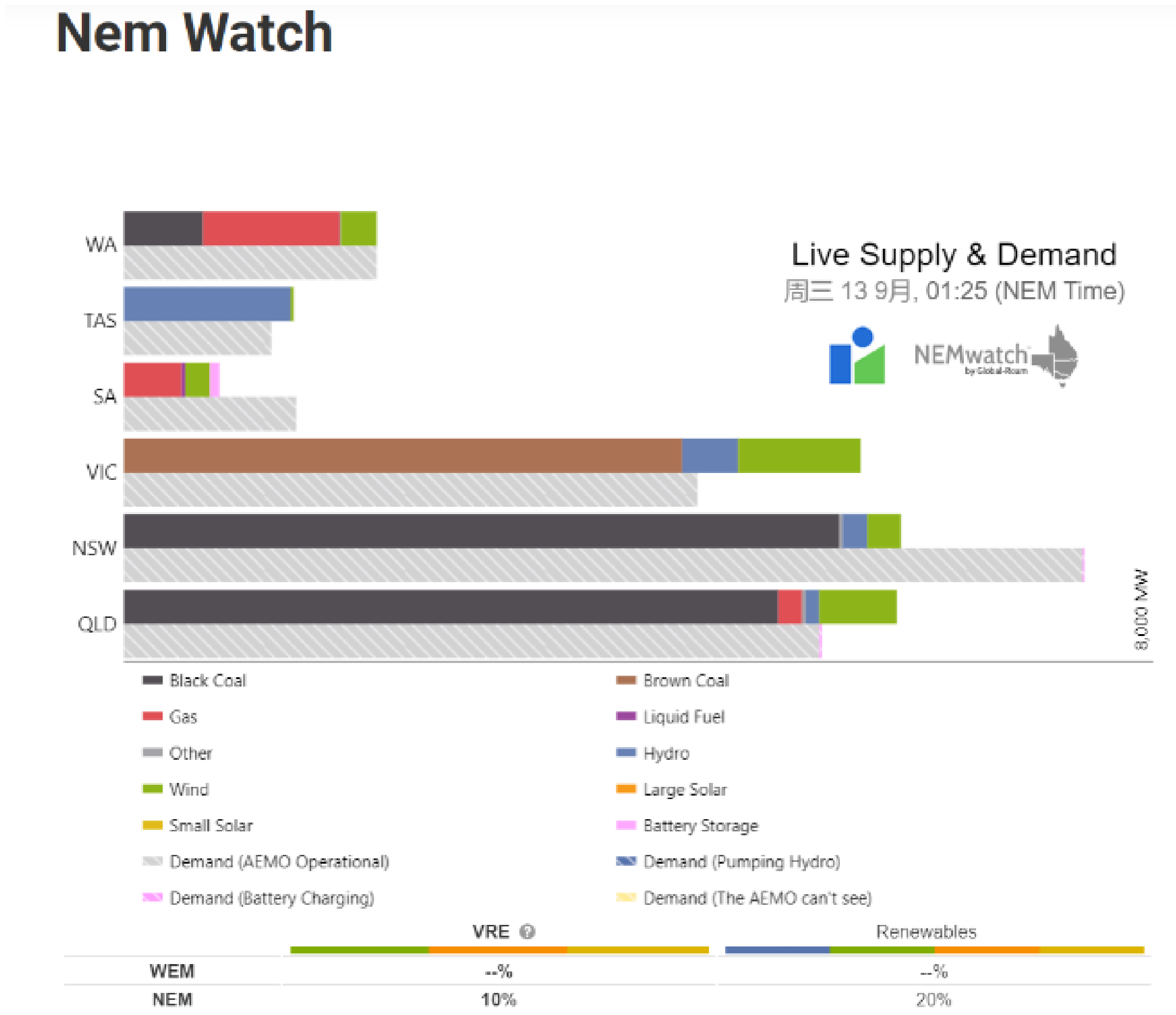
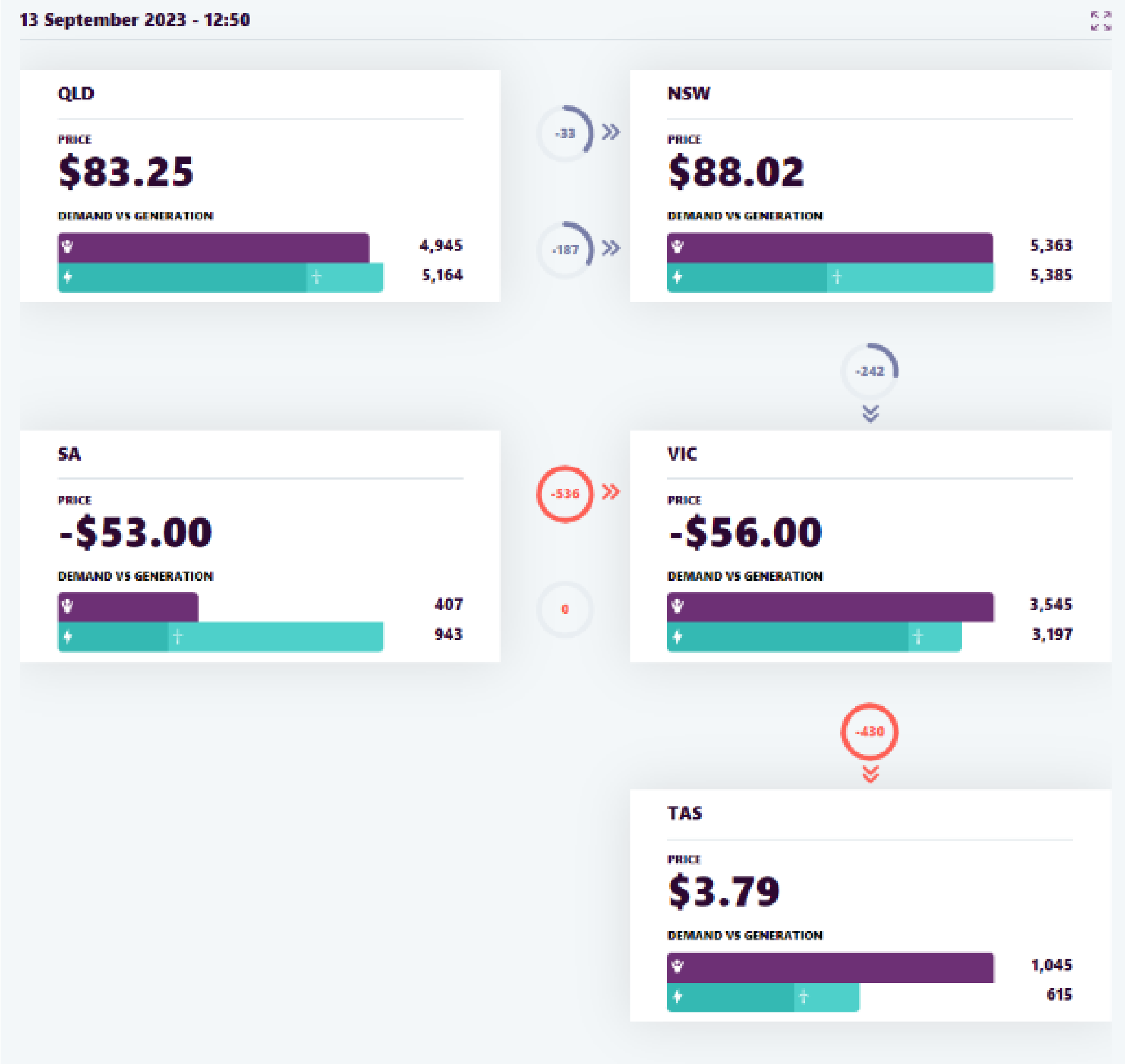


Figure 20: AEMO dispatch overview and NEM supply and demand on 13th Sep. 2023 (Data source: AEMO and NEM)

On the very same day as the high price event, South Australia experienced a significant low-price event (Figure 21). On September 13, 2023, at 12:50 PM, robust wind and solar resources enabled South Australian power stations to inject a substantial volume of electricity into the grid. This surge in supply not only precipitated a marked reduction in electricity prices within the state but also facilitated electricity exports to Victoria and Tasmania, thereby exerting a downward pressure on prices in these regions as well. Frequent fluctuations in energy supply pose a significant challenge to grid stability.



13 September 2023 - 12:50
QLD
PRICE
$83.25
DEMAND VS GENERATION
4,945
5,164
-33
-187
NSW
PRICE
$88.02
DEMAND VS GENERATION
5,363
5,385
-242
SA
PRICE
-$53.00
DEMAND VS GENERATION
407
943
-536
0
VIC
PRICE
-$56.00
DEMAND VS GENERATION
3,545
3,197
-430
TAS
PRICE
$3.79
DEMAND VS GENERATION
1,045
615

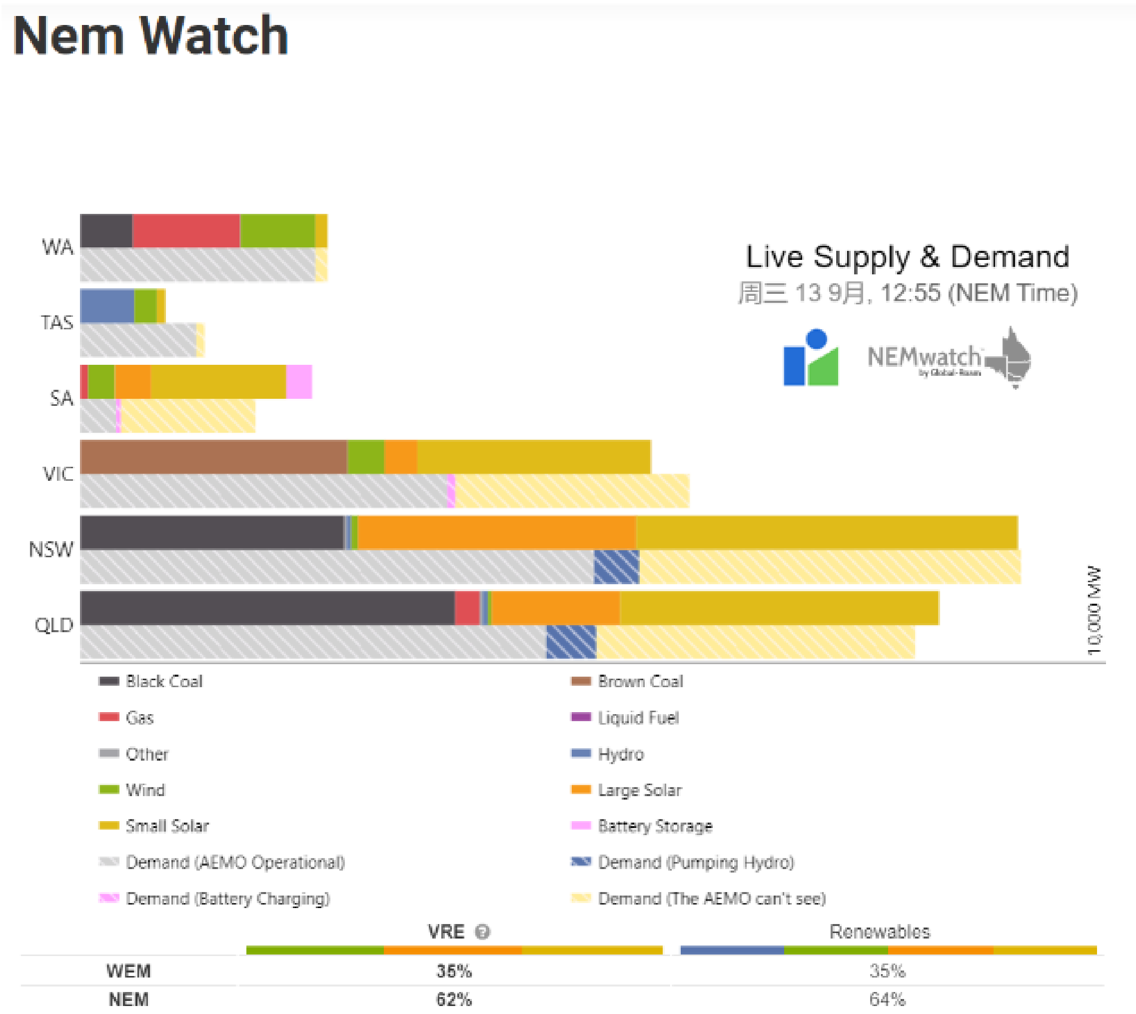


Figure 21: AEMO dispatch overview and NEM supply and Demand in 13th.Sep. 2023 (Data source: AEMO and NEM)

In Australia, wind speed, measured in meters per second (m/s) (see Figure 12, p. 26), is the conventional physical quantity used to describe wind energy potential. Although most studies characterise the central tendency of wind resources using the mean wind power density, this approach has limitations. Specifically, focusing solely on the total mean wind power density can lead to the oversight of critical factors such as wind intermittency, variability, and temporal distribution. These elements are vital as they can significantly affect energy generation capabilities (Hallgren et al., 2014b). Heard et al. (2015) critique the limitations of wind power in South Australia, highlighting challenges such as variability and the reliance on a coal-intensive grid (regular import of electricity from Victoria when wind generation low or unavailable, this could undermine decarbonization efforts), despite the state's significant investments in wind-generated electricity. They argue that the constraints of wind energy, including its intermittent nature and the associated system costs of integrating such sources into the grid places limits on the future contributions of wind power to the state's energy mix.

Similar challenges affect solar resources, where energy generation from solar panels may be influenced by factors such as weather conditions, seasonal variations, and sunlight intensity. Moreover, the most common form of intermittency is the diurnal cycle, with substantial energy contributions to the grid during daylight hours but none after sunset, as illustrated in Figures 20 and 21. This pattern underscores the inherent limitations of solar generators in providing consistent energy supply.

Unlike fossil fuels, the intermittency of non-hydro renewable energy (NHRE) sources can lead to imbalances between supply and demand (Richardson and Harvey, 2015; Hirth and Ziegenhagen, 2015). For instance, as illustrated in Figures 20 and 21, photovoltaics (PV) systems can only generate electricity during daylight hours. This capability aligns well with industrial production and midday electricity demands, such as cooling and operations. However, solar PV cannot meet energy demands at night, such as heating. Similarly, the supply of wind-generated electricity is contingent upon wind strength, which may not correspond to periods of peak human demand.

To mitigate the challenges posed by the intermittency of NHRE, Energy storage technologies, such as battery storage power stations (BESS), pumped hydro energy storage (PHES), compressed air energy storage, and hydrogen energy storage, facilitate the storage of energy when variable NHRE sources are producing and make it available during periods when these sources are inactive or during peak demand times.

The South Australian government is exploring what the role of battery system could play for energy storage and grid stability. There were four grid level batteries established by the end of 2023. The first three battery storage power stations are co-located with large NHRE generation, and AGL Torrens Island battery is co-located with the Torrens gas power station (Table 3). Through co-location, the battery can reduce the transmission cost.

Site name	Capacity (MW)	Complete year	Site location	co-located
Hornsdale Power Reserve	100 (First step) 50 (Second step)	2017 2020	Jamestown	Hornsdale Wind Farm
Dalrymple BESS	30	2018	Lower Yorke Peninsula	Wattle Point Wind Farm
Lake Bonney BESS	25	2023	Mount Gambier	Lake Bonney wind farm
AGL Torrens Island BESS	250	2022	Torrens Island	AGL's Torrens Island B gas plants and Barket Inlet Power Station

Table 3: List of the grid-level batteries of South Australia (AEMO, 2021b, ElectraNet, 2022b)

Furthermore, South Australia also exploring the PHES as a possible pathway to storing energy to mitigate the NHRE variability. PHES is a technology that utilizes the differential elevation between two reservoirs to generate hydroelectric power through the movement of water. This technique involves pumping water to a higher elevation reservoir when electricity prices are low and subsequently releasing it to generate electricity during periods of high electricity demand. While this technology is not widely developed in Australia, it has reached maturity in several countries, including the United States and Japan, where it is used to enhance energy storage and grid stability. Energy Australia and Arup established a PHES project, with Federal funding, near Port Augusta called Cultana Pumped Hydro Energy Storage in 2020. This project is designed to have the ability to discharge 225 MW with 8 hours pumping and only a third of the cost compared with battery system (ARENA, 2022a).

BESS and PHES are both technologies that have the gap to widely deployed. BESS offers several advantages, such as mitigating the intermittency and variability of NHRE, integrating energy, enhancing grid stability, and providing electricity during critical situations (Saldarini et al., 2023). However, the primary barrier to the widespread adoption of BESS is its cost, which remains non-competitive compared to fossil fuel generation. Alessandro Saldarini et al. have reported that different types of Lithium-Ion batteries incur costs ranging from USD 95–160 per kWh, equivalent to approximately AUD 147-247, while Solid-State batteries cost around AUD 124-140 per kWh in 2023. In contrast, NEM average wholesale electricity price in the fourth quarter was only AUD 48 per kWh (AEMO, 2024). Furthermore, according to Figure 22, the cost of electricity from battery discharge ranks as the third highest, exceeding the average price, and surpassing even brown coal and some gas technologies in 2022 in South Australia.

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Figure 22 South Australia average electricity price by technology type (Havyatt. et al., 2022)

PHES has encountered significant obstacles in South Australia, notably the setbacks experienced with the Cultana PHES project. EnergyAustralia deemed this investment unsuccessful, rendering a negative financial investment decision due to several factors, including higher-than-expected capital costs, revenue uncertainty, and uncertainties surrounding energy technology development and the timeframe for obtaining development approvals (ARENA, 2022b). This decision has potentially dampened the enthusiasm of other investors considering similar projects in the region. Moreover, the environmental impact of PHES poses additional challenges for South Australia, which lacks areas that are not environmentally sensitive to support such projects (ARENA, 2017). Consequently, the government requires more time and a more thorough process to evaluate development proposals.

Despite facing challenges in integrating variable NHRE and storing NHRE energy, South Australia has a significant opportunity to overcome these obstacles in the near future. With concerted efforts from various societal sectors, new pathways are continually being explored and developed. Firstly, the impact of variable NHRE resources can be mitigated by geographically dispersing generators. Willow et al. (2014b) mentioned that wind intermittency could be through aggregating geographically dispersed wind farms. They also believed that compared to wind farms located in areas with high but variable wind speeds, sites with slightly weaker but more consistent winds can better stabilize electricity generation. Similarly, the generation stability of solar resource also could be improved through geographical dispersal, which could reduce the impact of localized weather conditions, improving the correlation between PV production and electricity demand (Richardson and Harvey, 2015). However, generators should not be located far from existing network facility to avoid unnecessary transmission costs.

Furthermore, the synergy of batteries and NHRE will also improve generation stability. Battery energy storage systems with wind and solar farms enhances the reliability and dispatchability of wind power (Tarcaa et al., 2017, Prasad et al., 2017). That is a reason for investors to collocate BESS projects with power stations. Due to rapid technological advancements, there has been a notable reduction in the cost of batteries, accompanied by an increase in their cycle frequency (Saldarini et al., 2023). Over the last three decades, the price of lithium-ion battery cells has decreased by 97%. This drastic decrease continued with prices halving between 2014 and 2018 alone (Chandler, 2021, Ritchie, 2021). Consequently, batteries hold significant potential as a choice for integrating variable renewable energies and for energy storage in South Australia. This development positions them as a crucial element in the region's energy infrastructure, catering to both current and future energy needs.

Although PHES has encountered setbacks in South Australia, it remains a promising candidate for energy storage. Despite the high initial costs associated with establishing such projects, the long operational lifespan of these systems results in lower average costs over time. In New South Wales, the construction of the Snowy 2.0 project—an expansion of the mid-20th century reservoir network—illustrates the continued interest in PHES. This project is expected to discharge 200 MWh per hour with 175 hours, totally provide 350,000 MWh of energy to the grid (Snowy Hydro Limited, 2024). Although a feasibility study confirmed that the project is both technically and financially viable (ARENA, 2021), its progress has been delayed by the pandemic, disruptions in global supply chains, and variable geological conditions (Hannam, 2024). If the project can be successfully implemented according to the updated plan and play a crucial role in the scheduling of intermittent energy within the

National Energy Market (NEM), it would significantly bolster confidence among potential investors in South Australia's PHES initiatives.

The government of South Australia is actively developing the next generation of energy sources, focusing on hydrogen as a key component for integrating NHRE into the power generation mix. The South Australian government views hydrogen as a viable option for manufacturing fuel during periods of abundant NHRE supply, with the potential to generate electricity when needed (South Australian Government, 2022a). If this technology and industry mature, it could significantly aid the South Australian power grid in managing the variability of NHRE. This approach underlines the strategic vision of leveraging advanced energy storage solutions to enhance grid reliability and sustainability.

Additionally, it is worth mentioning that community-owned NHRE projects are also thriving in South Australia. The achievement of the Hepburn Wind Project (Australian Government, 2024) in Victoria has inspired many communities in South Australia to consider community-owned NHRE projects. This pioneering wind farm has demonstrated the feasibility and benefits of community-led renewable initiatives. For example, Mitcham solar bulk buy program (City of Mitcham, 2024) which aims to bridge between resident and the pre-vetted supplier to buy solar panel and family battery systems below market price. This program aims to establish a community-based Virtual Power Plant under relevant corporation technical support which allow the residents’ solar panels and batteries to trade energy with grid (ShineHub Pty Limited, 2021). The project is managed and funded by the local community through cooperative models or community investment schemes, allowing members to benefit directly from the energy savings and contribute to sustainability efforts in their region.

5.2 The electricity price

From 2007 to 2017, nationwide electricity prices in Australia increased by approximately 56%, with residential bills rising by 35% (ACCC, 2018). This trend has continued, with prices in 2023 now 76% higher than in 2007 (ACCC, 2023). The Parliament of Australia's 2013 brief indicated that the long-term increase in nationwide prices is due to multiple factors, including rising gas prices, the deployment and upgrading of network components, and various policy impacts (Swoboda, 2013).

South Australia's electricity prices have often been criticized for being high compared to other states in Australia (Harmsen, 2017; Kelsall, 2023), a situation influenced by several factors. The factors might include the cost of network cost, wholesale (including NHRE facility deployment cost and energy intermittent cost) cost, environmental cost and retail cost, which are discussed above section. This section mainly focuses on network cost and wholesale cost and discusses the barriers and opportunities.

According to Figure 23, electricity prices in South Australia have consistently exceeded the Australian average since 1983, indicating that the trend of rising electricity costs began well before the grid's transition to NHRE. Originally, the increase in electricity prices was primarily attributed to increasing demand and market failure to supply. As time progressed, subsequent rises in prices were likely influenced by increases in fuel costs (Havyatt. et al., 2022). Additionally, fluctuations in energy policy, such as the implementation of a carbon tax and the introduction of Renewable energy certificates (RECs), have also played a significant role in contributing to price volatility. In recent years, there has been an increasing discussion regarding the correlation between electricity prices and NHRE. Analyses suggest that the intermittency of NHRE resources, along with the accelerated deployment of related infrastructure, may have further exacerbated the rise in prices (Harmsen, 2017).

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Figure 23: South Australian residential electricity price compared with the Australian average (Havyatt. et al., 2022)

Figure removed due to copyright restriction.

Figure 24: South Australian energy cost stack (Havyatt. et al., 2022)

According to the data presented in Figure 24, compared to 2008, the wholesale, network, and environmental costs of the South Australian grid have all significantly increased. However, the wholesale costs began to decrease after 2018. As depicted in Figure 25 and detailed by David Havyatt et al. (2020), South Australia's electricity grid incurs higher costs in network and environmental expenditures compared to other states. South Australia’s network costs are nearly 50% higher than those of other states. Unlike other state Network costs trending downward, the South Australian costs have remained high in recent years. Network costs are primarily composed of transmission use of service charges, distribution use of service charges, and other related costs. According to Figure 24, network costs constitute about 50% of the total electricity costs in South Australia.

In many instances, the costs associated with the energy sector's decarbonization transition projects are borne by investors but are often supported by governmental funding. Furthermore, due to competition among wholesalers, the wholesale electricity prices do not typically experience drastic fluctuations as a result of the grid's transition to NHRE. However, network corporations are required to establish new transmission lines and ancillary facilities for newly deployed power plants and maintain them (Bolton and Hawkes, 2013). Additionally, electricity grid providers face challenges in integrating various types of NHRE during the energy transition. This includes deploying different models of transformers to enable a variety of large and small projects, as well as home solar systems, to connect to the grid. These requirements underscore the complex and costly infrastructure investments needed to support a sustainable energy future (Nergy Networks Australia, 2021). For example, the old Eyre Peninsula Link was be decommissioned after almost 50 years operational life in 2023 (ElectraNet, 2023), and be replaced by new lines that are designed with update possibility to support potential new renewable energy project transmission demand (ElectraNet, 2022a). These costs in the energy transition process will be passed down to residents through the electricity bill.

Contributing to network costs in South Australia is the dispersed settlement pattern outside of major urban centres, the need for infrastructure development for newly deployed energy projects, and a smaller population base compared to other states, which implies higher per household costs for network construction and maintenance, exacerbate these price increases. Environmental costs typically account for 5-15% of the electricity bill, as shown in Figure 24. As implied by Figure 25, in South Australia, these costs are nearly 50% higher than other states. They primarily consist of environmental policy expenses, including RECs, feed-in tariffs (FITs), and the Retailer Energy Efficiency Scheme. Specifically, the FITs policy accounted for approximately 43% of all environmental costs, while large and small size RECs accounted for about 50% in 2020 (AEMC, 2021). This substantial financial burden reflects the state's aggressive policies towards encouraging renewable energy adoption and energy efficiency measures, which, while promoting sustainability, also translate into higher costs reflected in the consumer electricity bills.

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Figure 25: Network cost and environmental cost in SA (red) compared with states in the NEM (Havyatt et al., 2022)

The Coober Pedy case study serves as a compelling example of NHRE transition and reduced network costs, as mentioned in the previous chapter. Coober Pedy is a remote community and operates off-grid. The community has established its own grid and upgraded it to a high renewable penetration system that includes a wind farm, solar panels, a battery system, a flywheel, resistors, and a diesel generator (EDL, 2024) The battery and flywheel store energy for the grid, while resistors help smooth out power supply fluctuations from intermittent energy sources. The diesel generator activates when renewable energy is insufficient and stored energy levels are low. After updating the grid, the community reduced its diesel consumption by more than 70% (Coober Pedy RBTA, 2023) and eliminated the need to pay for long-distance electricity transmission and infrastructure maintenance. Additionally, Coober Pedy uses solar panels to operate a reverse osmosis plant, purifying brackish water for local use (Munari et al., 2009).

This scenario presents an opportunity for both remote communities and network corporations. If it is determined that the cost-effectiveness of establishing and maintaining transmission infrastructure is less favourable compared to off-grid electricity generation, grid providers could propose to local communities the establishment of their own community grids, instead of joining the state grid as was customary in the past. This approach not only reduces the network costs that account for approximately half of the local residents' electricity bills but also allows network corporations to eliminate a significant cost on transmission and distribution. Moreover, households in the state grid would benefit from reduced network costs.

According to the Australian government's latest and ambitious energy transition plan, the Australian grid's renewable energy penetration is projected to reach 80% by 2030 (Australia Government, 2024c). In response, state and territory governments are expected to increasingly focus on enhancing the renewable energy penetration within their electricity grids. South Australia, a leader in the transition to NHRE, is already nearing this target. Unlike other states that are currently initiating decarbonization projects and bearing the associated costs, South Australia can be considered to have "first paid" for the future bill. This positions South Australia advantageously, having already invested in the infrastructure and policy frameworks necessary to meet these future energy standards.

5.3 REZ policy

While South Australia has forged ahead with its energy transition over the past 15 years, other states are now in the process of catching up. In November 2019, the New South Wales Government announced Australia’s first Renewable Energy Zone (REZ) plan (ARENA, 2020). Initially, the NSW Government aimed to use this policy to stimulate private investment in renewable energy within the Central-West Orana region, aiming to reverse the recent downtrend in renewable energy investments. However, following this initiative, as the number of REZ candidates increased and Victoria responded similarly, the policy gradually gained traction and was adopted by the Australian Energy Market Operator (AEMO). In its 2021 report, AEMO outlined a federal energy policy that included 35 REZs and four offshore wind zone candidates (AEMO, 2021a).

As REZ policy became a federal level plan, its aim is to facilitate the transition towards a more sustainable and low-carbon energy system by identifying and promoting areas across the country with high potential for renewable energy generation, such as wind, solar, and hydro. The establishment of REZs is intended to align investor interest with government policy, consumer values, and the geographical distribution of renewable resources, thereby maximizing value across the energy supply chain. Those regions should include generator, storage and transmission infostructure (NSW Government, 2024), eventually replacing traditional fossil fuel power stations (Pack et al., 2021).

The New South Wales government has announced a substantial allocation of funds to support REZ plans, aimed at facilitating the state grid's energy transition. In addition to funding of AUD 1.2 billion in 2022 for deploying new energy facilities in 5 REZs and 2 offshore wind zone candidates (Kean, 2022), the state government also committed an additional AUD 1.8 billion in 2023 to further aid the transition (NSW Government, 2023). Of this amount, AUD 1 billion is designated for the establishment of the Energy Security Corporation, which will be responsible for investing in energy storage industries to ensure the stability and reliability of NSW's electricity grid. The remaining AUD 800 million is allocated to the Transmission Acceleration Facility, which will facilitate the integration of REZs into the grid and support the deployment of other critical infrastructure.

In February 2021, the Victorian government released Renewable Energy Zones Development Plan (Victoria Government, 2021). This plan describes VicGrid's role in managing the planning and development of REZs, including generators, networks and other infrastructure development. Moreover, the state government funded VicGrid AUD 540 million to strengthen the grid and develop REZs together with private investors.

In contrast to these neighbouring states, the South Australian government has not specified any particular policies, established any agencies, or funded projects to support the development of REZs. Most relevant planning documents have been issued by the AEMO rather than by the state government itself. In contrast to the emphasis on Electric Vehicles (EV) infrastructure and hydrogen energy industries discussed in the previous chapter, which are seen as future development directions, the South Australian government does not appear to regard REZs as a key policy in its energy transition strategy. On the state government energy transition website, “Leading the green economy” (South Australian Government, 2022c), the term is not even mentioned once, let alone having a specific page to provide detailed information and future strategy. This indicates that the state government takes a different focus to enhancing its energy infrastructure and diversifying its energy sources.

However, there is some evidence that the South Australian private sector is engaging with the REZ project deployment. For example, one of the renewable energy producers, Neoen, in Australia has commenced work on one of South Australia's largest renewable energy projects within the Goyder Renewables Zone (Colthorpe, 2022), shown in Figure 26 along with and other REZs candidate location.

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Figure 26: Australian Renewable Energy Zone candidates (Australia Government, 2023)

South Australia once pioneered wind energy policies as a part of its NHRE transition, securing a leadership position in energy transition policy. However, the current lukewarm attitude towards the opportunity of the new transition policy, such as REZs, might lead to an erosion of South Australia's policy leadership or allow other states to catch up. This shift could impact South Australia's ability to maintain its forefront status in the renewable energy sector, as other states potentially capitalize on more aggressive REZ implementations to advance their own NHRE transitions.

5.4 Conclusion

This chapter outlines the current challenges and barriers South Australia faces in its energy sector transition. As a pioneer in the energy transition, the main challenge for SA's grid is managing the variability and intermittency of NHRE. The high cost of Battery storage power station (BESS) technology limits its rapid large-scale deployment by the market. Additionally, investor confidence has been undermined by the economic failure of the first deployed

PHES project. The rising electricity bills also draw criticism towards the NHRE transition. Network costs account for about half of the electricity bill expenses, while expenditures related to environmental policies are also driving up the bills. These factors may potentially destabilize South Australia's leadership in the NHRE transition. Despite these challenges, opportunities still exist, such as the rapid advancements in battery technology, community engagement, hydrogen energy technologies, and the development of NHRE grids in remote communities.

CHAPTER 6. CONCLUSION

This thesis has investigated the factors contributing to South Australia's high penetration of non-hydro renewable energy NHRE in its power grid. It explored the policies, investments, and technological advancements that have facilitated this transition and highlighted the challenges and opportunities that come with such an ambitious energy shift.

Summary of Findings

The core findings of this thesis indicate that South Australia's high NHRE penetration is rooted in the global and national context, and the policy framework. These achievements will continue to drive this trend. However, South Australia also faces several challenges that hinder further increases in NHRE penetration.

In the early 2000s, global efforts to reduce carbon emissions were already underway, and that is the period when South Australia started on its energy transition. When Australia signed the Paris Agreement in 2016, it further spurred domestic political and public momentum to seek alternatives to fossil fuels. NHRE emerged as a viable solution due to the limitations of traditional hydropower and fossil fuels.

Federal and South Australian environmental policies have significantly promoted NHRE deployment through their policy frameworks. The Renewable Energy Target (RET) at the federal level, a primary policy to boost renewable energy, has encouraged more investors to shift towards renewable energy. In South Australia, political stability, along with feed-in tariff (FiT), wind and other energy policies, has facilitated the rapid deployment of both large and small-scale projects over the past two decades. As a result, South Australia's grid has seen substantial NHRE penetration, significantly reducing natural gas consumption. This achievement and current situation, combined with additional economic benefits, has further motivated both the South Australian government and the public to support the energy transition.

The variability and intermittency of NHRE, high costs of storage technology, and rising electricity bills are notable challenges. However, advancements in battery technology, hydrogen energy, and community engagement present significant opportunities.

Implications

South Australia's journey towards high penetration of NHRE offers several valuable lessons for other regions aiming to transition to renewable energy. The first experience is to implement robust renewable energy policies, such as the Renewable Energy RET, FiT, and wind power policies, and to maintain the stability of these policies. This approach incentivizes investment and the deployment of renewable technologies. The second lesson relates to engaging the community. This was started with the FiT policy which South Australia was the first state to adopt. More recently, community-owned projects that help lower-income households access affordable energy have emerged as a new incentive for NHRE deployment. Third, the South Australia case shows the effectiveness of providing economic incentives and support for households and businesses to adopt renewable energy solutions, such as FiT, wind or solar subsidy. This can accelerate NHRE projects deployment. The South Australia state has also demonstrated that proactively addressing challenges is crucial for the energy transition. Challenges such as grid stability, energy storage, and cost increases necessitate timely and effective strategies to overcome obstacles in the transition process.

Challenges and Limitations

One of the primary challenges in this thesis is the availability and reliability of data. Comprehensive and up-to-date information on South Australia's energy transition, particularly detailed statistics on NHRE deployment, economic impacts, and policy outcomes, is limited or not readily accessible. This can lead to gaps in the analysis and potentially affect the accuracy and depth of the research findings. Analysing the effectiveness of policy and regulatory frameworks also poses a significant challenge. Energy policies are dynamic and can vary significantly over time and across different political administrations. This variability can complicate the assessment of long-term policy impacts and the formulation of consistent policy recommendations.

The thesis relies on various technological and economic assumptions, such as the future cost trajectory of renewable energy technologies and the scalability of storage solutions like BESS and hydrogen. These assumptions are subject to uncertainty and can impact the projected outcomes and recommendations.

The technical complexity of integrating NHRE into the existing grid infrastructure, including managing intermittency and ensuring grid stability, is a significant limitation. The thesis may not fully capture the technical nuances and challenges associated with large-scale renewable energy integration, which can impact the feasibility and effectiveness of proposed solutions.

Evaluating the economic and social impacts of the energy transition involves a wide range of variables and potential outcomes. This complexity can make it difficult to draw definitive conclusions and may require further empirical research and analysis to fully understand the broader implications of the transition.

There is clearly a need for ongoing research to address these challenges and limitations. Future studies could focus on detailed case studies of other regions, more comprehensive data collection, and advanced modelling techniques to improve the accuracy and applicability of the findings.

Final Thoughts

The energy transition in South Australia provides a compelling case study of how regional policies, community engagement, and technological advancements can converge to achieve significant progress in renewable energy adoption. The state's success underscores the importance of a supportive policy framework, substantial investment in technology, and active participation from the public. As other regions consider similar transitions, they can draw valuable lessons from South Australia's approach, particularly the emphasis on stable pollical framework, robust policies implement, and fostering economic benefits for local communities.

However, this transition is not without challenges. Technical, economic, and policy-related obstacles need to be addressed to sustain and expand these achievements. Continued innovation, strategic investment, and collaborative efforts are essential to overcome these hurdles and ensure a resilient and sustainable energy future.

Furthermore, it is worth noting that South Australia's leading position in energy transition will be eroded as other jurisdictions invest in Renewable energy Zone (REZ) policies. If the state wants to maintain its leadership, it should focus more on implementing energy transition policies rather than relying on technological breakthroughs in hydrogen energy or electricity vehicle (EV).

Ultimately, the journey of South Australia in embracing non-hydro renewable energy highlights the potential for sub-national regional leadership in global energy transitions. By learning from these experiences and adapting strategies to local contexts, other regions can contribute significantly to the global efforts in mitigating climate change and promoting sustainable development. Especially jurisdictions in countries like Canada and the United States, where sub-national governments have taxing authority, will wield greater influence over energy policy and government investments compared to South Australia.

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