BEYOND CARBON – ASSESSING AUSTRALIA'S FUTURE ENERGY TRANSITION SCENARIOS AND HOW THEY MEET SUSTAINABILITY CRITERIA

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Teemu Brasier

Examiner(s): Associate Professor Michael Child

Junior Researcher Husain Patel

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Energy Systems

Environmental Technology

Teemu Brasier

Beyond Carbon – Assessing Australia's Future Energy Transition Scenarios and How They Meet Sustainability Criteria.

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During the Paris agreement 2015, a major step was taken in the following commitment period, and a new goal for reducing emissions was proposed. In order for these agreements to succeed, the participation needed to be global, and thus all member states were expected to make policy changes in reflection of their emissions. This thesis focuses on the 3 transition scenarios put forward in 2023 by the Australian Energy Market Operator in response to Australia's commitment to the 2015 Paris agreements, these being Green Energy Exports (GEE), Step Change (SC) and Progressive Change (PC). Each transition scenario was compared and evaluated using the stoplight method, and through this, possible effects on Planetary Boundaries other than just Climate Change were assessed. The main factors of each scenario, for example electrification or decarbonisation were assessed, as their role in Australia's energy transition may be vital. Research like this is essential in order to gauge possible implications in the future, as an energy transition may end up becoming harmful if many negative implications come out of it. This study found that while GEE and SC had heavier investments overall in some factors (electrification, decarbonisation, personal battery usage, etc) the effects of these transitions may be diminished if done incorrectly. This is especially shown through the increase in EVs, which may be sourced from places cheaply or unsustainably made. PC in general showed a lack of investment in comparison to GEE and SC and may not be able to meet climate goals at all. This study compares these scenarios, and in doing so shows possible future flaws within them.

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SYMBOLS AND ABBREVIATIONS

Abbreviations

AEMO	Australian Energy Market Operator
BCA	Building Code of Australia
BEV	Battery Electric Vehicle
CBD	Central Business District
ChAFTA	China-Australia free trade agreement
DAC	Direct Air Capture
E3	Equipment Energy Efficiency
GEE	Green Energy Exports
HS	Hydrogen Superpower
LNG	Liquid Natural Gas
NABERS	National Australian Build Environmental Rating System
NCC	National Construction Code
NEMT	Net Energy Metering
NEM	National Electricity Market
NMC	Nickel manganese cobalt batteries
PC	Progressive Change
SC	Step Change
SP	Steady Progress
SRES	Small-scale Renewable Energy Scheme

Symbols

Mt CO_2e/year	Metric ton of CO2 emitted per year

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1 Introduction

Reducing carbon emissions and other greenhouse gas emissions is seen as the most crucial way to mitigate and halt global warming. During the Paris Agreement 2015, a major step was taken in the following commitment period (2013-2020) (Droge S, 2016), and a new goal for the 196 members was needed. A goal of limiting emissions was introduced, firstly to limit the increase in global temperature to well below 2°C above pre-industrial levels and attempt to limit that even further to 1.5°C below pre-industrial levels. It should be noted that the goal of below 1.5°C above the pre-industrial global temperatures will have drastically reduced global warming effects in comparison to below 2°, including environmental, economic, and in general health risks (Ebi KL, 2018). In order for this limitation in temperature increase to be achievable, the participation needed to be global, and thus all member states were expected to make policy changes in reflection of their emissions. However, there are more issues than just carbon emissions to fix when it comes to the interests of our planet's health. The concept of Planetary Boundaries was introduced in 2009 and aims to define the environmental limits of the planet within which humanity can continue to operate safely (Steffen W, 2015). These boundaries include Climate Change, Novel Entities, Stratospheric Ozone Depletion, Atmospheric Aerosol Loading, Ocean Acidification, Biogeochemical Flows, Freshwater Change, Land-System Change and Biosphere Integrity. Ignoring the boundaries that are not related to global emissions may become catastrophic in the future. Therefore, countries need to keep these boundaries in mind when planning their methods for reducing emissions and meeting their Paris agreement commitments.

In response to the commitment goals required to meet the Paris Agreement quota set for Australia, 2030 and 2050 goals were introduced, which were a 43% emission reduction and a reduction to net zero emissions, respectively. The Australian Energy Market Operator (AEMO) has published a report detailing and forecasting 3 future energy scenarios, each scenario predicting different plausible futures for energy demand and how these demands are met. These three scenarios are "Green Energy Exports" (GEE), "Step Change" (SC) and "Progressive Change" (PC), each with varying approaches and goals, especially in terms of their approach to the "Below 1.5C temperature goal". GEE is a refinement of the Hydrogen Superpower scenario that is covered in 2021 Inputs, Assumptions and Scenarios Report also

by AEMO (Livingstone T, 2021). This scenario aims for below 1.5°C above preindustrial temperatures. SC refines the 2021 Step Change scenario (Livingstone T, 2021) and ultimately aims for a below 2°C increase but may also be compatible with below 1.5°C increase. This scenario promotes strong transport and industrial electrification, as well as the utilisation of low emission alternatives to support industry. The final scenario covered is the PC scenario, in which the difficulties of meeting Australia's commitments to the Paris Agreement is explored. Through these reports and changes in policy, several Sustainability Criteria are found. The need to go beyond carbon, and to establish further sustainability criteria or guardrails is a field that will need more research and consideration from the wider scientific community. This is already shown through studies such as Child et al. (2018), an article on Sustainability guardrails for energy scenarios, which highlights the need to add planetary boundaries into global decision making.

1.1 Objectives, Scopes and Limitations

This research intends to explore the differences between the respected scenarios, and through the differences between these scenarios explore various factors. These are factors that may contribute to the difficulties Australia's future energy transition may have in terms of sustainability. Sustainability in this sense means not only emissions, but whether there are any detrimental factors in these predicted scenarios. This thesis will also assess whether various sustainability criteria or drivers that have come about due to the energy transition are achievable. Some focus on social and economic aspects will be covered, but much of the focus will cover environmental and energy aspects with regards to all the Planetary Boundaries. This thesis excludes individual state legislative change and will examine the goals and motivations of these scenarios at a complete federal level. The initial chapters of the thesis will aim to cover the scenarios in detail, during which their predicted results will be analysed, and the possible unsustainable aspects will be assessed. The first section of this thesis (Section 2) will review AEMO's energy predictions and scenarios and identifying drivers of change that can be derived from these developments. Building the information gathered from these scenarios, Section 4 will examine the impacts that the main focuses of these scenarios have, and what they are. As well, it will present a final comparison of the

three energy scenarios using a stoplight method to show how a change of usage in the focuses may affect sustainability. Research for this thesis will be done with information sourced from publications and articles. The main sources of these publications will be LUTPub, with some cross examination using Google Scholar.

2 Australia's Future energy scenarios

The three energy scenarios proposed by AEMO can be seen as an update of 2021s scenarios, with most scenarios updated or in the case of the Slow Change scenario, completely removed. This section will cover the current scenarios, how they have changed and their purpose.

2.1 Comparing 2023 to 2021 scenarios

The three 2023 scenarios for 2030 and 2050 are scenarios that are refined versions of the 2021 scenarios. These changes are made in accordance with changing efforts being required to meet the Paris Agreement commitments. It should be noted that 2021s scenarios were 4 in number, so 2 scenarios were combined into the Progressive Change scenario in 2023.

The 2021 Hydrogen Superpower scenario has become the 2023 Green Energy Exports scenario, which still shows a strong shift toward electrification, but a lower scale in hydrogen production. The 2023 Step Change scenario has remained similar to its 2021 version, with little to no differences. The 2023 Progressive Change scenario is similar to the 2021 Progressive Change scenario and the 2021 Slow Change scenario and can be seen as a mixture of the two, with a focus on decarbonisation investments. The PC scenario is planned to meet Australia's 43% emissions reduction target.

2.1.1 Green Energy Exports Evolution (GEE).

> "A scenario with very rapid and widespread transformation of the economy making a very significant contribution from the electricity sector aimed at achieving a temperature rise limited to 1.5°C. Consumer investments are very high, and global demand for green energy contributes to a new and very strong green energy export economy." – (AEMO, 2023, 17)

The purpose of the GEE is to test a rapid change to decarbonisation, and it is a scenario that strongly uses biomethane, green hydrogen and electrification, resulting in a scenario that aims to rapidly transform Australia's energy market. In Table 1, a comparison of how this scenario has changed since 2021 is set out.

Table 1 - 2023's Green Energy Exports – Data from 2021 and 2023 AEMO Report. (AEMO, 2023) (Livingstone T, 2021)

Changes from 2021 report to 2023 (Hydrogen Superpower - Green Energy Exports)		2021	2023	+/-
Electrification	% of road transport that is EV by 2040	76%	72%	+4
	% of residential EVs still relying on convenience charging by 2040	40%	38%	-2
	Industrial electrification by 2040	66 TWh	36 TWh	-24
	Residential electrification by 2040	10 TWh	9 TWh	-1
	Energy efficiency savings by 2040	44 TWh	41 TWh	-3
Underlying Consumption	NEMT underlying consumption by 2040	329 TWh	345 TWh	+16
	Hydrogen consumption (domestic), 2040	64 TWh	50 TWh	-14
	Hydrogen consumption (export), including green steel, 2040	221 TWh	183 TWh	-38
	Total underlying consumption by 2040	614 TWh	578 TWh	-36
Supply	Distributed PV Generation	83 TWh	92 TWh	+9
	% of household daily consumption potential stored in batteries	35%	22%	-13
	% of underlying consumption net DER by 2040	13%	16%	+3
	Estimate of % coal in generation by 2040	0%	0%	0
	Estimate of NEM emissions production by 2040 ($MT\ CO_2$-e)	1	2	+1

As is shown in Table 1, The GEE scenario derives from 2021's Hydrogen Superpower (HS) scenario and undergoes multiple changes in the process. Overall, there is a large focus on reducing demand, with H2 consumption plummeting across all domestic and export usage. This is replaced by an increase in Net Energy Metering consumption. NEMT is an annual billing mechanism which allows users to generate their own electricity and is a clear indication for Australia's plan to enforce the usage of housing with solar panels, reducing consumption of commercial electricity.

2.1.2 Step Change Evolution (SC)

> "A scenario with strong industry and consumer energy investments to decarbonise, and actions to lower emissions across Australia's economy above current levels. In this scenario the NEMT provides a strong and economy-enabling contribution to that purpose through a fast-paced transformation." – (AEMO 2023, 18)

The Step Change scenario (SC) addresses decarbonisation of the current energy system through electrification and directly aims to contribute to the global effort of limiting global temperature increase to well below 2℃ above preindustrial levels. Below is a graph depicting the change in this scenario from 2021.

Table 2 - 2021-2023 SC scenario change - Data from 2021 and 2023 AEMO Report. (AEMO, 2023) (Livingstone T, 2021)

Changes from 2021 report to 2023 (2021 Step Change - 2023 Step Change)		2021	2023	+/-
Electrification	% of road transport that is EV by 2040	58%	60%	+2
	% of residential EVs still relying on convenience charging by 2040	47%	46%	-1
	Industrial electrification by 2040	45 TWh	25 TWh	-20
	Residential electrification by 2040	9 TWh	9 TWh	0
	Energy efficiency savings by 2040	44 TWh	36 TWh	-18
Underlying Consumption	NEMT underlying consumption by 2040	279 TWh	299 TWh	+20
	Hydrogen consumption (domestic), 2040	15 TWh	28 TWh	+13
	Hydrogen consumption (export), including green steel, 2040	0 TWh	7 TWh	+7
	Total underlying consumption by 2040	294 TWh	335 TWh	+41
Supply	Distributed PV Generation	66 TWh	77 TWh	+11
	% of household daily consumption potential stored in batteries	32%	21%	-11
	% of underlying consumption net DER by 2040	22%	23%	+1
	Estimate of % coal in generation by 2040	5%	NA	NA
	Estimate of NEM emissions production by 2040 (MT CO_2-e)	10	1	-9

Table 2 shows the changes that SC scenario underwent when transitioning from the 2021 version to 2023 version. Starting with electrification, industrial, overall savings are decreased, and residential remains the same. EV road transport is to increase 2% and percentage of residential EV's relying on convenience charging is lowered slightly. Overall, it seems that a greater focus on personal energy generation and electrification is being forecasted, as opposed to industrial. Consumption across the board is increased, with a total increase of 41 TWh. This makes sense as the SC scenario promotes H2 (hydrogen) and NEMT consumption. For supply, PV generation is substantially increased, again driving towards personal power generation. Notably, power potential stored in batteries is lowered by over a third of initial estimates, despite PV generation increasing.

2.1.3 Progressive Change Evolution (PC).

"A scenario that assumes ongoing challenges in global economic conditions that limits broader actions that could increase the current pace of change of Australia's transition to net zero. The scale of action therefore focuses on achieving current domestic and global policy objectives. Under this scenario the pace of decarbonisation across the economy may be inconsistent with limiting temperature rise to below 2°C by 2100 even if current energy sector objectives are met. Consistently, under this scenario, less ambitious actions are taken in other sectors of the economy, there are assumed to be significant supply chain constraints, and/or more measured global action." – (AEMO, 2023, 19)

Table 3 - 2021-2023 PC Progressive Change - Data from 2021 and 2023 AEMO Report. (AEMO, 2023) (Livingstone T, 2021)

Changes from 2021 report to 2023 (2021 Steady Progress - 2023 Progressive Change)		2021 SP	2023 PC	+/-
Electrification	% of road transport that is EV by 2040	44%	32%	-12
	% of residential EVs still relying on convenience charging by 2040	61%	56%	-5
	Industrial electrification by 2040	8 TWh	20 TWh	+12
	Residential electrification by 2040	0 TWh	6 TWh	+6
	Energy efficiency savings by 2040	25 TWh	26 TWh	+1
Underlying Consumption	NEMT underlying consumption by 2040	245 TWH	230 TWh	-15
	Hydrogen consumption (domestic), 2040	0 TWh	15 TWh	+15
	Hydrogen consumption (export), including green steel, 2040	0 TWh	0 TWh	0
	Total underlying consumption by 2040	245 TWh	246 TWh	+1
Supply	Distributed PV Generation	51 TWh	45 TWh	-6
	% of household daily consumption potential stored in batteries	12%	3%	-9
	% of underlying consumption net DER by 2040	21%	18%	-3
	Estimate of % coal in generation by 2040	20-25%	NA	NA
	Estimate of NEM emissions production by 2040 (MT CO_2-e)	TBD	22	+22

In order to simplify the comparison process, instead of both slow change and steady progress being used in the comparison, only Steady progress will be used to compare the development of Progressive change from 2021 as shown in Table 3. First of all, notably electrification in general has gone down 12%, but despite this industrial electrification and residential

electrification have increased by 12 and 6 TWh respectively. This shows a smaller lack of focus on personal electrification, especially in terms of residential EV usage.

2.2 Summary of importance of scenarios.

In section 2.1, different drivers of change from the scenario changes were identified. Each scenario has a different main specialisation which said scenario focuses for the future. These scenarios are important as they define future goals and estimations, and the changes these scenarios go through throughout the years will show a comprehensive roadmap of Australia´s energy goals and the changes they go through leading up to 2050 and net zero emissions. The key indicators assessed are, electrification, decarbonisation, hydrogen and biomethane, and finally PV generation.

3 Methods

This chapter introduces the Methods and ways that sustainability is defined in the context of this thesis. The data and research that is the basis of this thesis will be defined here, as well as how this data and research is gathered. The overall result of this study will first assess the changes the 2023 energy scenarios propose, analysis of what these changes are will be conducted. The final result will combine these two sections into a final analysis of sustainability and viability for Australia’s future energy scenarios.

3.1 General Methods

The general method follows research and data gathering through sources from Australia, especially from the AEMO’s scenario report. Any data and research gathered and conducted will be explained once introduced and presented.

3.1.1 Stoplight Method

The Stoplight Method is a comprehensive and graphically simple method that will be used to present the sustainability of several factors presented through this report. While the overall sustainability of scenarios will be a yes/no assessment, it is important to consider that these scenarios cover a large range of factors including NEM billing, thus smaller differences between the scenarios will be assessed in this way. The stoplight method uses green, amber and red colours to describe different levels of results. Sustainability in the context of this thesis indicates a factor will improve whatever the overall topic is. For example, electrification may do well for emissions overall, however the environmental costs associated with mining batteries may prove an issue. For this thesis, Green will indicate that the section of the criteria is sustainable, and should not cause problems for the future, environmental, economic or social aspect. Amber will describe a criterion that is sustainable but may lead to issues in the future. Red describes a criterion that is not sustainable even now and may become an issue in the future.

3.1.2 Planetary boundaries

Planetary boundaries are defined by the Stockholm Resilience Centre as “A set of nine planetary boundaries within which humanity can continue to develop and thrive for generations to come” (Stockholm Resilience Centre, 2023). As mentioned in Section 1, these boundaries define alternative concerns aside from carbon emissions, which is usually the main focus of many studies. The effects these scenarios will have on the planetary boundaries will be assessed as even if a scenario is considered to be sustainable in terms of its energy and emission handling, the scenario may come at a cost to one of the boundaries (For example, GEE has a major focus on electrification, which may result in an increase in Novel Entities being produced). Climate change and Novel entities are the main focus of this paper as information on other Planetary Boundaries specifically relating to the three scenarios has been difficult to come by, and thus have been excluded from the paper.

3.1.3 Materials

As this report is a comparison of the AEMO's scenarios, the base data is gathered from its 2023 report. In the executive summary section, a comprehensive graph shows information on predicted data concerning goals like percentage of road transport that is BEV or amount of industrial electrification. The changes made to this information from previous reports as well as current information concerning these goals is used to predict and assess the future impacts of these scenarios.

3.2 Presentation

The main presentation of data and results will be in tables, using red, amber and green when the Stoplight Method is used. Discussion will follow these graphs, usually explaining what is shown and reasons will be given for why the factor or section is deemed sustainable or not sustainable. The majority of data in terms of comparing the scenarios is gathered from the AEMO 2023 scenario report, with secondary data to back up claims being gathered from various articles, with an attempt being made to have most be sourced from Australian sources.

4 Results and Discussion.

Section 2 identified the changes made to accomplish the scenarios energy goals. Section 4 now examines what the main factors in Australia's future energy generation will revolve around and discuss the results.

4.1 Analysis of main factors

Section 4.1 will cover an analysis on the main factors identified in the Australian Energy Market Operators scenario report. The plotted outcomes of each scenario will be assessed on possible future repercussions.

4.1.1 Electrification

Electrification in Australia is a vital process in reducing emissions, particularly in terms of public transportation. While Australia has been slow to embrace this transition, in order to fulfil their Paris agreements of 43% emissions reduction (compared to 2005 levels) by 2030 and net zero by 2050, it is a necessary step. “Rewiring the Nation Framework” is a framework proposed by the federal government on October 2022 (AEMO, 2023), which aims prepare the electrical grid for the increase in renewables and general decarbonisation of the power grid. This would allow processes like electrification of public transport to go smoother. A large part of electrification in Australia is reworking its public transport. The short-term costs of battery electric vehicles (BEVs) to be utilised as public transportation is higher than maintaining the current fleet of buses. However, the long-term economics to maintain them well make up for initial costs (Say K, 2023), meaning electrification of public transport makes sense both environmentally and economically. This is proven by how fuel prices can fluctuate, especially when the resource from this fuel is sourced internationally as shown by the price impact of international disputes (Qi Zhanhg, 2024). However, the price of electricity, especially from national renewable resources has the potential to lower electricity prices permanently, especially considering Australia’s potential for PV energy generation (Solargis, 2021). As it has been stated that both GEE and SC put a heavy focus on general electrification, with both being noted as having “a strong use of electrification” (AEMO, 2023).

While BEVs are considered to be more environmentally friendly, especially in terms of emissions, the process to create the EV batteries may be more environmentally detrimental than people believe. Compared to Internal Combustion Engine Vehicles, BEVs have the potential to reduce emissions over the course of their usage (Broadbent GH et al, 2024). However, in terms of toxicity potential and metal and mineral consumption, BEVs have a higher impact (Xia X & Li P, 2022). Despite this, electrification of public transport is the future for Australia, especially around areas like Melbourne Central Business District (CBD) or Sydney. It is also important to note that Australia is a very large country, and many BEVs may struggle to meet the distances expected of them when travelling across the country, for example from Adelaide to Perth. The distance by car is 2 694.7 km, and with the average

range of high-end vehicles in 2022 being 364-630 km (Prabuddha C, 2022), BEVs may not make the distance without significant investment into public charging stations.

Electrification in vehicles is extremely important for Australia to meet its climate goals, and Australia falls far behind other countries when it comes to use of Electric EVs. China has the largest fleet of Electric vehicles, with 4.5 million (IEA 2021b), and has exceeded its 2050 target for new energy sales already (IEA 2023b). In 2020, Europe had the largest annual increase with 3.2 million (IEA, 2021b), and has increased its electric car sales by 15% in 2022 (IEA, 2023b). Australia however falls behind the global average of 4.6%, with only 1% of new car sales being EVs (IEA, 2021b).

For Green Energy Exports, it is the highest of all 3 scenarios in terms of general electrification, shown through table 1. GEE has the highest investments from transport and industry, aiming to have 35 TWh in 2030 and 142 TWh by 2050. It is noted that a lot of what will drive this change is the high rates of electrification in industrial sectors. Electrification will also focus on replacing natural gas, although alternative fuels like hydrogen and biomethane will also be used as a replacement.

In the Step change scenario, a future where electrification across industrial usage is reduced or delayed is examined, and the role of biomethane is introduced. The SC scenario has a relatively high degree of electrification, and like GEE, aims for a majority of EVs on the road to be achieved. This scenario aims to switch residential heating from gas to electricity and aims to use “appropriate decarbonisation” in industry and manufacturing. While lower than GEE, the amount of electrification in total equals to 25 TWh in 2030 and 121 TWh in 2050. Like GEE, electrification will be used to replace gas heating.

Finally, Progressive Change has the overall lowest rate of electrification, particularly through its transport sector, although it remains that electrification through EVs is still significant. PC states that due to challenging economic conditions, investment in residential and commercial electrification is stunted. As a result of this, the amount of electrification is far lower than other scenarios, with 16 TWh in 2030 and 82 TWh in 2050. While electrification is still expected to replace natural gas usage, it is noted to be far lower than the other scenarios.

When it comes to the effects of electrification on the Planetary Boundaries selected, there are positives and negatives. The manufacturing process of EV batteries can be taxing for the

environment. Nickel, Manganese, cobalt batteries (NMC) for instance, is one of the most common batteries on the road, and is comprised of nickel, aluminium, lithium, cobalt and other materials. The mining and toxicity of these batteries can be taxing for the environment. However, as soon as these cars are in operation, EVs emissions are far better than standard combustion-based cars. This is due to how emissions from combustion-based cars are constant, whereas an EV charged with green energy produces overall lower emissions during its usage lifecycle (John E, 2021).

4.1.2 Decarbonisation

Decarbonisation is the process of turning away from using carbon emitting fuels and processes. Australia's energy generation has historically been heavily reliant on coal, due to its natural abundance in the country and ease of use, as well as continued trade with China (Feng F, 2024). However, in order to meet the emission goals, decarbonisation is vital to the future of Australia's energy scenarios.

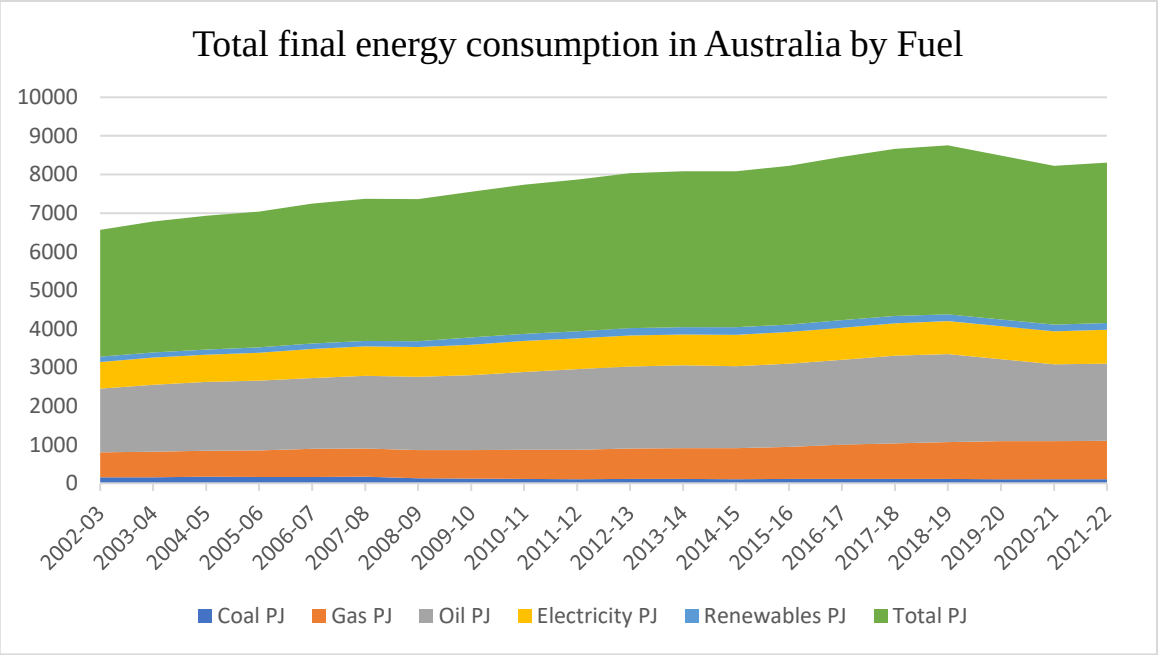

Figure 1 – Australian Total Final Energy Consumption by Fuel Type. (Australian Energy Update, 2024)

Australia faces several challenges in its decarbonization journey. Its comparatively high consumption of fossil fuels over the last few decades has made any transition away from fossil fuels to be a tough one as shown in Figure 1. Most pressing is the political and

economic interests associated with the fossil fuel industry, particularly Australia's trading routes with China. With Australia being by far the largest coal exporter in the world, The China – Australia Free Trade Agreement (ChAFTA) was implemented. ChAFTA is an agreement that was implemented on December 20th, 2015. ChAFTA took a decade to negotiate and dictates that 85.4% of traded goods between the two have the tariffs cut to zero (Xiang, 2017). Australia may need to rethink terms of the agreement in order to meet climate goals, as coal mined and exported overseas remains an emission, no matter where it is released.

In terms of the three scenarios, a four-pillar method is used to broadly classify how Australia's economic transition will be approached.

These four pillars are:

- Fuel switching: Switching to electrification, zero emission or near zero emissions from fossil fuels.
- Non-energy emissions reduction: Offsetting of residual emissions.
- Energy efficiency: Energy waste reduction.
- Electricity sector decarbonisation: How fast carbon intensity of electricity generation approaches zero.

As is the trend with the scenarios, the magnitude of commitment and investment in these pillars going from high to low is Green Energy Exports, Step Change, and then Progressive Change. The commitment the Australian government has shown to decarbonisation also allowed the AEMO to cut the 2021 IASR's Slow Change scenario from the list of scenarios. The data in the table below highlights the levels of investment each scenario will have in these pillars. While the scenarios are investing in the same pillars, they are at different levels of commitment.

Table 4 - Comparison of the four pillars. (AEMO, 2023, p50)

Forecast Utilisation of the Four Pillars by Scenario			
Scenarios	Green Energy Exports	Step Change	Progressive Change
Non-energy emissions reduction	Medium	Low	Low
Energy efficiency	High	Medium	Low
Electricity sector decarbonisation	High	Medium	Low
Fuel switching	High	Medium	Low

Fuel switching differs slightly between each scenario. This will be covered further in Section 4.1.3. However, the key connection to decarbonisation is that overall natural gas use declines throughout all scenarios. In GEE, this decline is quick, in SC, the decline is quick over the period to 2050, and in PC, natural gas use declines gradually up until 2050. Biomethane production is strongest in GEE, but not competitive in SC. It is noted that for PC, biomethane replaces most of the natural gas towards the end of the 2040's.

In general, the scenarios show varying levels of ambitions for energy efficiency, but all show relatively high levels of ambition. By 2050, there is forecasted to be a 30-50% avoidance of energy usage. A forecast growth for energy efficiency is delivered by a close examination of what investments will be worth investment. In order to encourage investments to this end, energy efficiency policies have been implemented by Australian governments (AEMO, 2023). Some key policies affect building energy performance, such as the National Construction Code (NCC) updated in 2022, which builds on and adds to the Building Code of Australia (BCA) 2010. Some policies like the National Australian Build Environment Rating System (NABERS) handles building rating and disclosure. Focuses on office and commercial buildings comes from the Commercial Building Disclosure (CBD) program. Finally, appliances and equipment are regulated by the Equipment Energy Efficiency (E3) program in order to ensure labelling and energy performance standards are enforced.

The final pillar covers the use of reducing non-energy related emissions through sequestration, focusing on the land use sector. GEE relies heavily on emissions sequestration to stay aligned with the 1.5℃ decarbonization pathway for the Australian economy. Sequestration efforts begin earlier compared to other scenarios, gradually increasing and stabilizing at approximately 142 million tonnes of carbon dioxide equivalent per year by 2034. From 2030, Direct Air Capture (DAC) technology begins contributing to emissions reduction, but early efforts in other sequestration methods and land use changes are

forecasted to help minimize dependence on DAC. In comparison to GEE, SC is slower when it comes to sequestration, reaching 65 Mt CO2-e/year in 2040, and reaching 159 Mt CO2-e/year only by 2050. SC makes up for this through relying heavily on DAC which begins in the late 2030s and becomes a more critical component of sequestration, compensating for the slower pace of earlier sequestration activities compared to the GEE scenario. With PC, sequestration gradually increases to 38 Mt CO2-e/year by 2030, remains steady for a decade, and then rises to 162 Mt CO2-e/year by 2050. DAC is introduced the latest among all scenarios but plays a significant role in achieving net-zero targets 2040-2050. Due to decarbonization also covering electrification to an extent, novel entities are expected to still be an issue across all scenarios.

4.1.3 Hydrogen and Biomethane

AEMO's forecasts consider hydrogen production from electrolysis only, utilising green electricity to split water molecules into hydrogen and oxygen. Produced this way, green hydrogen is produced. Hydrogen can be stored as a fuel through various methods, each with its advantages and disadvantages. Australia has many depleted reservoirs with which to store hydrogen (Amirthan, 2023) and thus could benefit from its utilisation. Biomethane is forecasted to be a key substitute for Liquid Natural Gas (LNG) across all scenarios. As of AEMO's 2023 report, biomethane and synthetic methane are allowed but no specific targets have been set to introduce it. Hydrogen and biomethane usage are encompassed in fuel switching, one of the 4 pillars for decarbonisation that was briefly covered in section 4.1.2. By 2030, distribution of hydrogen in residential and commercial sectors reaches 8-10% by volume across all scenarios. Without physical alteration to the gas operating or distribution system, a 10% hydrogen blending share is predicted to be the max possible share by 2030.

Hydrogen usage is minimal in the PC scenario, reflecting reduced economic activity and limited technological advancements that may lower the cost of emerging technologies like hydrogen electrolysis. The SC scenario shows moderate domestic hydrogen consumption, primarily in the industrial and transport sectors, supporting trends in electrification and biomethane use. The GEE scenario exhibits the highest uptake, driven by rapid cost reductions through a high learning rate and substantial hydrogen exports.

PC does not predict any exportation of hydrogen to Australia's international neighbours, and SC purely assumes a relatively low 0.2 Mt by 2050. GEE predicts 8.0 Mt by 2050 and is shown to be the only scenario that expects rapid advancement in the exportation of hydrogen.

In terms of biomethane production, SC contains the lowest usage, with less than 10 PJ per annum by 2050. Uncharacteristically, PC is just under GEE by 2050, and during 2051, is expected to overtake GEE, making up for its lack of development up until 2045. GEE is the only scenario predicted to invest early, with over 50 PJ per annum by 2026, and a steady rise to nearly 150 PJ per annum by 2050.

4.1.4 PV Generation.

Australia has potential when it comes to using PV as a sustainable form of energy generation. Due to its abundance of empty land and high levels of sunlight, the potential for solar as an energy source is clear, and as shown in some reports like Cecilia D's report on solar potential (Cecilia D, 2024), many innovative ways to harness this potential can still be found. Reflecting this, all scenarios show an ongoing increase in the growth of PV Solar energy generation which focuses around Australia's east and south coasts (AEMO, 2023 p151-152).

Rooftop solar continues to be one of Australia's key sources of renewable energy not just for the entire power grid, but even for everyday Australians (Liam S, 2023). By 2023, rooftop solar produces 3.5 TWh per year. Besides wind, rooftop solar is one of the largest sources for renewable electricity generation, producing around 11.2% percent of the power supply (Clean Energy Council, 2023). The main issue that comes with Australia's success in this field, is that this growth slowed in 2022. From 2016 to 2021, the nationally installed systems per year increased from 132,752 units to 377,460 units. However, in 2022 and 2023, the number of units installed per year decreased to 315,753 and 314,507 respectively (Clean Energy Council, 2023). This decrease in number of units installed per year could affect Australia's growth as a rooftop solar leader and hinder its growth in the field of solar power generation. However, a steady growth in installed soler systems will keep the installed capacity high, allowing for a large portion of Australia's renewable energy production to still play a key role in meeting the Paris Agreement goals for 2030 and 2050. In order to aid

the growth of rooftop solar units, battery attachments to the systems have grown steadily since they began their use before 2020. In the 4th quarter of 2023, as many as 153,387 units have been installed since 2020, which may keep rooftop solar as a key factor in producing renewable energy. The Small-Scale Renewable Energy Scheme (SRES) is a federal incentive which aids Australians by cutting energy bills and provides security against blackouts.

When it comes to the differences in the scenarios in how they approach batteries and PV in general, Both GEE and SC show a higher investment and interest. While PC still increases its share of distributed PV generation, it lacks behind GEE and SC, as is shown in Table 5. Distributed PV generation had around 35% PV uptake in 2023 and is expected to rise to 70-90% across all scenarios by 2050 (AEMO, 2023 p68).

Table 5 - Scenarios and PV, Info from tables 1, 2 and 3.

Scenarios	GEE	SC	PC
Distributed PV generation (TWh)	92	77	45
% of household daily consumption potential stored in batteries	22%	21%	3%

In terms of distributed battery forecasts, GEE is forecasted to have an increase to around 37 GW, SC is forecasted to around 35 GW, and PC is forecasted to be around 5 GW. PCs lacking in distributed battery may have the potential to hinder this scenario's ability to meet the climate agreements, as the increase in battery storage use alongside the increase in rooftop solar units is a key combination for Australians to reduce personal reliance on non-renewable energies.

4.2 Overview of discussion and Results.

Table 6 - Electrification results

Electrification			
Scenarios	Green Energy Exports	Step Change	Progressive Change
Overall impact	GEE	SC	PC
Planetary Boundaries			
Novel entities	Due to uncertainty with increased battery production	Due to uncertainty with increased battery production	Due to uncertainty with increased battery production
Climate change	Increased Electrification on all sectors is overall positive	Lack of investment compared to GEE	Lacks Electrification compared to other scenarios.

The results of the scenarios approach to electrification can be seen in Table 6. It shows that while electrification (especially in the transport sector) faces many challenges, particularly in initial cost of EVs and their environmental impacts during production, it may be beneficial financially and environmentally. Therefore, both GEE and SC may meet expectations due to their increase in electrification investment and focus of changing the energy grid. In contrast, PC may not meet expectations when it comes to electrification due to economic challenges, resulting in its lower electrification rates. The problems arising from increased use of produced EVs in terms of battery production is overshadowed by the long-term effects of using EVs as opposed to traditional transportation. As has been stated, this is due to the emissions produced from traditional combustion engines continuously emitting emissions during their usage lifetime.

Table 7- Decarbonisation Results

Decarbonisation			
Scenarios	Green Energy Exports	Step Change	Progressive Change
Overall impact	GEE	SC	PC
Planetary Boundaries			
Novel entities	Due to challenges shared with electrification, may not improve this boundary.	Due to challenges shared with electrification, may not improve this boundary.	Due to challenges shared with electrification, may not improve this boundary.
Climate change	Expected to meet net zero emissions by 2050	Expected to meet net zero emissions by 2050	May not meet carbon emission goals due to lack of initial investment.

The results of the scenarios approach to decarbonisation can be found in Table 7. It shows that political and economic challenges prove to be the biggest challenges in transitioning away from carbon emitting fuels. In order for Australia to meet its carbon goals, all scenarios take this into account. Particularly PC challenges this difficulty, and as such may not meet expectations in the decarbonisation sector, with lower investment across all four pillars delaying its potential for emission mitigation. On the other hand, both GEE and SC show promise due to their higher levels of investment in key pillars like fuel switching, energy efficiency, and carbon sequestration. GEE stands out for its rapid decline in natural gas use and early adoption of sequestration methods, aligning it closely with the 1.5°C decarbonization pathway. SC also offers a viable pathway, though its slower pace in early sequestration and reliance on DAC in later years may delay its impact, preventing it from meeting its goals.

Table 8 - Hydrogen and Biomethane

Hydrogen and Biomethane Utilisation			
Scenarios	Green Energy Exports	Step Change	Progressive Change
Overall impact from factor	GEE	SC	PC
Planetary Boundaries			
Novel entities	Largely unaffected by fuel switching	Largely unaffected by fuel switching	Largely unaffected by fuel switching
Climate change		Not as much or late utilisation of power switching	Not as much or late utilisation of power switching

Overall, all scenarios show investment in utilisation of hydrogen and biomethane. While hydrogen and biomethane usage is more environmental than fossil fuels when produced sustainably, the benefits gained from this may be diminished when early development is delayed as is seen in Table 8. SC and PC's approach to utilising this change is delayed, thus the environmental impact may prove a challenge for this sector to aid in meeting their goals. GEE, however, has early and significant investment in production, thus potentially minimising emissions sooner and promoting cleaner energy use.

Table 9 - PV power Generation

PV Power Generation			
Scenarios	Green Energy Exports	Step Change	Progressive Change
Overall impact from factor	GEE	SC	PC
Planetary Boundaries			
Novel entities	Increased Battery production	Increased Battery production	Increased Battery production
Climate change	Home power offsetting reliance on fossil fuels	Home power offsetting reliance on fossil fuels	Less utilisation of PV

Australia's potential for solar energy is immense, with all scenarios forecasting significant growth in photovoltaic (PV) systems, especially rooftop solar as shown in Table 9. GEE and SC lead in investment, with higher distributed PV generation, 92 TWh and 77 TWh by 2050,

and substantial battery storage capacity 37 GW and 35 GW. These scenarios emphasize integrating PV with battery systems, potentially reducing reliance on non-renewables. PC however has a severely limited investment in battery storage, potentially limiting the usage of solar panels in the residential sector.

The study on these scenarios shows that although all scenarios aim to meet Australia's goals of meeting the Paris climate agreement, not all scenarios may succeed successfully for sustainably. GEE emerges as the most promising scenario due to its aggressive push toward renewable energy, electrification, and carbon sequestration. However, even this pathway must be implemented with careful consideration of environmental and social impacts, such as land use for renewable projects and resource extraction for batteries. If GEE is to meet Australia's energy goals, methods in transitioning Australia's energy grid and its approach to decarbonisation need to be done so sustainably. The result of this paper also questions the wisdom of adopting slower change scenarios, as a lacking scenario may be a waste of investment which may be needed for higher action scenarios.

5 Conclusion

The results of this research show that while a plan to increase electrification in a power grid and transition away from fossil fuels may meet climate goals, a lack of haste may hinder whether this transition is done in time. Global temperatures continue to rise, and a plan that relies too heavily on late development of low emission fuels or lack of general electrification may not allow a country to meet its climate agreements. General electrification through these scenarios is achievable, but will require a heavy investment, and it is uncertain if a medium or low investment may show results that are needed. Decarbonisation is also shown to be achievable, however a general medium to low investment across all scenarios for non-energy emissions reduction might prove to hinder results. Solar growth in Australia proves to be a backbone for clean energy generation, and across all scenarios should prove to aid in the energy transition process.

The overall analysis of these scenarios raises a broader question: is a slower transition even a viable option, given the urgency of climate action? The risks associated with small,

incremental change, as shown by the PC scenario, suggest that insufficient investment and delayed action could possibly result in detriments like higher long-term costs, and an inability to meet international climate commitments.

In terms of the effects on planetary boundaries, the result does not show perfect improvement across all scenarios. Australia's reliance on imported EVs may show a negative approach to vehicle electrification, as the sustainability of these imported EV's during the production process can be put into question. Much of the success of the scenarios sustainability targets especially when it comes to electrification relies on investment into new technologies, thus there is some uncertainty in these sections of the scenarios. This study was limited in that individual state legislation was not analysed, as these have very little amount of change between the scenarios. Furthermore, there is very little difference observed in wind between the scenarios, and nuclear was not mentioned at all.

The result of this study should act as a guideline for further research into each sector and what further implications may arise. Especially a look at the investment cost/benefit for each sector would prove to show what path Australia should take from this point forth.

Ultimately, Australia's ability to align its energy transition with the Paris Agreement may depend on the level of commitment to rapid decarbonisation. Policymakers and industry leaders should take these scenario outcomes as an indication that half-measures may not be enough.

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