Industry Super Australia

Modernising Electricity Sectors

A guide to long-run investment decisions

Discussion Paper - June 2019

About Industry Super Australia

Industry Super Australia (ISA) is a research and advocacy body for Industry SuperFunds. ISA manages collective projects on behalf of a number of industry superannuation funds with the objective of maximising the retirement savings of over five million industry super members.

The views expressed in this discussion belong to the authors and do not necessarily reflect those of ISA. Please direct questions and comments to:

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ENERGY REPORT

HERE'S THE STATS

THE FACTS

- Energy carried by wires is used for heating, cooling & lighting homes & workplaces.
- 35% of energy used today.
- Replace 13 GW of Antique coal-fired generation by mid-2030s.

Source: AEMO, Dept. of Environment & Energy.

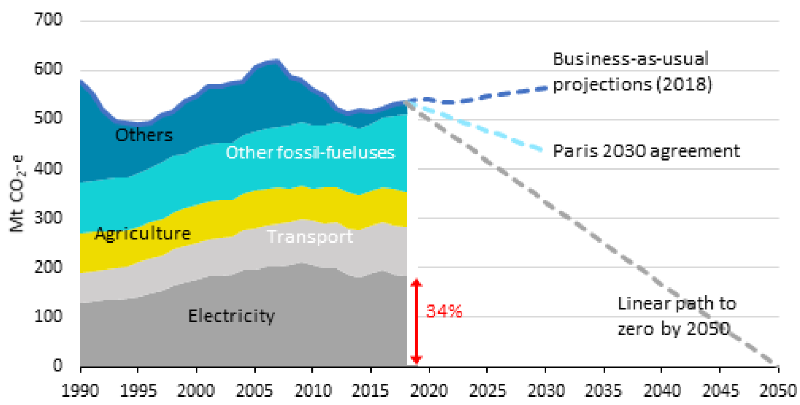
THE KEY POINTS

1. Prosperity, safety & security
2. Underpinning economic competitiveness
3. Driving productivity and jobs
4. Supporting growing population

SO WE'RE FACED WITH A TRILEMMA... HOW DO WE BALANCE THE GENERATION OF

CHEAP ENERGY | **RELIABLE ENERGY** | **LOW EMISSION ENERGY**

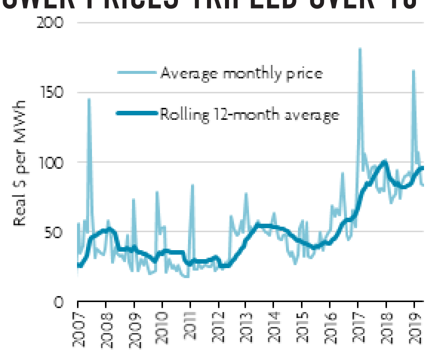
CO_2 EMISSIONS STILL RISING, NEED ZERO EMISSIONS BY LATER IN 21C[ST]



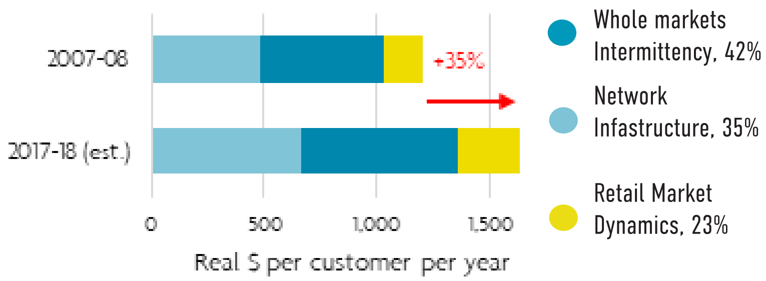
Achievable by reforming the electricity sector

NEED BOLD PLAN & ACTIONS

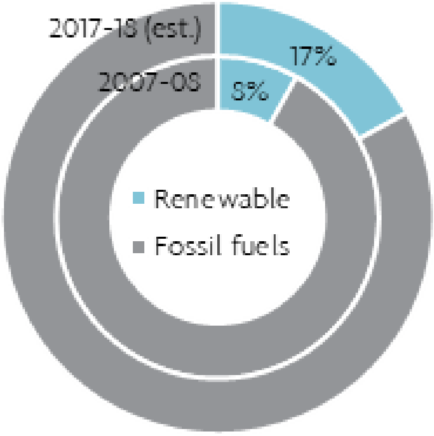
POWER PRICES TRIPLED OVER 10-YEARS



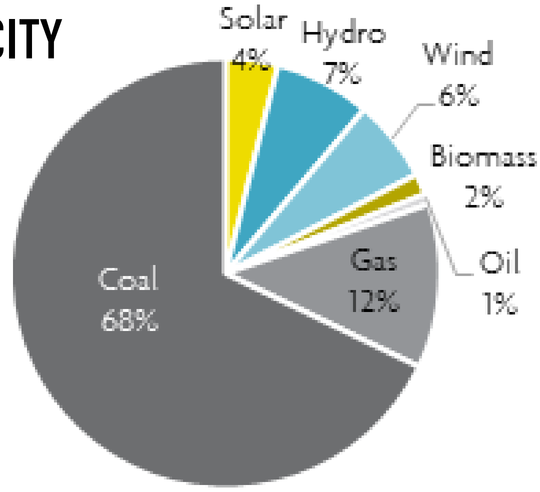
KEY FACTORS DRIVING PRICES



ENERGY MIX MUST PIVOT TO RENEWABLES & NEW FIRM CAPACITY



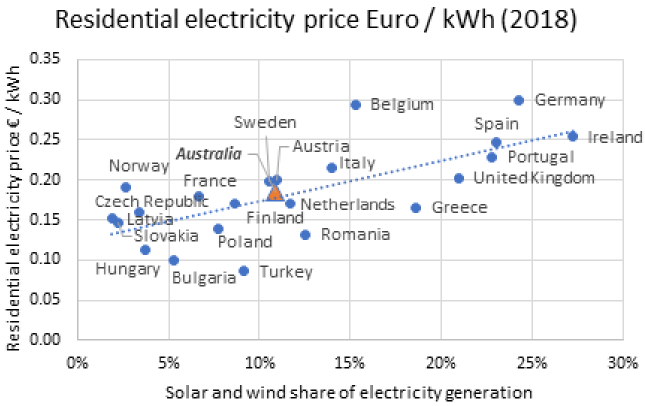
Last Decade



Today

More intermittent supply = higher prices w/o offsetting changes in the grid

INTERNATIONAL EVIDENCE



Source: EuroStat, BP Statistical Review of World Energy & AEMC

INVESTORS' PROBLEMS

- Price spikes should drive investment
- Not in absence of robust policy
- So market 'gamed' by speculators
- Risk to invest in firm capacity

NEED SIGNIFICANT NEW FIRM CAPACITY

Need 15GW of new firm capacity by 2037.

INDUSTRY SUPER CAN HELP

- ✓ Framing long-term vision
- ✓ Drive short-termer's out market
- ✓ Assisting govt. with policy frameworks
- ✓ Making strategic investments in energy grids
- ✓ Investing in new technologies and start-ups

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Executive summary

Societies around the world are facing high levels of uncertainty about energy and emissions and this creates unprecedented problems for investors.

The aim of our discussion paper is to help industry superannuation funds build the capacity to understand and deal with uncertainty in the context modernising the electricity sector. It is an attempt to provide a general overview of the issues and clear principled guidance on investment and policy. It is not intended to be another set of middle-of-the-road investment hints. In fact, one of the themes is that a good deal of mainstream thinking may be misleading.

We aim to assist industry superannuation fund thinking about decision making under uncertainty and how to assess the alternative technological options and costs. We also provide some key take-outs for investors.

We also attempt to outline some features of an optimal policy response. Some understanding of this is essential to help industry superannuation funds engage with government and for formulating long-run investment strategies.

Underpinning our analysis is the assertion that the best public policy outcomes come from laying down basic principles that help us think through the relative merits of alternative approaches.

Principles

The suggestions that stem from this paper are based on eight principles:

1. Optimality – start with the end goal in mind and find the best way of reaching it.
2. Efficiency – dealing with market failures simply and at their source. Over time reducing emissions at the lowest possible cost whilst minimising collateral impacts.
3. Equity – while targeting market failures, pricing externalities, quarantine the disadvantaged.
4. Fair trading – treating participants equally, agnostic to technologies and market structure.
5. Stewardship – make choices in members' long-term interests.
6. Merit – addressing issues on their merits, whilst avoiding ideological prejudices.
7. Comparability – comparing alternatives on a like-for-like basis.
8. Flexibility - always leaving room for alternative technical approaches and advances.

Key takeout

The lack of a genuine long-term technology neutral energy policy is a major factor undermining fund investment. Industry superannuation funds stand ready to allocate capital towards the electricity sector but need to see governments put in place a comprehensive energy policy framework that deals with reliability, competitiveness and emissions reduction aspects. This is vital to provide the necessary certainty for investors.

In the absence of a comprehensive policy agreement, investors can take two broad approaches:

- Long-term solution – this is the high road that anticipates future government decisions, making strategic investments to fill gaps in networks and replacing existing fossil fuel generation with alternative technologies.
- Business-as-usual – this is the low road where investors seek to capitalise on price movements in electricity markets and/or to maximise public subsidies paid to participants.

Industry superannuation funds should attempt to nudge the sector towards a long-term solution.

It is also suggested that a carbon price be adopted to ensure the full social cost of emissions is counted and that markets work properly. All proceeds should be reimbursed to the public.

Specific takeouts

Among the more specific messages for investors in this discussion paper are:

- The energy sector is being disrupted. This means that pattern recognition (historical risk-return trends) are a poor guide to investment. To navigate a way through you must begin by working backwards from end goals to the present day.
- Even without climate change the existing fleet of base load generators needs replacing. This is an opportunity for modernisation must assist energy reliability, competitiveness and emissions reduction.
- A rough summation of our technical analysis is that there is no simple solution to Australia's energy trilemma right now. This also means there is no reason to exclude any of the major technological contenders considered below from the current or future energy mix.
- Minimising volatility for a given rate of return in an investment portfolio is a virtue wherever possible, in the same way utilities engineer-out variation in electrical systems. Part of this involves investing only in feasible technologies and solid policy frameworks.
  - Only speculators or gamblers invest in a limited and undiversified profile of technologies. This is not investing, nor evidence-based policy making.
- Still there are a wide range of investment opportunities in both the long-term and the business-as-usual cases.
  - Whilst funds can clearly benefit from business-as-usual the principle of stewardship and concern with the long-run stability of their investment portfolio creates an imperative to nudge the sector toward the high road.
  - In the event of poor policy making, far-sighted funds may be able to see the opportunities associated with pre-empting future government decision-making to fill pot holes in grids, replace existing network capacity, or develop innovative financial products that better help to manage risks both here and overseas.
- To fulfil its obligations to its members the sector needs to engage with government in designing the long-term investment instruments needed to modernise the energy sector. It should also be engaged in building capacity and expertise in energy related investments.
  - Consideration should be given to stabilising electricity markets using the type of long-term supply agreements which underpin overseas markets and would assist diversification of the technology mix in the electricity system.

Overview

Societies across the world face high levels of uncertainty in their electricity sectors produced by difficulties in emissions reduction and by rapid shifts in technology. As an example of the challenges the sector faces, the IPCC special report released in October 2018 reduced the time horizon for obtaining zero emissions from late this century to 2050.[1,2] Any attempt to approach this target would require changes in the global energy production mix at an unanticipated rate. The uncertainties this produces in terms of global reactions, rate of climate change, technological mixes and international economic pressures is acute in Australia. There is a pressing need to modernise our electricity sector. This must be done in a way that meets three goals simultaneously:

1. Reliability.
2. Affordability.
3. Emissions reduction.[3]

The way to balance the elements in this trilemma is not clear. Certainly, domestic policy responses so far have not created an environment that produces a stable and coherent investment environment.

There are considerable difficulties for industry superannuation funds in trying to understand future developments and in formulating investment strategies. There are also large opportunities.

The aim of this discussion paper is to provide a framework for industry superannuation funds to think through these issues. It is an attempt to provide a general overview of the nature of the problem faced as the foundation for clear principled guidance on investment.

To achieve these aims it is necessary to develop a viewpoint with a scale and time horizon commensurate with the responsibility of the superannuation funds to their members and the community at large. It also requires time horizons consistent with the lifespan of the investments being considered.

It is also necessary to consider possible policy directions for government. These will impact on long- and short-term investments. It is imperative that industry superannuation funds have a coherent position to take to government in any discussion of future directions and the design of financial instruments.

To this end some effort is devoted to thinking about the type of policies that will be consistent with long-term energy security and sustainability and, by implication, the directions that industry superannuation should support in order to ensure the long-term interests of its membership.

This discussion is not intended to provide another set of middle-of-the-road investment hints that more or less follows the herd. In fact, one of the themes is that mainstream thinking may be misleading in many areas. It is often based on a partial analysis of the problem that ignores its economy-wide implications. Its assessment of technologies is sometimes weak. It is also often based on time horizons that are too short.

[1] IPCC, 2018.

[2] Zero emission is used as a shorthand for very low emissions or close to zero on balance when natural and other processes that reduce greenhouse gas concentrations are considered.

[3] This is the energy trilemma which underpinned much of the Turnbull Government's thinking on climate change policy which flowed out of the Finkel Review.

Rebuilding and modernising Australia's energy structure will require significant investment. The opportunities for superannuation funds and other long-term investors will depend on their capacity to participate in secure financing arrangements. Some of these may involve partnership with government. It will also depend on their capacity to assess opportunities provided by changes in technologies and policy settings.

In brief, the adjustment task facing the Australian economy centres on the rate at which the economy decarbonises. This is not simply a question about the rate at which the electricity sector replaces existing coal-fired generation. It also involves longer-term questions about shifts in transport and other industrial sectors.

It follows that the focus should not only be on the ability of solar and wind to fill gaps in current electricity production. It should also be on the trajectories that will provide the required energy and reliability on a larger scale.

We will examine:

- Australia's electricity sector and problems with energy security and emissions.
- The nature of uncertainty and the analytical tools available to deal with this.
- Issues and problems with some common approaches to the problems of uncertainty.
- Costs and capacities of the available technologies.
- How (and over what time period) to effectively replace Australia's ageing fleet of generators to make electricity more affordable and help the nation meet its longer-term climate goals.
- Longer-term policy options for government in a scenario where a sustainable path is followed.
- The circumstances under which Australian superannuation funds' investment is justifiable on a risk-return basis and feasible technological targets.
- The different approaches that the investment community might take in the absence of a robust policy framework from governments.
- Questions about how superannuation funds and institutional investors more broadly can assist governments in the transition.
- A set of subsidiary questions regarding policy frameworks and the intellectual tools we have for dealing with unprecedented problems.

Underpinning our analysis is the assertion that the best public policy outcomes come from laying down basic principles that help us think through the relative merits of alternative approaches.

Principles

Our analysis is anchored by the following eight principles:

1. Optimality – back-solving, starting with the desired outcome or end point and then finding the best pathway to reach it.
2. Efficiency – dealing with market failures simply and at their source. Over time reducing emissions at the lowest possible cost whilst minimising collateral impacts.
3. Equity – while targeting market failures, pricing externalities, quarantine the disadvantaged.
4. Fair trading – treating participants equally, agnostic to technologies and market structure.
5. Stewardship – choices in members' long-term interests.
6. Merit – addressing issues on their merits, whilst avoiding ideological prejudices and bias.
7. Comparability – comparing alternatives on a like-for-like basis.

8. Flexibility – leaving room for alternative technical approaches and advances.

These principles force us to think clearly about issues. The first principle is fundamental to this discussion paper. It is sometimes called the Bellman principle in mathematics. It says start from the end state and work backwards to find the optimal trajectory. Roughly, if you don't know where you are going you are unlikely to be on the best path to get there. This avoids wasting resources on short-run investments that may prove to be on the wrong trajectory and strand assets at later times. Efficiency fair trading and merit mean that we must be technologically neutral. All possible technologies and market and non-market solutions must be considered simply in terms of merit. Flexibility and capacity building are needed to support to deal with uncertainty. To satisfy these principles we also need to reassess our analytical techniques. Off-the-shelf approaches may fail the efficiency and merit tests.

In some cases, following these principles will produce discussion and recommendations that go against conventional wisdom and taken-for-granted assumptions. No attempt is made to avoid this. Our aim is to provide the best analysis possible. It is not to simply be popular or 'run' with the herd.

One example of this is that nuclear energy is not excluded from the study. This seems to have caused alarm. It does not mean we are pro-nuclear any more than not excluding solar means we are pro-solar. We are, however, pro the principle of optimisation.

We begin by describing the sector and underscoring its importance to the economy. We then describe how we think about decision making under uncertainty. We then assess the alternative technological options and costs. Finally, we describe key take-outs for investors and for policy makers.

The importance of electricity

The Australian economy requires cheaper electricity and alternative energy sources, along with secure supply to remain globally competitive. Our nation with its burgeoning population is hungry for new and improved infrastructure. More roads, tunnels and pipelines. More buildings, brick pits, new aluminium smelters, steelworks, concreate and paper manufacturers, chemical works and refineries. But no one is building them and some are closing down.[4] The reason is that all of it requires more energy and we have experienced a policy induced energy drought in Australia. In 2018 the regulatory uncertainty surrounding climate policy is high and rising.

The electricity sector is important to Australia's security, competitiveness and the overall efficient functioning of the economy on many levels.

Electricity is used by all sectors across the economy and as such it is a cost input for all sectors. Rising electricity costs lift total costs and prices for output, reducing enterprise competitiveness.

Export oriented businesses that have a significant input cost share of electricity are significantly impacted by rising electricity prices in terms of their trade position. For Australia, several key export industries, such as the aluminium industry, are particularly energy intensive and so are especially vulnerable to cost hikes. Exacerbating this is the fact that many competing exporting countries have their plants powered by much lower carbon emitting electricity sources, such as hydroelectricity.

For households, electricity is the predominant form of energy consumption and increases in household electricity prices can lead to reduced consumption of many other goods and services. Furthermore, lower income households are disproportionally impacted by rising energy costs since they spend a much higher share of their income on electricity bills.

[4] Phillips, S., 2018.

The production, distribution and transmission of electricity is itself a significant segment of the Australian economy. In 2017-18, the sector contributed $25 billion to GDP (1.4 per cent of total activity) and employed around 68,000 people.[5]

In recent years, electricity has been one of Australia's least productive industries, showing flat or negative productivity growth for several years.[6] The Switzerland based IMD's 2019 World Competitiveness Yearbook, compares and ranks 63 countries based on more than 340 business competitiveness criteria. Two thirds of the criteria are based on statistical indicators and one third is based on a survey of more than 6000 international executives conducted in March/April this year. The Yearbook includes a rank for the adequacy and efficiency of energy infrastructure. In 2019, Australia ranked 55th on energy infrastructure compared to 29th a decade ago. This has occurred alongside a deterioration in Australia's overall ranking on the survey coming in at 18th this year - Australia hasn't ranked in the top 10 most competitive nations since 2011. Clearly, we need a complete overhaul of policy before large swathes of heavy industry goes offshore. If that happens Governments will then face huge economic and social adjustment burden as whole industries need to transition to new workplaces in new regions.

Emission targets

The scientific consensus is that emissions of greenhouse gases need to be close to zero before the end of this century. It seems reasonable to assume there is currently no path to achieving this end that does not involve replacing existing technologies with some zero emission alternatives. This provides the end point we need under the principle of optimality.

Reaching this end point presents a problem for Australian policy makers. It has been almost impossible to separate energy and climate issues in terms of investment decision-making and public policy in Australia for the past decade.

It is argued that domestic and international pressures for appropriate responses may change rapidly. This creates a serious risk of being left with inappropriate infrastructure and stranded energy generation assets unless properly managed.

The challenge of uncertainty

The electricity sector faces high levels of uncertainty produced by difficulties in dealing with the problem of reducing emissions and by rapid shifts in technology and international expectations.

The term uncertainty is used to refer to situations where it is difficult to say which of the possible future states of the world will occur or to assign a meaningful numerical probability to their occurrence. The outcome of a coin toss is not uncertain, for example. It can be described in terms of probabilities. Uncertainty refers to situations where it is difficult or impossible to assign a meaningful numerical probability to future states of the world.

It is important not to confuse uncertainty with ignorance. Uncertainty doesn't mean that everything is equally likely. It is possible to determine directions of movement and technological and economic barriers and impediments to certain types of development. In addition, the recognition that possible outcomes are uncertain also carries information. It provides a framework for thinking about events and signposts for investment.[7]

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[5] ABS 5204.0, 2018.

[6] ABS 5260.0.55.002, 2018.

[7] Examples of uncertainty:

- Acceptability uncertainty. Even if risks are known, what are the cut-offs for acceptability? Is playing climate Russian roulette with a probability of 1/3 acceptable? Is 1/10 or 1/30 acceptable?
- Asset value uncertainty. Will climate policy strand the values of fossil fuel-based assets?

This discussion paper represents the authors' attempt to understand these uncertainties and suggestions for dealing with them. Our primary objective is to provide decision-makers and other long-term investors with a framework for thinking through lumpy investment decisions.

Lack of policy certainty

The lack of a genuine long-term technology neutral energy policy is a major factor undermining fund investment. Certainly, investors looking for longer-term solutions such as possible clean coal technologies, or gas-fired base load, and especially (small or large-scale) nuclear, would be placed in an extremely risky position. Right now, it seems the only politically acceptable investments appear to be relatively small scale, quickly deployed renewable wind or solar projects. As this discussion paper shows, it is far from certain that this is a complete solution or puts us on the optimal trajectory.

The reality is that even without climate change the existing fleet of base load generators needs replacing. AEMO expects that about 60 per cent of current coal-fired generation capacity will retire by 2040.[8] And they cannot all be replaced by small-scale renewables in the existing grid. Either the grid design radically changes, or new baseload of some type is built. Both require large-scale and costly changes.

In the normal course, portfolio investors would be lining up to fund long-term solutions in this changing industry for Australia. But so far, the silence from investors is deafening. This is no surprise given the uncertainties around climate policy in recent years and related Environmental, Social and Governance (ESG) risks. Without consistent policy settings adopted by Australian governments this situation is unlikely to change.

On the other hand, we believe there is room for optimism. Much of the uncertainty discussed in this discussion paper can be managed if properly understood. A large part of this will be actions on the part of government to support revenue streams and technological decision making.

It is stressed that these actions will require innovative financial arrangements and investor involvement. These need to go beyond exposing firms to unacceptable risks or Private Public Partnerships. A good example of such financial innovation is the Oresund Bridge between Denmark and Sweden.

In the larger picture, certainty that the ageing fleet of generators must be replaced means that it should be a market ripe for long-term successful investments. From great uncertainty, if managed well, comes great opportunity. Whoever the winners are, they will likely be holding profitable and successful assets.

Lack of supply agreements

The problem of uncertainty is made worse by fluctuations on the demand side. The Australian electricity market lacks the long-term contractual framework which underpins markets overseas such as the United States' Power Purchase Agreements (PPAs). In the United States (US), for example, 20-year PPAs are currently awarded for solar, wind, hydro and nuclear power

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- Time uncertainty. Even if the direction of policy and economic changes are known when will they occur?
- Political uncertainty. Will the political costs of action to reduce emissions change? If so, when and how fast? Will changes be domestic or international?
- Climate uncertainty. At what times and rates will various climate change impacts occur? How soon is action necessary? Recent IPCC reports have dramatically reduced the time available for example.
- Portfolio uncertainty. To avoid wealth decreases when interest rates increase, should I add electricity assets to my portfolio or not?

[8] AEMO, 2018c. pp. 21-22.

generation.[9] The lack of these long-term contracts inhibits the development of the Australian market.

Need for better analytics

The intellectual frameworks and taken-for-granted assumptions often used in our policy models may create distortions in policy analysis and make them ill-suited as guides for long run thinking. It is essential to examine these frameworks to ensure the problems we are trying to solve are properly understood and appropriate technologies and costings are employed. Without this we run the ever-present risk of systematic error.

If the trajectory for the development of the energy system is pushed away from the optimal path by ill-suited models the economy may suffer on-going costs. Infrastructure and technologies may be inadequate. This in turn creates distortions and other knock-on difficulties across the system. This in turn may require increasing levels of support by subsidies and special deals.

Facing up to hard constraints

The problem of electricity reliability, affordability and emission reduction involves hard capacity constraints, beyond the simple comparisons of plant level costs now very familiar to financial analysts.

- The hard constraints on the electricity system over time are partly due to the need to reduce emissions by some specified amount and time.
- The value of a technology is evaluated in this discussion paper as the intersection of its capacity and full system costs.

Emissions targets are hard because levels cannot be replaced by substitute goods or traded off at the margin. [10] An energy technology that is lowest cost per unit is not necessarily the best choice if it cannot meet capacity and reliability requirements. Absence of substitutes means that questions like, 'can we afford to meet these targets? 'don't make the usual sense.

Once the emissions and capacity constraints are accepted, the question becomes: 'What is the best way to achieve these? Which technologies and strategies can provide the capacity within the emissions targets? Can they meet the time constraints?

Ill-suited economic policy models

Among other problems with some of our accepted thought patterns is confusion between uncertainty and risk. For example, a debate that centres on a decimal point in a growth parameter seems similarly out of scale when discussing the possibility of economic collapse.

To be clear, it is not being argued that the numbers being assigned to risk are wrong. It is that the treatment of risk, uncertainty and hard constraints is inappropriate.

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[9] There is significant investor demand to own these PPAs due to the long-dated, contracted revenues that are either set at a fixed price in the agreement, or at times have a fixed price component along with a CPI escalator (common in older PPAs). Utility PPAs are also attractive since they are backed by investment grade counterparties, which make them financeable at relatively low interest rates; United States. Utilities typically have superior credit ratings relative to other energy companies of similar size in that country. The long-dated revenues, CPI escalators and investment grade credit rating of the 'off-taker' (the utility), all support the cash flow visibility of the underlying assets in the eyes of long-term investors and provide attractive returns on a risk-adjusted basis.

[10] We do not consider geo-engineering.

Another issue is confusion around discount rates. The use of fixed discount rates or a discount rate derived from standard commercial rates makes no sense. It may lead to poor estimates of the net present value of future economic states.

Ill-suited frameworks for thinking about political changes

It is also necessary to think more carefully about political changes. These are fast compared with economic and technological change and are both international and domestic. They are major contributors to uncertainty, but they are difficult to predict. On the other hand, we can use better or worse frameworks for thinking about them. We can develop better perspectives in order to hedge our policy and investment decisions more wisely.

In this section we suggest a more systematic discussion than that commonly found in the literature. This gives a better understanding of international and domestic pressures and allow us to develop some important insights. Among these is the non-linear effect of ratcheting on policy.[11]

Need for more careful assessment of technologies

The choice of technology also needs to be based on sound analytical principles and models. It needs to be made independent of quick political fixes and short-term expediency. It needs to be technologically neutral.

The analysis needs to take long-term constraints and targets into account rather than relying on short-term considerations of commercial return. The common practice of relying heavily on estimates of levelised cost and market tests applied to developments in isolation can be misleading. Worse, it may cause serious economic damage to the national economy if narrowly defined economic gains lock-in long-term inefficiencies.

In this discussion paper we try to provide a more careful analysis of comparative costs. We show how this varies according to the measure used, for example market price, cost of unit of emissions avoided, total net social value and so on.

As will be clear, these different measures have important implications for policy trajectories.

Principled policy choices

Whatever energy and emissions reduction policies are adopted need to pass the test 'what is the best means of achieving the long-run targets at the lowest possible overall cost?', in order to satisfy the efficiency principle. This may not be the same as short-term marginal cost. In the end it will be necessary to replace existing baseload and gas generation capacity with lower emissions technologies. Unfortunately, the challenge of doing this is severe. There are, however, better and worse approaches. We will explore these issues as part of our attempt to give the industry superannuation funds some guidance on the policies that are likely to emerge and should be supported in future.

The best long-term policies will involve conscious choices by government over technologies, grids and energy transitions more generally and where necessary it may also require direct involvement and carefully thought-out guidelines. The possible options and range of choices over technology financing and the grid are discussed in detail throughout.

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[11] The Oxford Dictionary defines ratcheting as a situation or process that is perceived to be changing in a series of irreversible steps. Around the world governments face increasing pressure to respond to global warming. Whilst responses are uncertain, the direction of policy change over time is going one way – towards emissions reductions - and political pressure for change will only increase as time goes by. This realisation is essential for managing uncertainty as it gives long term planners in the economic and financial sphere a strong lead on the future.

The idea of leaving the transition to a modern electricity grid to the market and short-term profit considerations is misguided in a situation where the market is clearly imperfect and cannot deal with uncertainties or externalities.

The one thing that would most help remedy market distortions is the introduction of a price on emissions with the proceeds reimbursed to the public. This is seen as a necessary but not a sufficient condition for achieving long run efficiency. It is a straightforward textbook way of dealing with externalities and avoiding market distortions. It is widely supported by the international economic community.[12] It is also supported in Australia by economists such as Geoff Carmody.[13]

Introducing a price of this kind is consistent with the analysis of this paper and is strongly recommended. It is so well covered in the literature that we do not develop it further. It is about the only policy suggestion we make which is considered 'self-evident'.

Industry superannuation funds stand ready to allocate capital towards the electricity sector but need to see governments put in place the appropriate frameworks that deal with the underlying externality (carbon pollution) and provide the necessary certainty for investors.

Sticking to our principles?

If a first-best approach is not possible, it is necessary to find substitute arrangements that satisfy our principles that are politically feasible.

One approach would be an emission intensity scheme, where a production side levy is imposed on emissions, so that heavy emitters (and their customers) bear the burden.

Another approach is to tender contracts to neutral - lower emissions - energy sources to replace capacity that is now ageing and about to go out of business.

Both approaches achieve, through economic regulation, an orderly and a cost-effective replacement of all existing high-emitting generation capacity. However, compared to first-best approaches such as a market mechanism (or carbon price), it does not deliver economy-wide efficiency gains. Certainly, it places too much of the adjustment burden on domestic users of electricity (firms and households). Therefore, these alternative approaches are far costlier than a market-based mechanism.

Both alternatives support sensible long-term decision making and so encourage investment in lower emission technologies. So they are far better than doing nothing at all.

The likely energy mix going forward

The future of the energy market in Australia relies largely on the policy responses of governments. Although these cannot be predicted with certainty, the approach of this discussion paper is to identify the most feasible, cost effective adjustment path over the medium-term.

The principle of efficiency suggests that this trajectory will involve adopting a mix of generating capacities. These will include renewable technologies including solar, wind, hydro and battery storage with some pumped hydro and combined cycle (CC) gas generation as a backup. Gas produces significant emissions,[14] and this may operate as a strong inhibiting factor on its long-run value without carbon capture and storage. Coal seems increasingly risky unless carbon capture and storage becomes an option. It is difficult to see how these problems can be

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[12] World Bank, 2017.

[13] Committee for Economic Development of Australia, 2011. pp. 9-25.

[14] About half of the emissions from coal.

resolved without some nuclear in the mix and the principles of optimality, fairness and merit would suggest it should not be discounted. Alternative technologies and costs are analysed in detail in Section 4.

It is also suggested that these technological decisions be made in advance of making serious investments in upgrading the transmission grid.

Will government react appropriately? It is certainly the case that large institutional investors have an interest in pushing for best practice responses and this will certainly be a major factor in the policy response. Possible reactions are analysed further in Section 4. It is suggested that there is a ratcheting effect that may push government towards tracking optimal policy settings over time.

Rationale for institutional investors

In the absence of a comprehensive policy agreement, industry superannuation funds face a difficult task in acting as stewards in their members' interests and accepting their broader responsibilities to the community. They can take two broad approaches:

- Long-term solution – this is the high road that seeks to influence and anticipate future government decisions. It is concerned with making strategic investments to fill gaps in networks, replacing existing fossil fuel generation with alternative technologies.
- Business-as-usual – this is the low road or the 'party investor' approach. It seeks investments to capitalise price movements in electricity markets, and/or to maximise public subsidy paid to participants.

Industry superannuation funds can clearly benefit from business-as-usual. On the other hand, the principle of stewardship and concern with the long-run stability of their investment portfolio creates an imperative to nudge the sector toward the high road.

The speed at which governments set in place robust frameworks to deal with the adjustment task will determine the signals sent to portfolio investors about relative merits of different investment approaches. The overall economic costs associated with the policy will depend on the extent to which they track the optimal trajectory. This will also determine the extent to which successive waves of capital flow into dynamic investment proposals which unlock virtuous rounds of productivity growth which fund managers can unlock through alternative generation infrastructure.

Leave dogma at the door

Our preferred macro-policy alternative is some form of carbon price together with long-term contracts to energy market participants to replace capacity that is now ageing and about to go out of business.

This approach is consistent with the efficiency principle. It would be based on a genuinely technologically neutral discovery process which looks at uncovering what delivers the best combination of lowest cost, reliability and emissions reduction. This process should be guided by a panel of scientists and policy experts. It should be unencumbered by pre-existing policy taboos and assorted medieval quackery.

The question should not be "renewables or coal". The focus should be on the best strategy to reduce atmospheric greenhouse emissions.

Pursuit of a global solution

It is in Australia's interest to be a good global citizen. IPCC reports show Australia is a country that sits at the higher end of potential damage from climate change and it would be a net beneficiary of action to reduce the potential impact.

It is argued in Section 4 that the international and domestic situation could change rapidly. Failure to begin reducing emissions now increases the risks of stranded assets and possible retaliatory action from trading partners which could be potentially damaging for a small open economy.

Another important avenue of international co-operation studied below is research and development. This could be an area where Australia can contribute disproportionately and perhaps fashion new industries and jobs.

Policy suggestions

The analytical approach is to think decades into the future and examine how to develop a realistic and diversified technology mix. The idea is to think clearly about the problem and back solve to today. Changes may come rapidly and there is a danger of being too far along a sub-optimal road that will seriously damage the economy and portfolio values broadly. For long-term investors the message is about the same. Spread, hedge and engage with government.

Our attempts to deal with uncertainty and the structure of the electricity industry in Australia has generated several suggestions. Many of these overlap and need to be carried out simultaneously.

1. The principles of long-term optimality and dynamic efficiency say that policies should be guided by the objectives that have to be met in order to reach a stable economic state and that steps should be taken to institutionalise these objectives. They should make sense in terms of these objectives and be guided by no-regrets strategies rather than short term market or political considerations. To allow markets to begin to reflect real social costs it is necessary that some form of carbon pricing be adopted.
2. The principle of fairness says that policies should be neutral to technology and market structures. The choice of market structure requires careful thought and cannot be divorced from decisions about technology.
   - Markets do require more planning.
   - Markets do require more competition. In accordance with the original 1997 National Electricity Market (NEM) rules private investors/operators are only beneficial in the context the pro competition rules and a prohibition vertical integration of retail and generation ownership.
3. Be flexible in the face of possibly rapid change and leave room for alternative technical approaches. Australia lacks capacity in key areas. It runs a risk of being trapped without the financial or technical flexibility to expand or switch course.
4. Use analytical tools that are appropriate to judge policies on their merit
5. Encourage investment via long-term supply contracts underwritten by governments. These may be 20 years plus. But there are no off-the-shelf answers here.
6. Recognising that governments may need to formerly underwrite markets or indeed act as a generator of last resort. Don’t violate the merit principle.
7. Establish a new independent expert panel with advisory authority to bring stability to the policy process.
8. Establish a public authority for transmission and distribution planning.
9. Set emission targets as high as practicable. This comes out of our modelling. Emissions are easier to ramp up than to wind back.
10. Review company taxation arrangements to make greenfield investment more attractive.

11. Review industry policy and structural adjustment assistance to aid in insulating or transitioning those regions and sectors that are bearing most of the adjustment burden of fossil fuel reductions.
12. Define clear roles for long-term portfolio investors. They may also wish to consider co-investment options with superannuation funds in greenfield sites given that many funds have deep experience with these projects.
13. Extend domestic research efforts focussed on alternative fuels and join with international bodies in co-operative research efforts, enhancing Australia's status in this area.

Summary of this discussion paper

Section 1 provides the basic technical, economic and historical background through which to consider the economic contribution made by electricity generation to the Australian economy and its regional communities.

Section 2 briefly discusses the empirical data of Australia's fossil fuel emissions track record and future trends along with the recent history and current policy developments in emissions policy in Australia and globally. The emission targets that come out of this provide a range of feasible goals for policy. These are then used to structure the discussion of problems and of the policy and investor responses.

In Section 3, the politics and economics of energy markets and emissions are discussed. This is intended to deal with the issue of ill-suited economic and political models. A strong focus in this section is a detailed look at the role of uncertainty in the decision-making process for emission targets, domestically and globally, and policy settings. It also develops a little game theory to help explore possible outcomes for future global negotiations around emission targets.

Some of the more detailed and complex material underpinning Section 3 are developed further in Appendices A, B and C. In C we look at a dynamic model of emissions abatement. This shows that an optimum trajectory requires high levels of expenditure in the initial stages.

Section 4 looks at full impact costings and capacity assessments of wind, solar, CC gas and nuclear generation. We attempt to compare the costs of alternative generation capacities on an apples-for-apples basis in terms of their ability to contribute to the long-run zero-emissions target. We build up our comparison in stages. Eventually we take and make estimates of the full systems costs associated with different technologies into account and capacity of each technology to deliver lower emissions. In the later parts of this section we make some specific comments about the Australian economy, policy and investing.

Section 5 considers the opportunity set open to long-term portfolio investors considering the preceding analysis of uncertainty and our best guesses at future developments around the electricity sector in Australia and overseas.

A precondition for large-scale involvement in the energy sector by the funds management sector is stability in policy settings and engagement in policy development and evaluation. In the event of poor policy making, far-sighted funds may be able to see the opportunities associated with pre-empting future government decision-making to fill pot holes in grids, replace existing network capacity, or develop innovative financial products that better help to manage risks both here and overseas. Certainly, long-term investors need to remind governments of the need for creating a stable investment environment and to press government to give clear signals on carbon pricing and other policies.

These alternatives correspond to the long-term solution and the business-as-usual scenarios. We find that the more constructive 'higher road' and a more predatory 'lower road' each present opportunities and challenges for investors and governments. Finally, this section considers a set of factors that investors should consider when considering particular investment opportunities and structuring broader portfolios.

In Section 6 we look at a range of policy options that could be deployed to promote investment in the sector. These range from the seemingly obvious, such as having a long-term goal or coordinating energy and industry policy, to the complex, establishing a mechanism for investor of last resort if more market-based solutions fail to transform the sector.

This section also outlines some of the ways in which the industry can engage with the policy community in constructing creative financial instruments in order to accelerate major infrastructure developments and to stabilise investment portfolios.

Finally, Section 7 provides a summary of the major insights from the paper.

1. Australia's electricity sector

Australia's electricity is considered in this section. This provides the backdrop needed to think through the challenges it faces in the coming years.

1.1 Electricity 101

Whilst the electricity market is influenced by the basic economic principles of supply and demand there are several features that mean it's a complicated, networked and interdependent system of private and public sector players bound by the physics and engineering realities of electrical systems.

Electric power, like mechanical power, is the rate of doing work, or work per unit of time, and is measured in watts. The term wattage is used colloquially to mean "electric power in watts."

Units are:

- W is a watt. This is a unit of electrical or some other form of energy.
- Wh is a watt hour. This is the amount of energy used to get an appliance such as a lamp with a rating of one watt operated for one hour. If it were operated for three hours, it would use three times the energy or three Wh.
- kW is a kilowatt or a thousand watts.
- MW a megawatt or one million watts.
- kWh is a kilowatt used for an hour or half a kilowatt used for two hours etc.
- MWh is one million Watt for one hour or two million watts for one half hour etc.
- GW is a Gigawatt or one billion (a thousand million) watts. GWh is a gigawatt hour.
- Terrawatt is a thousand Gigawatts or a trillion watts.
- Gl or giga-litre is a billion litres of water.

The capacity of an electricity network, or an individual generator, is stated in the amount of electric power it can deliver per unit of time, usually in MW. For example, the Loy Yang B brown coal power station in the La Trobe valley has capacity of 980 MW.

One kilowatt (kW) of electric power operating for one hour is known as one kilowatt hour (kWh). Electricity is typically sold by the kilowatt hour (kWh), megawatt hour (MWh), gigawatt hour (GWh) and the terawatt hour (TWh) for larger volumes.

Finally, the number of TWh's produced annually is the common measure for Australia's, or the NEM's, aggregated electricity demand.

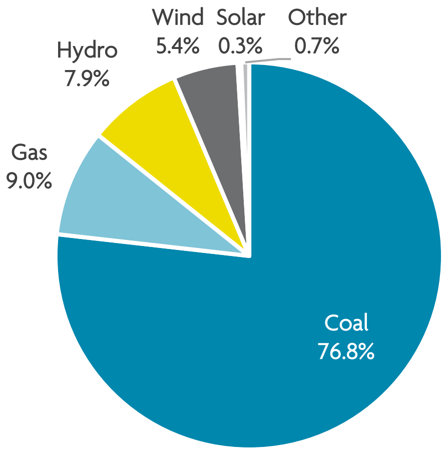
1.2 Electricity supply

Australia's electricity sector is broadly divided into five networks: the National Electricity Market (NEM) across eastern Australia; the south-west and north-west interconnected systems (SWIS and NWIS) in Western Australia; and the Darwin–Katherine and Alice Springs systems in the Northern Territory. Some electricity is also produced off-grid to supply remote users such as mines and farms.

The largest of the five networks is the NEM,[15] covering the eastern seaboard from Queensland to Victoria, including Tasmania and South Australia.

- It is one of the world's longest interconnected electricity system with an end-to-end distance of 5,000 kms and over 40,000 km of transmission wires.
- It is a wholesale electricity market that began operation in December 1998.
- Each state system is connected to adjoining states through large transmission wires known as interconnectors.
- It incorporates a large set of rules to establish a real-time wholesale 'market' for the supply and demand of electricity such that, in effect, a producer of electricity in Queensland can supply a user in Victoria.
- It has a capacity of almost 54,421 MW (including rooftop solar) at December 2017.
- It supplies around 200 Terawatt hours (TWh) of electricity annually from around 132 generators (excluding rooftop solar) at a value of $16.6 billion to around 9 million customers.
- The generators in the NEM use a combination of fossil fuel and renewable technologies to produce electricity. The majority is produced by coal-fired generators (Figure 1).

Figure 1. Generation mix in the NEM in 2016-17



Source: AEMO, Fact Sheet – The National Electricity Market, 2018.
Note: Excludes roof-top solar.

Table 1 provides a breakdown of generation capacity by state and technology for the NEM. The table excludes rooftop solar. Whilst the share of coal-fired generation is high, it is on a downward trend with recent closures of generators in Victoria, South Australia, New South Wales and Queensland.

[15] AEMO, 2018a.

Table 1. Generation capacity (MW) in 2016-17, by state and technology

	Coal	Gas	Water	Wind	Solar	Biomass	Storage	Other	Total
NSW	10,160	2,283	2,706	1,307	452	163	0	9	17,080
VIC	4,630	2,461	2,288	1,496	6	57	0	0	10,938
QLD	8,186	3,698	738	12	365	419	0	1	13,420
SA	0	3,141	4	1,809	122	20	100	145	5,341
TAS	0	386	2,287	373	0	5	0	0	3,051

Source: AEMO, 2018b.
Note: Snowy Hydro is split between NSW and VIC.

1.3 Regulation

The day to day operation of the NEM is carried out by the Australian Energy Market Operator (AEMO) according to the National Electricity Rules created and amended by the Australian Energy Market Commission (AEMC), established by the Council of Australian Governments (COAG). In turn, the National Energy Regulator (AER), part of the Australian Competition and Consumer Commission (ACCC), is responsible for enforcing the rules established by the AEMC.

The NEM operates as a wholesale commodity exchange across the five interconnected states. Since electricity cannot be stored easily the market works as a 'pool', or spot market, where power supply and demand is matched in real time through a centrally co-ordinated dispatch process.

Generators offer to supply the market with specified amounts of electricity at specific prices for set periods of time. Generators can re-submit offers at any time.

From all the bids offered, AEMO decides which generators will be deployed to produce electricity with the cheapest generator put into operation first. In this way, the NEM is designed to meet electricity demand in the most cost-efficient way.

In delivering electricity, a dispatch price is determined every five minutes and six dispatch prices are averaged every half-hour to determine the spot price for each NEM region. The spot price, or settlement price, is then used as the basis for settling all electricity traded in the NEM. That is, all successful bidders are paid the 30-minute spot price. However, starting 1 July 2021, there will be no averaging, and settlements will take place every five minutes.[16]

In addition, the National Electricity Rules set out a maximum market price of $14,500 per MWh,[17] which is adjusted for inflation annually and reviewed every 4 years by AER to ensure they align with the NEM reliability standard.

Due to the wide and rapid swings in supply and demand, the spot price can be volatile; the 5-minute dispatch price more so. To manage the financial risks associated with spot price volatility, market participants use a range of financial contracts, such as swaps and hedges, options and futures contracts to lock in a firm price for electricity that will either be produced or consumed at a given time in the future.

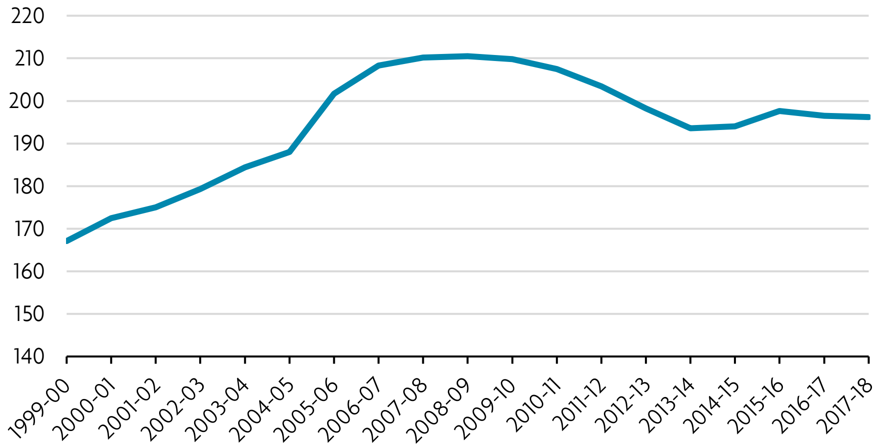
[16] AEMO, 2017.

[17] AEMO, 2018d.

1.4 Electricity demand

NEM electricity demand has grown steadily over time from the late 1990's to the mid-2000's in response to strong economic growth and rising household energy demand. From its peak in 2008-09, electricity demand has declined. From 2010 onwards, in response to rising retail prices and various subsidy schemes, rooftop solar starts to supply an increasing share of household electricity demand, offsetting the demand for wholesale electricity. New generation via rooftop solar increased from zero to around 4.2 per cent of total electricity demand by 2017-18.[18]

Figure 2. NEM electricity demand (TWh), 1999 – 2018



Source: AER, 2017.

Recently there has been a small increase in electricity demand from 2014-15 onwards. In 2015-16 electricity demand grew 2 per cent to 198 terawatt hours with increases across all mainland regions. Queensland had the strongest increase in demand to meet the energy needs of its growing LNG industry.

AEMO in July 2017 forecast that demand in the NEM would be flat for the next 20 years. While population growth and switching from gas to electric appliances will lead to some demand growth, energy efficiency gains and continued growth in rooftop solar are likely to be enough to meet it.[19]

Queensland demand is expected to grow faster than the average to meet the needs of its expanding LNG industry. Conversely, South Australian demand from the NEM is expected to decrease 0.5 per cent annually reflecting in part the region's high take-up rate of rooftop solar.[20]

1.4.1 Wholesale prices

Prices in the NEM are wholesale prices for the output of generators reflecting supply and demand conditions and, to some degree at some periods of time, the strategic market behaviour of the more powerful market participants.

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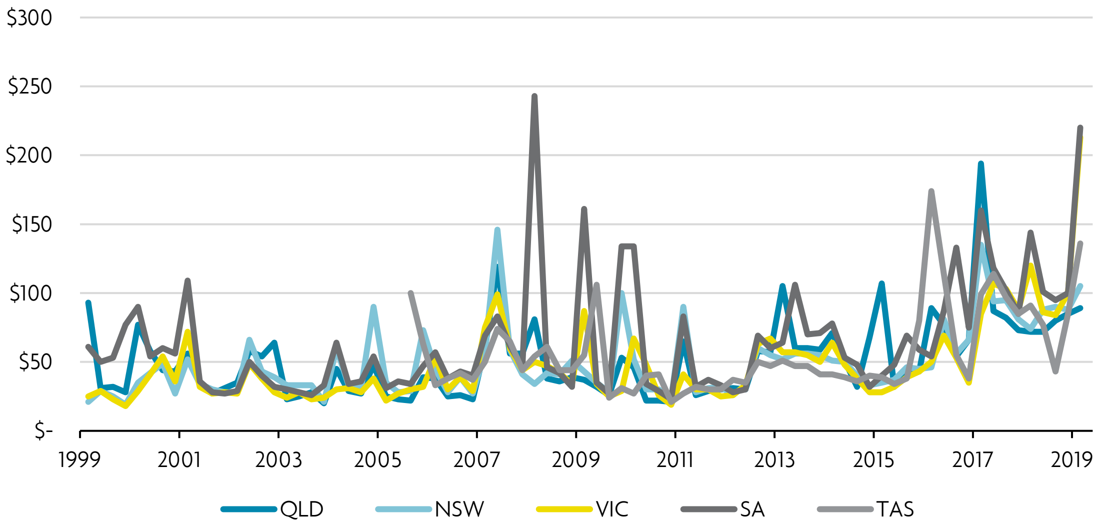
[18] AEMO, 2018c.

[19] AEMO, 2016.

[20] AEMO, 2019.

Figure 3. Average electricity spot price ($ per MWh) in the NEM



Source: AER, Quarterly Volume Weighted Average Spot Prices, 2018.

Over time, wholesale prices (while displaying a large degree of volatility) have on average remained relatively unchanged from 1999 to around the end of 2012 (Figure 3). Since then NEM prices have been trending upward and were most pronounced from the third quarter of 2015.

The causes for higher prices and volatility are complex and differ across regions, although common trends are evident.[21] In a general sense, there has been a tightening of the supply-demand balance with the closure, or moth-balling, of a significant amount of coal-fired generation that coincided with a resurgence of peak demand. The reduction in supply meant that gas fired generation was often the marginal producer, setting the dispatch price, at a time of record high domestic gas prices.[22]

There is concern also that higher prices are being partly caused by the gaming of price setting procedures in the NEM. Gaming happens because prices paid to producers are an average of a series of 5-minute price movements. Large spikes in a single 5-minute period can significantly lift the average. In turn, 5-minute price spikes can be 'manufactured' by some fossil-fuel generators by withdrawing offers and re-bidding into the market at strategic times.[23]

1.4.2 Retail prices

Retail or end-user prices reflect not just the wholesale price but also transmission and distribution charges along with retail margins.

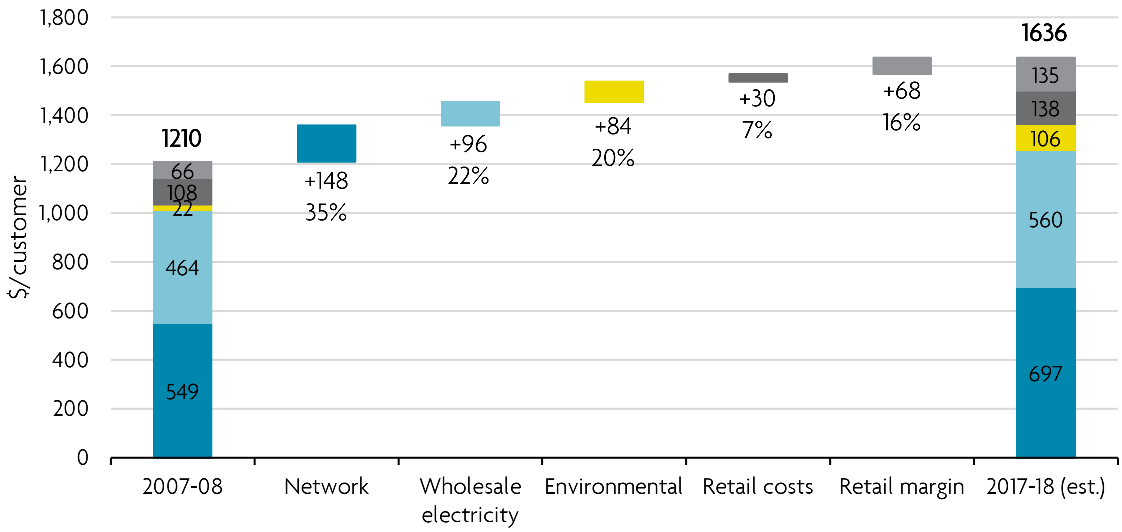
While recent increases in retail electricity prices have largely been driven by higher wholesale prices, this has not always been the case. Over the last 10 years, the biggest contributor to rising retail electricity prices has been network charges (for poles and wires) followed by the combined impact of retail costs and margins (Figure 4).

[21] For more detail see AER, 2017.

[22] Australian Energy Regulator (AER), 2017, p. 51.

[23] Slezak, M., 2016.

Figure 4. Change in average residential electricity prices, real $2016-17, excl. GST



Source: ACCC, Retail Electricity Pricing Inquiry - Final Report, Jun 2018.

The rising cost of network charges over the last 10 years has been caused partly by over-investment in the transmission network on the back of now incorrect forecasts for continued growth in electricity demand. The cost of the over-investment in poles and wires was passed on to users via favourable outcomes of pricing decisions by the regulators.[24] In turn, higher prices to end users encouraged energy efficiency and the installation of solar panels that lowered consumer demand. This means that higher transmission investment costs are being spread over an even lower volume of electricity.

1.5 How electricity drives Australia's competitiveness

Rising electricity costs lift total costs and prices for output, reducing competitiveness. Some sectors rely on electricity significantly more than others. If the sectors that use large shares of electricity are also export orientated, then changing electricity prices can significantly impact Australia's trade position. Some of Australia's key export industries are heavily dependent on electricity usage in their production process. For example, the aluminium industry in Australia has a total (non-own use) cost of around $8.1 billion in 2015-16, of which an estimated 19 per cent, or $1.6 billion is electricity cost.[25] On the contrary, many competing aluminium exporting countries have their plants powered by much lower carbon emitting electricity sources such as hydro.

For households, electricity is the predominant form of energy consumption. Increases in household electricity prices can negatively affect the household budget leading to a reduced consumption of many other goods and services. Lower income households are disproportionally impacted by rising energy costs since they spend a much higher share of their income on electricity bills.

The production, distribution and transmission of electricity is itself a significant segment of the Australian economy. In 2017, the sector contributed $25 billion or 1.4 per cent to GDP and employed around 68,000 people[26]. Recently however, the sector has been one of Australia's

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[24] ACCC, 2018.

[25] ABS 5209.0.55.001, 2018.

[26] ABS 5204.0, 2018.

least productive industries[27], showing flat or negative productivity growth for several years, mainly because of the large increase in labour resources used in electricity retailing.

1.6 Projections – starting at the end

In the face of uncertainties surrounding the sector it is impossible to make serious projections without considering emission problems and changes in technology. It is also necessary to pay attention to changes in the political and economic environment. Even in the more stable environment of the past decade, recent guesses, like those that encouraged the gold-plating of the transmission network, did not turn out so well.

From an investment perspective the issues that must be faced include the possibility of the sector continuing to operate with the existing coal fired generation or whether an injection of new, large-scale, baseload and other energy mixes will be necessary. If so, what are the likely mixes and what are the investment opportunities?

How do we do this? Our preferred approach is to start at the end and work back in accordance with the first of our principles. This leaves investors with a range of possible future environments to consider. The two extremes are:

1. **Systems change.** This is the path required for long-run optimality. It is the environment where an attempt is made to reduce emissions to zero in some reasonable time scale. In this case, there will be a demand for large-scale investment and this will create opportunities for long-term portfolio investors to benefit from, and create wealth through, involvement in constructing new generation facilities and associated infrastructure. It will also make it necessary to be innovative in constructing new investment instruments.
2. **Business-as-usual.** This is the medium-term future where there are no major structural changes and provides for opportunistic investments. In this case, the system would continue with perhaps coal and gas providing a lion's share of the baseload, with a gradual increase in renewables as part of the energy mix. Investment opportunities would be along the lines of the more familiar investments in equities with some hedging to offset uncertainty. There may also be the possibility of limited partnerships with government to minimise downside losses.

Both environments carry a great deal of uncertainty and create similar problems for our analytical techniques. They impact the analysis in different time scales and in different ways.

In the first case, uncertainties are high, but so are the opportunities.

In the second case, there might be some short-term investment certainty and opportunities for low road activities. On the other hand, the medium to long term is problematic. For example, if Australia and the rest of the world do not act to reduce emissions, economic growth will stall, and asset values will begin to fall in the face of climate change. For example, the US Energy Information Administration has predicted that the US economy will shrink by at least 10 per cent before the end of the century without action to limit climate change (US Energy Information, 2018). If the rest of the world does act and Australia does not, then there is a high possibility that Australia would face retaliation and stranded assets.

It must be stressed that these are the ends of a scale and the choices are not necessarily between the 0, 1 alternatives. It is possible that an optimal investment program would include elements of large-scale new infrastructure and equity holdings in existing energy assets.

If we think about the alternatives it is only the first that satisfies the long-run optimality and gives a stable end state. The second is not sustainable in the long run. This does not mean that

[27] ABS 5260.0.55.002, 2018.

no attempt can be made to argue that emission problems do not need to be addressed or that only small-scale actions need to be taken. What it means is that any such trajectory will, in the medium to long term, lead to major inefficiencies and losses of production, and possible large social costs in terms of industrial dislocation.

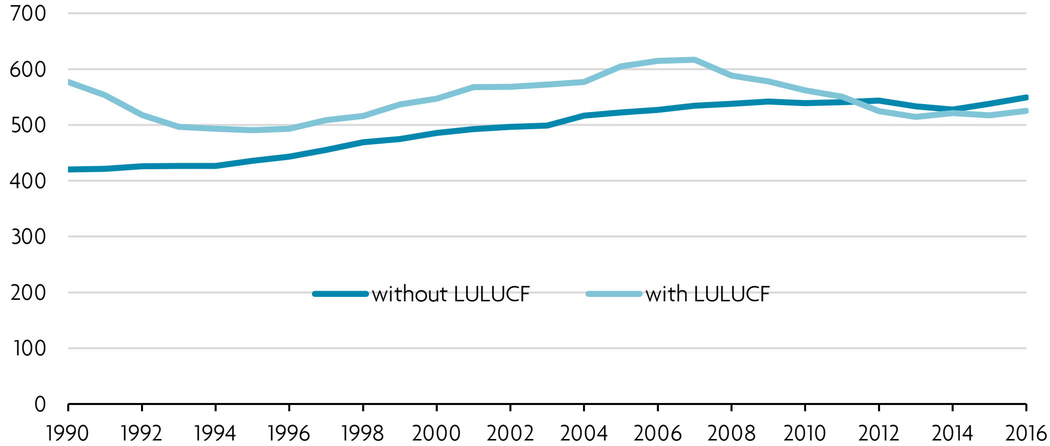
2. Australia's emissions – history and future

Australia's recent emissions track record and the challenges of moving to a zero-emissions future are examined in this section.

2.1 Emission empirics

Broadly speaking Australia's total greenhouse gas emissions have been constantly increasing with a slight downturn during the period in which a carbon price was imposed if land use and clearance figures are excluded. If these figures are included, there is a reduction from 2007 owing to extensive land use emissions in the run up to that year. Land use figures are not of interest to this discussion paper.

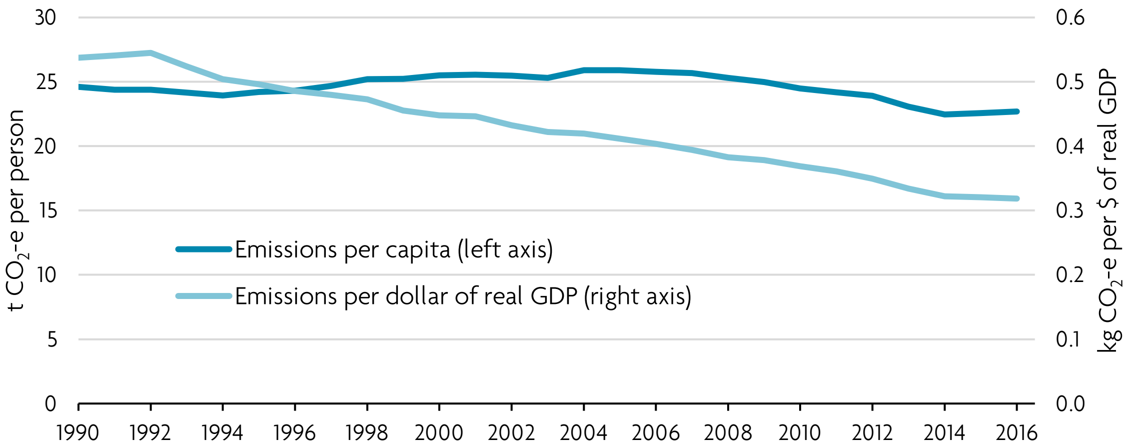
Figure 5. Australia's total greenhouse gas emissions (Mt $C0_2$ equivalent)



Source: United Nations Framework Convention on Climate Change, GHG Profiles - Annex 1, 2018.

On a dollar of GDP basis, Australia's emissions are on a steady downward trend since the 1990's. On a per capita basis, emissions have fallen since 2006 as the result of population increase.

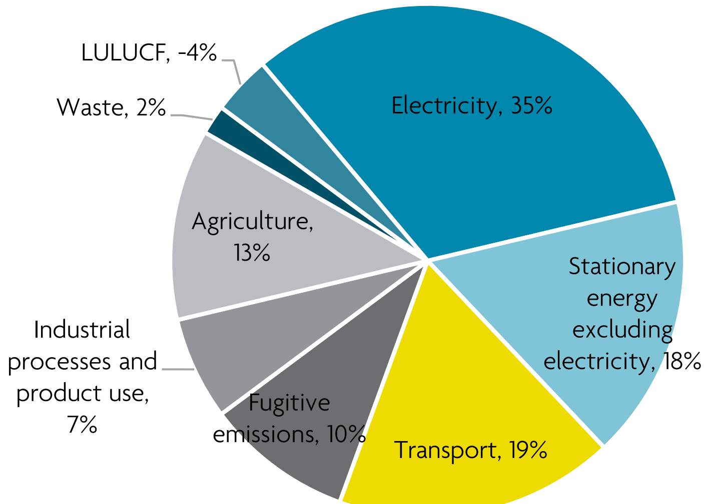
Figure 6. Australia's total emissions (excl. LULUCF) per capita and per GDP



Source: United Nations Framework Convention on Climate Change, GHG Profiles Annex 1, 2018; ABS 3101.0 Table 4; ABS 5204.0 Table 1.

Across the sectors, electricity is the largest emitter primarily from the combustion of fossil fuels, mainly coal. Over the years, the electricity sector has also been the source of the largest growth in emissions up 42 per cent since 1990. In 2017, emissions from the electricity sector accounted for 35 per cent of all emissions, followed by 19 per cent from transport and 18 per cent from the other stationary energy sectors.

Figure 7. Emissions contribution by sector in Australia, Dec 2017



Source: Department of the Environment and Energy, Quarterly Update of Australia's National Greenhouse Gas Inventory, Dec 2017.

2.2 Recent history of emissions policy

Australia's first genuine policy response to climate change took place in 1997, when the then Prime Minister John Howard announced that an additional 2 per cent of electricity would be supplied by renewable sources by 2010. The policy, known as the Mandatory Renewable Energy Target scheme (MRET), commenced in 2001 with the 2 per cent additional renewables adding to the then current share of 8 per cent.[28]

Following the election of the Rudd government in 2007, the ratification of the Kyoto Protocol soon after, and before the government's comprehensive Carbon Pollution Reduction Scheme (CPRS) was at least twice rejected by the Senate, the renewables energy target was lifted in 2009 to 20 per cent, or 45,000 GWh by 2020. This policy, then rebadged as the Renewable Energy Target (RET) was the second major policy aimed to reduce emissions in the electricity sector.[28]

Early in 2011, the RET was separated into two schemes the Large-Scale Renewable Energy Target and the Small Renewable Energy Scheme. Later in 2011, the then Gillard government passed the Emissions Trade Scheme (ETS) legislation which came into effect on 1 July 2012 with an initial fixed price on emissions of $23 a tonne, amongst other policy measures.[29]

After the election of the Abbott government in 2013, key planks of the ETS, including the carbon price, were repealed in July 2014. Then in 2015, the RET target was lowered to 33,000 GWh by 2020, or around 23.5 per cent of generation.[30]

Coming up to the current state of play, the Paris agreement adopted in December 2015 committed Australia to achieve a 26-28 per cent reduction on 2005 emissions by 2030 and globally to limit warming to well below a 2°C increase on pre-industrial levels. In 2016, the COAG

[28] John, A., 2014.

[29] Thompson, J., 2011.

[30] Tomaras, J., 2016.

energy ministers established the Finkel review as an independent review of the national electricity system.[31]

Whilst the Finkel Review stopped short of recommending a long-term emission target, suggesting it was a political decision, it did incorporate the Paris targets for 2030 and zero electricity sector emissions by 2070 into its analysis.

2.3 Current emissions policy

The Morrison Government's central emissions reduction policy is not grounded directly on a price mechanism but seeks to purchase emission reductions from firms. Underpinning this a $3.5 billion climate solutions package[32] to be spent over the years from 2019 to 2030. Its stated aim is to reduce emissions by 26 to 28 per cent from the 2005 emission levels by 2030.

- Around $2 billion is allocated to a climate solutions fund – an extension of the current emissions reduction fund. The money will be used to pay farmers and other groups who reduce emissions or prevent carbon dioxide release into the atmosphere, such as by retaining native vegetation or making their businesses more energy efficient.
- Around $1.38 billion is allocated to the Snowy Hydro expansion. The project would pump water uphill into dams and release it at times of high electricity demand, acting as a giant battery and backing up intermittent energy produced by wind and solar.

The Coalition intends to achieve this aim by using carry-over carbon credits from the Kyoto protocol period. Including these credits means that Australia needs only reduce its cumulative emissions over the period 2021 to 2030 by 328 Mt CO_2-e or about half of the required target.[33,34]

The Government is also consulting on a national hydrogen strategy and said Australia could be a global leader in developing the resource[35]. The economic and technological details of this are yet unclear and may be the subject of an addition to this discussion paper.

It is also interesting to note that the Morrison Government intends to scrap the National Energy Guarantee (NEG),[36] the recommended policy of the independent Energy Security Board (ESB) which was formed out of the recommendations of the Finkel review, under the previous Turnbull Government. The NEG comprised two parts: a retailer reliability obligation and an emissions guarantee.

- The reliability obligation requires electricity retailers to invest in enough dispatchable supply to cover a set of amounts of their peak load in a region, if a shortfall is expected.
- The emission guarantee requires retailers to meet a targeted emissions level for the electricity they purchased from the wholesale market. The emission target under the NEG is set at a 26 per cent reduction of 2005 levels. This leaves approximately two-thirds of Australia's Paris commitments to come from sectors other than electricity.

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[31] Finkel, A., 2017.

[32] Department of the Environment and Energy, 2019.

[33] Packham, B., 2018.

[34] The carry-over is controversial because it is not yet clear that it will be agreed under international carbon accounting rules after 2020 and several countries have already made it clear they will not use any carryover.

[35] Department of Industry, Innovation and Science, 2019.

[36] Benson, S., 2018.

Whilst the Morrison Government is proceeding with the retailer reliability obligation of the NEG, it is not imposing the emissions obligation.

2.4 State and territory policies and targets

Currently, a range of state and territory based renewable energy policies are in place that often extend the RET in terms of both the target and the period of operation. Some states also have economy-wide emission targets. Table 2 summarises the various policies and targets across Australia's states and territories.

Tasmania, ACT, and South Australia led the way on renewable energy progress. Victoria and Queensland are catching up on the race towards net-zero emissions. About 60 per cent of Australia's new renewable-energy projects (in terms of generation capacity) are being constructed in Victoria and Queensland. Western Australia, Northern Territory, and New South Wales are lagging behind the other states and territories and falling short of what is required for Australia to do its fair share to tackle climate change. However, despite having a low share of renewable energy, Western Australia has the highest proportion of households with rooftop solar. New South Wales does not have a renewable energy target but has initiatives to double the state's level of renewable energy capacity by 2021. Western Australia is the only region to have no policies for either renewable energy or broader emissions targets.[37,38]

Table 2. Summary of state's and territory's renewable and emission targets, 2018

	% renewable	% solar households	Renewable capacity (kW) per capita	Renewable energy targets	Net-zero emission targets
TAS	96	14	0.7	100% by 2022	Net-zero by 2050
ACT	77	14	1.1	100% by 2020	Net-zero by 2045
SA	53	32	1.1	-	Net-zero by 2050
VIC	21	16	0.3	40% by 2025	Net-zero by 2050
QLD	10	33	0.1	50% by 2030	Net-zero by 2050
NSW	15	18	0.2	-	Net-zero by 2050
NT	4	14	0.1	50% by 2030	-
WA	16	27	0.2	-	-

Source: Clean Energy Council, 2019; Climate Council, 2018.

2.5 Future emissions

The path of Australia's emissions will depend on domestic pressures and international commitments. These pressures may come from the voting public. They may also come from the investment community. In the latter case, time horizons may be greater than those of political parties and there may be an increasing awareness of the damage poor energy decisions can inflict on asset values

37 Clean Energy Council, 2019.

38 Climate Council, 2018.

As it currently stands, the Paris agreement runs over the period to 2030 suggesting some stability and certainty over emission targets for this time period. But, as discussed more fully in Section 4 below, global political situations could change rapidly in response to one off environmental outcomes and new targets or goals. The opinions of some that the Paris targets are now within easy reach even without a proper long-term or short-term emission plan may find themselves in a poor bargaining position.

Under the Paris agreement, Australia's commitment to a 26-28 per cent reduction on 2005 emissions (597 Mt CO_2-e) by 2030 implies a fall in emission level to 430-442 Mt CO_2-e by 2030. From the projected 2020 emission level of 540 Mt CO_2-e, the cumulative abatement task over the period 2020 to 2030 is estimated to be 695-762 Mt CO_2-e.[39]

The abandoned NEG policy has a target of a 26 per cent reduction in the NEM emissions from the 2005 level of 176 Mt CO_2-e.[40] If this target was to be adopted to the whole electricity sector, the 26 per cent reduction means a reduction to 146 Mt CO_2-e by 2030[41] implying that the non-electricity sectors must also make a 26 per cent reduction (to 296 Mt CO_2-e by 2030) in order for Australia to meet its commitment to the Paris agreement.

While the NEM has achieved in 2017-18 a 14 per cent reduction from its 2005 emission level, the emissions from the electricity sector in Western Australia and Northern Territory have increased since 2005, dragging down the emissions-reduction 2017-18 progress of the whole electricity sector to 6 per cent below the 2005 level. On the other hand, the non-electricity sectors have achieved a reduction in emissions from their 2005 level by 13 per cent in 2017-18.[41]

Since electricity is the largest contributor to aggregate emissions, and the source of some of the cheapest abatement opportunities, it is concerning that the electricity sector has done very little to cut its emissions. Hence, unless further extensive and cheap emission cuts can be found outside the electricity sector, Australia is not on track to meet its Paris climate target.

It might be argued that a more logical starting point for per sector targets would see each sector undertake abatement in proportion to their projected business-as-usual emissions levels. Under such a scenario, given that the electricity sector will account for 29 per cent of the projected emissions in 2030[42], the electricity emissions level by 2030 should be 128 Mt CO_2-e or below. In other words, the emissions reduction 2030 target for the electricity sector should be at least 35 per cent below its 2005 level, much higher than the target under the abandoned NEG policy.

We argue that electricity should bear an even heavier share of the initial burden because:

- it is the easiest and least expensive sector to make extensive cuts; and
- it provides the preconditions for other sectors to make cuts by substituting electricity for other energy sources. Transport is a good example.

Without electricity reform as a leading component, other energy users don't have much option beyond efficiency in energy use. This may in fact be inefficient from a total standpoint. The Department of the Environment and Energy projected the aggregate emissions to reach 563 Mt CO_2-e by 2030 but provides no projection to 2050.[39]

These various future projected emissions scenarios are outlined in Figure 8.

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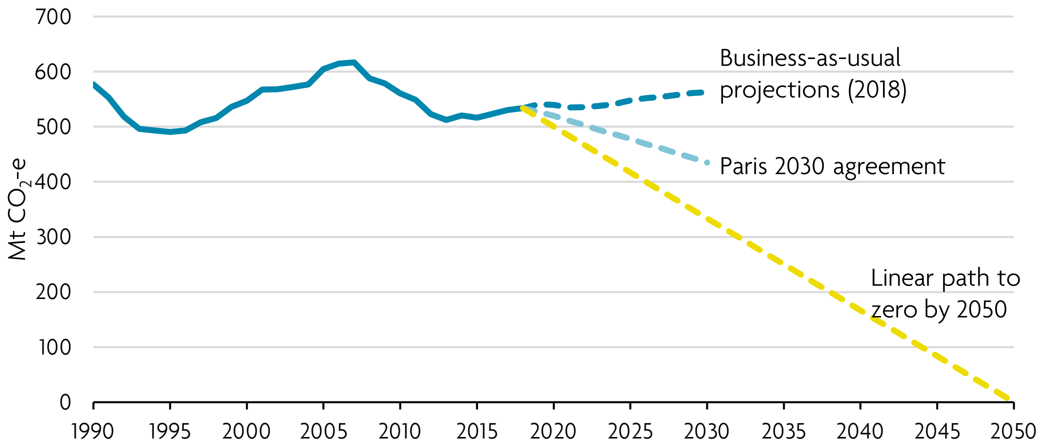
[39] Department of the Environment and Energy, 2018b. p. 3.

[40] COAG Energy Council, 2018. p.17

[41] Department of the Environment and Energy, 2018c.

[42] Department of the Environment and Energy, 2018b. p. 12.

Figure 8. Australia's emissions – history and projections



Source: Department of the Environment and Energy, Australia's emissions projections 2018.

Beyond 2030, the path for Australia's emissions and energy production will be guided by domestic politics and the outcomes of the international agreements, which are highly uncertain. See Section 4 and appendices.

Assuming international agreement is achieved, the nominal target for discussion in this paper is zero net emissions by 2050, the same as the current commitments of several Australian states and territories.

2.6 Where to from here?

Attempting to meet reduction targets of this magnitude will require a major reworking of generating assets and infrastructure. This creates a challenge to the investment community and unprecedented opportunities for involvement. There is already considerable evidence of willingness on the part of investors to face these challenges.[43] On the other hand, there is a great deal to be done in understanding the nature of the challenges and the uncertainties surrounding energy and emissions.

In the next two sections we attempt to work through these challenges. It is our view that the uncertainties they entail must be dealt with head on. This will mean acknowledging the difference between uncertainty and risk. It will mean:

- thinking systematically about dealing with uncertainty rather than pretending to have knowledge that doesn't exist;
- factoring in the potential for rapid changes in politics and public opinion; and
- rethinking many of our standard economic approaches and taken for granted assumptions about technology.

[43] Investor Group, 2018.

3. Energy and emissions – politics, economics and uncertainty

The problem of providing a framework for analysing political and economic uncertainties around Australia's electricity sector is considered in this section. It reinforces one of the main themes of this discussion paper. We find that it is dangerous to assume certainty where it doesn't exist. To this end we examine some of the toolkit currently used by economists to understand large-scale and incompletely known future events. This is not an abstract exercise. It is impossible to make a reasonable assessment of policy options without a sound intellectual structure.

We pay attention to risk assessment and the use of discount rates. It is argued that the concept of discounting is being misapplied and that this leads to poor estimates and faulty investment advice.

Some of the issues raised may be unfamiliar. Readers can skip most of this section and just move down to the last sub-section for an overview if required. Also, some of the more detailed material underpinning this section is developed in Appendices A, B and C.

As with the rest of this discussion paper, it will be useful to bear in mind the distinction between what should be done and what will be done. It is important to understand the former in order to construct a solid approach to the latter.

3.1 General uncertainty and ratcheting

The main themes in what follows, are briefly summarised to provide an overview. This underplays the complexity of the problem since each element interacts with one another.

Technology and feasibility

The hard constraints on the system are partly given by the need to reduce emissions by some specified amount and time. Once these are accepted, the question becomes: 'What is the best way to achieve this?' Should, for example, a strategy of attempting to get all our energy needs using solar and wind be adopted? What about a strategy based on carbon capture and storage? Since the problem is dynamic what assumptions about new technologies are permissible? What timelines are acceptable? How rapidly might technologies change? Would it be possible, for example, for nuclear fusion to become commercially viable? Would new technologies make it possible to overshoot the risk target and then draw back? See Section 4 for further discussion.

Economics and policy

Each mix of technologies and trajectories of implementation will have different costs and benefits and it is the task of economic analysis to determine the most desirable paths in terms of some standard of welfare. Now the unknowns begin to escalate. How is welfare to be assessed and how does risk fit in? In what sense is a risk acceptable for future generations? What is the measure for welfare? Is the metric given by the amount of resources or consumption that would need to be sacrificed in the present to reduce risk? Reduce risk to what level?

Public opinion and politics

Political uncertainties are in some ways the most volatile. This volatility is partly domestic and partly the result of the fact that emissions standards are subject to international agreements. It is also possible that small economies like Australia may be forced by larger economies to adhere to their shared standards.

Total levels of uncertainty are multiplied by interactions. For example, as the technological possibilities change, so do the economic calculations and political perceptions.

Rapidity of change

This may result from shifts in technology as in the examples above or from political changes back through acceptable technologies or economic settings. Moreover, a climate event may spark a rapid change through the economic and political system and create pressure for new technologies.

Despite these uncertainties change has the important characteristic in that it ratchets along a single dimension. Climate shocks or increased information can only have the effect of increasing, rather than decreasing, political pressures to reduce emissions in all countries.

In what follows, we elaborate on the political and economic aspects sketched out immediately above. This will be kept at an informal level. A more detailed analysis of the game theory and the mathematical structure of the economic arguments is developed further in Appendices A, B and C. In many cases, we simply point to these results.

It seems most useful to start with the political aspects of uncertainty. Technology is dealt with separately in Section 4.

3.2 Political uncertainty

The problem of political uncertainty is particularly acute for both short-term, or business-as-usual, and long-term systems change and is given considerable attention in this discussion paper. It has domestic and international dimensions.

3.2.1 Domestic policy and ratcheting

The most useful way to deal with domestic policy is to consider the tension between what needs to be done considering climate science and what is being done. In the short term, Australia's climate policy has undergone a series of abrupt changes as summarised in Section 2 of this paper. There remains a very large scope for volatility and abrupt change. Some of this is unavoidable. It might be possible for large investors to reduce elements of short run uncertainties by seeking policies and programs that buttress against sharp and unpredictable downside losses. Some possibilities in this regard are discussed in Section 6.

One thing to note, however, is that they are likely to be increasingly uni-dimensional and this gives some important insights into the direction of investment strategies. That is, instead of policy jumping between concerns with reducing emissions and support for fossil fuel, the most likely discontinuities are in the direction of increased emissions reduction. This is the ratcheting referred to above. This characteristic of a one-dimensional uncertainty can give us some insight and the issue will be further explored below.

There are four factors that influence ratcheting.

1. Although the timing of climate events contains elements of uncertainty, their impact can only be in one direction. Increasing evidence of climate related damages from coastal flooding, storms, coral die offs and the likes can only serve to increase public awareness of the issues and increase pressures on governments.
2. It is not anticipated that new scientific findings will decrease concerns or the urgency of action. The IPCC report released on 8 October 2018[44] has significantly reduced the time available and increased the estimated costs of climate damage. This is a significant jump up in perceptions of the issues.

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[44] IPCC, 2018.

3. Increasing understanding in the business, finance, agriculture, military and insurance sectors of the economy of the cost of climate related events is also emerging as an issue. For its part, business will be increasingly reluctant to invest in energy assets that are out of step with science and developing practice in other economies to avoid the possibility of being stranded. One example here is the refusal of AGL to keep the Lidell power plant operating despite government pressures.[45]
4. Demands from business for long-term and settled energy policies will increase. This will push in the direction of an economically rational response rather than one that is driven by ideology.

3.2.2 International political system

International issues can be divided into short-term concerns and more systematic, long-term concerns.

Short term

In the short term, there are questions concerning the extent to which political events are an aberration and whether the international system will move to more stable pathways that track some of the concerns of climate science. In this, large countries with competitive democracies have most of the characteristics of the Australian polity. What is less clear is whether a revision to a stable path will occur gradually or in some discontinuous manner. This last question is particularly important. A rapid change in the settings of large economies might impact heavily on Australia if it commits to a path which is heavily fossil fuel dependent. Low levels of flexibility may create a situation where assets are stranded, and high future expenditures are required (see Section 5). Considering the most recent IPCC report, pressures for a rapid policy response, and hence degrees of international uncertainty, have increased.

The impact on Australia of international policy settings will come through the usual trade mechanisms and through agreements on emissions targets. The second will be the most significant. Currently, the Paris agreements on emissions is in force. Already there is a significant body of opinion that it is inadequate, and this includes the most recent IPCC report. There are no globally agreed emissions targets beyond 2030. In addition, there is currently a threat by the US to withdraw from its commitments and the present Australian government is discussing abandoning its targets. In both cases the situation is very fluid.

What is certain is that there will be continuing international negotiations. This also opens the possibilities of trade retaliation and other measures if some countries attempt to evade contributing less than their share to emissions reductions. An example of this is the statement by the European Union that any trade agreement would need to include conditions on sustainability and emissions. [46]

Long term

International agreements come under the heading of long-term concerns. In order to get some understanding of developments we need to consider the forces that shape negotiation and the formation of these agreements.

For simplicity it will be assumed the process whereby emissions are reduced imposes a cost. This is not at all clear but let us assume it is true for the present discussion. Costs are considered in more detail in Section 5.

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[45] Murphy, K., 2018.

[46] Morgan, S., 2018.

At a crude first approximation the international situation might look like a prisoners' dilemma. The idea here is that for every individual country, the returns for not co-operating outweigh the returns from paying the costs of co-operation. In this case no-one co-operates, and emissions remain unchanged. Even if the game is repeated the situation doesn't change much since there is no solid basis for a strategy of punishing defectors. See Appendix A for more detail on this.

A better interpretation would be to look at it as a game with payoffs that depend on the number of contributors and on domestic political considerations. In this there are conditions under which it may give a greater payoff for some countries to reduce emissions even when other countries are not co-operating. If so, it may also be in their interest to threaten sanctions or other forms of retaliation against non-co-operators.

It is also possible that the optimum strategy may quickly flip from 'not co-operate' to 'co-operate' once political costs reach a certain threshold point. In other words, the political domain may exhibit a fast dynamic whilst the economy transitions on a slow dynamic.

It is all very well to appeal to intuition. To have any confidence is necessary to carry out some rigorous modelling. This is done in Appendix A.

3.3 Economics of uncertainty

The problem of climate instability is characterised by extreme uncertainty about downsides, uniqueness of events, and hard constraints that appear in the form of things like irreversibility and non-substitutability. In addition, there are no options for hedging, limited or zero possibility for trade-offs and inability to quantify possible catastrophic outcomes. In contrast, the standard approach in economics is mostly designed to deal with repeated and quantifiable interactions and marginal changes. This means that the intellectual frameworks and thought patterns that seem natural and obvious may create a tendency to either overlook important aspects or be misleading.

One consequence of this is that a good deal of analysis can be distracted by what are essentially second or third order considerations. The changes required to replace existing technologies, the coarseness of our information, uncertainties about technologies and the economic consequences and the possibility of catastrophic outcomes if targets are not met, should cause us to question the appropriateness of tools designed to deal with marginal changes under perfect knowledge.

Another consequence is considerable variation between the recommendations of climate scientists and economists. For example, climate scientists mostly claim that any temperature increase above 2 degrees centigrade presents an unacceptable risk of runaway climate change. Economists, like Nordhaus, argue for a much higher figure on the grounds that this will give the greatest economic return. If we have different approaches can we say that one is better in any sense? To be clear, it is not being argued that the numbers being assigned to risk are wrong. It is that the treatment of risk, uncertainty and hard constraints is inappropriate.

In what follows, references to economics and economic approaches are meant to cover the most standard literature. The work of Nordhaus and Stern and the extensive debates around this are well known examples.[47] There are other approaches in the literature that are critical of some of the key assumptions. A good example here is the work of Weitzman on risk.[48]

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[47] Stern, N., 2006, Nordhaus, W., 2007, Nordhaus, W., 2008.

[48] Weitzman, M., 2009.

3.3.1 Cost benefit analysis

The aggregation of expected costs and benefits across time is the best approach we have for examining many problems which involve externalities.[49] It is not clear, however, whether this framework is appropriate for dealing with the collapse of complete economic systems. An approach that makes sense in comparing the costs and benefits of say better traffic management and more heart surgery, holding everything else constant, loses its leverage when dealing with a large-scale single event. In the former case, similar circumstances can be compared, and the issue of metrics is washed out. In the latter this cannot happen. In other words, the cost benefit apparatus may work well for changes at the margin but may not be so good for a whole range of changes.

Consider issues around irreversibility. If it is possible to substitute between assets, allocating a monetary value may make sense. If one factory is burnt down it is possible to build another. Where substitution of other goods for environmental assets is impossible this is more complicated. It is even more complicated again where a large portion of the value of the asset may be its utility, rather than its market value. Even where there is a well-defined, economic gain from an environmental good, it still may not be possible to calculate the total economic loss because of uncertainties and interconnections. For example, how bad would it really be if bees disappear?

As another illustration, consider potential loss of life. Assume we can place a value on individual lives. It is not clear, however, that this scales to the loss of entire communities in any reasonable manner. It is also not clear what the moral basis is for accepting a risk on behalf of entire communities.

3.3.2 Expected values, uncertainty and downside losses

The process of assigning costs and benefits to future outcomes by treating uncertainties in terms of probabilities and calculating an expected value, brings a sense of predictability to energy and emissions problems which is not justified by existing levels of knowledge or understanding. Where do the probabilities come from? They can't be justified on a frequential basis because we are only burning one planet. They cannot come from the physical properties of the variables because these are too complicated to assess.

To see how this plays out in calculations consider the standard method of constructing expected values. This is a sum of probabilities multiplied by consequences. For example, let $c = (c_1, c_2, c_3, \ldots, \text{etc})$ be possible temperatures and p_i be the probability of temperature c_i. The cost of temperature c_i is written $v(c_i)$. If $E[c]$ is the expected value we have:

$$E[c] = \sum_i p_i v(c_i)$$

This is sensible where we have a good idea of the values for each of the v and p terms. If we don't, the whole procedure becomes more questionable.

In addition, any probability distribution we could estimate will have a spread of possible outcomes, some of which are associated with high to catastrophic costs. These large downside losses, or what are called fat tails, may make it impossible to carry out the required summation because the integral $E[c]$ may not converge. In other words, it may not give a number that can be used to represent future costs.

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[49] A consequence of an industrial or commercial activity which affects other parties without this being reflected in market prices, such as the pollution of waterways from a factory disposing of industrial chemicals into a local stream.

One way this might be avoided is simple truncating or cutting off the probability spread at some point to give a finite sum. Unfortunately, this may arbitrarily remove a loss region with infinite expected value.

It might be thought that some sort of stop loss function on utilities could be used. In this case the loss of all life on earth might be assigned some lower bound B where B is a large negative number. Again, the problem persists. How is this consistent with any understanding of utility? How big should B be?

3.3.3 Discount rates

The discount rate is central to valuing future events and to the treatment of costs and benefits. It is also rather troubling. For example, as absurd as it may seem, at a discount rate of about 10 per cent, the entire world's current GDP in two hundred years' time would be worth less today than a luxury car.

The appropriate value of this rate has been extensively discussed in economics and it is the focus in debates about the differences in the recommendations of Stern and Nordhaus on expenditure on emissions reduction. There is also a large literature on the ethics of discounting the lives of future generations. A notable exception here is the work of Weitzman who concentrates on the relation between discounting and risk.[50] No attempt is made to summarise this literature here. It is only intended to consider some questions that the discount problem raises.

In Appendix B the discount rate is treated in more detail. For the current discussion the main point is that changes are not marginal and affect the entire system. In this case a fixed discount rate or a discount rate derived from standard commercial rates makes no sense. This is because the growth rate and future utilities will depend on efforts at reducing future emissions. This is roughly consistent with the approach taken by Stern and later by Garnaut.[51] Nordhaus also makes the rate of discount depend on the emissions control trajectory but in a much more muted sense. He has also suggested using the current market rates.

It follows from this that for some level of expenditure x the discount rate can be expressed as:

$$\delta(x) = p + f(g(x))$$

where f represents how the utility from a change in consumption changes with growth.

Assume that f increases as g increases. It follows that the higher the growth rate the higher the discount rate. This makes sense. If growth is large, then future generations are better off so their welfare can be discounted more.

What if f decreases as g increases? If there is the possibility that future states of the world may be worse than present states, then assigning a positive, or any, value to $f(g)$ is questionable. For example, if it is estimated that if average temperatures increase by 3-degrees C, the world economy might shrink by something like 30 per cent.[52]

In this case the discount rate might go negative. Is this plausible?

- If we expect to find ourselves in a post-holocaust, Mad Max style world in 50 years, we might be prepared to pay ten bags of wheat now or ten barrels of oil now to receive one later.

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[50] Weitzman, M., 2009.

[51] Garnaut, R., 2016.

[52] Burke, M., et al., 2015, Wallace-Wells, D., 2018.

- If we don't know how bad these future states might be, how do we evaluate f? How do we assign utilities to growth becoming negative?
- To provide some intuition, a negative growth rate that reduces GDP by say 30 per cent in some future time may have a much greater impact on utility than simply a 30 per cent reduction in current consumption.
- It gets worse. In order to put uncertainty into a formal framework, the expected value problem must be dealt with.

Weitzman has attempted to do this. Leaving the mathematical details aside, let the price of a future sure unit of consumption be M. Then if uncertainty is taken into account the expected value, $E[M]$, goes to infinity for an arbitrarily large value of loss due to catastrophic climate change. In terms of the previous we should be willing to pay an arbitrarily large number of bags of wheat now for a bag in the future.

- If we think about this in terms of discount it means that f, and hence δ, becomes an arbitrarily large negative.
- It is not clear what to do with this finding and we will return to it in a subsequent mathematical analysis. What is clear for the present, however, is that usual cost benefit applications related to climate change are problematic.

3.4 Policy lessons for dealing with political and economic uncertainty

Here are some of the lessons that can be derived from the discussion above.

On the negative side:

- It is dangerous to assume certainty where it does not exist. Except in the very short term, climate prediction and economic analyses given in exact numbers can be misleading. This has clear implications for investment strategies. These are taken up in Section 6.
- It is a mistake to rely on off-the-shelf technologies. Some of the economic predictions about optimal trajectories of even a decade ago were seriously in error. To be fair, these have been corrected to some degree. Nonetheless, this raises serious doubts about some of the techniques being used.
- Things may change very rapidly on the political and, to a lesser degree, on the economic fronts.

On the more positive side there are things that can be understood:

1. It is reasonable to expect that actions to avoid emissions will ratchet.
2. As a corollary of 1., it is also reasonable to expect any action will track long-term optimal pathways.
3. Tracking is not the same as following, of course. It is clearly possible that actions may be too little too late. Nonetheless, 1. and 2. have clear implications for the way in which long-term investment portfolios should orient.
4. In thinking about political settings, Appendix A shows that international co-operation may flip from 'not co-operate' to 'co-operate' once political costs reach a certain threshold.

On the analytical side:

- Once the role of uncertainty is specified it is also possible to improve the tools we apply. This should facilitate a more refined analysis and better policy.

- At worst, a proper appreciation of uncertainty means it is possible to avoid mistakes in constructing investment portfolios.
- At best, it is possible to put together portfolios and to construct investment instruments that provide hedges downside risk and balanced growth in a rapidly changing environment.

3.5 Policy lessons from the discount factor

It is noted that low to negative discount rates as the result of negative growth are something more than a possibility. In November 2018 a Congress mandated report by the US National Climate Assessment predicted that the US economy would shrink by at least 10 per cent as the result of climate change.[53] It would be unreasonable to assume the damage would be less for Australia.

If the discount factor depends on current expenditures, then many existing economic models and estimates may need to be reworked. For example, a high discount rate penalises technologies with big upfront costs but long-term output. If this rate depends on the technology itself the comparative costs of technologies may be change. This is discussed further in Section 4.

If there is a single point it is that **a serious justification would be needed for continuing to use commercial rates of discount for assessing long-term energy programs and technological options.**

3.6 Appendices

This section has three appendices. Most of the mathematics has been supressed but there is an irreducible minimum which partly reflects the complexity of the issues.

Appendix A expands on the points made about political interaction and attempts to provide a better framework for analysing the possible dynamics.

Appendix B expands on the argument that the discount factor should be made a function of expenditure.

Appendix C explores an alternative analytical framework for assessing the dynamics of technological replacement. It says, among other things, that one way to avoid the problems in economic analysis may be to take the targets set by climate science as given and determine the best trajectories.

[53] Wallace-Wells, D., 2018.

4. Energy and emissions – technological capacity, costs and uncertainty

The decisions that policy makers and investors need to make about the technologies required to meet Australia's long-term needs are not straightforward. In this section we attempt to compare the costs of alternative generation capacities on an apples-for-apples basis and in terms of their ability to contribute to the long-run zero-emissions target. We build up our comparison in stages. Eventually we try to estimate systems costs with reference to the long-run target of zero emissions and the capacities of different technologies. The main factor considered here is the backup required for security of supply. This still falls short of total systems cost since some grid level costs are not included. In the later parts of this section we make some specific comments about the Australian economy, policy and investing.

Our main point is that there is no simple long-run solution to the energy trilemma so there is no strong reason to exclude any of major technologies examined in this section below from the future energy mix.

Subsidiary messages include the following:

- Real costs of different technologies are uncertain and there is a significant difference between long-run total costs and short-term plant cost figures
- Decisions that do not consider the long-run trajectory of emissions may cause significant distortions and impose needless economic distortions over time.
- It is important not to limit technological capacity. This might include taking early steps to acquire some nuclear expertise.
- Assets, including solar and wind, can become stranded.
- Market mechanisms and grid designs will favour some technologies over others.

4.1 Basic concepts

The comparison of each technology presented below takes full costs and capacity into account.

4.1.1 Total systems costs

Total costs of providing electricity can be thought of in three parts. These are:

- The plant-level costs. They include construction and some of the immediate infrastructure. They are usually given by commercial figures and captured in the levelised costs of electricity (LCOE).
- Grid costs. These include the plant-level costs and the costs on the grid in terms of new connections, strengthening, providing buffering and back-up etc.
  - This covers the additional infrastructure necessary for system stabilising and frequency and voltage control (for example, transformers and circuit breakers) to accommodate decentralised and intermittent generation.
  - They also include the cost of energy security. This includes back-up against failure of generation to meet demand over a longer period. It also includes spinning reserves or the costs of keeping plant in operation without output to be available to fill supply gaps.
- Externalities. They include plant and grid costs along with spill over impacts such as health costs, loss of land for agriculture, environmental costs, risks of failing to meet emissions targets, waste disposal and so on.

Both policy and investment decision making must attempt to take all three cost elements into account when comparing the merits of different options (Figure 9).

Figure 9. Total systems costs of electricity

Underpinning our comparison of technologies is the economist's notion of opportunity cost. This requires that comparisons of alternatives include the benefit foregone of persuing one strategy over another. For example, investing in technology mix A has an opportunity cost measured in the amount of benefit foregone by not investing in B or C, etc.

The opportunity cost approach means that all major technologies need to be considered. This is also consistent with the principle of fair trading. To be clear, failure to exclude nuclear does not mean we are pro-nuclear any more than failing to exclude solar means we are pro-solar. We are just pro-the principle of optimisation.[54]

4.1.2 Capacity

Once we have compared full cost below, we then produce back-of-the-envelope calculations, which account for those costs, but also the capacity of each technology to contribute to the long-run goal of zero-emission in an optimal and efficient way.

The main distinction we make here is between nameplate capacity (or rated capacity) and output capacity:

- Nameplate capacity is the rated capacity of an installation and indicates its maximum output.
- Output capacity is the average amount of energy that an installation achieves over time under normal operation.

For example, nameplate and output capacity are roughly the same for coal, gas and nuclear. For solar and wind, the output capacity is less than about half nameplate capacity.

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[54] Serious nuclear power plant accidents include the Fukushima Daiichi nuclear disaster (2011), the Chernobyl disaster (1986), the Three Mile Island accident (1979) have produced a behavioural bias in otherwise rational people. The bias is a prejudice against anything nuclear, no matter how much potential it may have, or how cost effective it may be, or how it may contribute to future energy reliability, affordability and emissions reduction. Nuclear power is the now the ugly duckling of the power generation industry. People somehow dismiss it as immoral, even more immoral then burning coal.

It reminds the authors of the story 'Anatomy of an undervalued pitcher' told by Michael Lewis in the book Money Ball (2003). This the tale of an obscure, soft-tossing Double-A pitcher, Chad Bradford, who had the strangest pitching action imaginable. When he pitched, he looked funny and threw the most incredibly soft pitches. But he was also one of the most efficient pitchers in baseball. He was hardly ever walked on, hardly ever hit for home runs, and usually struck out at least one batter per innings.

Unfortunately for Chad, whilst he was an incredibly effective relief pitcher, achieving strikeouts by the dozen, his team the Chicago White socks didn't trust his statistics. They just judged him on the way he looked. So they demoted him to the minor leagues for a time.

Eventually it took the empiricist, former player, and manager of the Oakland As, Bill Beane to see through the fog and trade for the pitcher, allowing him to escape from the minor leagues. The key was to judge the pitcher's output objectively, gauging his future value on a sensible apples-and-apples comparison.

Our back-of-the-envelope calculations also assume that all primary energy is to be generated from renewable electricity rather thermal sources. Replacing thermal energy with electricity does involve efficiency losses, but these will be ignored so we can place solar and wind on a comparable basis with other generation technologies.

Our back-of-the-envelope calculations are very crude. This largely reflects the uncertainties around long-run costs. But within the range of the uncertainties presented, they are a useful guide. At best they are considered meaningful with a 20-30 per cent range of reliability and our confidence in this range diminishes with the length of our projection.

Our back-of-the-envelope calculations are based on the most up-to-date freely available data which sometimes is quite limited.

- We are very grateful for any suggestions regarding how to improve our data sources.
- We plan to produce an annual update of the tables in this section.

4.2 Difficulties in comparing technologies

The costs of alternative technologies are examined below by looking at data sourced from various reports under different assumptions.

The difficulty of comparing the cost of technologies is that they have different properties and may not be substitutable. There is no straightforward way to compare costs or even to determine which costs should be considered. Among the issues are:

- Is the objective to maximise community welfare or to maximise returns from short-term investment?
- Is cost taken to mean the accounting cost of plant production or cost per unit of carbon dioxide avoided or something else?
- Are buffering costs to be included?[55]
- What about grid level costs and the costs of energy security?
- What does fair trading mean in terms of cost comparison?
  - Should the cost of technology A that has been subsidised to get development at scale be compared with technology B that has not been subsidised? Should the comparison be with the projected cost of subsidising B to get development at scale?
  - Answers to these questions may significantly affect cost figures. This is particularly the case in comparing solar, wind and nuclear.

It is also important to note that differences in the services provided by different technologies mean that many of the stand-alone cost figures currently available may not be meaningful. In addition, they may be swamped by other factors such as technological change, material availability, speed of deployment and political demands.

In keeping with the previous discussion of economic analysis, an attempt is made below to work through these issues systematically rather than to pull a set of figures off the shelf. Any such figures are misleading without an understanding of how they are derived. This is particularly the case with the frequently used levelised cost figures.

A further difficulty is that there is intense pressure on energy technology to evolve. Various claims are frequently made about breakthroughs in storage and even micro-reactors or fusion. These need to be dealt with in a measured way.

[55] Buffering costs are associated with smoothing out rapid variations in supply relative to demand.

4.3 Technologies not compared

The most important technologies seem to be solar, wind, nuclear in various forms, coal and combined cycle (CC) gas generation and carbon capture and storage. We exclude the following:

- Biomass. This is excluded because of its high emissions intensity. Although biomass is sometimes considered renewable, in purely accounting terms it does nothing to reduce emissions and may cause them to increase. [56]
- Hydro. There is little opportunity for capacity development potential across the world on a reasonable scale. It is considered as a storage technology for solar and wind back-up.
- Tidal and wave power and geothermal. These cannot be developed on the scale required.
- Hydrogen as a store of energy. The practicalities and relative costs of different technologies required to produce it at scale are unclear.[57]

Over the next decade or so, it is reasonable to assume that we will see the deployment of current technologies with roughly the same relative full cost structure (including system-wide costs and the need for back-up) they have right now.

Advances in technologies already existing are likely to be most significant in battery storage and in nuclear reactors. Both are areas of intense research.

- Batteries will see improvement on current designs and the possibility of alternatives and any significant advances would improve the scope of solar and wind.
- Nuclear would include advanced reactors being developed by the Generation IV International Forum and small modular reactors and micro-reactors.[58]

It is also possible that there will be technological disruption in some form. This is discussed below. However, hoping for the best is usually not considered a good basis for analysis, nor a good insurance policy.

4.4 Plant level cost comparisons using levelised costs

The most commonly cited commercial comparison of technologies is based on levelised cost. This makes costs subject to interest rates and usually does not consider system-wide costs and the need for back-up. This raises questions about differences between commercial discount rates and social discount rates and about the measure's suitability as a guide for longer-term policy decisions. These questions were discussed in Section 3.

Levelised costs have two components:

- Cost. This is obtained by taking all the costs in each time period, usually a year, and discounting them to present values. These are then summed across the relevant period, which is usually taken to be about 30 years.
- Output. This is obtained by taking the electricity generated in each time period and summing across the relevant interval. This may or may not be discounted.

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[56] Scientific American, 2018.

[57] The production of hydrogen is energy intensive and much of the analysis will depend on factors covered in this section. It might also provide energy storage. We will consider hydrogen in an addition to this discussion paper.

[58] Generation IV nuclear reactors refers to a group of new designs put together and being financed by an international government consortium. Two are slow and the other four are fast breeders. What they have in common are passive safety features (that is they can't melt down or overheat) and simplicity. At least four of them are designed to produce hydrogen as a joint product.

In most cases the levelised cost is the first sum divided by the second. Let LC be the levelised cost, c_i and e_i cost and energy generated in period i with d_i the discount factor, then:

$$LC = \frac{\sum_i c_i\, d_i}{\sum_i e_i\, d_i}$$

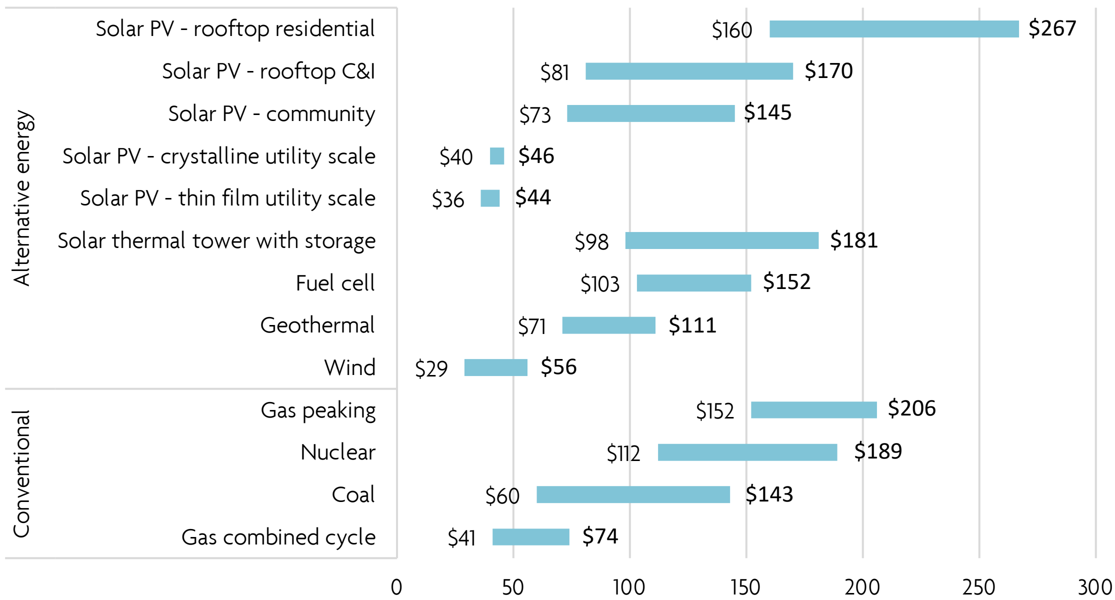
Levelised costs will depend partly on whether they only include plant level data, whether tax and subsidies are included, and whether all output is counted or only output at economic value. They are also sensitive to assumptions about the rate of interest for systems with a long life. Some of the problems with discount rates have already been discussed in Section 3 and Appendix B. So simply applying a commercial discount rate may result in large distortions.

We include three different sets of levelised cost estimates to give a rough idea of the range of variation in plant level cost figures.

4.4.1 Lazard figures

The financial advisory firm Lazard provides a set of industry standard figures for different electricity generation technologies.[59] These are presented in Figure 10.

Figure 10. Lazard's levelised cost of energy ($US/MWh) in 2018



Source: Lazard's Levelised cost of energy analysis, version 12.0.

4.4.2 OECD figures

The OECD provide a set of figures for levelised cost at a three per cent interest rate. In $US per MWh at the plant level these are given in their Tables ES.1 and ES.2 as:

- Solar PV commercial: 100
- On-shore wind: 70
- Nuclear: 50

[59] Lazard, 2018.

- Coal (with partial carbon costs): 80.[60]

4.4.3 Energy Information Reform Project figures for advanced nuclear

The projected cost of new build nuclear reactors has been estimated by the Energy Innovation Reform Project. Their figures give some idea of the outcome if new generation nuclear reactors were developed at scale. They use a costing framework developed by the Generation IV International Forum to assess data from a group of companies actively developing new era reactors including small modular units and fast neutron reactors.[61] Their findings are summarised in Table 3.

Table 3. Cost summary ($US per MWh) for advanced nuclear reactors

	Average	Minimum	Maximum
Capital cost total	4	2	6
Operating cost total	21	14	30
Levelized cost of electricity	60	36	90

Source: Energy Innovation Reform Project 2018, Table 2, p. 2.

4.4.4 Note on levelised costs comparisons

The differences between the OECD and the Lazard figures are largely due to different assumptions about capital and operating costs and interest rates. For example, Lazard applies a discount rate of 8 per cent and the OECD figure is for 3 per cent. An 8 per cent rate makes the value of output from a reactor in 30 years only about 10 per cent of its original and negligible after 50 years.

The Energy Information Reform Project figures estimate the projected costs if advanced reactors are produced at scale. In this case modularisation and factory production become important. Lazard and OECD figures do not account for these scale economies.

We do not consider levelised costs to be a good metric for long-term investment or policy decisions. We now attempt to broaden our perspective by looking at grid-level cost estimates.

4.5 Cost comparisons including grid costs

The OECD gives estimates of grid-level costs for various technologies.[62] In order to provide a simple comparison with our previous figures, the OECD figures have been aggregated with the previous data on levelised cost to give total grid level costs.

It will be noted that grid costs are sensitive to penetration level. This refers to the percentage of the electricity grid occupied by the technology. As the penetration of the grid by intermittent sources increases, the cost of buffering and dealing with surges or gaps in output increase.

It must be remembered that electricity is usually less than about 20 per cent of primary energy. So 10 per cent of electricity is about 2 per cent of primary energy. This begins to hint at some of the issues to be faced if we move towards 100 per cent renewable sources in primary energy.

[60] OECD, 2018, pp. 6-7.

[61] Energy Information Reform Project, 2018.

[62] OECD, 2018. pp. 17-19.

To compile Table 4, we have taken the low estimate for nuclear from the Energy Information Reform Project figures. Lazard estimates are used for low and high costs otherwise, as these are most favourable to wind and solar.

Table 4. Composite total grid-level costs ($US per MWh)

Penetration level	10%		30%	
Cost range	**Low**	**High**	**Low**	**High**
Nuclear	38	192	38	192
Coal	61	144	61	144
Gas	42	75	42	75
Onshore wind	44	71	57	84
Solar PV	74	82	80	88

Source: OECD 2018, Energy Innovation Reform Project 2018, Lazard 2017.

4.6 Cost comparisons including value of emissions

The Brookings Institution has made a broad assessment of opportunity costs by comparing technologies across a range of factors that might give a view of their overall value to an electricity system.[63] The major factors considered are avoided emissions, energy costs, and avoided capacity costs. Avoided emissions are what it says. Avoided energy costs are fuel that would otherwise be used. Avoided capacity costs are the cost of building alternative plants. Their figures implicitly include some grid level costs, capturing capacity factors such as reliability.

The Brookings estimates are sensitive to assumptions about fuel costs, interest rates, etc., and this leaves some room for alternative estimates. Nonetheless, their comparisons are important. If the values of displaced emissions and capacity factors are not explicitly identified they would be set at zero by default. [64]

The crucial factors underpinning the Brookings analysis are the type of plant they assume is replaced, and the assumption made about carbon prices. If, for example, a coal-fired plant is displaced, the costs and emissions benefits will be greater than if a CC gas plant is displaced.

Consider the case where a coal fired plants is being displaced and emissions are valued at $US 50 per tonne. The results are summarised in Table 5. Benefits are given in terms of comparative cost savings in MW of installed capacity per year. In this case CC gas gives the greatest net benefit. If we only consider zero emissions scalable technologies then we have wind, nuclear and solar.

If carbon price goes to $US100 a tonne then nuclear provides the most benefit. The figures can be calculated from the Table 5 by multiplying component pieces of the calculation by two. They are nuclear $US484,084, wind $US344,132 and solar $US125,233 per MW installed capacity.[65]

The most important reason for the difference in total net benefits is that nuclear and CC gas have higher capacity factors and displace more emissions and energy. They are also not

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[63] Frank, C., 2016.

[64] It is anticipated that these figures will be reviewed in an addition to this report.

[65] Carbon at $US100 a tonne is a reasonable figure. See Carr, M., 2018.

intermittent and displace more capacity. For example, a solar plant with a capacity factor of say 30 per cent will displace less than 30 per cent of a fossil fuel plant.

Table 5. Brookings' net benefits ($US per MW) of different technologies

Benefits per year	Wind	Solar	Hydro	Nuclear	CC Gas
Avoided emissions	170,896	112,029	149,383	380,141	374,718
Avoided energy costs	112,539	82,438	111,519	246,655	243,479
Avoided capacity costs	107,154	67,363	103,249	248,298	246,125
Total benefits	390,589	261,831	364,151	875,094	864,321
CO_2 emissions costs	0	0	0	0	140,408
Energy costs	0	0	0	73,714	173,022
Capacity costs	204,526	229,319	228,395	692,207	111,512
Other costs	10,827	19,308	0	5,230	0
Total costs	215,353	248,627	228,395	771,151	424,942
Total net benefits	175,236	13,204	135,756	103,943	439,379

Source: Frank, C. R., 2016. New results on the net benefits of low-carbon electricity technologies.

It is noted for reference that Lazard produces different figures on cost of carbon displaced.[66] This gives the cost of saving a tonne of carbon as: CC gas $US46, nuclear $US55, wind $US33, and solar photovoltaic $US15. Lazard assumes a higher capital cost for nuclear plants than Brookings and a shorter plant life. It also does not consider the benefits of capacity avoided.

4.7 Comparing capacities and costs for zero emissions: back-of-the-envelope calculations

The problem of dealing with capacities and costs to achieve the long-run target of zero emissions is projected here with some rough back-of-the-envelope calculations. These are only intended as a guide. They may be the best that can be provided given the degree of uncertainty around technologies. For a discussion of the dangers of false precision see Section 3.

It must be stressed that the zero emissions target produces different cost structures than the Lazard, Brookings and the OECD figures. At zero emissions, capacity constraints and costs of total systems back-up become major issues.

As before, the analysis:

- concentrates on long-run pathways. If a technology cannot meet the zero emissions goal under reasonable conditions, then there are serious questions about whether it contributes to an appropriate emissions reducing trajectory.

[66] Lazard, 2017.

- looks at different technologies when deployed at scale to meet the target of zero emissions. Scalability is essential because a technology that might work well at, say 10 per cent of primary energy, might not work at 50 per cent.
- looks at options sequentially.
  - What would happen if we ran the system entirely on technology A with backup B?
  - What about backup C, etc?
  - What about running half the system on technology A, with backup B, and half on A with backup C?

Any system will be a mixture of different technologies and demand management. Without some basic assessment of what the parts look like individually it is difficult to get an appreciation of practicalities for various combinations. Nor is it easy to see if they satisfy the efficiency and merit principles.

Below are our (very) rough comparison figures. In producing these figures, we have tried to be conservative by using latest installations and proposed plants for solar and wind.

4.7.1 Solar

Photovoltaic

The capital costs for solar photovoltaic plants can be estimated using data from any one of the many recently built installations in the United States. Topaz in California is taken as a reference.[67] This is one of the largest photovoltaic plants in the world. It has a nameplate capacity of 550 MW and had a construction cost of $US2.4 billion. Given the capacity factor is about 27 per cent, the capital cost is about $US16 billion per GW output, which is a bit less than Moree in Australia at the same scale.[68]

In terms of Australia, a proposed plant in Darlington Point - near Griffith in New South Wales - has a projected capital cost of $450 million and a nameplate of approximately 300 MW. [69] It is anticipated to produce 685 GWh of electricity per year. If this is scaled it has a projected capital cost of about $5.8 billion ($US4.4 billion) per GW output.

Thermal

The advantage of solar thermal is that it may not require back-up, depending on its storage capacity. One example of large scale solar thermal plant is the Ivanpah system in California, which became operational in 2014. It has a nameplate capacity of 392 MW and an output of 940 GWh per year. The total construction cost was $US2.2 billion, which means the capital cost is about $US21 billion per GW output.

Another example of an older plant is the Gemasolar CSP plant in Andalucía with a capital cost of about $US25 billion per GW output.[70]

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[67] First Solar, 2018. Topaz is used here because total cost figures are readily available. Other large plants in the United States have approximately the same capacity and age.

[68] Martin, J., 2011.

[69] Edify Energy, 2018.

[70] Brook, B., 2011.

4.7.2 Wind

In this sub-section we compare the cost-capability combination of existing and proposed wind generation plants. For comparison we restrict our attention to on-shore facilities. These are much less expensive than off-shore.

On-shore wind

Capital costs for on-shore wind farms typically range between $US1 - 2 billion per GW of nameplate capacity. They have a capacity factor of between 0.3 and 0.4, so about $US2.5 to 6.7 billion per GW of output.

Total grid costs are difficult to assess. Roughly, they increase plant costs by about 50 per cent. This brings the overall cost estimate range to $US3.8 to 10 billion per GW output.[71]

For Australia, a proposed wind farm in Victoria under the name Dundonnel has a nameplate capacity of 336MW and a projected cost of $ 560 million. At a capacity factor of about 40 per cent, this gives a cost of $4.2 billion ($US3.2 billion) per GW output without grid costs.[72]

4.7.3 Nuclear

The high cost case for nuclear is Olkiluoto, built in Finland by Areva.[73] Its final cost is about $US6 to 7 billion per GW of nameplate capacity.[74] Output capacity is about 0.8 to 0.9 of nameplate capacity. For comparison, a South Korean consortium is building four power stations in the United Arab Emirates at $US4.5 billion per GW capacity[75] and the Chinese are currently building the Westinghouse AP1000 at between $US1.8 and $US2.6 billion per GW.[76]

On these figures the overnight capital cost of nuclear using the most expensive case is about twice the cost of on-shore wind and up to twice solar photovoltaic.[77] It should also be noted that the economic lives of solar or wind facilities is about half the life of a nuclear plant, which has not been considered.

4.8 Comparing capacities and costs: potential energy and battery storage

The best storage for intermittent generation seems to be some form of battery using either potential energy or chemicals or some form of heat retention like molten salt or graphite slabs. As already stated, hydrogen will be considered in a later study. Kinetic energy is also a possibility. This might be obtained by high speed centrifuges but is prohibitively expensive and will not be discussed.

The cheapest and easiest store of potential energy is to work against gravity by pumping water or elevating some other mass such as a lump of concrete and releasing the energy when needed. Hydro water storage seems the most efficient.

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71 Post, W., 2013.

72 Tilt Renewables, 2018.

73 Paul, S., 2018.

74 Neither Hinkley Point C nor Chinese new builds have been taken as a base. Hinkley Point C seems to be an outlier in terms of technology and financial arrangements.

75 Stanley, B., & Lee, H., 2018.

76 World Nuclear Association, 2019.

77 These figures ignore the economic life of different each plant types.

It must be stressed that the discussion of capacity is for replacement of total primary energy. In a way this is unrealistic for a single technology, but it gives a sense of the difficulties involved.

In what follows we look at the question of back-up. It would also be possible to look at other metrics such as the percentage of capacity that gives, say, $x\%$ reliability. Different metrics will be roughly equivalent.

It is not clear how much back-up is needed. This will depend on the technology mix. If we had a complete solar and wind system, one-and-a-half days would seem reasonable, although this would probably not guarantee total reliability. One day would seem too low.

Back-up is calculated for 100 per cent of primary energy. If it is thought that only half that is needed, simply divide the figures. If three days are required, multiply by two.

4.8.1 Potential energy storage for Australia

Potential energy storage has the advantage of being almost instantly variable. There is some capacity in existing hydro schemes, but at scale pumped storage would be necessary.

Figures on pumped hydro vary according to topography and energy requirements. It is doubtful that it is technically feasible for large economies like the USA, China, India and much of Europe to cover a substantial proportion of their back-up requirements in this way.

A recent Australian National University report has calculated that there is enough storage capacity to provide back-up for a solar and wind system that provides all primary energy in Australia.[78] This is correct, but capacity is not the same as feasibility. We now look at this.

Total energy consumption in Australia is currently about 1,750 TWh per year or 200 GWh per hour or 7.2 TWh per one-and-a-half days. Remember that we are ignoring thermal energy and trying to replace everything with electricity. The Snowy Mountains scheme has a capacity of 4.1 GW. If run at full capacity, a full system back-up would require about 49 Snowy Mountain schemes with duplicated dams at the bottom end.[79]

It is difficult to do a full cost estimation from figures on concrete, steel, land acquisition, etc. To get a very crude estimate under the best possible case consider the Snowy Mountains 2.0 scheme. The project builds on the original Snowy scheme. This project has an estimated cost of $7 billion for a capacity of two GW, about half of the original Snowy scheme.[80]

Based on the Snowy case, Australia needs about a hundred Snowy Mountain 2.0 schemes at a total cost of $700 billion ($US525 billion). Opportunity costs are about 100 to 150 nuclear reactors. This would provide well over half Australia's current primary energy needs.

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[78] Blakers, A., 2018.

[79] It might be possible to reconfigure the system and the pipes to run larger turbines and reduce this figure. For example, ignore engineering limitations and make the tunnels and turbines and pipes 47 times larger. A simple application of Newton's second laws tells us that we would need to run about 3,000 Glitres of water to get the required back-up. This is between one-and-a-half to six times the active storage capacity of the existing Snowy scheme. Equivalently, we would need about six Snowy Mountains with tunnels and turbines about seven times the existing capacity. All these still does not solve the problem of supply when back-up is required for closely spaced periods.

[80] Hutchens, G., 2017.

4.8.2 Battery storage for Australia

The Tesla lithium-ion battery built for South Australia has a capacity of 100 MW and a storage capacity of about one hour. It costs $90 million to build.[81, 82]

Assume we want Tesla batteries to provide the primary energy backup for the 7.2 TWh required for one and a half days.

To calculate the number of batteries required, remember that a battery will only run for one hour. This means we need to divide the 7.2 TWh by 100 MWh to get 72,000 batteries. This gives a total cost of $6.5 trillion ($US4.9 trillion). **In terms of opportunity costs, this is about ten times that of the pumped hydro or about 1,000 nuclear reactors.**

It is also interesting to consider the possibility of decentralising to the household level by using batteries. Household use is about 10 to 15 per cent of total energy. To get an estimate, the cheapest form of rechargeable batteries is lead acid. The minimum cost for a battery with a storage capacity of 2.5 kWh is about $US200.

On current figures the average daily household energy consumption is 30 kWh. Assuming the price of batteries remains the same, it is necessary to consider limits on how far batteries can be depleted and expected life. Assuming we can extract half the available energy, it would cost about $US7,000 per household every ten years or so to provide backup for 36 hours.

If the transport fleet is switched to electric vehicles, there would be an increase in storage capacity. On the other hand, there may also be peak time loads. It is hard to estimate the contribution this would make.

To repeat our caveat, these calculations are only rough guides. For example, it is not suggested that any attempt should be made to provide all back-up using batteries. Nonetheless any linear combination of possible back-up facilities will run into the same issues.

The key takeout is that intermittent technologies may not provide the best means of delivering all primary energy. It is also doubtful whether they are the best means of providing all electricity at current levels of demand.

We summarise the cost figures and back-of-the-envelope calculations in Table 6.

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[81] McConnell, D., 2017.

[82] Keane, D., 2018.

Table 6. Comparison of technologies: back-of-the-envelope calculations

Technology	Installation	Billion $US per GW of output	Backup required?
Electricity generation – overnight capital cost*			
Solar PV	Darling Pt.-Topaz	4 – 16	Yes
Solar thermal	Ivanpah, California	21-25	No
Wind	Dundonnel-world average	3 – 7	Yes
Nuclear	Olkiluoto, Finland	6 – 7	No
Cost of back-up for 1.5 days		**Billion $US per GW of output**	**Billion $US for total system needs**
Pumped hydro	Like Snowy Mountains	2.6	525
Battery	Like Tesla in SA	24	4,900

*Note: *Overnight costs exclude grid-level costs.*

4.9 Carbon capture and storage

Coal produces about 30 per cent of the world's primary energy and about 75 per cent of Australia's electricity. In the US, the average age of stations is at the design-life of 40 years. Whereas in Australia, most coal-fired plants have had their design-life extended. There are also discussions about building new power stations. China currently uses coal for over 60 per cent of its energy. It currently has plans to build up to another 1,000 power stations.[83]

One critical technology in Australia and elsewhere will be carbon capture and storage. This could be used to retrofit existing plants, build new plants and capture emissions from the industrial sector.

So far, there are several experimental plants but little commercial development in the pipe-line. Among the problems this presents are the substantial energy requirements of the process and finding storage locations at the scale required. Energy costs will depend on the type of plant and efficiency but may be in the order of 40 per cent.

It is estimated that the cost of carbon capture and storage would be in the order of $US70 a tonne at a minimum, although it is difficult to guess for a technology that is untested at scale. Retrofitting might be even more expensive.[84]

If the price remains at the current 'best guess', coal would become more expensive than solar, wind and nuclear, and there would be little incentive to build new stations. It would, however, be significant in reducing emissions from other sectors and reduce the pressure to shift the primary source of electricity.

At this stage, uncertainties around commercial development mean that carbon capture and storage must be left on the watch list for desirable technologies.

[83] Institute for Energy Research (IER), 2018.

[84] Temple, J., 2018.

4.10 Grid design and distribution

Grid structure and the energy market are important elements in determining the viability and cost of different technologies. A large capacity integrated grid will favour the wide dispersal of solar and wind. A fragmented grid will reduce the cost of local solutions. If energy markets are large-scale and predictable, high capital cost dispatchable systems with long-run, low costs, are favoured. If energy markets fluctuate according to spot demands, low up-front cost and flexible forms of generation are favoured.

The difficulty is that a significant portion of total value and total cost of different technologies does not necessarily appear in market transactions (see the previous discussion of levelised costs and net benefits). **It follows that there is no reason why a grid structure that evolves according to market demand is appropriate for the policy settings that maximise long run welfare.** This means that it may be necessary to exercise some administrative control over grid design. It will also be necessary to incorporate grid level costs as discussed previously.

4.10.1 East-West transmission

Extending the Eastern grid will only give marginal benefits. For example, wind capacity often drops below five per cent. This means that only five per cent or less of new capacity can be guaranteed at any one time.

Consider building additional capacity on an East-West Axis and assume that gaps in generation do not correlate. Assume also that an additional transmission capacity of 20 per cent of primary energy is needed. Note this is a flow problem and not a storage problem.

For a total distance of about 4,000 km, using prices for lines currently under construction from France to the United Kingdom gives a cost in the range $US 2 to 10 million per GW km. Using the lower figure gives a total cost of about **$US320 billion.** It is possible that lower land costs and transmission standards would bring in a lesser figure.

4.10.2 Marketing

Markets and grid are also determinants of technology. Currently the East Coast of Australia is covered by the National Energy Market. The short-term nature of price signals in this market may fail to encourage long-term focus in investment and optimal choices of technology.

This problem has been noted by Garnaut who points to distortions in the wholesale market.[85] He makes the point that more efficiency in the market will help the allocation of resources amongst existing suppliers, but it will not bring about the structure that is best suited to deal with new technologies and optimal mix of resources.

A similar point is made by Rath who acknowledges that there is widespread awareness of the need to make changes in the regulatory system. He says, however, that these do not go far enough and that 'much more radical changes are needed than tweaks to a system that's predicated on fossil fuels and the 20th century energy value chain.' [86]

As an example of how market instruments might be used, consider the problem of dealing with intermittency. If intermittent renewables are mandated, large-scale dispatchable power generation may become uneconomical because total demand falls. On the other hand, it may be required to cover gaps in output.

It may be possible to solve this problem with a dual market structure with government sponsored power purchasing agreements. Power purchasing agreements are commonly used in

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[85] Garnaut, R., 2016.

[86] Rath, M., 2017.

the United States and could be used by governments here to provide a vehicle for long-term stable pricing models. Alternatively, governments could offer a price guarantee or strike price as is done for some wind and solar farms in Australia and for the Hinkley Point C reactor.[87]

4.11 Technology and electricity production in Australia: some lessons

The Australian electricity landscape has several specific features including heavy reliance on coal, and extensive opportunities for solar. In addition, energy policy is characterised by the possibility of rapid change and there seems to be a growing demand that government addresses the current high level of emissions (see Appendix A).

What effect is this likely to have on the technology mix? In the short run there is considerable scope for increasing the use of solar and wind because of the large buffering potential of existing fossil fuel plants. It is likely that as the expansion of gas generation increases, current generation coal will almost certainly decline. Ultra-critical coal fired power plants could reduce emissions by up to 40 per cent compared with the current ageing fleet. This will not be enough to satisfy demands for emissions reduction. In addition, there seems to be a reluctance in the private sector to invest, and the political cost of supporting coal is increasing.

In the longer term, there is greater uncertainty. It is possible that the unit costs of solar and wind will fall, although it would be reasonable to assume that the rate of the decrease will be slow. As their penetration increases their capacity to displace fossil fuels will decrease without an increase in back-up sources to harden the network.

If schemes like Snowy 2.0 can be brought on line they will provide additional buffering and may allow for the further expansion of solar and wind. Other programs to store potential energy may also help, but at increasing expense and possible environmental cost.

It is difficult to see what would happen if solar and wind went beyond, say, 50 per cent of electricity or about 10 per cent of primary energy. The Tesla battery in South Australia has been a commercial and practical success, and extended use of this technology would alleviate short-term fluctuations. As discussed already, it would not alleviate concerns about security.

It is possible that beyond about 50 per cent of electricity, some solar and wind may become stranded assets. This would begin to raise serious questions about the trajectory of the energy system.

If carbon capture and storage were to become commercial, then coal would become a viable part of the mix. This would create a strong incentive to shift to new coal fired plants, which may be a more cost-effective option than retrofitting an already ageing fleet. Any such move could be supported by appropriate changes to the electricity market and government sponsored PPA's as already discussed.

If carbon capture and storage is not developed the eventual transition away from coal is almost certain. One strong option is CC gas combined with solar and wind. The economics of this are very sensitive to gas prices on the world market. In addition, this option is limited by the fact that emissions from gas remain high. This again raises the problem of long-term commitments to technologies that may be pushing along sub-optimal trajectories.

It would also be desirable for Australia to spread its technological options. One important step would be to build some capacity to operate a nuclear facility. This would provide insurance against failure in alternative options or rapid change in technology. A single reactor would be a relatively small investment.

[87] Paul, S., 2018.

In the absence of policies to modernise generation and spread options, Australia may be in a difficult position. If the rest of the world, or public opinion, demands measures to reduce emissions, there is a danger that it might be stranded with an inappropriate technology mix and skills set.

5. Take-outs for investors

This section provides our best guesses about developments in Australia and overseas and about opportunities for long-term portfolio investors. The task is to translate the preceding discussion of technological constraints and possible shifts in political pressures into an investment framework.

Industry superannuation funds should stand ready to allocate capital towards the electricity sector. However, they need Australian governments to put in place comprehensive policy frameworks that deal with negative externality associated with carbon pollution. These frameworks provide certainty for investors.

In the absence of a broader framework agreement, broadly speaking there are two approaches that can be taken by portfolio managers, each presents opportunities and challenges for investors and governments. Either a high road or a low road, contrasting long-term stable solutions with business-as-usual. In keeping with the stewardship and optimality principles, industry superannuation funds should attempt to nudge the sector towards the high road.

Finally, this section considers a set of factors that investors should consider when examining particular investment opportunities and structuring portfolios. These include: structural barriers to expansion; generating synergies from existing asset holdings; generating value for investors; profiting from the prejudices of others; and finally taking a forward-looking perspective.

5.1 The adjustment tasks

Assuming a broad international agreement on climate change is achieved, the nominal target for discussion in this paper is zero net emissions around 2050, in line with the current commitments of several Australian states and territories. This target is judged to reduce emissions to levels that leave an acceptable risk of catastrophic climate change.

5.1.1 Targets

The target for assessing policy should be to modernise the electricity sector to get zero net emissions around 2050 or sometime thereafter. It is doubtful this goal will be met but it provides a clear focus for the direction of change. As shown above, attempting to meet reduction targets of this magnitude will require a major reworking of generating assets and infrastructure. Portfolio investors need to keep one eye firmly fixed on energy production, but the other eye on ancillary developments in energy storage and distribution.

One argument is that all sectors of the Australian economy should undertake abatement in proportion to their projected BAU emissions levels. Under such a scenario, the electricity sector should target a reduction in 2030 emissions levels to at least 35 per cent below its 2005 level, as discussed in Section 2.5.

The burden of adjustment should be heavier in the electricity sector, especially in the initial stages, for two reasons:

1. Large-scale emission reductions in the electricity sector are relatively cheap and can be achieved quickly.
2. Emissions reduction in the sector are a necessary condition for energy substitution in other sectors, to the extent that it is possible to replace fossil fuels.

5.1.2 Technologies

From an investment perspective the technical issues that must be faced include: the possibility of the electricity sector continuing to operate with existing coal fired generation; or whether an injection of new, large-scale, baseload and other energy mixes will be necessary. In the absence of carbon capture and storage, the first of these possibilities seems increasingly unlikely. If the second, what are the likely mixes and what are the associated investment opportunities?

Changes in the mix of generating capacity will demand new grid design, new storage and transmission capacity, changes to market structures, and changes in demand management.

Among the obvious areas to be studied as investment opportunities are:

- Financial instruments and innovation tied to government support for large infrastructural projects and energy modernisation.
- Solar and wind at relatively low levels of the total energy supply.
- Materials used in solar and wind.
- Battery technologies.
- Developments in the grid and the energy market.
- Vehicles for buffering intermittent supply and possible opportunities to invest directly in the technology and the delivery systems.
- CC gas as a short to medium-term back-up.
- Transport. This includes the materials and the infrastructure of charging stations and distribution required for a progressive displacement of internal combustion with electricity.
- Hydrogen technologies.

It is unlikely that nuclear offers opportunities for investment in the short term although the technical limits and cost of other solutions may cause a rapid shift in public sentiment. It should be placed on a watching brief.

Carbon capture and storage should also be placed on a watching brief. If it can be developed at scale it would significantly affect the value of coal assets.

5.1.3 The policy reaction function

The question remains how completely and quickly authorities should respond to these policy challenges to lay out a stable policy backbone against which portfolio investors can make strategic decisions. We characterise two broad alternative responses for investors immediately below.

5.2 Two broad approaches

Broadly speaking there are two broad approaches to take to electricity investment which present opportunities and challenges for portfolio managers.

5.2.1 High road to reform – the 'propriety' investor

Savvy investors know that the longer run policy game (twenty years or more) moves in one direction (towards the 'high road' scenario). The question for portfolio managers is whether:

1. to seek to invest into policy 'short-termism' so profiting the existing state of policy stalemate in Australia and abroad;
2. to disengage until policy signals are more settled;
3. or seek to anticipate more coherent future policy arrangements by undertaking strategic investments today; or
4. all the above, on a case-by-case basis.

We argue that the extent to which portfolio managers behave with a longer timeframe in mind, the more they will adopt a propriety style of investing. This means that they will be seeking a far-sighted and sustainable path in terms of decision-making.

Presumably, a precondition for large-scale involvement in the energy sector by the funds management sector is the stability in policy settings and engagement in policy development and evaluation as a pre-condition. That said, far-sighted funds may be able to see the opportunities (as well as the risks) associated with pre-empting future government decision-making to fill pot-holes in grids, replace existing network capacity, or develop innovative financial products that better help in managing risks both here and overseas.

Certainly, long-term investors need to remind governments of the need for creating a stable investment environment and to press government to give clear signals on carbon pricing and other policies.

Once long-term policies are settled upon by governments, investors can deploy capital with the same degree of certainty, that would be associated with any other infrastructure proposal.

Long-term gains

Once long-term policy is settled, it will propel the quantity and quality of portfolio investment into sectors. The impact of this will be as follows:

- the easier it will be to facilitate the long-term adjustment task for the Australian economy;
- the more related technological, supply-chain and spill over benefits will be achieved which will justify a virtuous spiral of progressive rounds of business investment which will then fire productivity in the national economy; and
- the higher the returns generated on a diversified portfolio, including new generation and related infrastructure assets.

As has been pointed out in Section 2 and throughout this discussion paper, the high road to reform is the only stable long-run equilibrium, although this reality may still take another ten years or more to become apparent to financial markets.

In time, it would be expected that changes in technology and markets will track long-term optimal pathways. This gives some clues for the way in which long-term investment portfolios should orient.

But right now, policy settings are driving an arbitrage 'party' in occurring in the international investment community centred on energy investment and climate change.

5.2.2 Low road to reform or business-as-usual – the 'party' investor

The problem in taking the low reform road, or failing to reform at all, is that bad policies may steer investment towards long-lived infrastructure and technological solutions that only survive because of subsidies and special deals. This creates a situation of messy and uncertain supply and price volatility which is economically destructive.[88]

Adverse outcomes stem from policies that subsidise suppliers of intermittent renewable energy over traditional baseload generators:

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[88] In different terms this creates a game in which agents can pursue narrow opportunities for manipulation and arbitrage to maximise their returns. It is an elementary theorem in mathematics that the outcome of a non-co-operative game, or a Nash equilibrium, is almost never welfare optimal (see Appendix A).

- As the prevalence of intermittent renewables supply rises there are more periods of the day when the price of renewables generation falls to negligible levels.
- Baseload generators begin to experience lower rates of returns due to losses they occur at these times.
- Over time the more marginal of these baseload plants shut down.
- To shore up supply more investment is needed.
- But most of that investment mainly flows to intermittent renewables generation, which further undercuts traditional baseload generation.
- This resulting dynamic can create a downward spiral of supply unreliability and price volatility.

Remaining on this adjustment path will be economically destructive and interfere with the value of long-term portfolios for investors. Realistically, the low road may be the norm over the next one to two decades.

Under Australia's current policy trajectory, it is likely that strategic behaviours by market participants will interfere with the adjustment process, allowing for only small to moderate changes in emissions.

Electricity markets do not have the characteristics of a pure market and so short-term policies may create opportunities for strategic actions through arbitrage and rent seeking. The mix of poorly regulated markets and the absence of a market-based climate policy is the worst of all worlds. It is almost guaranteed to produce outcomes that are far from optimal.[89]

Arbitragers

Wherever electricity generation programs require short-term back-up or injections to stabilise supply, there are opportunities for new participants to game the system.

- If entrants observe significant within-day and within-year variations in prices, they may seek to take a commercial advantage by holding back supply for peak pricing times.
- If entrants observe significant regional price variations and/or subsidy payments from governments, they can install capacity in strategic regional locations to exploit price peaks or subsidy payments.

Existing market participants can join 'the party' also. For example:

- owners of utility assets can seek to gold plate existing asset holdings to maximise the scope for discretionary price increases; and
- big generator-retailers can seek to delay extensions or replace existing capacity to exacerbate existing supply shortages in markets at certain peak times.

All these behaviours have become 'the normal operating procedure' over the last decade in the electricity systems around the world, including the NEM.

Investors have been incentivised by governments to join in the arbitrage 'party'. By adopting renewables subsidies, for example, governments are saying that they don't care about overall

[89] This partly illustrates the mistake of trying to treat things that are not a pure market as if they were. Nash equilibria are almost never welfare optimal and in some cases the deviation can be extreme. This is a problem for essential goods like energy.

costs and inefficiency, nor the flow-on consequences for the reliability of the electricity systems they are overseeing.

The infamous example is the Californian electricity crisis in 2000-01. Energy prices rose approximately 800 per cent above their previous base level. This resulted in widespread black outs and brown outs. The cause was mainly suppliers such as Enron manipulating supply to create artificial shortages.

Whilst every situation market is unique, and the conditions exploited by Enron in California last decade may no longer apply, there are plenty of instances of investors gaming electricity markets around the world. For example, in Nevada, Warren Buffett's Berkshire Hathaway has made another fortune with NV Energy. In Australia, Trevor St Baker's ERM Power Ltd and the publicly owned Snowy Hydro are using market peaks and troughs to their advantage.[90]

The Duck Curve

The problem of managing overall electricity supply in the face of significant, but peaky solar and wind is typically represented by a figure known as the Duck Curve.

Figure 11 represents the Duck Curve case for California for the years 2014 through to the present day. Each curve shows the net load that had to be met in that year in terms of total electricity from all sources minus solar and wind generation. It represents the demand that must be met with other dispatchable sources such as gas, hydro, nuclear and or imported electricity at different times during the day.

- It shows that as solar and wind generation has increased from 2015 to the present day, the demand for other sources of generation in the middle hours of the day has fallen sharply.
- It highlights that during long periods of the day baseload producers cannot break even, as large quantities of cheap renewables are generated from wind and solar. Only by evening time, or when wind is less prevalent, is baseload provision cost effective once again.
- It illustrates that for approximately half of each day, non-solar sources are needed to meet close to 100 per cent of total energy demand. On not-infrequent occasions when wind capacity drops the burden falls entirely on non-solar and non-wind.
- It suggests that even without a failure of solar and wind due to unfavourable weather patterns, close to total back-up capacity must be maintained.
- It underscores that current policy settings do not really consider the problem of the non-availability of wind and solar over a period of days.

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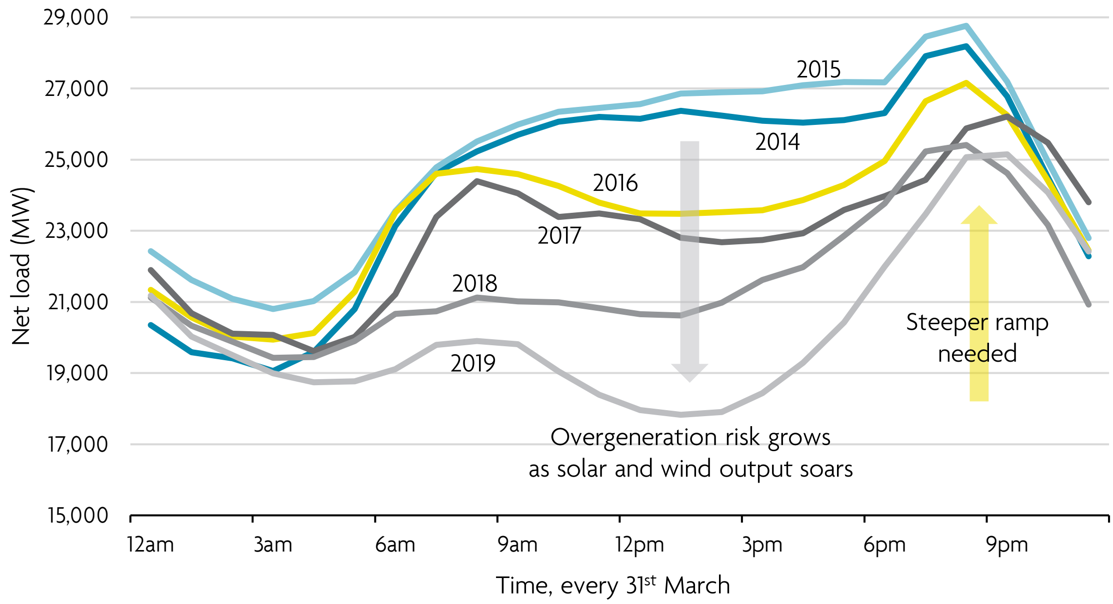
[90] Additional investment via Snowy 2.0 by the Australian Government might only bolster the ability of Snowy Hydro to game the market.

How could future entrants' game the NEM? Speculative opportunities available under the NEM might include the following:

- Investing in gas generation, say 35 MW in Queensland, 20 MW in South Australia, and a further 100MW on either side of the border where the Snowy transmission line is located. The strategy would be to feed supply into the market when you can make money.
- Putting in place thermal batteries around Snowy Hydro and heating them during the day with the 'cheap' renewables energy and then selling the energy in the evening. This is technically challenging given the existing state of technology. Molten salt is the usual medium here but very expensive. Hydrogen or graphite are possible storage solutions but are unproven and their adopting would require significant changes to the grid.
- Installing gas capacity and putting in transmission lines in Mildura to capture Adelaide demand in peak periods, and similarly, installing capacity near Portland to support the smelter.

In the presence of the Duck Curve, investors are incentivised to take advantage of short run arbitrage opportunities rather than seek longer term supply options. This should suggest that there are benefits from moving to a more refined set of policy proposals on climate change.

Figure 11. The California ISO 'duck curve'



Source: California ISO, Historical hourly load data from EMS.
Note: The net load is the total electric demand in the system minus solar and wind generation. It represents the demand that must be met with other dispatchable sources such as gas, hydro, and imported electricity.

There are gravitational forces associated with renewables which, combined with our unchanged 20th Century transmission structure, are exacerbating our adjustment burden.

Structurally prices are on the rise and the only thing that is keeping them down in countries like Australia is the present legacy baseload assets that remain in operation for now, tempering the impact of the negative within-day prices.

So, Duck Curve phenomena are unlikely to resolve themselves over the next ten or twenty years unless governments can find effective means to bring forward the necessary generation capacity to stabilise the grid. More than likely, the volatility we are experiencing now will continue for some years to come.

The Duck Curve phenomena are an advanced economy problem, observed in Australia, California, Germany, etc. It is a recipe for the destruction of heavy industry which is offshoring.

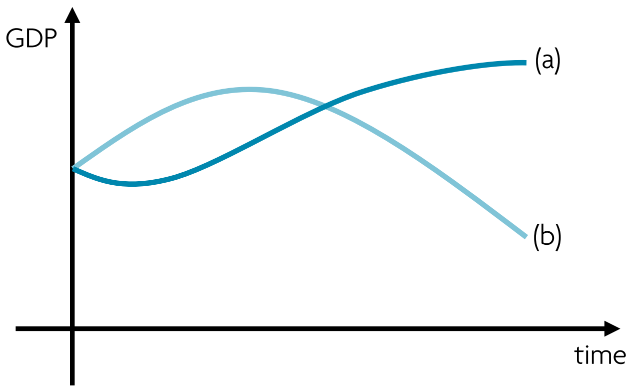
Costs of short-termism

Arbitrage and rent-seeking behaviours by producers can lead to sub-optimal investment levels and technological choices that neither exert downward pressure wholesale prices, nor maximise necessary emission reductions. Certainly, the goal of achieving zero emissions within a reasonable timeframe is undermined.

Without effective, front-loaded policy actions to reduce emissions, the baseline trajectory is for the climate to become increasingly unstable. This may create a negative feedback loop which could slow down or even reduce productive capacity. The progression of this undershooting would be as follows:

- Initially, the appearance of steady, if not slow, growth via a smooth trajectory.[91]
- Increasing pressure from investors and communities.
- Increasing opportunities for gaming of the electricity networks of major economies by well-placed agents could produce sub-optimal outcomes.
- Secular stagnation and decreasing growth over time.
  - Either dynamic deadweight losses (i.e. lower growth rates), or the possibility of wealth destruction?
  - In the extreme, it will put downward pressure on discount rates (the more policy frameworks fail).
  - This may eventually lead to political and social instability.
- It is possible to make some rough guesses at the trajectory of the Australian economy under the assumption that the rest of the world is stable.
  - In the business-as-usual scenario, it would be anticipated that the economy would track a normal trajectory over the short term and then enter a period of long run decline as the costs related to an outdated energy sector begin to accumulate. This is illustrated in Figure 12 (b).
  - In the optimal long run scenario, the economy might experience a short-term output hit, slowing relative to the business-as-usual case, and then move back to a normal potential growth path. This is illustrated in Figure 12 (a).[92]

Figure 12. Possible growth trajectories under (a) high road (b) low road responses



Any investment bet on the low road should be hedged. Pressures to switch to the long run path will continue to build and policy may switch dramatically. Beyond 2030, the path for Australia's emissions and energy production will be guided by domestic politics and the outcomes of the international agreements, which are highly uncertain. See Section 4 and appendices.

[91] Assumptions of stable covariances between assets implying consistent risk adjusted performance through time may work in the very short run if at all.

[92] An initial slowing may not occur. It may be offset by the economic stimulus and growth in confidence engendered by a decisive government response.

If the rest of the world does not respond, it could be assumed that the international economy would move to a more unstable state as well. In this case, catastrophe investing becomes a possible option for industry superannuation funds.

5.3 Other considerations

Significant opportunities are open to superannuation funds to partner in providing finance (equity and debt) for network changes around electricity. These could include changes in the mix of generating capacity that demands new grid designs, new storage and transmission capacity, changes to market structures, and changes in demand management, including the design and establishment of market instruments to achieve these goals.

Below are some practical considerations that need to be borne in mind to facilitate the transition.

5.3.1 Limits to network expansion

In one sense, there are very limited direct investment opportunities in Australian electricity and the broader energy sectors since many of the higher value existing assets display characteristics of natural monopolies. This means that there is unlikely to be many competing assets in each sector. For example, there is unlikely to ever be more than one electricity transmission organisation in New South Wales. Existing assets and/or their owners are likely to remain dominant in their subsectors simply by virtue of their incumbent status.

Table 7 provides a run-down of the spread and concentration of assets across the states and territories in Australia's electricity sector.

Table 7. Matrix of electricity assets and ownership, 2019

		NSW	VIC	QLD	SA	TAS	WA
Generation capacity (GW)	Conventional	12.4	7.1	11.9	3.2	0.4	4.7
	Alternative	4.9	4.4	1.9	2.2	2.6	0.9
Transmission		TransGrid	AusNet	Powerlink	ElectraNet	TasNetworks	Western Power
Distribution		ActewAGL	United Energy Dist.	Energex	SA Power Networks	TasNetworks	Western Power
		Ausgrid	Jemena	Ergon			Horizon Power
		Endeavour	Powercor				
		Essential	AusNet				
			Citipower				
Retailing		19	19	12	15	Aurora	Synergy

Source: ISA analysis of data from AEMO and various state government websites.
Note: Light blue coloured cells indicate that the assets are owned by government.

Developing opportunities outside the existing large generators-retailers will significantly require greenfield investment and pinpointing strategic opportunities, such as:

- Financing medium-sized and small renewable projects outside the large providers.
- Developing battery storage options alongside existing renewable operations.
- Purchasing ageing (stranded) fossil fuel generation assets, provided that game-changing emissions reduction technologies are feasible.
- Developing new, but unproven, renewable energy generation capacity such as CSIRO's hydrogen technology.
- Developing longer-term financial instruments and supporting market makers, to facilitate consumer driven behavioural change.
- Substitution of existing network asset holdings with more profitable disruptor technologies which in a net sense generate value for investors.

5.3.2 Building on existing holdings

Portfolio managers must be cognisant of their existing asset holdings and look to generate value via network externalities and supply-chain benefits. For instance, looking forward, the transformation of the electricity sector may reduce the need for existing transmission infrastructure. Existing players are likely to be required to cross subsidise this planned obsolescence with investment in new renewables generation.

Extending and modernising Australia's electricity generation assets will require commensurate levels of financing by long-term portfolio investors in the form of both equity and debt. There is an opportunity here for industry superannuation funds to work in partnership with existing industry players and government to achieve this structural adjustment.

Industry superannuation fund holdings

Industry superannuation funds currently hold at least $40 billion in energy sector investments worldwide. This estimate is based on our informal survey of investment officers from industry funds with three billion dollars or more of funds under management, as well as IFM Investors. Table 8 provides a high-level summary of some industry funds holdings within the energy sector.

- Their greatest exposure to energy and electricity assets via listed equity holdings. The motivation for holding most of these assets is to replicate weightings in a broader market index, rather than as an explicit decision to hold energy assets.
- Their assets cover most aspects of the electricity sector from generation, transmission and distribution and now gas sector related assets. Previously, industry superannuation funds have been owners of renewable energy assets, such as Pacific Hydro, and Newport power station.

Table 8. Industry super fund holdings of energy assets, selected funds, 2018

Fund name	Net assets (A$ billion)	Exposure to energy assets (%)	Has direct ownership of energy assets
AustralianSuper	140.1	6 – 8	✓
SunSuper	56.4	6 – 8	✓
REST	51.6	6 – 8	✓
HESTA	46.8	6 – 8	✓
CBUS	45.6	3 – 5	✓
HOSTPLUS	33.7	5 – 7	
Equip Super	14.8	3 – 5	
Care Super	14.8	3 – 5	
MTAA Super	11.6	6 – 8	✓
Mine Super	10.7	5 – 7	
MyLifeMyMoney	9.5	6 – 8	✓
NGS Super	9.0	2 – 4	
LUCRF	6.4	3 – 5	
TWU Super	5.4	2 – 4	
IFM Investors	117.0	6 – 8	✓

Source: ISA survey, APRA Annual Fund-level Superannuation Statistics (Jun-2018).
Note: IFM Investors is a collective vehicle with multiple industry fund owners.

The fact that industry funds have much experience in investing in the electricity sector makes expansion, and negotiation with government, that much easier. Certainly, the lessons learned in the sector should help in identifying future successful investment opportunities. Furthermore, in a physical sense, existing asset locations may have significant scope for expansion.

Thinking strategically, since industry funds are currently invested in a sector undergoing significant transformation pressures, it is prudent that investment officers and their asset advisors engage in the public policy development processes, including environmental, social and governance (ESG) concerns. The idea being that policy leadership will also be an aide to staying abreast of the most profitable investment opportunities.

It has already been made clear that important and difficult challenges face institutional investors when making decisions about the energy and electricity sectors.

This should not be taken to mean that the sector should be avoided by industry superannuation funds. If anything, the message is the opposite. What seems to be called for is active engagement to ensure that investment opportunities are both created and realised. Potential returns from technological change and disrupting existing distribution models are too big to ignore. In this respect there is a good argument for the industry taking an active role.

5.3.3 Value generation

The significant amounts of finance that many projects will require create opportunities for the investment industry to work in partnership with existing providers and government, as well as going-it-alone. In thinking about partnership with government the industry should take an active stance. Many large-scale investments will require innovative financial arrangements. These will work best when co-designed with the industry. We return to this in Section 6.

Among the provisos that should hold are the following:

- Investors need to see the upside or value for their portfolios.
- Asset acquisition decisions will need to be made on a case-by-case basis employing conventional hurdle rates (see the discussion of limitations of discount rates in Section 3).[93]
- A serious limitation would be the inability to apply usual commercial rates of discount for assessing long-term energy programs and technological options.
- Capturing value from asset purchases or greenfield projects must occur against the backdrop of balancing existing portfolios and real asset holdings.
- Investment portfolios and other instruments should be put together to provide hedges against downside risk and to provide balanced and secure returns in a rapidly changing environment.
- Investors must not assume opportunities 'exist', but they can be made. For example, to the extent that the electricity sector transforms into a much less centralised structure, there could be significant investment opportunities in developing local and micro grids and the associated infrastructure needed to support them.
- Investors must not assume certainty where it doesn't exist.
- Investments need to be based on sound analysis of technologies and an understanding of the overall direction of future changes. Investing based on past returns seems ill advised.
- At worst a proper appreciation of uncertainty means it is possible to avoid mistakes in constructing investment portfolios and misunderstandings of the dynamics of change.
- Interactions with government must be carefully designed.

5.3.4 Realising bias

A possible consequence of existing levels of uncertainty is that many existing assets may be undervalued because the action has been delayed. This presents a valuation opportunity as policy settings change and some of this can be anticipated.

In addition, many asset classes may be poorly valued due to a variety of cognitive biases (ideology, complexity, etc), or because of the ability of various groups to steer policy makers and the political debate (such as the large generator-retailers). The disruption of present arrangements would present significant investment opportunities.

[93] One issue that requires attention are discount rates, for short-term investment market rates may apply. In the longer-term it is difficult to assess the appropriate rate to be applied to long-term returns in a world where adjustments are not marginal. It is similarly difficult to assess the discount rate for assessing large-scale technological options and this should be a matter to be considered in the design of investment instruments.

Another ‘bias’ consideration is the extent to which certain investment opportunities are just discounted due to perceived ‘political’ or social risks, without technical due diligence. This seems to be an obvious ‘mispricing’ opportunity. For example:

It might also be worthwhile putting carbon capture and storage on the watch list. Whilst coal looks like a bad bet, a significant advance in carbon capture and storage technologies would probably create a significant upturn in the value of new coal fired facilities. Against this is the risk of resistance from stakeholders including the members of superannuation funds themselves.

It might also be worthwhile putting nuclear on a watch list.[94] In particular, developments in small nuclear reactors might have some interest, especially if we move to a more decentralised transmission network.

On the other hand, some renewable assets might be overvalued for similar reasons.

5.3.5 Forward looking analysis

It is important to realise that past performance may be a very poor guide to future returns. As we have already seen, the conditions faced are volatile in a way that is perhaps unprecedented and that policy settings may change rapidly.

Whilst, there are diversification benefits to investing in energy assets, that case is mainly based on employing historical data (the era of fossil fuel baseload generation), so we confine this analysis to Appendix D.

Even in the more stable environment of the past decade, recent guesses, like those that encouraged the gold-plating of the transmission network, did not turn out so well. Even small changes in the sector such as a better storage technology could lead to sudden changes in the performance of different classes of assets.

[94] In watching developments in nuclear energy some attention should be given to the supply chain. Obvious targets are raw materials. In addition, experience has shown that only a thin field of companies has the capacity to deliver manufactured inputs of the quality needed.

6. Take-outs for policy makers

The opportunities and investment environment faced by the superannuation funds will be largely determined by government policy. In the short-term policy may be driven by electoral expediency. On the other hand, long run developments will come closer to an optimum under the appropriate conditions.

There is considerable incentive for the industry superannuation funds, as stewards of members' interest, to influence policy formation and to support settings that will provide for stability and a modern and growing economy. For these reasons it is necessary to consider some of the policy settings necessary to modernising the energy sector. Understanding these will allow industry superannuation funds to better assess long-term investment strategies. It will also help in formulating a coherent position to take to government in any discussion of future directions and the design of financial instruments.

6.1 Policy approach

The most efficient way to help align policy with long-run optimality is to ensure that the market begins to price greenhouse emissions as a broadly based, technology-neutral carbon price or equivalent market pricing mechanism. This is a necessary condition for markets to be efficient. It meets the test that economists apply to all transactions – prices should reflect costs of production and consumption. This is not enough, however. As noted previously, for the most part energy is not a pure (or Walrasian) market. It is unlikely that short-term local responses would automatically factor in the overall structure of the grid, technological change and emissions goals to be consistent with longer-term optimal trajectories. It follows that some thought must be given to the overall direction of development.

A tax on emissions could take several different forms. For this discussion paper, the main objective is that the cost of emissions be fully considered. There would also seem to be strong arguments for returning the proceeds to make the tax neutral and for minimising welfare losses by compensating low income households.

An alternative to a direct tax is some form of emissions trading scheme. It is hard to argue this produces greater efficiency, and the experience with trading schemes in goods like emissions and water has, generally, been negative.

On the best available estimates the global community has around forty years to reverse the growth in the stockpile of emissions in order to avoid irreversible consequences. Given the lags associated with policy decision making and building alternative generation capacity, that really means adopting the best policy approaches we have right now.

We suggest that rather than being shackled by past approaches, governments support a genuinely technologically neutral discovery process to manage these issues. The aim is to uncover the technologies that can deliver the best combination of low emissions at the lowest cost and reliable supply. This process should be unencumbered by pre-existing policy taboos. The question should not be "renewables or coal". The focus should be on the best strategy to reduce atmospheric greenhouse emissions. This is the outcome that matters.

6.2 Policy suggestions

In the discussion below, we suggest policies that will help the transition of the wider economy and particularly the electricity sector to a lower carbon footprint. The policies are broadly arranged from the straight forward, relatively simple, 'understand the problem and task better' initiatives, to broader market-based incentives to fire-up investment in the sector, and finally on to more direct government involvement in the challenge if needed.

6.2.1 No-regrets policy

The approach of the Australian government should be to choose policy options that best support grid architecture and broader policy goals. That approach should be to audit existing capacity and feasible technologies and make assessments based on best scientific advice.

At a minimum the government should adopt a no-regrets strategy of gradually replacing existing baseload and gas generation capacity with lower emissions technology. As far as possible, this should occur without providing subsidies for technologies or producers. In order to avoid issues of gaming discussed above, it is desirable that public outlays do not act to distort choices between options.

6.2.2 Technological neutrality

The changes required will be long term and complex and it is important that options be assessed in truly neutral terms regarding technology choices and possible market structures.

We believe that the principle of fairness dictates that policies should be neutral to technology and market structures. The choice of market structure requires careful thought and cannot be divorced from decisions about technology.

- Markets certainly do require more planning.
- Markets certainly do require more competition. In accordance with the original 1997 NEM rules private investors/operators are only beneficial in the context the pro competition rules and a prohibition vertical integration of retail and generation ownership.

To support objectivity in assessing options an expert panel should be established to provide technical guidance to government on issues related to technology. It is important that such a panel has some institutional weight and credibility in the view of the public.

An important element in technological choice is the development of capacity. Uncertainties around the pace of change and technological developments mean that it is essential to have the ability to choose between a wide range of policy options. There are potential problems for Australia in this regard. It currently runs the risk of being trapped by a lack of flexibility.

One problem is that Australia has no capacity to build or operate a nuclear facility. This result follows from the mathematical principle that a constrained solution to an optimality problem can never be better than an unconstrained solution.

This lack of capacity puts Australia in the minority of first world economies. It is also lagging several second and third world economies in our region and elsewhere such as Argentina, Mexico, Bangladesh and Turkey and geographical neighbours such as Indonesia and Vietnam.

This exposes the economy to considerable risk since it is far from obvious that solar and wind can provide all primary energy in any feasible combination.

In this case we are dealing with a widely deployed and rapidly developing technology. This means that the current barriers to nuclear may be subject to rapid and unpredictable policy change.

It is important that our discussion paper does not fall prey to hysteria on this point. Our suggestion is neutral between technologies. It is a simple matter of reducing risk by developing the capacity to choose the most appropriate combination of low carbon options.

6.2.3 Long-term market architecture

The market architecture should be designed to ensure that full social cost is considered and that it provides stability for investors. As already discussed, careless reliance on poorly designed markets has created problems in other countries and this was illustrated with the example of the

Enron scandal in California.[95] One possibility is long-term supply contracts. In some cases, these may need to be underwritten by government.

It is important to note that the market structure will also tend to favour some technologies over others. It is difficult to set out detailed prescriptions, but it is necessary to be aware of this critical point in designing mechanisms to avoid the associated problems of rent seeking, moral hazard and lock in. It is also necessary to maintain as much flexibility as possible.

With these cautions in mind it is suggested that rather than fixating on the spot market for energy pricing, the NEM should be focussed on creating a competition for the long-term supply of capacity and energy at given emissions targets. This can be achieved by 'auctions' of longer-term contracts of 20 years duration or longer. These contracts would need to strike a balance between being enforceable by law to provide certainty to investors and being capable of responding to technological and other changes. These are not insurmountable mechanism design problems. Once the goals are clear they could then be worked through with the investment community.

- On the demand side, contracts would be purchased by state governments, but also private sector agents, motivated at securing reliability of supply and price.
- On the supply side, long-term asset equity owners in infrastructures appreciate the certainty of guaranteed rates of return on their investments.

Do we need the NEM?

Under a market underpinned by long-term supply contacts, we would still need a spot market in electricity and especially contracted prices tied to this market. Right now, the architecture supports the emerging contracts-for-difference market in renewables. Both the short-term market and the medium-term secondary market will support the functioning of the market for longer-term contracts we wish to introduce.

6.2.4 Governments to formerly underwrite markets

Government may eventually have to act as the investor or underwriter of last resort in the Australian electricity markets.

The simple idea is that if all other proposals fail to reduce emissions, as targeted or desired, then the Federal Government should step in directly with policies that foster the building and/or operation of low emission electricity generation and supporting infrastructure.

If the private ownership model failed, then government could invest directly in the infrastructure and contract out construction and operation of the assets. Perhaps the assets could be recycled in the future.

It is important that any large-scale involvement be undertaken with the understanding of the investment community and the public. There is already pressure from investors for governments to act decisively.[96] To this end, governments should begin to act as soon as possible. They need to set up mechanisms to engage with investors and to explore feasible courses of action.

6.2.5 Public authority for transmission and distribution planning

While more efficient markets can help in the allocation of resources among types of power generation and storage, they cannot play this role in defining efficient allocation of resources between network expansion and new forms of generation and storage. Electricity distribution

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95 McLean, B. & Elkind, P., 2004.

96 Carrington, D., 2018

and transmission networks are natural monopolies that require planning decisions in the public interest. The Australian regulatory system is poorly designed for taking decisions on maintenance and expansion of the networks.[97]

Major reform is required. It is important to shift the initiative in putting forward proposals for investment in network maintenance and expansion in the hands of a public body charged with taking decisions in the national interest. That would remove the conflict of interest embedded in current arrangements. Such a body would be charged with assessments of whether investment in network maintenance and expansion is likely to yield higher returns than investment in decentralised generation and storage. To do its important job well, the energy planning agency would need to have deep professional capacities, and insulation from the day-to-day vicissitudes of partisan politics. The Australian Energy Market Operator could be strengthened to perform this planning role.

6.2.6 Reforming taxation arrangements

Tax that also encourages large-scale capital-intensive investments, such as those needed to replace the ageing fleet of electricity generators and move to low emissions sector, would certainly be welfare enhancing.

One major step in this direction is the replacement of the current corporate income tax scheme with a cash flow tax.[98]

The rationale for the cash flow tax is to charge net cash flows rather than accounting profit. Net cash inflows are essentially sales proceeds less capital expenditures and operating costs incurred within the taxing jurisdiction, but not expenses related to interest, depreciation or related party services. So, the cash flow tax makes no distinction between capital and recurrent expenditure.

Under the existing company tax, typical capital-intensive projects, that have net negative cash flows in the early years of their operation, and because of the uneven treatment of depreciation and capex, have lower after-tax rates of return then their pre-tax rates of return.

Whereas, under the cash flow tax, new investments are incentivised since all capital expenditures can be deducted upfront and there is no wedge between pre and post-tax rates of return. So, taxation is neutral to the investment decision, unlike the company tax regime we have now.

Overall, the cash flow tax reform would have the effect of driving investment and innovation in new competing technologies.

6.2.7 Industry policy and structural adjustment

To the extent that the future composition of Australia's industrial base will heavily influence energy and electricity demand, it is paramount that industry, energy and climate policy are closely coordinated for the short, medium and long term. Also, an electricity policy that ignores the question of industrial composition and securing access to reliable and cheap electricity is a half-finished policy.

Industry policy

A broader vision would to be to develop a reliable and affordable energy system that maintains Australia's international competitiveness and enhances domestic productivity whilst pursuing emissions reductions at the lowest possible cost. Our vision aims at having the most productive

[97] Garnaut, R., 2016.

[98] Garnaut, R., et al. 2019.

economy across all sectors, trade exposed or otherwise, that is compatible with the desires, or need, to transition quickly to a low emissions economy.

The vision is one thing but having the structures in place to support a coordinated policy is another. A step in the right direction could be to ask the Productivity Commission (PC) to report on the interdependences between industry, energy and climate policy to better help policy makers, politicians and even the wider public aware of the issues and expand the climate debate beyond electricity. The task of coordination is made harder by Australia's three-tiered federal system and needs to be accommodated. The aim of the PC report could be a set of recommendations on how to implement a coordinated policy approach.

Structural adjustment

For affected industries and especially workers that are adversely impacted by climate policies, there must be structural adjustment assistance and the reasonable expectation of future employment. What we have in mind is a Button Car Plan for workers in fossil fuel industries.[99] Support would need to be both worker and region based due to the spatial layout of the electricity system. That is, certain regional areas are relatively heavily specialised in the electricity sector activities and just re-training the worker will do little for the affected regions unless jobs are created.

6.2.8 The role of long-term investors

The industry superannuation funds and other long-term portfolio investors will be critical in financing the changes required and in assisting governments with large infrastructural changes. Although commercial investment would be encouraged by any form of carbon price it may be necessary to go beyond this for large-scale projects and to accelerate change. In many cases special purposes arrangements and investment instruments will need to be put into place. These will need to be tailored to circumstances and cannot be determined in advance. It is impossible to do more here than cover some of the issues.

Government

The government may find it advantageous to construct investment vehicles that minimise downside risks and encourage long-term equity partners. In this regard, some changes may need to be made to the financial and taxation structure. Other forms of involvement may also be required depending on the objective.

Government may also consider direct involvement and co-investment options with superannuation funds for special projects. One example is in green field sites where many funds have deep experience.

Properly designed financing and project involvement may allow problems that have troubled large-scale infrastructure projects elsewhere to be avoided. An example is the Wylfa nuclear power plant in Wales. This project was recently abandoned by Hitachi because it was required to carry too much risk relative to the size of the company.[100]

Public private partnerships have been used in various forms for large-scale infrastructure, but these have had mixed success. They often represent an expensive and indirect financing apparatus which hides the full cost of the transaction to the general public. It is not clear that

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[99] The Button Car Plan was the informal name given to the Motor Industry Development Plan, an Australian Government structural adjustment program intended to rationalise the Australian motor vehicle industry and transition it to lower levels of protection, whilst proving the necessary assistance for retraining and relocating affected workers. It took its name from Senator John Button, the then federal Minister for Commerce, Trade and Industry. The scheme was announced in mid-1984.

[100] Plummer, R., 2019.

the imperative to maximise profits by contracting private partners produces infrastructure and services that are in the long-term interests of the public.[101]

There are many other examples of finance to draw on. Many of these involve some form of government guaranteed finance or other special instruments.

Recent large-scale projects in Europe are the Øresund bridge and the Fehmarnbelt Fixed Link.[102] In both cases the projects were financed by special bond issues guaranteed by government and the construction was directly managed by public agencies. In other cases, government guaranteed finance is used for projects that are managed in partnership with the companies that will operate the facility. Other cases involve a consortium of financial institutions providing backing with appropriate conditions and stop loss guarantees.[103] In all these, substantial involvement by long-term portfolio investors is required. In addition, the issues and other financial instruments could provide a large source of guaranteed financial returns.

A crucial issue here is the development of managerial and financial expertise in both the investment industry and government. This process takes time. As with the technological capacity previously discussed there are substantial gains in flexibility and options from building capacity in the provision of financial instruments and management of large-scale projects. Without that, it is difficult to see how it will be possible to avoid repeating past mistakes in large-scale infrastructure projects.

Industry

Industry superannuation funds and investors across the globe need to engage with government and become part of the wider discussion. The policies adopted will directly affect energy portfolios and indirectly affect a much broader class of asset holdings. The dangers inherent in bad decisions are already being recognised by the investment community.[104] There is already some recognition of this in organisations like the Investor Group on Climate Change.[105] It would seem to be unwise for industry superannuation funds not to take part in this debate.

Industry involvement would mirror government action in some respects. Investors may find it advantageous to enter discussion directly with government on joint investment. The design of investment vehicles and stop loss arrangements should also be subjects for industry input and advice. To continue the example of Oresund bridge and the Fehmarnbelt Fixed Link, it would seem essential that superannuation funds become a party to designing the financial instruments and bond issues that can be used to support any such large-scale projects. In these cases, the aim would be to secure a stable return for the fund and its investors. It would also be to ensure that projects are carried out in a way that provide the best possible outcomes for the economy at large. This is not only in the interests of the fund investors but also part of a more general concern with stabilising other sectors of the industry portfolio.

In addition, governments are often struggling with time horizons that are shorter than those of portfolio investors. Clear focus on longer-term economic goals and welfare considerations and input from the industry may well be an important addition to the decision-making process and public perceptions.

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[101] European Court of Auditors, 2018.

[102] Falbe-Hansen, K. & Nissen, J., 2000; ARUP, 2019.

[103] Rosik, P., 2018.

[104] Carrington, D., 2018.

[105] Investor Group on Climate Change, 2019.

In order to engage properly it is necessary that industry superannuation funds develop an in-house expertise and a sound position. This requires capacity building in finance and management within the investment sector.

If the investment sector is going to take a lead in these areas it needs to go beyond simply expanding the business-as-usual. It is also necessary to give serious attention to the intellectual foundations driving investment analysis. As this discussion paper has argued, simple reliance on off-the-shelf technologies and taken for granted assumptions can lead to poor policy and misleading investment advice.

It is argued in Section 4 that the international and domestic situation could change rapidly. Failure to begin reducing emissions now increases the risks of stranded assets and possible retaliatory action from trading partners.

6.2.9 Enhanced public R&D

It would also be desirable for Australia to join with international bodies in co-operative research efforts. Apart from enhancing Australia's status as a global citizen this would give access to the latest technologies and build capacity in both the public and the private sectors.

It is reasonable to assume that this participation would lead to applications that can be tailored to local circumstances and to collaboration with more local initiatives. It would be a mistake, however, to assume that an abundance of potential means that research should be exclusively, or even largely, home grown.

Efforts in research could also be tied to the suggestion of an advisory body with perhaps annual public reports.

6.2.10 A global solution

It is in Australia's interest from both a moral and from a more narrowly economic perspective to be an active participant in efforts to reduce emissions and stabilise the climate. It is often claimed that Australia only produces a small percentage of the world's emissions or that Australia cannot solve the problems alone and should either do nothing or follow others. This claim is childish. No one country can solve the problem of global emissions. It is either a joint effort or no effort at all.

6.3 Summing up

The preferred market realignment at a macro-level is some efficient market pricing mechanism. In conjunction with this, or in its absence, there is a need to look carefully at the architecture of the energy market. Among the mechanisms to be considered are various forms of PPA and long-term contracts to energy market participants to replace poorly suited existing capacity.

Other policies should be based on a genuinely technologically neutral discovery process which looks at uncovering what delivers the best combination of lowest cost, reliability and emission reduction. This process should be unencumbered by pre-existing policy taboos. The question should not be "renewables or coal". The focus should be on the best strategy to reduce atmospheric greenhouse emissions.

It is also for Australia to build technological capacity. Australia carries a much higher level of risk than most first world countries by not having the ability to incorporate nuclear energy into its mix.

It was also suggested that dogma about markets and government should be ignored in favour of effective policy. Where necessary government may have to intervene to get the pace and direction of change required.

Investors and business

It will be necessary for government to provide the settings and security necessary for large-scale investment and to look at innovative ways to finance large-scale changes in energy production. These need to engage long-term portfolio investors. They also need to go beyond the more routine private public partnerships and leaving it to the market.

It is also imperative that government engage with investors, business and the community as soon as possible. Without the advice and co-operation of investors, large-scale change will be almost impossible. Without public understanding, the determination will be at best fragile.

To this end, setting up an advisory committee with enough public standing and links to business would appear to be an important and immediate step. As with technology, capacity building in developing financial instruments will also be worthwhile.

It is in Australia's interest to be an active participant in efforts to reduce emissions. International co-operation could also be enhanced by participation in research and development.

7. Conclusions

This section provides an overall summary of the main points developed in this discussion paper together with a few additional comments. It is written in a more informal and speculative manner to reinforce the key messages of what has sometimes been a lengthy analysis of complicated issues.

The main takeaways are that the problem of building Australia's energy structure for the future is characterised by high levels of uncertainty and requires serious analysis and innovation in policies and investment. It is important to recognize that energy and emissions problems are characterised by hard constraints and irreversibility. This means that many of our off-the-shelf ways of thinking may be misleading.

Treating middle-of-the-road policy options and investment strategies as the default setting may be a mistake if you subscribe to the idea that there are bargains to be made. There is no bargain with hard constraints. Questions such as, 'can we afford to invest in the electricity sector to meet a specific target?', don't have the same meaning as in an economic context where there is a choice between substitutable outcomes.

If poor choices are made the resulting infrastructure and technologies may have to be increasingly supported by subsidies and special deals. The Duck Curve illustrated a simple recipe for arbitrage and rent seeking. Another example is the Enron scandal.

In short, our view is that assuming climate scientists are wrong and that large-scale changes will not be necessary in the medium term is a serious mistake and a bad bet for investors.

7.1 Future states

The description of possible futures has two extremes.

7.1.1 Business-as-usual

This is the current trajectory with small to moderate changes in emissions. Its main characteristics are:

- Short run appearance of a smooth trajectory.
  - The assumptions of stable covariances between assets implying consistent risk adjusted performance through time may work in the short run only.
- Increasing pressure from investors and the community.
- Gaming the system and welfare sub-optimality.
- Stagnation and decreasing growth.
- In the extreme, downward pressure on discount rates.
- Investment opportunities in short-term supply, storage and network arrangements, forward purchases and other physical or control vehicles that can shift energy between periods of excess and shortfall.

7.1.2 Long term optimality – systems change

This is the trajectory where action is taken internationally and in Australia to reduce emissions to levels that leave an acceptable risk of catastrophic climate change. This is the only stable long run equilibrium. Without action to reduce emissions, the only trajectory is for the climate to become increasingly unstable and drive the economy towards severe-to-extreme reductions in productive capacity.

This trajectory raises several theoretical and practical issues.

What we know – theoretical

- The most efficient policy is to front load technological transformations in order to reduce emissions as fast as possible.
- Increasing signs of climate change and public awareness of the issues, together with investor awareness of long-term dangers, will increase demand for government responses. The long run policy game only moves in one direction.
- Investment in electricity will be increasingly geared towards replacing high with low emission generation and related infrastructure.
- Policy options are constrained to a small set, but the mix will vary according to regional conditions.
- Energy markets are characterised by radical uncertainty. The changes required and the lack of clarity about policies and technology, are unprecedented that challenges need to be addressed head on.
- Uncertainty needs to be properly addressed rather than ignored, in favour of off-the-shelf technologies and ways of thinking should be abandoned.
- Conventional cost benefit assessments may not give a good guide to policy and investment decisions.
- Usage of conventional discount factors may produce poor policy decisions.
- Major opportunities will be created for industry superannuation to partner in providing finance for major infrastructural change.
- It will be necessary for industry superannuation to engage with government in order to reduce uncertainty and create a stable investment environment.
- It will be necessary to engage with government to create innovative financial instruments.

What we know – technical

- The emission reductions will require zero emission electricity. They will also require substituting electricity for many thermal energy applications in areas such as transport.
- Technology choices need to be based on their effectiveness in achieving emissions reduction.
- There is no argument to exclude any major emissions reduction technology on cost grounds. Capacity to displace fossil fuels should be the main basis for the decision.
- Changes in the mix of generating capacity will demand new grid design, new storage and transmission capacity, changes to market structures, and changes in demand management.
- We need to act NOW with the available technologies.

What we know – investment and policy

The superannuation industry should accept its responsibility to the long-term interests of its members and the wider community and engage with government in formulating policy and designing the appropriate financial instruments to finance change.

- The most useful policy move would be to put a price on emissions to bring the cost of production in line with actual cost and allow markets to function properly.

- The long run approach with front loaded response will future proof the economy and increase Australia's international standing.
- Government involvement is essential to boost major infrastructural changes and reduce investment uncertainty. It cannot be expected that the market will be able to attract the required investments.
- Policy signals need to be non-distortionary and consistent.
- Grid design and markets for energy are important. The choice of market structures may depend on the mix of technologies which is chosen.
- An advisory body with scientific input and public standing would be an important element in formulating policy and getting the public support.
- Investors must not assume certainty where it doesn't exist. Portfolios and interactions with government must be carefully designed.
- Investors need to see the upside for their portfolios. Financial and taxation instruments need to be designed in collaboration with the investment community.
- It is important to build awareness and understanding of the electricity sector and climate issues in relevant areas of the public sector and the industry superannuation funds.
- It is dangerous to rely on low-level information and herding. Put bluntly, there is a lot of bad analysis and investment advice within ready reach of the general public.

7.2 Remarks on possible futures

The discussion of climate instability and related economic issues sometimes seems to have a poor grasp of the physical constraints built into the problem. The systems-change-future is the only long run stable state. Roughly speaking the only options for the international economy are to carry on as usual with a decline in asset values in the life time of those currently being born or plan to change energy production.

The Australian community will not succeed in free riding on the efforts of other nations to obtain the benefits of others acting, without making changes. This was explored in Section 3 and Appendix A. The success in the free rider strategy is based on a limited view of strategic options and their associated values. It ignores international and domestic political pressures and the costs of being left with an inappropriate mix of energy producing technologies.

Underlying much of the political and economic discussion is that change will be an economic burden, which may not necessarily be the case. It is difficult to get an estimate of the opportunity costs and total economic value of large energy related projects. At the very least, it would seem unwarranted to claim that an attempt to prepare the energy system for the future would cause serious economic problems. In some circumstances, such projects may be growth enhancing.

An intangible that has been repeatedly emphasised is capacity building. This applies on the government side to the management and financing of large infrastructural projects. It also applies to the industry superannuation funds in managing energy portfolios and designing financial instruments. This is another area where there are significant payoffs and little cost associated with beginning to move early.

It was noted that Australia is one of the few first world economies without nuclear power and experience in managing a nuclear plant. This seems to be undesirable. It pre-empts the ability to make decisions between all major options for emission reduction.

Although the future is uncertain, some reasonable guesses can be made about the rough trajectories of economic development and asset values in Australia if we assume stability in the rest of the world.

- In business-as-usual, the economy might track a normal trajectory and then enter a period of long-run period of decline.
- In the long-run optimal solution, an initial slowing relative to business-as-usual is expected and the economy might then move to a normal trend growth path. But this initial slowing may be avoided if policy action engenders business which leads to an upswing in activity.

If the rest of the world does not respond, increasing instability might be expected. Catastrophe investing is possible in the short run.

7.3 Equity investments

Industry superannuation funds may benefit from energy investment in the current market and from developing new investment instruments. Uncertainty will still be a major factor in the short-term future. A possible consequence of existing levels of uncertainty is that many asset classes may be undervalued because action has been delayed. This may present opportunities for rapid growth as policy settings change and some of this can be anticipated. In addition, many asset classes may be poorly valued for ideological reasons, or because of the ability of various groups to capture policy makers and the political debate. If handled carefully, this may also present significant investment opportunities.

Insofar as investment is treated as a free market operation, decisions will need to be made on a case-by-case basis employing conventional hurdle rates. In addition, engagement with government will continue to be an issue. Among the considerations here are:

- The need for industry to press government to give clear signals on carbon pricing and other policies.
- Scarcity of opportunities in the existing market.
- The possibility of creating an energy portfolio that takes advantage of the new opportunities arising outside the existing large suppliers.
- It is important to realise the benefits from balancing existing portfolios and real asset holdings.
- It is important to be active and see investments as an opportunity to build capacity in developing longer-term financial instruments and market makers.
- If there is a move from market transactions to a more expansive involvement it will also be important to offset risk by developing counter-party alignment in and outside of government.

Among the obvious targets for equity investment are vehicles for buffering intermittent supply and possible opportunities to invest directly in the technology and the delivery systems. This extends to battery technology and related materials. It also includes the grid and the energy market.

Another important class of investments will be around electric vehicles, which includes materials, the supply chain and networks required for charging.

It is also worthwhile keeping a watching brief on carbon capture and storage and hydrogen.

In watching developments in nuclear energy, attention should be given to the supply chain. Obvious targets are raw materials. In addition, only a thin field of companies in Australia will have the capacity to deliver manufactured inputs of the quality needed.

Appendix A. Game theory and co-operation

The aim in this section is to expand on the discussion in Section 4 and to provide a framework for thinking about the issues of co-operation.

A.1 The main questions

The models in this appendix are only intended to give some better tools for thinking about trajectories. As already cautioned, there is nothing to suggest that co-operation will be adequate or that the process will not be derailed for narrow political gain. Nonetheless, to make a start on informed guesses, it is necessary to understand the basics.

The two possible types of models are explored. The first is a game theory model and corresponds to the case where actions are thought of as calculative. The second deals with the case where actions are driven by more general motivations such as environmental concerns, global citizenship, values and world views and the like. These motivations will be called altruism for want of a better term. This may be positive or negative. We concentrate on the following, more specific questions:

1. Under what conditions would countries co-operate if they acted strategically?
2. If countries reacted to the actions of other countries in an altruistic manner, what would be the dynamics of the system?

A.2 A simple model

The simplest game theory model has two players with two strategies and we concentrate on two variants of a basic model. The game is set out as follows. Write the strategies of player one and two as $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ respectively. Payoffs are given as a_{ij} or b_{ij} where a_{ij} represents the j-th payoff from the i-th strategy.

Figure 13. The basic model

	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$
$\boldsymbol{\alpha_1}$	$a_{11}b_{11}$	$a_{12}b_{21}$
$\boldsymbol{\alpha_2}$	$a_{21}b_{12}$	$a_{22}b_{22}$

To get some orientation, consider the simplest collective goods game often called the prisoners' dilemma. This was discussed briefly in Section 4 and is frequently mentioned in popular debate.

Player one is country one and player two is all other countries. Let w be the climate damage avoided and assume that w is fixed if all other countries contribute. In other words, player one's contribution doesn't make any, or much, difference.

Let c be the cost of contributing. Let α_1 and β_1 be a strategy of contributing and α_2 and β_2 be a strategy of non-contributing. Player one has the α strategies.

The payoff table for player one is given in Figure 14.

Figure 14. Pay off table for player one

	β_1	β_2
α_1	$w - c$	$-c$
α_2	w	0

In this case, it is obvious that regardless of the strategies of everyone else, country one is better off not contributing. This means that no-one contributes, and the outcome is zero. Much of the discussion of international co-operation is focused on possible solutions to this problem. As a result, many political and economic factors and elements in the structure of interactions between countries are overlooked.

A.3 Emissions reduction where payoffs depend on the number of contributors

The idea here is that the amount of emission reduction or temperature change avoided depends on the number of countries that contribute, and we are interested in how the return from contributing affects the strategies. This is radically simplified, without loss of generality, by assuming that there are n countries and they are all the same size.

Let the strategies be the same as before and change the payoffs to treat as a function of the number of countries, n, that contribute, that: is $w = w(n)$.

If it is assumed each country contributes the same portion of some set cost c where m is the number of countries, then: $a_{1,1} = b_{1,1} = w(n) - c/m$.

To get a picture, redraw the game with the payoffs for player one shown in Figure 15.

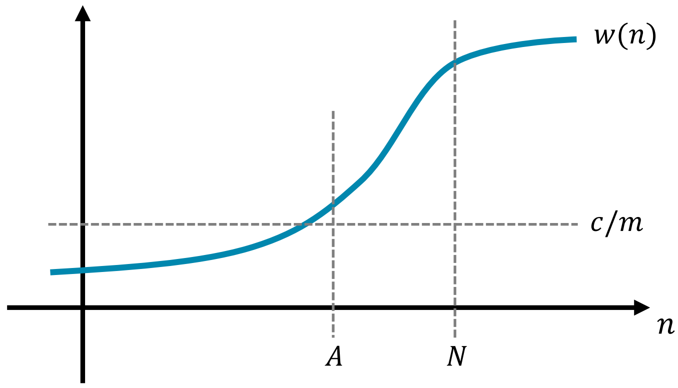
Figure 15. Payoff that depends on the number of contributors

	β_1	β_2
α_1	$w(n) - c/m$	$-c/m$
α_2	$w(n-1)$	0

It is obvious that for $w(n) - c/m > w(n-1)$ for all n, there is no dominant strategy. One plausible assumption is that each additional country adds more value than its predecessors, up to some value of n. This is justified as follows. A small contribution may not have a great deal of affect but as contributions increase the rate at which emissions and secondary feedbacks into the stock of carbon dioxide and methane are reduced increases. In this case, the result would be something like Figure 16 where $w(x)$ is treated as a smooth curve interpolating the integer values of n.

For the co-operation to be optimal, it is necessary that the change in the payoff for an additional contributor be greater than the cost for the additional participant. In other words, the derivative of the payoff with respect to contributions is $\partial w/\partial n > c/m$ for a sufficiently high value of n, say $n > A$. In other words, the marginal contribution of each new country must be greater than the marginal cost. In this case, we have an assurance game. Provided the early movers with $n < A$ can be assured that other countries will also contribute, it is in their interests to do so. It is never optimal for any country in $n < N$ to withdraw because $w(n) - c/m > w(n-1)$.

Figure 16. Example of a payoff function depending on contributors



While it is true that real world agreements are more complicated and that a proper analysis would require development of this model in several ways, it is also true that countries will not always do what is in their best interests. Nonetheless, the point remains that it is not necessarily against the individual interest of each country to co-operate.

A.4 Model of emissions reduction with political costs

The model is now reformulated to consider political costs. For simplicity, assume that a country that does not contribute gets the full benefit of emissions reduction but that there is a domestic constituency in favour of action on climate change. To capture this let the value of not contributing when everyone else contributes be $w - b$. If no other countries contribute, the cost is $-sb$ for some $s > 1$. This is justified by the assumption that getting the full benefit of emissions reduction in (α_2, β_1) provokes less political opposition than the case where there is no emissions reduction. Letting the cost to the decision makers of political opposition be b and replacing c/m by c the game has the payoff table for player one as shown in Figure 17.

If $w - c > w - b$ then the dominant strategy is for all countries to co-operate.

Figure 17. Political costs

	β_1	β_2
α_1	$w - c$	$-c$
α_2	$w - b$	$-sb$

It is more interesting to consider the case where $b < c$ and the best response to β_1 is α_2. Let s have values such that $sb > c$ for $c > b$. In this case, if all other players co-operate each individual player is better off defecting. On the other hand, if all other players defect each individual player is better off co-operating. In other words, there is no equilibrium in pure strategies. It follows that it may pay some countries to co-operate and others to defect. In fact, this must be the case from the Nash equilibrium theory. If so, one question is, what portion of countries choose to co-operate and what portion choose to defect?

A little calculation shows that if we again think of countries as being on a continuum the proportion that co-operate would be given by

$$p = \frac{sb - c}{b(s - c)}$$

In order to see how the proportion of the population that contributes changes as s changes, write the change in p for a change in s as $\partial p/\partial s$. Differentiating the expression above gives $\partial p/\partial s > 0$. This means that as s increases the fraction of the population that contributes to emissions reductions increases. In a similar manner, as b increases, so does the fraction of the population that contributes to emissions reductions.

A.5 Model for altruism and dynamics

The notion of altruism might be captured in conditional response functions. For example, it might be assumed that individuals are inclined to respond positively as the portion of other individuals in the system who respond positively increase. Following from the previous it will again be assumed there are two agents. Player one has strategy α, and β is the average of all other agents.

Let the response $\alpha(t)$ or $\beta(t)$ be thought of in terms of the resources in money or time devoted to some activity at time t. Assume that agents increase their rate of response as the resources devoted by the other agent increase but slow it down as the amount of resources they have already spent increases. In the absence of any contribution by the other agent, each player might increase or decrease its own contribution depending on its altruism.

Writing the change in contribution per unit of time given by $\mathrm{d}\alpha/\mathrm{d}t$ as $\dot{\alpha}$, it is possible to represent the response functions as:

$$\dot{\alpha} = -a\alpha + b\beta + c$$

$$\dot{\beta} = d\alpha - m\,\beta + r$$

where $a, b, d, m > 0$ are constants. c and r are also constants and can have either sign.

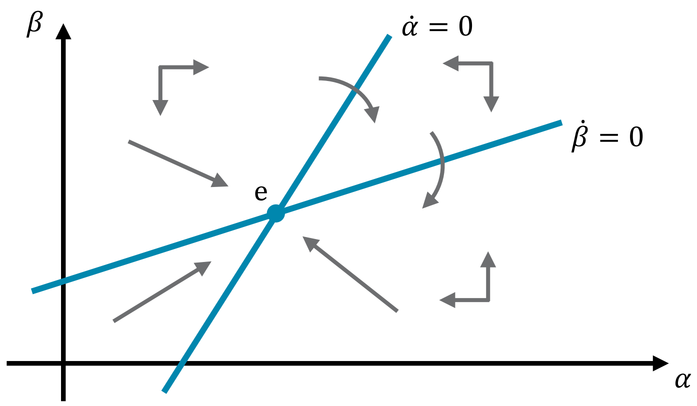
If $c > 0$ the α country would contribute even if the average contribution were zero. If $c < 0$ the average contribution must be above some threshold before the α country does anything.

In order to see the dynamics of the system we analyse the phase space. There are two interesting possibilities.

A.6 Positive altruism with c > 0, r > 0

In this case, everyone is prepared to make some positive level of contribution even if no one else contributes. The dynamics are given in the phase diagram in Figure 18. This shows that from any initial position the system moves to an equilibrium given by the point $e = (e_1, e_2)$ where $e_1 > c$ and $e_2 > r$.

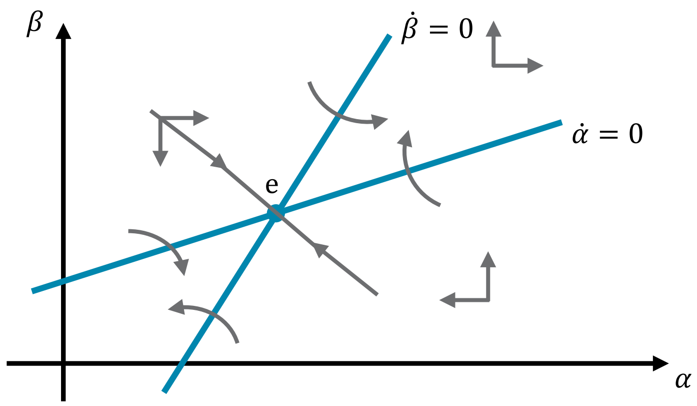
Figure 18. Dynamics of the system with positive altruism



A.7 Conditional co-operation with c < 0, r < 0

In this case, everyone is prepared to co-operate if others have co-operated above some threshold. The phase portrait is shown in Figure 19. It shows that from any initial position the system either moves to the equilibrium e, or moves to an equilibrium where no-one co-operates. In the middle top right segment, the dynamics blow up and do not correspond to any feasible path.

Figure 19. Conditional co-operation



It will be noted that any deviation from e pushes the system towards the equilibrium where no one co-operates.

In part, the models in this section tell a similar story to those on A.2. Co-operation is either founded on assurance or political support if actions are strategic. Any attempt to build co-operation on conditionality alone may not be successful.

Appendix B. Discounting

This appendix considers the discount factor in more detail. All that is intended here is to illustrate the basic point that it is often applied inappropriately. This may produce serious distortions in policy advice.

B.1 The discount problem

The discount factor is discussed using a simple two period model. For the points being made this entails no loss of generality. Period one is now and two is some future time. The decision rule is that the cost of climate change is to be an equal burden in each time period. Other decision rules are possible such as maximising the total value of expenditure across both time periods simultaneously. This produces the same argument but is not considered.

In order to construct the model, expenditure in period one is expressed as a fraction of total product and denoted as $x \in [0, 1]$. Cost of climate change in period two is written as $c(x)$.

There are several ways in which the problem of determining the best level of expenditure might be solved. In what follows consider the case where the amount to be spent now is equated to the cost in the next period as:

$$x = c(x)(1 - \delta)$$

where δ is the one period discount rate. Note that the cost in the future depends on the expenditure in the present.

What do we know about δ?

B.2 The discount rate as a function of expenditure on emissions

The basic expression for discounting is given by the Ramsey equation[106]. Let δ be the discount rate, p the rate of pure-time preference and θ be a parameter which represents the proportional change in marginal utility divided by proportional change in consumption. In other words, θ says how strongly economic growth affects utility or how much marginal utilities will change for a change in the rate of growth. Note that θ is derived for small changes in g. This gives:

$$\delta = p + \theta g$$

If the comparison is between marginal changes in, say, expenditure on roads or health then it may make sense to assume that the discount factor is exogenous.

In the case where changes are not marginal, and the growth rate depends on efforts at reducing emissions, the discount rate will be a function of expenditure, x:

$$\delta(x) = p + f(g(x))$$

where the parameter θ is replaced with the much more general function f as discussed in Section 4, which is meant to represent the proportional change in marginal utility for a proportional change in consumption over any range.

It follows that the problem to be solved is to find x such that:

$$x = c(x)(1 - \delta(x))$$

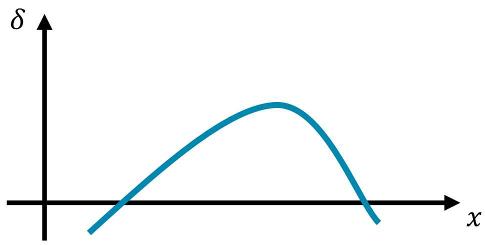
[106] Ackerman, 2007

It should be noted there is nothing in the expression to say that $\delta(x) > 0$ for all x. This raises the somewhat unexpected possibility that the discount rate can become negative as discussed in Section 4.

It might also be assumed that as expenditure on emissions reduction increases and the range of temperature changes decreases, we would get more certainty. In Weitzman's terms we would slim the fat tails and push the discount rate away from large negative values.

A reasonable set of assumptions for the discount rate would be that for $x = 0$ there would be a catastrophic shift in the climate with a large reduction in output and $\delta < 0$. For $x = 1$, the total output would be spent on emissions reduction. Although this might leave economic growth, consumption would go to zero and $\delta \leq 0$. If we assume that δ is well behaved it will look something like Figure 20 for our two-period model.

Figure 20. Example of a discount rate



Appendix C. Optimal trajectories with hard constraints

This appendix returns to a point made in the economic analysis in Section 4. Namely, that an alternative to much economic analysis would be to take the targets set by climate science as given and then work out the optimum trajectories for achieving these. This approach reduces the uncertainty because it avoids generating targets and optimal levels of the end state temperatures by imposing assumptions from economic theory onto a physical problem.

In what follows we discuss one example of such an approach that has some interesting conclusions for the optimal trajectories. **It shows that the optimal trajectory for emissions reduction may require a front-loading expenditure and that it may also be better to undershoot the maximum permissible targets for emission stocks.** These results have important implications for our best guesses about future developments and investment strategies.

C.1 Hard constraints

Section 4 claimed that there is an alternative analytical framework that avoids the problems associated with converting a problem in climate science into a problem in economics and compounding uncertainties. This framework starts from the structure of the problem and takes the task of economics to be finding the least-cost path to achieve the given targets. This does not, of course, avoid all the uncertainty. What it does is avoid the tendency to either mask the uncertainty beneath layers of assumptions about the expected values and utilities or to determine the level of acceptable risk, and hence the uncertainty, from assumptions that are not related to the original problem.

It is necessary to adopt a view different from conventional thinking around climate change. In the approach we explore in this discussion paper, the purpose of models is to provide us with aids to thinking. They are metaphors that give the overall direction of policy and aid discussion. They need to be augmented by expert knowledge and best guesses where there is uncertainty.

It also follows that models are not required to be predictive or be able to produce hard numbers that give a definitive policy program. All they are required to do is tell us the consequences of their assumptions. In as much as there is a prediction, it is only in the weak sense, that a pretend world has been constructed.

It should be noted that this view is consistent with the position taken in this discussion paper about uncertainty. We will illustrate one of the possibilities suggested with a summary of recent paper by Coram and Katzner.[107] Since the underlying mathematics is available in the sited reference, we simply state results.

C.2 Details

The central assumption is that emissions of greenhouse gases cannot be reduced to the required extent without replacing existing technologies with zero-emissions alternatives. Coram and Katzner determine the properties of the path of expenditure that will keep the stock of emissions below some upper limit at terminal time while bringing the rate of change in emissions to zero at that time. The analysis was done for a simple model in which the economy produces a single good that can be used for consumption or for producing the new technology. The trade-off between consumption and producing the new technology across the time period is specified in the performance index to be maximised. A trajectory of expenditure is optimal if it

[107] Coram & Katzner, 2018

meets the end point conditions while minimising the loss of consumption. Depreciation is ignored.

To construct the model, the terminal stock of emissions, the terminal time and the rate at which new technologies replace old (and so on) are specified as parameters, which can be adjusted. For example, the terminal upper bound on the stock of emissions is given as $\bar{e}$, which may be given any reasonable value and the model will give the corresponding trajectory. In the same manner, the terminal time is given as T and may take any reasonable positive value and so on. The model gives paths but leaves the parameters open.

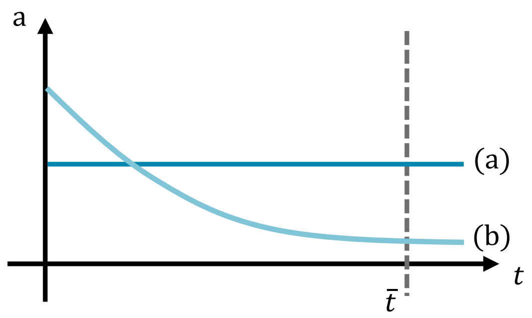
If discounting is ignored for simplicity, it turns out the model gives some strong results that run counter to a lot of our intuitions and much of the neo-classical literature. Some, but by no means all, are summarised below. However, it must be stressed that the intuitive explanations given below are after the fact. They are cobbled together to try and explain the mathematics of what a five-dimensional dynamic system can tell us in terms of something more familiar.

C.3 Results

C.3.1 High terminal stock

If the permissible upper bound to the stock of atmospheric emissions is sufficiently high, the optimal program is to steer the system to a lower level of the stock of emissions than is allowable. This is the constant path labelled (a) in Figure 21. It is followed for any terminal stock of emissions above some specified level, no matter how high this level may be.

Figure 21. Optimal controls for high terminal stock (a) and low terminal stock (b)



This finding runs counter to a lot of economic thinking and to most of the positions taken by the Australian governments in international negotiations. In nearly all those negotiations, there is a tendency to either directly, or through offered cuts, push for the highest possible limit on the stock on economic grounds. According to the model, this is bad strategy.

Why would it be optimal to aim for a lower target than the permissible upper bound? Why should the optimum rate of expenditure of resources be constant? Why should this be true regardless of how the value of the cost function appears in the performance index? It would have been thought that as the performance index changes the optimum level of expenditure changes over some time interval. Below is a rough explanation.

Notice that the optimisation problem involves an end state condition on the upper bound for the stock and on the rate of change at some terminal time, and both targets must be met at terminal time. Without both conditions, the program wouldn't make sense. This brings several elements in the dynamics into play simultaneously.

To illustrate this, suppose, for example, that the stock of emissions is allowed to get high. In this case, the rate at which it is increasing will accelerate and a high rate of change in expenditure will be required to meet the terminal target on stock, but this would make it difficult to reduce the rate of change very rapidly to get it to zero at the terminal time. To shift the illustration, think of trying to get a rocket to some end point with zero velocity at minimum fuel consumption. If it comes in too hot, then a lot of fuel will be required to get its velocity to zero. However, if a lower end point target is selected then the initial build up is less and the subsequent rate of change as the target is approached is less. This means that the total expenditure required to meet the lower target is less.

C.3.2 Low terminal stock

In this case, the optimal solution is always to steer the terminal stock of emissions to its upper bound. Trajectories of expenditure are illustrated in path (b) in Figure 21.

In short, the optimal trajectory of expenditure is either constant for a high terminal stock of emissions or starts high and ramps down. This runs counter to the recommendation at versions of the Nordhaus model which suggest starting low and ramp-up emissions reduction. It is more consistent with Stern and Garnaut. The intuition is that if an early build-up of emissions is allowed it becomes increasingly expensive to drive them down later and the rate at which they must be driven down increases. An increase in this target rate will have a non-linear effect on the cost function.

C.4 Penalties for weak technologies

Different technologies will have different capacities to displace carbon emitting generation. For example, weaker technologies such as solar and wind have a heavy and non-linear cost penalty and increase the risk of failing to meet targets.

Why should this be the case? It is obvious that weak technologies might be too slow to reach the target. On the other hand, why don't linear costs mean linear penalties?

One of the concerns operating is that weaker technologies replace emissions more slowly. To put expenditure on an optimal trajectory a faster initial rate of stock build-up must be allowed in order not to drive initial expenditures above their optimal long-run pathway. This initial build up begins to incur a progressive penalty through subsequent time and pushes total costs higher than what our intuition about a linear response would suggest.

C.5 Remark on discounting

What if a non-zero discount factor were added? In this case, there is no logical problem of the sort discussed in Appendix B, because the end points are determined, but the results are trivial. If the discount rate were positive, the curves in Figure 21 would become less steep negative.

Appendix D. Historical investment analysis

This section provides an investment analysis in the energy economy that is undergoing a transformation from being fossil-fuel reliant to being renewable focused. As the future is difficult to predict, the analysis was necessarily made with a basis on past performances and short-term considerations. It is worth observing, however, the changing dynamics in the market to get a perspective of what might occur in the future.

Is it important to bear in mind that past performance when considering future returns? Pattern recognition (analysis of historical risk-return trends) probably has no relevance in the world of investing under uncertainty. This environment is more challenging, more disrupted and more reliant on the mix of future technologies and policy frameworks. As such we place a disclaimer on the analysis presented in this appendix.

The analysis throughout Appendix D is mostly based on the returns of listed companies in the period between 2002 and 2018. The returns were aggregated into sectoral data based on the companies' market capitalisation. Unlisted assets were excluded from the analysis due to difficulties in obtaining the data. However, the patterns in the results of the analysis for the recent years (around 2006 onwards) can be loosely extrapolated to the unlisted space, given the large representation of listed companies in the world economy in the recent years.

Sectoral classification in the analysis is based on the Global Industry Classification Standard (GICS). Under the GICS, the electricity segment is a subset of two sectors: the energy and the utilities sector, with a much larger overlap in the utilities than in the energy sector. The energy sector includes industries with businesses ranging from mining, exploration, refining, storage, and transport of coal, oil, and gas. The utilities sector covers business areas such as electricity generation and retailing, gas and water distribution, and renewable power supply.

Although the energy sector seems exclusive from the electricity segment, there is a considerable intersection between the two. The sectoral crossover is especially prevalent among large oil and gas companies which are classified under the GICS to be in the energy sector but have part of their businesses in electricity generation and retailing, and recently broadened their dominance to the renewable power subsector.

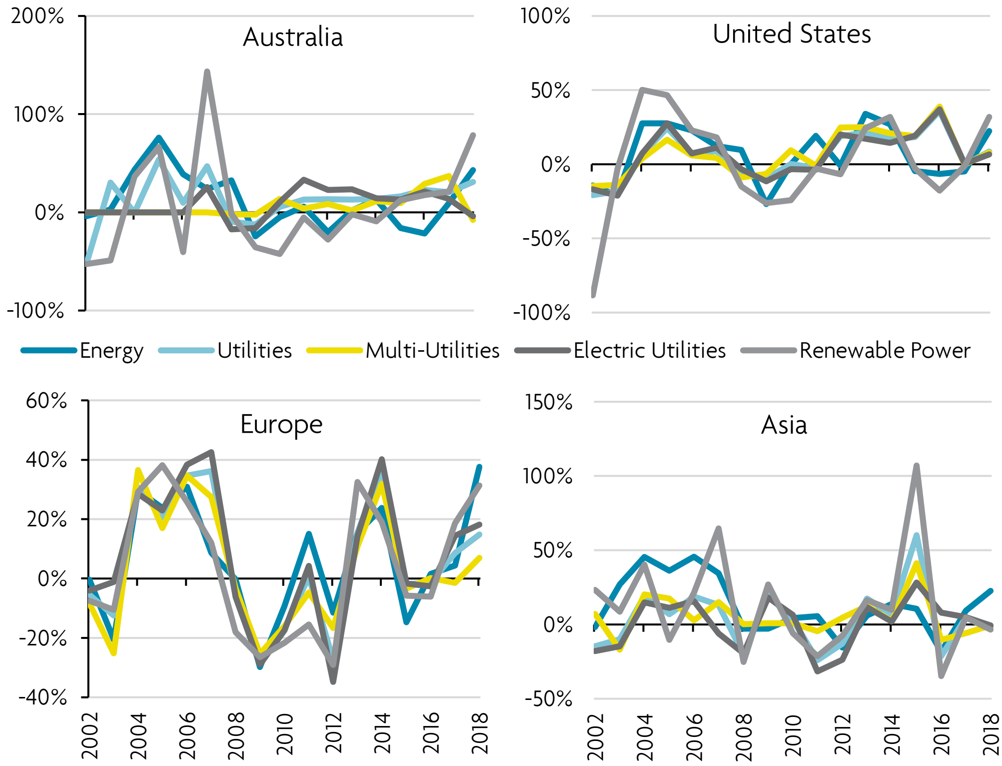
The main differences between the energy and the utilities sector can be expected, in theory from an investment perspective, to be as follows:

- The energy sector is highly exposed to the volatility associated with global oil prices, suggesting higher but volatile returns.
- The utilities sector is heavily regulated, suggesting lower but stable returns. This aspect makes investments in the utilities sector conventionally considered to be bond like and provide returns with a small to negative correlation to the broader equities market.
- In Australia, the energy sector is export orientated, whereas the utilities sector is primarily driven by domestic demand. As such, energy-sector investments can provide more exposure to global economic trends. In contrast, utilities-sector investments can provide greater exposure to domestic market conditions.

D.1 Return performance

The annual returns of listed companies in the energy and utilities sector in Australia and overseas are plotted in Figure 22.

Figure 22. Annual returns of energy, utilities and others, 2002 – 2018, selected regions



Source: ISA analysis of S&P equities data.

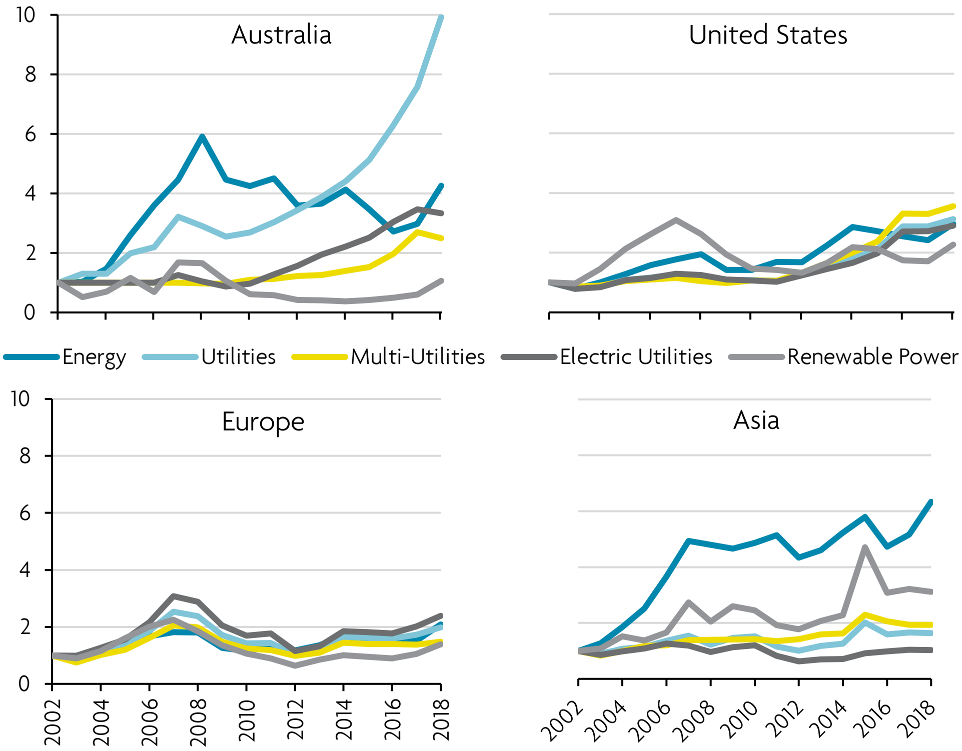
The cumulative total returns over the period 2002 to 2018 are shown in Figure 23. Also plotted in these figures are the returns of listed companies in some subsectors of utilities that are more closely related to electricity investments, namely: multi-utilities, electric utilities, and renewable power.

It should be emphasized that the performance of the subsectors and sectors plotted in Figure 22 and Figure 23 do not fully reflect the performance of the businesses in each of the subsectors and sectors, because some of the constituent companies have businesses spanning multiple subsectors and sectors.

The annual returns between the energy and utilities companies shown in Figure 22 seem to be positively correlated. This correlation stems from not only an inherent factor, but also the imperfect sector classification of the companies with businesses spanning multiple sectors. Both the energy and utilities sectors as well as their subsectors showed large volatilities between 2002 and 2018 and a vulnerability to the general market movements particularly during the GFC.

The volatilities in the utilities sector, albeit looking slightly smaller than those in the energy sector, contrast with the conventional expectation that utilities-sector investments perform similarly to fixed-income investments. Of particular note is the spike in the returns of Australia's renewable-power subsector in 2007, around the election of the Rudd Government, perhaps the last time there was certainty around climate change policy in Australia. The performance of the renewable-power subsector in all the four regions can be seen to rise turbulently since 2013.

Figure 23. Index of total returns: energy, utilities, and others, selected regions



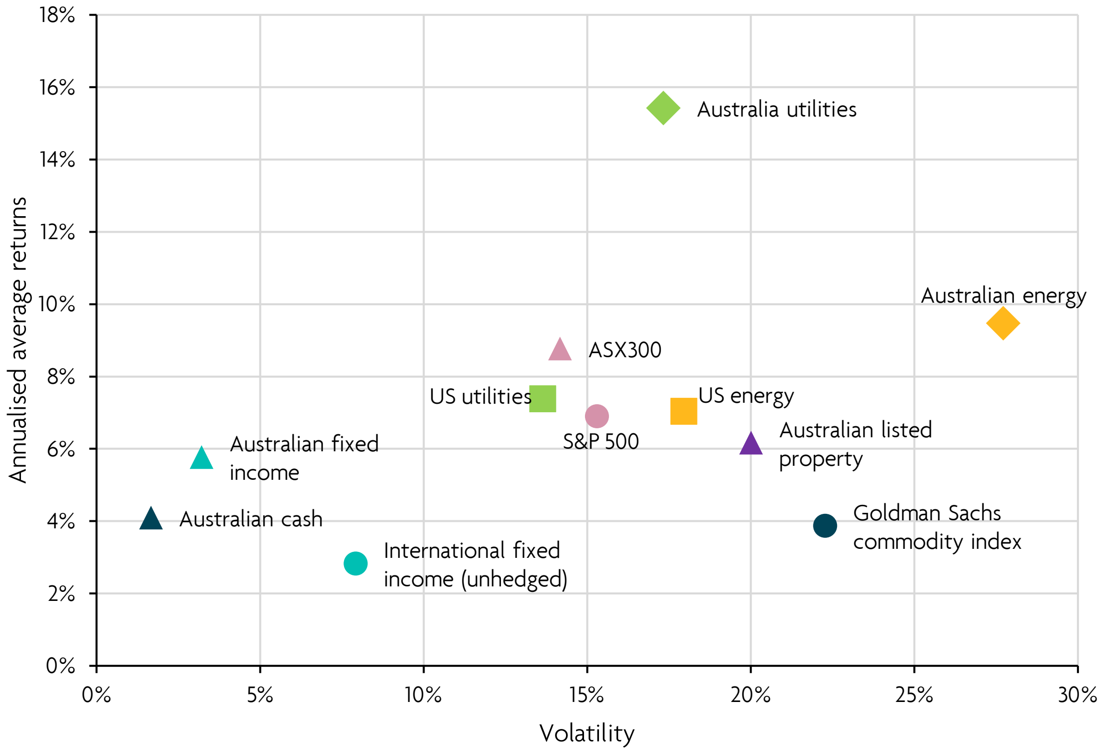
Source: ISA analysis of S&P equities data.

The total returns of the energy and utilities sector in Australia over the period 2002 to 2018 are strikingly large. The energy sector yielded over 300 per cent returns, and the utilities sector yielded almost 900 per cent returns. Annualised, they represent a return of 8.9 and 14.5 per cent, respectively. The total returns of the energy sector in Asia was similarly large.

The total returns of the renewable-power subsector were the highest in Asia than in the other three regions. Most of the growth in Asia's renewable-energy industry is attributable to China. In Australia, US, and Europe, the total returns on renewable assets remain below their 2007 levels. Over the past decade, the relative growth in renewable-energy industry can be seen to correlate with the relative growth in GDP between countries.

The risk-return performance of energy and utilities equities in Australia over the period 2002 to 2018 is presented in Figure 24. It shows that the energy and utilities assets provide the highest returns compared to various other assets classes, albeit with relatively higher volatility levels. The combined high returns and high volatility of the energy and utility assets suggests that such investment on their own could be a risky proposition unless they can be blended with a group of negatively correlated investments, which, if allocated appropriately, could yield higher portfolio risk adjusted returns.

Figure 24. Comparison of investment risk-returns across asset classes, 2002 – 2018



Source: ISA analysis of S&P equities data, Bloomberg BACM0 index, and RBA overnight cash rate.
Note: Financial year analysis.

Whilst part of the volatilities can be attributed to the impacts of the GFC, there are also significant underlying volatilities over the period 2002 to 2018. The volatilities in the annual returns of energy and utilities equities in Australia, US, Europe, and Asia are listed in Table 9 for the period before and after the GFC, and the period 2002 to 2018. Excluding the utilities in Asia, the volatility figures are all lower after the GFC than before the GFC. Australia's energy equities display the highest volatilities compared to the other regions, reflecting the economic fluctuations that Australia faced as a net energy exporter.

Table 9. Investment returns volatility, 2002 – 2018

	Energy				Utilities			
	Australia	US	Europe	Asia	Australia	US	Europe	Asia
2002 – 2008	22.2 %	16.9 %	18.5 %	16.5 %	23.7 %	13.3 %	19.6 %	14.9 %
2009 – 2018	19.2 %	15.0 %	16.6 %	12.5 %	6.9 %	11.9 %	17.8 %	23.9 %
2002 – 2018	27.7 %	18.0 %	19.5 %	19.3 %	17.3 %	13.6 %	21.2 %	20.5 %

Source: ISA analysis of S&P equities data
Note: Volatility was calculated by taking the standard deviation of returns with respect to the annualised rate of the returns.

D.2 Correlation matrix

Moving from sectoral volatilities to co-variance trends provides some interesting observations. The annual return correlations over the period between 2002 and 2018 among commodities, fixed income, energy equities, utilities equities, and all other equities in Australia as well as overseas are presented in Table 10.

Both Australia's and international's equities had positive correlations among the energy sector, the utilities sector, and all other sectors of equities. However, no correlation existed between Australia's energy and utilities equities and international other equities.

A stronger correlation between the energy and the utilities sectors existed in the international market than in Australia's (0.73 versus 0.40). Australia's utilities were only mildly correlated with international energy, in line with the fact that Australia satisfies its own energy needs.

Between commodities and energy, a strong positive correlation existed in both Australia and the international market. Between commodities and utilities, negligible correlation was present for both Australia and overseas, indicating some stability of the utilities sector with respect to commodity prices.

Both Australia's and international's energy equities were negatively correlated with their fixed-income securities. On the other hand, a small to negligible negative correlation existed between the utilities and the fixed-income assets in both Australia and overseas. This defies the conventional expectation that utilities assets are bond-like.

Table 10. Correlation matrix for energy and utility equities, 2002 – 2018

			Australia				International			
		Commodities	Fixed income	Energy	Utilities	Other equities	Fixed income	Energy	Utilities	Other equities
Commodities		1	-0.45	0.72	-0.04	0.39	-0.41	0.66	0.22	-0.05
Australia	Fixed income	-0.45	1	-0.45	-0.06	-0.67	0.38	-0.61	-0.52	-0.59
	Energy	0.72	-0.45	1	0.40	0.64	-0.52	0.84	0.51	0.08
	Utilities	-0.04	-0.06	0.40	1	0.47	-0.39	0.28	0.33	0.10
	Other equities	0.39	-0.67	0.64	0.47	1	-0.60	0.86	0.78	0.64
International	Fixed income	-0.41	0.38	-0.52	-0.39	-0.60	1	-0.47	-0.15	0.04
	Energy	0.66	-0.61	0.84	0.28	0.86	-0.47	1	0.73	0.46
	Utilities	0.22	-0.52	0.51	0.33	0.78	-0.15	0.73	1	0.66
	Other equities	-0.05	-0.59	0.08	0.10	0.64	0.04	0.46	0.66	1

Source: ISA analysis of S&P equities data, Bloomberg BACM0 index, and Goldman Sachs commodity index.
Note: Financial year analysis. Other equities include all equities except energy and utility equities. Red, black, and blue numbers indicate negative, negligible, and positive correlations, respectively.

D.3 Duration premia

Given their negligible correlations with fixed-income assets, utilities assets have a duration profile most likely to be insensitive to changes in long-term interest rates. On the other hand, energy assets, being correlated with commodities, have a positive duration characteristic whereby asset value is expected to increase with rising interest rates. The duration profiles compared to those of other asset classes are presented in Table 11.

Table 11. Comparison of duration impacts across asset classes, 2002 – 2018

Asset type	Value	Effect on asset price when key interest rates are expected to rise	Estimated effect on asset value from a 100-bps permanent change in key interest rates
Bonds	$201 trillion	▼ Variable	0% to -11%
Residential property	$162 trillion	▼ Less inelastic	0% to -5.9%
Infrastructure	$21 trillion	▼ Less inelastic	0% to -6.8%
Utilities	$39 billion*	▼ Variable	0% to -1.2%
Energy	$110 billion*	▲ Likely	0 % to 5.9%
Equities	$67 trillion	▲ If rate rise is small ▼ If rate rise is large	0 % to -14%
Commercial real estate	$27 trillion	▼ Most impacted	0% to -11.9%
Agriculture property	$31 trillion	▲ Most likely	0% to 15%*

Source: ISA analysis with data from Duxton Asset Management, GMO LLC, IFM Investors, S&P.
*Note: Energy and utilities are proxied by ASX listed companies. *Australian-based market value.*

D.4 Diversification

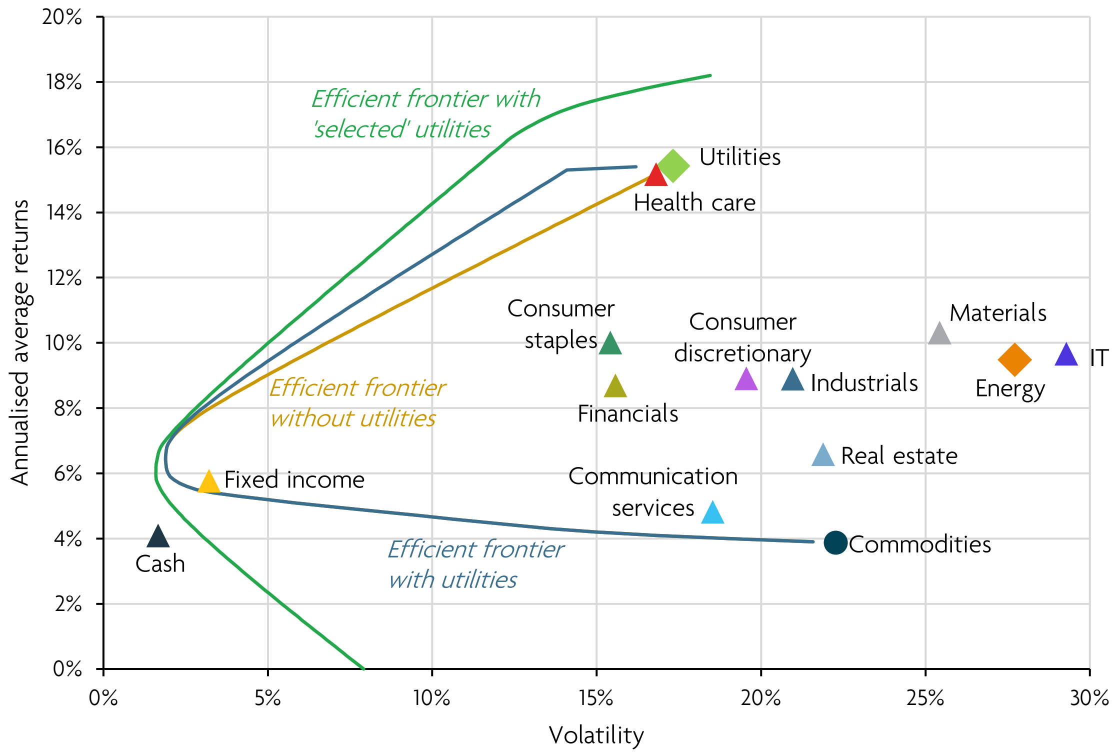
A well curated mix of assets can minimize a portfolio risk for a given target return. To assess the diversification benefits of having energy and utilities assets in a portfolio of Australian assets, we performed a KKT optimization[108] on Australia's investment market for the period 2002 to 2018. The optimization results are plotted in returns-volatility space in Figure 25.

The asset classes chosen for the optimization include Goldman Sachs commodity index, Bloomberg BACM0 index (Australian fixed income), and eleven Australian equity sectors as shown in the figure. The data for the eleven equity sectors were aggregated from the performance data of all ASX-listed companies in the respective sectors with weighting based on their market capitalisations.

The efficient frontier (the set of portfolios with minimum risk) is shown by the blue line in the figure. It was found that utilities equities are a necessary component in the optimal portfolios with a target return of 7 per cent and above, and that the optimal portfolios with greater returns require greater proportion of utilities assets. If utilities were excluded from the optimization, the efficient frontier would have higher volatilities for any given returns above the 7 per cent threshold, as shown by the brown line.

[108] The Karush-Kuhn-Tucker (KKT) optimization in this analysis attempts to minimize the volatility of the portfolio returns for any given target return with a condition that short-selling is not allowed.

Figure 25. Portfolio impacts of utility investments, Australia, 2002 – 2018



Source: ISA Analysis of S&P data.

On the other hand, energy assets were found to provide no diversification benefits. However, including energy assets in a portfolio may prove to be valuable as a hedge against inflation over time, given their positive correlation with commodity prices.

By segregating the utilities sector into its subsectors[109] and including the subsectors into the optimization, a further reduction in the portfolio risks can be obtained. The efficient frontier of this larger set of asset classes is shown by the green line in Figure 25. Gas utilities, multi-utilities, water utilities, and renewable power equities were found to form an integral part of the optimal portfolios.

D.5 Concluding remarks

There is no reason to believe that the results of the analysis in this Appendix will hold true into the future, especially given the changing global landscape surrounding climate change policy and the emergence of new and better power generation technologies. Nevertheless, an emerging trend is apparent from this analysis that investments in renewable-energy industry are becoming attractive with higher returns and greater diversification benefits.

[109] Electric utilities, gas utilities, multi-utilities, water utilities, and renewable power.

References

Ackerman, F., 2007. *Debating Climate Economics: The Stern Review vs. Its Critics.* [Online] Available at: http://www.ase.tufts.edu/gdae/Pubs/rp/SternDebateReport.pdf

ARUP, 2019. *Fehmarnbelt fixed link*. [Online] Available at: https://www.arup.com/projects/fehmarnbelt-fixed-link

Australian Bureau of Statistics (ABS), 2018. *3101.0 – Australian Demographic Statistics, Sep 2018.* [Online] Available at: https://www.abs.gov.au/ausstats/abs@.nsf/mf/5260.0.55.002

Australian Bureau of Statistics (ABS), 2018. *5204.0 – Australian System of National Accounts, 2017-18*. [Online] Available at: https://www.abs.gov.au/ausstats/abs@.nsf/mf/5204.0

Australian Bureau of Statistics (ABS), 2018. *5209.0.55.001 – Australian National Accounts: Input-Output Tables, 2015-16*. [Online] Available at: https://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/5209.0.55.001

Australian Bureau of Statistics (ABS), 2018. *5260.0.55.002 – Estimates of Industry Multifactor Productivity, 2017-18*. [Online] Available at: https://www.abs.gov.au/ausstats/abs@.nsf/mf/5260.0.55.002

Australian Competition & Consumer Commission (ACCC), 2018. *Restoring electricity affordability and Australia's competitive advantage – Retail electricity Pricing Inquiry - Final Report.* [Online] Available at: https://www.accc.gov.au/regulated-infrastructure/energy/electricity-supply-prices-inquiry/final-report

Australian Energy Market Operator (AEMO), 2016. *National Electricity Forecasting Report – For the National Electricity Market*. [Online] Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEFR/2016/2016-National-Electricity-Forecasting-Report-NEFR.pdf

Australian Energy Market Operator (AEMO), 2017. *Five-minute settlement: High level design*. [Online] Available at: https://www.aemc.gov.au/sites/default/files/content/b862be5a-4460-4b72-a90b-8f73117f301c/5MS-HLD-Final-4-Sep.pdf.

Australian Energy Market Operator (AEMO), 2018a. *Fact Sheet – The National Electricity Market.* [Online] Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/National-Electricity-Market-Fact-Sheet.pdf

Australian Energy Market Operator (AEMO), 2018b. *Generation Information Page.* [Online] Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information

Australian Energy Market Operator (AEMO), 2018c. *Integrated System Plan for the National Electricity Market.* [Online] Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf

Australian Energy Market Operator (AEMO), 2018d. *Market notice 63243*. [Online] Available at: http://aemo.com.au/Market-Notices?searchString=63243

Australian Energy Market Operator (AEMO), 2019. *Quarterly Energy Dynamics Q1 2019*. [Online] Available at: https://www.aemo.com.au/-/media/Files/Media_Centre/2019/QED-Q1-2019.pdf

Australian Energy Regulator (AER), 2017. *State of the energy market - May 2017.* [Online] Available at: https://www.aer.gov.au/publications/state-of-the-energy-market-reports/state-of-the-energy-market-may-2017

Australian Energy Regulator (AER), 2018. *Quarterly volume weighted average spot prices.* [Online] Available at: https://www.aer.gov.au/wholesale-markets/wholesale-statistics/quarterly-volume-weighted-average-spot-prices

Benson, S., 2018. *National energy guarantee 'dead' as Morrison sets new course*. The Australian. [Online] Available at: https://www.theaustralian.com.au/nation/climate/national-energy-guarantee-dead-as-morrison-sets-new-course/news-story/1e0db1f87ba30117317cdcc24f537a88

Blakers, A. et al., 2018. *Sites for pumped hydro energy storage.* [Online] Available at: http://re100.eng.anu.edu.au/research/phes/

Brook, B., 2011. *TCASE 15: Comparison of four 'clean energy' projects.* [Online] Available at: https://bravenewclimate.com/2011/10/21/tcase15/

Burke, M., Hsiang, S. M. & Miguel, E., 2015. *Global non-linear effect of temperature on economic production.* [Online] Available at: https://www.nature.com/articles/nature15725

Carr, M. October 2018. How High Does Carbon Need to Be? Somewhere From $20-$27,000. Bloomberg. [Online] Available at: https://www.bloomberg.com/news/articles/2018-10-10/how-much-does-carbon-need-to-cost-somewhere-from-20-to-27-000

Carringtone, D., 2018. *Tackle climate or face financial crash, say world's biggest investors*. The Guardian. [Online] Available at: https://www.theguardian.com/environment/2018/dec/10/tackle-climate-or-face-financial-crash-say-worlds-biggest-investors

Clean Energy Council, 2018. *National Energy Guarantee.* [Online] Available at: https://www.cleanenergycouncil.org.au/policy-advocacy/national-energy-guarantee.html

Clean Energy Council, 2019. *Clean Energy Australia – Report 2019*. [Online] Available at: https://www.cleanenergycouncil.org.au/resources/resources-hub/clean-energy-australia-report

Climate Council, 2018. *Powering progress: States Renewable Energy Race*. [Online] Available at: https://www.climatecouncil.org.au/resources/states-renewable-energy/

COAG Energy Council, 2018. *National Energy Guarantee – Final Detailed Design*. [Online] Available at: http://www.coagenergycouncil.gov.au/publications/energy-security-board-%E2%80%93-final-detailed-design-national-energy-guarantee

Committee for Economic Development of Australia (CEDA), 2011. *A Taxing Debate – The forgotten issues of climate policy*. [Online] Available at: https://www.ceda.com.au/CEDA/media/Attachments/pdf/15616-a%20taxing%20debate%20-%20the%20forgotten%20issues%20of%20climate%20policy.pdf

Coram, A. & Katzner, D., 2018. *Reducing fossil fuel-emissions: dynamic paths for alternative energy producing technologies*. Energy Economics, 70(C), pp. 179-189. [Online] Available at: https://doi.org/10.1016/j.eneco.2017.12.028

Davenport, C. & Pierre-Louis, K., 2018. *U.S. Climate Report Warns of Damaged Environment and Shrinking Economy*. New York Times [Online] Available at: https://www.nytimes.com/2018/11/23/climate/us-climate-report.html

De Finetti, B., 1938. *Course on Probability Calculus at the University of Padova.* [Online] Available at: https://digital.library.pitt.edu/islandora/object/pitt%3A31735033466289

Department of the Environment and Energy, 2018a. *Australian Energy Update 2018.* [Online] Available at: https://www.energy.gov.au/publications/australian-energy-update-2018

Department of the Environment and Energy, 2018b. *Australia's emission projections 2018.* [Online] Available at: https://www.environment.gov.au/climate-change/publications/emissions-projections-2018

Department of the Environment and Energy, 2018c. *Quarterly Update of Australia's National Greenhouse Gas Inventory for September 2018.* [Online] Available at: https://www.environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/publications/quarterly-update-australias-national-greenhouse-gas-inventory-sept-2018

Department of the Environment and Energy, 2019. *Climate Solutions Package*. [Online] Available at: http://www.environment.gov.au/climate-change/publications/climate-solutions-package

Department of Industry, Innovation and Science, 2019. *National hydrogen strategy open for public consultation*. [Online] Available at: https://www.minister.industry.gov.au/ministers/canavan/media-releases/national-hydrogen-strategy-open-public-consultation

Edify Energy, 2019. *Octopus Investments and Edify Energy finance new $450 million solar farm.* [Online] Available at: http://edifyenergy.com/octopus-investments-and-edify-energy-finance-new-450-million-solar-farm/

Energy Information Reform Project, 2018. *What Will Advanced Nuclear Power Plants Cost? – A Standardized Cost Analysis of Advanced Nuclear Technologies in Commercial Development*. [Online] Available at: https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf

European Court of Auditors, 2018. *Public Private Partnerships in the EU: Widespread shortcomings and limited benefits*. [Online] Available at: https://www.eca.europa.eu/Lists/ECADocuments/SR18_09/SR_PPP_EN.pdf

Falbe-Hansen, K. & Nissen, J., 2000. *The Øresund bridge completion*. The Arup Journal, 3, pp 20-27.

Finkel, A., 2017. *Independent Review into the Future Security of the National Electricity Market – Blueprint for the Future*. [Online] Available at: https://www.energy.gov.au/publications/independent-review-future-security-national-electricity-market-blueprint-future

First Solar, 2018. *Topaz Solar Farm*. [Online] Available at: http://www.firstsolar.com/en/Resources/Projects/Topaz-Solar-Farm

Frank, C., 2016. *New results on the net benefits of low carbon electricity technologies*. Brookings. [Online] Available at: https://www.brookings.edu/blog/planetpolicy/2016/10/17/new-results-on-the-net-benefits-of-low-carbon-electricity-technologies/

Garnaut, R., 2016. *The Economics of the Future Energy System*. Renewable Energy Summit. [Interview] (7 October 2016).

Garnaut, R., Emerson, C., Finighan, R. & Anthony, S., 2019. *Replacing Corporate Income Tax with a Cash Flow Tax*. Melbourne Economic Forum. [Online] Available at: https://www.industrysuper.com/media/replacing-corporate-income-tax-with-a-cash-flow-tax/

Harvey, C. & Heikkinen, N., 2018. *Congress Says Biomass is Carbon-Neutral, but Scientists Disagree*. E&E News. [Online] Available at: https://www.scientificamerican.com/article/congress-says-biomass-is-carbon-neutral-but-scientists-disagree/

Hutchens, G., 2017. *Snowy Hydro 2.0 is viable but will cost billions more than predicted, study says*. The Guardian. [Online] Available at: https://www.theguardian.com/australia-news/2017/dec/21/snowy-hydro-2-viable-government-backed-study

Institute for Energy Research (IER), 2018. *Is Coal Dead in China?*. [Online] Available at: https://www.instituteforenergyresearch.org/fossil-fuels/coal/coal-dead-china/

Investor Group on Climate Change, 2019. *Investors need to understand the true cost of carbon*. [Online] Available at: https://igcc.org.au/investors-need-to-understand-the-true-cost-of-carbon/

Intergovernmental Panel on Climate Change (IPCC), 2018. *Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments*. [Online] Available at: https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/

John, A., 2014. *The Renewable Energy Target: a quick guide*. Parliament of Australia. [Online] Available at: https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1314/QG/RenewableEnergy

Keane, D., 2018. *Tesla battery cost revealed two years after blackout*. ABC News. [Online] Available at: https://www.abc.net.au/news/2018-09-27/tesla-battery-cost-revealed-two-years-after-blackout/10310680

Kelp, O., 2018. *The NEG Emissions Obligation - Does it do Enough?*. Acil Allen Consulting. [Online] Available at: https://www.acilallen.com.au/insights/neg-emissions

Law Quarter, 2018. *A Short Guide to Power Purchase Agreements (PPA) in Australia*. [Online] Available at: https://lawquarter.com.au/short-guide-power-purchase-agreements-ppa-australia/

Lazard, 2018. *Lazard's Levelised Cost of Energy Analysis – Version 12.0*. [Online] Available at: https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

Lewis, M., 2003. *Moneyball*. W.W. Norton and Company, New York.

Martin, J., 2011. *Solar Flagship Program Winners: Moree Solar Farm, Chinchilla CSP plant*. Solar Choice. [Online] Available at: https://www.solarchoice.net.au/blog/news/solar-flagship-program-winners-moree-solar-farm-in-central-tablelands-220611/

McConnell, D., 2017. *Yes, SA's battery is a massive battery, but it can do much more besides*. The Conversation. [Online] Available at: https://theconversation.com/yes-sas-battery-is-a-massive-battery-but-it-can-do-much-more-besides-88480

McLean, B. & Elkind, P., 2004. *The Smartest Guys in the Room: The Amazing Rise and Scandalous Fall of Enron*. Portfolio Trade.

Morgan, S., 2018. *Australia's new PM risks climate trade-off with EU*. Euractiv.com. [Online] Available at: https://www.euractiv.com/section/climate-environment/news/australias-new-pm-risks-climate-trade-off-with-eu/

Murphy, K., 2018. *AGL rejects Alinta's bid for Liddell power plant, confirming its closure*. The Guardian. [Online] Available at: https://www.theguardian.com/australia-news/2018/may/21/agl-rejects-alintas-bid-for-liddell-power-plant-confirming-its-closure

Murphy, K., 2018. *What is the national energy guarantee and why is it taking so long?*. The Guardian. [Online] Available at: https://www.theguardian.com/australia-news/2018/jul/26/what-is-the-national-energy-guarantee-and-why-is-it-taking-so-long

Nordhaus, W., 2007. *A review of the Stern Review on the economics of global warming*. Journal of Economic Literature, 45(3), pp. 686-702. [Online] Available at: https://doi.org/10.3386/w12741

Nordhaus, W., 2009. *A Question of Balance: Weighing the Options on Global Warming Policies*. Yale University Press.

OECD Nuclear Energy Agency, 2012. *Nuclear Energy and Renewables: System Effects in Low-carbon Electricity Systems.* [Online] Available at: http://www.oecd-nea.org/ndd/reports/2012/system-effects-exec-sum.pdf

Packham, B., 2018. *Australia will use carry-over emissions credits to meet 2030 Paris emissions target*. The Australian. [Online] Available at: https://www.theaustralian.com.au/nation/politics/australia-set-to-dramatically-overshoot-paris-emissions-target/news-story/231724f59971f56a6b88d9fbc83bbe18

Paul, S., 2018. *Australia states power ahead with renewables after national policy collapses*. Thomson Reuters. [Online] Available at: https://www.reuters.com/article/us-australia-renewables/australia-states-power-ahead-with-renewables-after-national-policy-collapses-idUSKCN1LR10L

Phillips, S., 2018. *What matters for business in the climate policy debate*. The Sydney Morning Herald. [Online] Available at: https://www.smh.com.au/money/investing/what-matters-for-business-in-the-climate-policy-debate-20180821-p4zyti.html

Plummer, R., 2019. *Hitachi to decide on fate of UK nuclear plant*. BBC News. [Online] Available at: https://www.bbc.com/news/business-46855799

Post, W., 2013. *A More Realistic Cost of Wind Energy*. Energy Central. [Online] Available at: https://www.energycentral.com/c/ec/more-realistic-cost-wind-energy

PwC Australia, 2017. *Optimising Energy*. [Online] Available at: https://www.pwc.com.au/publications/corporate-power-purchase-agreements-nov17.html

Rath, M., 2017. *Energy industry will be unrecognisable within a decade*. The Australian Financial Review. [Online] Available at: https://www.afr.com/news/economy/energy-industry-will-be-unrecognisable-within-a-decade-20171009-gyx821

Rosik, P., 2018. *The state is always present in the financing of nuclear power plants. Central European Financial Observer*. [Online] Available at: https://financialobserver.eu/poland/the-state-is-always-present-in-the-financing-of-nuclear-power-plants/

Skinner, B. & Kitchen, C., 2018. *Victoria's Renewables Reverse Auction: Known knowns and some known unknowns*. Australian Energy Council. [Online] Available at: https://www.energycouncil.com.au/analysis/vic-renewables-reverse-auction-known-knowns-and-some-known-unknowns/

Slezak, M., 2016. *Electricity price spikes caused by energy companies 'gaming' the system, report finds*. The Guardian. [Online] Available at: https://www.theguardian.com/australia-news/2016/aug/11/electricity-price-spikes-caused-by-energy-companies-gaming-the-system-report-finds

Stanley, B. & Lee, H., 2018. *U.A.E. Completes First of Four Korean-Built Nuclear Reactors*. Bloomberg. [Online] Available at: https://www.bloomberg.com/news/articles/2018-03-26/u-a-e-completes-korean-built-nuclear-power-plant-seoul-says

Stern, N., 2006. *The Economics of Climate Change*. Cambridge University Press. [Online] Available at: https://doi.org/10.1017/CBO9780511817434

Talberg, A., Hui, S. & Loynes, K., 2016. *Australian climate change policy to 2015: a chronology*. Parliamentary Library. [Online] Available at: https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1516/Climate2015

Temple, J., 2018. *The carbon-capture era may finally be starting*. MIT Technology Review. [Online] Available at: https://www.technologyreview.com/s/610296/the-carbon-capture-era-may-finally-be-starting/

Thompson, J., 2011. *Carbon tax passes Senate*. ABC News. [Online] Available at: https://www.abc.net.au/news/2011-11-08/carbon-tax-passes-senate/3652438

Tilt Renewables, 2018. *NZX/ASX Market Announcement: Tilt Renewables announces Dundonnell Final Investment Decision and Interim Results*. [Online] Available at: https://www.tiltrenewables.com/documents/236/Tilt_Renewables_Interim_Results__Dundonnell_FID_Announcement_31_October_2018.pdf

Tomaras, J., 2016. *Renewable energy policy: retreat, renewal and revitalisation?*. Parliament of Australia. [Online] Available at: https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/BriefingBook45p/RenewableEnergy

Twidale, S., 2017. *Global carbon prices must soar to meet Paris climate target – report*. Thomson Reuters. [Online] Available at: https://uk.reuters.com/article/uk-climatechange-carbon-prices-idUKKBN18P0PL

United Nations Framework Convention on Climate Change (UNFCCC), 2018. *GHG Profiles - Annex 1, Australia*. [Online] Available at: https://di.unfccc.int/ghg_profile_annex1

US Energy Information Administration, 2019. *Annual Energy Outlook 2019.* [Online] Available at: https://www.eia.gov/outlooks/aeo/

State Government of Victoria, 2018. *Victorian Renewable Energy Auction Scheme.* [Online] Available at: https://www.energy.vic.gov.au/renewable-energy/victorian-renewable-energy-auction-scheme

Wallace-Wells, D., 2018. *UN Says Climate Genocide Is Coming. It's Actually Worse Than That*. New York Magazine. [Online] Available at: https://nymag.com/intelligencer/amp/2018/10/un-says-climate-genocide-coming-but-its-worse-than-that.html

Weitzman, M., 2009. *On modelling and interpreting the economics of catastrophic climate change*. The Review of Economics and Statistics, 91(1), pp. 1-19. [Online] Available at: https://doi.org/10.1162/rest.91.1.1

World Bank. 2017. *Results Briefs. Carbon Pricing.* Available at: https://www.worldbank.org/en/results/2017/12/01/carbon-pricing

World Nuclear Association, 2019. *Economics of Nuclear Power.* [Online] Available at: http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx

Yaxley, L. & Henderson, A., 2018. *Tony Abbott wants Australia to pull out of the Paris Climate deal he supported as PM*. ABC News. [Online] Available at: https://www.abc.net.au/news/2018-07-04/tonney-abbott-says-pull-out-of-paris-climate-agreement/9937972

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