Decarbonising the Australian Economy: A First Step

Akhtar Kalam[1], Warren Weeks[1], and Brad Hogan[1]

[1]Victoria University

July 19, 2023

Abstract

In response to pressure from all sides, governments around the world have com-mitted to decarbonising their economies within the next thirty years. Taken literally, this would involve eliminating the use of naturally occurring hydrocarbons such as coal, natural gas, and oil. However, based on their analysis of data drawn from ac-ademic papers, the Australian Federal Government, energy industry bodies, and manufacturers of electricity generating equipment, the authors believe at this time, such elimination of fossil fuel use is simply not possible. That said, by moving to a connected energy island (CEI) power generation topology, the data suggest we can at once: create a sustainably robust energy supply, move Australia closer to its environmental targets, and underpin the country's future economic well-being.

1. **Article title**: Decarbonising the Australian Economy: A First Step
2. **Running head/short title:** Decarbonising Australia
3. **Names of all authors in the same order as mentioned in ScholarOne**: Kalam. Akhtar; Weeks, Warren A. and Hogan, Brad
4. **Author's contribution**: 1. Kalam: Project administration, resources, supervision, Writing – review & editing; 2. Weeks: Conceptualization, Investigation, Validation, Writing original draft; 3. Hogan: Software, Writing – review & editing
5. **Affiliation of all authors**: Victoria University
6. **Postal and E-mail address of the corresponding author**: Victoria University, College of Sport, Health and Engineering, P.O. Box 14428, Melbourne, VIC, AU
7. **Funding information (Please mention "Funding: None" if you have not received any support for your research)**: None
8. **Conflict of Interest statement**: No
9. **Permission to reproduce materials from other sources (mention "None" if not applicable for your article)**: None
10. **Data Availability statement**: Data derived from public domain resources.

Decarbonising the Australian Economy: A First Step

Akhtar Kalam, Warren A. Weeks and Brad Hogan

Smart Energy Research Unit
College of Engineering and Science
Victoria University
Melbourne, Australia

Abstract: In response to pressure from all sides, governments around the world have committed to decarbonising their economies within the next thirty years. Taken literally, this would involve eliminating the use of naturally occurring hydrocarbons such as coal, natural gas, and oil. However, based on their analysis of data drawn from academic papers, the Australian Federal Government, energy industry bodies, and manufacturers of electricity generating equipment, the authors believe at this time, such elimination of fossil fuel use is simply not possible.
That said, by moving to a connected energy island (CEI) power generation topology, the data suggest we can at once: create a sustainably robust energy supply, move Australia closer to its environmental targets, and underpin the country's future economic well-being.

Keywords: Decarbonisation; Hydrogen based energy; Australian energy landscape; Renewables; Energy Island.

Table of Contents

1. Introduction

Removing naturally occurring hydrocarbons from all our industrial processes while simultaneously delivering the necessary quantum of reliable, affordable energy to maintain economic health rates is a difficult problem [1]. In part, that is because our global reliance on coal, oil, and natural gas goes far beyond their use in energy production. Petrochemical derivatives like lubricants and fertilisers keep the wheels of our global society spinning and our crops growing. Some 99% of every plastic, metal, glass, ceramic, wooden or fabric product in use today – including those used in solar panel and wind turbine production – rely on fossil fuels for their existence [2]. To entirely decouple our global economy from fossil fuel-based products for many lifetimes may be impossible, if ever. With that in mind, the authors believe any moves to decarbonise our economy should begin with strategically sound, more tightly focused initiatives - such as deploying proven transition-centric energy generation technologies [3, 4]. This approach can yield positive outcomes in the short term while also enabling our climate action end game. In essence, we can keep one eye on the future while doing the best we can with what we have right now [5].

2. Hypothesis

To achieve our various short and long-term environmental goals, we must maintain our country's ability to fund these endeavours by protecting our collective prosperity. That means keeping the lights on and the wheels of industry turning.
Affordable, reliable, sustainable electricity generation is achievable by deploying transition-capable, base-load and intermittent energy technologies – but only if they are brought together in a flexible, manageable network topology, such as the connected energy island (CEI) concept.

3. The Situation

Australia's electric power generation is through the consumption of fossil fuels as well as the application of several renewable energy harvesting methods [3, 6]:

- Coal: 54.8%, Oil: 1.7%, and Natural Gas: 20.82% (a fossil fuel total of ~77%),
- Hydro-Power: ~6%,
- Solar Panel Installations - both domestic and industrial-scale: ~8%,
- Wind Turbines:~8%, and
- Bioenergy: ~1%.

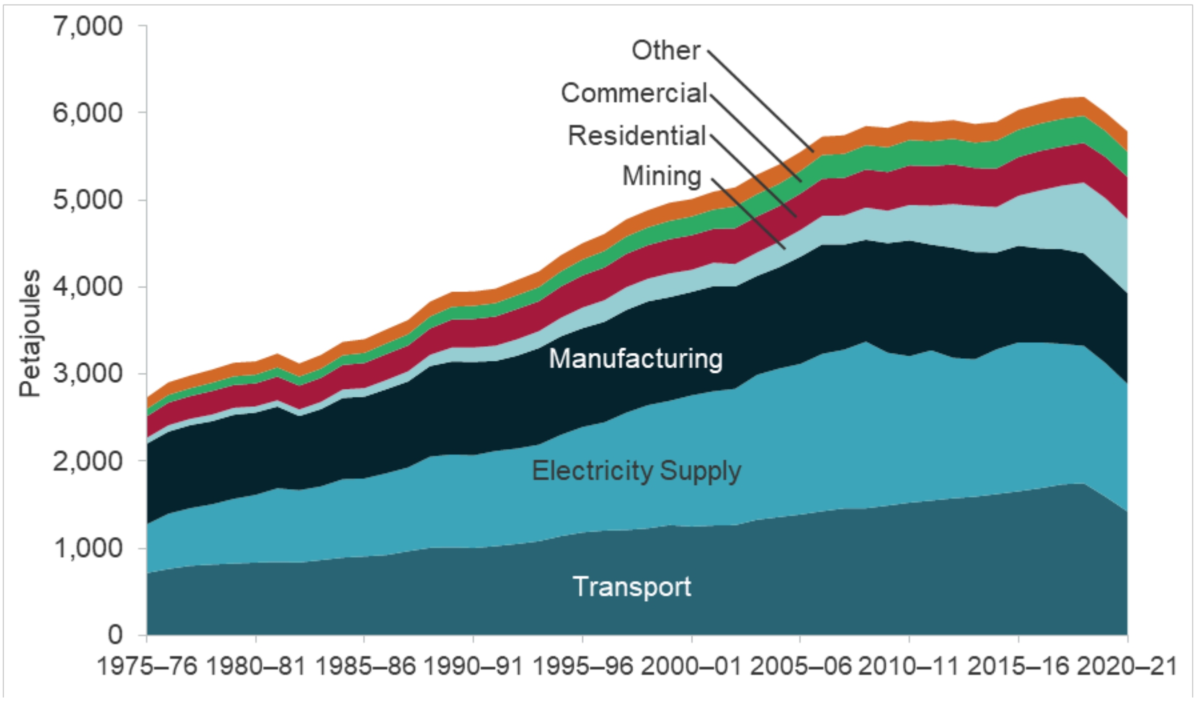

Figure 1. Australian Energy Consumption by Sectors [7]

Those states lying on the eastern seaboard share electric power via a common electricity grid; however, this has proven to be both a blessing and a curse. On the plus side, it has allowed one state with excess generating capacity to sell its extra power to another in need. However, creating a common grid has also allowed some states to skimp on their investments in power generation, winding back their production capacity and relying more and more on large-scale electricity generators elsewhere in the country. Those current - mostly coal-fired - generators are aging and breaking down more often. With no significant investment in newer, more efficient and reliable base-load generators, the entire grid will inevitably weaken and fail [3, 8].
As evidence of this, a recent supply squeeze has seen power prices jump dramatically across the country, necessitating load shedding and costly market intervention by the energy regulator and market operator [9].

In light of these events, the key questions asked of governments are:

- What technology can add reliable 24x7, flexible base-load power generation in the shortest time?
- Which power generation technology can meet the joint criteria of timeliness, sustainability, and cost efficiency from capital expenditure, operational perspectives, and cost per Megawatt?
- Should private hands hold these new power sources? Should the public own it? Alternatively, should they be assets held in a public/private partnership.

- Should governments declare power generation as a special class of essential service - enabling them to enforce decisions regarding these assets that more appropriately serve the public interest? If so …
- How can governments address their constituents' energy supply and cost requirements while concurrently avoiding sovereign risk and protecting the commercial viability of energy suppliers.

4. Energy Decarbonisation: Think Big, Start Small

Government data suggests Australia is sufficiently reliant on fossil fuels as to make it impossible to eliminate their use in the short term [3]. Providing the energy needed to run our economy without fossil fuels would require the equivalent of 1,555TWh of electrical energy annually.

In simple output terms - i.e. ignoring the complexities of energy storage, transmission, land acquisition or ongoing operational costs - AEMO puts the capital cost of generating that quantum of electricity using offshore wind turbines at $2.3 trillion, or $ 862 billion using solar panels. Using land-based wind turbines would cost $ 825 billion, while H_2-compatible gas turbine generators would cost $484 billion [10].

Despite presenting a simplified view of the cost of decarbonisation, these figures nonetheless cast doubt over the veracity of recent claims that in just a few years, and with the expenditure of tens of billions of dollars, Australia can move away from its reliance on fossil fuels [3, 11].

We posit that Australia's decarbonisation should begin with a more modest but no less significant undertaking - reshaping the electricity generation sector: This sector accounts for ~ 10% of Australia's fossil fuel usage.

5. Exploring the Connected Energy Island Concept: A Victorian Hypothetical

Regarding its electricity generation, Victoria is Australia's second most coal-reliant state (~68%), but as shown in Figure 1, it also generates a substantial input from renewables – totalling ~27% of its power.

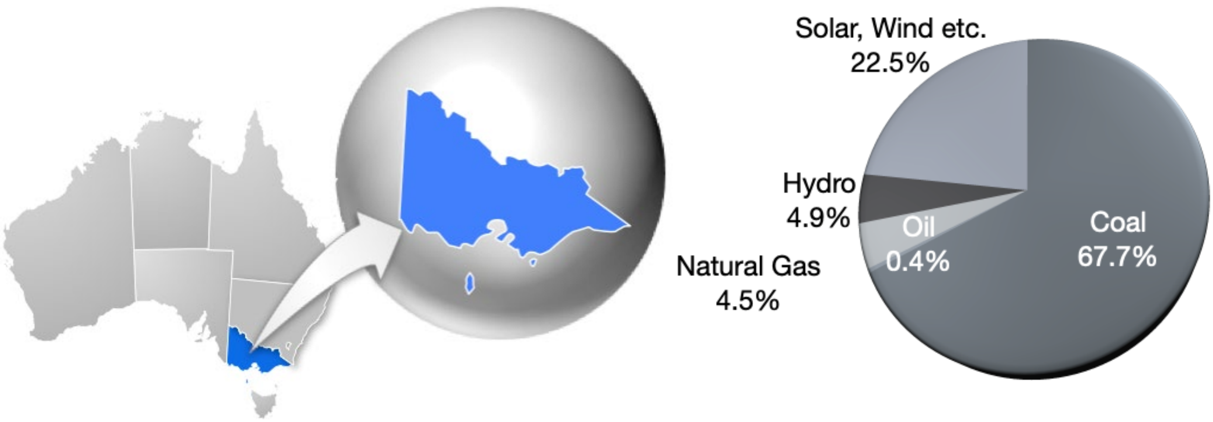

Figure 2. The breakdown of fossil fuel-fired and renewable electricity generation in Victoria

This juxtaposition of heavy reliance on coal to fire aging, and base-load power plants, with substantial uptake of renewable technologies [3, 6], makes Victoria an ideal subject for exploring the connected energy island concept (CEI).
However, another factor in the state's qualification as the ideal test-bed is the HESC or Hydrogen Energy Supply Chain project.
Located in the Latrobe Valley, close to the State's large lignite deposits and existing base-load grid infrastructure, this gasification pilot plant is paving the way for a full-scale hydrogen production facility, incorporating CO_2 sequestration [3, 12].
Completing a full-scale H_2 production facility represents the last key element needed to successfully implement Victoria's CEI.

To summarise, the five factors that make Victoria the ideal state for a CEI implementation are:

- A ready supply of an initial first-phase fuel source to power new, high-efficiency, Natural gas to H_2 gas turbine generators.
- The promise of nearby H_2 fuel availability.
- Easy access to the main grid infrastructure
- Sufficient available land … and
- A local government and community that is favourably disposed to such a development.

As shown in Figure 2, a CEI employs a flexible "building block" approach, which can support various network topologies, allowing designers to leverage maximum advantage from their existing grid layouts.
In Victoria, that means co-locating the bulk of new base-load generating capacity with the soon-to-be-retired coal-fired plants.

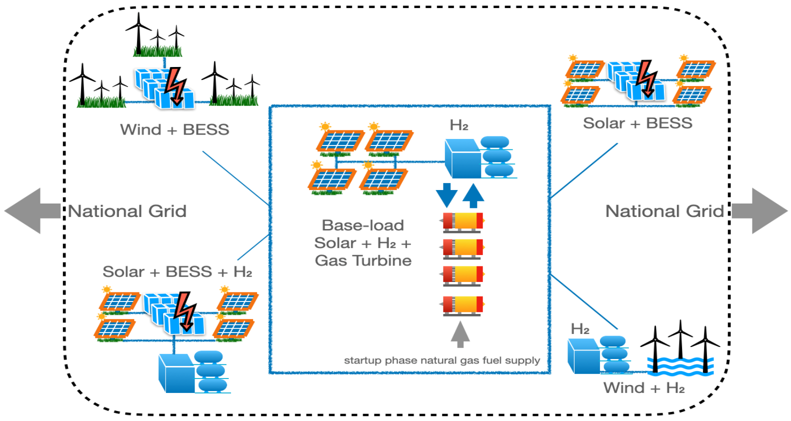

Figure 3. The topology of Victoria's hypothetical connected energy island

Apart from taking a share of the energy fed into the national grid from the nation's hydro-electric resource – Victoria's energy island would apply a mix of energy harvesting, electricity generation, H_2 production and energy storage technologies to create a more robust, manageable, self-sufficient electricity network.
Importantly in the CEI, the absence of the kinds of kinetic or thermal inertia found in current large-scale generating facilities is by replacing smaller, rapid response BESS (Battery Energy Storage Systems) - tethered variously to gas turbine, solar or wind energy sources.
Automatically directing the short-term oversupply to BESS installations, and variously directing longer-term excess power from non-synchronous energy sources to BESS or H_2 production/storage facilities as needed. Even accounting for energy transfer losses, the more complete integration and manageability of base-load, intermittent, peaking, and energy storage resources would be more stable, efficient, and less prone to "disorder" than the current arrangement [8].
Additionally, the CEI serves to insulate each state from energy policy missteps by others. The situation in which one state decides to deploy predominantly intermittent energy systems while burdening another with the responsibility of delivering secure base-load power would largely need to be updated.

6. Estimated capacity, costs, timeline, and policy ramifications

The 2019-20 period Victoria consumed 101,720 GW/hrs of electric power, with 68% of that coming from base-load or industrial plants consuming coal or oil [6].
The pathway to an energy island sees these older power plants replaced with high-efficiency gas turbine installations, capable of running on natural gas initially – but transitioning to hydrogen as the local hydrogen supply chain becomes established.
Deploying this kind of technology offers many advantages:

- It can be done in a relatively short time-frame
- The capital cost per kilowatt is low
- It delivers secure base-load capacity, with far greater generating flexibility and redundancy than that found in coal fired plants [13].
- It sets a clear path to a clean fuel transition, and
- It supports the extensive deployment of renewable energy harvesting systems.

Victoria's energy island would comprise:

- 56 combined cycle gas turbine units
- 20 solar harvesting installations
    - Ten onshore wind farms;
    - Six offshore wind farms;
    - 36 tethered BESS (battery systems); and
    - 36 hydrogen electrolysers.

Initially, baseload power would be generated using LNG and blue H_2 fuel. However, subsequent stages could see the entire system transition to green H_2 - generated by tethering electrolysers to onshore and offshore wind turbines. Integrating grid-scale battery systems (BESS) into each of the solar installations.

Further, along the timeline, either BESS or tethering electrolysers to all remaining solar and wind-harvesting installations gives a centrally managed, network-wide battery storage *and* H_2 production capability.

Our design, and the resulting costings, are based on output modelling for a network capable of providing ~150% of the state's electricity demands across all the hours of an average day.

Hourly demand figures underpinning our calculations came from Government data on Victoria's annual electricity consumption, overlaid on AEMO's general demand curve for an average 24-hour period [6, 8].

The aggregate capital cost of our hypothetical CEI (Figure 3) in today's dollars would be ~$90.7 billion, or $9.07 billion per annum, plus inflation and other costs by completing the project within a decade. The annual operating costs of the completed energy island would be ~$1.9 billion.

Victoria's Hypothetical Energy Island

Installation Type	The Numbers	CapEx ($Millions)	OpEx p.a. ($Millions)	CapEx Cost per kW	Est. Years to Deploy
Gas Turbines	56	$33,969	$630	$1,500.00	2
Solar Farms	20	$5,470	$68	$1,075.00	2-3
Wind Turbine Farms - onshore	10	$5,676	$79	$1,700	3-5
Wind Turbine Farms off-shore	6	$34,727	$949	$5,430.00	4-5
BESS (batteries) 8Hr 800MW	36	$9,972	$142	N/A	2.5
H2 Electrolysers - 10MW	36	$839	$25	N/A	3.5
Totals		$90,652	$1,893		

Figure 4. Hypothetical Energy Island Costings and Deployment Times

Once fully installed, the network would have a total annual generating capacity of 153.4 TWh, with the potential to produce ~865,000 tonnes of green hydrogen per annum. This represents a further energy potential of 2.8 TW of energy.

7. The Bankability of the Connected Energy Island Concept

In 2013, the American National Renewable Energy Laboratory (NREL) released a framework for assessing projects in the renewable energy sector [14]. This work was

undertaken in recognition of the fact that many renewable energy projects are so large in scope and so potentially costly that fatal flaws in those projects need to be identified and analysed quickly and accurately to avoid the investment of scarce capital in what would prove to be losing propositions.
The NREL framework identified the key element considered before descending into any detailed technical examination of a project as its motivation.

To examine the genuineness of that motivation – and its resulting *bankability* - it suggested an interrogation of the following aspects of a project:

- Baseline Knowledge,
- Economics,
- Policy,
- Technology, and
- Consensus.

We applied this bankability framework to the energy island concept as follows:

<u>Baseline knowledge</u>

Undoubtedly, as a country, we have a good understanding of what it takes to develop and maintain a successful electricity grid, and we possess the appropriate skillsets [3]. Further, there is a growing acknowledgement that the present grid is failing – in some part at least due to the introduction of difficult-to-manage intermittent energy sources, but also as the result of a decline in base-load capacity [3, 8]

<u>Economics</u>

While energy island cost/benefit data needs to be fully explored – initial calculations based on AEMO's costing suggest the project is viable. The estimated capital cost per kilowatt for all onshore elements is broadly in line with global renewables baselines. In addition, in terms of the financial impact on the economy, data from the Australian Treasury, the Australian Bureau of Statistics, and IMF, suggest such infrastructural investments in Australia have a positive multiplier effect on GDP of ~1.3 times that of the investment [15] - a 30% positive economic "return".

<u>Policy</u>

Given the nation's widely known commitment to action on climate change, this is unlikely to be an impediment to the commencement and continuation of a connected energy island program.

<u>Technology</u>

Each of the building blocks in the proposed island's network is widely employed around the world, and well proven.

<u>Consensus</u>

Even if there is often disagreement on exactly how or how fast to do it, there can be little argument that there is general support among policy makers, scientists, and the public for the need to move away from our dependence on fossil fuels.

Based on this, the authors believe that the concept of the CEI is indeed bankable.

8. Discussion

Because replacing the current state power grid with a CEI involves significant expenditure, local, state, and federal governments, energy companies and private investors would likely jointly fund the program. Beyond that however, the authors believe there may be need for some adjustments to government policy, to speed its deployment.

Specifically, these policies would involve:

1. Removing royalties on coal and natural gas where usage is as feedstock for the production of H_2 and H_2 based fuels – in conjunction with carbon capture practices.
2. Taking steps to encourage the establishment of a local, large-scale solar panel manufacturing facility – modeled on the successful, smaller plant currently operating in South Australia.
3. Expanding the building code to specify that constructing all new residential and commercial buildings to include solar panel and battery storage capacity deemed appropriate to deliver a level of self-sufficiency in the event of grid stress [3].

Given the very substantial investment that must inevitably be made in harvesting solar energy, the authors believe that adoption of the CEI concept can deliver to Victoria the opportunity to at once as follows:

- Cement its place as a centre of expertise and manufacturer of the necessary enabling technologies,
- Increase the State's manufacturing base, and
- Create a secure supply chain for these key products.

9 Conclusions

Despite the insistence of various influential individuals and organisations that developed countries around the globe should eliminate fossil fuel use, we must face the reality that our current suite of technologies is not up to the task.
When applied to current terrestrial energy harvesting techniques, the laws of physics dictate that "pound for pound", solar and wind harvesting technologies must always deliver many orders of magnitude less energy than our current hydrocarbon or

nuclear energy sources. In everyday terms, attempting to run an entire economy solely on today's renewable platforms is similar to trying to smelt steel with candles.

Further compounding the challenge of eliminating the use of naturally occurring hydrocarbons is that some 99% of all manufactured products rely on them as feedstock rather than fuel. Hydrocarbons are the essential and currently irreplaceable raw material enabling the production of practically all our plastics, lubricants, adhesives and fertilisers. These are fundamental to producing the bulk of our food … and manufacturing virtually every product or service, we take for granted.

None of the aforementioned means we should abandon our attempts to walk more gently on the planet we all share. However, the steps we take regarding climate action must be carefully calculated and considered. Governments must be aware of the potentially huge financial and human cost that rushed, poorly thought-out climate-centric decisions can impose on their citizens for future generations.

References

[1] H. Rittel and M. Webber, "Dilemmas in a General Theory of Planning," 1973. [Online]. Available: https://www.jstor.org/stable/4531523.

[2] Center for International Environmental Law, "FOSSIL FUELS & PLASTIC," 2022. [Online]. Available: https://www.ciel.org/issue/fossil-fuels-plastic/.

[3] U. O. Melbourne, "How to make net zero happen Mobilisation report July 2023," 2023. [Online]. Available: https://www.netzeroaustralia.net.au/wp-content/uploads/2023/07/Net-Zero-Australia-Mobilisation-How-to-make-net-zero-happen-12-July-23.pdf.

[4] M. Wappler, D. Unguder, X. Lu, H. Ohlmeyer, H. Teschke, and W. Lueke, "Building the green hydrogen market – Current state and outlook on green hydrogen demand and electrolyzer manufacturing," *International Journal of Hydrogen Energy,* vol. 47, no. 79, pp. 33551-33570, 2022, doi: 10.1016/j.ijhydene.2022.07.253.

[5] O. Ono, "FLEXIBILITY IS CRUCIAL FOR A SUSTAINABLE ENERGY TRANSITION," 2022. [Online]. Available: https://asian-power.com/solution-center/flexibility-crucial-sustainable-energy-transition

[6] S. Department of Industry, Energy and Resources, "Australian Energy Update 2021," 2021. [Online]. Available: https://www.energy.gov.au/publications/australian-energy-update-2021.

[7] E. Australian Government Department of Climate Change, the Environment and Water, "Australian Energy Update 2022," 2022.

[8] AEMO, "AEMO observations: Operational and market challenges to reliability and security in the NEM," 2018. [Online]. Available:

https://www.aemc.gov.au/sites/default/files/2018-03/AEMO%20-%20received%2020%20March%202018.pdf.

[9] P. Hannam, "Australia's energy crisis explained: from price caps to the suspension of electricity trading," 2022. [Online]. Available: https://www.theguardian.com/australia-news/2022/jun/15/australias-energy-crisis-explained-from-price-caps-to-the-suspension-of-electricity-trading.

[10] AEMO, Aurecon, and P. Halder, "2020 Costs and Technical Parameter Review, Reference 510177," 2020. [Online]. Available: https://aemo.com.au/-/media/files/major-publications/isp/2022-forecasting-assumptions-update/2021-cost-and-technical-parameters-review_rev3-21-march-2022.pdf?la=en.

[11] R. Tuffield, "Failure of immense dimension': Victorian academics call for action on climate change, news.com.au," 2021. [Online]. Available: https://www.news.com.au/technology/environment/climate-change/failure-of-immense-dimesion-victorian-academics-call-for-action-on-climate-change/news-story/b410a122670016175d4f3c0433f55ff7.

[12] HESC, "HESC - Hydrogen Energy Supply Chain Project," 2022. [Online]. Available: https://www.hydrogenenergysupplychain.com/about-hesc/

[13] Gonzalez-Salazara, K. T, and P. L, "Review of the operational flexibility and emissions of gas- and coal-fired power plants in a future with growing renewables, Renewable and Sustainable Energy Review, Volume 82 1st July 2017," 2017.

[14] R. Springer, "A Framework for Project Development in the Renewable Energy Sector," 2013. [Online]. Available: https://www.nrel.gov/docs/fy13osti/57963.pdf .

[15] D. Gruen, "The Return of Fiscal Policy," 2009. [Online]. Available: https://treasury.gov.au/speech/the-return-of-fiscal-policy.