Decarbonising the Australian economy: A first step

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REVIEW

Decarbonising the Australian economy: A first step

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Abstract

Amidst mounting global pressure, governments worldwide have embarked on a collective journey towards decarbonising their economies within the next 30 years. This ambitious goal necessitates the phasing out of naturally occurring hydrocarbons such as coal, natural gas, and oil. However, our analysis of data from academic papers, Australian Federal Government publications, and reports from energy industry bodies and manufacturers of electricity-generating equipment suggests that such a complete elimination of fossil fuel use is not feasible. The data we've gathered, however, indicate that transitioning to a connected energy island power generation topology could at least create a sustainably robust energy supply capable of propelling Australia towards its environmental targets while bolstering its future economic well-being.

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 complex 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]. Because of that, to entirely decouple our global economy from fossil fuel-based products may be impossible, or at least improbable for the foreseeable future. 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 moving us closer to our climate action end game. In this way, we can keep one eye on the future while doing our best with what we have right now [5].

2 | HYPOTHESIS

To make any meaningful progress toward achieving our various short and long-term environmental goals, we must also 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. However, even restricting our thinking to reducing our fossil fuel use in power generation, delivering a more sustainable, affordable and reliable electricity supply can only be accomplished by implementing a suite of transition-enabling, baseload, and intermittent energy technologies. Even then, this can only succeed if all the elements are combined in a well-planned, flexible, managed network topology, such as the connected energy island (CEI) concept.

3 | THE SITUATION

As can be seen in Figure 1, electricity generation contributes significantly to satisfying Australia's overall energy appetite. That power is generated 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%.

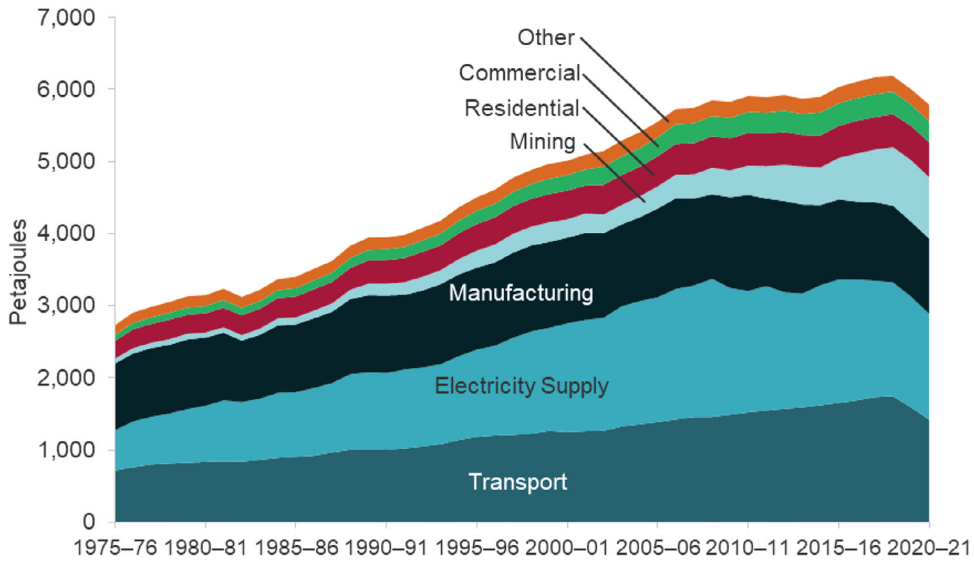

FIGURE 1 Australian energy consumption by sectors [7].

Those states lying on the eastern seaboard share electric power via a standard electricity grid; however, establishing electric power as a shared resource has proven to be both a blessing and a curse. On the plus side, it has allowed any state with excess generating capacity to sell its extra power to another in need—but it has also seen some states skimp on their own investments in power generation, resulting in their ever-increasing reliance on large-scale electricity generators elsewhere in the country.

Meanwhile, most of the coal-fired current generators—the ones being relied on ever more heavily—are ageing and breaking down more often. Without 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].

Considering these events, the critical questions asked of governments are:

- What technology can add reliable, 24×7, 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 a special class of essential services, 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]. Looking across all industry sectors—not just electricity generation—the total energy needed to run our economy without fossil fuels would require us to sustainably generate the equivalent of 1,555 TWh of electrical energy annually. That national hunger for energy dwarfs our total electricity output, which now stands at just ~265 TWh.

Determining the cost of bridging the whole-of-economy energy gap (between 265 and 1,555 TWh) has proven to be both a challenging and contentious exercise. Indeed, even the transition of the current power grid alone has not been without controversy [10].

In terms of a whole-of-economy net-zero transition exercise, figures from the nation's energy market operator (AEMO) put the cost of renewables at ~$2.3 trillion for the purchase of offshore wind turbines, ~$0.86 trillion for solar panels, or $0.82 trillion for land-based wind turbines.

Importantly, however, the market operator's charter precludes it from considering any potentially substantial ancillary costs such as transmission line or infrastructure upgrades, large-scale land acquisition, the opportunity cost of forced acquisition of productive farmland, or any other ongoing operational and maintenance activities. In the absence of official data regarding these key costs, they remain significant unknowns in any determination of the likely overall impost of net-zero transition on Australia's $1.98 trillion economy.

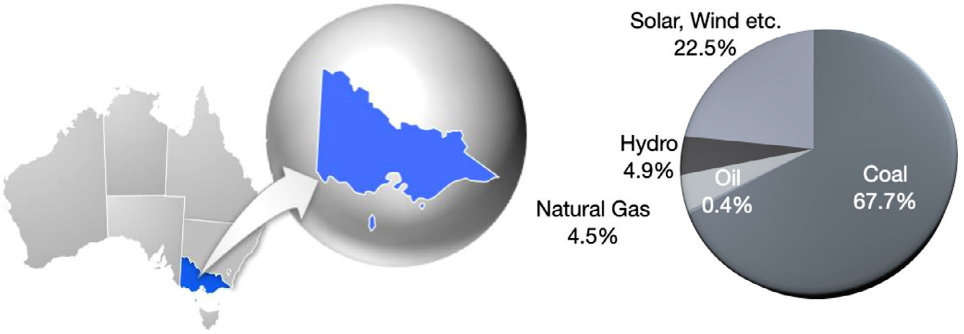

FIGURE 2 The breakdown of fossil fuel-fired and renewable electricity generation in Victoria.

Even restricting the focus to just implementing renewables in the existing power grid, we can see substantial variability in cost estimates over time. According to the Commonwealth Scientific and Industrial Research Organisation (CSIRO) [11], whereas the estimated cost of transitioning power generation was estimated to be ∼\$1.0 trillion in 2017, the researchers now believe that—despite the ongoing upward inflationary pressure on costs—the likely price tag has fallen to half a trillion dollars: a still substantial number. Importantly, the CSIRO's figures also do not consider any ancillary costs.

Despite our attempts to present a simplified view of the potential cost of decarbonisation, the sheer scale of this endeavour, substantial set of unknowns, and variability in capital cost estimates between expert bodies all conspire to cast doubt over the veracity of recent claims that Australia can move away from its reliance on fossil fuels in just a few years, and with the affordable expenditure of a few tens or even hundreds of billions of dollars [3, 11].

With that in mind, 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 just ∼10% of Australia's fossil fuel usage but is critical in ensuring the country's future prosperity by literally keeping the economic lights on.

We propose using a connected energy island topology to maximise the utility of existing infrastructure, apply new technologies to "firm up" weather-dependent generation systems, and better control the cost of transition in real terms.

5 | EXPLORING THE CONNECTED ENERGY ISLAND CONCEPT: A VICTORIAN HYPOTHETICAL

The authors have selected Victoria as the target for their hypothetical CEI rollout for several reasons.

From a logistics perspective, Victoria is one of Australia's most geographically compact states, making installing and servicing grid-scale electrical infrastructure less time-consuming and costly. Further, regarding electricity generation, Victoria is Australia's second most coal-reliant state (∼68%), making it a key transition point in the move to renewable energy generation. But as shown in Figure 2, it generates a substantial input from renewables, totalling ∼27% of its power [3, 6]. That means the state already supports a skills base in renewables technologies, and as a result, implementing a renewables-centric CEI topology should be quicker and easier than if those skills had to be brought in or developed from scratch.

Another factor in the state's qualification as the ideal test bed is the presence of 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]. This project enjoys the full support of the local governing body, which sees its development as the first step along a path toward greater employment opportunities for its constituents.

Access to a full-scale H_2 production facility is also key to the longer-term implementation of our vision for Victoria's CEI.

Lastly, regarding factors contributing positively to the financial viability of a distributed grid system, such as the CEI, a report by the Victorian Essential Services Commission identified the rollout of advanced metering infrastructure throughout the state as a billing technology already in place. The commission sees this as an enabling platform, supporting a market for new grid services unavailable in other jurisdictions. [20]

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

- The state's compactness makes establishing a distributed grid system logistically easier.
- The reliance on coal makes it a logical transition point to renewables.
- There is an existing skills base in renewable technologies.
- There is the promise of virtually unlimited H_2 fuel availability nearby.
- Sites are available that deliver easy access to the current central grid infrastructure.
- A local government and community favourably disposed to such a development.
- The state's existing advanced metering infrastructure can support the remuneration of smaller distributed generators, which is a feature of the CEI concept.

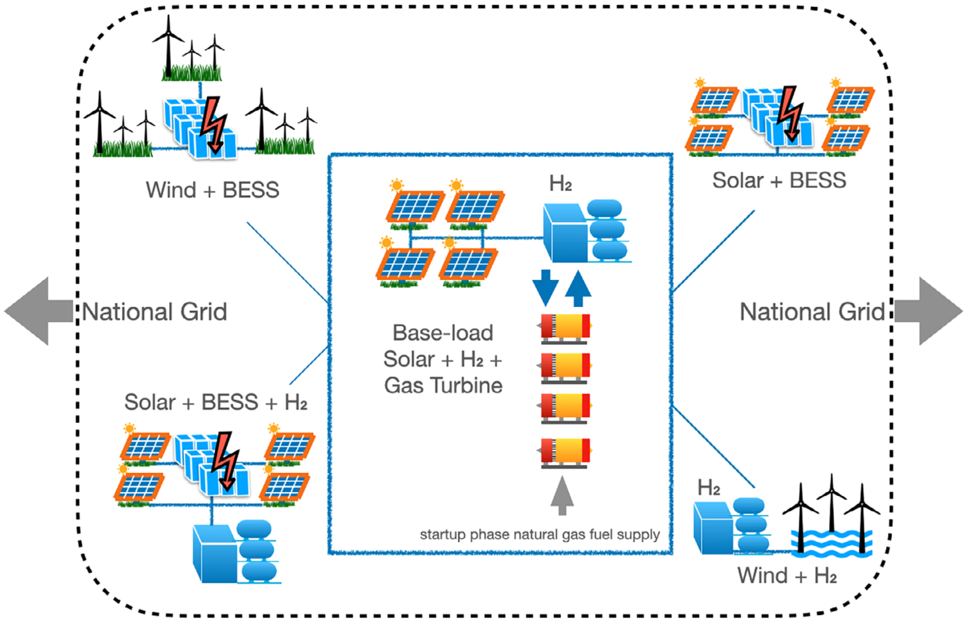

FIGURE 3 The topology of Victoria's hypothetical connected energy island.

As shown in Figure 3, a CEI employs a flexible "building block" approach that can support various network topologies. This allows designers to maximise the benefits of their existing grid layouts.

In Victoria, that means co-locating the bulk of new base-load generating capacity with soon-to-be-retired coal-fired plants.

Apart from taking a share of the energy fed into the national grid from the nation's hydroelectric 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.

Significantly, in the CEI, the absence of the kinds of kinetic or thermal inertia found in current large-scale generating facilities is achieved by replacing these with smaller, rapid-response BESS (battery energy storage systems) tethered variously to gas turbine, solar, or wind energy sources.

The system automatically directs any short-term oversupply to BESS installations and can direct 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 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]. The CEI topology and integrated management systems virtually eliminate "spilled" power—elevating weather-dependent energy harvesting installations to the category of more productive "firm" grid contributors.

Additionally, the CEI insulates each state from other states' energy policy missteps—for instance, when one state decides to deploy predominantly intermittent energy systems, thus burdening others with the responsibility and capital cost of delivering more than their fair share of the overall secure base-load power.

Lastly, it should be noted that the building block nature of the CEI model is entirely technology agnostic—allowing for virtually any power-generating system to be incorporated into the managed network. So, whether in response to population growth or the retirement of older generating plants, new technologies—ranging from the latest compressed air/hydrogen hybrid storage systems to small modular nuclear power plants—can be accommodated by the CEI model. This essentially "future-proofs" a power network allowing governments to at once squeeze the maximum value from every dollar invested—while continuing to honour their various climate commitments.

6 | ESTIMATED CAPACITY, COSTS, TIMELINE, AND POLICY RAMIFICATIONS

In 2019–2020, Victoria consumed 101,720 GW/h 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, initially capable of running on natural gas 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,

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.

➢ It delivers secure base-load capacity with far greater generating flexibility and redundancy than 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 hypothetical 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, base-load power would be generated using LNG and blue H_2 fuel. However, subsequent stages would see the entire system transition to green H_2, generated by tethering electrolysers to onshore and offshore wind turbines. Grid-scale battery systems (BESS) would be integrated into each solar installation.

Further, along the timeline, either BESS or tethering electrolysers to all remaining solar and wind-harvesting installations provide 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 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-h period [6, 8].

The aggregate capital cost of our hypothetical CEI (Figure 4) 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 expenses of the completed energy island would be ~$1.9 billion.

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

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 investing scarce capital in what would prove to be losing propositions.

The NREL's framework—BEPTC—identified the key elements to be 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—NREL 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:

7.1 | Baseline knowledge

As a country, we understand what it takes to develop and maintain a successful electricity grid, and we possess the appropriate skill sets to do so [3]. Further, there is a growing acknowledgment 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]

In terms of evaluating Victoria's selection as the site for establishing our hypothetical CEI system, the state possesses the requisite deep baseline knowledge in every discipline required to successfully implement the CEI model.

Specifically, it has long-held grid-scale electricity generation and management experience, a physically robust pre-existing power infrastructure, substantial traditional energy generation skills, and broad renewables expertise.

7.2 | Economics

While energy island cost/benefit data are yet 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 aligns 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."

7.3 | Policy

Given the nation's widely known commitment to action on climate change and the CEI's ability to incorporate both existing and emerging technologies into its energy mix, no government policy or change in direction is likely to impede the commencement and continuation of a connected energy island program.

7.4 | Technology

Each building block in the proposed energy island's network is widely employed worldwide and well-proven. Incorporating only proven technologies into the CEI assures the network's stable operation.

7.5 | Consensus

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 policymakers, 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 expenditures, local, state, and federal governments, energy companies, and private investors would likely fund the program jointly. Beyond that, however, the authors believe some adjustments to government policy may be needed to speed its deployment.

Specifically, these policies would involve:

1. Removing royalties on coal and natural gas where usage is as feedstock for producing 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—modelled on the successful, smaller plant currently operating in South Australia.
3. Expanding the building code to specify that all new residential and commercial buildings must include solar panels and battery storage capacity to deliver self-sufficiency during 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 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 critical 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 consistently 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 like smelting 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 fertilizers. These are fundamental to producing the bulk of our food … and manufacturing virtually every product or service we take for granted.

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

AUTHOR CONTRIBUTIONS

Akhtar Kalam: Project administration; resources; supervision; writing—review and editing. **Warren Weeks**: Conceptualization; investigation; validation; writing—original draft. **Brad Hogan**: Funding acquisition; software; writing—review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data derived from public domain resources.

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