Impact of Energy-related Uncertainties and Climate Policies on Australia's Energy Transition

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Abstract

This study investigates the impact of energy-related uncertainty, oil market shocks, climate vulnerability, and policy uncertainty on the energy transition (ET) in Australia, using data from 1990 to 2020. Dynamic Autoregressive Distributed Lag (ARDL) simulation model is employed for the analysis. The long-run results reveal that energy-related uncertainty negatively affects ET, while oil supply shocks and aggregate demand shocks positively drive the transition. However, climate policy uncertainty poses a significant barrier to ET progress over the long term. In the short run, energy-related uncertainty and aggregate demand shocks positively influence ET, whereas oil prices negatively affect it. Climate vulnerability, however, has an insignificant impact in the short term. These findings suggest that energy-related factors play a more critical role in shaping ET in Australia both in the short and long term compared to climate change considerations.

Keywords: Oil supply shock; aggregate demand shock; Oil price shock; Economic uncertainty; Climate vulnerability; Renewable energy

1. Introduction

The intersection of two key challenges looms large in the contemporary energy landscape: the inherent uncertainty induced by oil shocks characterizing the energy market and the concurrent transition to renewable resources as a pivotal strategy to attain zero-emission targets (Hafner & Tagliapietra, 2020). Addressing energy market uncertainty is essential to providing a stable environment for renewable energy investments. Simultaneously, the transition to renewables offers the potential to reduce the long-term uncertainties associated with fossil fuel dependence (Krane & Idel, 2021; Pfenninger et al., 2014). The impact of oil market uncertainty on the global economy has been a significant concern since the 1970s, prompting extensive research into the macroeconomic repercussions of fluctuations in oil prices. The oil market exhibits significant price uncertainty, which can be attributed to various factors, including geopolitical conflicts, disruptions in supply, and changes in global demand (Kilian, 2009). The fluctuation in prices can substantially affect energy costs for consumers and businesses, thereby posing difficulties in effectively strategizing and allocating funds for energy expenditures (Byrnes, 2013).

Though a voluminous body of literature has evolved investigating the bearings of oil prices for macroeconomic performance and policies e.g., to name a few, (Barsky & Kilian, 2002; Hamilton et al., 2008; Kilian, 2008), examining the adaptation strategies of various economies to oil market dynamics is a relatively less ventured area of oil research. The transition from nonrenewable to renewable energy can be regarded as an adaptation strategy driven by oil market dynamics. The presence of uncertainty in oil markets is a crucial factor to consider when examining the necessity of an energy transition (Esmaeili et al., 2024). An energy transition is also imperative for addressing pressing environmental concerns. Fossil fuels, which have served as the primary sources of energy for decades, release greenhouse gases when burned, contributing significantly to climate change. The demand for oil can be influenced by the uncertainty surrounding future climate policies and regulations (Goulder & Parry, 2008). As an increasing number of nations pledge to decrease their greenhouse gas emissions, the regulatory framework becomes more uncertain, thereby affecting investment choices within the oil industry and exerting an influence on the worldwide shift towards sustainable energy (Masini & Menichetti, 2013). The adoption of low-carbon energy sources can assist businesses and governments in effectively navigating the current policy landscape characterized by uncertainty (Uyarra et al., 2016).

Oil market dynamics are multifaceted and may induce varying responses with respect to the energy policies of the countries. For instance, higher levels of oil prices may induce oil-exporting countries to invest more in the traditional energy sector, hampering energy diversification (Dubash & Florini, 2011; Karanfil & Omgba, 2023). On the other hand, oil prices may play a crucial role in shaping the energy transition, with higher prices stimulating exploration and investment in alternative energy sources (Fouquet, 2016). It is argued that one of the factors contributing to the growing appeal of renewable energy to lessen reliance on oil is the unpredictability of oil prices.

Although there is a lot of discourse in favor of clean energy, technologies, policies, and investments in supportive infrastructure are still in the early stages (Sen & Ganguly, 2017). In this transition process, climate policies and financial development play a key role.

Since the theoretical works of (Friedman, 1968) and (Bernanke, 1983), economic analysis has focused a significant amount of attention on the study of uncertainty in the state of the economy. Recent research, such as that published by (Brogaard & Detzel, 2015; Julio & Yook, 2012) and (Handley & Limao, 2015), provides evidence that uncertainty in macroeconomic aggregate variables has a negative impact on economic growth and investment. However, some studies concentrate on the economic effects of uncertainty in the energy market. According to the research conducted by (Balcilar et al., 2019; Bernanke, 1983; Pindyck, 1993, 1999), one of the effects of uncertainty relates to fluctuations in energy prices, which can lead to uncertainty regarding the path of energy prices in the future.

Literature on the energy transition has recently emerged, and existing studies can be divided into three strands. One which discusses the impact of uncertainty induced by oil price shocks and its impact on energy transition (Balcilar et al., 2019; Murshed et al., 2021); The second strand of literature examines the role of environmental, fiscal, and monetary policies on energy transition (Campiglio, 2016; Chen et al., 2019; Hu et al., 2022; Tol, 2023; Wang et al., 2023) and the third strand of literature discourses the role of financial and technological development on energy transition (Alariqi et al., 2023; Bai & Lin, 2023; Irfan et al., 2023; Yang et al., 2024). However, one might consider that the system is absorbing the uncertainty induced by oil shocks due to the strength of the financial system, especially in developed countries. This would allow countries to shift towards other immediately available non-renewable energy resources, such as coal and gas, and even enable them to purchase oil at higher prices, which would disentangle the effect on the energy transition. On the other hand, it can appear that strict environmental policies and concerns may make it difficult for countries to switch to other resources, preventing the effect of energy transition from being disentangled.

Building on the three strands of opinion discussed, this study adds to the existing literature by exploring the impact of energy-related uncertainty, oil market shocks, climate vulnerability, and policy uncertainty on the energy transition (ET) in Australia. Australia's heavy reliance on fossil fuels, heightened exposure to energy-related and climate vulnerabilities, and active policy debates surrounding its energy transition make it a compelling case for examining how various uncertainties and shocks influence the shift toward sustainable energy pathways.

2. Research Method

As discussed earlier, the study's objectives pertain to measuring the responsiveness of energy transition towards the uncertainty, energy market and climate dynamics in Australia. Accordingly, the general form of the study's model is given in Equation 1:

$$eti_t = f(eui_t, op_t, os_t, ad_t, cvi_t, cpu_t) \quad (1)$$

Where eui represents the comprehensive energy transition index, eui is energy-related uncertainty, op is oil-specific demand measured by real oil prices, os is oil supply, and ad is oil demand measured by world economic activity, cvi is climate vulnerability index, and cpu is climate policy uncertainty.

However, following (Kilian, 2009) our empirical approach considers all three types of oil market shocks: oil price shock, oil supply shock, and aggregate demand shock as the major indicators of energy market dynamics. Along with this, energy-related uncertainty is also considered an important indicator of energy market dynamics. Therefore,

$$EMD = [eui, op, os, ad] \quad (2)$$

EMD represents energy market dynamics.

Whereas, climate vulnerability index and climate policy uncertainty are considered important indicators to measure climate dynamics. Therefore,

$$CD = [cvi, cpu] \quad (03)$$

CD represents climate dynamics.

Consequently, the empirical form of the model given in Equation 1 takes the following form:

$$eti_t = \alpha_0 + \alpha_1 eui_t + \alpha_2 op_t + \alpha_3 os_t + \alpha_4 ad_t + \alpha_5 cvi_t + \alpha_6 cpu_t + \gamma_t \quad (04)$$

All the variables included in the model are pertinent to examine the responsiveness of energy transition towards energy-market dynamics and climate dynamics, such that, oil prices play a significant role in shaping the energy transition process through various channels. The volatility of oil prices can have both positive and negative effects on investment decisions and the competitiveness of renewable energy sources. For instance, when oil prices are low, non-renewable energy sources may become more economically appealing and cost-effective, impeding the adoption of renewable energy. Conversely, high oil prices can incentivize investments in renewable energy compared to conventional energy sources. However, during periods of low oil prices, there may be decreased investment in renewable energy projects due to the perceived cost competitiveness of traditional energy sources (Murshed et al., 2021).

Similarly, oil supply disruptions can impact the energy transition process in both positive and negative ways. These disruptions can lead to fluctuations in oil prices, wherein an increase in oil supply has the potential to lower prices, thus potentially impeding investments in renewable

energy sources (Boer et al., 2023). Nonetheless, abrupt oil supply shocks resulting from geopolitical tensions or natural disasters may prompt policy responses aimed at enhancing energy security by reducing reliance on oil imports and encouraging advancements in the energy transition. The effects of such shocks are also contingent upon factors such as sustained policy efforts and technological advancements (Özkan et al., 2024).

Moreover, effectively managing aggregate demand, fostering energy efficiency, and expediting the uptake of renewable energy technologies are pivotal strategies in realizing a sustainable energy transition and mitigating worldwide environmental issues. Therefore, this study intends to examine the impact of aggregate demand on the energy transition process. Changes in the aggregate demand can positively influence the energy transition process. Heightened aggregate demand can stimulate investments and advancement in renewable energy technologies. Additionally, higher aggregate demand spurs greater oil demand, leading to increased prices, thereby potentially expediting the shift toward sustainable energy sources. However, aggregate demand can also hinder the energy transition through the lock-in effect, as highlighted by (Pieroni, 2023)

According to (Balcilar et al., 2019), different types of uncertainties have strong time-varying effects on the energy transition process. Both, climate policy uncertainty, and energy-related uncertainty exert a negative impact on the energy transition process Energy related uncertainty referring to varying energy policies, market dynamics, and technological advancements can hinder investments in renewable energy projects and infrastructure. Additionally, geopolitical tensions, conflicts, or trade disputes can also destabilize the global energy markets, impacting the accessibility and cost of energy resources and impeding the energy transition process. Similarly, increased uncertainty in climate policies can influence firms' investment decisions, potentially leading to delays or insufficient investment in renewable energy projects. This is often exacerbated by firms' susceptibility to financing constraints, which can magnify their response to fluctuations in climate policies. Contrary to this, fluctuations in climate policy could prompt a shift in the energy structure, resulting in greater adoption of renewable energy sources (for example, as discussed by (Liang et al., 2022) and (Wakiyama & Zusman, 2021) also propose that the enactment of climate-oriented policies leads to significant advancements in renewable energy utilization and reductions in greenhouse gas emissions. Moreover, climate vulnerability also impedes the energy transition process by exacerbating energy security risks and affecting technological advancement.

Data and Variables

The data spans from 1990 to 2020, with detailed information presented in Table 1. Additionally, Table 2 provides the descriptive statistics for the variables analyzed in this study.

Table 1: Data and Variable Transformation		
Variable Name	**Variable Description**	**Data Source**
Eti	Comprehensive Energy Transition Index	Hu et al., 2022
Eui	Energy-related Uncertainty Index	Dang, et al., (2023)
Op	Oil price	International Energy Agency Review, March 2022, and Kilian (2019) index
Os	Oil Supply	
Ad	Aggregate economic activity	
Cvi	Climate Vulnerability Index	Wen at al., (2020)
Cpu	Climate Policy Uncertainty	Gavriilidis, K. (2021)

Table 2: Descriptive Statistics				
Variable Name	**Mean**	**SD**	**Min**	**Max**
Eti	0.17	0.10	0.02	0.38
Eui	23.34	5.49	13.36	37.23
Op	313.08	202.00	79.97	702.38
Os	83.12	10.54	66.79	100.5
Ad	1.84	56.16	-90.08	144.024
Cvi	0.32	0.011	0.30	0.33
Cpu	94.41	40.87	34.92	218.63
Source: Authors own tabulation				

Econometric Approach

To analyze the measure of the responsiveness of energy transition towards energy market dynamics and climate dynamics in Australia, this study applies the novel Dynamic Autoregressive Distributed Lag Simulations model (DARDL), on the time series data from the year 1990 to 2020.

The novel dynamic ARDL simulations model developed by (Jordan & Philips, 2018) is highly effective for examining cointegration as well as long-run and short-run equilibrium relationships in both levels and differences. The dynamic ARDL representation of the above model (equation 04) is given as follows:

$$\Delta eti_t = \rho_0 + \rho_1 eti_{t-1} + \rho_2 \Delta eui_t + \rho_3 eui_{t-1} + \rho_4 \Delta op_t + \rho_5 op_{t-1} + \rho_6 \Delta os_t + \rho_7 os_{t-1} + \rho_8 \Delta ad_t + \rho_9 ad_{t-1} + \rho_{10} \Delta cvi_t + \rho_{11} cvi_{t-1} + \rho_{12} \Delta cpu_t + \rho_{13} cpu_{t-1} + \rho_{10} ECT_{t-1} + \Gamma_t$$

3. Results and Discussion

Unit Root Test

For a novel Dynamic ARDL simulations model, the dependent variable must be stationary at the first difference, or I(1). Meanwhile, the independent variables (regressors) can be stationary either at levels, I(0), or at the first difference, I(1)**.** A unit root test was conducted to assess the stationarity and determine the order of integration of the variables. The results are reported in Table 3 which indicates that all variables are I(1).

Table 3: Unit Root Tests

Variables	**ADF test**		
	T-statistic		
	Level	**Difference**	**Conclusion**
Eti	-1.35	-12.76***	I(1)
Eui	-0.14	-7.45***	I(1)
Op	-0.58	-4.53***	I(1)
Os	2.38	-2.62**	I(1)
Ad	-1.84	2.41**	I(1)
Cvi	-0.73	-9.36***	I(1)
Cpu	1.60	-6.50***	I(1)
Source: Authors own calculation			

Dynamic ARDL Simulation Model

Pertaining to the objectives of the study, Table 4 explains the results of the dynamic ARDL simulation models. The results show that the value of ECT is negative and significant, exhibiting convergence to equilibrium. Moreover, the results show that the energy-related uncertainty index has a long-term negative impact on energy transition, such that, a one percent increase in the energy-related uncertainty brings about a decrease of 0.27% in the process of the energy transition, whereas, during the short run, energy-related uncertainty index positively and significantly affects the energy transition process i.e. one percent increase in the energy-

related uncertainty favorably bring about an increase of 0.19% in the energy transition process. However, oil prices in the long run exhibit a weak and insignificant impact on the energy transition process, and during the short run, it negatively and significantly but not to a large extent influence the energy transition process in Australia.

Moreover, oil supply positively and significantly affects the energy transition process during the long run, but negatively and insignificantly during the short run. In the long run, one percent increase in the oil supply brings about 0.012% increase in the energy transition process, whereas, in the short run, one percent increase in the oil supply brings about 0.0045% decline in the energy transition process. This shows that during the long run, higher oil prices facilitate the energy transition process in Australia. Otherwise, aggregate demand positively and significantly affects the energy transition process during the long run and short run. In the long run, a one percent increase in the aggregate demand brings about a 0.0010% increase in the energy transition process, whereas, in the short run, a one percent increase in the aggregate demand brings about a 0.0006% increase in the energy transition process. The positive impact shows that heightened aggregate demand could incentivize investments in renewable energy technologies and other climate change adaptations, thereby fostering the energy transition (Maradin et al., 2017).

However, among the indicators of climate dynamics, the climate vulnerability index negatively albeit insignificantly affects the energy transition process both during the long run and short run, pointing out less responsiveness of the climate vulnerability index towards the energy transition process. Similarly, climate policy uncertainty negatively and significantly affects the energy transition process during the long run, such that, a one percent increase in climate policy uncertainty brings about a decrease of 0.12% in the transition towards renewable energy. But during the short run, climate policy uncertainty negatively and insignificantly affects the energy transition process. Overall, it can be concluded that energy transition is more responsive towards the energy market dynamics and less responsive towards climate dynamics. However, the results are further authenticated through the counterfactual analysis of the model presented in Figure 1.

Table 04: Response of ET to Energy Market Dynamics and Climate Dynamics					
Model: $eti_t = \alpha_0 + \alpha_1 eui_t + \alpha_2 op_t + \alpha_3 os_t + \alpha_4 ad_t + \alpha_5 cvi_t + \alpha_6 cpu_t + \gamma_t$					
Variables	**Coefficients**				
ECT	-1.766*** (0.18)				
	Long run Results			**Short run Results**	
Eui	-0.27*** (0.05)			0.19** (0.05)	
Op	-0.0001 (0.00009)			-0.0002** (0.0001)	
Os	0.012*** (0.002)			-0.0045 (0.006)	
Ad	0.0010*** (0.0002)			0.0006* (0.0003)	
Cvi	-1.76 (2.451)			-1.15 (1.70)	
Cpu	-0.12** (0.046)			-0.07 (0.05)	
F-stat	10.30***			no. of obs	30
F-stat bound	I (0)	I (1)	cointegration	Root MSE	0.04
	2.82	4.80			
R^2	0.90			Adj R^2	0.80
Source: Authors' own tabulation of results obtained from dynamic ARDL model					

Figure 1: Response of ETI to Energy Market Dynamics and Climate Dynamics

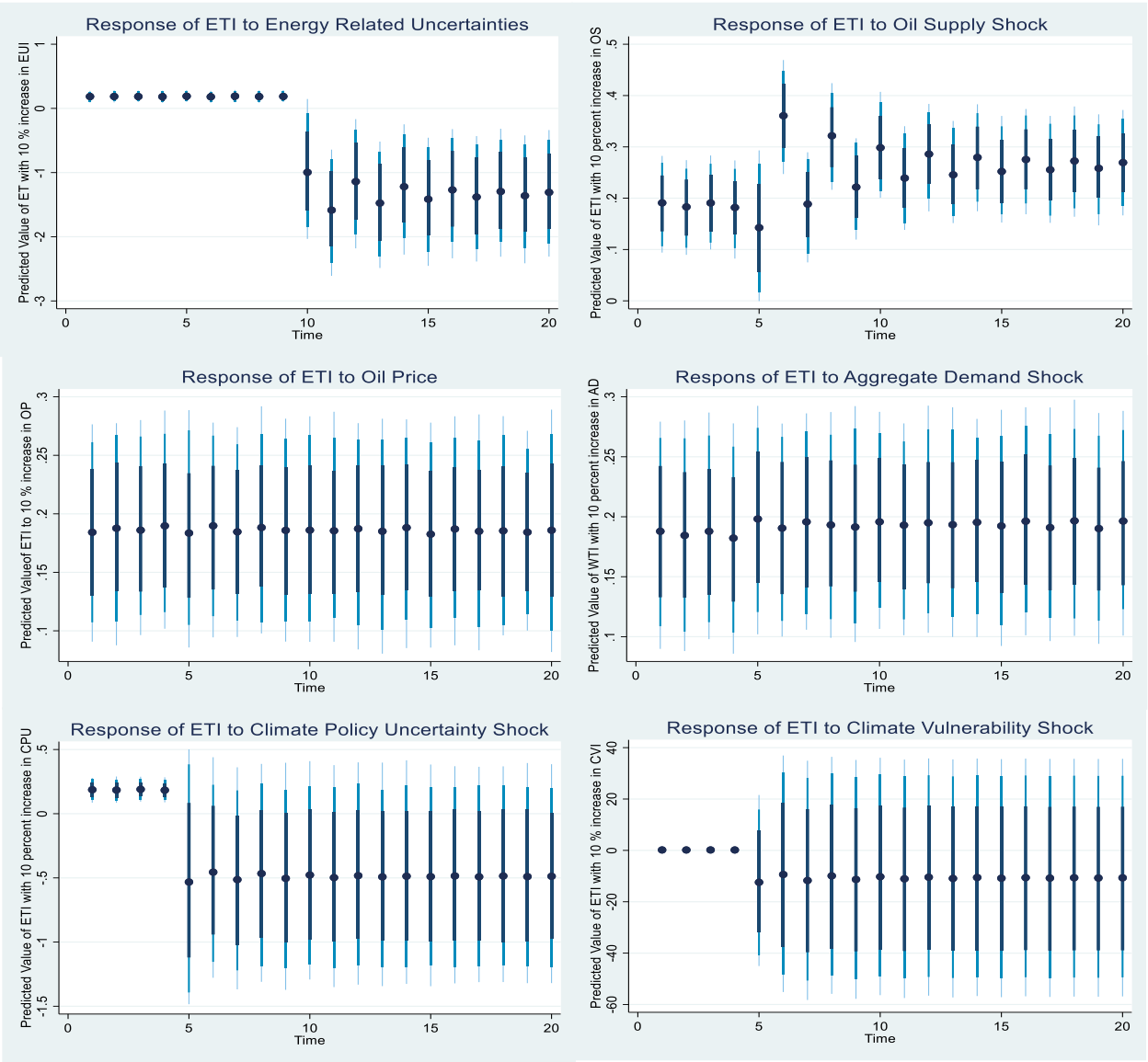


Figure 01 portrays the results of dynamic ARDL post-estimation simulations when a positive 10% counterfactual shock is given to different indicators of energy market dynamics and climate dynamics at the time (t)=5. The first graph shows that a positive 10% counterfactual shock given to energy-related uncertainties positively influences the energy transition index during the short run but then declines to a predicted value of about -1% at t=5, and then manifests a mixed trend in the long run. The second graph illustrates the response of energy transition index to one of the major energy market dynamics i.e. oil supply shock. The counterfactual analysis shows that a positive 10% counterfactual shock to oil supply shock shows an increasing trend in the process of energy transition during the short run but then declines to a predicted value of about 0.13% at t=5, afterwards the energy transition process becomes uncertain due to oscillations as shown in the graph over the long run. Whereas, a positive 10% counterfactual shock given to oil prices allows the energy transition index to follow an increasing trend during the short run but then slightly declines to a predicted value of about 0.18% at t=5, thereafter, sustaining the steady trend over the long run.

The response of the comprehensive energy transition index to aggregate demand shock shows that the process of energy transition firstly follows the declining trend during the short run but then eventually increases to a predicted value of about 0.2% at t=5, and then sustains the steady trend over the long run. Similarly, the responsiveness of the energy transition index to climate policy uncertainty shows that a positive 10% counterfactual shock to climate policy uncertainty brings about a significant increase in the energy transition process during the short run, eventually declining to a predicted value of about -0.5% at t=5 and then following the steady trend during the long run. However, the last graph of Figure 01 shows that a positive 10% counterfactual shock given to the climate vulnerability index allows the energy transition process to follow an increasing trend during the short run but then manifests a significant decline to a predicted value of about -20% over the long run.

4. Conclusion

This study provides a comprehensive evaluation of how energy market dynamics and climate policy uncertainties influence the energy transition (ET) in Australia. Using a novel Dynamic Autoregressive Distributed Lag (ARDL) simulation model, the findings reveal significant short-term and long-term effects of these factors on ET. Energy-related uncertainty and aggregate demand shocks positively drive ET in the short term, reflecting the potential for economic activity and policy interventions to stimulate renewable energy adoption. However, in the long term, energy-related uncertainty negatively impacts ET, underscoring the need for stability and strategic planning in the energy market.

Oil market dynamics emerge as critical determinants of ET, with oil supply shocks having a positive long-term effect while exhibiting mixed short-term results. This highlights the dual role of oil market fluctuations in both facilitating and hindering renewable energy adoption depending on the time horizon and the economic context. Aggregate demand contributes positively to ET in both the short and long term, demonstrating the importance of robust economic activity in fostering renewable energy investments. However, oil prices and climate vulnerability show limited responsiveness to ET, indicating that these factors, while relevant, are not as impactful in shaping Australia's energy landscape. Conversely, climate policy uncertainty negatively affects ET in the long run, signaling the detrimental role of regulatory unpredictability in renewable energy investment and infrastructure development. The findings emphasize that while energy market dynamics are the primary drivers of ET, the role of climate-related dynamics, particularly policy frameworks, cannot be disregarded. A clear and stable regulatory environment is essential to mitigate uncertainty, encourage private sector investments, and ensure sustained progress toward decarbonization.

Policy implications from this study suggest that to accelerate the energy transition, Australia must prioritize reducing regulatory uncertainties, fostering innovation in renewable technologies, and maintaining consistent support for clean energy projects. Policymakers should also focus on integrating robust climate policies with economic incentives to create a synergistic effect that supports both environmental and economic objectives. Future research

could expand on this work by exploring cross-country comparisons, examining the influence of technological advancements, and incorporating global supply chain dynamics into the analysis. Additionally, further investigation into the interaction between fiscal and monetary policies with energy transition efforts could provide deeper insights. By addressing the identified barriers and leveraging the opportunities, Australia can achieve a sustainable energy future, balancing economic growth with environmental stewardship.

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