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Greenhouse gas (GHG) emissions in Australian states and territories: Determinants and policy implications

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Abstract

In order to implement effective climate mitigation policies, it is imperative to understand the determinants of GHG emissions. Our research indicates, no state and territory level analysis of Australia, for the determinants of GHG emissions has yet been carried out. This paper identifies the main determinants that affect GHG emissions growth in Australia and assesses their impact in the main Australian states and territories. It performs a rigorous statistical analysis and contrasts the significance of determinants using Feasible Generalised Least Squares (FGLS) Regression and the Linear Panel Data Model with Random effects for the period 1990–2018 for seven states and territories of Australia. We find a mix of GHG determinants in being significant for different states and territories while some show none of the determinants as being significant. Environmental policy analysis is later carried out and then compared with the empirical findings of this study. It is found that it is only in the latter half of the period under observation that some states and territories have instituted encouraging climate change policies while the rest lag behind. Heterogeneous climate mitigation policies, at state and territory level, will have to be implemented to decouple the significance of GHG emissions from its determinants. Also, the ready and comprehensive availability of data for unique variables, such as Savanna burning, will give clearer direction to heterogeneous and customized climate change policy solutions. Lastly, climate mitigation success in TAS (Tasmania), could serve as a leading case study to institute similar renewable energy measures in other states and territories.

1. Introduction

According to [1], human activities are assessed to have caused approximately 1˚C of global warming above pre-industrial levels. If these levels do not stabilize at 1.5˚C before 2100, there will be irreversible or lost lasting effects on a wide range of climatic factors [1]. These include loss of precious ecosystems, melting of glaciers, rise in global sea levels, an onslaught of natural disasters etc. [1].

and you will get the data for GHG emissions. For ABS, https://www.abs.gov.au/, you just need to put in the names of the determinants of GHG emissions (Primary Energy Consumption, Population, Construction, Mining, Structure of the Economy, Agriculture, Forestry and Fishery, Energy Intensity, Exports, Imports and Gross State Product) in the search field of the website. Others would be able to access these data in the same manner as the authors. The authors confirm that they did not have any special access privileges that others would not have.

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[2] and [3] found that the increasing atmospheric CO_2 concentration has been universally accepted to be the main driver of global warming. He further noted that global CO_2 has steadily declined since 1990, however even at this rate of decrease, according to various scientists, the target of 1.5˚C will be difficult to achieve given that we are already standing at a 1.1˚C increase. [4] have sufficient evidence to state that among countries such as U.S., India, some nations of the EU, and China will very likely cause global warming to reach 5. 1˚C. Also, according to the authors, the US and Australia, combined, are only slightly behind in hurling global temperature to rise over 4C above pre-industrial levels.

Australia is the world's sixth largest country and among the top twenty largest global greenhouse gas (GHG) emitters [5]. [6] informs that the geographical set in Australia is comprised of the Commonwealth (federal) government, six states and two territories, and about 560 municipalities. Here, environmental responsibilities are shared [6]. It is observed that political cycles are relatively short which negatively affects long-term policy planning [6]. Since the 1992 Intergovernmental Agreement on the Environment, states and territories have had the principal role in environmental protection [6]. This defines responsibilities shared between the federal and subnational levels [5]. Moreover, Australia's per capita CO_2 emissions tend to be the highest amongst OECD countries, making it difficult to stem back emissions, as per international standards unless states and territories, individually and collectively, take firm action [5].

According to the [7], the main contributor to Australia's GHG emissions at the sector level, in the period 1990–2018, is the stationary energy sector, with a contribution that ranges from 300 Mt CO_2-e in 1990 to 420 Mt CO_2-e in 2018. The second largest contributor to Australia's GHG emissions is the agriculture sector, with participation in national total emissions that ranged from 100 Mt CO_2-e in 1990 to 90 Mt Co_2-e in 2017 [7]. The third highest emitting sector in Australia was LULUCF, with a contribution range for the period 1990–2017 of 200 Mt CO_2-e and -20 Mt CO_2-e, respectively [7].

As shown in Table 1 (figures taken from [7]) at the state and territory level, the change in GHG emissions in the period 1990–2018 ranged between -817% in Tasmania (TAS) and 18.84% in the Northern Territory (NT). The economic development of all the states was roughly similar in the two decades under observation. Four states and territories showed a decrease in GHG emissions. These include -52.575 in South Australia (SA), -34.06% in New South Wales (NSW), -7.25% in Queensland (QLD) and -7.16 in Victoria (VIC). Further, the highest change in emissions was seen in the NT. The only other positive change in emissions was in Western Australia (WA) by 17.24%. The differences between states and territories in the GHG emissions change for the period 1990–2018 are explained by the diverse economic, political, demographic, climatic, and behavioural characteristics of each. This means that there are different drivers for GHG emissions growth in them. However, in certain states and

Table 1. Australia's GHG emission growth and percentage change 1990–2018.

State/Territory	% of Change 1990–2018		
	GHG	GSP	PoP
NSW	-34.06%	75.46%	27.27%
VIC	-7.16%	75.92%	32.23%
QLD	-7.25%	82.93%	42.14%
SA	-52.57%	70.71%	17.53%
WA	17.24%	84.86%	37.86%
TA	-817%	70.99%	12.50%
NT	18.84%	83.21%	33.80%

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territories, it is seen that none of the drivers seems to explain the change in GHG emissions. These could be attributed to the higher intensity and number of times climate change policies were instituted at the state or territory level. Most of the states and territories have reported a decrease in emissions over the years. Emission management actions and policies vary across sectors, the great decline in land use change emissions over the observed period and structural changes in the economy are gauged to be responsible for less emissions [8].

The understanding of both the main factors determining GHG emissions growth and the differences in the impact of these factors at the state or territory level are of extreme importance. This is to enhance the design and implementation of state and territory driven appropriate mitigation to minimize emissions at the overall national level in Australia.

1.1 Contribution

After carrying out an exhaustive search, we found that although there are studies that have studied determinants of GHG emissions in Australia, no analysis has yet been carried out to account for the heterogeneity in states and territories data. This makes this study the first of its kind for carrying out state and territory-level GHG emissions analysis in Australia. The objective of this paper is to identify the main determinants that affect GHG emissions growth and assess their impact and differences, state and territory-wise, in Australia. For this, we gathered data on a consistent dataset (which includes data from the Australian Greenhouse Emissions Information System, Department of Industry, Science, Energy and Resources of Australia and Australian Bureau of Statistics) for the years 1990–2018 on the seven states and territories. We identified an extended list of determinants of GHG emissions. The compatibility of the variables selected through comparing and contrasting the significance of each determinant for explaining GHG emissions growth was carried out. Furthermore, we explored whether there are significant differences between states or territories regarding the impact of each determinant in the GHG emission growth. Finally, we carried out a thorough discussion by assessing the statistical results and environmental policy development in Australia.

2. Literature review

The objective of this paper is to overcome the selection and modelling limitations of earlier works. The literature review below lists methods and determinants of GHG emissions in other data sets along with their limitations.

To select the explanatory factors, we considered statistical significance as in previous studies. A study of Australia's greenhouse gas emissions was done by [9]. The author found that the current gulf between growth and exports was the key problem in need of addressing. But there was sparsity in the selection of variables which is not present in our research. Also, input-output models are severely restricted which casts doubt on the significance of the results.

Using Johansen Cointegration Technique [10] found no causal link between CO_2 emissions and economic growth in Australia (from 1965–2007). This is why we eliminated economic growth from the study.

Several studies have used regression analysis to determine drivers of GHG emissions. Regression analysis mathematically finds out which variables have an impact. The authors in [11] used 40 years (1971–2012) data to analyze changes in GHG emissions in ten countries. They used multiple linear regression model based on the Kaya identity. It was found that heterogeneous factors were critical for explaining GHG emission evolution in different countries (carbon intensity for China, GDP for US, Canada and India etc.). However, it is imperative to mention that the data was not taken from the same source, hence giving rise to the problem of the non-homogeneity of data. The heterogeneity of data gives rise to the possibility of errors in the data modelling.

A large number of studies have used different variations of decomposition analysis. It is a statistical technique in which predetermined variables are extrapolated from the economy and each of their impacts is gauged for GHG emissions growth. It also provides a better understanding of the impact of various variables on energy use. [12] and [13] improved the decomposition analysis by employing different regression techniques for assessing the heterogeneity of GHG emissions and emission intensity. Sector-specific CO_2 decomposition was done by [14]. The author used Logarithmic Mean Divisia Index (LMDI) method on electricity generation in seven Asia-Pacific and North American countries. They found that the production effect was the major factor responsible for rising in CO_2 emissions during the period 1990–2005 as well as the projected values till 2030. [15] used time-series and cross-sectional decomposition and found that growth in per capita GDP and population were the two chief drivers to the increase in CO_2 emissions in most cases in APEC countries. Structural or Index Decomposition Analysis (IDA) extended from energy consumption to energy-related CO_2 emission studies by research carried out since 1991 [16] and [17]. [18] also undertook decomposition analysis and applied it to a larger sample (1971–2010). They found that economic growth was the main driver for increasing CO_2 emissions among G-20 countries. [19] used decomposition analysis, Theil index, to study inequality in CO_2 emissions across different countries. They studied carbon intensity of electricity production, electricity intensity of GDP, economic growth in terms of labour productivity and employment rate. They found that economic growth in terms of labour productivity was the responsible variable for global inequality in CO_2 emissions. [9] using LMDI, found that over 1978–2010 energy efficiency played a leading role in a 17% reduction in CO_2 emissions aggregate intensity in Australia. More recently, [20] used LMDI decomposition and decoupling analysis methods. Their research implied that energy intensity and per capita GDP were the principal factors of CO_2 emissions in OECD countries. But decomposition analysis faces certain limitations, such as not allowing for hypothesis testing. Hence, empirically tested results cannot be derived. Moreover, these studies faced limited identification problem casting doubt over their results.

Our study does not suffer from limited identification problem in terms of comprehensiveness of variables. The data gathered is from homogenous sources. We do not have sparsity in the data, unlike previous studies. Also, we carry out regression analyses for hypothesis testing and gauging the significance of GHG determinants. A comprehensive list of the explanatory variables that we initially selected along with their causal theory, supporting literature and expected sign, are summarized in the table in Table 2.

3. The methodological framework of the study

First, we conducted the methodological review to find out determinants applicable to the dataset. Next, *multicollinearity*, *stationarity and heteroskedasticity* tests were done on the data to find a suitable model. Multicollinearity test was done to determine whether several independent variables in a model were correlated.

After filtering out variables, *time series data model* (FGLS Regression) was used on the state and territory level and *the panel data model* was used on Australia for the time period 1990–2018. This method can estimate coefficients of a multiple linear regression model and their covariance matrix in the presence of nonspherical innovations with an unknown covariance matrix. We then carried out the climate change policy analysis both on the national level as well as on the state and territory level. Later, the panel data model was applied by decade (1990–99, 2000–09 and 2010–18) to check for robustness of results. Finally, the results of time

Table 2. Causal relationship for each determinant of GHG emissions.

	Variable	Rationale	Sign	Study
1	Primary Energy [PE]	PE is total energy demand of a state or territory. Its increase will cause increase in emissions.	+	[21] and [22]
2	Structure of the economy [SE]	These include economic characteristics that support innovation through industrial processes and product use sector. They are machinery intensive so give higher emissions primarily driven by the growth in hydrofluorocarbons (HFCs) used in refrigeration and air-conditioning equipment; they replace ozone depleting chemicals phased out by the Montreal Protocol.	+	[23] and [24]
3	Agriculture, Forestry and Fishery [AFF]	AFF cause an increase in emissions.	+	[25] and [26].
4	Population [Pop]	A higher population would cause more production and consumption, and so increased aggregate demand would cause higher GHG emissions.	+	[11] and [27]
5	Gross State Product [GSP]	Higher GSP warrants more industrial and agricultural processes as well as consumption and higher GHG emissions.	+	[11], [13], [15] and [20]
6	Imports [M]	Consumption of imported goods leads to higher emissions.	+	[28] and [29]
7	Exports [X]	Production of exported goods causes higher emissions.	+	[29] and [30]
8	Construction [Con]	Building and construction have a high carbon foot print due to their processes.	+	[31], Hong et al., [32] and [33].
9	Mining [Mn]	Mining leads to an increase in emissions.	+	[34–36]
10	Energy Intensity [EI]	Energy intensity is the volume of emissions per unit of GDP. Higher energy intensity means higher emissions.	-	[20] and [37]

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series model and panel data models along with the crux from the discourse of climate change policies were combined to produce discussion and conclusions.

3.1 Data

This empirical research focused only on the seven states and territories of Australia for comparative analysis. Our sample included the following states: New South Wales (NSW), Northern Territory (NT), Queensland (QLD), South Australia (SA), Victoria (VIC), Tasmania (TAS) and Western Australia (WA). Annual data from 1990–2018 was used.

We obtained 10 potential regressors: *Primary Energy Consumption (PE)*, *Population (Pop)*, *Construction (Con)*, *Mining (Mn)*, *Structure of the Economy (SE)*, *Agriculture*, *Forestry and Fishery (AFF)*, *Energy Intensity (EI)*, *Exports (X)*, *Imports (M) and Gross State Product (GSP)*. The independent variable was *GHG emissions*. Table 2 below shows the causal relationship of each of these variables with *GHG emissions* as stated by the literature outlined in it. All variables except *EI* have a positive causal relationship with *GHG emissions*.

To find evidence of stationarity, we performed Augmented Dickey–Fuller test (ADF). Stationarity means stability in any aspects of a variable. The null hypothesis for the test is that the data is non-stationary. It is rejected if the p-value is less than 0.05. We found that all the variables showed stationarity issues by performing ADF on level-variable and first difference of the log-variable at 5% level with -3.568 and 1% level with -3.220 as the critical values. All series exhibited signs of unit root. Hence, the issue was solved by transforming the data by taking natural logs for the final model application.

Next, to address another problem found in literature, the multicollinearity of regressors, we analyzed the correlation between variables between each pair of transformed (ln) variables. At first glance, the correlation matrices showed that some of the variables were highly correlated. These included Exports, Imports and Population. Hence, these variables were omitted due to implied multicollinearity.

The set of variables used for our empirical research was the natural log for the dependent variable (*GHG*) and seven regressors; *Primary Energy Consumption (PE)*, *Population (Pop)*, *Construction (Con)*, *Mining (Mn)*, *Structure of the Economy (SE)*, *Agriculture*, *forestry and fishery (AFF) and Energy Intensity (EI)*.

Our sample contained balanced time series data with five regressors for seven Australian states over 28 years (1991–2018).

Further to this, heteroskedasticity was measured through Breusch Pagan Test at a 5% confidence level; the critical value is 18.307. The results suggest that the p-values for all the states show that there is not sufficient evidence to imply the presence of heteroscedasticity.

Normality was measured through Jarque Bera (JB) Tet. The test measures the skewness and kurtosis of data to see if it forms a normal distribution. JB was done at a 5% confidence level; the critical value is 5.991. The null hypothesis H_0 is that the samples from all states and territories follow normal distribution. The results suggest that the computed p-value is greater than the significance level (alpha = 0.05). Hence we can reject the null hypothesis H_0 that the samples from all states follow normal distribution.

Durbin Watson (DW) test was done on the data to find evidence of autocorrelation. This is a test for autocorrelation in the residuals from a statistical regression analysis. The DW statistic will always have a value between 0 and 4. A value of 2.0 means that there is no autocorrelation detected in the sample. Autocorrelation was found in all the states except SA and WA according to the Durbin Watson (DW) statistic. There is evidence of positive autocorrelation in all the other states (DW is between 0 and 2). Owing to autocorrelation, OLS (Ordinary Least Squares) would not have given consistent estimators or robust standard errors, hence Feasible Generalized Least Squares (FGLS) was used for the data, as discussed in the next section.

3.2 Models

We used two models for empirical testing. The first model is the Feasible Generalised Least Squares (FGLS) Regression and the second model is the Linear Panel Data Model with Random effects. The first model was used to assess the differences in impact of each determinant (H_{1a}). The second model was used to gauge if the determinants selected were significant for explaining GHG emission growth in Australia (H_{1b}).

Since some data showed signs of heteroscedasticity and autocorrelation among error terms, we have used Feasible Generalized Least Squares (FGLS) for regression instead of simply using Ordinary Least Squares (OLS). In the presence of heteroskedastic errors, it is found that regression using Feasible Generalized Least Squares (FGLS) offers potential efficiency gains over OLS [38]. The specification of FGLS model with AR (1) errors is as follows:

$$Y_i = \beta_o + \beta_1 X_{i1} + \ldots + \beta_k X_{ik} + u_i \quad (1)$$

$$u_i = \rho\ u_{i-1} + v_i \quad (2)$$

Differencing:

$$(Y_i - \rho\ Y_{i-1}) = \beta_o(1-\rho) + \beta_1(X_i - \rho\ X_{i-1}) + \ldots + v_i \quad (3)$$

After estimating (1) by OLS and obtaining the residuals e_i, we obtain an estimate of ρ, ρ' from the regression

$$e_i = \rho e_{i-1} + \varepsilon_i, \text{ where } \varepsilon_i \text{ is an error term.} \quad (4)$$

We then substitute ρ' for ρ in (3) to obtain

$$(Y_i - \rho\ Y_{i-1}) = \beta_o(1-\rho) + \beta_1(X_i - \rho X_{i-1}) + \ldots + \xi_i, \qquad i = 2, 3, \ldots, N \quad (5)$$

Which can be written as:

$$Y_i^* = \beta_o^* + \beta_1^* X_i^* + \ldots + \xi_i \quad (6)$$

$$\text{Where, } Y_i^* = Y_i - \rho\, Y_{i-1},\ \beta_o^* = 1 - \rho,\ \beta_1^* = \beta_1 \text{ and } X_i^* = X_i - \rho X_{i-1} \quad (7)$$

OLS is applied to (6) to obtain β_o^{**}, β_1^{**},Estimates of the coefficients in the original Eq (1) is given by:

$$\beta_1 = \beta_1^* \quad (8)$$

and since

$$\beta_o = \beta_o^* / (1 - \rho) \quad (9)$$

If we had stopped at this stage, this would be the two step Cochrane-Orcutt estimates. But we substituted our estimates β_0', β_1', β_3', . . ., β_7' back into the original Eq (1) to obtain the new residuals:

$$e_t^{**} = Y_i - \beta_0 - \beta_1 X_1 - \beta_2 X_2 - \ldots - \beta_7 X_7 \quad (10)$$

We then used the residuals in (3) to obtain a new estimate for 'ρ'. This new estimate was used in (5). This way, we proceeded until the estimate of 'ρ' in (5) changed by less than a negligible amount from one iteration to the next. This is how we obtained the iterative Cochrane-Orcutt estimates.

The second model used was Linear Panel Data Model; random effects–Feasible Generalised Least Squares (FGLS). Its expression is as follows:

$$y_{i,t} = (x + a)^n \sum_{k=1}^{K} .\beta_k . x_{i,k,t} + \mu_{i,t}$$

Here, the estimation is:

$$\mu_{i,t} = \beta_0 + \gamma_{i,t} + \varepsilon_{i,t},\ \gamma_{i,t} \sim i.i.d(0,\ O_i^2)\ and\ \varepsilon_{i,t} \sim i.i.d(0,\ O_i^2).$$

The above estimation would give a Random Effect Panel Data Model. The parameter estimation was done by Generalised Least Squares (GLS) which is a variant of OLS. Selecting a fixed or random effect model depends on the relationship between the fixed effects and regressors. This selection is usually made using the Hausman test. The null hypothesis of this test is that the correlation among individual effects and regressors is zero. If the null hypothesis is accepted, then random effects is used otherwise we employ fixed effects.

4. Results

By looking at iterative Cochrane-Orcutt estimates' results, it becomes evident that only NSW, VIC and QLD show significance in certain variables. The results for SA, WA, TAS and NT show that none of the determinants were found to be significant in these states and territories.

Particularly, EI is significant in NSW, VIC and QLD. PE and Pop are significant in both NSW and QLD. Con is significant in only VIC. And SE is significant in only QLD.

In the Panel Data Model, Hausman test was used to discriminate between fixed and random effects. The value of the test was 2.844 with a p-value of 0.828. Hence, the null correlation among individual effects and regressors was accepted and decided that the random effects panel data was efficient. The results of the parameter estimators and their significance using the random effect panel data model show that all variables except Pop are significant.

5. Analysis

The first model tested shows various results for the explanatory power of the independent determinants in determining GHG emissions. The value of R^2 ranges from 85% in Victoria to 27% in NT. Overall, normality or heteroscedasticity was not found in the data. There might be model specification issues with SA, WA, TAS and NT because none of the independent variables was found to be significant in them.

The results for the random effect Panel Data Model show that all determinants are significant for explaining GHG emissions growth except population. This indicates that at the national level, except for population, all the determinants analysed explain changes in GHG emissions.

This discussion goes into deeper detail, as we tie statistical results with the development of Australia's climate change policies on national as well as state and territory levels, over the years.

5.1. Australia's national and state (or territory) climate change policies

In Australia, states and territories have their own policies and instruments. According to [39], during the mid-1990s, concurring with free market economic ideology, certain industries such as coal, oil, natural gas and other extractive industries, along with other multinational corporations, such as the energy-intensive aluminium smelting industry got together and influenced the Australian government [40]. These emissions were characterised by few intensive, geographical locations [41]. Also, the politicians in power were staunch supporters of stimulating economic growth and sceptical of climate change [42]. Although the CO_2 emission targets were instituted, former science minister Barry Jones in World Meteorological Day address (1992), in favour of combatting economic growth, was reported to withdraw support for climate change and put climate mitigation policies on the back burner. However, even with these forces, in December 1992, Australia was the ninth country to ratify the UNFCCC. In April, 1998 Australia signed the Kyoto Protocol, along with 20 other countries. However, Australia did not ratify the Kyoto protocol. This meant that the emission targets were not legally binding [41].

The initial lukewarm response to climate change in the field, as opposed to on paper, led Australia's climate mitigation policies towards lower emission reduction as opposed to a more responsible climate change policy. This was especially visible in NSW for the first decade under consideration, where unlike other Australian jurisdictions, including VIC, TAS, SA and the ACT, there were no legal mechanisms or all-embracing climate action in place [43]. It was only later that the state government decided to introduce changes in its environmental policy. This is apparent from decreasing emissions from NSW since 2008 (Fig 1). Similarly in QLD, limited policy measures [44] translated into causing emissions to remain highest among all the other territories and states, and rising since 2016. The case is the opposite for TAS whose target to run on 100% renewable energy has been achieved [45]. Since the 1990s, Tasmania's overall emissions have been constant, and since 2012 they have started decreasing.

Australian Government's Carbon Pollution Reduction Scheme (CPRS) that caused much stir during 2008–09 met its gloomy fate when lobbying caused changes to subsequent proposals, favouring carbon intensive industries. In June 2002, the Howard Government claimed to the Australian Parliament that ratifying the Kyoto Protocol was not in the national interest [46]. But in December 2007, Prime Minister Kevin Rudd ratified the Kyoto Protocol, as promised during the 2007 election campaign [47]. The on and off policy circus became visible in some states, for instance, VIC's emissions increased till 2012, but then decreased. This is because policies that ran up to The Victorian Climate Change Act 2017 were not favourable,

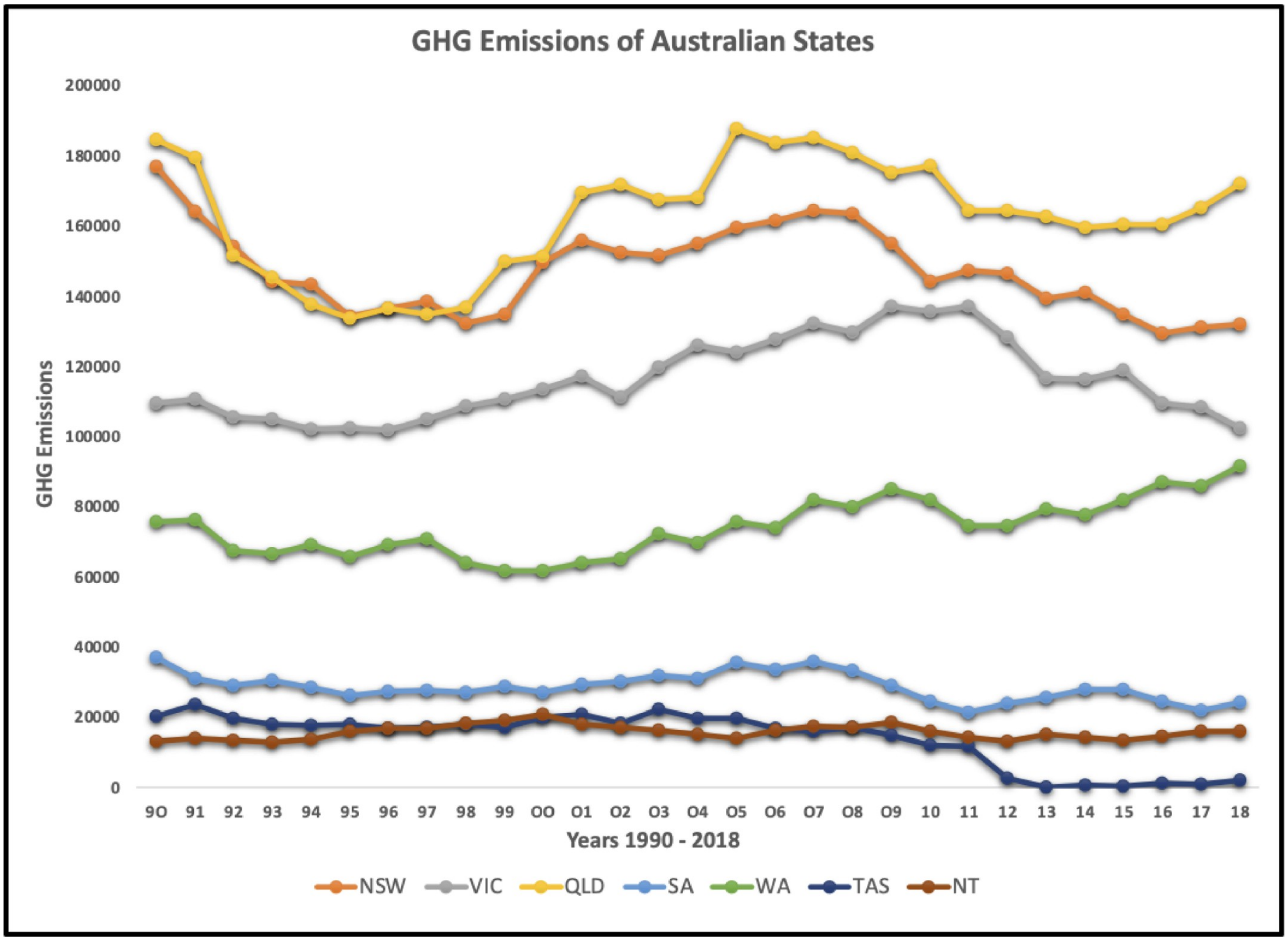

Fig 1. GHG emissions in Australia.

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but the act replaced the earlier. Climate Change Act 2010 (VIC) and was a comprehensive legal framework unlike earlier policy activities (Project Victoria) that undid actions that reduced Australia's emissions through energy-demand management strategies [48].

Some states such as SA, NT and WA have had stable emissions over the past two decades (Fig 1) although SA was the first Australian state to legislate targets to reduce greenhouse emissions [49]. But it seems that a blend of policies and a general stability in demand-led emissions seem to have not decreased emissions although no notable increase was seen in all three cases. Owing to rising emissions in some states and territories and non-changing emissions in others, Australia could not meet its Kyoto 2008–12 target [5]. In December 2015, at COP21, Australia announced it had a net zero emissions target by 2100 [50]. However, due to the political and economic factors embedded deep in the environmental landscape of Australia, a greener future remains uncertain. Thus, if Paris Agreement goals are to be met, the government needs to streamline its approach and clarify how existing and new instruments could be implemented [51] and [52].

5.2 Robustness of results

We subdivided the sample by decade; 1990–1999, 2000–2009 and 2010–2018 as shown below in Table 3. This was done to check robustness of results using the Panel Data Model. The

Table 3. Analysis by decade- panel data model estimates where * and ** show significance at 5% and 1% respectively.

	1990–2018	p	1990–1999	p	2000–2009	p	2010–2018	p
Intercept	20.127	0.283	23.937	**0.004****	7.835	0.575	−1.477	0.978
PE	3.011	**0.002****	0.242	0.477	1.539	**0.027***	1.695	0.620
Pop	0.593	0.565	−1.727	**0.006****	0.697	0.375	1.121	0.725
Con	−0.433	**0.048***	0.315	**8.86e-07****	−0.167	**0.069***	0.103	0.904
Mn	−0.283	**0.025***	−0.124	**0.070***	−0.131	**0.006****	0.027	0.949
SE	−0.510	**0.066***	−0.219	0.129	−0.294	0.080	−1.522	0.324
AFF	−0.870	**0.000****	0.200	**0.003****	−0.067	0.361	−0.490	0.497
EI	−2.249	**0.030***	0.269	**0.000****	−1.271	0.075	0.217	0.952

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analysis by states and territories using multiple linear regression models could not be performed as the degrees of freedom of the estimation would have lead to inconsistent results. This analysis is done to assess the dynamics of the parameters, i.e., to analyse if the effect of each determinant has changed during the given time period.

The results indicate that only in 1990–1999 the intercept was significant at 1% which means that it shows different results as compared with other decades. This decade was marked with overall skepticism in Australia regarding climate change [53]. Due to this reason, it seems that other than SE all other estimates were found to be significant in determining GHG emissions. This confirms the failing of climate change policy in Australia for the decade. The temporal evolution of estimates is such that all of them appear to be decreasing by the time that we reach the decade of 2010–2018. In 1999–2018, only Pop was not significant. During 1999–99 Pop and SE were insignificant at 5% while other variables, such as PE and AFF, exhibited 1% significance. In 2000–09, we saw a general weakening of the relationship between the determinants and GHG emissions. Lastly, in 2010–18 none of the determinants remained significant. This result aligns with the projections of a report by [5] that observed that Australia is on track to reach its 2020 emission reduction target although it is still too early to know whether it would achieve its goal of zero emissions by 2050.

6. Discussion

According to the literature, the determinants chosen in this study are among the most significant of all variables that can determine GHG emissions in a given data set. However, one limitation to be noted is that some unique variables, such as Savanna burning, for instance, which contributed heavily to the NT emission in 2009 [54] were not included due to non-availability of data. Also, some variables which have contributed heavily to emissions over the years have either limited or no data available to reflect their exclusive contribution to GHG emissions e.g. Transport and LULUCF.

Some variables were found to be chief contributors in only some, but not in the majority of states and territories, so they were not included in the statistical analysis. This is because time series regression does not take into account the unique characteristics of the data set. Hence, this seems to be the reason that in some states and territories (QLD, SA, TAS and WA), none of the given determinants was found to be significant.

Moreover, an analysis of variables significant from year to year shows huge disparities. For example, [54] compares emissions from different sectors in 2005 to 2017 levels. In NSW and WA, initially, transport and energy sector were notable contributors to GHG emissions, but they dropped to almost zero in 2017, while waste, which contributed practically zero became a chief variable later. In SA, LULUCF (Land Use, Land Use Change and Forestry) became a main contributor in 2017. Mn and Con which had zero contribution in 2005 became notable variables later in VIC and WA. This uneven contribution of variables over the years, further explains why in some states some or all of these variables were not found to be statistically significant. This is a limitation of FGLS regression.

Further, there is a significant probability that a variable might seem insignificant because of good policies that decoupled the link between GHG emissions and the given determinant rather than one or more of the reasons listed above. Different states and territories have different experiences in this regard as already discussed in section 5.1.

PE and EI have been significant determinants in the case of NSW and QLD. One unit change in energy intensity causes GHG emissions to change by a high elasticity. Both these states are two of the highest emitters of GHG emissions in Australia. This result shows that since the past two decades, even with the breadth and width of climate change policies introduced in these two states, the strength of their link with emissions could not be made tenuous.

Pop has been an important determinant in GHG emissions, meaning that demand led emissions are still strong in both NSW and QLD. Pop has a negative sign which means that with one unit increase in population, emissions decrease by a respective unit. It might mean that with increase in population, policies are getting more and more stringent. Also, a higher EI would mean it would be more expensive to convert energy into GSP; EI is found to be an important determinant for both states.

Con and EI seem to be significant variables in VIC. This is because there has been no policy that determined building and construction rules over the past few decades [48]. Although, since 2012 its emissions have been decreasing, no significant or effective renewable energy policies have been instituted as discussed in section 5.1.

NT, SA and TAS emitted lowest GHG emissions which have averaged over 1990s levels. Among these states, TAS has achieved 100% renewable energy target. It also seems that TAS has devised successful policies to maintain emissions in its highest emission producing sector, LULUCF, followed by emissions from Mn, AFF and Waste [45]. But it seems that if the state is aiming at zero emissions by 2050, sectors other than energy, need to be targeted as well. Other states could also use the renewable energy policy model employed in TAS. Transport was a chief contributor in SA over the sample period [55], but there was no data available to reflect its contribution. It might be that due to favourable policies, emissions were stable and so none of the determinants was found to be significant, but this cannot be said with certainty because neither full data for the chief contributors were available nor any record of matching policies could be found. Further, there have been no favourable actions by the NT government in the past years, and so, NT's emissions have not declined from 1990s levels. We can cautiously infer that environmental policies were perhaps successful in weakening the link between emissions and sources in cases such as NT, TAS and SA, as discussed, but we cannot state this with complete certainty due to a lack of relevant policy data.

WA's emissions are expected to rise rapidly during the short to medium term. Also, WA's gas consumption is highest among all the states and territories in Australia [55]. Gas is consumed mostly by large industrial and mining users, the mineral processing sector, and electricity generation at high levels. This means that PE, Mn and SE should have been significant determinants for WA. However, this seems not to be the case, perhaps because more reflective variables such as quantified electricity supply should have been used, although there is limitation to the availability of data for this variable.

Mn and AFF were two variables that were not found to be significant in any of the states or territories. In section 5.1., we discussed that Australia was unable to become a forerunner of climate mitigation policies because of the problem of small firm lobbying. However, after the 1990s, the government steered its efforts towards environmentally friendly policies. Also, while it is complex to move towards 100% renewable energy, legislation can, with fuller force, target emissions produced by the manufacturing sector. It seems that with recent effective policies, SE, decoupled from growth in emissions. Regarding AFF, one plausible explanation of it being non-significant is that this variable counts both forestry and fishery in its composition. Agriculture is critical for a more holistic study because it is one of the top three contributors to GHG emissions in any state or territory [44]. And while we have seen agriculture to be a significant potential contributor to GHG emissions, forestry and fishery might have skewed statistical output towards rendering it insignificant. Further, no information regarding agriculture was available, so we used AFF to reflect it. Hence, a proper measure of Agriculture is required.

Lastly, when comparing robustness of results through Panel modelling, we find that during 1990–2018 all the determinants were found to be significant. Particularly, during 1990–99 most of the variables were significant. It reflects the national policy of Australia for not being sufficiently green in the 1990s. Although, this does not reflect favourable policies instituted on sub levels, such as in TAS, SA and ACT during the decade. Although by the decade of 2010–18, none of the variables remained significant. It seems that overall climate change policy has been effective, progressively, but [56] stated that emissions were reported to be highest in 2017 (in Australia) in the past two million years. This could be due to some outlier year or years, or due to certain states and territories. More research is needed in this regard. However, both our panel data model and an independent study [5] observations indicate that Australia has been positively moving towards more stringent climate change policies (in at least a few states).

7. Conclusion

We have explored factors affecting GHG emissions by taking into account state and territory heterogeneity. Normally, a good environment-friendly policy decouples the relationship of emissions with a particular variable. However, only the presence of a policy is not sufficient. There have been major policy changes and actions done in Australia both on a national level as well as in states and territories as per climate change, but lobbying by the industry and a general scepticism has led only some of the states or territories to report encouraging decrease in GHG emissions.

The conclusions can be summarised as follows:

1. The uneven impact of the main determinants of GHG emission growth suggests that a differentiated application of Australian policies at state and territory level will enhance the efficiency of mitigation efforts in Australia.
2. Improvements in renewable energy, such as in TAS, will be crucial for future reductions in GHG emissions moving forward and also to achieve the mitigation goals agreed in the Paris Agreement.
3. Moreover, it is also to be kept into consideration that without a state or territory analysis, the results can mislead us into thinking that the environmental policy is stronger than the case in reality. So, it should be cautioned that the idiosyncratic effects, as per state or territory, should be taken into account.
4. Lastly, imagining a 100% green future, as evidenced, by all the determinants chosen, seems to be a probable task, but the fact that some of them are still significant, on territory or state level, shows that the work of Australia in mitigating GHG emissions is far from done.

The study also had some limitations:

1. Certain variables were not included because they did not contribute majorly in all states and territories. Also, for some variables, limited or no data was available.
2. One limitation of time series regression is that it does not take into account significance of variables in specific time periods, hence, in many states, variables that were otherwise significant in certain time periods did not make it to the list of final significant variables to be studied. Future studies can employ more overarching statistical methods and data gathering techniques that address these limitations to present a more holistic picture.

Author Contributions

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