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Reassessing Emissions in the Lucky Country: Consumption, Production & Outsourcing in Australia (1995 – 2009)

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Abstract

Despite a small population, Australia is globally relevant as the largest per capita emitter of greenhouse gases in the OECD and the world's largest exporter of coal. Australia is also uniquely positioned amongst developed nations as being both acutely exposed to climate change impacts and being without coherent energy and emissions policies. This study reassesses Australia's emissions profile utilising multi-region input-output analysis and the 2013 release of the World Input Output Database. The study asks how trade has influenced Australia's emissions profile and whether Australia has outsourced emissions through foreign trade. The results show that Australia experienced a significant turning point during the study period, shifting from being a net-exporter to net-importer of emissions. This was driven by a 120 per cent increase in emissions embodied in Australian imports, most of which occurred after 2001. This increase was fueled by the increasing share of imports from China, and the greater carbon intensity of these imports. As a result, although Australia's production emissions began to stagnate at the end of the study period, consumption emissions continued to rise and Australia's carbon leakage markedly increased. A technology-adjusted balance of emissions embodied in trade analysis also revealed that 52 per cent of Australia's negative emissions balance in 2009 was driven by trade-induced emissions outsourcing. This study demonstrates the importance of tracking consumption emissions as the true indicator of a country's carbon footprint.

Key words: Input-Output, CO_2, Carbon Leakage, Climate Change, Embodied Emissions, Trade, Australia.

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Thank you to my mother, Rhonda Small, and my late father, Hans Löfgren, for their unconditional love, guidance and proof-reading (!) through my many years of study. Finally, I reserve the deepest gratitude for my wife and best friend, Chloe Gray. Thank you for your patience, love and endless support through our years together.

All we do to combat the climate emergency and protect our natural world is for the benefit of future generations. As such, I dedicate this to my beautiful children, Oskar and Otis.

Kaj Löfgren
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Author’s Note

The Lucky Country refers to the book by the same name, written by Donald Horne in 1964. The title of the book is deeply ironic, and Horne is damning of 1960s Australia. Horne’s critique can be summed up with his now famous words from the final chapter:

> *“Australia is a lucky country run mainly by second rate people who share its luck. It lives on other people's ideas, and, although its ordinary people are adaptable, most of its leaders (in all fields) so lack curiosity about the events that surround them that they are often taken by surprise”* (Horne, 1964).

This assessment of Australia in the 1960s can surely also be applied to Australia’s political leadership over the last 12 years, due to the complete failure on energy and emissions policies. With Australia’s natural endowment of renewable energy resources and acute exposure to climate change impacts, this period of political failure will be rightly condemned by future generations.

Finally, whilst the economic history presented here is limited to Australia’s colonial history, the author acknowledges the 60,000+ year history of Aboriginal and Torres Strait Islander people in Australia and their ongoing connection to country (see Hunter, 2015). The author also acknowledges the enduring gap in socioeconomic outcomes between Indigenous and non-Indigenous Australians, and the often-ignored Indigenous contributions to Australia’s ongoing social and economic development (see Altman & Biddle, 2015).

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Abbreviations

AU$	Australian Dollars
BRIC	Brazil, Russia, India & China
BEET	Balance of Emissions Embodied in Trade
CBA	Consumption Based Accounting
CID	Centre for International Development
CO_2	Carbon Dioxide
DFAT	Department of Foreign Affairs and Trade (Australia)
EDGAR	Emissions Database for Global Atmospheric Research
EEE	Emissions Embodied in Exports
EEI	Emissions Embodied in Imports
EKC	Environmental Kuznets Curve
FD	Final Demand
GDP	Gross Domestic Product
GEM	Global Economic Monitor
IMF	International Monetary Fund
IO	Input-Output
MER	Market Exchange Rates
MRIO	Multi-Region Input-Output
NSW	New South Wales
OECD	Organisation for Economic Cooperation and Development
PBA	Production Based Accounting
PPP	Purchase Power Parity
PTT	Pollution Terms of Trade
RLIM	Refined Laspeyres Index Method
ROW	Rest of World
SO_2	Sulphur Dioxide
TBEET	Technology-Adjusted Balance of Emissions Embodied in Trade
TCBA	Technology-Adjusted Consumption Based Accounting
TEEE	Technology-Adjusted Emissions Embodied in Exports
TEEI	Technology-Adjusted Emissions Embodied in Imports
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US$	US Dollars
WIOD	World Input Output Database
WIOT	World Input-Output Table
WTO	World Trade Organisation

1 Introduction

I love a sunburnt country,
A land of sweeping plains,
Of ragged mountain ranges,
Of droughts and flooding rains.
(*Dorothea Mackellar, 1908*)

Australia is the largest per capita emitter of greenhouse gases in the OECD (OECD, 2019). As Hatfield-Dodds et al (2015) write, despite its small population of 25 million people, "Australia is globally relevant: a major exporter of energy, mineral and agriculture products, with high per capita income, greenhouse gas emissions, water extractions, and habitat loss" (p.49). After some promising falls in carbon emissions between 2009 and 2014, Australian emissions have now returned to record highs largely due to monumental political instability over the past ten years (Slezak, 2017). Successive Prime Ministers have fallen, and governments collapsed, principally due to failures in environmental and energy policy (Crabb, 2018). Furthermore, the existential threat of the climate emergency (Allen et al, 2018; Steffen et al, 2018; Schröder & Storm, 2018) is ever-present in Australia. Australia has always been a continent of extreme weather; a country of *droughts and flooding rains* (Mackellar, 1908). However, these extreme weather events have increased in frequency and ferocity, with drought, fires and floods often simultaneously affecting different parts of the country. Temperature records continue to be set, with January 2019 most recently declared as the hottest month ever recorded (Bureau of Meteorology, 2019). The Australian Bureau of Meteorology even introduced a new colour (incandescent purple) on the temperature charts to account for regular temperatures above 50 degrees centigrade (Carrington, 2013). Australia's extreme per capita emissions status, despite being on the frontline of climate change effects, is a disturbing paradox.

Globalisation and expanding trade have been critical for the development of the Australian economy (Pomfret, 2015). Historically, Australia's major exports have shifted from gold in the nineteenth century, to wool in the early-mid twentieth century, and finally to resources (coal and iron ore) in the twentieth century. Australia's major trading partners have also shifted, from the UK, the US and Japan throughout the twentieth century, to China since the start of the twenty-first century (DFAT, 2016). In 2008 China became Australia's largest trading partner for both exports and imports (ibid). The global trading landscape has also developed in two important ways in recent decades. Firstly, dramatically reduced transaction costs (due to the opening up of economies and improved transport) resulted in significantly increased global trade in both intermediate and final products. Secondly, this resulted in the internationalisation of supply chains, with goods increasingly produced in multiple countries. The rise in globalisation and the increased importance of intermediate trade generated a critical connection between emissions and trade.

Emissions have traditionally been measured based on the production of goods and services within a geographic territory. This measure (defined as Production-Based Accounting, or PBA) is used in almost all national accounting models and international agreements (Levitt et al, 2017). However, this method ignores emissions embodied in trade and the role of demand and consumption in driving global production. PBA could incentivise countries to decarbonise their own economies whilst relying on the importation of carbon intensive goods from other nations. Thus, the field of Consumption-Based Accounting (CBA) emerged. CBA employs multi-region input-output (MRIO) analysis to examine emissions embodied in trade and allocates responsibility at the point of consumption rather than production. The balance of emissions embodied in trade (BEET) can then be calculated, creating an indicator of whether a country is a net importer or exporter of emissions. Jiborn et al (2018) and Baumert et al (2018) made significant recent contributions to the BEET model by introducing a technology-adjusted approach for measuring emissions displacement (known as the TBEET model). The TBEET methodology enables a focus on the scale and composition of emissions embodied in exports and imports whilst cancelling out "noise stemming from general differences in carbon efficiency between countries" (Jiborn et al, 2018, p.28).

Ultimately, while national responses to climate change are necessary, neither climate change nor our economic system operates within territorial boundaries. Along with territorial emissions reductions, we need to better understand the distributed environmental impact of a globalised and hyperconnected modern production system. Australia's globally relevant emission status, frontline climate impacts, frustrating political context and the changing nature of international trade, demand a deeper analysis of the relationship between emissions and trade. This thesis aims to thoroughly reassess this relationship utilising input output analysis and PBA, CBA, BEET and TBEET methodologies.

1.1 Research Question

The core research question for this thesis is: *has Australia outsourced carbon emissions through foreign trade since 1995?* In order to answer this question, this study will examine how the changing nature of trade affected Australia's emissions profile. This will lead to an analysis of Australia's emissions trajectory after the study period, and the subsequent implications for Australia's policy priorities and political paradigms into the future.

1.2 Aim & Scope

To answer the research question, this thesis will calculate Australia's emissions history between 1995 and 2009. This will include domestic and household emissions, alongside emissions embodied in exports and imports. This will allow an analysis of Australia's total production and consumption emissions, and an analysis of the BEET. This study will then apply the TBEET methodology to reassess Australia's emissions embodied in trade. Finally, an innovative extension will be utilised to examine the post-study period up until 2014.

1.3 Outline of this Thesis

This thesis is organised as follows. It begins with context and background on Australia, including an outline of Australia's energy and trade history, climate policies and the long-term pattern of emissions. Chapter 3 provides a literature review, outlining the framework for this study and the field of emissions displacement. Chapters 4 and 5 outline the data and methodology used. Chapter 6 presents the full results and associated analysis. Chapter 7 presents an extension to the study, to address the period between 2010 and 2014. Chapter 8 discusses the research question and post-study period. Finally, the thesis concludes with a discussion of policy priorities and political paradigms in chapter 9.

2 The Australian Context

2.1 A Coal Story

Australia's economic history is powered by coal. Coal was first discovered by settlers as early as 1791 and convicts were soon put to work in the newly established coal mines in New South Wales (NSW) and Tasmania (Baer, 2016). Comerford (1997) writes that the British government was initially interested in Australian coal to fuel the steam-powered sea routes in the India and Southern Oceans. Mines were established in NSW, Victoria and Tasmania throughout the first half of the nineteenth century, with state rewards offered for the discovery of workable coal seams (Baer, 2016). Baer (2016) notes that the intertwining of the state and the coal industry from this early period (and indeed the use of convict labour) placed coal at the centre of Australia's political psyche, with long term consequences for the economy and the environment.

After a strong early period of mining growth in the nineteenth century, the mining industry was severely affected by the collapse of metal prices after the first World War, increased industrial unrest and the Great Depression (Coal and Mineral Industries Division, 1999). Coal production fell by a third as a result of the Depression, and coal exports collapsed from a high of 14 million tonnes in the mid 1920s to only 50,000 tonnes in the late 1940s (ibid). However, the shock of World War Two increased the demand for Australian metals. This was followed by a period of political stability, a range of technical advances and the expansion of the world economy in the 1950s and 1960s. All these factors set the scene for "the emergence of a world class mining industry" in Australia (McKay et al, 1998). Japan surfaced as a major buyer of Australian coal (in particular coking coal) in the 1960s and 1970s and this further accelerated Australia's status as an international leader in coal exports (Coal and Mineral Industries Division, 1999).

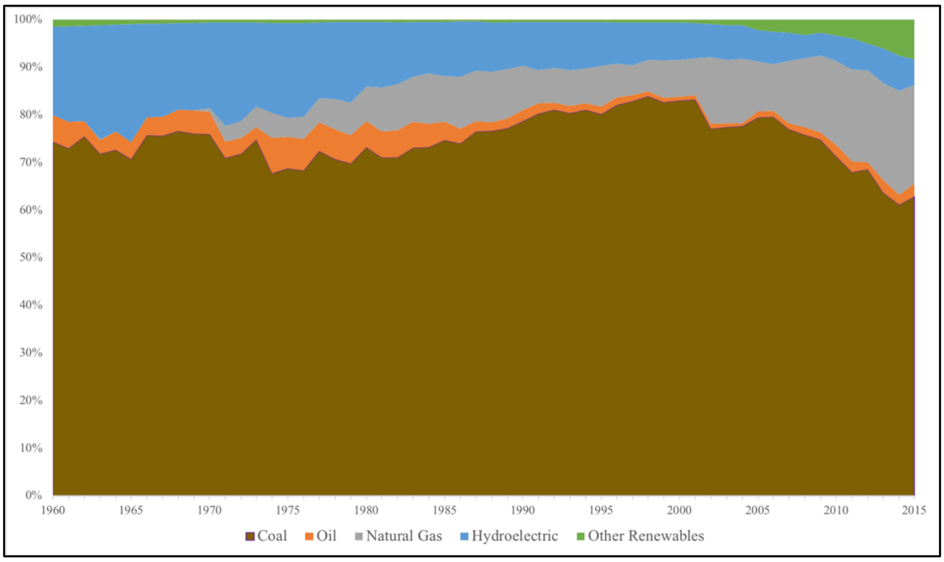
The oil price shocks of the 1970s shifted the economics of the mining industry, with greater incentives for oil and gas exploration, and further coal mines. This was followed by the rapid opening up of the Australian economy in the 1980s and 1990s, which included Australia overtaking the US as the largest exporter of coal in 1984, a leading position Australia still holds today (Baer, 2016, p.197). The Asian economic crisis of the late 1990s negatively affected coal prices, but this quickly shifted into a boom period with China's rapid industrialisation after 2002. China's rapid increase in demand for coal and other metals saw the coal price peak at more than 600 per cent above 2002 prices (Robson, 2015, p. 307). The Global Financial Crisis had a short-term impact on prices, but China's stimulus spending ensured this was only temporary (ibid). Robson (2015) argues that "the huge increase in mining export income, had an immense impact on the structure of the entire Australian economy and on the nation's policy processes and outcomes" (p.307). Ultimately, from settlement to the modern day, coal has played a critical role in Australia's economic growth and political priorities.

2.2 Energy & Electricity

Figure 2.1 illustrates Australia's long-term reliance on coal within the electricity mix. Natural gas emerged in response to the oil shocks of the 1970s and in recent times gas has taken an increasingly larger share at the expense of coal. In the face of reducing coal prices and aging coal-fired power stations, the proportion of coal use has declined. However, a more detailed look at the electricity mix indicates that there has only been a small absolute reduction in coal use since 2000 (see figure 2.2). An increase in natural gas, alongside the introduction of a material amount of solar and wind, continue to see an increase in electricity generation. Due largely to the ready availability of fossil fuels Australia has never pursued nuclear power, however Australia does possess uranium reserves and exports these to Europe and Asia. There has also been a limited increase in other renewables, however growth in solar and wind has been inhibited by considerable policy instability (Lucas, 2017).

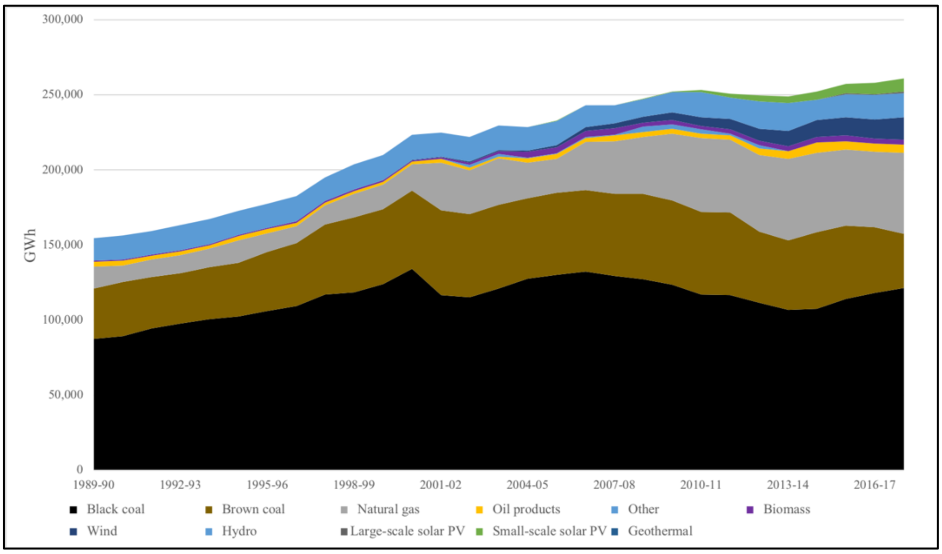
Australia shares a coal-dominated electricity mix with a number of nations, including most prominently China and the United States (see figure A.1 in Appendix A). Whilst Australia's overall energy use per capita has remained remarkably stable since 1990, at 5000-6000 tonnes of oil equivalent, China has begun a slow convergence with Australia from below and the US has started a downwards trajectory since the 2008 financial crisis (see figure 2.3). It is a similar story for Australia's energy use per $1,000 GDP, which has been steadily declining since 1990 and is converging with both China and the US (see figure 2.4). Australia stands out, however, as the only country in this group that is a net energy exporter (see figure 2.5). In 1960 Australia imported more than 30 per cent of its energy needs, however a combination of new coal mines, trade liberalisation and global economic expansion saw a dramatic increase in coal exports. This was initially driven by the emergence of Japan as a major buyer of Australian coal. Japan remains the top buyer of Australian coal in 2016, with China, South Korea and India being the other major consumers (CID, 2019).

Figure 2.1: Australia's Electricity Mix (1960 - 2015)



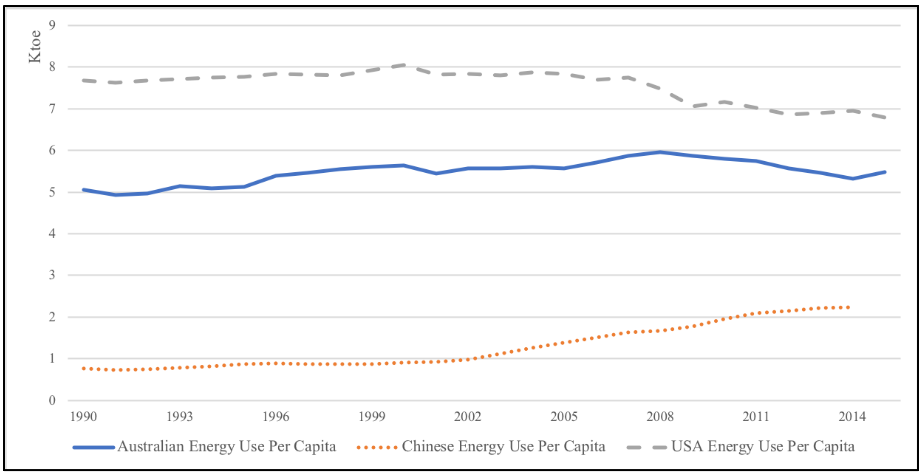
Source: World Bank (2019), Author's Construction.

Figure 2.2: Australia's Electricity Mix (detailed, 1989 - 2018)



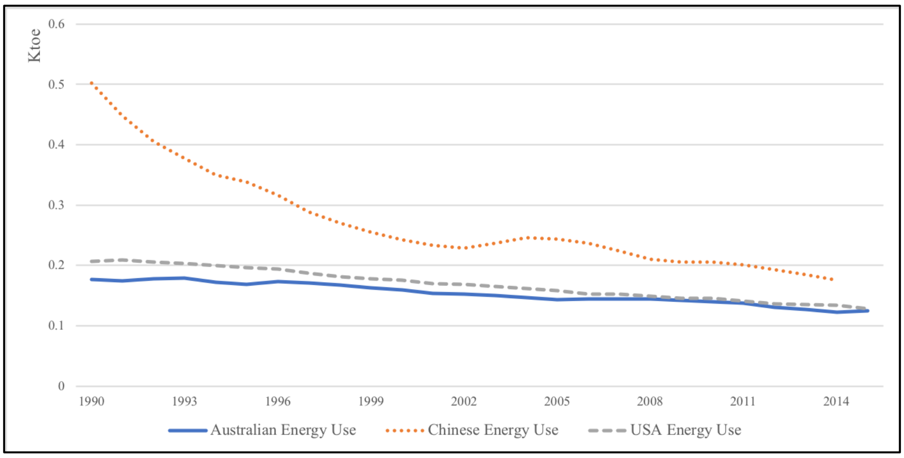
Source: DEE (2019a), Author's Construction.

Figure 2.3: Energy Use Per Capita (1990 - 2015)



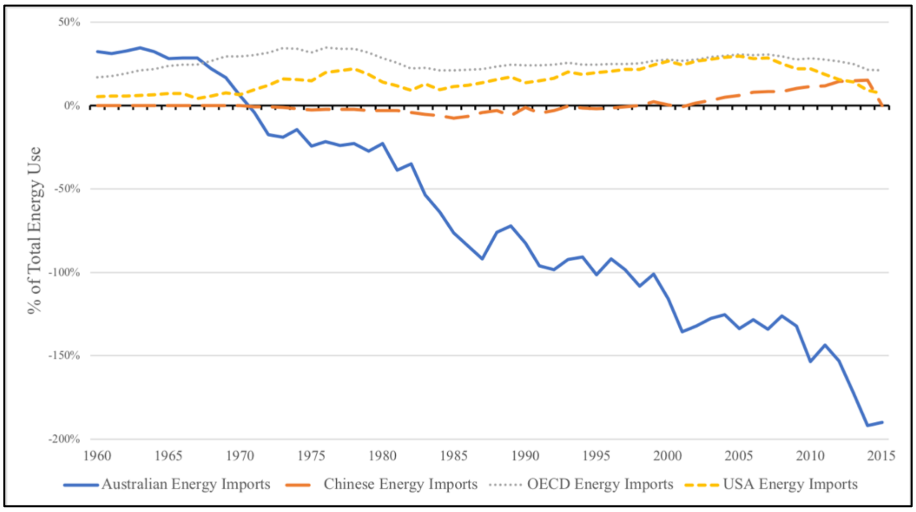
Source: World Bank (2019), Author's Construction.

Figure 2.4: Energy Intensity (energy use per $1,000 GDP, constant 2011, PPP)



Source: World Bank (2019), Author's Construction.

Figure 2.5: Net Energy Imports (1960 – 2015)

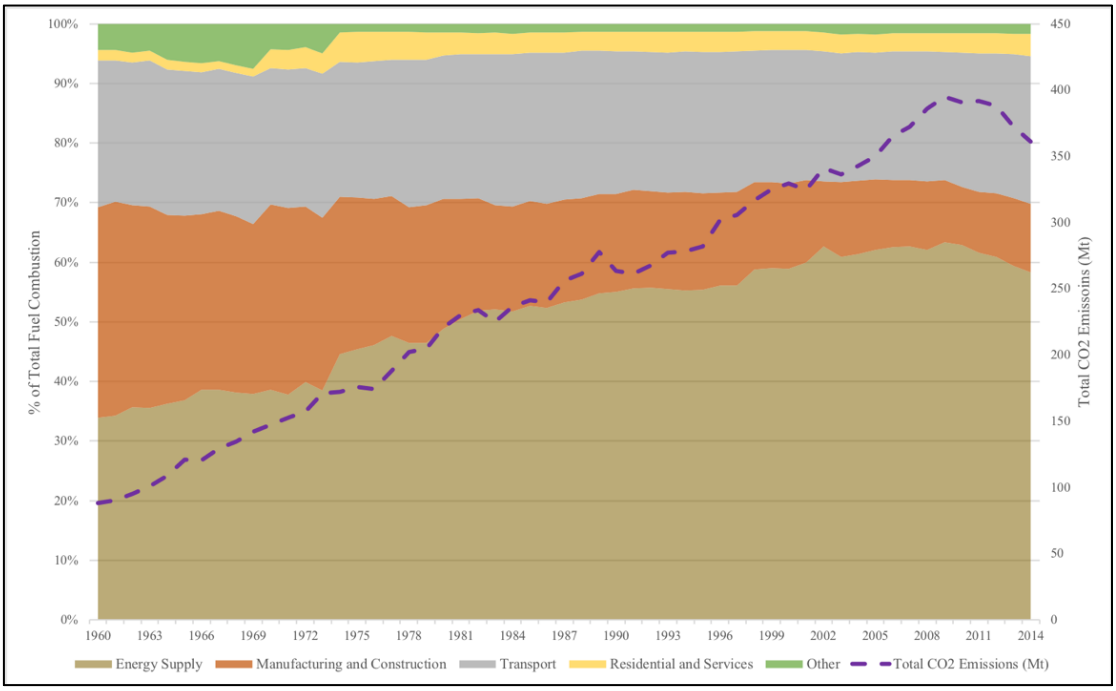


Source: World Bank (2019), Author's Construction.

2.3 CO_2 Emissions

Australia's CO_2 emissions have risen dramatically since 1960, to a high of almost 400 Mt in 2008 (see figure 2.6). A short period of emissions reduction can be seen from 2008 to 2014, which coincides with both the financial crisis and a range of progressive climate policies (including a short-lived carbon pricing mechanism). Unfortunately, since the dismantling of Australia's carbon pricing mechanism in 2014, emissions have sky-rocketed once more to a record high of 558 Mt CO_2-e in 2018 (ndevr, 2019). An increasing proportion of Australia's emissions come from the energy supply sectors, reaching above 60 per cent in recent years. This increase was due to the declining manufacturing industry, which has decreased from 35 to 11 per cent of overall emissions. The contribution of transport to Australia's emissions has remained largely constant over the last 50 years, at between 20 and 25 per cent.

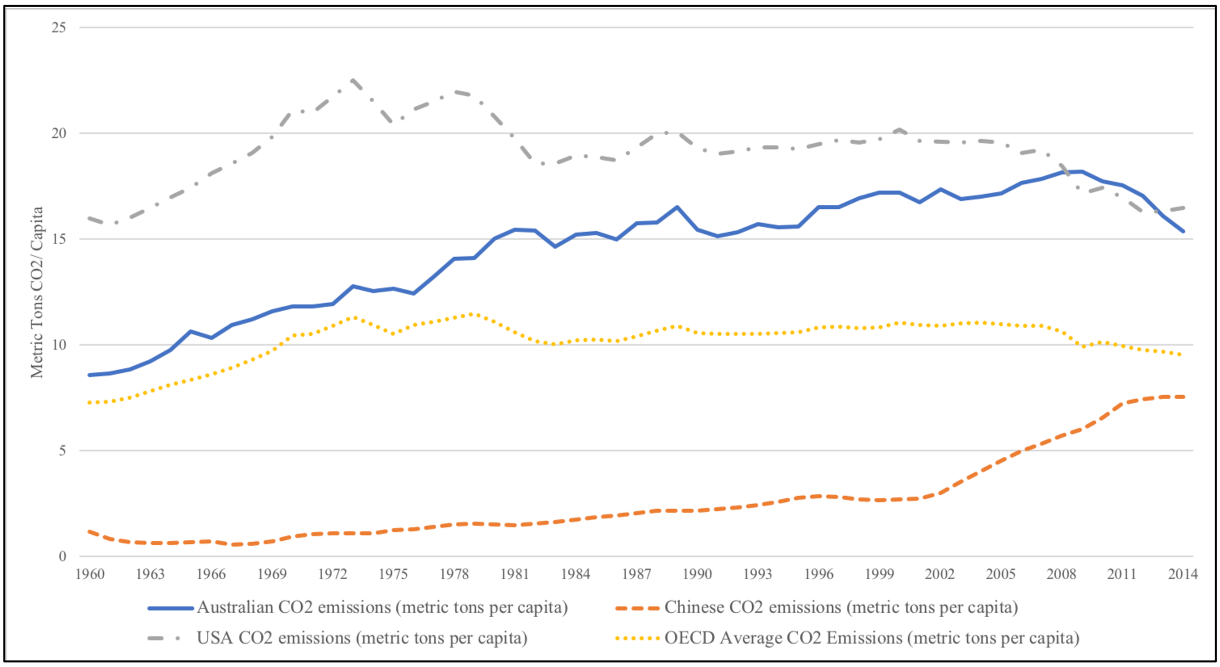
Figure 2.6: Long Term CO_2 Emissions, Sector Analysis (1960 - 2014)



Source: World Bank (2019), Author's Construction.

Emissions per capita have also risen dramatically in Australia after being close to the OECD average in 1960 (see figure 2.7). Australia CO_2 emissions per capita are now second only to the US within the OECD (Australia has the highest total greenhouse emissions per capita in the OECD). This is unsurprising given the dominance of coal in Australia's energy mix and coal's status as the most emissions intensive energy source (Kander et al, 2013).

Figure 2.7: CO_2 Emissions Per Capita (1960 – 2014)



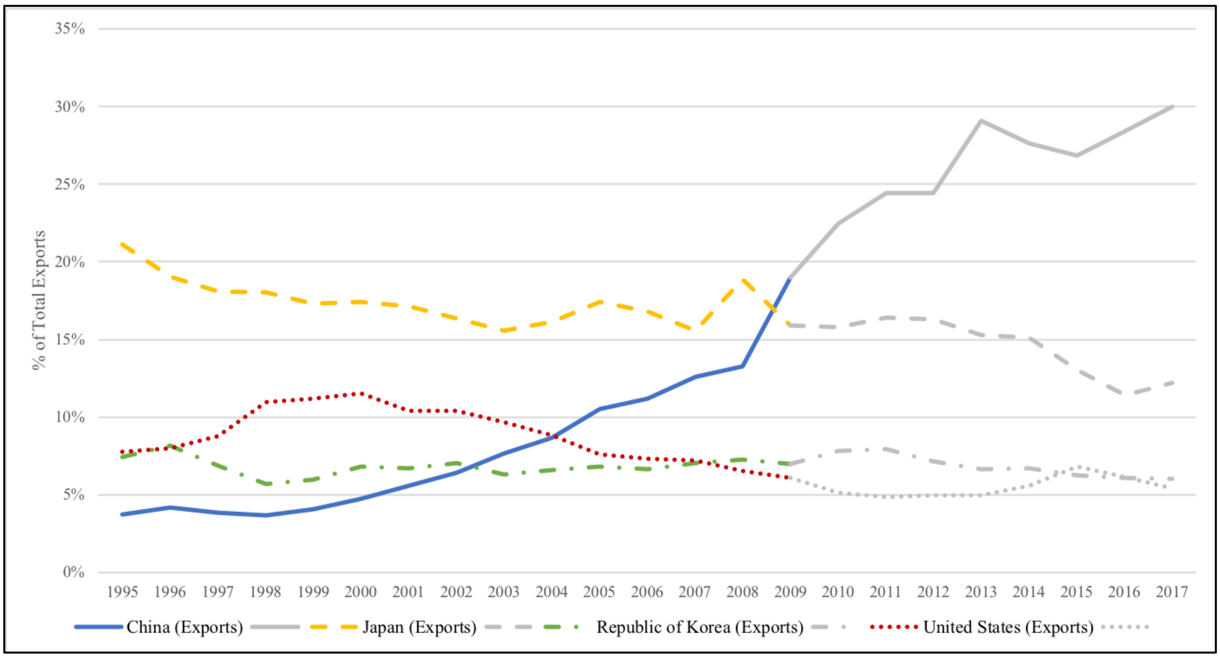
Source: World Bank (2019), Author's Construction

2.4 Australia's Trade Landscape

2.4.1 Major Trading Partners

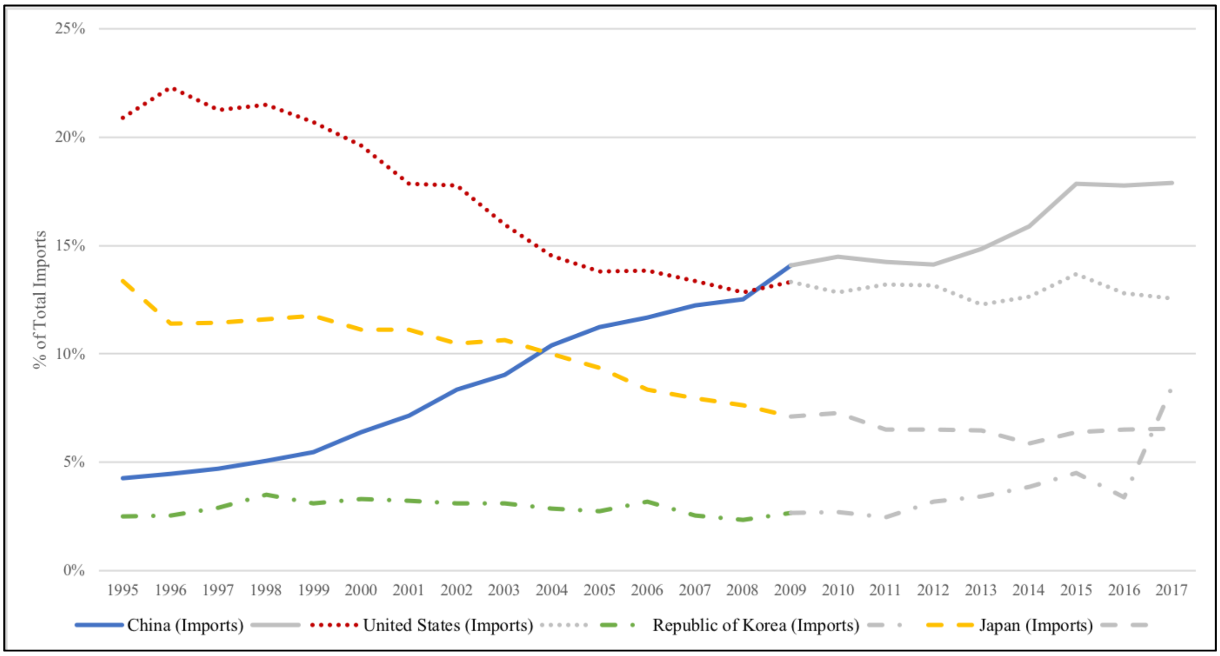
Australia's trade landscape has shifted considerably since federation (1901). Australia's colonial relationship with the UK led to a dominant trading relationship for the first half of the twentieth century. Aside from a short-lived period during World War II when imports from the US overtook the UK, this dominance lasted until the 1970s. Japan and the US then emerged as Australia's major import partners, whilst Japan's demand for coking coal drove their dominance as Australia's major export partner. However, the trading landscape shifted again during the period of this study (highlighted in colour below). Figures 2.8 and 2.9 illustrate this shift, showing Australia's top four trading partners (as at 2017) and their shares of imports and exports since 1995. This demonstrates the emergence of China as Australia's leading import and export partner. As Ville and Withers (2015) note, "Australia has set foot in the Asian century" (p.2).

Figure 2.8: Australia's Major Export Partners (1995 - 2017)



Source: DFAT (2019), Author's Construction.

Figure 2.9: Australia's Major Import Partners (1995 - 2017)

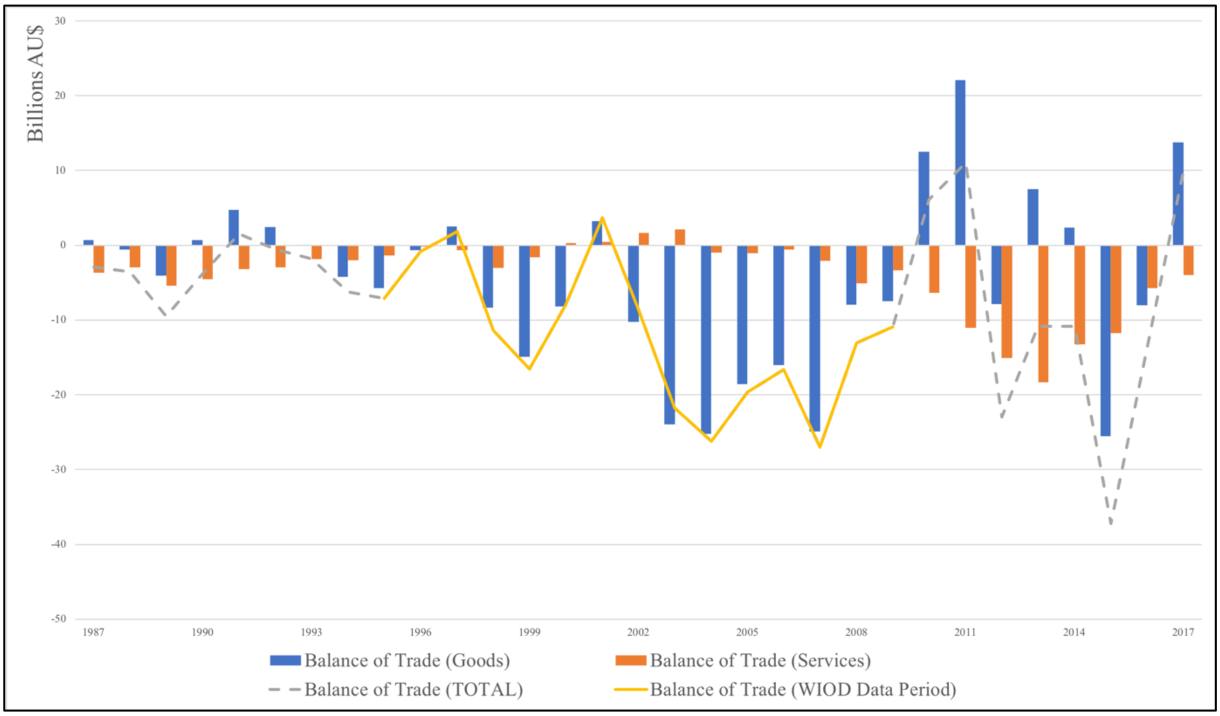


Source: DFAT (2019), Author's Construction.

2.4.2 Monetary Balance of Trade

Australia's balance of trade has remained largely negative since the late 1980s. Figure 2.10 outlines this trend, including the separate contribution of goods and services. This negative trend is unsurprising as Australia's economy has experienced continued economic growth in this period, including a large mining-driven economic boom in the early 2000s. Economic theory suggests that as real incomes rise during periods of economic growth (in well-functioning economies), demand increases, the consumption of goods and services grows, and the overall value of imports increases (Barro, 2007). This can sometimes result in a negative balance of trade.

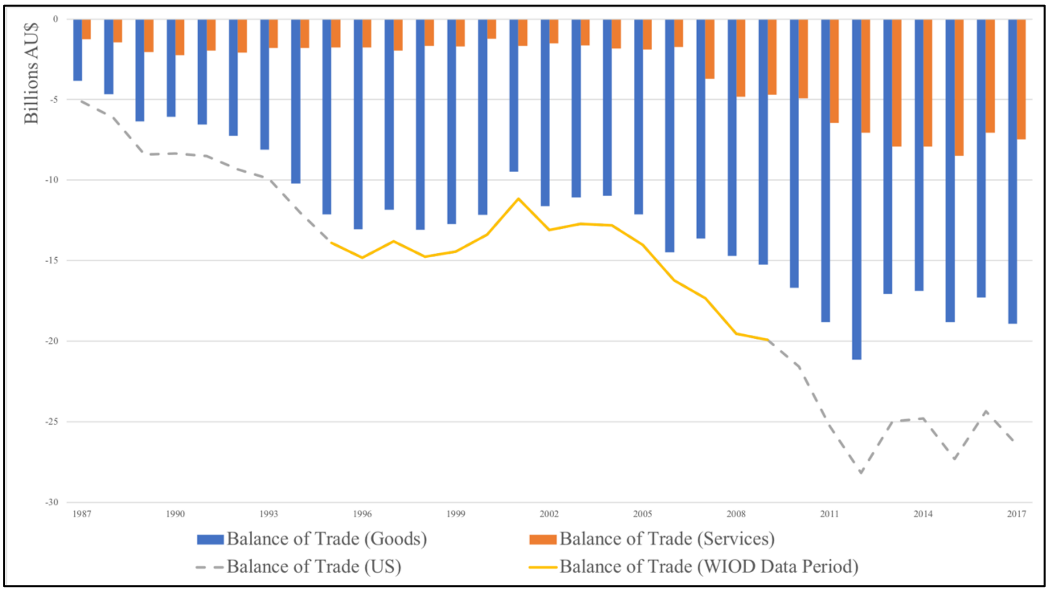
Figure 2.10: Australia's Balance of Trade (1987 - 2017)



Source: DFAT (2019), Author's Construction.

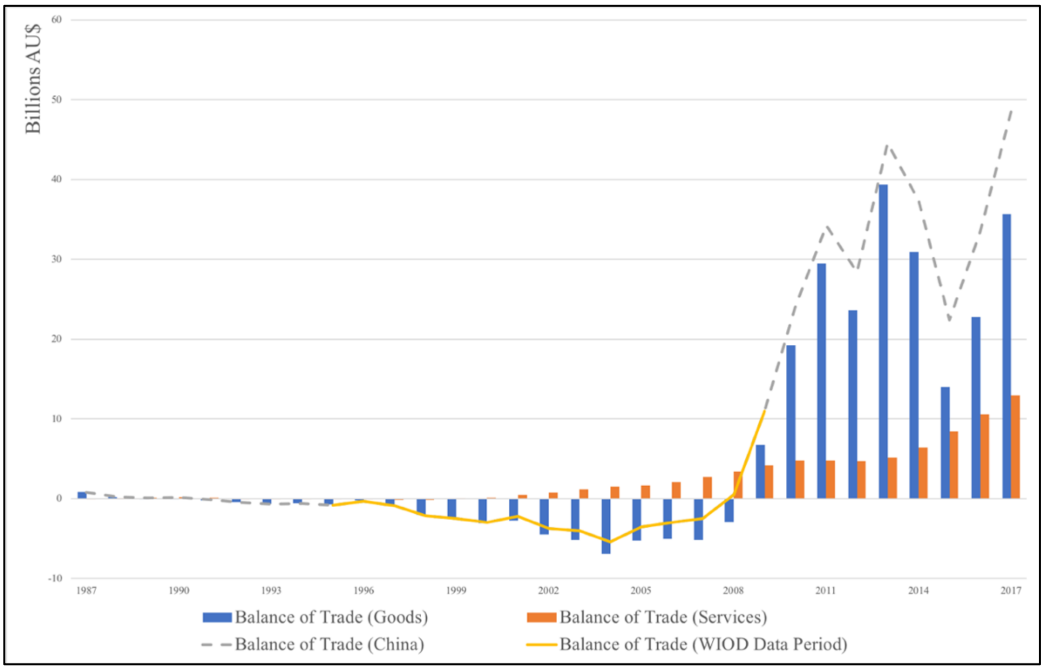
Figures 2.11 and 2.12 illustrate the country-specific balance of trade between Australia and China, and Australia and the US. The Australia/US balance of trade is increasingly negative since the late 1980s, driven most recently by a surge in services flowing into Australia. The Australia/China balance of trade reveals an increasingly negative balance in the period of this study, as China's trade liberalisation from 2001 resulted in a significant increase in Australian imports from China (largely consumer products, textiles and electronics). This trend shifted with the 2008 financial crisis as China implemented a large stimulus program and thermal coal imports from Australia rose dramatically. As Keating (2015) writes, "China's economic boom led to an Australian resources boom" (p.455). This created a rising trade surplus. However, long-term Chinese infrastructure investments designed to exploit domestic inland coal fields are now producing increasing coal output. As such, there is increasing anxiety that demand for Australian coal may begin to diminish (Farrer & Smee, 2019).

Figure 2.11: Australia's Balance of Trade with the US (1987 - 2017)



Source: DFAT (2019), Author's Construction.

Figure 2.12: Australia's Balance of Trade with China (1987 - 2017)



Source: DFAT (2019), Author's Construction.

2.5 Australia's Recent History of Climate Policy Failure

The Australian state and the coal industry have been deeply intertwined since settlement (Baer, 2016). In fact, Baer (2016) argues that "Australia's poor record in renewables is explicable in large part because of coal mining's dominance in the corporate/state nexus" (p.201). Krien (2017) also writes about these interlinkages, noting the many politicians who join mining companies and fossil fuel lobby groups after leaving public service. This intimate relationship, and the historic economic importance of the coal industry, crippled Australia's ability to design and implement an appropriate policy response to rising emissions. The fossil fuel industry and coal lobby in Australia, once self-described as the *Greenhouse Mafia,* has dominated public discussions and policy development for more than two decades (Pearse, 2009). This resulted in coordinated industry and political opposition to any significant mechanism designed to combat rising emissions (Baer, 2016, p.197). This also led to chaotic and hyper-political responses to climate-induced water crises and drought (Mercer et al, 2007 & Lucas, 2018). The vulnerability of Australia's 'rocks and crops' economy to international commodity prices no doubt also played a role in the initial failure of Australia to ratify the Kyoto Agreement (Mercer et al, 2007, p.273). However, it is the self-destructive politics surrounding energy and emissions policy that have caused long-term damage to Australia's ability to respond to climate change. A full account of the politics of the last decade can be found in Appendix B, but suffice to say Australia implemented and then removed a carbon pricing mechanism (2012-2014), instigated and removed a plethora of half-baked direct-intervention emissions policies, and had seven Prime Ministers in that time. This disastrous recent political history leaves Australia languishing behind the western world in regard to energy and emissions policies and serves as a stark backdrop to this study.

3 Literature & Theory Review

3.1 Growth, Production & the Environment

3.1.1 Economics & Externalities

Economic theory proposes that individuals and firms will choose the level of energy inputs based on the equalisation point of the marginal value product of energy and the marginal cost of energy inputs (Sachs, 1999). However, the marginal cost of energy does not equal the true social cost of energy, which includes the environmental damages that result from energy usage (ibid). Hence the environmental damage can be interpreted as an economic externality which leads to economic inefficiencies (Rezai et al, 1999). The framing of environmental damage as a negative externality is not new. The British economist Arthur Pigou proposed the idea of pollution as a negative externality in his 1932 book *The Economics of Welfare.* Written in response to terrible smog in London, Pigou's solution was to impose an "externality tax" to internalise the externalities in the price of a good. This is now known as a "Pigouvian tax" (Owen, 2004). In the face of the rising threat of climate change, greenhouse gas emissions can be interpreted as a classic case of a negative economic externality. In this context, a number of largely western nations have imposed a market-based response such as a carbon tax or emissions trading scheme. These are designed to equalise the marginal cost of energy with the true social cost. From an economic perspective it is hard to argue with Nobel Prize winning economist Joseph Stiglitz (2006) when he writes that "not paying the cost of damage to the environment is a subsidy, just as not paying the full costs of workers would be" (p.2). Unfortunately, not all nations have imposed a market-based response to rising emissions. As a result, some countries with carbon taxes have explored charging import fees on goods that arrive from countries without carbon pricing mechanisms, known as carbon border adjustments. Whilst the efficacy of this approach is debated (see Jakob et al, 2014; Foure et al, 2016; and Rocchi et al, 2018), it highlights the continued attempts of the international community to address this negative externality, and the complexity involved in the role of international trade as a pillar of economic growth.

3.1.2 The Environmental Kuznets Curve

The links between production, economic growth and environmental degradation have been well studied (see Panayotou, 1993; Grossman & Kruger, 1991 & 1994; Stern, 2004; Copeland & Taylor, 2004; Mehra & Das, 2008; Afionis et al, 2017, and many more). Much of this research has examined the pattern of environmental degradation through a state's development process. Grossman & Kruger (1991, 1994) and Panayotou (1993) famously proposed the Environmental Kuznets Curve (EKC) hypothesis, describing an inverted U-shaped relationship between various environmental indicators and income per capita. Adopting the famous pattern of inequality proposed and developed by Simon Kuznets (1955, 1965, 1966), Grossman & Kruger (1991, 1994) and Panayotou (1993) insist that there is no evidence that environmental degradation continuously increases with economic growth. Rather, they identified a *turning point* where economic growth actually improves environmental quality. Beckerman (1992) argues strongly for this thesis, claiming brashly that "the best – and probably the only – way to attain a decent environment in most countries is to become rich" (p.482). However, many empirical EKC studies focus on a limited range of environmental indicators. For example, Grossman and Kruger (1994) assess urban air pollution, alongside oxygen levels in river basins, and concentrations of faecal matter and heavy metals in river basins. Crucially, the study does not cover CO_2 emissions. Furthermore, much of the empirical evidence for the EKC is deeply contested (see Shabaz & Sinha, 2017).

Given the above, how should we interpret the value of the EKC? Galeotti and Lanza (2005) assess a range of studies of CO_2 emissions and economic growth and the best they can conclude is that a bell-shaped EKC relationship is "a possibility that cannot be ignored" (p.1387). In contrast, Stern (2004) shows that despite some pollutants exhibiting an EKC-like form, many EKC results have a "very flimsy statistical foundation" and that skepticism is required with many of the broad claims based on a hypothetical EKC (p.1419). Copeland and Taylor (2004) express similar skepticism. Furthermore, from an econometric perspective, Stern et al (1996) argue that the reduced form model of many EKC studies makes them unsuitable as a policy tool (p.1159). However, despite this disagreement (or perhaps because of it), the EKC remains a potent area of study. Part of the persistence of the hypothesis can be attributed to the broad range of potential theories that underpin it. The original theory of the EKC was based on the changing nature of emissions intensity across a society's economic transition, from an agricultural to manufacturing economy, and then subsequently to a service economy

(Panayotou, 1993). Alternatively, Galeotti & Lanza (2005) argue that, as a country becomes richer, technological progress allows them to substitute dirty technology for cleaner alternatives. Finally, Antweiler et al (2001) and Cole (2004) explore the role of free trade and emissions displacement as the underpinning mechanism of the EKC hypothesis. If countries in the development process increasingly outsource their emissions through foreign trade, then this may be the driver of the downwards trajectory of the EKC. Antweiler et al (2001) find that freer trade is net-positive for the environment, whilst Cole (2004) finds little contributory effect of trade on the EKC. They are followed by a broad range of more recent country-specific studies which find an important role for trade in emissions and environmental degradation (see He, 2009; Ozatac, 2017; Rana, 2019). Given the deeply contested empirical results surrounding the EKC hypothesis, it is safe to say there can be no universal application of the thesis. Furthermore, given the mixed results for the influence of trade, it is clear that a deeper understanding is needed of the role of the fragmented and globalised production processes.

3.1.3 Spiders, Snakes & Globalised Production

Gereffi (1999) writes that "the explosive growth of imports in developed countries indicates that the center of gravity for the production and export of many manufactures has moved to an ever-expanding array of newly industrializing economies" (p.37). This has involved the wholesale *offshoring* of production to lower cost environments.[1] Taking the textile industry as an example, Gereffi (1999) describes waves of production migration since the 1950s; initially from Europe and the US to Japan (1950s & 1960s), then from Japan to Hong Kong, South Korea and Taiwan (1970s & 1980s) and finally from these big three producers to China, South East Asia and even Latin America (1980s & 1990s) (p.49). Furthermore, driven by the collapsing cost of transportation, communication and coordination, Timmer et al (2004) explain how international *fragmentation* of production has also increased significantly since the early 1990s. Baldwin and Venables (2013) describe the archetypal shapes of this fragmentation as like snakes and spiders, with snakes involving linear production processes across multiple locations and spiders involving the production and assembling of parts in no particular order. Initially this fragmentation took place largely within regional areas, however since 2000 the

[1] Feng et al (2012) also show that distributed production can occur *within* countries, describing the shift of the manufacturing sector to poorer regions of China.

fragmentation has become truly global, with developing countries increasingly becoming suppliers of intermediate products (Timmer et al, 2004, p.106). As Los et al (2015) note, "there is consensus that the network of international trade in intermediate inputs, including parts and components, natural resources and services, has become increasingly dense" (p.67). The nature of this globalised production can be described using a simplified model for the production of a car in Germany. Firstly, bauxite is mined in Australia and then processed into raw aluminium in China. The car is then produced in Germany and sold in the US (Wiedmann & Lenzen, 2018, p.314). Ultimately, through the expansion of freer trade and collapsing transaction costs, a "global factory" has emerged with vastly distributed and fragmented production (Buckley & Ghauri, 2004).

In the context of this fragmented production, Ederington and Minier (2003) note that both environmental activists and labour unions have long advocated for the extension of free trade agreements to cover common environmental standards and labour conditions (p.139). Advocates argue that it is unfair for countries to gain a potential comparative advantage in these critical areas of human dignity and environmental sustainability. Economists argue that without free trade deals covering some domestic policy areas these domains may be used as a secondary means of protectionism (so-called "second-best" models, see Ederington & Minier, 2003). Whilst previous research finds little empirical support for a "second-best model" in regard to environmental regulation (see Grossman & Kruger, 1994, Low & Yeats, 1992 etc), Ederington and Minier (2003) argue that environmental policy may have a greater impact on net import levels than previously thought (p.149). Ultimately, the emergence of increasingly globalised and fragmented production has deep implications for the study of emissions. Grether and Mathys (2010) potently argue that "by disconnecting production from consumption sources, international trade leads to a worldwide distribution of polluting emissions" (p.19). A subject to which this thesis now turns.

3.2 Trade & Emissions Displacement

3.2.1 The Pollution Terms of Trade

Antweiler (1996) proposes a simple question, "do countries gain or lose environmentally from engaging in international trade?" (p.361). In an attempt to answer this question, Antweiler (1996) presents the idea of the pollution terms of trade (PTT), a simple ratio of the pollution content of $1 of exports to $1 of imports. Grether and Mathys (2010) argue that this measure of relative pollution intensity creates an effective international exchange rate of emissions, allowing for a genuine comparison between countries of differing sizes and industries (p.21). Due to a lack of international environmental and technology data at the time, Antweiler (1996) utilises a US technology matrix and standardises these technology factors across all countries. This likely explains the rather paradoxical finding that developed countries tend to have a high PTT. However, on a 100-point index, Antweiler (1996) finds that Australia's PTT is 51.8 indicating that the pollution content of $1 imports is almost twice as large as the pollution content of $1 of exports. In a follow up study, Grether and Mathys (2010) apply new data and updated methods that reverse the seeming paradox in Antweiler's (1996) original study. Grether and Mathys (2010) focus on SO_2 emissions and find that Australia's PTT increased from 1.7 in 1990 to 2.6 in 2000 (p.30). This indicates that Australia's exports were becoming more emissions intensive over time. By removing trade volumes as a factor and relying on a simple ratio, Grether and Mathys (2010) argue that the PTT is an effective long run structural indicator. Davis and Caldeira (2010) utilise the first part of the pollution terms of trade, known as the carbon intensity of trade. This is defined as the kg of CO_2 per $ of imports or exports. Davis and Caldeira (2010) show that the carbon intensity of exports from Western Europe and Japan are low compared to emerging markets such as Russia, China and India (p.5688). However, the PTT and the carbon intensity of trade does not allow for the examination of total emissions, nor does it address the role of differing environmental regulations. Thus, this study now turns to the nature of carbon leakage.

3.2.2 Carbon Leakage & the Pollution Haven Hypothesis

Grether and Mathys (2010) note that "in an increasingly integrated but highly heterogeneous world, international trade leads to a spatial distribution of pollution across countries" (p.28). Although production emissions in many developed countries have stabilised or even begun to reduce, emissions in developing countries continue to rise dramatically (Peters et al, 2011, p.8903). In a comprehensive study of emissions transfers between 1990 and 2008, Peters et al (2011) find that emissions from the production of traded goods increased from 20 to 26 per cent of global emissions from 1990 to 2008 (p.8903). Davis and Caldeira (2010) find a similar figure of 23 per cent in 2004 (p.5687). These emissions transfers can be described as a form of carbon leakage. Although it is clear that there is an increasing transfer of global emissions, the cause and drivers of these transfers remains uncertain.

To assist in navigating this complexity, the literature describes two forms of carbon leakage: strong and weak (Peters et al, 2011). Strong carbon leakage, also known as policy-induced displacement, is defined as the increase in emissions in non-Annex B countries divided by the decrease in emissions in Annex-B countries (Peters & Hertwich, 2007).[2] This measures the production that actually shifts (rather than simply expands) from developed to developing countries, due to environmental regulation. Strong carbon leakage is underpinned by the *pollution haven hypothesis*. This states that increasing environmental regulatory powers in developed countries, combined with the liberalisation of trade, will incentivise polluting industries to shift to the developing world (Levinson & Taylor, 2008). This hypothesis is notoriously difficult to measure empirically. As Ferguson and Sanctuary (2019) note, "despite an intuitive appeal, empirically evaluating the leakage mechanism has proven difficult" (p.2). However, by reassessing the connection between abatement costs and trade flows, Levinson and Taylor (2008) find that the effect of increased pollution abatement costs is positive on imports in that sector, indicating domestic production may indeed shift to countries with lower environmental regulatory costs (p.249). Despite this, Copeland and Taylor (2004) caution that a pollution haven *effect* can be evidenced without the pollution haven *hypothesis* being proved

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[2] Annex B countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC) who have agreed to specific emissions targets under the Kyoto Protocol.

(p.9). In other words, the pollution haven effect is one of many trade factors and there is little empirical evidence to show that it is the dominant factor (ibid, p.67).

Weak carbon leakage refers to the total emissions embodied in imports in Annex B countries that originated in non-Annex B countries (Peters & Hertwich, 2007). This weak definition can be described as the broader displacement thesis and is much more commonplace in the literature. It fulfils a critical role in determining the relationship between consumption in developed countries and emissions in developing countries without sufficient environmental policies (Peters & Hertwich, 2007, p.1402). Weak carbon leakage will be measured in this study. This brings this thesis to the consumption and production nature of carbon emissions themselves, and the ethical question of who is ultimately responsible?

3.3 Consumption & Production Emissions

The dramatic expansion of international trade and the increased potential for carbon leakage generated significant debate in the literature regarding the responsibility for emissions and associated measurement techniques (Afionis et al, 2017; Fan et al, 2016; Davis & Caldeira, 2010; and many more). The traditional measurement technique, upon which all international agreements are based, is known as Production Based Accounting (PBA) (Levitt et al, 2017). PBA assigns responsibility for all emissions to the country where those emissions were generated. Hence, PBA is calculated as the sum total of all emissions produced within a geographic territory. Using PBA, some developed countries have reported "substantial reductions in territorial carbon emissions in combination with sustained economic growth" (Jiborn et al, 2018, p.27). These countries, where GDP continues to rise, argue there has been a "decoupling" of emissions and economic growth (see Andersson & Lövin, 2015; and Obama, 2017). However, PBA excludes emissions from international air and sea transportation and does not cater for the aforementioned role of carbon leakage (Franzen & Mader, 2018). Given this context, Levitt et al (2017) remind us "measures of emissions might be artificially low if a country is importing goods with significant GHG content" (p.211).

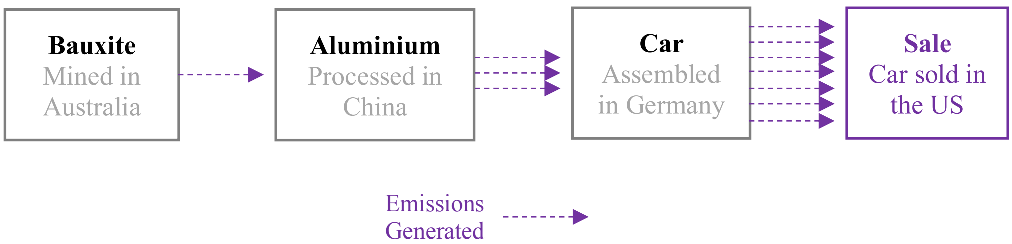
In response to the inherent deficiencies of the PBA methodology, the Consumption Based Accounting (CBA) methodology was developed. In contrast to PBA, the CBA approach assigns responsibility for emissions generated from production to the country in which final goods are consumed. In technical terms, CBA is calculated as PBA plus the emissions embodied in imports, minus the emissions embodied in exports (Suh, 2009). From an intuitive perspective, it is argued that those who benefit from a process (in the act of consumption) should carry responsibility for associated emissions (Davis & Caldeira, 2010). Minx et al (2009) describe CBA as the true measure of a country's "carbon footprint" (p.187). Global production is largely driven by consumption patterns (Muridian et al, 2002) and Afionis et al (2017) frame this as a question of justice and equity, noting that it is largely the increasing consumer demand in the affluent West that is placing the environment under unsustainable pressure. As such, these consumer countries should bear the responsibility for associated emissions. Afionis et al (2017) also raise the historical aspect of emissions responsibilities and the "ecological debt" generated by industrialised states as an argument for developed nations to now take greater responsibility (p.6). Critique of CBA centres around a range of technical concerns and the inherent complexities of the measurement methodology, alongside obvious political limitations (ibid). Due to these concerns, despite the theoretical advantages of this methodology, CBA is unlikely to replace PBA as the global measurement standard (ibid). However, CBA retains an important role in allowing a greater understanding of the global flow of emissions and the role of international trade.

Baumert et al (2018) write that "two competing narratives about carbon emission trends in developed countries are found in the literature" (p.228). The first is positive, centred around PBA and the stagnating or declining emissions across many developed countries. The second is negative, based on CBA and the dramatic increase in consumption emissions in these same countries. Boitier (2012) describes this reality as an increasing "CO_2 consumption surplus", where nations' CBA emissions now increasingly outnumber PBA emissions (p.8). Peters et al (2011) concur, writing that "most developed countries have increased their consumption-based emissions faster than their territorial emissions" (p.1). In response to this reality we clearly need to "expand the scale of analysis beyond the national political frontiers." (Muridian et al, 2001, p.52). In order to do this, this thesis introduces the balance of emissions embodied in trade.

3.4 The Balance of Emissions Embodied in Trade (BEET)

The nature of emissions embodied in trade can be highlighted by revisiting the simple example of the production of a German car, presented earlier in section 3.1.3. The emissions associated with each step in the production process (bauxite mining in Australia, manufacturing in China and the assembly in Germany), becomes embodied in the car itself (Weidmann and Lenzen, 2018). These embodied emissions are then transferred to the point of sale in the US (see figure 3.1 below).

Figure 3.1: The Nature of Emissions Embodied in Trade



In order to measure and understand international emissions flows we can utilise the balance of emissions embodied in trade (BEET) methodology. The BEET is the difference between PBA and CBA emissions. This is equal to the difference between emissions embodied in exports (EEE) and emissions embodied in imports (EEI). As Davis and Caldeira (2010) summarise, "a positive difference reflects the net export of emissions and a negative value indicates the net import of emissions" (p.5687).

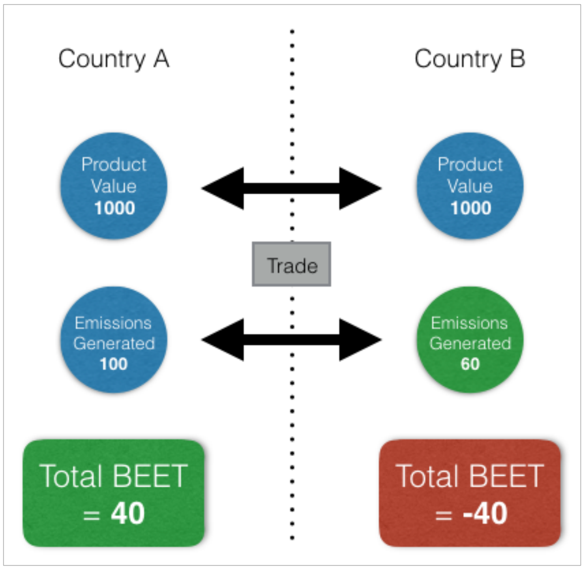
The dominant theme in studies examining the BEET is the increasing divide between developed countries as net importers of emissions and developing countries as net exporters of emissions (Peters et al, 2011; Boitier, 2012; Kanemoto et al, 2014; and many more). Boitier (2012) finds that the surplus of CBA emissions in the OECD has increased from 531 $MtCO_2$ in 1998 to 1,200 $MtCO_2$ in 2008, and a comparable deficit in BRIC countries growing from 980 $MtCO_2$ in 1995 to 2,230 $MtCO_2$ in 2008 (p. 10). Kanemoto et al (2014) conclude that "the shifting of CO_2 emissions from developed to developing countries is a substantial and growing problem" (p.52). However, more recent studies from Pan et al (2017) and Meng et al (2018) find that the difference between CBA and PBA emissions in developed countries has actually narrowed since 2007, largely due to the plateauing of emissions imported from developing countries. The most significant example of this structural shift is the reduction of emissions embodied in exports from China (-229MtCO2) between 2007 and 2012 (Pan et al, p. 936). These recent changes in BEET between developed and developing countries will be addressed in the analysis undertaken in this thesis.

The BEET methodology provides an important window on the quantative difference between a country or region's emissions embodied in trade over time. However, there are some challenges. Firstly, Lenzen et al (2007) argue that the principles of PBA and CBA are too purist and result in inevitable double counting of emissions (p.31). Instead, Lenzen et al (2007) propose a shared-responsibility model between producers and consumers. Secondly, the role of technology differences between nations and regions also create challenges to the interpretation of the BEET output. To address this second concern, this thesis turns to the technology-adjusted BEET.

3.5 Technology-Adjusted BEET (TBEET)

Jiborn et al (2018) and Baumert et al (2019) propose a technology-adjusted approach to the BEET methodology. They argue that the BEET method fails to "distinguish properly between different drivers of imbalances in flows of embodied emissions and are therefore misleading" (Jiborn et al, 2018, p.27). For true emissions displacement to occur, foreign trade must reduce domestic emissions and increase emissions abroad. However, a negative BEET can result from a difference in emissions intensive technology that actually does not result in an increase in emissions abroad (Jiborn et al, 2018, p.28). Utilising the work of Jakob and Marschinski (2013), Jiborn et al (2018) show that if a country has a less emissions intensive system of production than their trading partner, "even an exchange of exactly identical bundles of goods will result in a deficit in emissions embodied in trade" (p.28). Despite a negative BEET, this is clearly not an example of emissions displacement. Figure 3.2 illustrates the hypothetical trade of identical products between Country A and Country B. This reveals that the BEET methodology can mistake differences in emissions intensities (technology) for a structural imbalance of imports and exports (outsourcing).

Figure 3.2: BEET and Technology Differences (trading identical products)



Author's Construction, adapted from Baumert et al (2019)

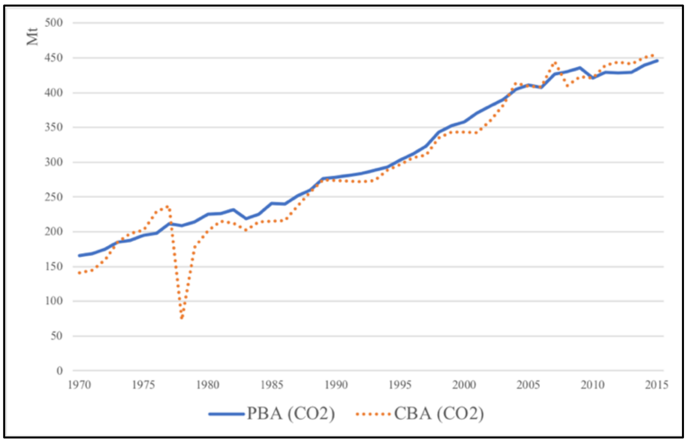
Baumert et al (2019) delve further and highlight the hypothetical case of a country with a high proportion of renewable energy in their energy mix that specialises in heavy industry exports and imports less energy intensive products (p.229). In this scenario the country could have a negative BEET despite their trading activity resulting in an actual *reduction* in global emissions (when compared to a no-trade scenario) (ibid, p.229). In order to correct for this and to focus the analysis on the scale and composition of the trade balance, Jiborn et al (2018) and Baumert et al (2019) propose to standardise carbon intensities using a world average for each sector across all countries. This simple adjustment is likened to correcting GDP accounts for inflation, allowing us to more deeply examine the drivers of emissions outsourcing (Baumert et al, 2019, p. 230).

The TBEET methodology has real-world effects. Jiborn et al (2018) find that outsourcing is actually less problematic than assumed under the BEET model. In one clear example, Baumert et al (2019) discover that the EU-27 actually has a positive TBEET, in contrast to previous studies that found a negative BEET (e.g. Peters et al, 2011). The TBEET method cancels out "irrelevant effects of general differences in energy systems and production technologies between countries" (Jiborn et al, 2018, p.29). Hence, the EU-27's negative BEET can be explained by increasingly emissions efficient production methodologies, rather than trade driven emissions outsourcing (Baumert et al, 2019, p.231). Both Jiborn et al (2018) and Baumert et al (2019) conclude that the global outsourcing of emissions is not always environmentally damaging. The TBEET methodology highlights that if countries with emissions intensive energy sources import their heavy industry goods from countries with ample renewable energy resources, then the climate will ultimately benefit (compared to a no-trade scenario). This would result in a more efficient and effective carbon distribution of global production and the planet would ultimately benefit (Baumert et al, 2019, p.235). Of course, this is unfortunately often not the case, with countries like Sweden and the UK, with relatively efficient modes of production (UK) and access to renewable energy resources (Sweden), increasingly importing energy intensive goods (Jiborn et al, 2018). Ultimately, the TBEET framework acts as a complement and extension to the BEET method.

3.6 The Australian Context & Scope of Work

Many studies have included Australia in comparative PBA and CBA emissions analysis (e.g. Peters & Hertwich, 2007; Davis & Caldeira, 2010; Arto et al, 2014). As an example, in a single-year study of PBA and CBA in 2001, Peters and Hertwich (2007) discover that Australia is one of only nine Annex-B countries that have higher PBA emissions (351MtCO_2) when compared to CBA (293.7MtCO_2). Moving forward in time, Davis and Caldeira (2010) find that Australia actually has the fourth highest CBA emissions per capita in 2004. In a comparative multi-year study, Arto et al (2014) find that whilst Australia had an emissions trade surplus in 1995, this turned into a deficit by 2009 (p.521). This aligns with the long-term work of the Eora database which shows that after a long period of a positive BEET for CO_2, Australia's BEET turned negative in 2006 (see figure 3.3; Moran et al, 2018).

Figure 3.3: CO_2 Emissions Per Capita, PBA & CBA (1970 - 2015)



Source: Eora (Moran et al, 2018), Author's Construction

There have also been a small number of Australia-specific studies (Lenzen, 1998; Wood, 2009). Levitt et al (2017) provide the most recent and comprehensive analysis of Australia's PBA and CBA emissions. Utilising the World Input Output Database (WIOD) and input-output analysis, Levitt et al (2017) examine Australia's CBA emissions from 1995 to 2009. The study finds that "emissions embodied in Australian imports have increased and have become more emission intensive" (Levitt et al, 2017, p.213). Australia's CBA emissions increased by 38% between 1995 and 2009, with an accelerating growth rate after 2000 (ibid, p.220). Australia's PBA emissions also rose but grew less slowly than CBA after 2001.[3] Levitt et al (2017) also highlight that there was a 1-year decline in CBA in 2008 which was likely due to the Global Financial Crisis (p.222). Ultimately, Levitt et al (2017) show that Australia shifted from being an emissions exporter to emissions importer over the study period and conclude that this is largely due to the changing nature of Australian trade with China. These findings align with Baumert et al (2019) who calculate Australia's BEET and TBEET as part of a comparative multi-year study utilising the WIOD dataset over the period 1995 to 2009. Baumert et al (2019) also show that Australia exhibited "a strong shift towards outsourcing during the period" (p.231).

The purpose of this thesis is to contribute to the relatively small group of Australia-specific studies and to analyse Australia's emissions history utilising PBA, CBA, BEET and TBEET methodologies. This thesis extends and deepens Levitt et al's (2017) work by including the newly developed TBEET methodology. As a single-country study, this thesis also contributes by focusing the work of Jiborn et al (2018) and Baumert et al (2019) on Australia's unique context. Finally, this thesis employs very recent data (Kulionis, 2019) and introduces an innovative extension model to address the period between 2009 and 2014.

[3] CBA emissions grew 4.5% per year between 2001-2005, compared to growth rates of less than 1% for PBA emissions in this same period (Levitt et al, 2017, p.222).

4 Data

4.1 World Input Output Database (WIOD)

4.1.1 Introduction

The study of trade flows and emissions transfers can be conducted using input-output (IO) analysis and IO tables. Since the mainstreaming of IO analysis across economics, a large range of multi-region IO tables have emerged. These include Eora, GTAP, OECD-Tiva, Exiobase and the World Input-Output Database (WIOD). For a range of reasons, including homogeneity of sectors across countries, adequate sector resolution, time-period, and ease of use, this study utilises the 2013 release of WIOD (Timmer et al, 2015).[4] WIOD13 includes a number of sub-databases which cover 41 countries (including *Rest of World*, ROW) and 35 sectors for the period 1995 to 2009. Appendix C lists the full range of countries and sectors included. This study utilises two sub-databases, the World Input Output Table and Environmental Accounts.

4.1.2 World Input Output Table

The World Input-Output Table (WIOT) is the central table in WIOD13, consisting of data from national statistics offices and international bodies (IMF, OECD, UN Comtrade etc). The complete WIOT has the dimensions of 1443 rows by 1641 columns and an outline is shown below (see table 4.1). This table is made up of a 1435 by 1435 interindustry matrix (shown in green below) consisting of 1435 country-industry pairs (41 countries with 35 sectors). There are also 205 Final Demand (FD) columns which include 5 different types of FD for each of the 41 countries (orange). For the purposes of this study the FD is aggregated to form 41 FD columns. Finally, summing across rows or columns yields the output (x). All WIOT data are expressed in US dollars utilising market exchange rates (MER).

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[4] There is a more recent (2016) release of WIOD, however this release does not yet contain data on CO_2 emissions. This updated database is utilised in the extension model presented in section 7, to cover the period to 2014.

Table 4.1: WIOT Overview

		Intermediate Consumption									Final Demand			
		Australia (A)			**Country 2 (B)**			**Country 41 (ROW)**			**A**	**B**	**ROW**	Output (x)
		Sector 1	…	Sector 35	Sector 1	…	Sector 35	Sector 1	…	Sector 35	fA	fB	fROW	
A	Sector 1	$Z_{AS1,AS1}$	…	$Z_{AS1,AS35}$	$Z_{AS1,BS1}$	…	$Z_{AS1,BS35}$	$Z_{AS1,ROWS1}$	…	$Z_{AS1,ROWS35}$	fA_{AS1}	fB_{AS1}	$fROW_{AS1}$	X_{AS1}
	…	…	…	…	…	…	…	…	…	…	…	…	…	…
	Sector 35	$Z_{AS35,AS1}$	…	$Z_{AS35,AS35}$	$Z_{AS35,BS1}$	…	$Z_{AS35,BS35}$	$Z_{AS35,ROWS1}$	…	$Z_{AS35,ROWS35}$	fA_{AS35}	fB_{AS35}	$fROW_{AS35}$	X_{AS35}
B	Sector 1	$Z_{BS1,AS1}$	…	$Z_{BS1,AS35}$	$Z_{BS1,BS1}$	…	$Z_{BS1,BS35}$	$Z_{BS1,ROWS1}$	…	$Z_{BS1,ROWS35}$	fA_{BS1}	fB_{BS1}	$fROW_{BS1}$	X_{BS1}
	…	…	…	…	…	…	…	…	…	…	…	…	…	…
	Sector 35	$Z_{BS35,AS1}$	…	$Z_{BS35,AS35}$	$Z_{BS35,BS1}$	…	$Z_{BS35,BS35}$	$Z_{BS35,ROWS1}$	…	$Z_{BS35,ROWS35}$	fA_{BS35}	fB_{BS35}	$fROW_{BS35}$	X_{BS35}
ROW	Sector 1	$Z_{ROWS1,AS1}$	…	$Z_{ROWS1,AS35}$	$Z_{ROWS1,BS1}$	…	$Z_{ROWS1,BS35}$	$Z_{ROWS1,ROWS1}$	…	$Z_{ROWS1,ROWS35}$	fA_{ROWS1}	fB_{ROWS1}	$fROW_{ROWS1}$	X_{ROWS1}
	…	…	…	…	…	…	…	…	…	…	…	…	…	…
	Sector 35	$Z_{ROWS35,AS1}$	…	$Z_{ROWS35,AS35}$	$Z_{ROWS35,BS1}$	…	$Z_{ROWS35,BS35}$	$Z_{ROWS35,ROWS1}$	…	$Z_{ROWS35,ROWS35}$	fA_{ROWS35}	fB_{ROWS35}	$fROW_{ROWS35}$	X_{ROWS35}
	VA	VA_{AS1}	…	VA_{AS35}	VA_{BS1}	…	VA_{BS35}	VA_{ROWS1}	…	VA_{ROWS35}				
	Output (x)	X_{AS1}	…	X_{AS35}	X_{BS1}	…	X_{BS35}	X_{ROWS1}	…	X_{ROWS35}				
1435 Rows		1435 Columns									41 Columns			1 Column

Author's Construction

Whereas the full WIOT contains 41 countries, the above simplified WIOT contains just three: Australia (A), Country 2 (B) and Country 41 (ROW). This table also shows only 2 of 35 sectors in each country. Hence, $Z_{AS1, AS1}$ represents domestic intermediate trade within sector 1 in Australia. $Z_{AS1,BS35}$ indicates intermediate trade from sector 1 in Australia to sector 35 in Country 2 (*exports* from A to B). Similarly $Z_{BS1,ROW35}$ represents intermediate trade from sector 1 in B to sector 35 in ROW. fA_{AS1} indicates the domestic final consumption from sector 1, whilst fB_{AS1} represents the exports from sector 1 in Australia for final use in B.

4.1.3 Environmental Accounts

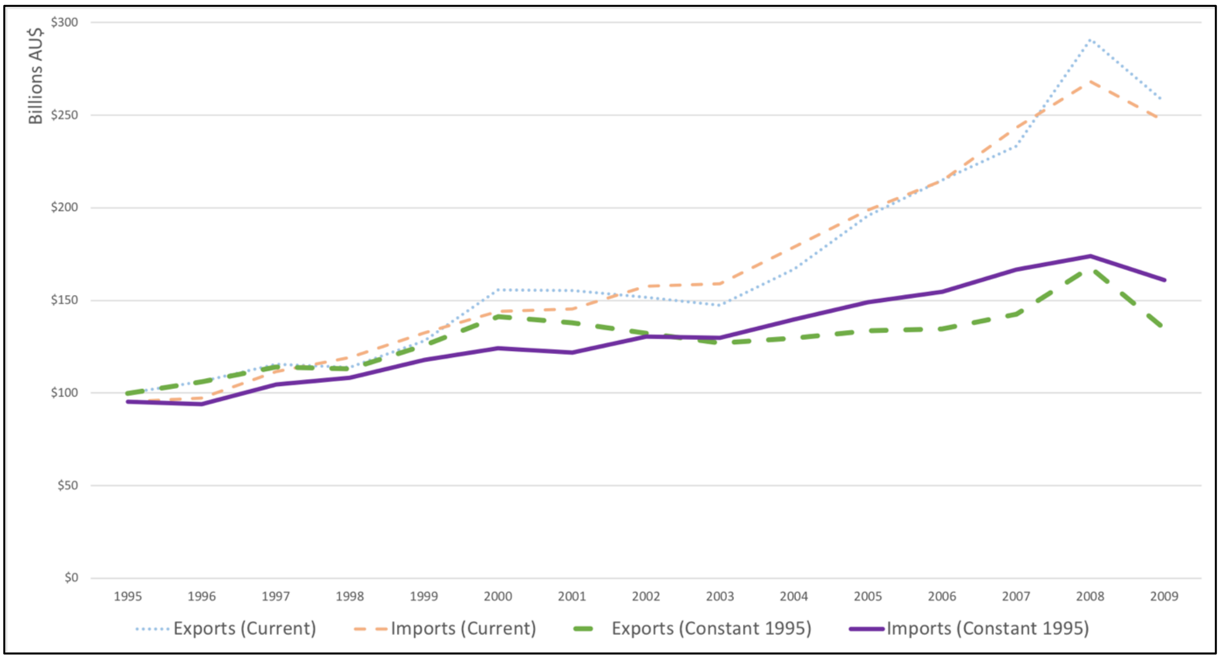
WIOD13 includes a range of environmental (satellite) accounts, including energy use, air pollutants, mineral and fossil resources, water use, land use and greenhouse gases, including CO_2 emissions (Genty et al, 2012). These satellite accounts accompany production and trade between all 35 sectors and 41 countries and were constructed using data from the UNFCCC, the Emissions Database for Global Atmospheric Research (EDGAR) and Eurostat. This study makes exclusive use of the CO_2 emissions data, which is expressed in 1000 tonnes.

4.2 Monetary Data

4.2.1 Current & Constant Prices

WIOD13 is reported in current prices. Emissions output is produced using this core data as per the method employed by Jiborn et al (2018) and Baumert et al (2019). This enables macro-level cross-study comparisons. However, when calculating the value of imports and exports, emissions intensities, pollution terms of trade, and the decomposition of TBEET, this thesis converts all data to constant 1995 prices. This study utilises sector-level industry deflators to convert Australia's export data, and country-level deflators to convert Australia's import data (deflators provided in WIOD13's social accounts). These conversions control for changes in relative prices and ensure that this study tracks changes in emissions rather than changes in relative prices between trading partners. The impact of the constant price conversion is the stabilisation of growth of both imports and exports (see figure 4.1). Appendix D provides a detailed description of the constant price conversion method employed here.

Figure 4.1: Import and Export Values (Current and Constant Prices, AU$)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

4.2.2 Exchange Rates

Trade is reported in WIOD13 as US dollars, converted using Market Exchange Rates (MER) for each country. The main alternative conversion technique is Purchase Power Parity (PPP) which includes the purchasing power of money in each country, manifested as the price of a common basket of goods. The PPP conversion can highlight significant challenges with the MER method, especially when comparing developing and developed countries. In response, Weber and Matthews (2007) use PPP and MER as lower and upper bound estimates in their analysis of emissions flows. Jakob and Marschinski (2013) directly preference PPP over MER, arguing that MER underestimates the output of developing countries (p.3). Ultimately, the true value of imports and exports lies somewhere between PPP and MER estimates. For the purposes of this study, due primarily to data availability, this thesis utilises MER prices as reported in WIOD13. Whilst the use of MER introduces some uncertainty, it does not materially affect the narrative emerging from this study. However, it is worth noting that Australia's trading partners from the developing world may seem less environmentally efficient than they actually are. Finally, this study follows Levitt et al (2017) and converts prices back into Australian dollars (AU$), utilising exchange rates from the World Bank's Global Economic Monitor (GEM) database. This conversion to AU$ is important as significant currency fluctuations in the study period create difficulties when interpreting carbon intensity results in US$.[5] Appendix D provides a detailed outline of this challenge and the importance of the conversion back into AU$.

4.3 Assumptions & Uncertainties

There are a range of inherent uncertainties and assumptions in the construction and use of IO tables, interlinked with the challenge of harmonising large data sets across countries, time and currencies (see Barrett et al, 2013 & Levitt et al, 2017). The first challenge is the collection of countries aggregated in the Rest of World (ROW) category. The core assumption in this grouping is that all countries share the same technology factor. For Australia, countries individually identified in WIOD13 account for between 64 and 80 per cent of total imports and exports within the study period (Levitt et al, 2017). WIOD was originally developed in the European context and hence the ROW category covers a larger portion of Australia's trading partners. Caution will therefore be taken when interpreting ROW results. The second uncertainty pertains to sector classification and harmonisation. This process involves grouping similar sectors together and assuming the same technology factor, potentially introducing error and uncertainty. However, despite the challenges of aggregating sector and country data, Peters et al (2012) compare studies using a variety of MRIO databases and finds that their results are robust. Barrett et al (2012) also conclude that the harmonisation processes greatly reduce uncertainty.

[5] Pomfret (2015) reports that the Australian dollar doubled in value against the US$ between 2000 and 2011.

5 Method

5.1 Introduction & History

Input-Output (IO) analysis was developed by Wasily Leontief (1936), for which he received the Nobel Memorial Prize in Economic Sciences in 1973. Miller and Blair (2009) note “the fundamental purpose of the input–output framework is to analyze the interdependence of industries in an economy” (p.1). The IO framework has been described as a “revolutionary departure” from previous work and created an entire field of study dedicated to the understanding of interlinkages within and between economies (Baumol, 2000, p.141). The basic framework and underlying mathematics have now been extended across many fields of study, including the analysis of energy and emissions. IO analysis began with complex matrix mathematics completed by hand, over days and weeks. Modern IO studies utilise a range of mathematical programming languages and software. This study was completed using MATLAB (by MathWorks) and MS Excel (by Microsoft).

5.2 Input-Output Analysis Overview

The data in a multi-region IO (MRIO) table describes the flow of products from each sector in each country (producers) to all domestic sectors and to all sectors across all other countries (consumers) (Miller & Blair, 2009, p.2). Mathematically, this can be described as a series of linear equations and solved using matrix algebra. The methodology outline below is based on Miller and Blair (2009) and Kulionis (2014), and carried out across each year in the study period: 1995-2009.

5.2.1 Linear Equations & Matrices

The simplified WIOT illustrated in the *data* section above (table 4.1) can also be represented in linear equation form (assuming *n* sectors, total output given by *x* and final demand given by *f*). Here, z_{ij} represents the interindustry flows from sector i to sector j (and to itself when i = j).

$$x_i = z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i \quad (1)$$

This equation can then be applied across all *n* sectors as follows:

$$\begin{aligned} x_1 &= z_{11} + \cdots + z_{1j} + \cdots + z_{1n} + f_1 \\ &\vdots \\ x_i &= z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i \\ &\vdots \\ x_n &= z_{n1} + \cdots + z_{nj} + \cdots + z_{nn} + f_n \end{aligned} \quad (2)$$

This can be represented in a simple matrix form:

$$\mathbf{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}, \quad \mathbf{Z} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nn} \end{bmatrix} \text{ and } \mathbf{f} = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix} \quad (3)$$

Using standard matrix notation (Miller & Blair, 2009, p.12), where i is a summation vector (a column vector of ones):

$$\mathbf{x} = \mathbf{Zi} + \mathbf{f} \quad (4)$$

5.2.2 Technical Coefficient

The technical coefficient matrix can be described as the production recipe for the economy. Leontief himself described technical coefficients as the “cooking recipe” (Polenske, 1999, p.341). More specifically, technical coefficients describe the inputs required to directly produce one unit of output. It is calculated as the intermediate input, z_{ij}, divided by the total inputs in that sector, x_j:

$$a_{ij} = \frac{z_{ij}}{x_j} \qquad 5$$

The full set of technical coefficients can be represented in an A-matrix as follows:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \qquad 6$$

5.2.3 Leontief Inverse

Any change in demand in one sector will generate output in many other sectors. The A-matrix captures first order effects but not the secondary, tertiary and further effects. To capture all effects requires the inter-dependence matrix, famously known as the *Leontief Inverse*. This can be derived by rearranging the equation for technical coefficients (5) as follows:

$$z_{ij} = a_{ij}\, x_j \qquad 7$$

This rearrangement can be substituted into the original set of linear equations (2), indicating the inter-dependence of interindustry flows and total outputs:

$$\begin{aligned} x_1 &= a_{11}\, x_1 + \cdots + a_{1i}\, x_i + \cdots + a_{1n}\, x_n + f_1 \\ &\vdots \\ x_i &= a_{i1}\, x_1 + \cdots + a_{ii}\, x_i + \cdots + a_{in}\, x_n + f_i \\ &\vdots \\ x_n &= a_{n1}\, x_1 + \cdots + a_{ni}\, x_i + \cdots + a_{nn}\, x_n + f_n \end{aligned} \qquad 8$$

A further rearrangement aligns all x values on the left:

$$\begin{aligned} x_1 - \ a_{11}\, x_1 - \cdots - \ a_{1i}\, x_i - \cdots - \ a_{1n}\, x_n &= f_1 \\ &\vdots \\ x_i - \ a_{i1}\, x_1 - \cdots - \ a_{ii}\, x_i - \cdots - \ a_{in}\, x_n &= f_i \\ &\vdots \\ x_n - \ a_{n1}\, x_1 - \cdots - \ a_{ni}\, x_i - \cdots - \ a_{nn}\, x_n &= f_n \end{aligned} \qquad 9$$

We can then group all values together, with x_1 values in the first equation, followed by x_2 values in the second equation etc.

$$\begin{aligned} (1 - \ a_{11})\, x_1 - \cdots - \ a_{1i}\, x_i - \cdots - \ a_{1n}\, x_n &= f_1 \\ &\vdots \\ - a_{i1}\, x_1 - \cdots + \ (1 - \ a_{ii})\, x_i - \cdots - \ a_{in}\, x_n &= f_i \\ &\vdots \\ - a_{n1}\, x_1 - \cdots - \ a_{ni}\, x_i - \cdots + \ (1 - \ a_{nn})\, x_n &= f_n \end{aligned} \qquad 10$$

Returning to matrix notation, where **I** represents an identity matrix (ones on the diagonal), the above can be represented as:

$$(\mathbf{I} - \mathbf{A})\, \mathbf{x} = \mathbf{f} \qquad 11$$

Hence, we can rewrite our original equation for x, as follows:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\, \mathbf{f} \qquad 12$$

Where L is equal to the *Leontief Inverse*, or inter-dependence matrix:

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} \qquad 13$$

The *Leontief Inverse* is the core of the IO methodology and allows us to calculate the output required across all sectors for a change in demand in any other sector.

5.2.4 Environmental Extension

Having derived the Leontief Inverse, we can now integrate the environmental extension. This is the same methodology that can be used for many extensions, including energy use, water or land use, pollutants or even employment.

Firstly, we calculate the emissions factor, d, for each sector. This is done by dividing the total emissions (g) in each sector by the total output, giving the emissions for each additional unit of output:

$$\mathrm{d} = \frac{g_j}{x_j} \qquad (14)$$

We diagonalise *d* and apply this emissions factor to equation (12) above to determine total emissions. ***f*** becomes **F** to indicate the application of this method to multi-region IO analysis:

$$\mathbf{E} = \hat{\mathbf{d}}\,(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{F} \qquad (15)$$

The final emissions matrix, **E**, can then be manipulated in MATLAB to generate meaningful output for this study. This includes generating emissions embodied in exports (EEE) and emissions embodied in imports (EEI), PBA emissions and CBA emissions. From these outputs the BEET can also be calculated (EEE – EEI). All results can also be analysed by sector and trading partner (e.g. import emissions by sector or BEET with a specific trading partner).

5.3 Technology Adjustment & Decomposition

5.3.1 TBEET

Calculating the TBEET requires the standardisation of emissions factors across trading partners. Jiborn et al (2018) and Baumert et al (2019) achieve this standardisation by applying a world average emission factor to each sector separately. This is calculated by first summing all emissions across sectors in each country (n), thereby creating a variable for total global emissions (G) for each sector (j):

$$\mathrm{G_j} = \sum^{n} g_j \qquad 16$$

Total global emissions for each sector is then divided by the total global output in each sector, producing a world average emission factor for each sector:

$$\mathrm{d_{wa}} = \frac{\mathrm{G_j}}{\mathrm{X_j}} \qquad 17$$

The world average emission factor can then be diagonalised and integrated into equation (15) to produce a technologically adjusted emissions matrix:

$$\mathbf{E}_{wa} = \hat{\mathbf{d}}_{\mathbf{wa}}\,(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{F} \qquad 18$$

This technologically adjusted emissions matrix can then be manipulated to produce TEEE, TEEI, TCBA, and finally, TBEET:

$$\mathrm{TBEET} = \mathrm{TEEE} - \mathrm{TEEI} \qquad 19$$

5.3.2 Decomposition

The final step in this study is the decomposition of TBEET. This allows an analysis of the influence of trade specialisation and the monetary trade balance. This study uses the decomposition method outlined in Baumert et al (2019), which is the additive and refined Laspeyres index method (RLIM). This methodology is based on work by Jakob and Marschinski (2013), who decompose BEET into four components: trade balance, trade specialisation, average production intensity and average carbon intensity of energy. The standardisation of technology in the TBEET method eliminates the last two components, leaving a focus on trade balance and specialisation.

The decomposition into trade specialisation and trade balance is calculated as follows (where Ex_n and Im_n denote total export and import value, for country n):

$$\Delta sp_n = \left(\frac{TEEE_n}{Ex_n} - \frac{TEEI_n}{Im_n}\right) * Im_n + \frac{1}{2}\left(\frac{TEEE_n}{Ex_n} - \frac{TEEI_n}{Im_n}\right) * (Ex_n - Im_n) \qquad 20$$

$$\Delta bal_n = \frac{TEEI_n}{Im_n} * (Ex_n - Im_n) + \frac{1}{2}\left(\frac{TEEE_n}{Ex_n} - \frac{TEEI_n}{Im_n}\right) (Ex_n - Im_n) \qquad 21$$

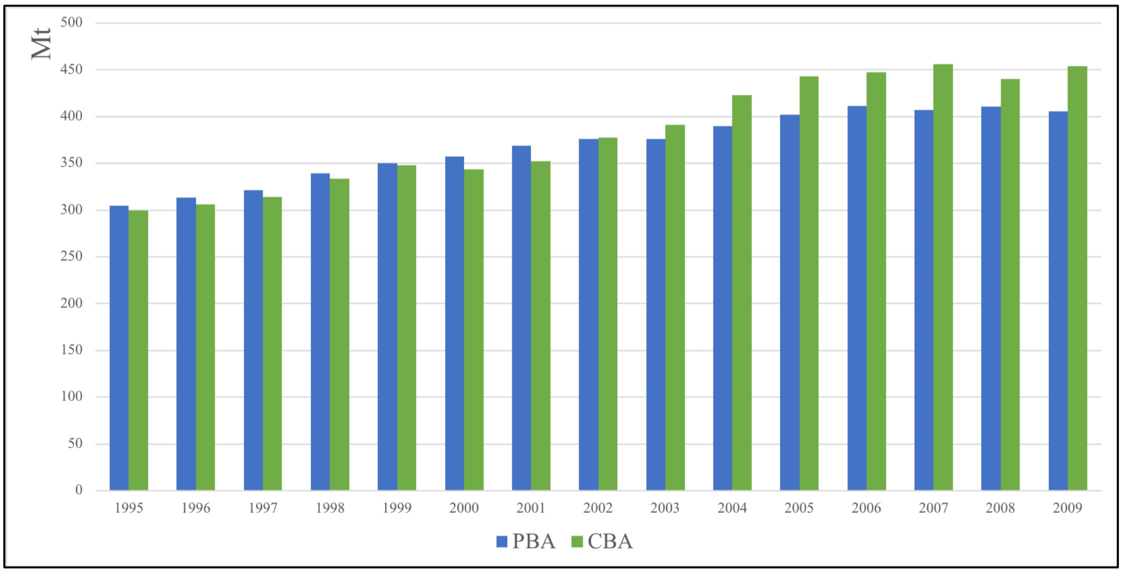
6 Results & Analysis

Results presented here are based on the author's own calculations. All references to emissions refer to CO_2 emissions only and full numerical results are presented in Appendix E. All MATLAB code and MS Excel calculations can be provided on request.

6.1 Production & Consumption Emissions

Figure 6.1 illustrates the changing nature of Australia's production and consumption emissions. Australia's production emissions increased from 305 million tonnes in 1995 to 405 million tonnes in 2009, a 33 per cent increase. Australia's consumption emissions rose even faster, increasing from 300 million tonnes in 1995 to 454 million tonnes in 2009, a 51 per cent increase. This increase is driven by a rapid increase between 2000 and 2005 when growth rates for consumption emissions were between 3 and 8 per cent per year. Production emissions peaked in 2006 at 412 million tonnes and consumption emissions peaked in 2007 at 456 million tonnes. This thesis now turns to an analysis of the import and export components of Australia's emissions (an analysis of the domestic component is included in Appendix F).

Figure 6.1: Australia's Production & Consumption Emissions (1995 - 2009)



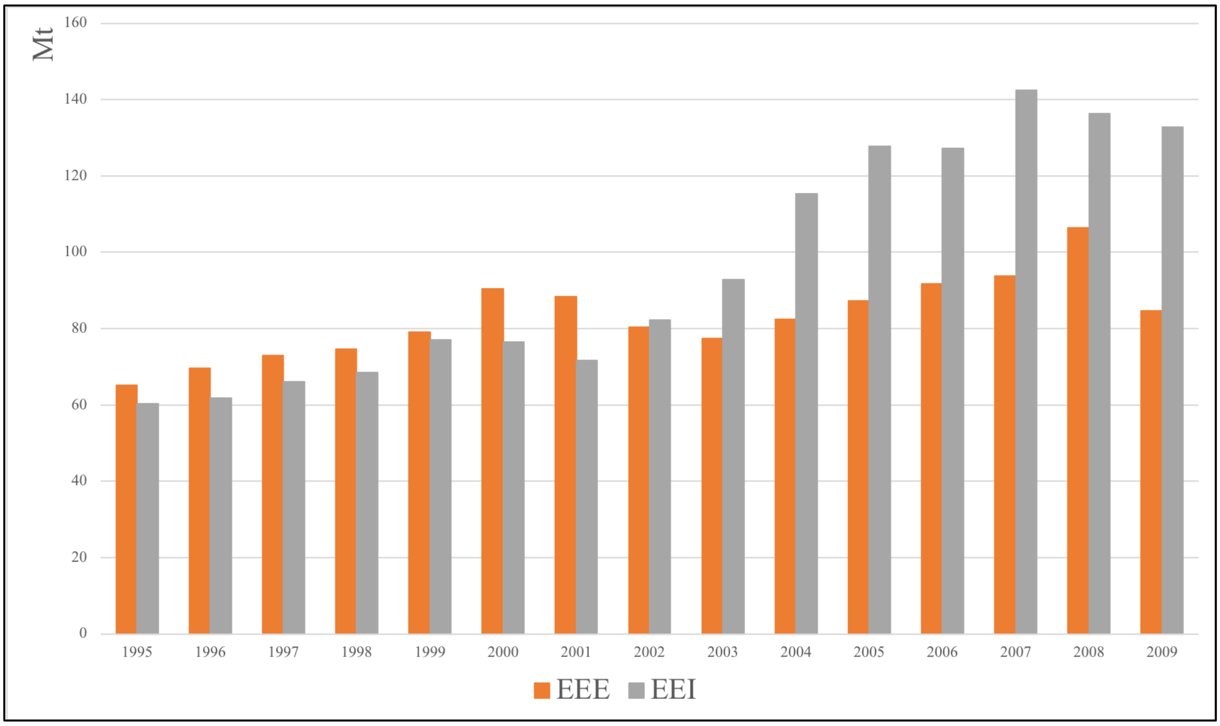
Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.2 Export & Import Emissions

6.2.1 Overview

Figure 6.2 shows Australia's emissions embodied in imports (EEI) and emissions embodied in exports (EEE) over the study period. EEE increased from 65 million tonnes in 1995 to 85 million tonnes in 2009, a 30 per cent increase. However, EEE as a share of PBA did not increase at all through the study period. In contrast, after a period of slow growth until 2001, EEI increased dramatically, from 72 million tonnes in 2001 to 133 million tonnes in 2009. Overall, EEI experienced a 120 per cent increase over the study period, including growth rates of between 10 and 24 per cent between 2002 and 2006. EEI as a share of PBA increased from 20 per cent in 1995 to 33 per cent in 2009. This growth in EEI explains the larger growth of CBA when compared to PBA, as discovered in section 6.1.

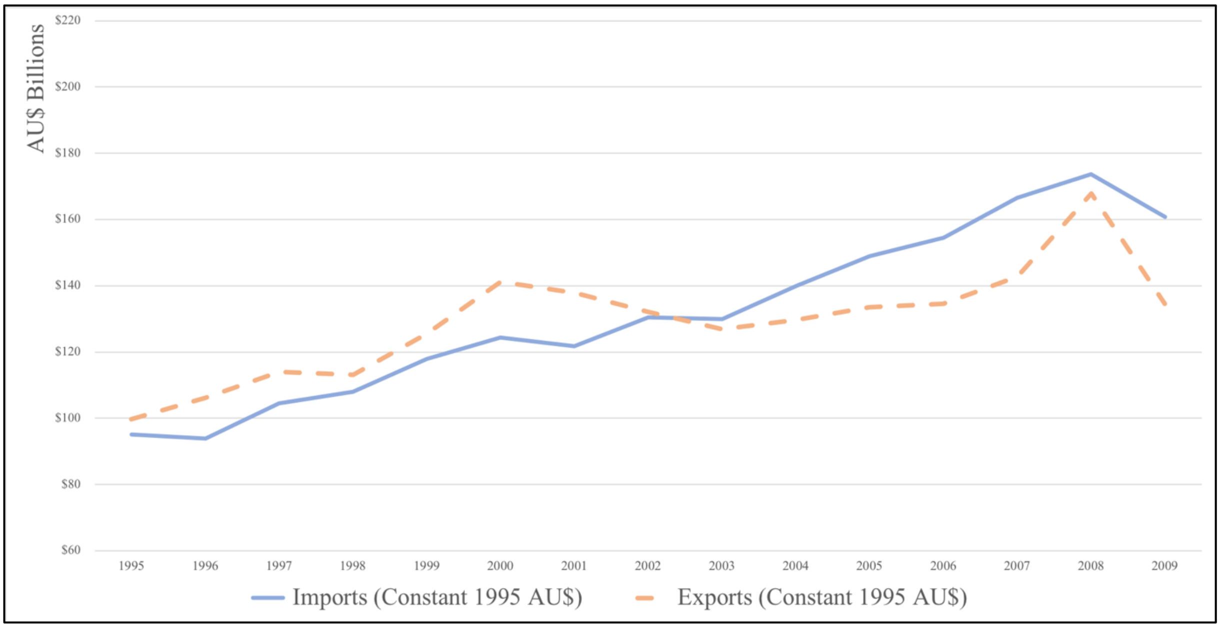
Figure 6.2: Australia's Import & Export Emissions (1995 - 2009)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

EEI and EEE are driven by the volume and composition (sectors and countries) of trade (Levitt et al, 2017). Figure 6.3 shows the value of Australia's imports and exports, expressed in constant 1995 AU$. Australian exports and imports both increase through the study period, contributing to Australia's overall rise in EEI and EEE from 1995 to 2009. The rises and falls in export value are matched by corresponding rises and falls in EEE (see figure 6.2 above). However, the steady rise in import value is not matched with a corresponding EEI. Instead, the EEI only begins to rise considerably after 2001. This indicates that the value of trade explains only part of the story of Australia's rising EEI. This study therefore turns to the carbon intensity of trade, initially utilising the pollution terms of trade methodology (based on Antweiler, 1996, and David & Caldeira, 2010), followed by a sector and country decomposition of EEI and EEE.

Figure 6.3: The Value of Imports & Exports (Constant 1995 AU$)



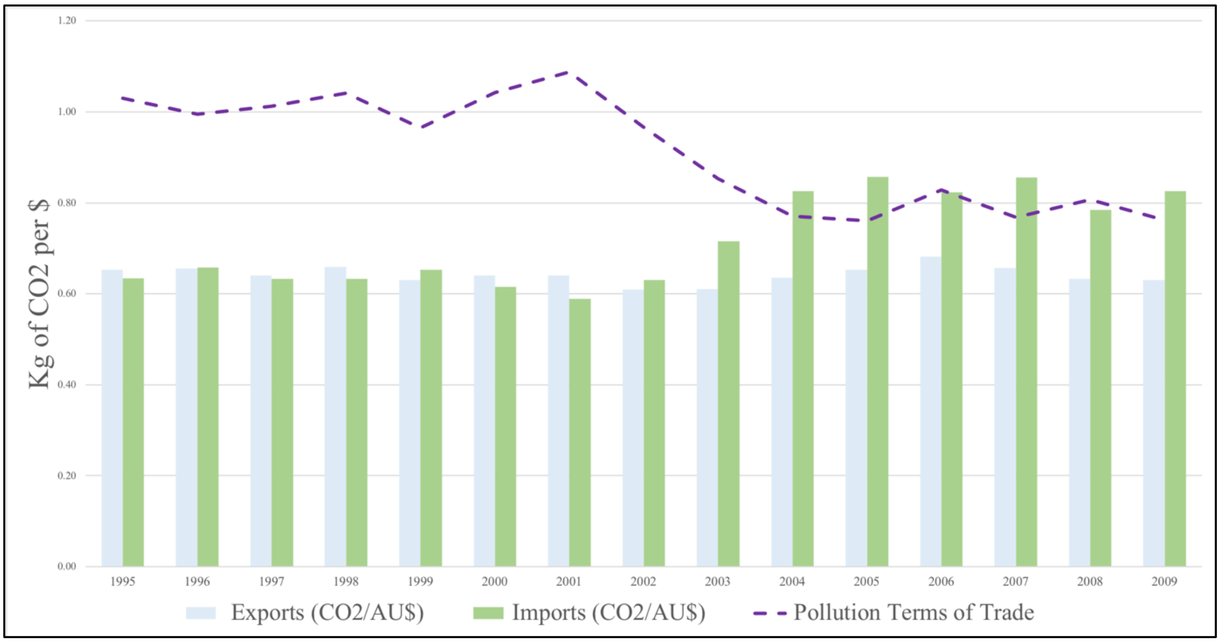
Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.2.2 Australia's Pollution Terms of Trade

Figure 6.4 outlines the carbon intensity of imports and exports, alongside the corresponding pollution terms of trade (ratio of the carbon intensity of exports to imports). This indicates that the carbon intensity of exports remained relatively stable throughout the study period. In contrast, the carbon intensity of imports fluctuated much more. Initially it dropped from 0.63kg/AU$ in 1995 to 0.59kg/AU$ in 2001. However, from this point the carbon intensity of imports turned and increased significantly, to a high of 0.86kg/AU$ in 2005, a 46 per cent increase. As a result, the pollution terms of trade falls after 2001, ending at 0.76 in 2009. Australia's exports became more carbon efficient when compared to imports, with a clear turning point in 2001. This analysis indicates that the sector and/or country composition of

Australian trade changed within the study period, resulting in a dramatic increase in the carbon intensity of imports.

Figure 6.4: Australia's Pollution Terms of Trade



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.2.3 Sector Analysis

An analysis of the sector composition of Australia's trade-based emissions reveals that the *electricity, gas and water supply* sector remain the biggest contributor to both EEE and EEI.[6] However, the growth in EEI for this sector was more significant (169 per cent), with most of this growth occurring after 2001. Four other sectors have recorded growth in EEI above 100 per cent, including *Air Transport* (212 per cent), *Basic and Fabricated Metals* (114 per cent), *Fuels* (192 per cent), *Mining* (155 per cent), and *Inland Transport* (112 per cent). In contrast, the only sector that registered growth above 100 per cent in EEE was *Air Transport* (131 per cent). Furthermore, export emissions for *Fuels* (*Coke, Refined Petroleum and Nuclear Fuel*) actually fell by 46 per cent.[7]

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[6] This is primarily due to this sector's emissions including those from electricity used in the production of *all* traded goods.
[7] A full visualisation for sector breakdowns of imports and export emissions can be found in Appendix F.

The importance of a sector breakdown of EEE and EEI becomes clear when segmenting sectors into energy and non-energy intensive groupings.[8] The increase in EEI is greater in energy intensive sectors (130 per cent) when compared to non-energy intensive sectors (99 per cent). Conversely, the increase in EEE is much greater in non-energy intensive sectors (58 per cent) when compared to energy-intensive sectors (24 per cent). This indicates the commencement of a structural shift in the economy, towards less energy-intensive production and an increased reliance on the importation of energy-intensive goods (see tables 6.1 and 6.2 below). However, although this structural shift is critical for future projections, the total energy-intensive share of imports and exports only shifted by 3 and 4 percentage points respectively across the study period. Furthermore, the top ten sectors in both import and export emissions remained unchanged from 1995 to 2009. As a result, although a structural shift may be commencing, the sector composition of trade does not alone explain the dramatic rise in EEI after 2001. Hence, this thesis moves to an analysis of Australia's trading partners.

Table 6.1: Energy & Non-Energy Intensive Imports

	Energy Intensive Imports	Non-Energy Intensive Imports	Total Imports	*Energy Intensive* Share of Total
1995 Emissions (Mt)	40.8	19.5	60.3	68%
2009 Emissions (Mt)	93.9	38.9	132.8	71%
% Increase	130%	99%	120%	

Table 6.2: Energy & Non-Energy Intensive Exports

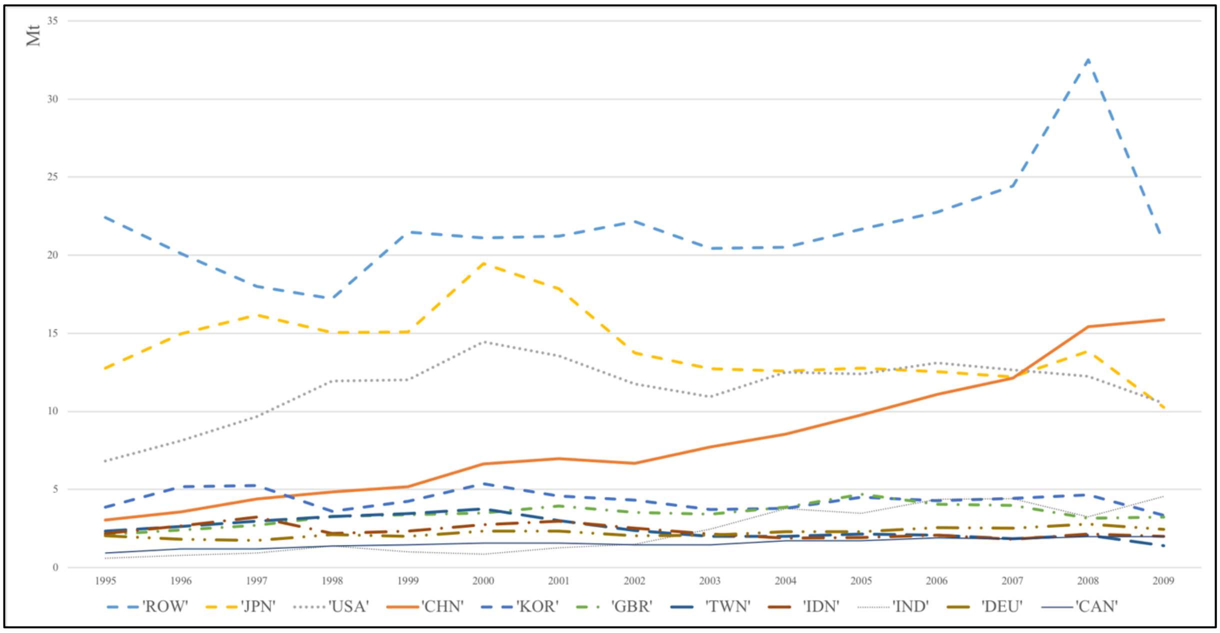
	Energy Intensive Exports	Non-Energy Intensive Exports	Total Exports	*Energy Intensive* Share of Total
1995 Emissions (Mt)	52.2	12.8	65.1	80%
2009 Emissions (Mt)	64.5	20.2	84.7	76%
% Increase	24%	58%	30%	

[8] Energy intensive sectors include: *Electricity, Gas and Water Supply* (17), *Basic and Fabricated Metals* (12), *Chemicals and Chemical Products* (9), *Other Non-Metallic Mineral* (11), *Coke, Refined Petroleum and Nuclear Fuel* (8), *Mining and Quarrying* (2), *Rubber and Plastics* (10), and *Agriculture, Hunting, Forestry, and Fishing* (1).

6.2.4 Country Analysis

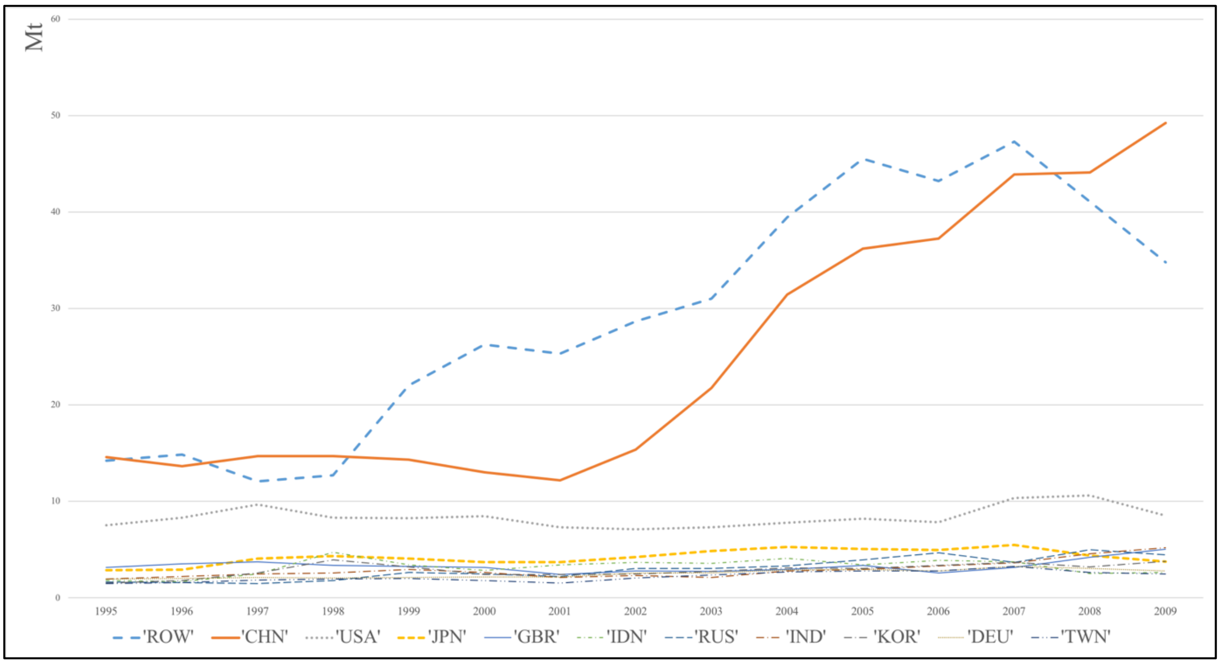
Figures 6.5 and 6.6 shows Australia's export and import emissions broken down into the top ten countries. These reveal dramatic changes in Australia's major trading partners. On the export side, EEE to China have increased from 3 million tonnes in 1995 to almost 16 million tonnes in 2009, a 422 per cent increase. EEE to India also increased dramatically, from a low base of 611 thousand tonnes in 1995 to 4.6 million tonnes in 2009, an almost 650 per cent increase. Conversely, EEE to Japan decreased by 20 per cent in the study period. On the import side, EEI from China have increased from 14.6 million tonnes in 1995 to 49 million tonnes in 2009, a dramatic 238 per cent increase. In comparison, emissions imported from the US only increased by 13 per cent in the same period. Emissions imported from Russia, India and Korea also experienced an increase over 100 per cent, but each make up less than 4 per cent of total emissions.

Figure 6.5: Australia's Export Emissions (top 10 countries, plus WIOD13 ROW category)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Figure 6.6: Australia's Import Emissions (top 10 countries, plus WIOD 13 ROW category)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

The country shares of EEI over time also paint a revealing picture. Table 6.3 shows that China's share of Australia's EEI decreased from 24 per cent in 1995 to 17 per cent in 2001, before skyrocketing to 37 per cent in 2009. Table 6.3 also shows that China's share of the overall increase in EEI is 48 per cent. The rise of China is aligned with the timing of Australia's EEI increase and the turning point in Australia's pollution terms of trade. This brings us to a closer examination of EEI from China.

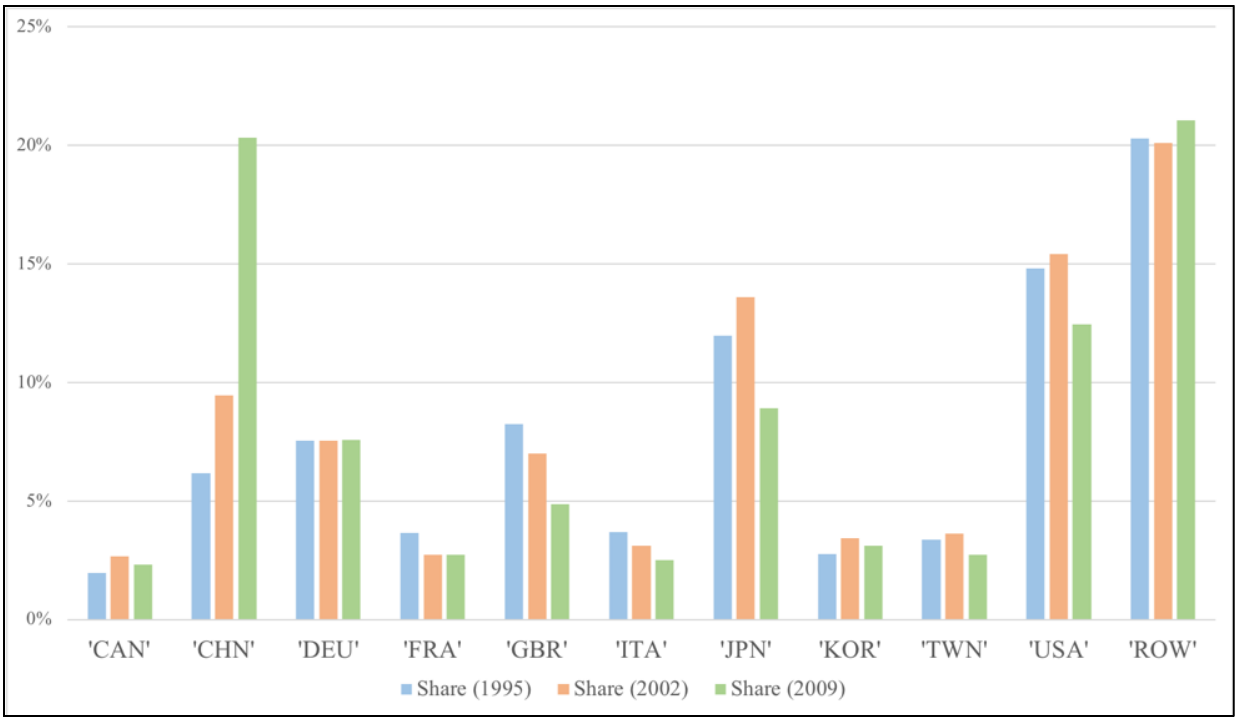
Table 6.3: China & ROW Shares of Rising EEI

	EEI from China	EEI from non-Annex B plus ROW	Total EEI	China Share
1995 Emissions (Mt)	14.6	36.0	60.3	24%
2001 Emissions (Mt)	12.2	47.8	71.7	17%
2009 Emissions (Mt)	49.3	99.4	132.8	37%
Total Change	34.7	63.4	72.5	**48%**
% Increase	238%	176%	120%	

6.2.5 Import Share & Carbon Intensity of EEI from China

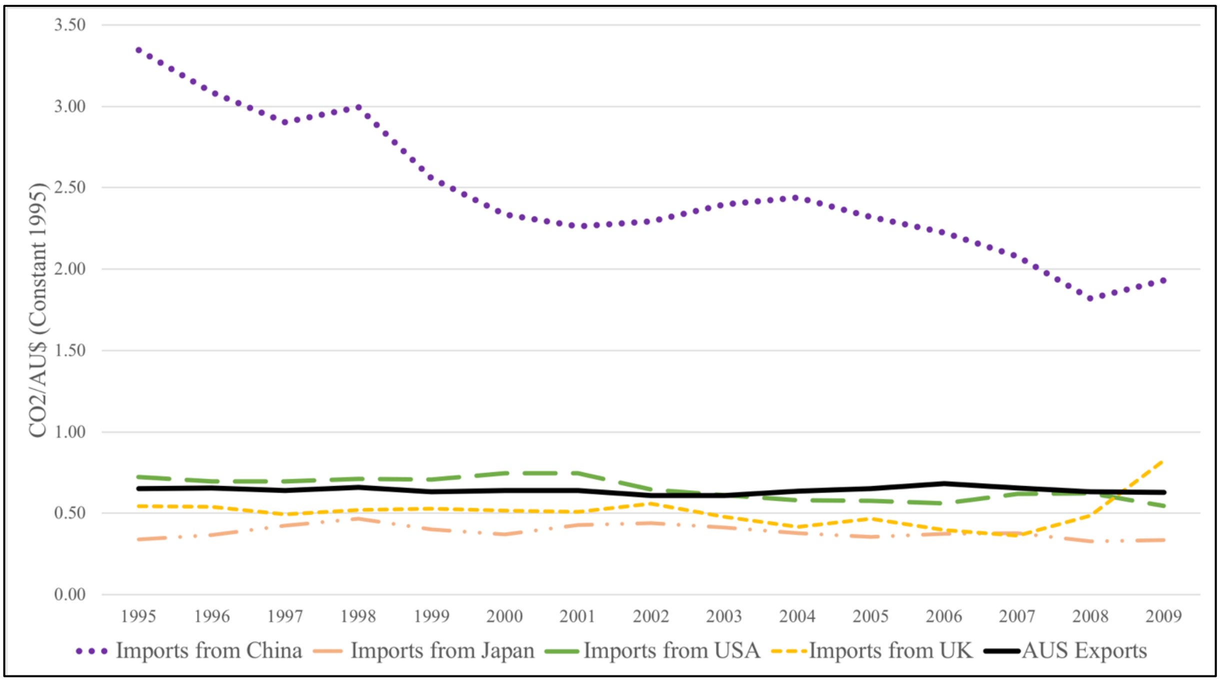
Figure 6.7 shows that China's share of import value increased from 6 per cent in 1995 to more than 20 per cent in 2009. This significant growth occurred due to the opening up of the Chinese economy and, more specifically, China joining the WTO in 2001. Most of this growth in China's share occurred after 2002, at the expense of the US, Japan and Great Britain. Figure 6.8 shows the carbon intensity of imports from the same trading partners. Despite the decreasing carbon intensity of imports from China, it remains considerably higher than all other nations throughout the study period. In 2009 the carbon intensity of imports from China was 1.93 kg/AU$, compared to 0.54 kg/AU$ for US imports, 0.33 kg/AU$ for Japanese imports, and 0.82 kg/AU$ for British imports. China's carbon intensity of imports is also considerably higher than the carbon intensity of Australia's exports. These differences are primarily driven by a much higher carbon intensity of energy use when compared to Australia's other trading partners (see figure H.1 in Appendix H). Ultimately, we can conclude that the increase in Australia's EEI is driven by a combination of the overall growth of Australian imports, the increased share of imports from China, and the considerably higher carbon intensity of Chinese imports.

Figure 6.7: Import Shares (top 10 trading partners, plus WIOD13 ROW category)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Figure 6.8: Carbon Intensity of Imports (by country)



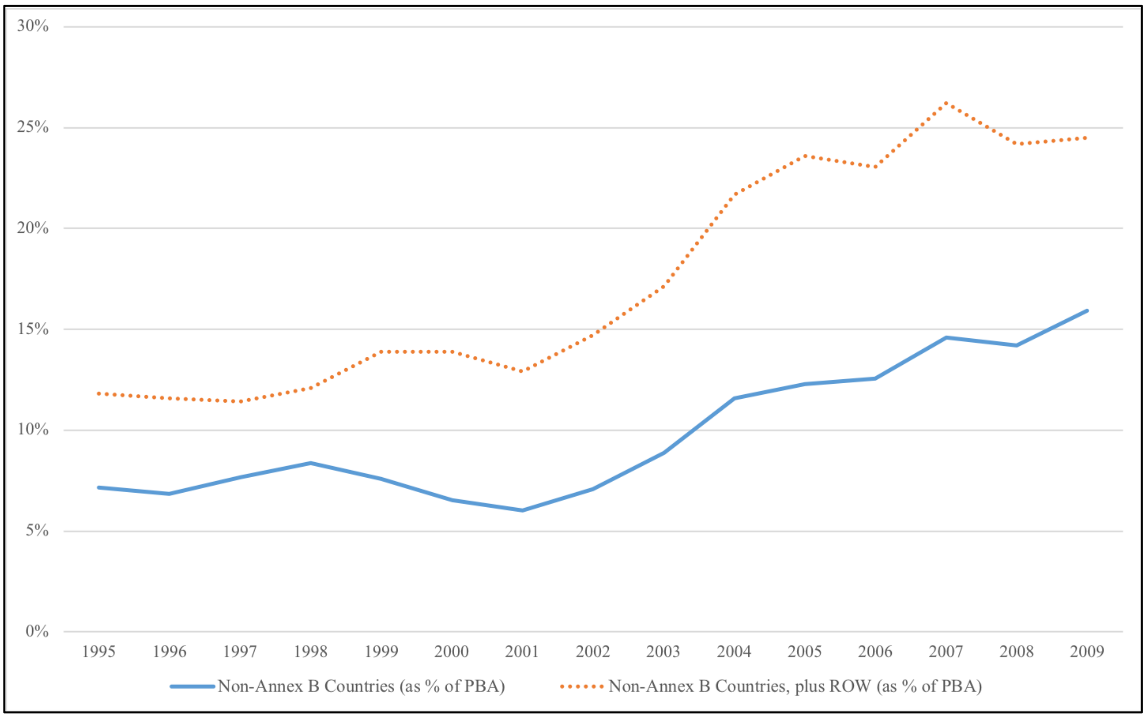
Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.2.6 Carbon Leakage

The final step in this analysis of EEE and EEI is to examine the implication of China's rise on Australia's carbon leakage. Figure 6.9 illustrates Australia's carbon leakage to non-Annex B countries as a percentage of PBA emissions. This shows the relative magnitude of carbon leakage. Two lines are shown here. The first (blue) line includes the non-Annex B countries explicitly listed in WIOD. The second (dotted orange) line adds the ROW category in WIOD13 as this grouping largely contains non-Annex B countries (there are some exceptions, such as Norway and Switzerland). The trend in both lines is the same; there is an increasing absolute carbon leakage throughout the study period. Including the ROW category, carbon leakage increased from 12 per cent of PBA (36 million tonnes) in 1995 to 25 per cent of PBA (99 million tonnes) in 2009.

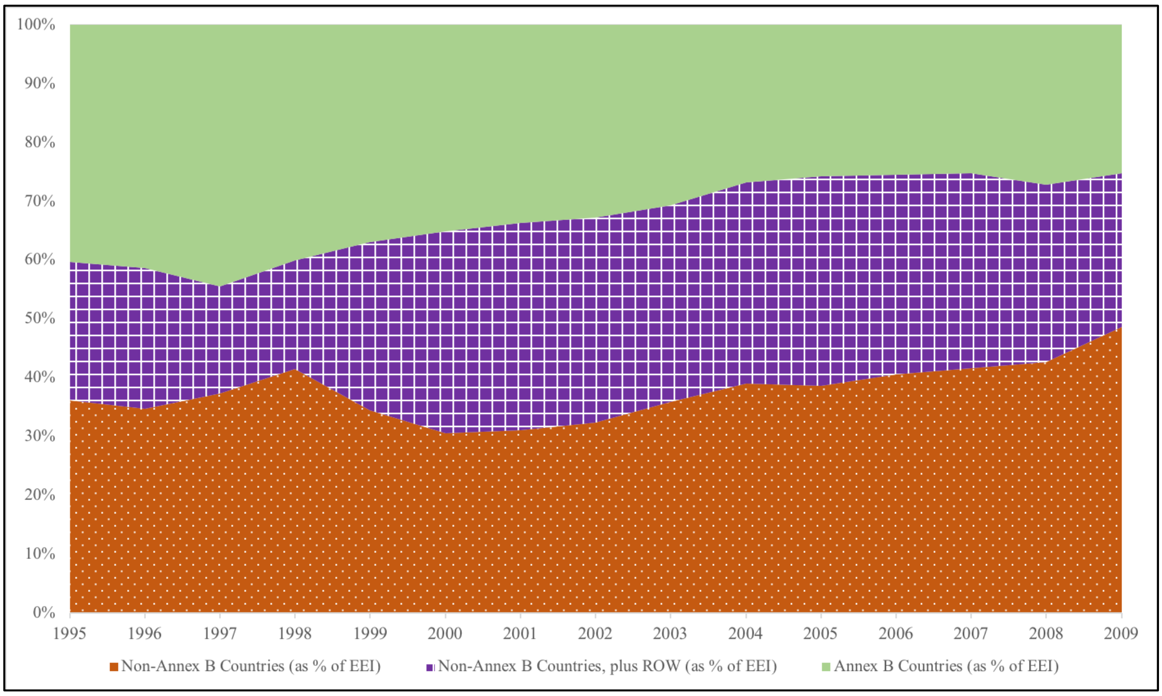
Figure 6.10 normalises carbon leakage relative to EEI, showing the increasing proportion of EEI coming from non-Annex B countries. The percentage of import emissions originating in non-Annex B countries (plus ROW) increases from 60 to 75 per cent. Ultimately, there is an increasing concern about carbon leakage from Australia to the developing world. This particularly accelerates after 2001, in line with findings above.

Figure 6.9: Australia's Carbon Leakage (as % of PBA)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Figure 6.10: Australia's Carbon Leakage (as % of EEI)



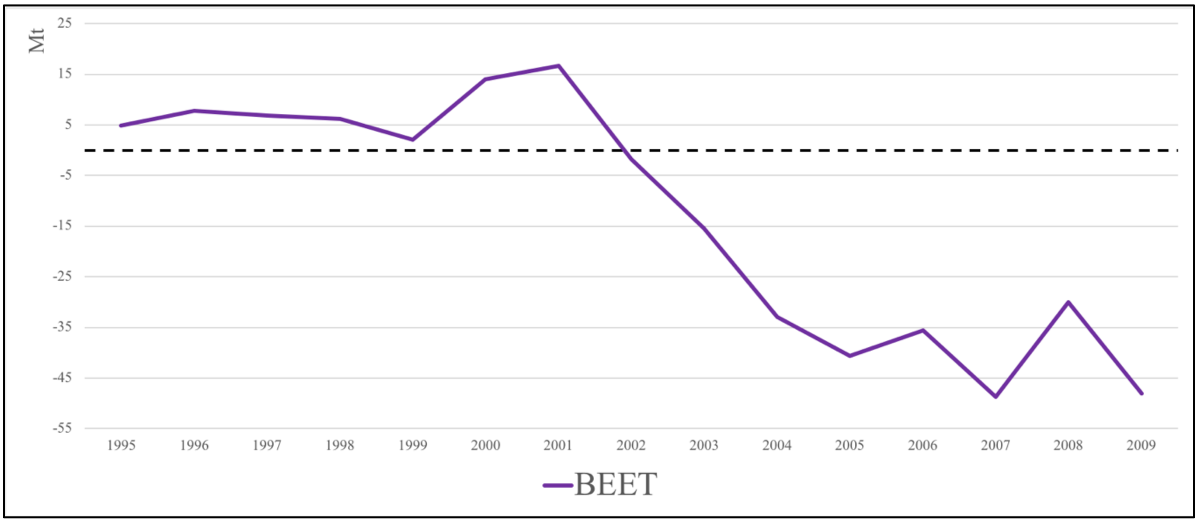
Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.3 BEET

6.3.1 Overview

The overall BEET is the difference between EEE and EEI. Figure 6.11 demonstrates how Australia's BEET shifted from positive in 1995 to negative in 2009. This indicates Australia had a dramatic shift towards outsourcing emissions in the study period. Once again, the turning point identified for Australia's overall BEET is 2001, coinciding with the rise of China as Australia's major trading partner and an increase in carbon intensity of imports.

Figure 6.11: Australia's BEET

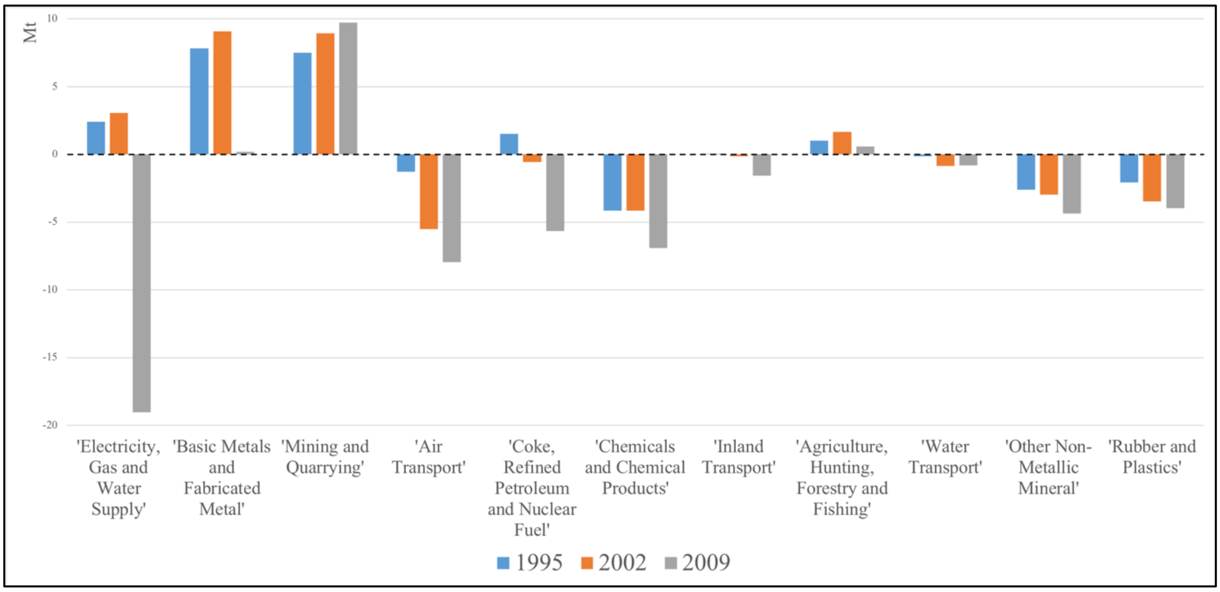


Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.3.2 BEET by Sector

Figure 6.12 presents the sector breakdown of Australia's BEET. This visualisation includes the sectors with the 11 largest import and export emissions, covering more than 85 per cent of Australia's import and export emissions. This reveals a significant shift towards a negative BEET for all sectors after 2002, aside from *Mining and Quarrying.* This shift included a change in direction for the BEET in three sectors at or after 2001, including the *Electricity, Gas and Water Supply,* the *Coke, Refined Petroleum and Nuclear Fuel* sector and (whilst more modest) the *Agriculture* sector. These changes also coincide with the broader turning point in Australia's emissions profile, around 2001.

Figure 6.12: Australia's BEET by Sector (1995 - 2009)



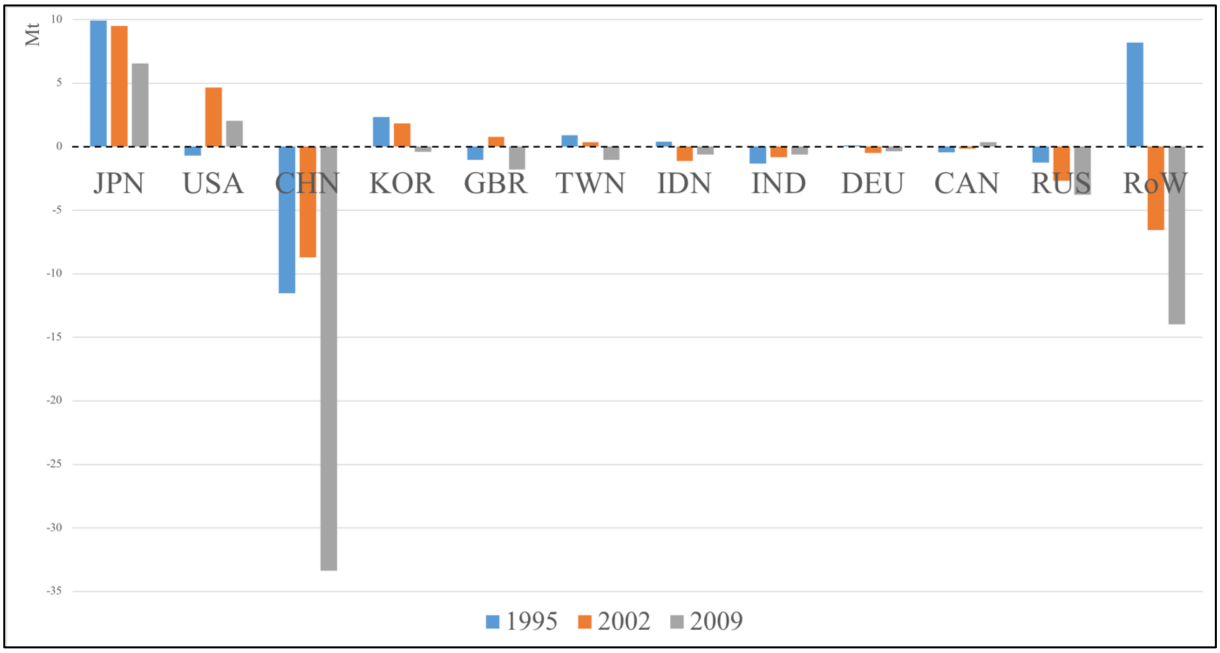
Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.3.3 BEET by Country

Figure 6.13 presents the trading partner breakdown of Australia's BEET. This visualisation contains countries with the 11 largest import and export emissions, plus the ROW category from WIOD13. This covers more than 90 per cent of Australia's import and export emissions. Figure 6.13 clearly captures a trend towards a negative BEET with almost all major trading partners, including Japan, China, Korea, Great Britain, Taiwan, Russia and ROW. However, the greatest shift is the trading relationship with China. After a small move towards a positive

BEET between 1995 and 2002, the BEET turned sharply negative revealing a shift towards the importation of embodied emissions from China. The BEET with ROW also turned sharply and significantly negative after 1995, indicating a broader trend. Australia's shift towards emissions outsourcing is consistent across almost all major trading partners. However, the most significant negative BEET is registered with China and ROW, aligning with the carbon leakage findings in section 6.2.6.

Figure 6.13: Australia's BEET by Country (1995 - 2009)



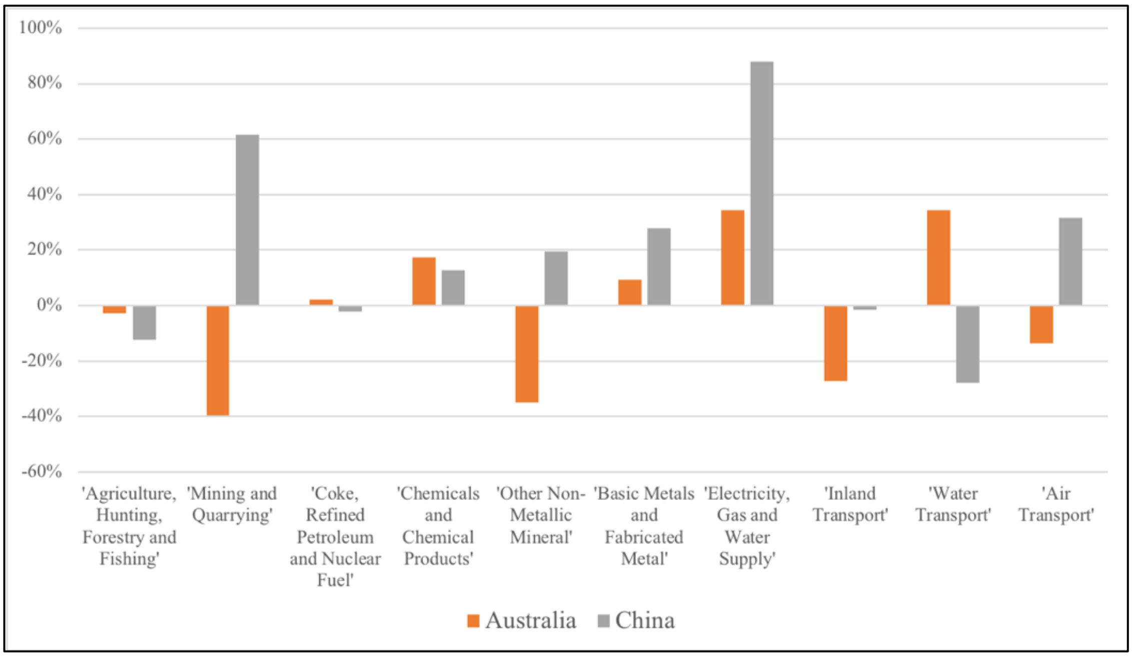
Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.4 TBEET

6.4.1 Context & Motivation

Figure 6.8 revealed that the carbon intensity of Chinese imports into Australia is significantly higher than imports from Australia's other trading partners. It is also higher than the carbon intensity of Australia's exports. However, the carbon intensity of imports from China fell by 42 per cent during the study period, from 3.34 kg/AU$ in 1995 to 1.93 kg/AU$ in 2009. Given the relatively small effect of sectoral changes on import emissions (identified in section 6.2.3), this decline is not driven by trade factors. The decline in carbon intensity *does* however affect the BEET between Australia and China. Hence, the BEET can mistake changes in emissions intensity with trade driven emissions outsourcing. Furthermore, figure 6.14 shows Australia and China's carbon efficiency by major sectors, compared to the *world average* in 2009. This reveals a mixed picture, where Australia has a better carbon efficiency in mining, compared to China and the world, but sits above the world average in other sectors (including electricity). Ultimately, technology differences play a considerable role in Australia's emissions trade balance. This is where the TBEET methodology is relevant: by standardising carbon efficiency across nations and focusing attention on trade-specialisation and trade balance, we can avoid mistaking improvements or changes in production technology with structural trade imbalances.

Figure 6.14: Carbon Efficiency by Sector, CO_2/US$ (compared to world average, 2009)

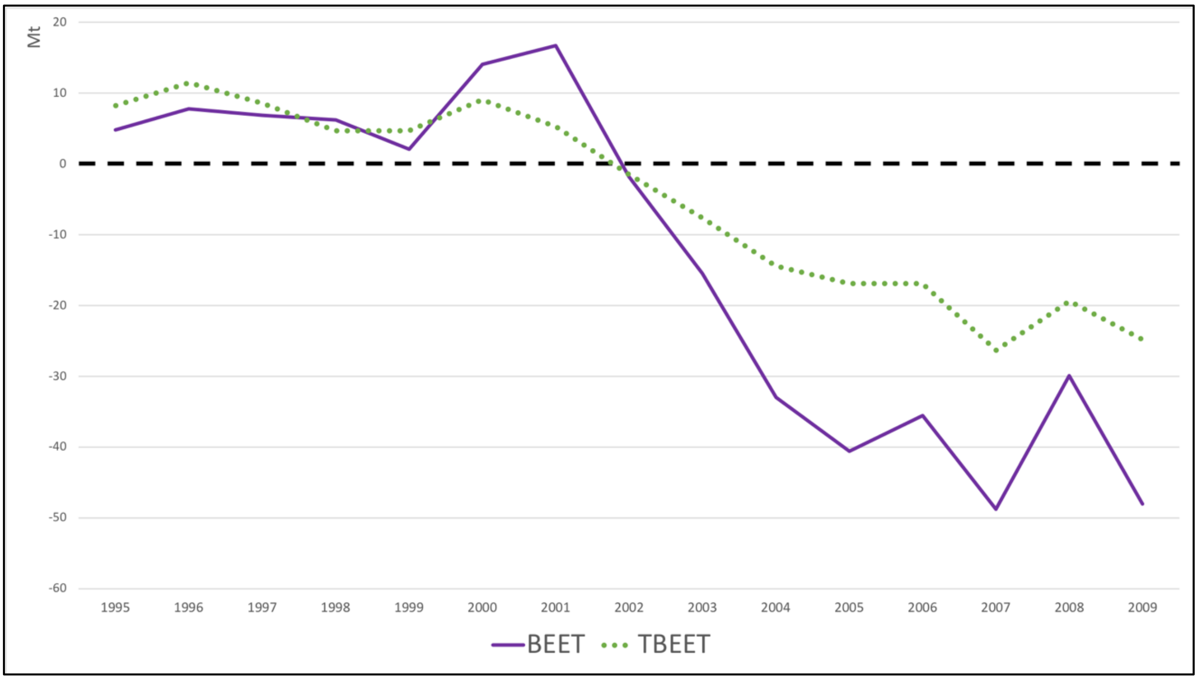


Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.4.2 TBEET Result

Drawing on the work of Jiborn et al (2018) and Baumert et al (2019), figure 6.15 compares Australia's BEET and TBEET for the study period. Both BEET and TBEET turn sharply negative after 2001, indicating that Australia began a shift towards the outsourcing of emissions. Interestingly, the TBEET averages only 48 per cent of the BEET value after 2001. This is in line with Baumert et al's (2019) global finding that "about half of what previous studies considered as outsourcing can be attributed to technology differences across nations" (p.231). Hence, a significant portion of Australia's negative BEET can be explained by technological differences in production, rather than trade induced emissions outsourcing. However, this still leaves approximately half of Australia's BEET directly attributable to trade factors after 2001, confirming Australia's status as an outsourcer of emissions. This TBEET analysis finds that 52 per cent of Australia's negative emissions balance in 2009 is due to trade driven emissions outsourcing. Furthermore, Australia's BEET and TBEET continue to decrease throughout the study period, indicating a risk of worsening outsourcing after 2009.

Figure 6.15: Australia's Technology-Adjusted BEET (1995 - 2009)

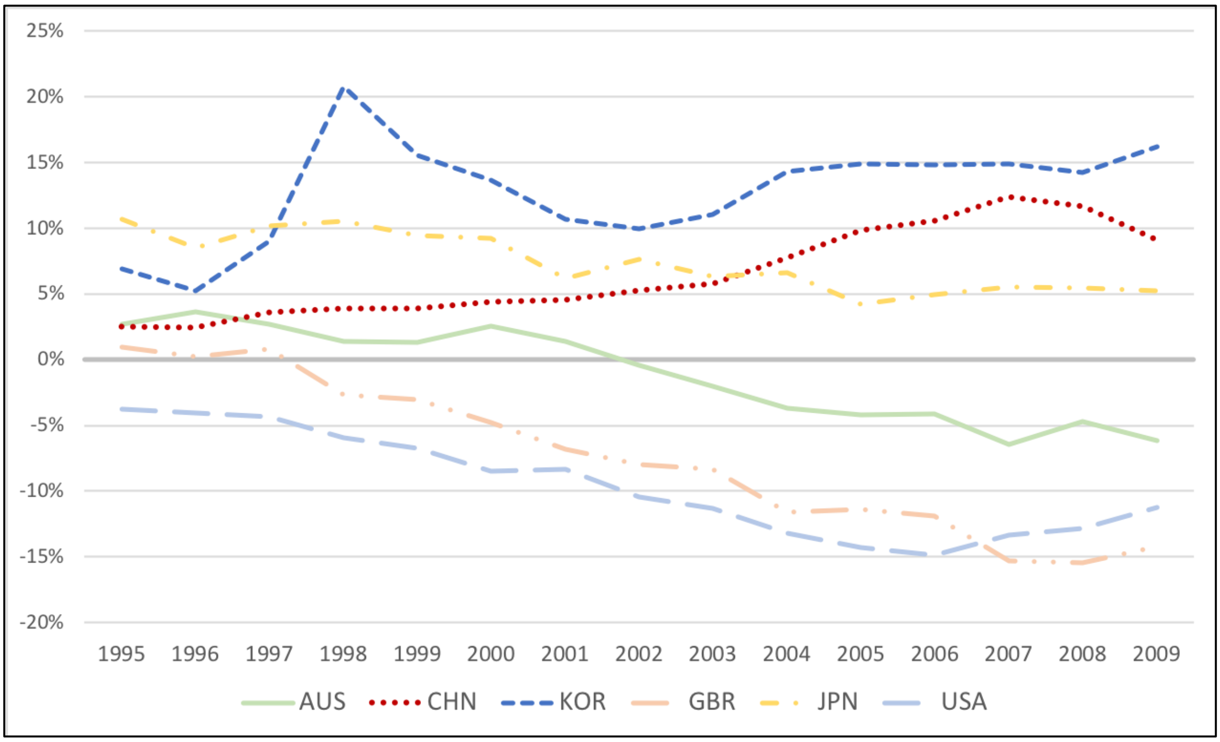


Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.4.3 Global Comparison

The TBEET result illustrates a dramatic turn in Australia's emissions profile, with Australia becoming a net-importer of emissions. This trend towards increased trade-driven emissions outsourcing is shared by most of Australia's historic trading partners. Figure 6.16 shows a global comparison of normalised TBEETs and reveals that China and South Korea are Australia's only major trading partners to record an increased TBEET over the study period. Trade factors are deepening China and South Korea's status as net-exporters of emissions. Baumert et al (2019) finds that it is an oversimplification to categorise the broader developing world as emissions exporters. However, it is clear from this analysis that China and South Korea are increasingly becoming "factories of the world" (Baumert et al, 2019).

Figure 6.16: Global TBEET Comparison (normalised, TBEET/PBA)

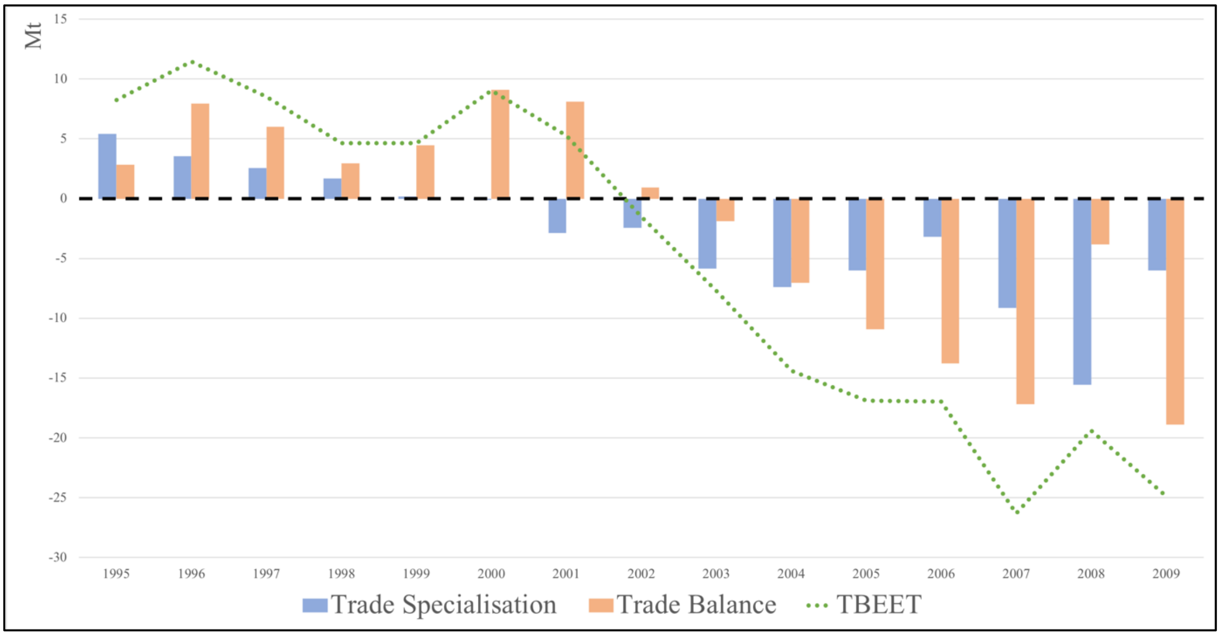


Source: Baumert et al (2019), Author's Construction.

6.4.4 Structural Decomposition

Figure 6.17 shows the decomposition of Australia's TBEET into trade specialisation and trade balance. Trade balance plays the dominant role throughout the study period. However, there are also some signs of trade specialisation. This aligns with findings in section 6.2.3 that energy insensitive sectors have begun to increase their share of imports, and conversely non-energy intensive sectors have begun to increase their share of exports. This TBEET analysis shows that whilst the increasing carbon intensity of Australia's imports is driving up EEI, this alone is not evidence of emissions outsourcing. Instead, once technology is standardised across trading partners, the greatest contributing factor to Australia's outsourcing of emissions is in fact the falling monetary trade balance. Taken together, the increasing carbon intensity of imports and the falling trade balance indicate a continued trend towards higher EEI and emissions outsourcing.

Figure 6.17: TBEET Decomposition (Constant 1995 AU$)

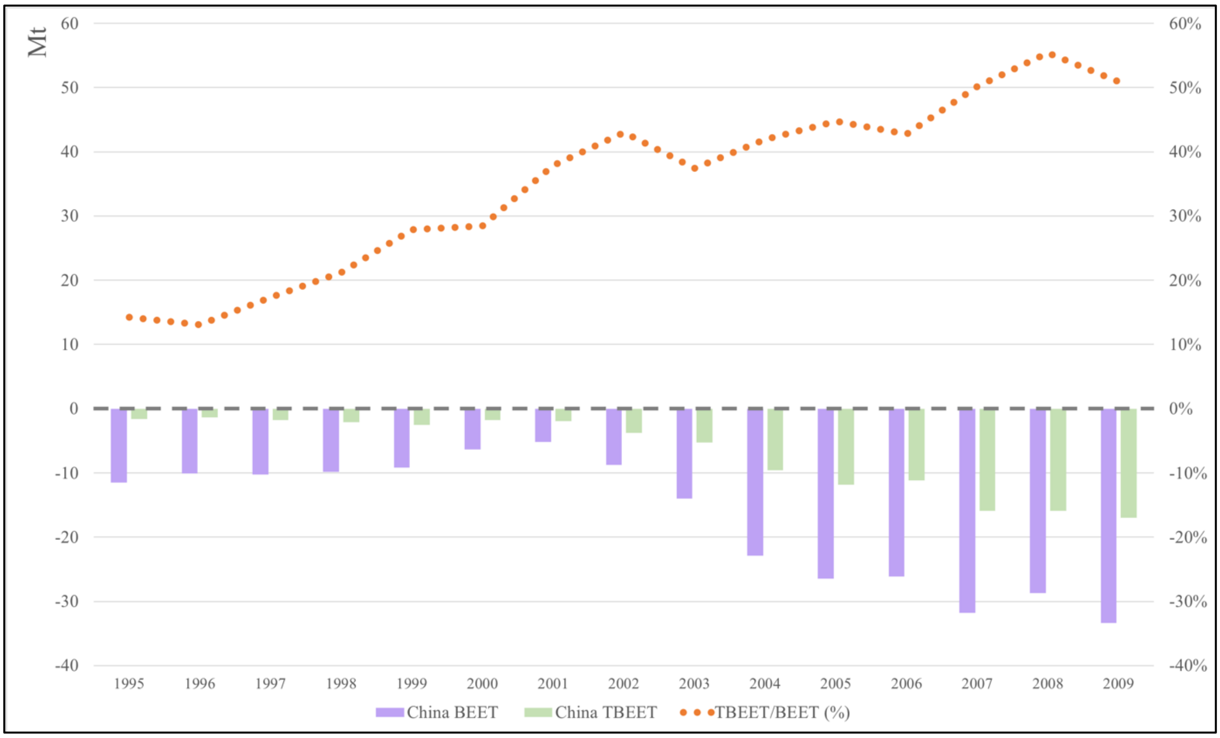


Source: WIOD13 (Timmer et al, 2015), Author's Construction.

6.4.5 China: TBEET & BEET

This final section compares Australia's country-specific BEET and TBEET with China. Figure 6.18 demonstrates how both measures turn sharply negative after 2001, consistent with the critical turning point determined in this study. This indicates increased outsourcing of emissions to China. However, the relative difference between the measures actually reduces throughout the study period, with TBEET beginning the period at 14 per cent of BEET and ending the study at 51 per cent of BEET. This shows that the vast majority of the emissions imbalance between Australia and China was initially the result of Australia's more carbon efficient production system. However, by the end of the study period, trade factors increase in importance and the role of technology difference between the two nations become (relatively) less important. As a result, the cause of Australia's emissions deficit to China in 2009 is driven (almost) equally by trade factors and technology differences. This intriguing finding will be explored further in section 8.

Figure 6.18: Australia's Emissions Balance with China (BEET vs TBEET)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

7 Extension

The study period concludes in 2009. However, recent political turbulence in Australia, combined with a continuously changing trade landscape and radical shifts in the Chinese economy, demand a closer look at Australia's emissions profile after 2009. This thesis ends with an innovative extrapolation of Australia's emissions through until the end of 2014.

7.1 The Approach

WIOD released an updated database in 2016 (WIOD16) which contains trade data up until the end of 2014 but does not yet include emissions accounts. However, Kulionis (2019) produced energy accounts for WIOD16 and these accounts will be employed here to extrapolate Australia's CO_2 emissions. The approach can be summarised in four steps. Firstly, this thesis confirms the correlation between CBA and PBA for energy use and CBA and PBA for CO_2 emissions. Secondly, the CO_2 data is extrapolated from 2009 to 2014 utilising the year-on-year percentage increases for energy use in Australia. However, this extrapolation assumes constant emissions intensity of energy in the extension years. Therefore, the third step involves the creation of a ratio of CO_2 emissions to energy use using Australian statistics between 2010 and 2014. This will create an adjustment factor for each year. Lastly, this study applies these adjustment factors to the extrapolation and use the extended and adjusted data to calculate and analyse Australia's extended BEET.

7.2 Data & Correlation

Step one involves a simple correlation check between energy data produced by Kulionis (2019) and the CO_2 data produced in this study (1995 – 2009). This analysis reveals a very strong correlation between each element of PBA and CBA, including domestic energy and emissions (0.98), emissions and energy embodied in exports (0.89), emissions and energy embodied in imports (0.99), and household emissions and energy (0.99). This results in a very strong PBA and CBA correlation between energy and emissions (0.99), as would be expected given the significant contribution of energy use to overall emissions. Full correlation results are shown in table I.1 in Appendix I.

7.3 A Simple Extension

Given the strong correlation between energy and emissions data, this thesis utilises the percentage change from each year's energy accounts (2010-2014) to extrapolate CO_2 emissions in this period. This starts with utilising the percentage change in domestic energy use from 2009 to 2010 and applying this to domestic CO_2 emissions in 2009 to create the CO_2 emissions in 2010. The 2010 value is then increased by the percentage change in domestic energy accounts from 2010 to 2011 to create the 2011 value. This is repeated year-on-year and then also for export, import and household emissions. Table 7.1 shows the extended values for CO_2 emissions, alongside their year-on-year percentage increases. This reveals that Australia's BEET continues to decrease to a minimum of -79Mt in 2012 before turning upwards. However, this extrapolation assumes that Australia's emissions intensity of energy use remains constant. The next step is to test this assumption.

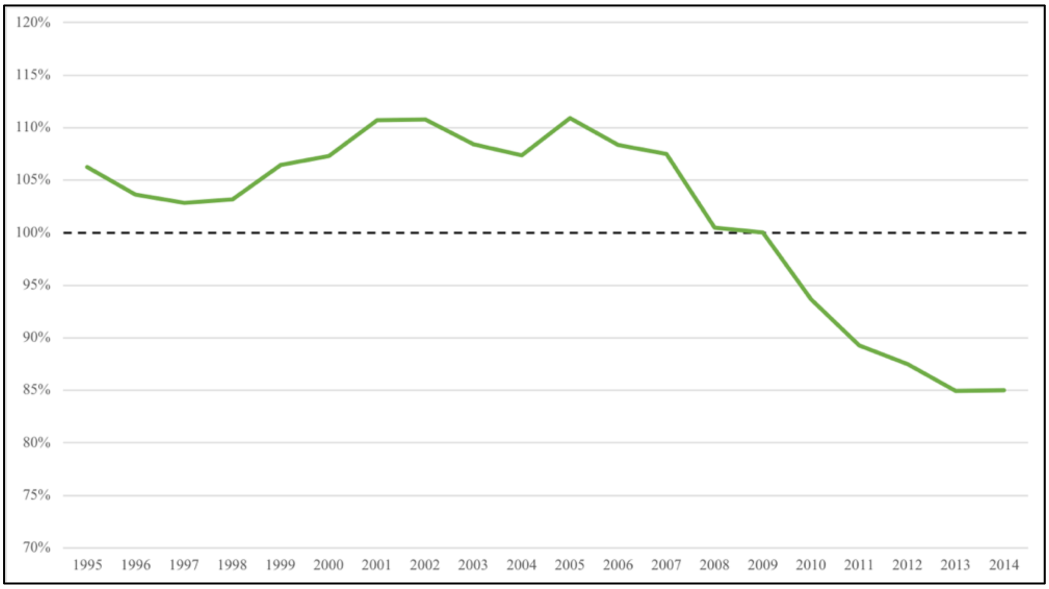
Table 7.1: CO_2 Emissions Extrapolation (2009 - 2014)

	2009	2010	2011	2012	2013	2014
		1%	1%	0%	-3%	-2%
Domestic Emissions	279598	283399	284956	283996	276224	271577
		4%	1%	-2%	5%	-3%
EEE	84727	87994	89221	87594	91758	89298
		7%	18%	0%	-3%	-5%
EEI	132807	142239	167693	167313	162576	153662
		-2%	1%	0%	0%	-2%
Household	41143	40484	41061	41158	40967	40061
PBA	405468	411877	415238	412749	408949	400936
CBA	453548	466121	493709	492467	479767	465300
BEET (Extension)	-48080	-54244	-78472	-79718	-70819	-64364

7.4 Emissions Intensity of Energy Use

This study has utilised national energy and emissions statistics to calculate the ratio of CO_2 emissions to energy use across the study period and extension years (DEE, 2019a & DEE, 2019b). This reveals a changing emissions intensity of energy use, as shown in figure 7.1. Taking the end of the study period (2009) as the base year, the emissions intensity of energy reduces by 15 percent by 2014. This improvement in emissions intensity needs to be considered in the extrapolation.

Figure 7.1: Australia's CO_2 Emissions Intensity of Energy Use (1995 - 2009)

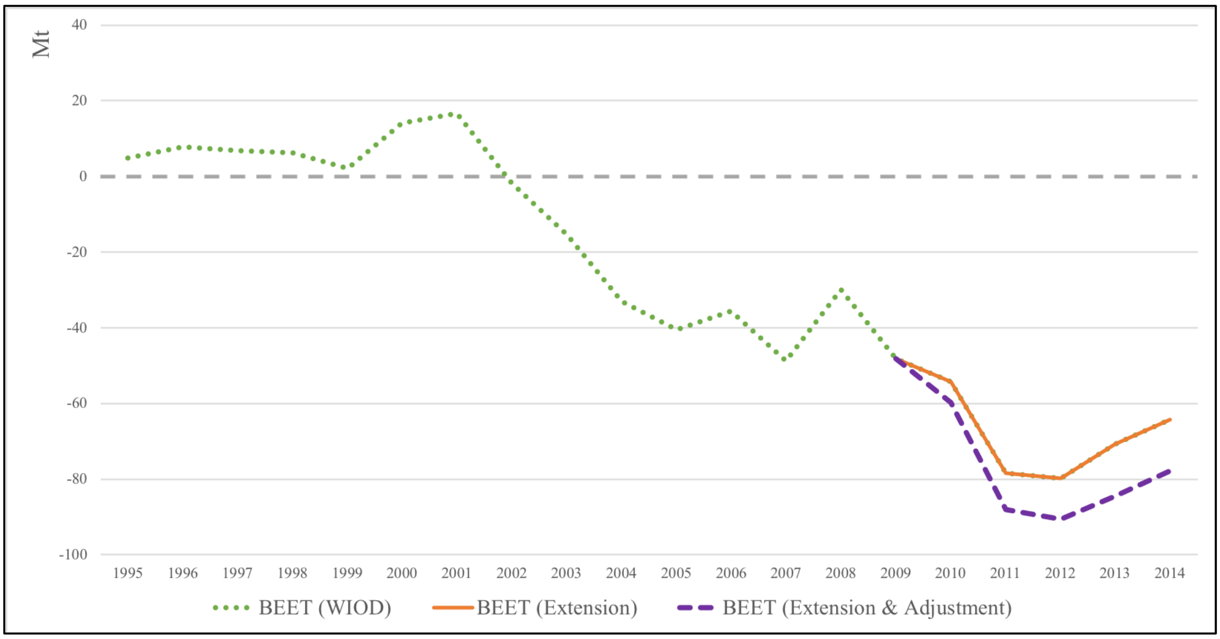


Source: DEE (2019a & 2019b), Author's Construction.

7.5 A BEET Extension (2010 – 2014)

The emissions intensity of energy use is applied as an adjustment factor to the extension result produced in table 7.1. The adjustment factor is applied to all emissions aside from EEI as the emissions intensity of energy use is assumed to stay constant at the global level (and over such a short term). The results of this adjustment are shown in figure 7.2 below. This reveals a deepening of Australia's BEET due to the relative improvement of Australia's emissions intensity of energy when compared to the global average.

Figure 7.2: Australia's Extended BEET (based on Kulionis, 2019)



Source: WIOD13 (Timmer et al, 2015), WIOD16 (Timmer et al, 2016) & Kulionis (2019). Author's Construction.

Australia's energy embodied in imports increased by 18 per cent in 2011. A corresponding increase in EEI resulted in a severe deepening of Australia's BEET after 2009. The adjustment performed above results in an even steeper fall in the BEET due to the lower projected EEE. The stagnation and upwards turn in the BEET from 2011 could be a sign of the changing trade balance with China. China's share of Australia's imports stagnated between 2009 and 2014 (see section 2.4.1). In contrast, Australian coal exports to China boomed and briefly generated a positive overall trade balance in 2010-2011 (see section 2.4.2). As Australia's exports increase, the BEET may continue to rise. This extension indicates another potential turning point in Australia's emissions history, in 2012, when import emissions plateau and Australia's emissions outsourcing begins to reduce. Ultimately, this projection is limited in insight due to the short time frame. However, it provides an intriguing invitation for further research.

8 Discussion

8.1 The Study Period (1995 – 2009)

The core research question for this thesis is *has Australia outsourced emissions through foreign trade since 1995?* The unequivocal answer to this question is yes. The study period encompassed a dramatic change in Australia's trading landscape which had a profound impact on Australia's emissions profile. In fact, the study period witnessed the turning point in Australia's emissions history, when Australia became an outsourcer of emissions. This shift was driven by the combination of an increase in imports from China and the greater carbon intensity of these imports. The study period witnessed China's rise from Australia's ninth largest export destination and fifth largest import partner in 1995, to first on both measures by 2009 (DFAT, 2019). This was triggered by China formally joining the WTO on 11 December 2001. The rising importance of China affected Australia's emissions profile in four key ways:

- Firstly, and most significantly, China's rise resulted in a large increase in EEI, growing overall consumption emissions and subsequently a collapsing BEET. Australia's increase in EEI was driven by both the overall increase in the total value of imports, combined with China's carbon intensive production system taking a growing share of Australia's imports. The increase in the carbon intensity of Australia's imports (and subsequent decrease in Australia's pollution terms of trade) was also caused by the simultaneous rise of imports from the ROW, largely made up of developing countries.

- Secondly, the increase in the EEI share for China and ROW resulted in an increase in Australia's carbon leakage to non-Annex B countries (see section 6.2.6). Furthermore, a sectoral breakdown of EEI reveals the start of a structural shift in Australia, towards less energy-intensive production and an increased reliance on the importation of energy-intensive goods (see section 6.2.3). This is part of a broader global trend across the study period, with China increasingly becoming the factory of the world (see section 6.4.3).

- Thirdly, the TBEET result indicates that half of Australia's negative emissions balance in 2009 was due to technology difference and half was due to trade induced emissions outsourcing. Ultimately, although an increase in carbon intensity of imports is not by itself evidence of emissions outsourcing, when combined with the falling trade balance and trade specialisation, there can be no doubt that Australia was outsourcing emissions in 2009.

- Finally, the Australia/China TBEET analysis reveals that the relative difference in carbon intensity of production between these nations has diminished over the study period. This is an intriguing finding that suggests China's carbon intensity of production is improving rapidly. This will undoubtedly influence Australia's future emissions profile.

Given Australia's higher than average energy intensity, the global environment would benefit if Australia imported energy-intensive goods from less energy-intensive economies. As Jiborn et al (2018) note, a neutral emissions balance is not the target, rather "each country should specialize according to comparative carbon advantage" (p. 34). However, this study has found that unfortunately Australia increased its imports from China in the study period, a country with an even worse energy intensity than Australia. In global terms, Australia's stagnating production emissions alongside rising consumption emissions is a pattern shared with many other western nations (Levitt et al, 2017). This study reinforces the need to track both production and consumption emissions to measure Australia's true carbon footprint and avoid emissions falling outside international agreements (Minx et al, 2009).

8.2 The Post-Study Period (2010 – today)

There are three major factors affecting Australia's emissions profile in the decade since the end of the study period. The first concerns Australia's political instability and rising PBA emissions. World Bank data for CO_2 emissions shows that Australia's PBA emissions grew until 2009, before falling until 2014. This fall coincides with the financial crisis and the introduction of Australia's carbon pricing mechanism (it also aligns with the reduction in energy intensity identified in section 7.4). However, political instability led to the repeal of the mechanism and abandonment of sensible emissions policies (see section 2.5). As a result, PBA emissions accelerated upwards once again, peaking in 2018, before continuing to rise in the first quarter of 2019 (ndevr, 2019). The impact of a rising PBA may be a rebalancing of Australia's BEET, alongside an increasing carbon intensity of Australian production (and increasing pollution terms of trade). The beginnings of this shift in Australia's BEET can be found in the turning point identified in the extension above.

The second major factor is the changing nature of trade between Australia and China. As noted in section 2.4.2, China implemented a significant stimulus program in response to the financial crisis in 2008 and 2009. This increased Chinese demand for Australian coal and exports boomed. Australia's balance of trade with China became positive and rose dramatically (see figure 2.12). Although there is some recent concern regarding the ongoing viability of Australian coal exports to China, there is little doubt that the last decade will have seen an increase in Australia's EEE. Once again, the evidence of this shift can be found in the upwards turn of the extended BEET in section 7.5.

Finally, the third major factor concerns the changing nature of the Chinese economy. The analysis of the Australia/China TBEET in section 6.4.5 shows that the carbon intensity of production of both nations began to converge during the study period. This convergence is also highlighted by the declining carbon intensity of imports from China over the study period (see figure 6.8 in section 6.2.5). This shift in China's carbon intensity is supported by the literature. Meng et al (2018) find that the overall carbon intensity of the Chinese economy fell by 27 per cent between 2004 and 2015. Pan et al (2017) note that the difference between the CBA and PBA emissions in developed countries began to reduce in 2007, driven largely by a decrease in emissions embodied in exports from China. In fact, Pan et al (2017) find that after the rapid growth in export emissions from China between 2002 and 2007, export emissions plateaued due to trade volume falls (triggered initially by the financial crisis) and also “accelerated improvements in CO_2 intensity” (p.942). This plateau is also identified in the global comparison of TBEET results presented in section 6.4.3: China’s TBEET rises until 2007 before flattening out. These carbon intensity improvements in China may reduce Australia’s EEI.

Ultimately, Australia’s emissions profile has shifted considerably over the last decade. The combined effect of Australia’s rising PBA emissions, an increasing balance of trade with China, and falling carbon intensity of Chinese production will likely have reduced Australia’s emissions outsourcing. This is reflected in the turning point identified in the extension in section 7.5. However, it is important to note that Australia’s policy failures of the last decade have led to continuously rising production emissions, wiping out any net gains from a potential reduction in imported emissions. The climate emergency demands a renewed and dedicated domestic policy focus in the years ahead.

9 Conclusion

9.1 Research Summary

Driven largely by microeconomic reforms in the 1980s, the opening up of the Australian economy and the subsequent mining boom, Australia experienced sustained economic growth throughout the study period (Keating, 2015). However, this growth had an impact on Australia's emissions profile, with production and consumption emissions rising. Critically, this study found that Australia experienced a sharp upswing in EEI after 2001, resulting in Australia becoming an outsourcer of emissions. This was driven by an increase in Australia's imports, an increase in the carbon intensity of these imports, and the rise of China as Australia's major trading partner. China's carbon intensive production largely replaced Australian imports from Japan, the US, and Great Britain, resulting in a surge in Australian EEI, a declining pollution terms of trade, increasing carbon leakage, and a declining BEET and TBEET. The conclusions presented here are in line with the work of Levitt et al (2017) but include the additional TBEET methodology and associated analysis. The TBEET results are in line with Baumert et al (2019), aside from the decomposition which here utilised constant pricing in AU$. In contrast with Baumert et al (2019), the TBEET decomposition highlights the considerable role of Australia's trade balance in driving a negative TBEET. This study finds that approximately half of Australia's BEET in 2009 can be attributed to emissions outsourcing due to trade factors, with the other half due to technology differences. The sector analysis and TBEET decomposition also highlighted the emergent role of trade specialisation in Australia's emissions profile. Finally, the extension presented in section 7 found that Australia's emissions profile reached a second turning point in 2012. The declining carbon intensity of Chinese production, combined with Australia's mining export boom and a changing trade balance, contribute to the likely reduction of Australia's emissions outsourcing in the post-study period.

9.2 Strengths, Limitations & Future Research

This thesis has contributed to the relatively small group of Australia-specific emissions studies by reassessing Australia's emissions profile and applying the TBEET methodology to this unique context. This study has also introduced an innovative extension model to address the period after 2009. Despite these strengths, there are a number of inherent limitations in this study. Firstly, this thesis relies on the accuracy of WIOD13. Secondly, the relatively coarse sector and country resolution mean that aggregation may affect results. This is particularly the case for the ROW category which largely captures developing nations but also includes Norway and Switzerland. This may create an overestimation of Australia's carbon leakage. Thirdly, this study only considered CO_2 emissions. Levitt et al (2017) found that CO_2 emissions made up on average 76 per cent of Australia's total consumption-based greenhouse gas emissions in the study period, and that this remained a consistent share throughout. As such, the conclusions presented here can reasonably be interpreted as representative of Australia's total emissions. Fourthly, the constant prices methodology utilised here allowed for interlinkages with Jiborn et al (2018) and Baumert et al (2019) but may introduce some sector-level uncertainty (see appendix D). Finally, the most significant limitation of this study is the lack of emissions data after 2009. This study has extrapolated findings until 2014 but further research is needed once emissions accounts are completed for WIOD16 and beyond. As Bill McKibben (2013) notes, "we need to envision the planet as a planet, not just a collection of nations, each pursuing its own advantage." This requires continued research on the impact of trade on global emissions flows, and the improvement and integration of consumption-based methods of emissions accounting.

9.3 Policy Priorities & Political Paradigms

Assessing the role of emissions transfers through trade is critical for understanding the policy settings required to reduce global emissions. However, the nuances of emissions embodied in trade mean little for Australia if PBA emissions continue to rise. Writing in 2013 about the need for Australia to keep its coal in the ground, environmentalist Bill McKibben, reflected that "official Australia seems to be stuck in a bizarre state of denial, the kind where you acknowledge that you have a problem, but not that you need to do anything about it." Although there are signs that the era of Australia's *Greenhouse Mafia* is over (Cox, 2019), there is still a concerted political and industry push for the construction of new coal mines. Hence the first policy priority presented here is a general one in relation to Australia's rising PBA: there can be no new coal mines opened in Australia. Secondly, the most assured structural way of reducing PBA emissions is through a carbon pricing mechanism. Although politically unlikely after a decade of policy failure, it is arguably environmentally essential. The third policy priority is to begin tracking and reporting on Australia's rising consumption emissions. Only then can a sensible policy mix be derived to tackle EEI. Finally, given Australia's high energy intensity compared to world average, Australia could seek to import energy-intensive goods from less energy intensive countries. This could be done whilst transitioning the domestic energy sector to renewable sources. As the largest exporter of coal in the world, Australia has a unique and important opportunity to lead the global transition away from fossil fuel extraction. Australia is blessed with abundant renewable resources and government needs to play a central role in planning and executing a just transition from a coal-powered economy to a renewable energy powerhouse.

References

Afionis, S. (2017). Consumption-Based Carbon Accounting: Does it Have a Future? *WIREs Climate Change*, vol.8, pp 1-19.

Allen, M.R., O.P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M.Wairiu, and K. Zickfeld. (2018). *Framing and Context*, in Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.), *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels.* In Press.

Altman, J. & Biddle, N. (2015). Refiguring Indigenous Economies, in Ville, S. & Withers, G. (eds), *The Cambridge Economic History of Australia*, Melbourne: Cambridge University Press, pp. 530-554.

Andersson, M. & Lövin, I. (2015). Sweden: Decoupling GDP Growth from CO2 Emissions is Possible. *World Bank Blog*

Antweiler, W. (1996). The Pollution Terms of Trade, *Economic Systems Research*, vol. 8, issue 4, pp. 361-366.

Antweiler, W., Copeland, B. & Taylor, M. (2001). Is Free Trade Good for the Environment? *The American Economic Review*, vol. 91, no. 4, pp. 877-908.

Arto, I., Rueda-Cantuche, J.M., Andreoni, V., Mongelli, I. & Genty, A. (2014). The Game of Trading Jobs for Emissions, *Energy Policy*, vol. 66, pp. 517-525.

Baer, H. (2016). The Nexus of the Coal Industry and the State in Australia: Historical Dimensions and Contemporary Challenges, *Energy Policy*, vol. 99, pp. 194-202 [accessed 9 April 2019]

Baldwin, R. & Venables, A. (2013). Spiders and Snakes: Offshoring and Agglomeration in the Global Economy, *Journal of International Economics*, vol. 90, pp. 245-254.

Barrett, J., Peters, G., Wiedmann, T., Scott, K., Lenzen, M., Roelich, K. & Le Quere, C. (2013). Consumption-Based GHG Emission Accounting: a UK Case Study, *Climate Policy*, vol. 13, no. 4, pp. 451-470.

Barro, R. (1997). *Macroeconomics*. John Wiley, US.

Baumert, N., Kander, A., Jiborn, M., Kulionis, V. & Nielsen, T. (2019). Global Outsourcing of Carbon Emissions 1995–2009: A Reassessment, *Environmental Science and Policy*, vol. 92, pp. 228-236.

Baumol, W. (2000). Leontief's Great Leap Forward: Beyond Quesnay, Marx and von Bortkiewicz, *Economic Systems Research*, vol. 12, no. 2, pp. 141-152.

Beckerman, W. (1992). Economic Growth and the Environment. Whose Growth? Whose Environment? *World Development*, vol. 20, no. 4, pp. 481-496

Boitier, B. (2012). CO2 Emissions Production-Based Accounting vs Consumption: Insights from the WIOD Databases, *WIOD Conference*

Buckley, P. & Ghauri, P. (2004). Globalisation, Economic Geography and the Strategy of Multinational Enterprises, *Journal of International Business Studies*, vol 35, pp.81–98

Bureau of Meteorology (2019). *Australia in January 2019*, Available at: http://www.bom.gov.au/climate/current/month/aus/archive/201901.summary.shtml [accessed 24 April 2019].

Carrington, D. (2013). *Australia Adds New Colour to Temperature Maps as Heat Soars*, The Guardian Online. Available at www.theguardian.com [accessed 12 April 2009].

Centre for International Development (CID, 2009). *Atlas of Economic Complexity*, Harvard University. Available at: http://www.atlas.cid.harvard.edu [accessed 24 April 2009].

Cole, M. (2003). Development, Trade, and The Environment: How Robust is the Environmental Kuznets Curve? *Environment and Development Economics*, vol 8, pp. 557-580 [accessed 9 April 2019].

Comerford, J. (1997). Coal and Colonials: The Founding of the Australian Coal Mining Industry. *United Mineworkers of Australia* (New South Wales Northern District Branch of the CFMEU, Mining and Energy Division), Aberdare, Australia.

Copeland, B. & Taylor, M. (2004). Trade, Growth, and the Environment, *Journal of Economic Literature*, vol. 42, no. 1, pp. 7-71.

Cox, L. (2019). *Rio Tinto Ready to Quit Minerals Council if it Doesn't Support Paris Climate Targets*, The Guardian Online, Available at: www.theguardian.com [accessed 23 April 2019]

Crabb, A. (2018). Australia's Recent Climate Change Policy: A Brief History of Seven Killings, *The ABC Online*, Available at: www.abc.net.au [accessed 12 April 2019]

Davis S.J., and Caldeira, K., (2010). "Consumption-Based Accounting of CO_2 Emissions", *Proceedings of National Academy of Science*, vol. 107, no. 12, pp.5687-5692.

Davis, S.J., Peters, G. & Caldeira, K. (2011). The Supply Chain of CO_2 Emissions, *Proceedings of National Academy of Science*, vol. 108, no. 45, pp. 18554–18559.

Department of the Environment and Energy (DEE, 2019a). *Australian Energy Statistics*. Available at: www.energy.gov.au [accessed 12 April 2009].

Department of the Environment and Energy (DEE, 2019b). Australian Greenhouse Emissions Information System (AGEIS). Available at: www.environment.gov.au

Department of Foreign Affairs and Trade (DFAT, 2016), *Australia's Trade Since Federation*.

Department of Foreign Affairs and Trade (DFAT, 2019), Trade Time Series Data. Available at: www.dfat.gov.au/trade/resources/trade-statistics [accessed 12 April 2019].

Dietzenbacher, E. & Temurshoev, U. (2012). Input-Output Analysis in Current and Constant Prices: Does it Matter? *Journal of Economic Structures*, vol. 1, pp. 1-18.

Ederington, J. & Minier, J. (2003). Is Environmental Policy a Secondary Trade Barrier? An Empirical Analysis, *Canadian Journal of Economics*, vol. 36, no. 1, pp.137-154.

Farrer, M. & Smee, B. (2019). Australia's Coal Bonanza at Risk as Chinese Import 'Ban' Spreads, *The Guardian*, Available at: www.theguardian.com [accessed 9 April 2019].

Fan, JL., Hou, YB., Wang, Q., Wang, C. & Wei, YM. (2016). Exploring the Characteristics of Production-Based and Consumption-Based Carbon Emissions of Major Economies: A Multiple-Dimension Comparison, *Applied Energy*, vol 184, pp. 790-799.

Feng, K., Siu, YL., Guan, D. & Hubacek, K. (2012). Analyzing Drivers of Regional Carbon Dioxide Emissions for China, *Journal of Industrial Ecology*, vol 16, no. 4, pp. 600-611.

Ferguson, S. & Sanctuary, M. (2019). Why is Carbon Leakage for Energy-Intensive Industry Hard to Find? *Environmental Economics and Policy Studies*, vol. 21, issue 1, pp.1-24.

Franzen, A. & Mader, S. (2018), Consumption-Based Versus Production-Based Accounting of CO_2 Emissions: Is There Evidence for Carbon Leakage? *Environmental Science and Policy*, vol. 84, pp. 34-40.

Foure, J., Guimbard, H. & Monjon, S. (2016). Border Carbon Adjustment and Trade Retaliation: What Would be the Cost for the European Union? *Energy Economics*, vol. 54, pp. 349-362.

Galeotti, M. & Lanza, A. (2005). Desperately Seeking Environmental Kuznets. *Environmental Modelling and Software*, vol. 20, pp.1379-1388.

Galeotti, M., Lanza, A. & Pauli, F. (2006). Reassessing the Environmental Kuznets Curve for CO2 Emissions: A Robustness Exercise, *Ecological Economics*, vol 57, pp.152-162

Genty, A., Arto, I. & Neuwahl, F. (2012). Final Database of Environmental Satellite Accounts: Technical Report on their Compilation. *WIOD Deliverable 4.6*, Documentation.

Gereffi, G. (1999). International Trade and Industrial Upgrading in the Apparel Commodity Chain, *Journal of International Economics*, vol. 48, pp.37–70

Grether, JM. & Mathys, N. (2013). The Pollution Terms of Trade and its Five Components, *Journal of Development Economics*, vol 100, issue 1, pp. 19-31.

Grossman, G. & Krueger, A. (1991). Environmental Impacts of a North American Free Trade Agreement, *NBER Working Paper Series,* Working Paper no.3914. National Bureau of Economic Research.

Grossman, G. & Krueger, A. (1994). Economic Growth and the Environment. *NBER Working Paper Series,* Working Paper no.4634. National Bureau of Economic Research.

Hatfield-Dodds, S., Schandl, H., Adams, P., Baynes, T., Brinsmead, T., Bryan, B., Chiew, F., Graham, P., Grundy, M., Harwood, T., McCallum, R., McCrea, R., McKeller, L., Newth, D., Nolan, M., Prosser, I. & Wonhas, A. (2015). Australia is 'Free to Choose' Economic Growth and Falling Environmental Pressures. *Nature*, vol. 527, pp. 49-53.

He, J. (2008). China's Industrial SO2 Emissions and its Economic Determinants: EKC's Reduced Vs. Structural Model and the Role of International Trade, *Environment and Development Economics*, vol 14, issue 2, pp. 227-262.

Horne, D. (1964). *The Lucky Country*, Sydney: Penguin.

Hunter, B. (2015). The Aboriginal Legacy, in Ville, S. & Withers, G. (eds), *The Cambridge Economic History of Australia*, Melbourne: Cambridge University Press, pp. 73-96.

IPCC (2018). Global Warming of 1.5^{0}C, Available at: https://www.ipcc.ch/sr15/ [accessed 6 January 2019]

Jakob, M. & Marschinski, M. (2013). Interpreting Trade-Related CO2 Emission Transfers, *Nature Climate Change*, vol. 3 (plus supplementary information).

Jakob, M., Steckel, J. & Edenhofer, O. (2014). Consumption- Versus Production-Based Emission Policies, *Annual Review of Resource Economics*, vol. 6, pp. 297-318.

Jiborn, M., Kander, A., Kulionis, V., Nielsen, H. & Moran, D. (2018). Decoupling or delusion? Measuring Emissions Displacement in Foreign Trade. *Global Environmental Change*, vol. 49, pp. 27-34.

Kander, A., P. Malanima and P. Warde (2013): *Power to the People - Energy in Europe over Five Centuries*, Princeton University Press

Kander, A., Jiborn, M., Moran, D. & Wiedmann T. (2015). National Greenhouse-Gas Accounting for Effective Climate Policy on International Trade, *Nature Climate Change*, May, vol 5, issue 5, p 431-435.

Kanemoto, K., Lenzen, M., Peters, G., Moran, D. & Geschke, A. (2014). Frameworks for Comparing Emissions Associated with Production, Consumption, And International Trade. *Environmental Science and Technology*, vol. 46, pp. 172-179.

Kanemoto, K., Moran, D., Lenzen, M. & Geschke, A. (2014). International Trade Undermines National Emission Reduction Targets: New Evidence from Air Pollution, *Global Environmental Change*, vol. 24, pp. 52-59.

Kanemoto, K., Moran, D. & Hertwich, E. (2016). Mapping the Carbon Footprint of Nations, *Environmental Science and Technology*, vol. 50, no. 19, pp. 10512–10517.

Keating, M. (2015). Evolution of Macroeconomic Strategy Since WW2, in Ville, S. & Withers, G. (eds), *The Cambridge Economic History of Australia*, Melbourne: Cambridge University Press, pp. 438-461.

Keeling, C. (1960). The Concentration and Isotopic Abundance of Carbon Dioxide in the Atmosphere, *Tellus*, vol. 12, no. 1, pp. 200-203.

Kulionis, V. (2014). CO_2 Emissions Embodied in International Trade of the UK, 1995-2009: A Multi-Region Input-Output Analysis, Master's Thesis. *Department of Economic History, School of Economics and Management,* Lund University, Sweden.

Kulionis, V. (2019). Energy Embodied in Trade, 1970 – 2014. Published PhD Thesis. *Department of Economic History, School of Economics and Management,* Lund University, Sweden.

Kuznets, S. (1955). Economic Growth and Income Inequality, *The American Economic Review*, vol. 45, no. 1, pp.1-28.

Kuznets, S. (1965). *Economic Growth and Structural Change*, New York: Norton

Kuznets, S. (1966). *Modern Economic Growth*, New Haven: Yale University Press

Lenzen, M. (1998). Primary Energy and Greenhouse Gases Embodied in Australian Final Consumption: An Input–Output Analysis, *Energy Policy*, vol. 26, no. 6, pp. 495-506.

Lenzen, M., Pade, L.-L., and Munksgaard, J. (2004). CO_2 Multipliers in Multi-Region Input-Output Models, *Economic Systems Research*, vol. 16, no. 4, pp. 391–412.

Lenzen, M., Murray, J., Sack, F. & Wiedmann, T. (2007). Shared Producer and Consumer Responsibility: Theory and Practice, *Ecological Economics*, vol. 61, pp. 27-42.

Lenzen, M., Kanemoto, K., Moran, D. & Geschke, A. (2012). Mapping the Structure of the World Economy, *Environmental Science and Technology*, vol. 46, no. 15, pp.8347-8381. Available at:

Lenzen, M., Kanemoto, K., Moran, D. & Geschke, A. (2013). Building Eora: A Global Multi-Region Input–Output Database at High Country and Sector Resolution, *Economic Systems Research*, vol 25. no. 1, pp.20-49.

Lenzen, M. (2016). Structural Analyses of Energy Use and Carbon Emissions – An Overview, *Economics Systems Research*, vol 28, no. 2, pp. 119-132.

Leontief, W. (1936). Quantitative Input and Output Relations in the Economic Systems of the United States, *The Review of Economic Statistics*, vol. 18, no. 3, pp.105-125.

Levinson, A. & Taylor, M. (2008). Unmasking the Pollution Haven Effect, *International Economic Review*, vol. 49, no. 1, pp.223-254.

Levitt, C.J., Saaby, M. & Sorensen, A. (2017). Australia's Consumption-Based Greenhouse Gas Emissions. *Australian Journal of Agricultural and Resource Economics*, vol 61, pp. 211-231.

Ljungberg, J. (ed) (2015). *Structural Analysis and the Process of Economic Development: Essays in Memory of Lennart Schön*, London: Routledge.

Los, B., Timmer, M. & de Vries, G. (2015). How Global Are Global Value Chains? A New Approach to Measure International Fragmentation, *Journal of Regional Science*, vol. 55, no. 1, pp. 66–92.

Low, P. & Yeats, A. (1992). Do "Dirty' Industries Migrate? *World Bank: Discussion Papers*. no. 159, pp. 89-103.

Löfgren, K. (2019). Reassessing Emissions Displacement in the Lucky Country. Consumption, Production & Decoupling in Australia (1990 – 2015), *Thesis Proposal*, Lund University (Research Design).

Lucas, A. (2017). Confected Conflict in the Wake of the South Australian Blackout: Diversionary Strategies and Policy Failure in Australia's Energy Sector, *Energy Research and Social Science*, vol 29, pp. 149-159.

Mackellar, D. (1908). *My Country*. First Published as *Core of My Heart* in The Spectator (5 September 1908, p.329). Available at: http://www.dorotheamackellar.com.au [accessed 29 April 2019]

Malik, A. & Lan, J. (2016). The Role of Outsourcing in Driving Global Carbon Emissions, *Economic Systems Research*, vol. 28, no. 2, pp. 168-182.

McKay, B., Lambert, I. & Miyazaki, S. (Australian Geological Survey Organisation, 2000). The Australian Mining Industry: From Settlement to 2000, *Australian Bureau of Statistics* (ABS). Available at: http://www.abs.gov.au [accessed 9 April 2019]

McKibben, B. (2013). *The Cost of Coal*, The Monthly Online, June 2013. Available at: www.themonthly.com.au [accessed 23 April 2019]

Mehra, M. & Das, S. (2008). North–South Trade and Pollution Migration: The Debate Revisited, *Environmental and Resource Economy*, vol 40, pp.139-164

Meng, J., Mi, Z., Guan, D., Li, J., Tao, S., Li, Y., Feng, K., Liu, J., Liu, Z., Wang, X., Zhang, Q. & Davis, S. (2018). The Rise of South–South Trade and its Effect on Global CO_2 Emissions, *Nature Communications*, vol. 9, Article No. 1871.

Mercer, D., Christesen, L. & Buxton, M. (2007). Squandering the Future: Climate Change, Policy Failure and the Water Crisis in Australia, *Futures*, vol. 39, issues 2-3, pp. 272-287.

Miller, R., & Blair, P. (2009). *Input–Output Analysis Foundations and Extensions* (Second Edition), Cambridge: Cambridge University Press.

Minx, J., Wiedmann, T., Wood, R., Peters, GP., Lenzen, M., Owen, A,. Scott, K., Barrett, J. Hubacek, K., Baiocchi, G., Paul, A., Dawkins, E., Briggs, J., Guan, D., Suh, S. & Ackerman, F. (2009). Input-Output Analysis and Carbon Footprinting: An Overview of Applications, *Economic Systems Research*, vol. 21, no. 3, pp. 187-216.

Moran, D. & Wood, R. (2014). Convergence Between the EORA, WIOD, EXIOBASE and OPENEU's Consumption-Based Carbon Accounts, *Economic Systems Research*, vol. 26, no. 3, pp. 245-261.

Moran, D., Kanemoto, K. and Geschke, A. (2018). Carbon Footprint of Nations (1970-2015), Eora MRIO.

Muradian, R., O'Connor, M. & Martinez-Alier, J. (2002). Embodied Pollution in Trade: Estimating the 'Environmental Load Displacement' of Industrialised Countries, *Ecological Economics*, vol. 41, pp. 51-67.

Ndevr Environmental. (2019) Tracking 2 Degrees, Available at: http://ndevrenvironmental.com.au/ [accessed 9 April 2019].

Obama, B. (2017). The Irreversible Momentum of Clean Energy, *Science*, vol. 355, pp. 126 – 129.

OECD. (2019). Total GHG per Capita, OECD.Stat. Available at: https://stats.oecd.org [accessed 9 April 2019].

Owen, A. (2004). Environmental Externalities, Market Distortions and the Economics of Renewable Energy Technologies, *The Energy Journal*, vol. 25, no. 3, pp. 127-156.

Ozatac, N., Gokmenoglu, K. & Taspinar, N. (2017). Testing the EKC Hypothesis by Considering Trade Openness, Urbanization, and Financial Development: the Case of Turkey, *Environmental Science and Pollution Research*, vol, 24, issue 20, pp. 16690–16701.

Pan, C., Peters, G. P., Andrew, R. M., Korsbakken, J. I., Li, S., Zhou, D., & Zhou, P. (2017). Emissions Embodied in Global Trade Have Plateaued Due to Structural Changes in China, *Earth's Future*, vol. 5, pp. 934–946.

Panayotou, T. (1993). Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development. Technical Report: International Labour Organization.

Pearse, G. (2009). Coal, Climate Change and the End of The Resources Boom. *Quarterly Essay*, No. 33.

Peters, G. & Hertwich, E. (2007). CO2 Embodied in International Trade with Implications for Global Climate Policy, *Environmental Science and Technology*, vol. 42, no. 5, pp.1401-1407.

Peters, G., Minx, J., Weberd, C. & Edenhofer, O. (2011). Growth in Emission Transfers via International Trade From 1990 to 2008, *Proceedings of National Academy of Science*, vol .108, no 21, pp. 8903-8908.

Peters, G., Davis, S. & Andrew, R. (2012). A Synthesis of Carbon in International Trade. *Biogeosciences*, vol. 9, pp. 3247–3276.

Pigou, A.C. (1932). *The Economics of Welfare*, London: Macmillan and Co.

Pomfret, R. (2015). Reorientation of Trade, Investment and Migration, in Ville, S. & Withers, G. (eds), *The Cambridge Economic History of Australia*, Melbourne: Cambridge University Press, pp. 397-418.

Rana, R. & Sharma, M. (2019). Dynamic Causality Testing for EKC Hypothesis, Pollution Haven Hypothesis and International Trade in India, *The Journal of International Trade and Economic Development*, vol. 28, issue 3, pp. 348-364.

Rezai, A., Foley, D. & Taylor, L. (2012). Global Warming and Economic Externalities, *Economic Theory*, vol. 49, issue 2, pp. 329-351.

Robson, A. (2015). The Australian Economy and Economic Policy During and After the Mining Boom, *Institute of Economic Affairs*, vol. 35, no. 2, pp.307-316.

Rocchi, P., Serrano, M., Roca, J. & Arto, I. (2018). Border Carbon Adjustments Based on Avoided Emissions: Addressing the Challenge of Its Design, *Ecological Economics*, vol, 145, pp. 126-136.

Sachs, J., Panayotou, T. & Peterson, A. (1999). Developing Countries and the Control of Climate Change: A Theoretical Perspective and Policy Implications, *Consulting Assistance on Economic Reform (CAER II)*, CAER II Discussion Paper No. 44.

Schröder, E. & Storm, S. (2018). Economic Growth and Carbon Emissions: The Road to 'Hothouse Earth' is Paved with Good Intentions. *Institute for New Economic Thinking*, Working Paper no. 84.

Shahbaz, M. & Sinha, A. (2018). Environmental Kuznets Curve for CO2 Emissions: A Literature Survey. *Journal of Economic Studies*, vol. 46, no. 1, pp.106-168.

Slezak, M. (2017). Australia's Greenhouse Gas Emissions Soar in Latest Figures, *The Guardian Online*. Available at: www.theguardian.com [accessed 9 April 2019].

Steffen, W., Rockström, J., Richardson, K., Lenton, T., Folke, L., Liverman, D., Summerhayes, C., Barnosky, A., Cornell, S., Crucifix, M., Donges, J., Fetzer, I., Lade, S., Scheffer, M., Winkelmann, R. & Schellnhuber, H. (2018). Trajectories of the Earth System in the Anthropocene, *Proceedings of National Academy of Science*, vol. 115, no 33, pp. 8252–8259.

Stern, D. (1998) Progress on the Environmental Kuznets Curve? *Environment and Development Economics*, vol. 3, pp.173–196.

Stern, D. (2004). The Rise and Fall of the Environmental Kuznets Curve, *World Development,* vol. 32, no. 8, pp. 1419–1439.

Stern, D., Common, M. & Barbier, E. (1996). Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development, *World Development*, vol. 24, no. 7, pp. 1151-l160.

Stiglitz, J. (2006). A New Agenda for Global Warming, *Economists' Voice*, July 2006

Suh, S. (2009). *Handbook of Input-Output Economics in Industrial Ecology: EcoEfficiency in Industry and Science*. Springer.

Sun, J.W. (1998). Changes in Energy Consumption and Energy Intensity: A Complete Decomposition Model, *Energy Economics*, vol. 20, issue 1, pp. 85-100.

Timmer, M.P., Erumban, A., Los, B., Stehrer, R. & de Vries, G. (2014). Slicing Up Global Value Chains, *Journal of Economic Perspectives*, vol. 28, no. 2, pp. 99–118.

Timmer, M.P., Dietzenbacher, E., Los, B., Stehrer, R. & Vries, G.J. (2015). An Illustrated User Guide to the World Input-Output Database: The Case of Global Automotive Production, *Review of International Economics*, vol. 23, no. 3, pp. 575-605.

Timmer, M.P., Los, B., Stehrer, R. & Vries, G.J. (2016). An Anatomy of the Global Trade Slowdown Based on the WIOD 2016 Release, *GGDC Research Memorandum Number 162*, University of Groningen.

Ville, S. & Withers, G. (2015). Introduction, in Ville, S. & Withers, G. (eds), *The Cambridge Economic History of Australia*, Melbourne: Cambridge University Press, pp. 1-8.

Weber, C. & Matthews, H. (2007). Quantifying the Global and Distributional Aspects of American Household Carbon Footprint, *Ecological Economics*, vol. 66, pp. 379 – 391.

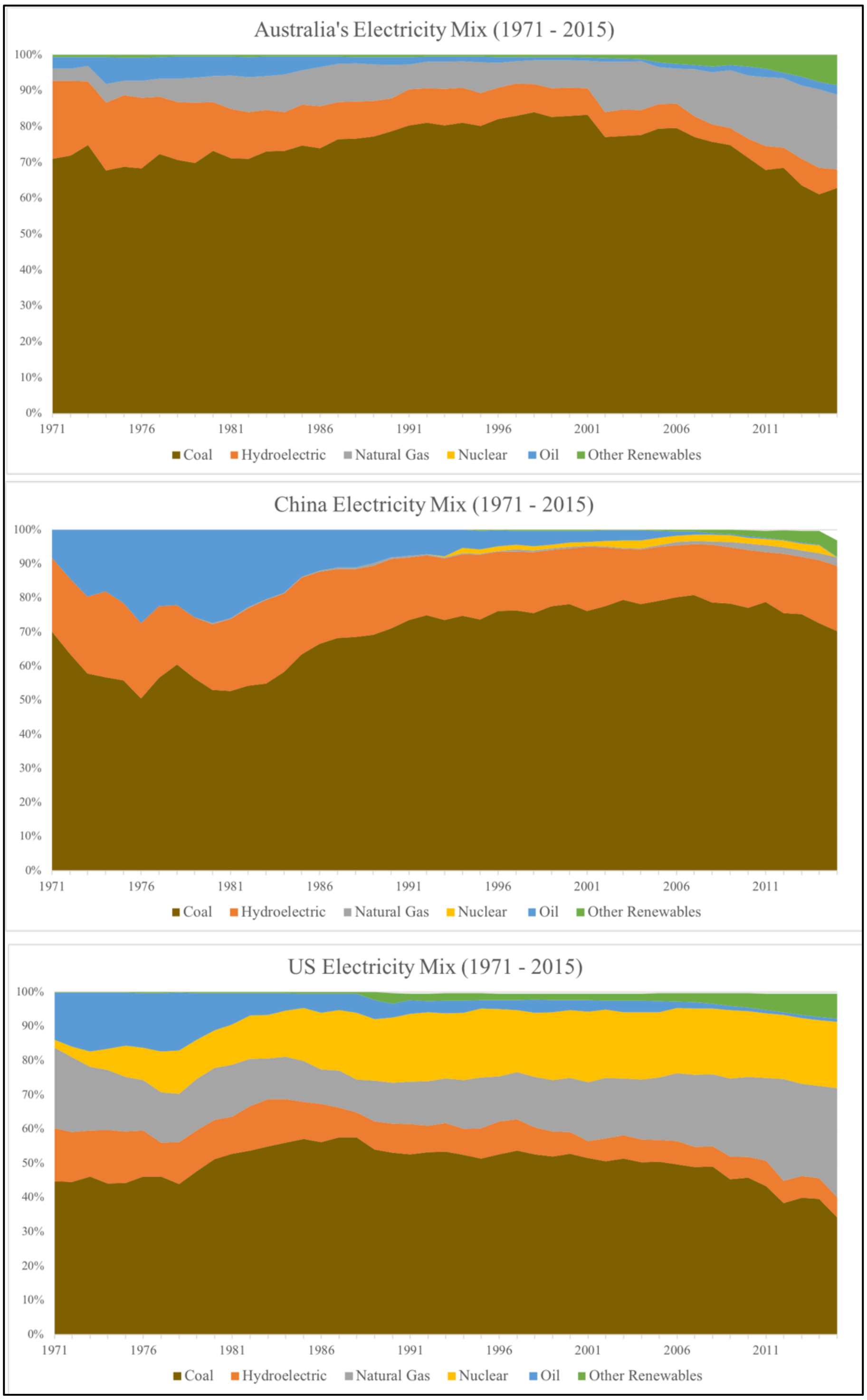
Wiedmann, T. & Lenzen, M. (2018). Environmental and Social Footprints of International Trade, *Nature Geoscience*, vol. 11, pp. 314-321.

Wood, R. (2009). *Structural Evolution of Economy and Environment in Australia*, PhD Thesis, The University of Sydney.

World Bank (2019). *Databank*, Available at: www.data.worldbank.org/country/australia [accessed 25 April 2019].

Appendix A: Electricity Mix Comparison

Figure A.1: Electricity Mix Comparison (Australia, China & the US)



Source: World Bank (2019), Author's Construction.

Appendix B: The Political Backdrop

Australia's political response to climate change has been an unmitigated disaster. This appendix provides a succinct summary of the last 12 years of emissions and energy policy failure: a tale of seven Prime Ministers and no meaningful outcomes.

Prime Minister John Howard reluctantly proposed an emissions trading scheme in 2007, on the eve of what would be his last election. His government was defeated by the progressive Labor Party, led by Kevin Rudd who famously declared climate change as "the most urgent moral challenge of our generation" (Crabb, 2018). An emissions trading scheme (ETS) was designed, and bi-partisan support reached with the new moderate opposition leader Malcolm Turnbull. However, before the deal could be finalised in parliament, and under concerted pressure from the Greenhouse Mafia, Turnbull was deposed as leader of his party and replaced with the arch-conservative Tony Abbott. The new political environment forced Prime Minister Kevin Rudd to abandon his ETS, immediately causing a collapse in popularity and eventually resulting in his party brutally replacing him as Prime Minister. The new Labor Prime Minister, Julia Gillard, pledged that there would not be a carbon tax under her new government, before introducing an ETS in the new parliament. Although not a tax, the ETS began with a fixed carbon price and hence was widely interpreted and attacked as a carbon tax mechanism. The ETS lasted less than two years, during which production emissions began falling for the first time. However, the perceived electoral betrayal haunted her government and after a vicious campaign from the Greenhouse Mafia, the media and a relentless opposition, she was eventually removed from office by her own party, with Kevin Rudd reinstalled as Prime Minister. His Labor government was then soundly defeated at the next election by conservatives led by Tony Abbott, who immediately removed the ETS. This left Australia once again without a market-based emissions mechanism. Instead, a plethora of direct intervention policies were adopted.

After falling in popularity, Tony Abbott was removed as Prime Minister by his conservative party and replaced with Malcolm Turnbull, the original opposition leader who agreed to adopt an ETS back in 2007! However, by now there was no mandate for a market-based mechanism and direct-intervention policies were continued. After narrowly winning the next election, Malcolm Turnbull's popularity waned and the hard-right forces in his party grew in confidence. This resulted in the removal of Malcolm Turnbull as Prime Minister and (after a shambolic process where the hard-right candidate failed to gain the required numbers) the installing of fellow moderate Scott Morrison as Prime Minister in mid-2018.

Finally, as this thesis is being written, Scott Morrison and his conservative party have just won a federal election in a shock result. Voters rejected further action on climate change and a suite of social reforms, in favour of a simple mandate of economic stability and lower taxes. Sadly, after seven Prime Ministers in 12 years, there is still no mandate for a market-based emissions policy or strong action on the climate emergency.

Appendix C: WIOD Sectors & Countries

Table C.1: WIOD Country Codes

WIOD Code	Country
Australia	AUS
Austria	AUT
Belgium	BEL
Bulgaria	BGR
Brazil	BRA
Canada	CAN
China	CHN
Cyprus	CYP
Czech R	CZE
Germany	DEU
Denmark	DNK
Spain	ESP
Estonia	EST
Finland	FIN
France	FRA
UK	GBR
Greece	GRC
Hungary	HUN
Indonesia	IDN
India	IND
Ireland	IRL
Italy	ITA
Japan	JPN
S Korea	KOR
Lituania	LTU
Luxemburg	LUX
Latvia	LVA
Mexico	MEX
Malta	MLT
Netherlands	NLD
Poland	POL
Portugal	PRT
Romania	ROU
Russia	RUS
Slovakia	SVK
Slovenia	SVN
Sweden	SWE
Turkey	TUR
Taiwan	TWN
USA	USA
Rest of World	RoW

Table C.2: WIOD Sector Codes

WIOD Code	Sector
AtB	Agriculture, Hunting, Forestry and Fishing
C	Mining and Quarrying
15t16	Food, Beverages and Tobacco
17t18	Textiles and Textile Products
19	Leather, Leather and Footwear
20	Wood and Products of Wood and Cork
21t22	Pulp, Paper, Paper , Printing and Publishing
23	Coke, Refined Petroleum and Nuclear Fuel
24	Chemicals and Chemical Products
25	Rubber and Plastics
26	Other Non-Metallic Mineral
27t28	Basic Metals and Fabricated Metal
29	Machinery, Nec
30t33	Electrical and Optical Equipment
34t35	Transport Equipment
36t37	Manufacturing, Nec; Recycling
E	Electricity, Gas and Water Supply
F	Construction
50	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
51	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
52	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
H	Hotels and Restaurants
60	Inland Transport
61	Water Transport
62	Air Transport
63	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
64	Post and Telecommunications
J	Financial Intermediation
70	Real Estate Activities
71t74	Renting of M&Eq and Other Business Activities
L	Public Admin and Defence; Compulsory Social Security
M	Education
N	Health and Social Work
O	Other Community, Social and Personal Services
P	Private Households with Employed Persons
HH	Households

Appendix D: Monetary Data, Currencies & Constant Price Conversions

This thesis builds on the work of Jiborn et al (2018) and Baumert et al (2019). Both these studies do not convert the core WIOD13 data to constant prices. As such, primarily in order to maintain alignment with these studies and allow for cross-study comparisons, this thesis calculates emissions utilising the core WIOD13 data in current prices. Whilst this method will not materially affect aggregate emissions results, there may be some minor price-effects in sector-level results. There are methods available to convert IO data to constant prices. For example, Levitt et al (2017) utilise a standard chaining methodology and previous-year-prices to convert to constant prices.[9] However, the primary objective of this study is to build on the methods developed in Jiborn et al (2018) and Baumert et at (2019). As such, the unchanged WIOD13 data will be used to calculate the emissions matrix.

The above approach allows for a macro alignment with Jiborn et al (2018) and Baumert et al (2019). However, when calculating emissions intensities, pollution terms of trade, and the decomposition of TBEET, export and import values are converted to constant prices. Two different techniques are used in the deflation of export and import values to constant prices. Firstly, the export values were extracted from WIOD13 by sector. The export values were converted using gross-output, sector-level deflators provided in WIOD13's social accounts. The deflated sector-level export values were then added together to create Australia's total export value for each year of the study (in 1995 constant prices).

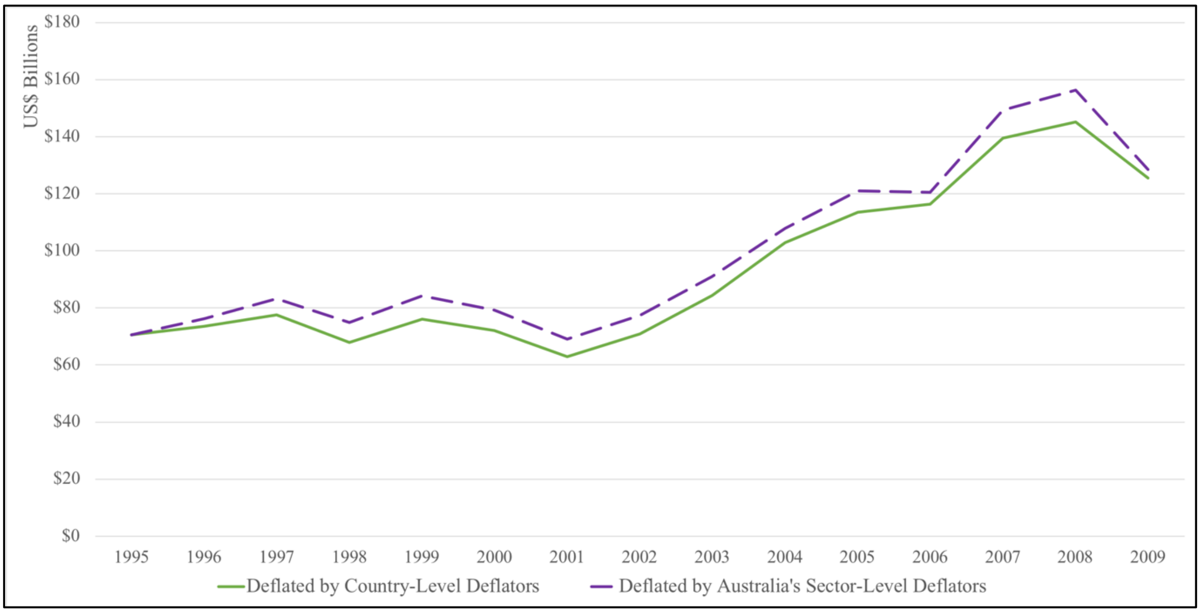
The import values were extracted from WIOD13 by country of origin. The import values were converted using gross-output, country-level deflators provided in WIOD13's social accounts. The ROW grouping received an average deflator from all listed countries in WIOD13, aside

[9] Alongside the sole focus of this thesis on CO_2, this difference in constant price methodology explains much of the difference in numerical results when comparing this thesis to Levitt et al (2017). However, the underlying narrative presented here aligns with Levitt et al's (2017) conclusions.

from severe outliers (Turkey, Romania and Bulgaria). The deflated country-level values were then added together to create the total import value for each year (in 1995 constant prices).[10]

It is worth noting that Australia's imports could have been deflated using Australia's sector-level deflators. This would have assumed that price changes in Australia's sectors match those in sectors in Australia's trading partners. However, the country-level deflators reveal that although China's aggregate deflator in 2009 is similar to Australia's, it is considerably larger than the US, Great Britain or Korea's. Thus, the choice needs to be made to respect the different price effects across each trading partner (by utilising aggregate country-level deflators) or go to the sector level (using Australia's sector-level deflators) and ignore differing price effects across Australia's trading partners. The author made the decision to respect the differing price effects across Australia's trading partners and utilise the country-level deflators. Regardless, figure D.1 reveals very similar deflated import values using both potential deflation methods.

Figure D.1: The Deflation of Australia's Imports (Two Methods)

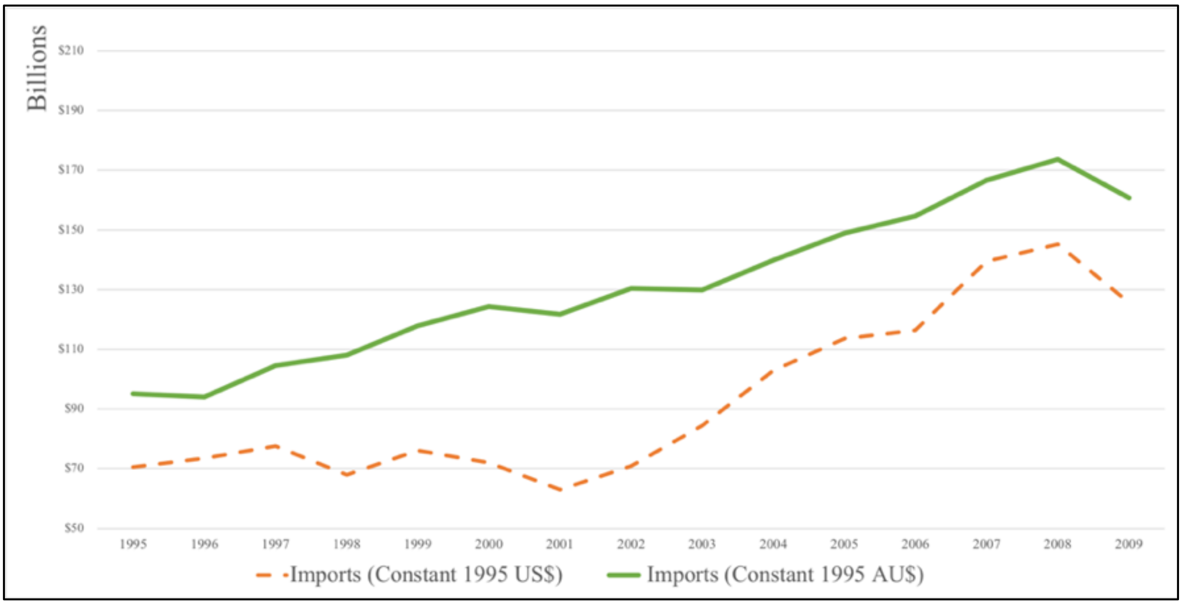


Source: WIOD13 (Timmer et al, 2015), Author's Construction.

10 The hybrid methodology outlined here builds on the methods presented in Dietzenbacher and Temurshoev (2012). They outline three methods to convert current to constant prices in IO analysis and show that the choice of method does not materially affect aggregate or sector level results. This thesis builds on Option A as outlined in Dietzenbacher and Temurshoev (2012): *deflation after gross output calculations in current prices.*

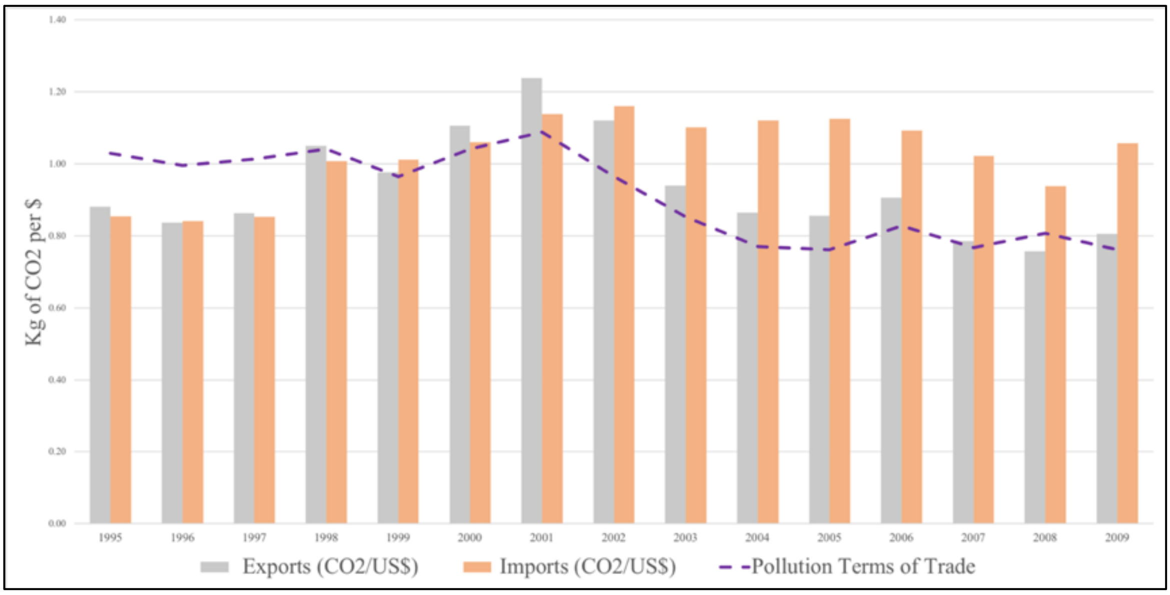
The last step in this method is a historic currency conversion. This is achieved using the World Bank's Global Economic Monitor (GEM) database (as demonstrated by Levitt et al, 2017). Figure D.2 illustrates the impact of this conversion on Australia's import values, due to significant fluctuations in Australia's currency value over the study period. The currency fluctuations also result in differing carbon intensity curves in AU$ and US$, as shown in figure D.3 and D.4. This highlights the importance of adopting the local currency in this study, with carbon intensities fluctuating wildly in regard to the US$ (figure D.3). However, the pollution terms of trade remain the same across both currencies, indicating the increased intensity of Australia's imports when compared to exports across the study period.

Figure D.2: The Value of Imports (US$ vs AU$)



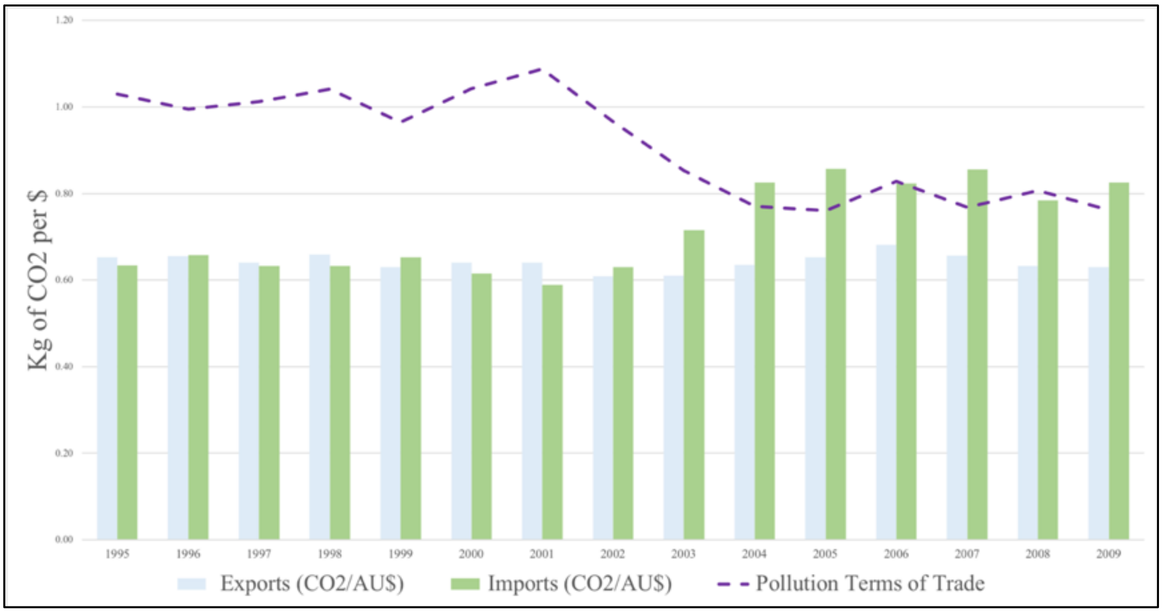
Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Figure D.3: Carbon Intensities & Pollution Terms of Trade (US$)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Figure D.4: Carbon Intensities & Pollution Terms of Trade (AU$)



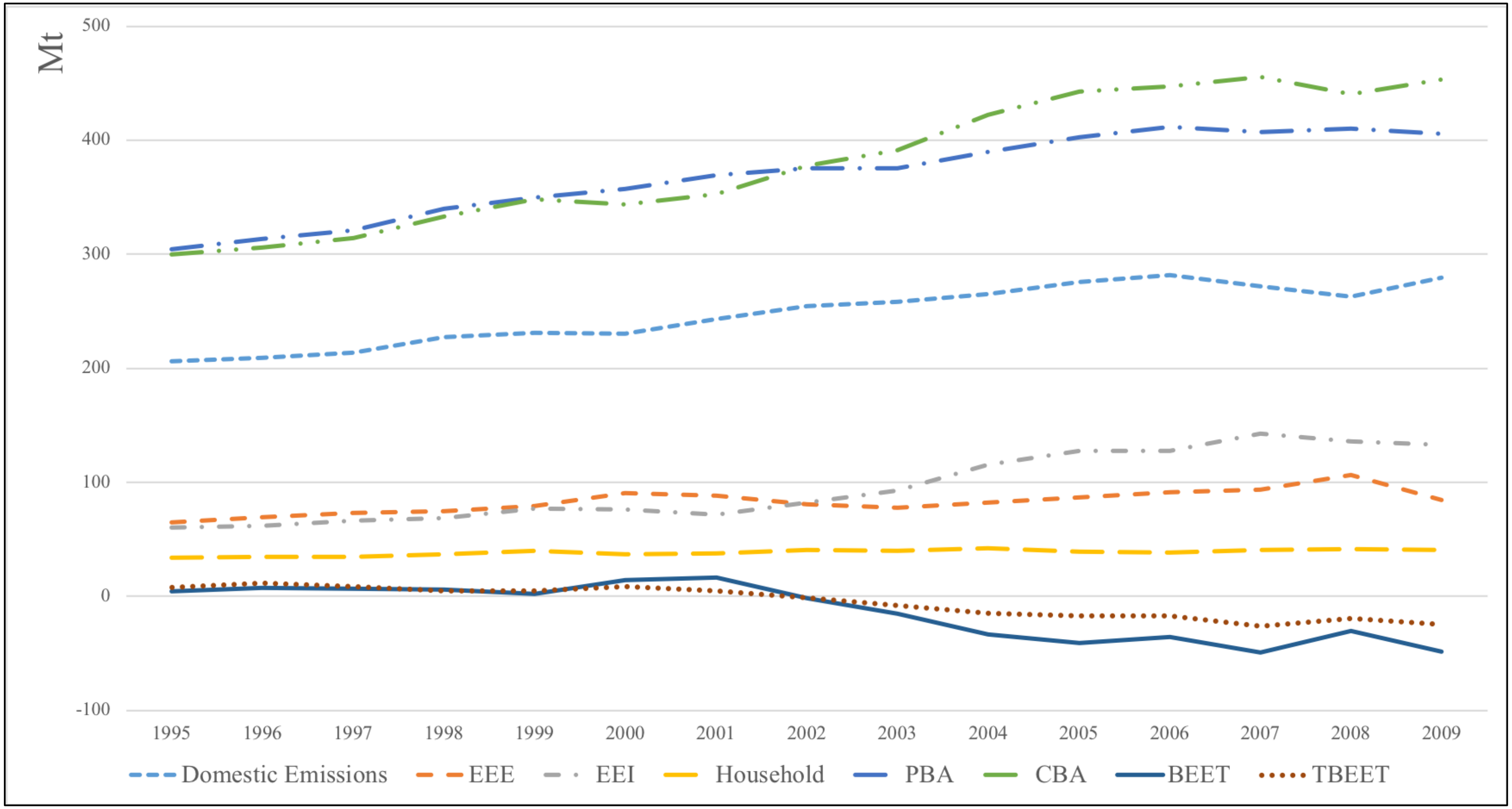
Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Appendix E: Australia's Emissions History

Table E.1: Australia's CO_2 Emissions Profile (1995 - 2009)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
CO2 Emissions															
Domestic Emissions	205887	209481	213658	227705	230911	230374	243095	254777	258661	265173	276059	281567	272305	262634	279598
EEE	65073	69535	73010	74622	79102	90521	88351	80472	77419	82417	87196	91740	93727	106325	84727
EEI	60264	61806	66134	68441	77030	76448	71694	82265	92881	115394	127769	127274	142503	136299	132807
Household Emissions	33749	34596	34533	37335	39972	36679	37660	40513	39725	41977	39046	38302	40898	41474	41143
PBA	304708	313611	321202	339661	349985	357574	369106	375762	375805	389567	402300	411609	406930	410433	405468
CBA	299899	305883	314325	333480	347913	343500	352450	377555	391267	422545	442874	447143	455706	440407	453548
BEET	**4809**	**7729**	**6876**	**6181**	**2072**	**14073**	**16657**	**-1794**	**-15462**	**-32977**	**-40574**	**-35535**	**-48776**	**-29974**	**-48080**
Carbon Intensity of Exports & Imports: Pollution Terms of Trade															
CO2/AU$ (Exports)	0.65	0.65	0.64	0.66	0.63	0.64	0.64	0.61	0.61	0.64	0.65	0.68	0.66	0.63	0.63
CO2/AU$ (Imports)	0.63	0.66	0.63	0.63	0.65	0.62	0.59	0.63	0.72	0.83	0.86	0.82	0.86	0.78	0.83
Pollution Terms of Trade	1.03	1.00	1.01	1.04	0.97	1.04	1.09	0.97	0.85	0.77	0.76	0.83	0.77	0.81	0.76
Carbon Leakage															
Non-Annex B (EEI)	21769	21454	24667	28390	26563	23339	22294	26658	33330	45072	49437	51683	59385	58222	64578
% of PBA	7%	7%	8%	8%	8%	7%	6%	7%	9%	12%	12%	13%	15%	14%	16%
% of EEI	36%	35%	37%	41%	34%	31%	31%	32%	36%	39%	39%	41%	42%	43%	49%
Non-Annex B, plus ROW (EEI)	35995	36279	36724	41063	48578	49605	47593	55337	64342	84498	94947	94904	106652	99306	99361
% of PBA	12%	12%	11%	12%	14%	14%	13%	15%	17%	22%	24%	23%	26%	24%	25%
% of EEI	60%	59%	56%	60%	63%	65%	66%	67%	69%	73%	74%	75%	75%	73%	75%
Technology-Adjusted BEET & Decomposition															
TBEET	**8227**	**11471**	**8543**	**4640**	**4634**	**9020**	**5257**	**-1511**	**-7696**	**-14404**	**-16895**	**-16958**	**-26316**	**-19381**	**-24876**
Trade Specialisation	5411	3530	2545	1690	180	-83	-2862	-2451	-5833	-7378	-5988	-3186	-9147	-15571	-6005
Trade Balance	2816	7941	5999	2950	4455	9103	8119	939	-1863	-7026	-10907	-13771	-17169	-3809	-18871

Figure E.1: Australia's Emissions History, Overview of Results (1995 – 2009)

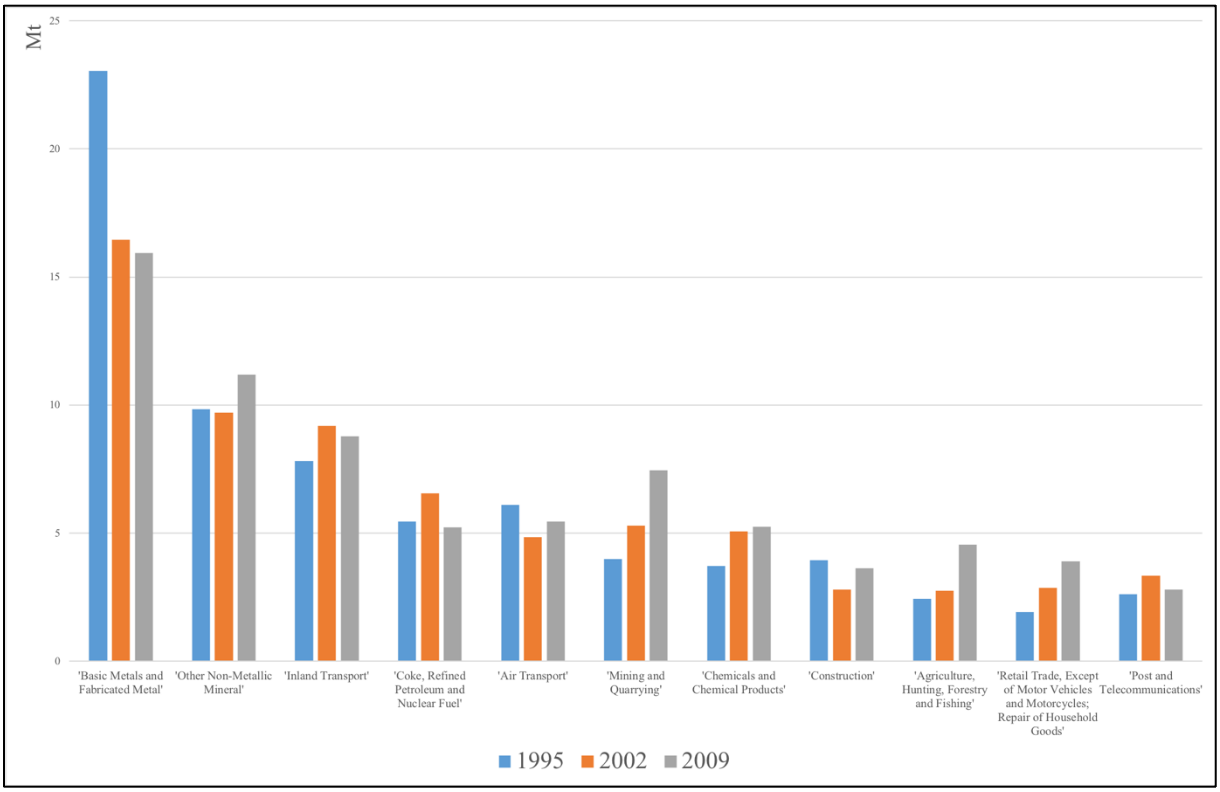


Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Appendix F: Domestic Emissions Analysis

The domestic component of Australia's emissions profile grew from 206 million tonnes in 1995 to 280 million tonnes in 2009, a 36 per cent increase. The *Electricity, Gas and Water Supply* sector dominates Australia's domestic emissions mix, rising from 56 per cent of domestic emissions in 1995, to 65 per cent of domestic emissions in 2009. Figure F.1 provides a clear view of the contribution of the other top domestic emitters. We can see the significant, but declining, contribution from basic and fabricated metals, no doubt a result of the collapse of Australian manufacturing in this period. Other notable sectors include Agriculture and Mining, both increasing in particular in between 2002 and 2009. Air and Inland Transport, Petroleum, Chemicals, and Construction continue to play an important role. Although not a focus of this study, it is important to note the continued rise of Australia's domestic emissions.

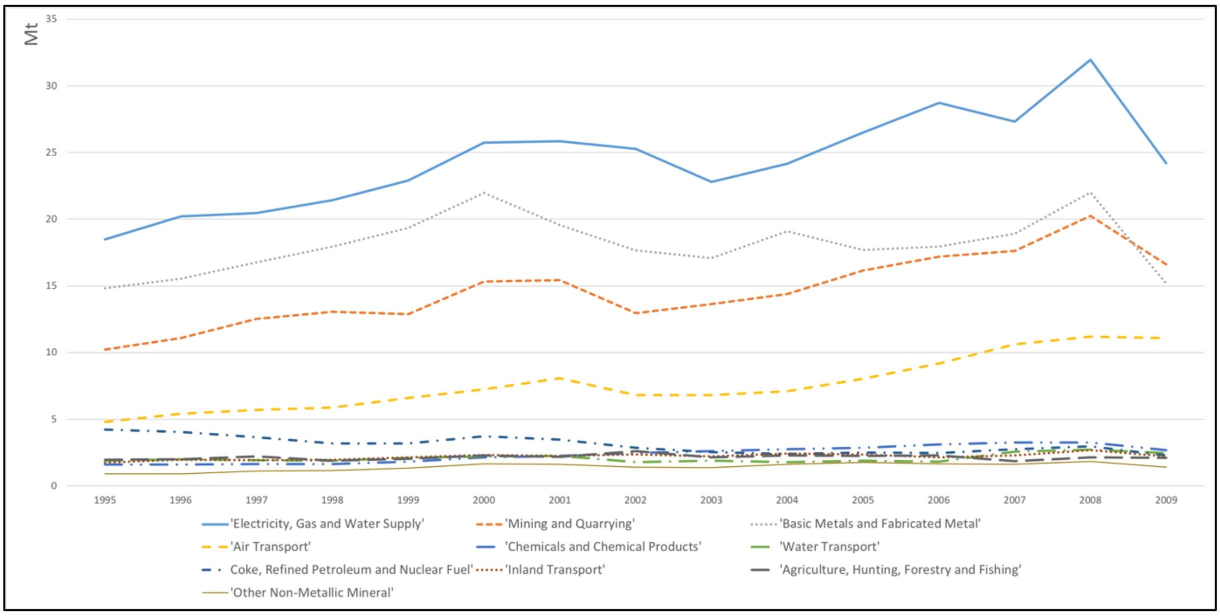
Figure F.1: Domestic Emissions Analysis by Sector (excl Electricity, Gas and Water)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

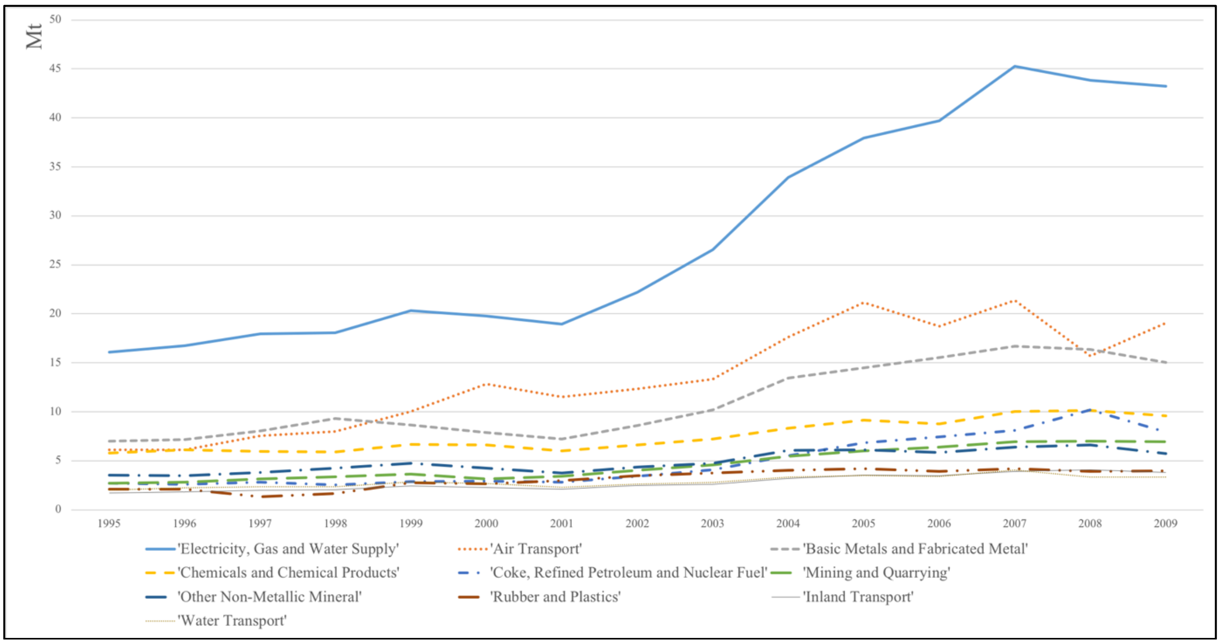
Appendix G: EEI & EEE by Sector

Figure G.1: Export Emissions by Sector (1995 - 2009)



Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Figure G.2: Import Emissions by Sector (1995 - 2009)

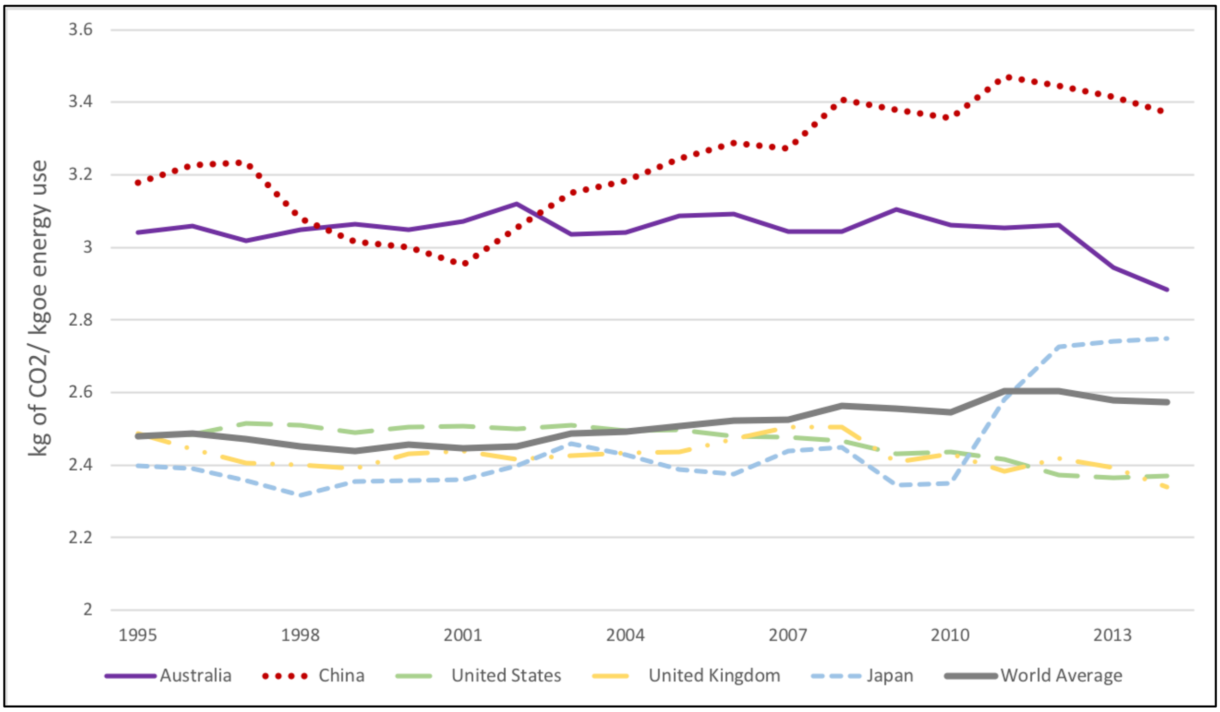


Source: WIOD13 (Timmer et al, 2015), Author's Construction.

Appendix H: Carbon Intensity of Energy Use

Figure H.1 shows that China's carbon intensity of energy use is significantly greater than Australia's and Australia's other major trading partners. However, it also reveals that Australia has a considerably higher carbon intensity of energy use than the world average.

Figure H.1: Carbon Intensity of Energy Use (1995 - 2014)



Source: World Bank (2019), Author's Construction.

Appendix I: Extension Data Correlation Check

Table I.1: Energy & Emissions Accounts, Correlation Coefficients

Correlation Table (1995-2009): CO2 Emissions (WIOD13) & Energy (Kulionis, 2018)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Correlation Coefficient
Domestic Emissions	205887	209481	213658	227705	230911	230374	243095	254777	258661	265173	276059	281567	272305	262634	279598	0.98
Domestic Energy	3953745	4092604	4142287	4473460	4491226	4263797	4483898	4737204	4872635	4876593	5005472	4996820	4957611	4817111	4945091	
EEE	65073	69535	73010	74622	79102	90521	88351	80472	77419	82417	87196	91740	93727	106325	84727	0.89
EEE	1685686	1754688	1783812	1722104	1733582	2120065	2009728	1865805	1794416	1795798	1928587	1952311	1974262	2100698	1923220	
EEI	60264	61806	66134	68441	77030	76448	71694	82265	92881	115394	127769	127274	142503	136299	132807	0.99
EEI	1687679	1735874	1840129	1828681	2113519	2287444	2164523	2496605	3015780	3661932	4051432	4141862	4476581	4676914	4210070	
Household	33749	34596	34533	37335	39972	36679	37660	40513	39725	41977	39046	38302	40898	41474	41143	0.99
Household	766417	780310	786049	833180	875889	833157	852926	906605	884737	909579	869324	859883	905255	922250	922113	
PBA	304708	313611	321202	339661	349985	357574	369106	375762	375805	389567	402300	411609	406930	410433	405468	0.99
PBA	6472588	6700218	6832703	7080301	7134387	7253186	7353510	7508264	7589301	7594504	7841389	7869404	7854326	7835973	7766173	
CBA	299899	305883	314325	333480	347913	343500	352450	377555	391267	422545	442874	447143	455706	440407	453548	0.99
CBA	6474581	6681404	6889021	7186879	7514324	7420565	7508305	8139064	8810665	9460638	9964235	10058955	10356646	10412188	10053023	
BEET (WIOD13)	**4809**	**7729**	**6876**	**6181**	**2072**	**14073**	**16657**	**-1794**	**-15462**	**-32977**	**-40574**	**-35535**	**-48776**	**-29974**	**-48080**	0.96
BEET (Kulionis, 2018))	**-1993**	**18814**	**-56318**	**-106577**	**-379937**	**-167379**	**-154795**	**-630800**	**-1221363**	**-1866135**	**-2122845**	**-2189551**	**-2502320**	**-2576216**	**-2286850**	

Source: WIOD13 (Timmer et al, 2015), WIOD16 (Timmer et al, 2016) & Kulionis (2019).