Statistical techniques for exploring trends in emissions and energy consumption in developed and developing countries

Summary prepared for BIEE annual conference, based on work with the Climate Change Authority

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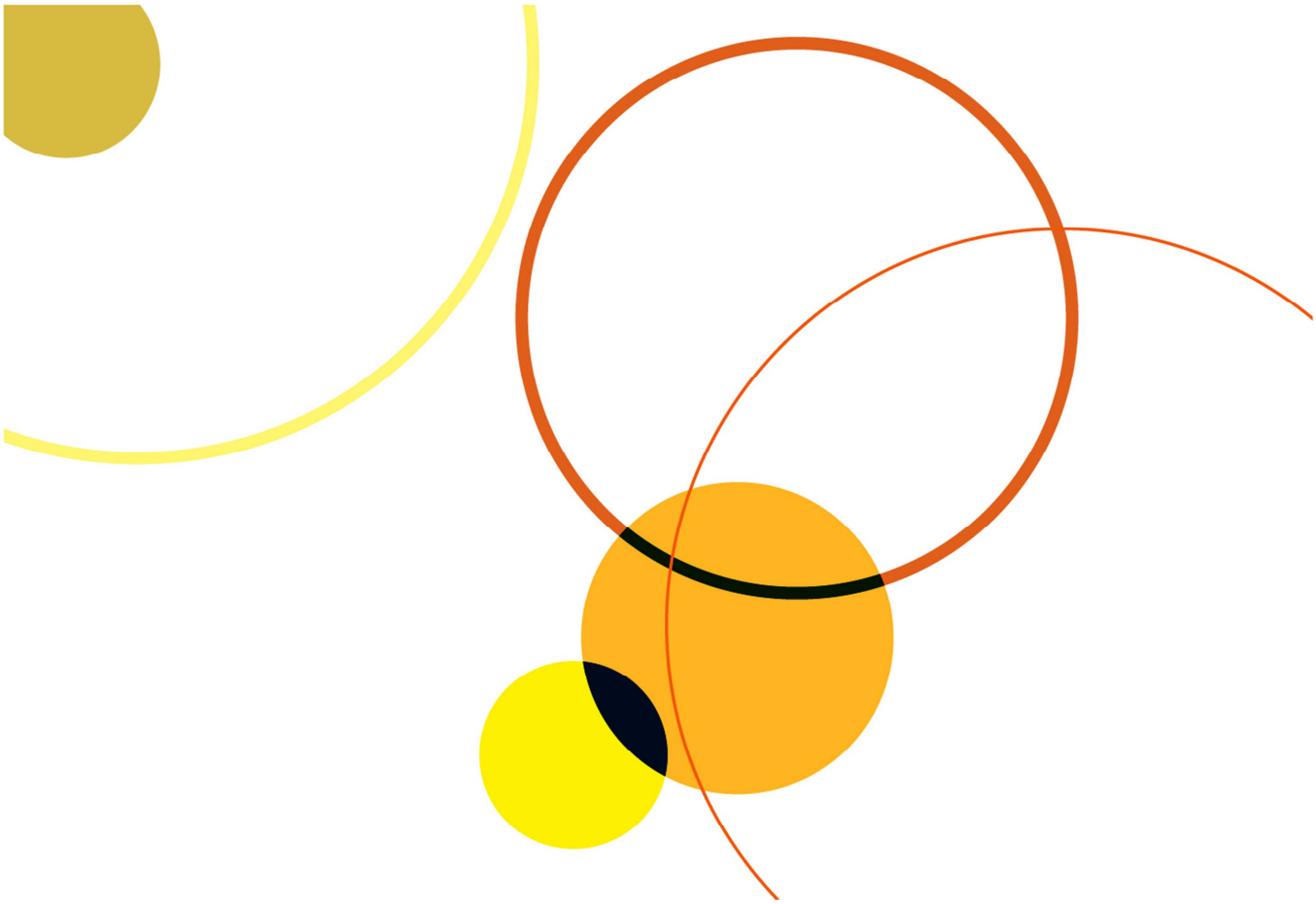


Abstract

This paper applies statistical techniques and identifies drivers in electricity demand and emissions intensity, demonstrating best practice in decomposition analysis. The paper is a short summary of a longer report that forms the foundation for the carbon budgeting of the Australian Climate Change Authority, published in February 2014.

Decomposition analysis breaks down the total change in an aggregate series of energy consumption or emissions production over a period of time, revealing the underlying drivers and quantifying the contribution of each.

The researcher can choose relatively freely the components of decomposition, to suit his or her investigation of specific issues. For example, changes in the emissions-intensity of electricity generation can be broken down into:

- **fossil fuel mix**: shifts between different fossil fuels due to, for instance, increased substitution of gas for black coal;
- **renewable share**: increased renewable electricity generation in the overall generation mix;
- **carbon intensity**: emissions intensity within each fossil fuel type has changed due to, for instance, increases in fuel quality; and
- **fuel efficiency**: efficiency of transforming fuel into power due to, for instance, better technology or increased utilisation of power plants.

Australia offers a striking example. Since 2008, electricity consumption in the National Electricity Market has been in decline, electricity generation emissions intensity has improved, and economy-wide emissions have fallen rapidly (including land use and land-use change). Through decomposition, the paper establishes the relative importance of the drivers underlying these changes.

The analysis shows that the recent fall in electricity consumption in the National Electricity Market was the consequence of falling activity in the manufacturing sector, offset by consumption increases in the residential and commercial and services sectors. Gas-fired and renewable electricity generation were the major drivers of the reduction in emissions intensity of electricity generation between 2008 and 2011, contributing approximately 80 per cent of the decline. Improvements in the carbon intensity within fuel types contributed the remaining share of the reduction, whereas changes in fuel efficiency have had virtually no impact. Decreases in emissions from land use and land-use change, in particular forestry, offset emissions from economic growth in other parts of the economy between 2008 and 2011.

Trends in electricity consumption, emissions intensity of electricity supply and economy-wide emissions have changed significantly in recent years. Since 2008, electricity consumption in the National Electricity Market has slowed; electricity generation emissions intensity has declined after having been fairly stable; and economy-wide emissions have fallen rapidly (including land use and land-use change).

1 Electricity consumption

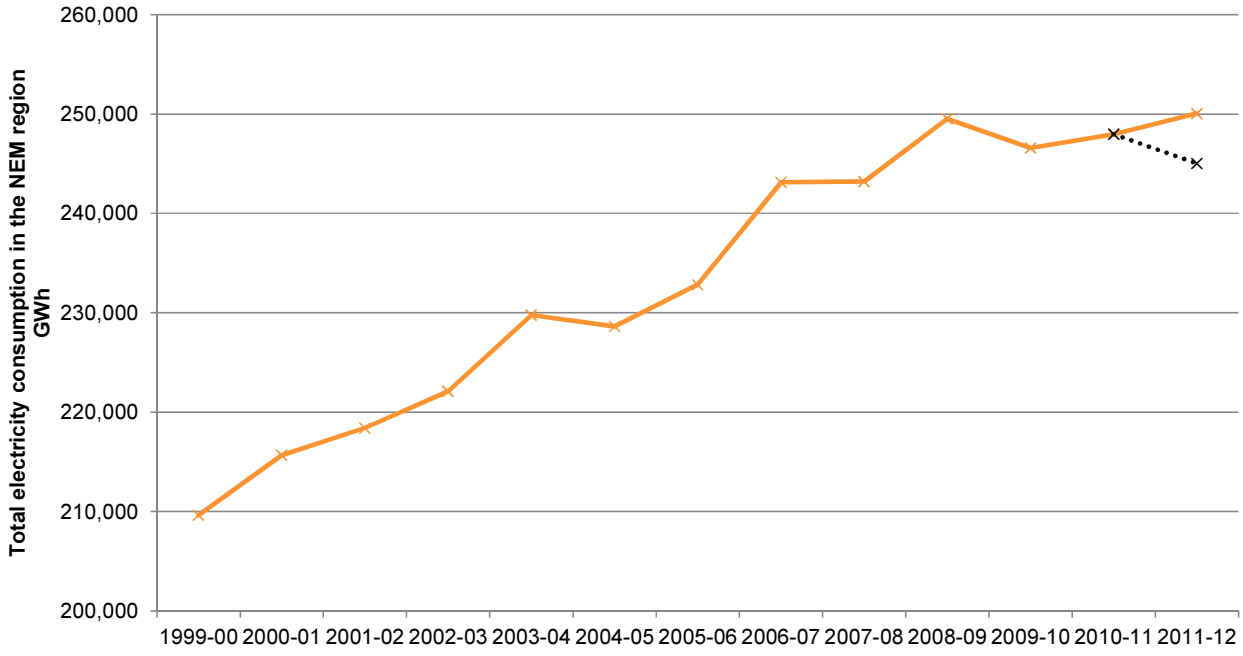
Electricity consumption in the National Electricity Market has recently started to stabilise and fall after a period of growth

1.1 Development of electricity consumption

Growth in electricity consumption in Australia slowed after 2008[1] due to higher electricity prices and lower economic growth. Electricity consumption in Australia grew by a compound annual growth rate (CAGR) of just 0.2 per cent after 2008, in contrast to 1.9 per cent between 2000 and 2008.

- electricity prices rose by around 60 per cent between 2008 and 2011;
- real GDP growth slowed from 3.4 per cent per year between 2000 and 2008 to 2.1 per cent between 2008 and 2011. This was particularly pronounced in emissions-intensive sectors such as manufacturing, in which electricity consumption fell by a CAGR of 4 per cent between 2008 and 2011.

Figure 1. **Electricity consumption in Australia grew rapidly between 2000 and 2009 and slowed down between 2009 and 2012**



Notes: *The commercial and services sector electricity consumption in 2012 jumps up by 11.8 per cent compared with 2011, which is potentially an erroneous observation. The dotted line shows how Australian electricity consumption behaves if the final data point for commercial and services sector electricity consumption is adjusted using past trends.*

Source: *Vivid Economics based on Australian Government Bureau of Resource and Energy Economics (2013)*

[1] All dates refer to fiscal years such that the fiscal year 2007-08 is shown as 2008.

In comparison with the whole of Australia, the change of trend after the global financial crisis broke out was stronger in the National Electricity Market (NEM). NEM electricity consumption grew faster in the years leading up to the crisis, at nearly 2 per cent per year, and then declined afterwards, at -0.4 per cent per annum, trimming 1.7 per cent off total NEM consumption between 2008 and 2012. This contrasts with the growth in electricity consumption outside the NEM, specifically in Western Australia (WA) and Northern Territory (NT). Similar drivers of changes in electricity consumption are at work in WA and NT, but relatively higher growth, in particular in mining, has led to increases in electricity consumption since 2008. This compares with falling consumption since 2008 in the NEM.

The recent change in electricity consumption in the NEM was driven by falling activity in the manufacturing sector, offset by consumption increases in the residential and commercial and services sectors. Sectoral trends in electricity consumption between 2008 and 2012 are shown in Table 1.

Table 1. **The share of electricity consumed by manufacturing declined between 2008 and 2012 whereas the share of commercial and services consumption grew in the same period**

Sector	Share of electricity consumption (per cent)	
	2008	2012*
Div. A Agriculture, forestry and fishing	1	1
Div. B Mining	5	6
Div. C Manufacturing	30	26
Div. D Electricity, gas, water & waste services	14	14
Div. E Construction	0	0
Div. I Transport & storage	2	2
Commercial and services	23	25*
Residential	24	26
Total	**100**	**100**

Notes: *2012 data is adjusted by using an estimated figure for commercial and services sector consumption that reflects the same sector use intensity (consumption GWh/real GVA) as in the year 2011. * indicates adjusted figure for commercial and services consumption in 2012 was used.*

Source: *Vivid Economics based on Australian Government Bureau of Resource and Energy Economics (2013)*

1.1.1 Manufacturing electricity consumption

Manufacturing electricity consumption in the NEM declined sharply (by 7.6 per cent from 2008 to 2011) due to slower growth and higher electricity prices:

- reduced activity (measured by Gross Value Added) in the manufacturing sector was a contributory factor, falling by 6.5 per cent between 2008 and 2012;
- manufacturing has responded more strongly to rising electricity prices than residential or commercial and services, identified statistically by a higher electricity price elasticity, of -0.55 compared with -0.42 in commercial and services and a low elasticity of -0.14 for residential.

Trends in manufacturing electricity consumption continue to be influenced by the activity of electro-intensive industries and the degree of restructuring away from manufacturing towards services.

1.1.2 Residential electricity consumption

Residential electricity consumption grew by a CAGR of 1.5 per cent between 2008 and 2011.

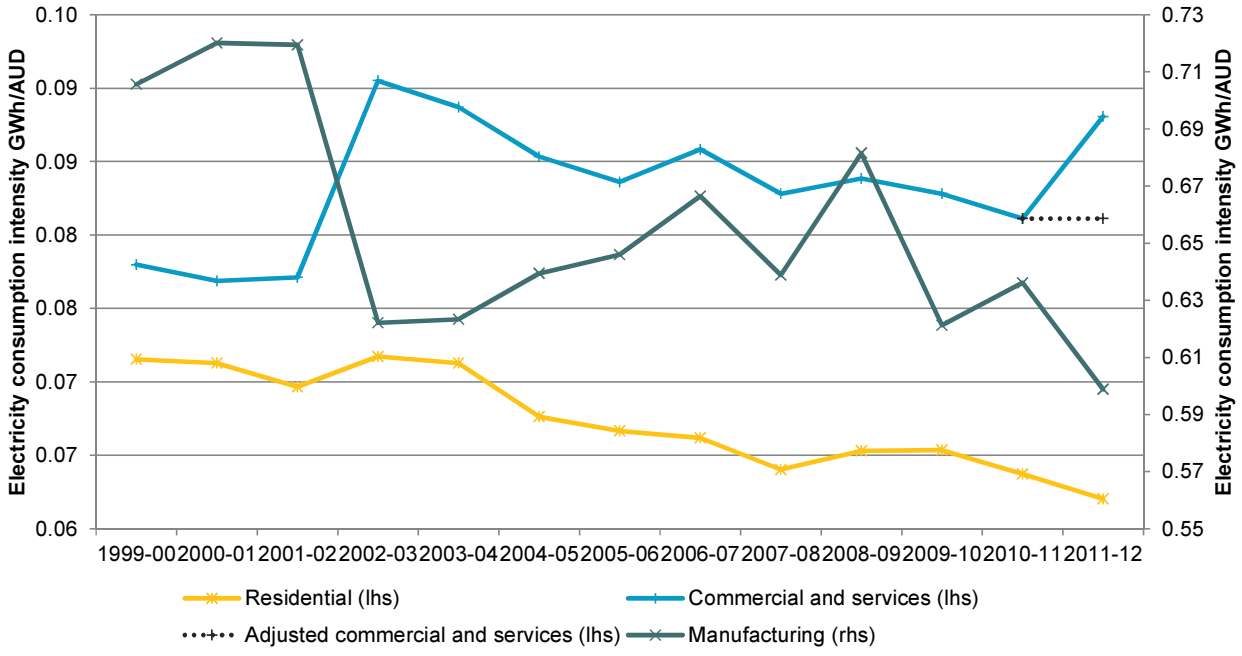
Residential electricity consumption has been less responsive to electricity price increases since 2008 than before 2008. This implies that residential electricity consumption is higher than would be expected given current levels of spending.

Residential electricity consumption per capita was static between 2003 and 2012, suggesting that higher consumption is due to population growth rather than higher spending per capita.

1.1.3 Commercial and services electricity consumption

Electricity consumption in commercial and services grew by 4.3 per cent between 2008 and 2011, largely as a result of a growth in activity. Higher electricity prices mitigated approximately one third of the increased electricity consumption.

Figure 2. **Electricity intensity, use per unit of GVA fell fastest in manufacturing in recent years, while commercial and services and residential exhibit similar, lower rates of improvement**



Notes: *Manufacturing represented by the right-hand axis. Intensity is measured as electricity consumption in GWh divided by chain volume measured GVA for both manufacturing and commercial sectors and as electricity consumption divided by chain volume measured final consumption expenditure for residential. The change in 2003 is due to a redefinition of sectors between manufacturing and commercial and services.*

Source: *Vivid Economics based on Australian Government Bureau of Resource and Energy Economics (2013) and Australian Bureau of Statistics (2013)*

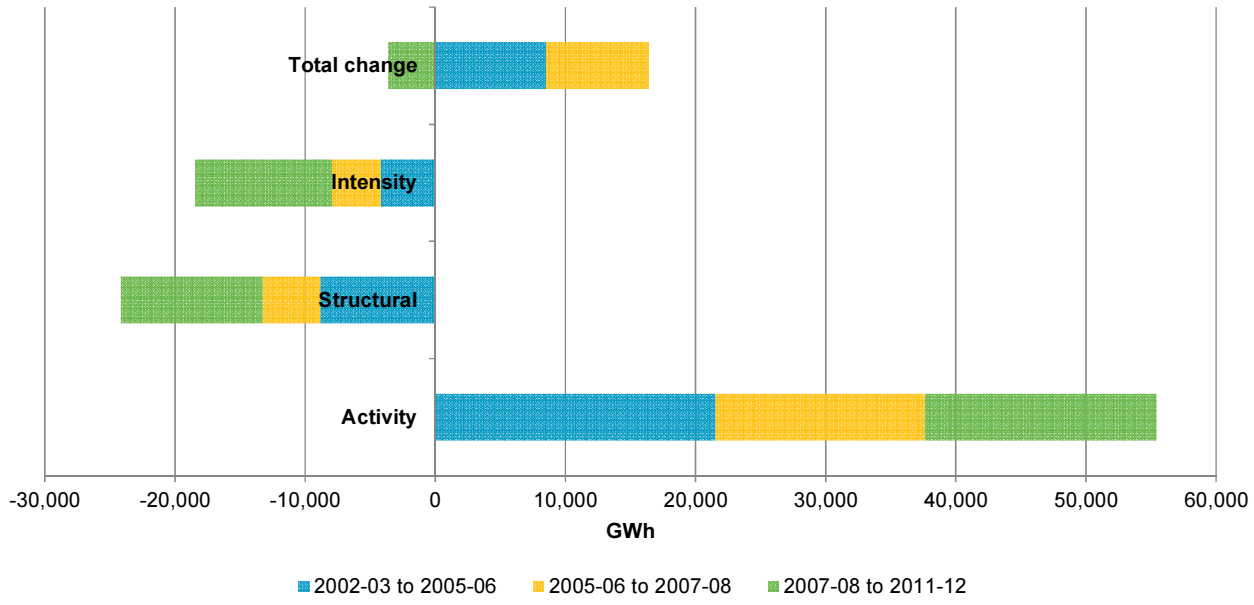
1.2 Decomposition

The statistical technique used for decomposition, Log Mean Divisia Index (LMDI), decomposes trends in electricity consumption into the three effects:

- **activity effect** (ΔE_{act}): the change in total electricity consumption due to changes in aggregate economic activity;
- **structural effect** (ΔE_{str}): the change in total electricity consumption due to changing shares of total economic activity between sectors;
- **intensity effect** (ΔE_{int}): the change in total electricity consumption due to changing energy intensity within sectors.

The activity effect is the main driver of electricity consumption in the NEM between 2003 and 2012. The activity effect drives up electricity consumption. Both, the structural effect and the intensity effect offset parts of the activity effect in the first two periods (2003 to 2006 and 2006 to 2008), though they are weakest in the second period. The intensity and structural effects are greatest in the third period (2008 and 2012), and more than offset the activity effect in that period, see Figure 3 and Figure 4.

Figure 3. **The NEM region restructured towards less electro-intensive sectors and the sectors themselves became less electro-intensive, while the economy grew**



Notes: *LMDI decomposition of growth of electricity consumption in the NEM region between 2003 and 2011-2012. Chain volume measure of sectoral GVA and income were used. Adjusted data is used for Commercial and services sector in 2012.*

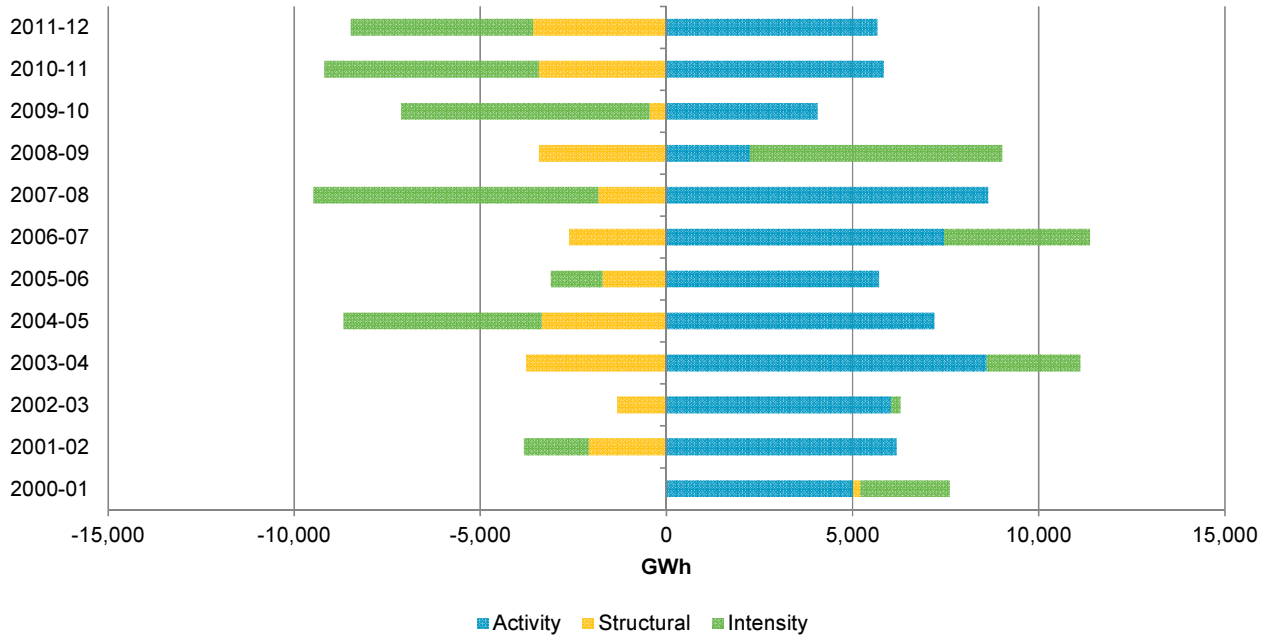
Source: *Vivid Economics based on Australian Government Bureau of Resource and Energy Economics (2013) and Australian Bureau of Statistics (2013)*

The total increase in electricity consumption between 2003 and 2012 was 6.4 per cent. Activity increased by 28 per cent, but the intensity effect offset one third of this figure and the structural effect a further 44 per cent. In total, three quarters of the increase in economic activity was offset by changes in the way electricity is used within the economy.

The structural effect has made a large contribution towards attenuating electricity consumption. It reduced consumption by -11,000 GWh in the period 2008 to 2012 and by -24,000 GWh in the period 2003 to 2012. In the period 2008 to 2012, a 5 per cent decrease in electricity consumption is the result of economic activity moving away from relatively high electricity intensive sectors. The contribution was 12 per cent over the whole period.

Almost equally important in abating consumption is improvement in intensity of use. It reduced consumption by -10,500 GWh in the period 2008 to 2012 and by -18,500 GWh in the period 2003 to 2012. In the last period a further 4.9 per cent of consumption was avoided through a more efficient use of electricity within broad sectors. The intensity improvement resulted in a reduction of 9.3 per cent over the whole period from 2003.

Figure 4. **Between 2010 and 2012, sectors became unanimously less electro-intensive**



Note: *LMDI decomposition of growth of electricity consumption in the NEM region between 2003 and 2011-2012. Chain volume measure of sectoral GVA and income were used. Adjusted data is used for Commercial and services sector in 2012.*

Source: *Vivid Economics based on Australian Government Bureau of Resource and Energy Economics (2013) and Australian Bureau of Statistics (2013)*

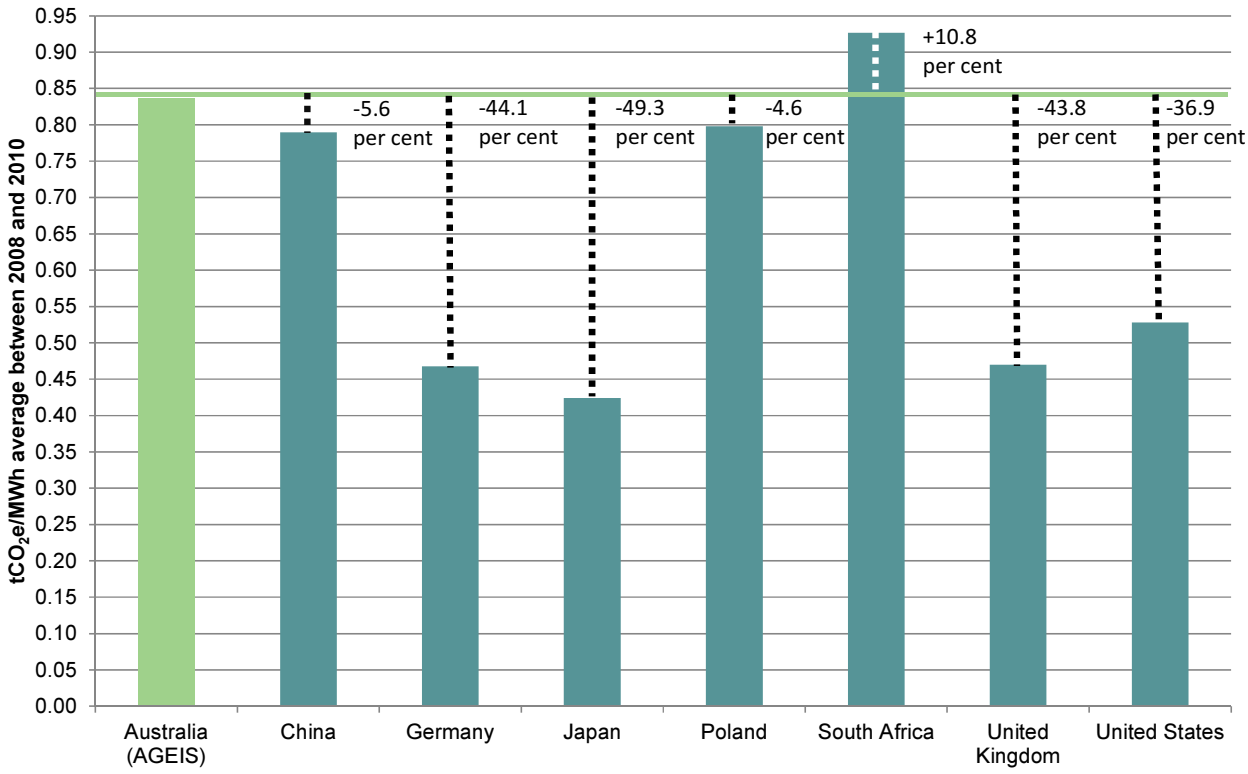
Although the restructuring of the economy between broad sectors is important in determining changes in electricity consumption over time, there is further restructuring *within* these broad sectors which is captured within the intensity effect. The intensity effect is itself a composite of subsectoral restructuring and improvements in electricity efficiency. Thus it is likely that restructuring as a whole, both at broad sector and subsector level, has played the most important role in mitigating electricity consumption as the economy has grown.

2 Emissions intensity of electricity supply

2.1 Development of electricity generation emissions intensity

The emissions intensity of electricity in Australia is relatively high: approximately 6 per cent higher than in China and 60 per cent higher than in the US.[2]

Figure 5. **Australia's emissions intensity of electricity generation is higher than in several countries**



Note: *Emissions intensity is defined as tons of CO_2 equivalent greenhouse gases emissions per 1 MWh of generated electricity from all energy sources.*

Source: *Vivid Economics based on International Energy Agency (2013), World Bank, Australian Government National Greenhouse Gas Inventory (2013) and Australian Government Bureau of Resource and Energy Economics (2013)*

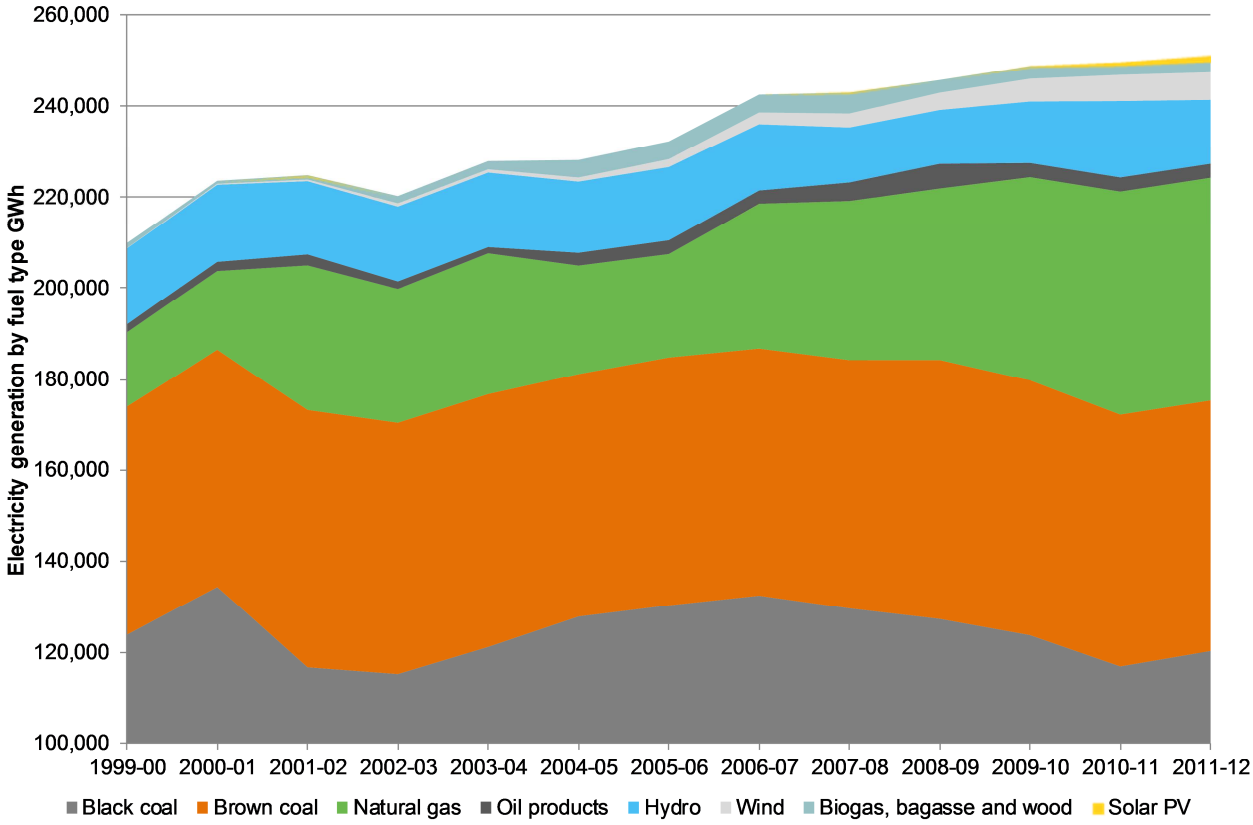
The emissions intensity of electricity supply fell by 6.3 per cent (from 0.84 to 0.79 tCO_2e/MWh) from 2008 to 2011. Recent data for the NEM region indicates a further decline of the emissions intensity of electricity supply of 4.5 per cent between 2012 and 2013, the period in which carbon prices were introduced.

[2] Compared with the average intensity of these countries between 2008 and 2010.

Gas-fired and renewable electricity generation were the major drivers of the reduction in emissions intensity between 2008 and 2011 and contributed 80 per cent of the decline. In this period:

- gas-fired generation increased from 14 per cent to 19 per cent of generation output; and
- renewables rose from 8 per cent to 10 per cent of generation output.

Figure 6. **Gas-fired generation and renewables increased from 2009 whereas black coal generation declined**



Note: *Electricity generation by fuel type. Black coal generation falls sharply in the year 2002 while total output is constant due to an increase in gas-fired electricity generation.*

Source: *Vivid Economics based on Australian Government Bureau of Resource and Energy Economics (2013)*

Improvements in the carbon intensity within fuel types contributed the remaining share of the reduction, whereas changes in fuel efficiency have had no statistically observed impact.

2.2 Decomposition

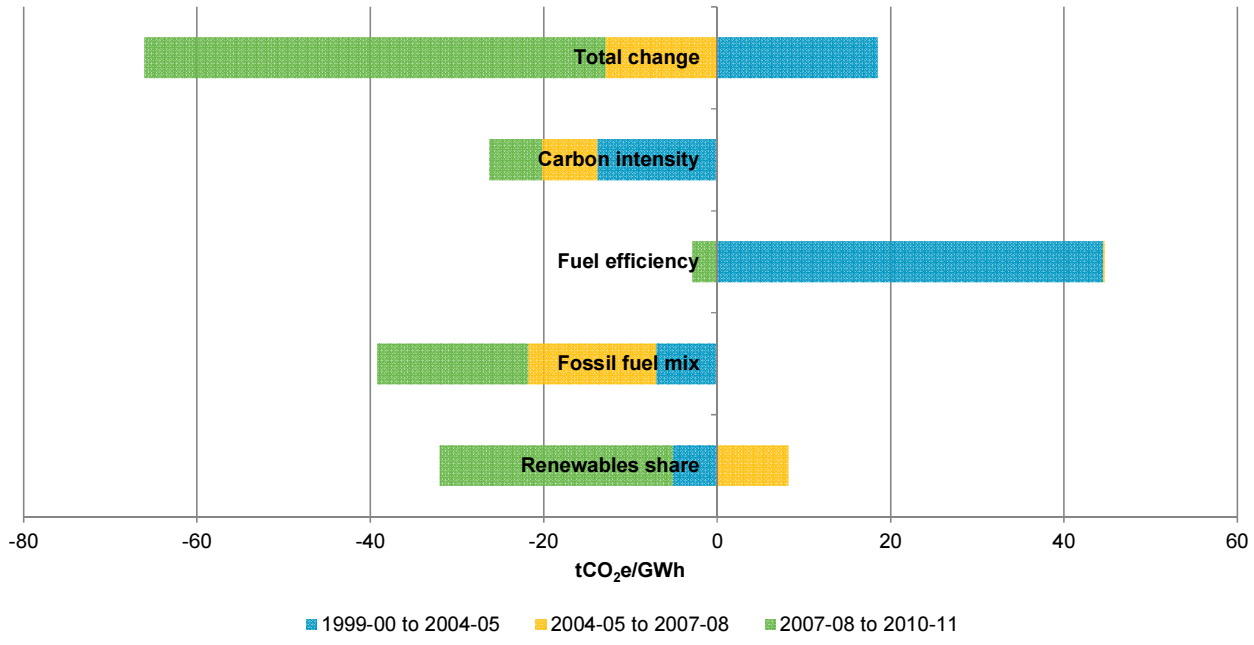
The changes in electricity generation emissions intensity can be decomposed into several effects, each capturing characteristics of the electricity market in Australia and the effects of the Mandatory Renewable Energy Target (M-RET) and solar feed-in tariffs. The analysis indicates whether the recent trends might continue for the next few years.

The four factors affecting electricity generation emissions intensity are:

- **fossil fuel mix**: how the shift between fossil fuels, black coal, brown coal and gas, has affected emissions, it measures for example if and by how much gas has replaced other fossil fuels such as black coal;
- **renewable share**: how increased renewable generation (share of total) has affected emissions, that is, how much increased renewable electricity generation in the overall generation mix changed the emissions intensity;
- **carbon intensity**: how changes in emissions intensity within each fuel type has changed, which is measured by emissions in metric tonnes of carbon dioxide for each fuel divided by fuel consumption in PJ of thermal input, and captures how changes in fuel quality and accounting for emissions has changed carbon emissions;
- **fuel efficiency**: how far fuel efficiency of transforming each fuel into power has changed, which is defined as electricity produced by each fuel divided by its input use, and captures factors like technology, power plant age and utilisation.

Changes in the fuel mix and renewable deployment are the principal factors at work. The effects of changes in carbon intensity and increases in fuel efficiency are particularly weak between 2008 and 2011, see Figure 7. The large decline in fuel efficiency between 2000 and 2005 is due to a sudden change in the ratio of electricity produced to fuel input in black coal in 2001.

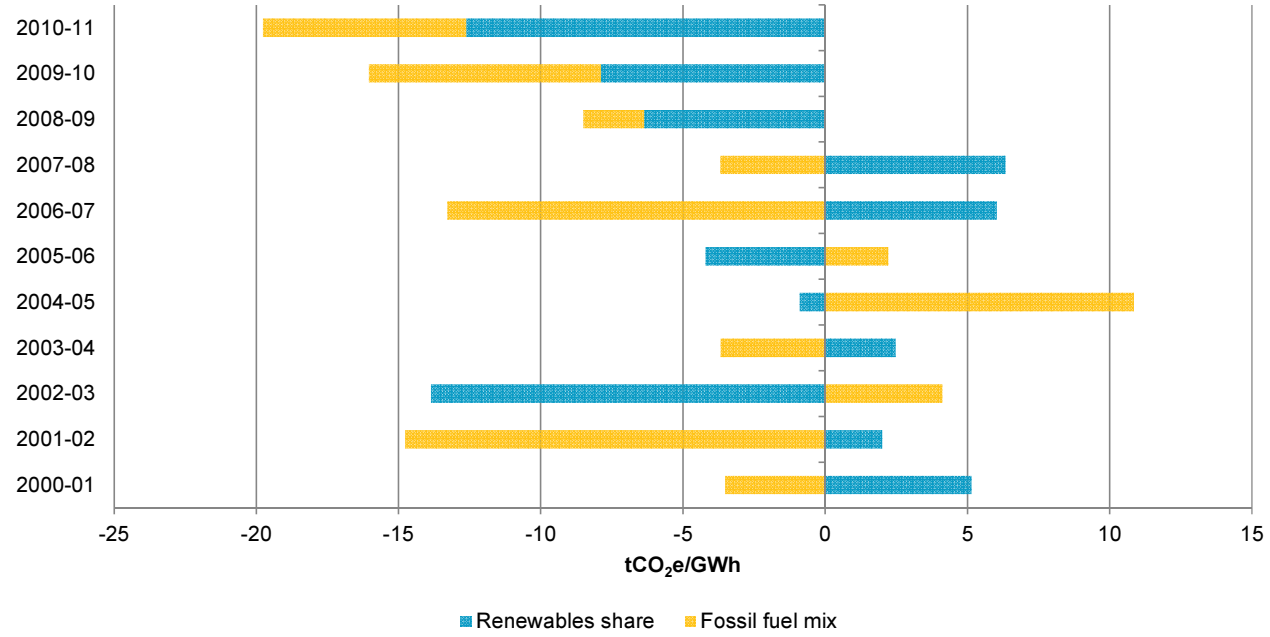
Figure 7. **The changes in the emissions intensity of electricity generation are mainly due to changes in the fossil fuel mix, increased renewable deployment and, to a lesser extent, a reduction in the carbon intensity of fuels**



Notes: ***carbon intensity:*** *changes in emissions intensity within each fuel type (emissions by fuel divided by fuel consumption);* ***fuel efficiency:*** *changes in electricity produced divided by fuel use;* ***fuel mix:*** *the shift between fossil fuels, that is, between black, brown coal and gas;* ***renewables share:*** *the effect of increased renewable generation.*

Source: *Vivid Economics based on Australian Government Bureau of Resource and Energy Economics (2013) and Australian Bureau of Statistics (2013)*

Figure 8. **Renewables have been consistently contributing to emissions intensity improvements since 2009**



Note: *LMDI decomposition of emissions intensity of electricity generation, two main effects yearly contribution.*

Source: *Vivid Economics based on BREE (2013) and AGEIS (2013)*

Electricity supply emissions intensity changes have been stimulated by policy. The Mandatory Renewable Energy Target (M-RET), which split into the Large and Small Scale Renewable Energy targets in 2011, is the major driver of increased renewables deployment. Other policies, such as the Queensland Gas Scheme and the New South Wales Greenhouse Gas Reduction Scheme, contributed to an increase in the share of gas-fired generation.

Solar PV has been supported by various state-wide solar feed-in-tariffs commencing in 2008, the Small Scale Renewable Energy Target and the accompanying solar feed-in-tariff, but made a minor contribution compared with wind. Solar PV constituted 0.6 per cent of generation output in 2012, up from 0.1 per cent in 2008. Wind contributed 2.4 per cent of generation output in 2011, up from 1.3 per cent in 2008. Solar PV generated less than a quarter as much output as wind in 2012.

Several sources suggest that gas prices will continue to rise in the future while coal prices are projected to be constant. This could mean that the costs of gas-fired generation, not including carbon prices, continue to be above the costs of coal-fired generation. Unless the carbon price mechanism tightens, to the disadvantage of coal and the advantage of gas, greater reliance may be placed on renewables as a contributor to improvements in the emissions intensity of electricity supply. Renewables themselves are currently supported by the LRET and SRET, and thus these policies, together with the carbon price mechanism, are the key determinants of future electricity emissions intensity.

3 Economy-wide emissions

3.1 Development of economy-wide emissions

Economy-wide emissions including land use, land-use change and forestry (LULUCF) were virtually unchanged between 1990 and 2011 at around 560 $MtCO_2e$.

Figure 9. **Emissions excluding LULUCF have risen since 1990 and stabilised after 2008**

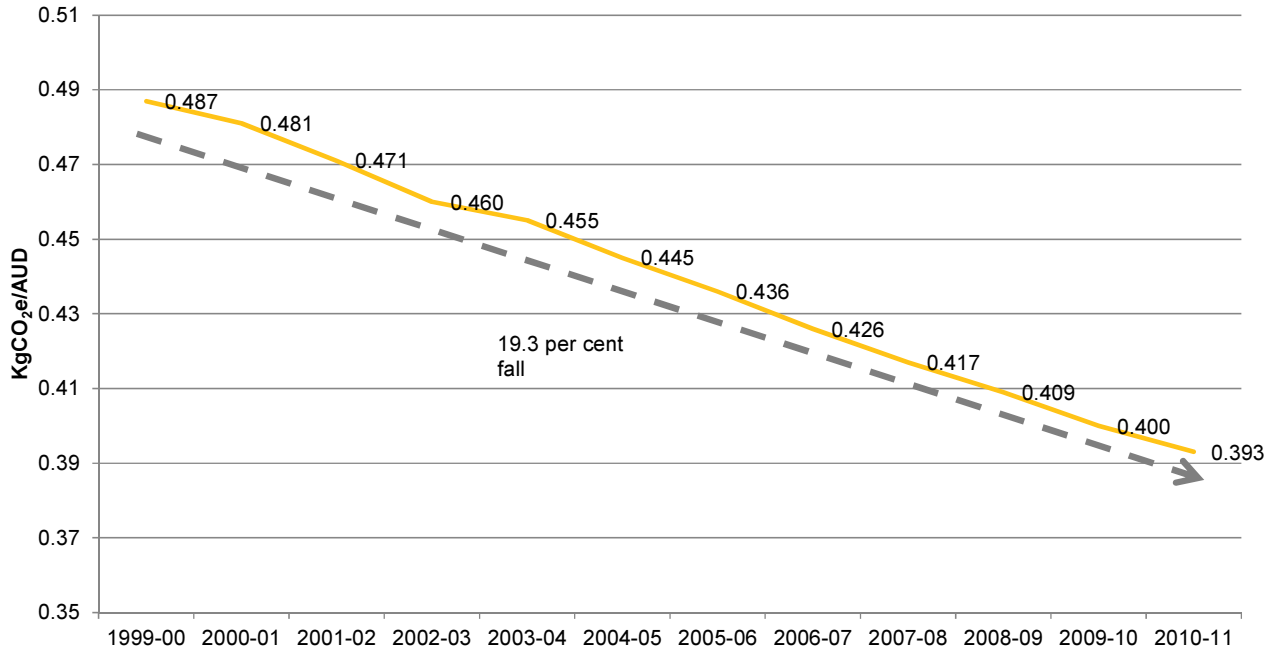
Note: *Land use, land-use change and forestry (LULUCF) emissions are available only in 1990 and from 2008.*

Source: *Vivid Economics based on AGEIS (2013)*

Changes in emissions from LULUCF, in particular forestry, offset emissions from economic growth in other parts of the economy between 2008 and 2011. LULUCF emissions fell while economy-wide emissions *excluding* LULUCF increased.

Emissions intensity continued to decline at a virtually unchanged rate of 1.9 per cent per year between 2000 and 2011, offsetting the effect of economic growth. The greatest driver of the decrease in emissions growth has been the improvement of emissions intensity within subsectors. This effect reduced emissions by approximately 80 $MtCO_2$ between 2000 and 2011. In addition, restructuring between sectors in the economy contributed a further 60 $MtCO_2$ reduction over this period.

Figure 10. **The economy-wide emissions intensity has been steadily declining between 2000 and 2011 at a rate of 1.9 per cent per year**



Note: *Overall emissions intensity in economy-wide CO_2e emissions over real GDP in AUD.*

Source: *Vivid Economics based on BREE (2013) and ABS (2013)*

However, since 2008, there has been a departure from these trends. Growth in emissions *excluding* LULUCF has slowed from 1.3 per cent per year between 2000 and 2008 to 0.1 per cent per year between 2008 and 2011. This was mainly due to electricity supply, which alone reduced economy-wide emissions excluding LULUCF by 1 per cent between 2008 and 2011. Lower economic growth after 2008 and higher emissions intensity in other economic sectors also contributed to the overall effect. A notable sector is mining, in which emissions grew between 2008 and 2011 due to increased activity and a higher emissions intensity.

3.2 Decomposition

To determine the drivers of changes in economy-wide emissions intensity, the LMDI decomposition method is used.

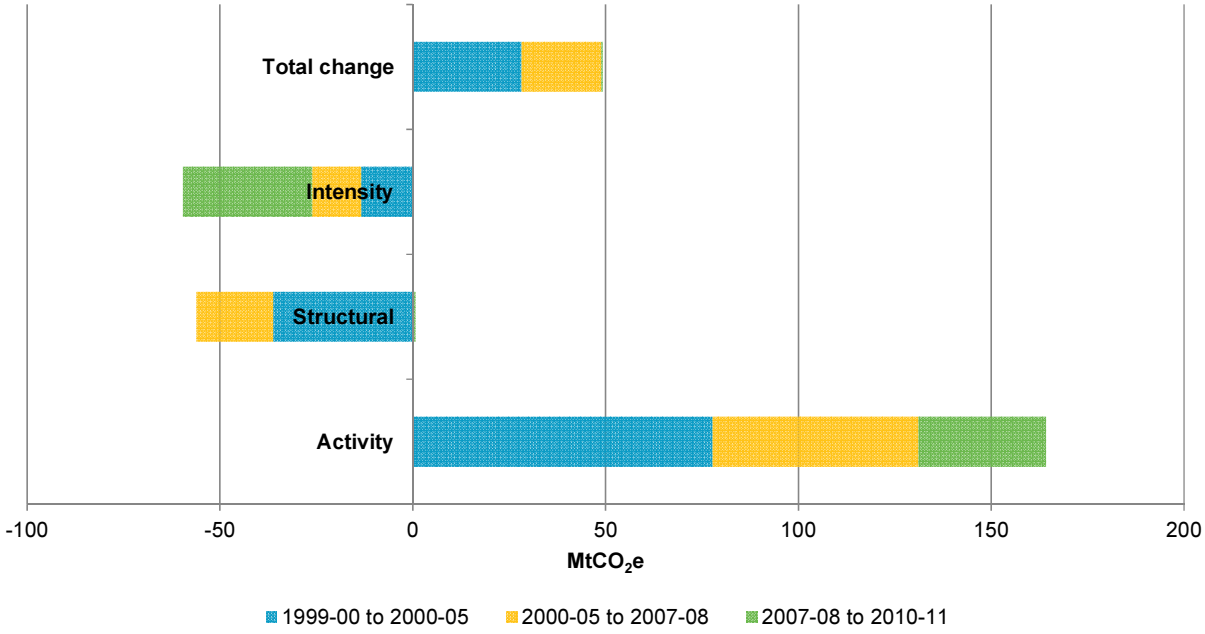
The result is a breakdown of the change in economy-wide emissions into three effects:

- **activity effect** (ΔE_{acti}): the change in economic activity across the whole economy;
- **structural effect** (ΔE_{str}): the change in economy emissions due to a restructuring of the shares of subsectors of the economy;
- **intensity effect** (ΔE_{int}): the change in economy emissions due to changes of structure or efficiency within subsectors of the economy.

Restructuring between sectors and subsectors, the structural effect, and efficiency changes within subsectors, the intensity effect, helped to offset higher emissions due to increased economic activity over the whole period, 2000 to 2008. In the last part of the period, from 2008 and 2011, the within subsectors intensity effect

was larger than before, implying that subsectors themselves have become less emissions intensive. However, the effect between sectors and subsectors, the structural effect, has in recent years contributed little, in contrast to the period 2000 to 2008, when it gave a stronger effect, as shown in Figure 11 and Figure 12.

Figure 11. **The intensity effect was greatest from 2008 to 2011, when it contributed a 7 per cent reduction in emissions**



Note: *LMDI decomposition of economy-wide emissions by sectors and subsectors (excluding residential emissions).*

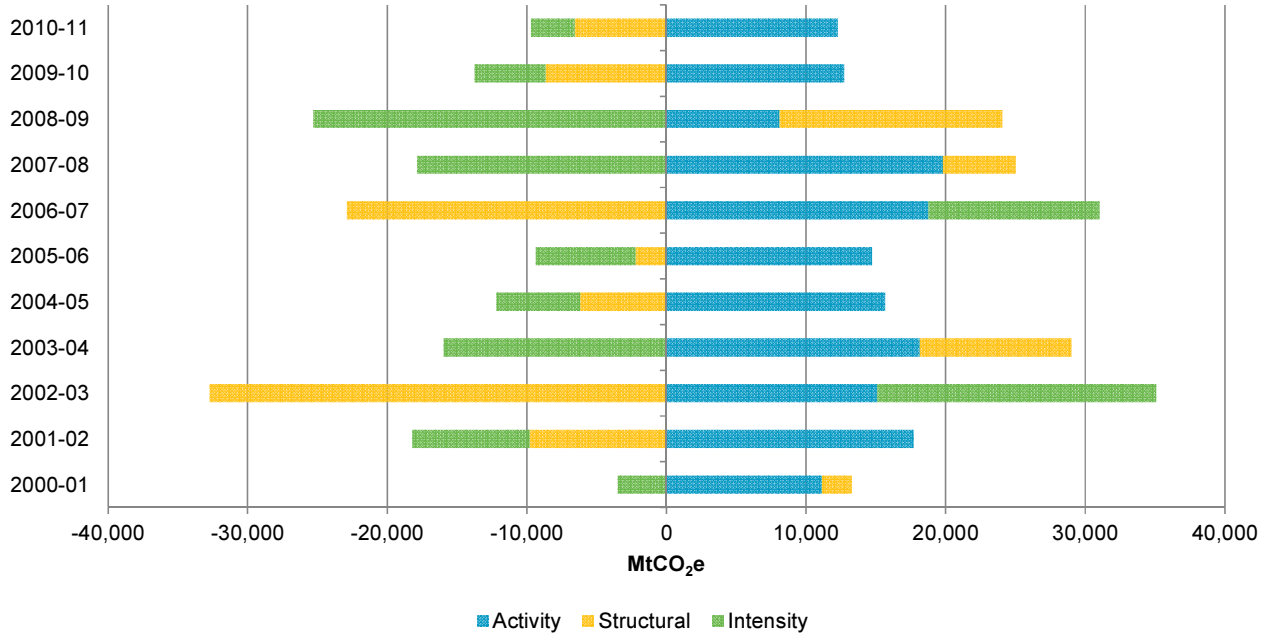
Source: *Vivid Economics based on Australian Government National Greenhouse Gas Inventory (2013) and Australian Government Bureau of Resource and Energy Economics (2013)*

The activity effect slowed down between 2008 and 2011, adding only 6.9 per cent to economy-wide emissions compared with 12 per cent between 2005 and 2008. This reflects the economic slowdown associated with the global financial crisis.

Restructuring from emissions intensive sectors to less emissions intensive sectors reduced economy-wide emissions by 4.7 per cent between 2005 and 2008, but this effect mildly reversed after 2008, when it increased economy-wide emissions by 0.3 per cent.

Individual sectors have become significantly less emissions intensive which, together with a decreased economic growth, have contributed significantly to the slowing down of emissions growth between 2008 and 2011 compared with previous periods.

Figure 12. **The intensity effect reduced emissions in almost every year since 2000**



Note: *LMDI decomposition of economy-wide emissions by sectors and subsectors (excluding residential emissions).*

Source: *Vivid Economics based on Australian Government National Greenhouse Gas Inventory (2013) and Australian Government Bureau of Resource and Energy Economics (2013)*

4 Outlook

Electricity price and economic growth projections show that electricity consumption is likely to start increasing again but at a rate below the trend observed between 2000 and 2008.

Electricity generation emissions intensity changes are responsive to policy in the long run. The policy environment is important for long-term decisions such as power plant construction, which influences the share of gas generation and renewables, as well as the level of incentives for small scale generation such as solar PV, which makes a much smaller contribution.

Further decreases in economy-wide emissions intensity in the future, together with stable or declining levels of emissions, would be consistent with:

- continuing strong renewable incentives;
- further substitution of gas for coal, encouraged by a carbon price, despite projected gas price increases; and
- additional structural change in the economy away from emissions-intensive subsectors such as manufacturing and mining.

Economy-wide emissions depend to a large extent on emissions from electricity. With consumption growing at a slower rate and electricity emissions intensity falling, increased emissions from expanding activity in sectors such as mining can be partially offset. Land use, land-use change and forestry emissions have been the main driver of economy-wide emissions in recent years and their future role will be critical to the aggregate trend.

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