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Centre for Climate and Energy Policy

AUSTRALIAN ENERGY TRANSITION INDICATORS

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Abstract

This paper specifies, and populates with data, a set of indicators which are designed to quantify the progress of Australia's energy system transition. The indicators are national in coverage and include all sources of energy supply and consumption. The major data sources used are all longstanding official Commonwealth statistical series, meaning that the indicators should be able to be updated each year with minimal risk of definitional discontinuities. Indicators are structured into four groups, covering emissions, energy supply, energy consumption, and the changing mix of fuel types and energy using technologies. Emissions indicators run from 2005, because that is the base year for the Paris Agreement, while all energy indicators run from 2009 because of a major data series discontinuity prior to 2009. All indicators end in 2019.

Total energy combustion emissions increased gradually from 2005 to 2016, but since then have been almost constant. However, as a share of total national emissions, energy combustion emissions increased markedly up to 2016, because of a decline in other emission sources. Using conventional energy accounting conventions, the renewable share of total primary energy supply increased from 4.2% in 2005 to 6.4% in 2019. However, if the substitution accounting method is applied to renewable electricity, the increase in the renewable share of primary supply is from 6.3% in 2005 to 11.7% in 2019. Total final energy consumption has grown steadily since 2009, and throughout this period the shares of types of final energy supplied to consumers have remained remarkably constant. Gross final energy consumption efficiency by households, measured as the reciprocal of residential energy consumption per capita, was almost constant up to 2011, but increased steadily from then until 2019. Similarly, economy-wide energy use productivity, measured as gross economic value added per unit of energy consumed, also increased steadily from 2011 to 2019. The services provided by energy are commonly sorted into three major groups: generation of electricity, the most versatile energy carrier which is capable of providing a wide range of other services; energy used to deliver transport and other forms of mobility; and energy used to deliver heat. Transition of electricity generation from almost exclusive reliance on coal towards a lower emissions mix of generation technologies is well underway. By contrast, no significant progress has been made in transitioning energy used by transport and other mobile equipment; reliance on petroleum fuel remains almost total and emissions are increasing steadily every year. Similarly, almost no progress has been made in transitioning away from gas and, in some sectors of manufacturing, coal, as the source of heat for manufacturing, commercial sector businesses and households. Total fossil fuel energy consumption in these sectors combined has decreased, but only because of the marked fall in Australian manufacturing activity over the period covered.

Keywords:
energy transition, greenhouse gas emissions, energy consumption, energy productivity, electricity generation, electrification

JEL Classification:
O13, Q40, Q43

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1 INTRODUCTION

The sources of energy used to supply the energy services demanded by Australian households and businesses are currently undergoing transition, as are many of the technologies used to both supply and consume useful energy. The most important part of the transition is on the supply side, away from almost exclusive dependence on fossil fuels, with their associated emissions of carbon dioxide, towards zero emission renewable supply sources. Less remarked, but potentially no less important, is transition on the demand side, by adoption of new technologies which can deliver the energy services which users require from reduced levels of energy supply.

The imperative behind this transition is of course the urgent need to reduce fossil fuel consumption as quickly as possible, so that Australia contributes to the global effort to minimise the extent of global climate change which will occur over coming decades.

The aim of this paper is to show in what parts of the whole energy system, and how quickly, the transition is occurring. It does this by specifying, and populating with data, a set of indicators which give a complete picture of Australia's progress in transitioning its energy system towards zero emission supply sources.

The indicators are divided into four groups: emissions, primary energy supply, final energy consumption, and fuel/technology mix, set out in four separate sections of this report. Each section is prefaced by a statement of what the objective of the transition for the parts of the energy system, described in that section, is or should be, and with a simple graph of the change in some key indicators between 2005 (or 2009 for energy) and 2019. The reasoning behind this approach is explained in Section 2.1 below. In most cases, presentation of an indicator or small group of indicators is followed by a short commentary, which summarises what the indicators show. Many of the commentaries also provide a brief explanation of the factors accounting for the observed trends

2 SOME METHODOLOGICAL ISSUES

2.1 Selection of indicators

Energy combustion emissions

In Australia's most recent complete National Greenhouse Gas Inventory (NGGI), for the financial Year 2018-19, **energy combustion emissions accounted for 72% of Australia's total net emissions**. This is a lower share than in most other OECD countries, but a much higher share than reported in Australia's NGGI for 2004-05, when the energy combustion share was only 58%. In absolute terms, Australia's energy combustion emissions increased by 5.6% between 2005 and 2018, while all other emissions sources decreased by 43% over the same period. Almost all of this substantial reduction is attributable to the land sector, which changed over the period from a major net source of emissions to a modest net sink for emissions.

Further large net reductions in the land sector, i.e. major increases in carbon sequestration in vegetation, are most unlikely in the near to medium term. In the NGGI, agricultural emissions were, after energy combustion, the next largest emissions source, contributing 14.2% of total net emissions, over two thirds of which arise from livestock, mainly cattle and sheep. Achieving major reductions from this source will be very difficult. The same goes, to varying degrees, for most of the other non-combustion emission sources. The overall conclusion is that Australia's energy combustion emissions must be the source of the great majority of near to medium term emission reductions, not only because energy combustion is the largest current source of emissions, but also because it offers the best prospect for delivering large reductions at a modest cost.

It follows that the pace and scale of the transition of Australia's whole energy system towards zero emission energy supply sources is the fundamental requirement for achieving large reductions in total national greenhouse gas emissions. The transition is already well underway in Australia's electricity system, from near exclusive reliance on generation based on coal and gas, to increasing reliance on wind and solar generation. However, negligible progress has been made on reducing emissions from other sources, such as transport, which are currently almost exclusively reliant on energy supplied from fossil fuels.

The current Commonwealth government has no formal target for emission reductions and no overall plan for reducing emissions. By contrast, each of the six state and two territory governments does have a formal target, in most cases for net zero emissions by 2050, and most have targets, plans and measures in place for transitioning their electricity supply towards zero emissions. However, none have targets or plans for other parts of their respective energy systems.

If there were a comprehensive national policy and associated plan for achieving an energy transition, such as a number of European and some other countries have adopted, the choice of indicators would be determined by the policies, goals and milestones set out in the plan. Australia has no such national policy and plan. As noted above, each of the six individual states and two territories has policies for transitioning their electricity supply towards generation from zero emission sources. This means that there is a *de facto* national policy for electricity supply, which is simply the sum of the eight individual policies. In public debate the term energy transition is widely used, but always to mean just electricity system transition. There is no formal policy at either the national or the state/territory level for transitioning energy used for either transport and other mobile equipment, or energy used to supply process heat, away from the current near exclusive dependence on fossil fuels.

In the absence of any such national policy, the choice of indicators reflects the author's judgement as to what currently appear to be the most prospective options for transitioning away from dependence on fossil fuels for supplying these energy services. For example, it is assumed that electric traction is now the most prospective option for transitioning road transport away from dependence on petroleum fuels. Other options are assessed as being either superseded, for example biofuels, or insufficiently mature, for example fuel cells using renewable hydrogen. Each of the individual sections of this paper, describing suggested indicators, is introduced by a statement of the assumed transition objective the indicator seeks to measure.

In addition, and most importantly, supplying a given level of energy services with less input of energy, by increasing the efficiency with which the supplied energy is used, will have to be a major component of a successful energy system transition. Total energy consumption per capita of national population is an overall measure of energy use efficiency, as is energy consumption per dollar of Gross Domestic Product (GDP), or its reciprocal, energy use productivity.

In many cases, what would seem to be the most appropriate indicator of transition progress is not feasible because of data limitations. The general approach taken to defining indicators is that the data sources on which they are based are ones which have both a substantial historical record and a good prospect of continuing to be available in future years. The historical record is important for establishing trends to date. Continued availability will be not just important, but essential, for being able to accurately assess future progress. If the definition of an indicator changes in the future, because a data series suddenly ceases to be available, the inevitable break in the time series of the indicator will introduce the need for judgement, and consequent unavoidable uncertainty about trends and progress.

2.2 What do energy statistics measure?

The final introductory topic concerns the interpretation of energy statistics, which provide the majority of the indicators presented here. Energy statistics use the energy content of the different fuels or energy sources as the unit of measure. Energy content is a concept based on thermodynamics. For energy sources which are used to deliver useful energy by undergoing combustion, energy content is the quantity of heat energy released into the surrounding environment when the fuel undergoes complete combustion. This definition applies to all fossil fuels and also to biofuels. The energy content of these fuels is measured in a calorimeter, which ensures that the fuel being tested undergoes complete combustion, and that all of the chemical energy released as heat can be measured

However, these conditions cannot be met in practice when a fuel undergoes combustion, so as to deliver useful energy, in the form of motive power (kinetic energy) or heat in a particular form, such as hot water. Depending on the process, only part of the energy content in the fuel ends up as useful energy. In many cases, including internal combustion engines, used to power transport, and steam engines, such as used to generate electricity in a thermal power station, useful energy delivered is much less than half of the energy content of the fuel. When useful energy is required as heat, for example in a water heater, useful energy delivered is more than half but still less than all the energy content of the fuel.

By contrast, when electricity is used to provide useful energy nearly all of the energy of the electricity used is converted into heat, kinetic energy etc. This difference has two very important implications for the interpretation of energy statistics.

Firstly, one unit of electricity used in final consumption can almost invariably deliver much more useful energy than one unit of petroleum products, gas or coal. If, conceptually, all of the internal combustion engine powered cars in Australia were replaced by electric vehicles, energy statistics would show that energy consumption by road passenger vehicles would fall to between half and quarter of its current value. Road transport would therefore appear as a much less important, though still large, component of Australia's total final energy consumption.

Secondly, the convention used to measure the primary energy delivered by hydro, wind and solar generation of electricity is not defined by, for example, the energy in the solar radiation falling on a solar panel, or the kinetic energy of water striking a turbine blade, but is measured simply as the quantity of electricity generated. This is a logical and practical convention for two reasons: firstly, radiant solar energy or kinetic energy of falling water is difficult to measure, and , secondly, it has no alternative use, as would be the case for, say, gas used in a power station. The effect, however, is to greatly under-state the real size of the contribution which renewable electricity generation is making to total primary energy supply.

The problem is recognised and partly addressed by the International Energy Agency (IEA) in compiling its energy statistics, which cover every country in the world. It uses what it terms the primary energy equivalent approach (IEA, 2020). It applies this to "the electricity and heat produced from non-combustible sources, such as nuclear, geothermal, solar, hydro, wind" (p. 248). Under this approach, heat generated is defined to be the primary energy form for nuclear, geothermal and solar thermal electricity generation. However, because the heat cannot actually be measured (or at least not without extreme difficulty and complexity), standardised assumed conversion efficiency factors are used to scale-up electricity generation to thermal energy – for example, scaling up electricity generated at a nuclear power station by assuming a 33% efficiency of converting reactor heat to electricity.

Unfortunately, for hydro, wind and solar photovoltaic generation there is no equivalent conversion process. Consequently, IEA statistics define electricity generated as the quantity of primary energy supplied, and, for Australia, the understatement of the contribution which renewable electricity generation is making to total primary energy supply remains.

The IEA document observes that the Agency previously used what it called the partial substitution method for calculating the primary energy equivalent of energy generated from non-combustion sources. The method defined that quantity as "the hypothetical amount of energy necessary to generate the same amount of electricity in thermal power plants, assuming an average generation efficiency" (p. 248). This method was abandoned for several reasons, including "the actual substitution values were hard to establish, as they depended on the efficiency of the marginal electricity production" (p. 249). However, the long-established and widely used *BP Statistical Review of World Energy* has always used this method (which it terms input-equivalent) for calculating the primary energy contribution of hydro, wind and solar PV, and continues to do so. In Australia's competitive wholesale electricity markets, where wind and solar are now the lowest marginal cost sources of generation, it is not immediately obvious why marginal, rather than average efficiency of thermal generation, should be used. Indeed, it could be argued that since new wind and solar generation generally displaces thermal electricity generated at older, less efficient thermal generators, the opposite approach would be more appropriate. The problem expressed by the IEA does not therefore arise.

This paper presents two alternative versions of primary energy supply, one using the current IEA method for calculating primary energy supplied by renewable electricity generation, and the other using the substitution method, based on the national average efficiency of thermal generation.

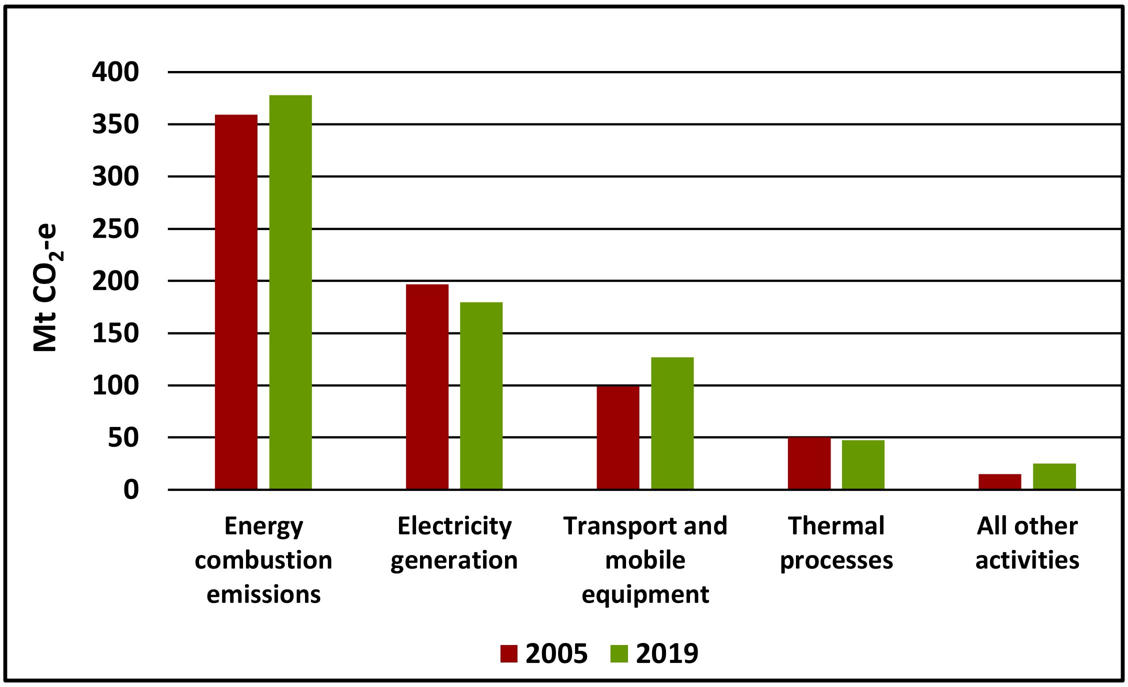
3 EMISSIONS

Objective: Reduce energy combustion emissions with an ultimate objective of reaching zero emissions

All emissions data are sourced from *Australia's National Greenhouse Gas Inventory* (NGGI). Emissions data for the year ending June 2019 were released on 19 April 2021.

Overview

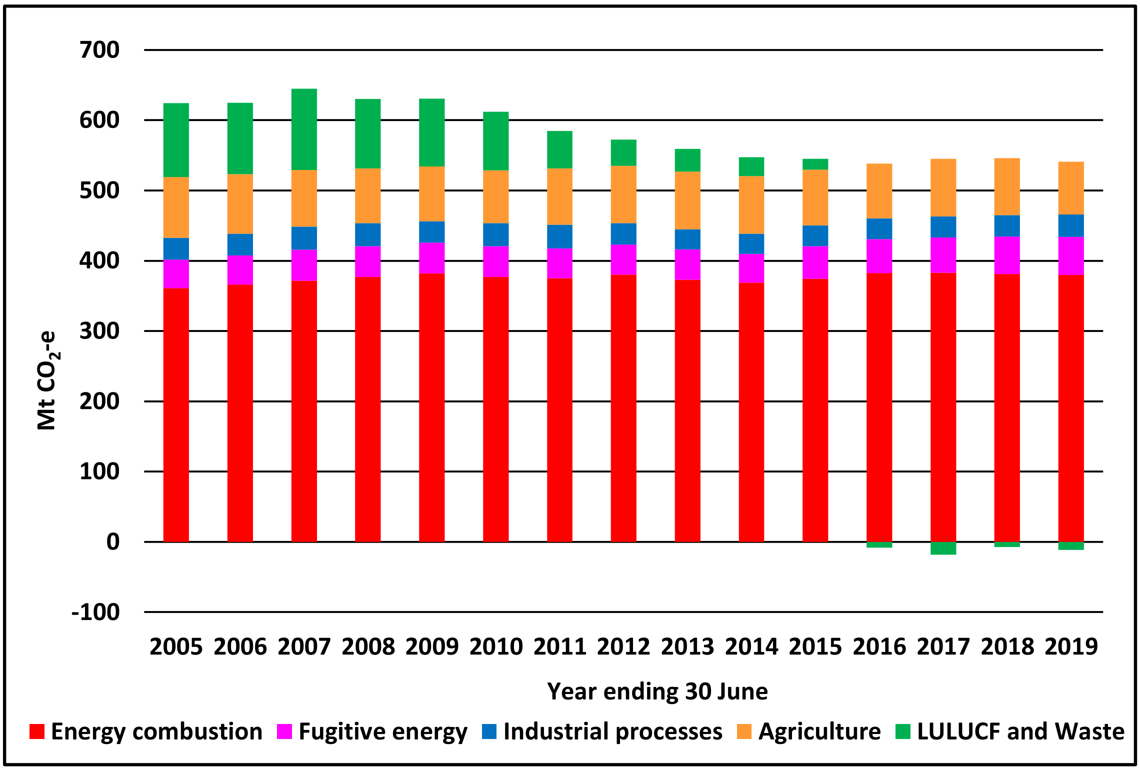
3.0 Energy combustion emissions by major source category, 2005 and 2019



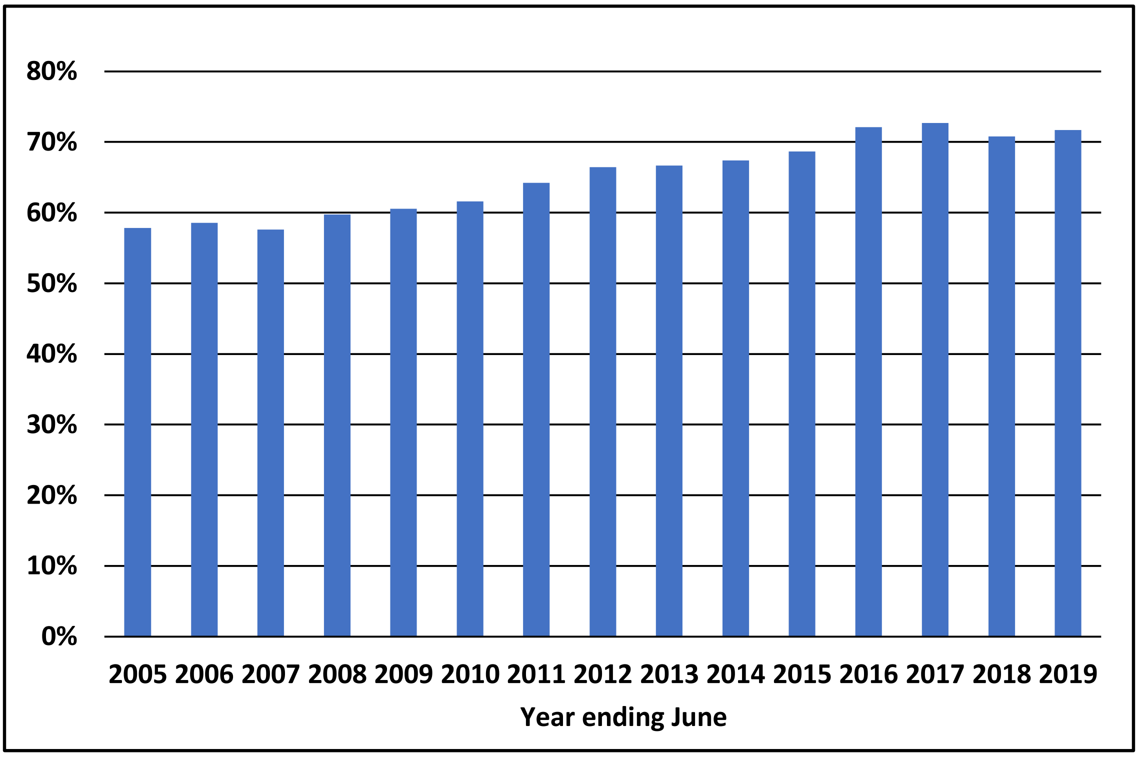
Total energy combustion emissions increased by 5.2% between 2005 and 2019. The main driver of this increase was emissions from transport and other mobile equipment (used in mining, agriculture, construction etc.), which increased by 28%. Emissions from the small All other category increased by 65%, caused by gas energy used to produce LNG for export. Emissions from electricity generation decreased by 9% and energy used to supply heat for manufacturing activities and to heat buildings decreased by 5%.

3.1 Energy combustion relative to all other emission sources

3.1.1 Total emissions by major source



3.1.2 Energy combustion emissions as a share of total emissions

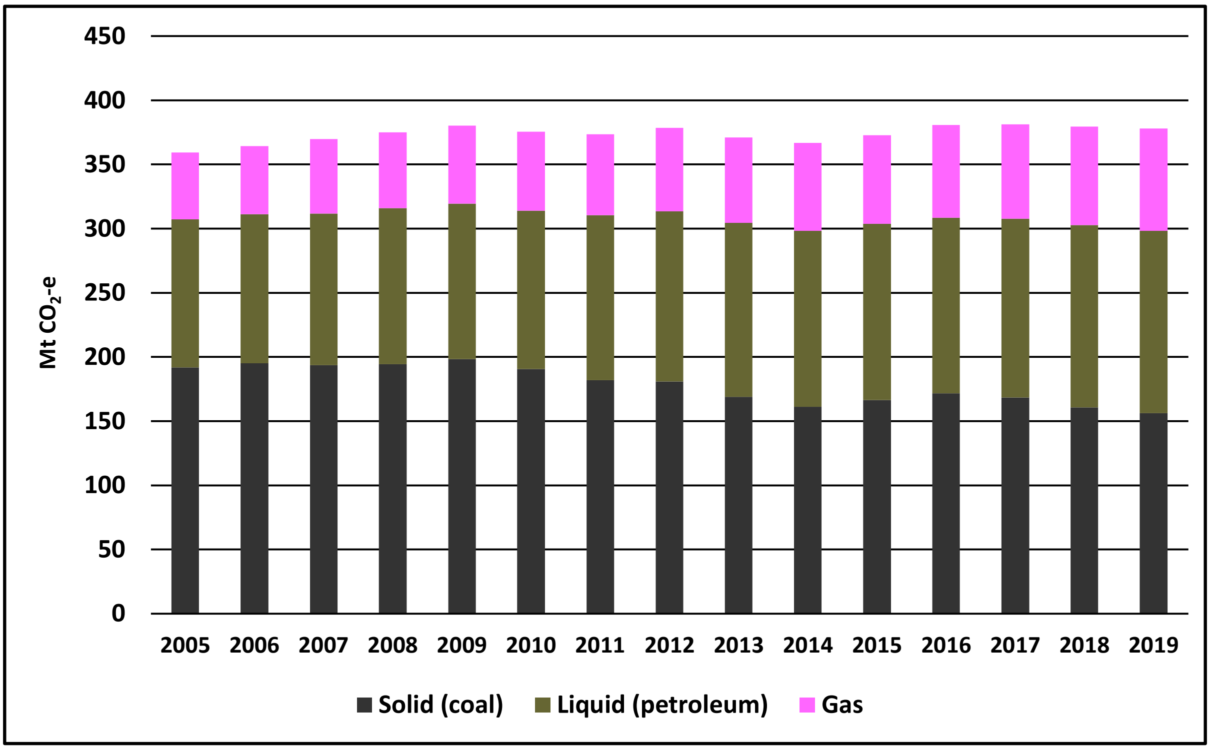


Commentary

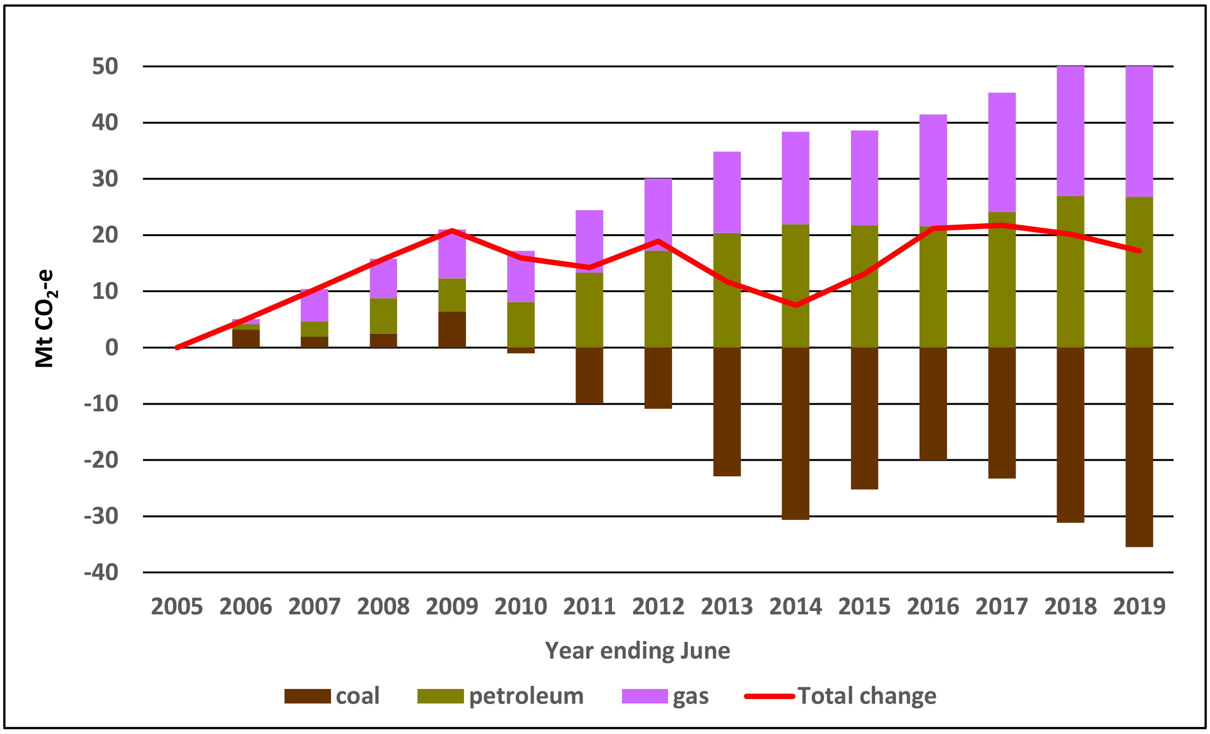
Total emissions fell in every year from 2007 to 2016 inclusive, since when they have slightly increased, but remained roughly constant. The decrease up to 2016 is almost entirely attributable to the dramatic fall in emissions from the land (Land Use, Land Use change and Forestry) sector, which changed from being a large net source of emissions to a modest net sink. By contrast, energy combustion emissions increased gradually over most of the period from 2005 to 2017, and then decreased slightly in 2018 and 2019. In 2019 energy combustion emissions were 5.1% higher than in 2005. Because of the fall in land sector emissions, the increase in energy combustion emissions as a share of total emissions was much larger – from 57.8% in 2005 to 71.7% in 2019. Strong growth in fugitive emissions from the coal mining and gas extraction industries contributed to the share of energy combustion emissions being slightly lower in 2018 and 2019 than in 2017.

3.2 Energy combustion emissions by fossil fuel type

3.2.1 Total energy combustion emissions by fossil fuel type



3.2.2 Changes in energy emissions since 2005 by fossil fuel type

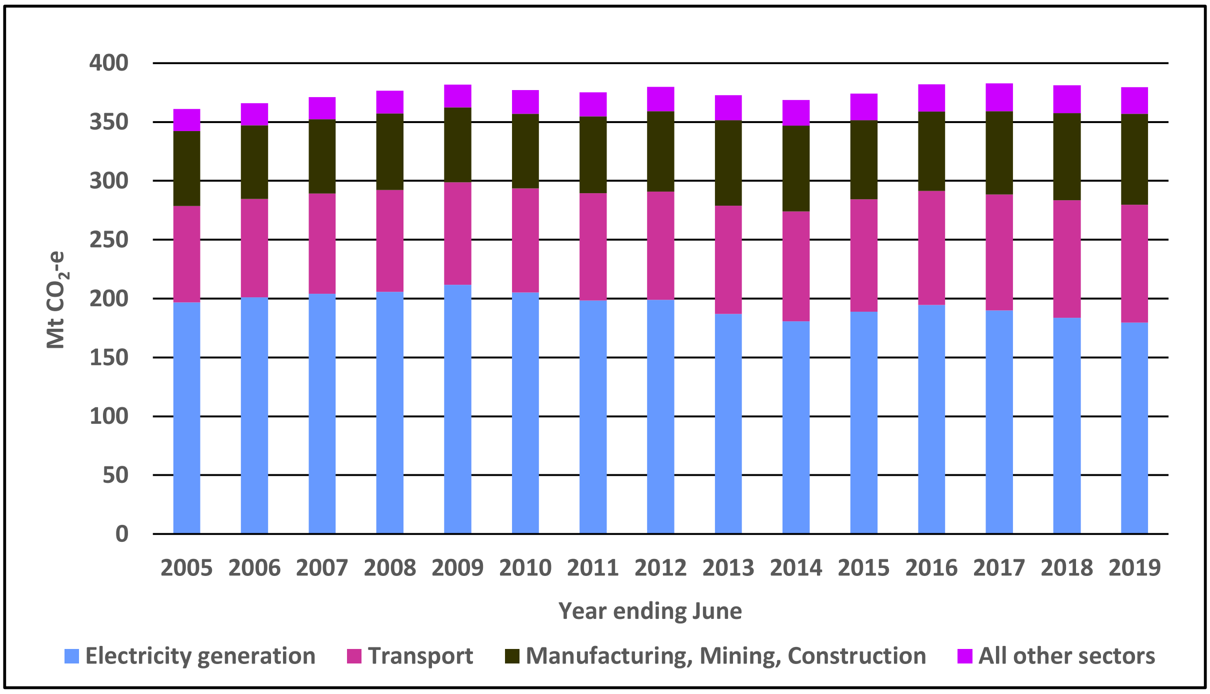


Commentary

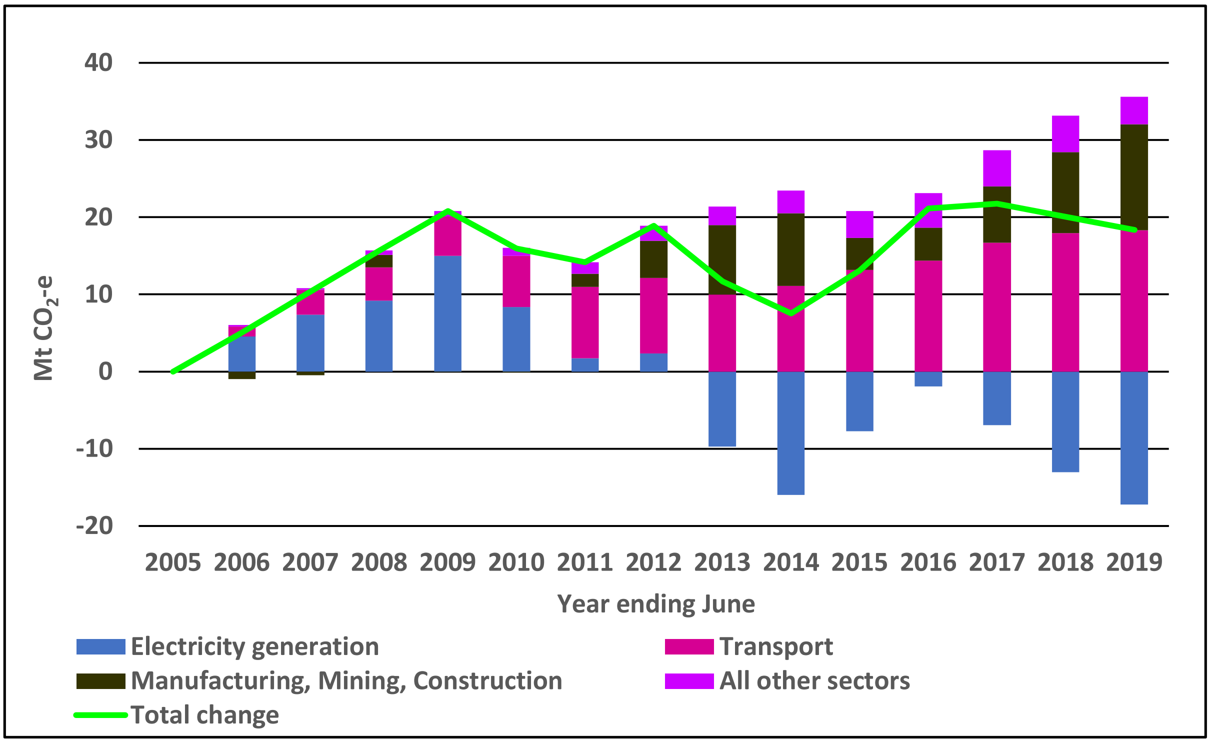
Total energy combustion emissions reached their highest ever level of 382.7 Mt CO_2-e in 2017, just higher than an earlier peak in 2009. In 2019, energy combustion emissions were 0.7% below the 2017 peak. 2009 was the year in which emissions from coal, most of which is used to generate electricity, reached their highest ever level. In 2019, emissions from coal were 21% below their 2009 peak. By contrast, emissions from both petroleum and gas continued to increase; emissions from gas reached a record level in 2019, while emissions from petroleum fell slightly in 2019 from their record level in 2018.

3.3 Energy combustion emissions by economic sector

3.3.1 Total energy combustion emissions by main economic sector



3.3.2 Changes in energy combustion emissions since 2005 by main economic sector



Commentary

Electricity generation emissions have been generally trending down since the peak in 2009. This trend was briefly accelerated during 2013 and 2014, when a carbon price was placed on electricity generation, but sharply reversed when the carbon pricing legislation was repealed. Emissions from road transport increased steadily in every year from 2006 to 2019, as did domestic aviation until 2018, before falling slightly in 2019. Emissions from manufacturing, mining and construction were driven by two opposite trends. Steady declines across most sectors of manufacturing caused emissions to fall, but this was offset during the years 2016 to 2019 by very strong increases in emissions from mining, mainly arising from diesel consumed by machinery used for open cut mining. Finally, “All other” sectors include the processing of gas to LNG, for export, an energy intensive activity which has greatly increased since 2016.

3.4 Energy combustion emissions by major activity or process type

For some years the Commonwealth government has been at pains to point out, correctly, that reducing energy combustion emissions will depend heavily on the availability of technical options to do so. What those technologies are, and what they will be required to achieve, will depend on the nature of the energy services currently being delivered by combustion of fossil fuels. Classifying combustion emissions by the nature of these energy services is therefore a very important alternative way of understanding combustion emissions, and the nature of the energy transitions which will be required to reduce those emissions.

The classification which we consider best fits the Australian energy systems consists of four groups of categories, as follows.

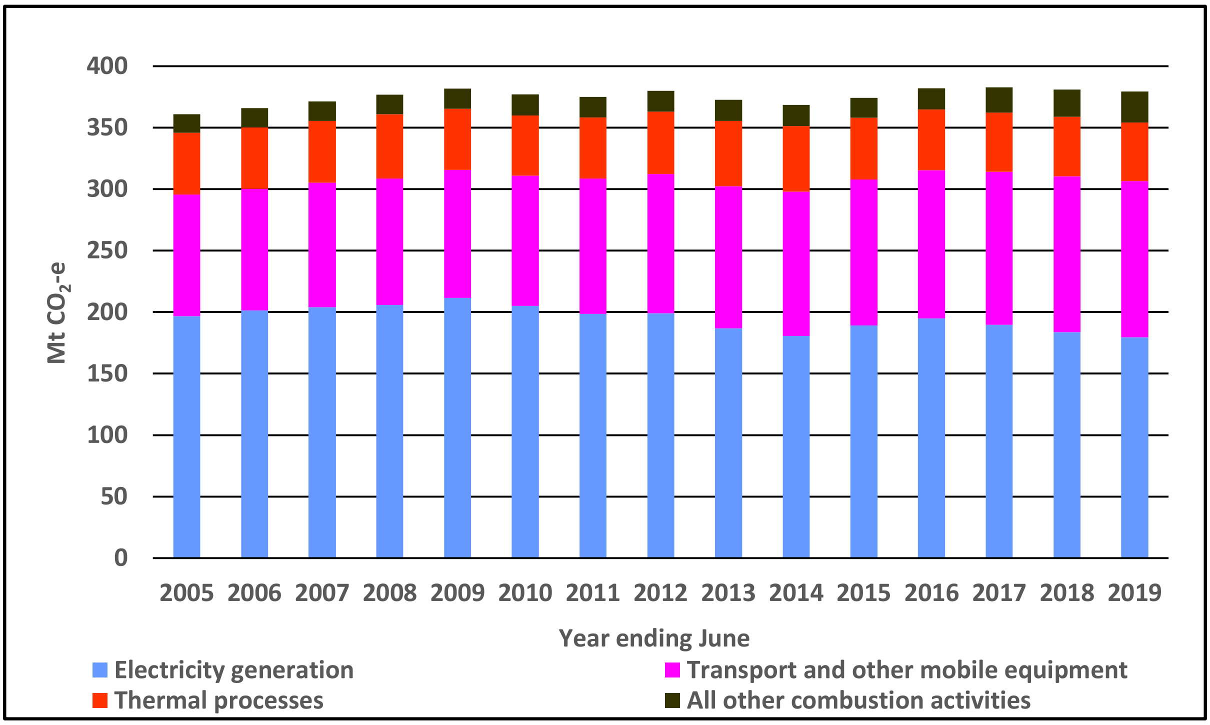
Electricity generation has the common feature of converting a variety of primary energy sources into electricity, which is by far the most versatile of all forms of secondary or final energy when supplied to consumers, and in many cases also delivers energy services at much higher efficiency than alternative types of secondary energy. Currently, fossil fuel combustion is used to generate most of the electricity generated and consumed in Australia.

Transport and other mobile equipment have the common feature of depending almost entirely on use of internal combustion engines. An important share of rail transport, and a currently very small share of road transport are powered by electricity, which of course produces no emissions at the point of use, but overall electricity accounts for only a tiny share of the total energy supplied. Emissions arising from non-transport mobile equipment are defined as all emissions arising from combustion of petroleum products in mining (excluding production of oil and gas), agriculture, forestry and fishing, and construction. The relatively modest emissions from use of coal and gas in these sectors are allocated to thermal processes.

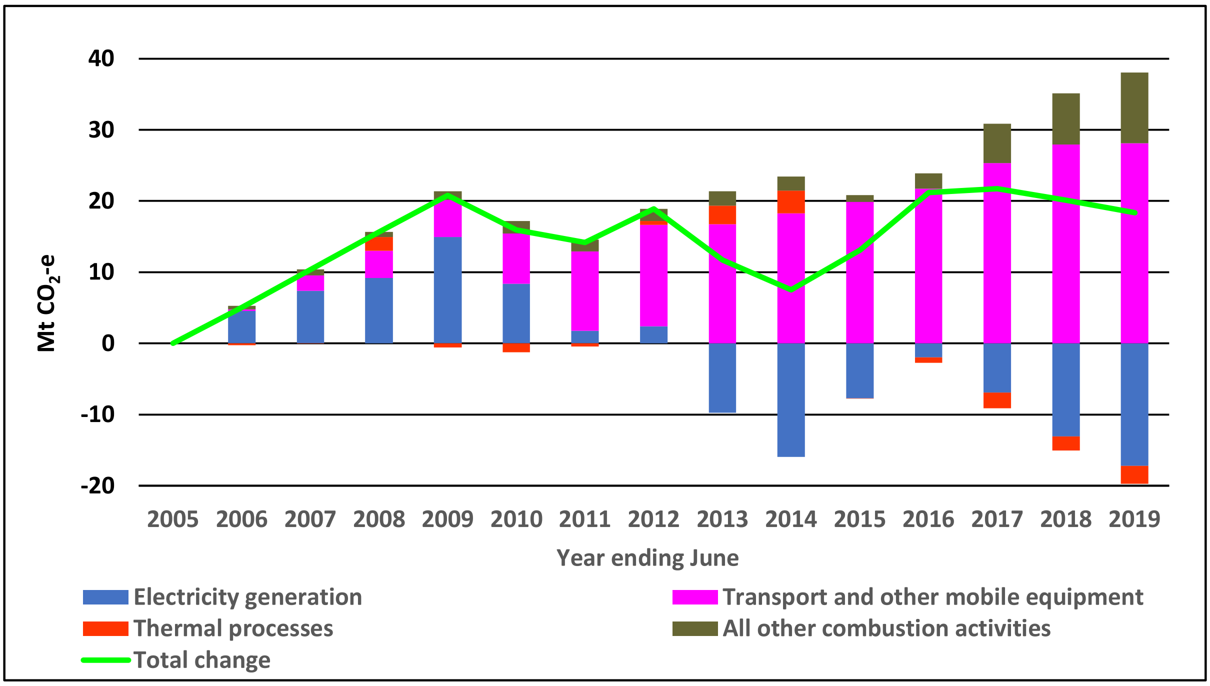
Thermal processes (supply of heat) are the most important activities for which energy combustion is used in the manufacturing, commercial/institutional and residential sectors.

All other combustion emissions is a residual classification used for a limited number of activities, all linked to the processing of primary fossil fuels. The characteristic of all of these activities is that energy for processing is provided by combustion of some of the primary fuel being processed. In other words, there is an intimate relationship between the fossil fuel being processed and the combustion activity, meaning that feasible technology options, such as fuel switching, are extremely limited. The main activities concerned are processing of crude oil and gas, including processing of gas to LNG, oil refining, and production of metallurgical coke.

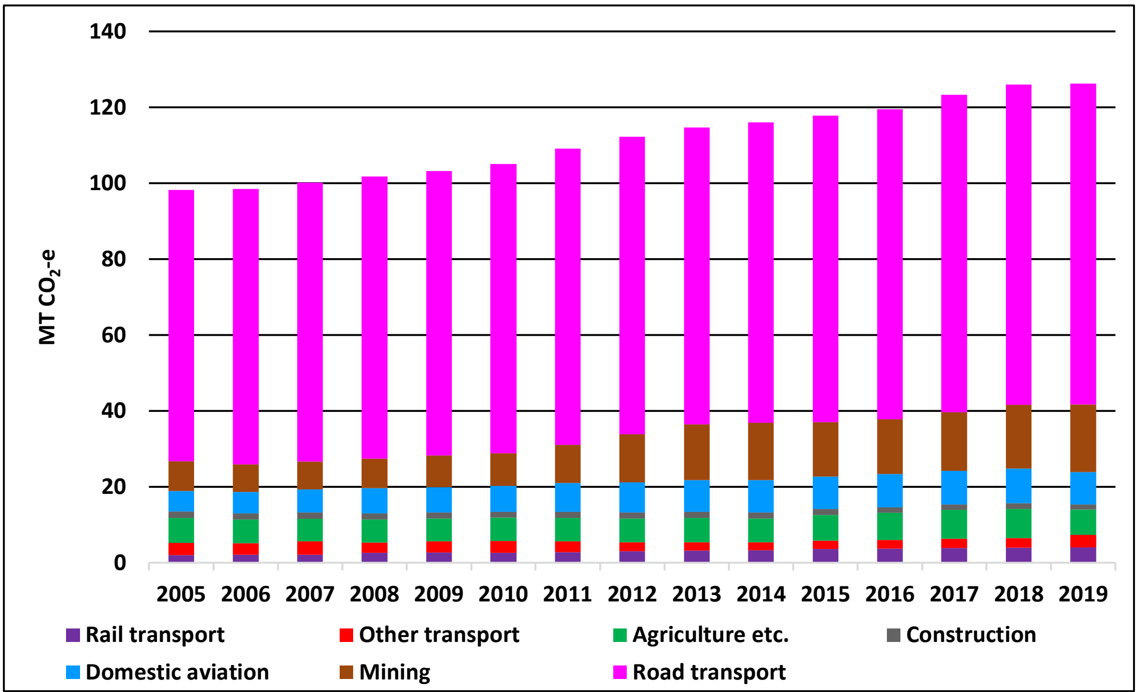
3.4.1 Total energy combustion emissions by main activity or process type



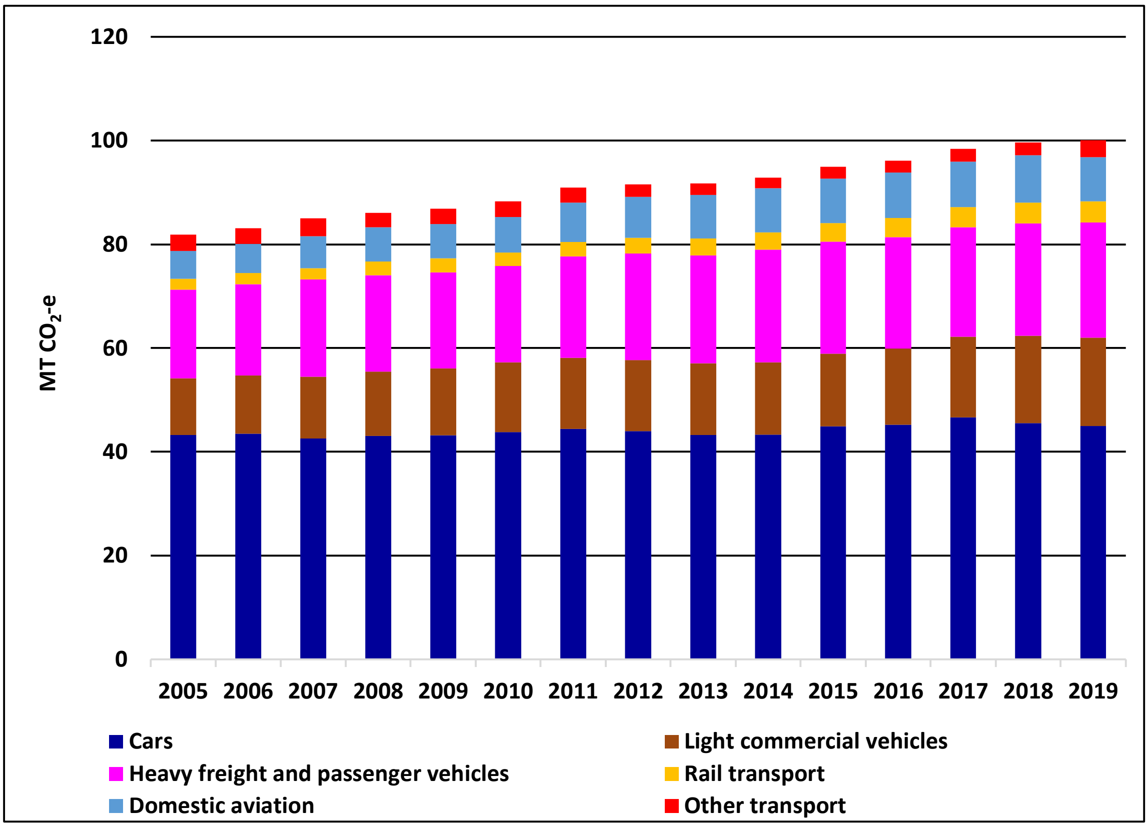
3.4.2 Changes in energy combustion emissions since 2005 by main activity or process type



3.4.3 Components of transport and other mobile equipment energy combustion emissions



3.4.4 Components of transport energy combustion emissions



Commentary

The classification by activity/process type shows, with striking clarity, that most of the growth in Australia's energy combustion emissions is being caused by growth in emissions from transport and use of other mobile equipment. In addition, the last few years have seen very rapid growth in emissions from the 'All other' emissions category, arising from the growth of the LNG industry.

Growth in emissions from these sources has been offset by reductions in emissions from electricity generation, driven by the shift towards wind and solar generation and away from coal and, to a lesser extent, gas. Emissions from energy combustion used to supply heat have fallen modestly, reflecting the steady decline of manufacturing activity in Australia.

Looking in more detail at transport and mobile equipment emissions, it is clear that almost all of the emissions and almost all of the growth in emissions has come from three components: road transport, which is by far the largest, mining, and domestic aviation. In turn, most of the growth in road transport in recent years has come from freight transport, though passenger vehicles (cars) are responsible for the largest share. Road transport, air transport and mining, together with the LNG industry, have been responsible for almost all of the growth in Australia's emissions since 2005. Between 2005 and 2015 emissions from road transport, domestic aviation and mining increased by 26 Mt CO_2-e, while emissions from all other energy combustion sources decreased by 6 Mt CO_2-e. Moreover, this figure includes an increase of 5 Mt CO_2-e from LNG, meaning that all other energy combustion emissions fell by 11 Mt CO_2-e.

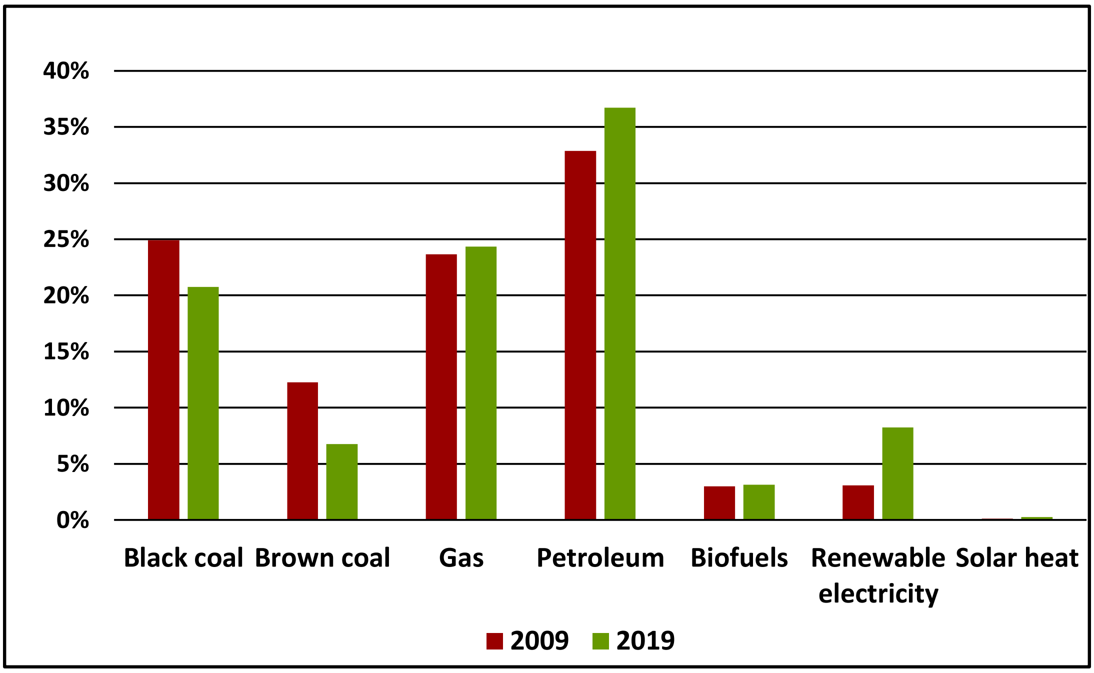
Apart from steady growth in fossil fuel combustion and emissions, the other common feature of road transport, aviation and mining is that they derive all but a tiny fraction of their energy requirements from petroleum products. In 2017-18, imports of petroleum products, mainly from refineries in Singapore, Korea and a number of other Asian countries, including China, accounted for 60% of total Australian consumption of petroleum products in volume terms. Imports from refineries in China supplied 3.5% of consumption. Imported crude oil, subsequently refined at Australian refineries, supplied a further 37% of total consumption, by volume. These figures were much the same in 2019-20. However, late in 2020 and early in 2021 the international oil companies which own and operate two of Australia's four remaining refineries announced that they would close within the next year or so. These facts suggest that reducing the use of petroleum products as a source of energy would have the double benefit of reducing Australia's greenhouse gas emissions and increasing national energy security.

4 PRIMARY FUEL MIX

Objective: Increase the share of renewable (zero emission) fuels in primary energy supply

Overview

4.0 Primary energy consumption shares by fuel type using the substitution calculation method, 2009 and 2019



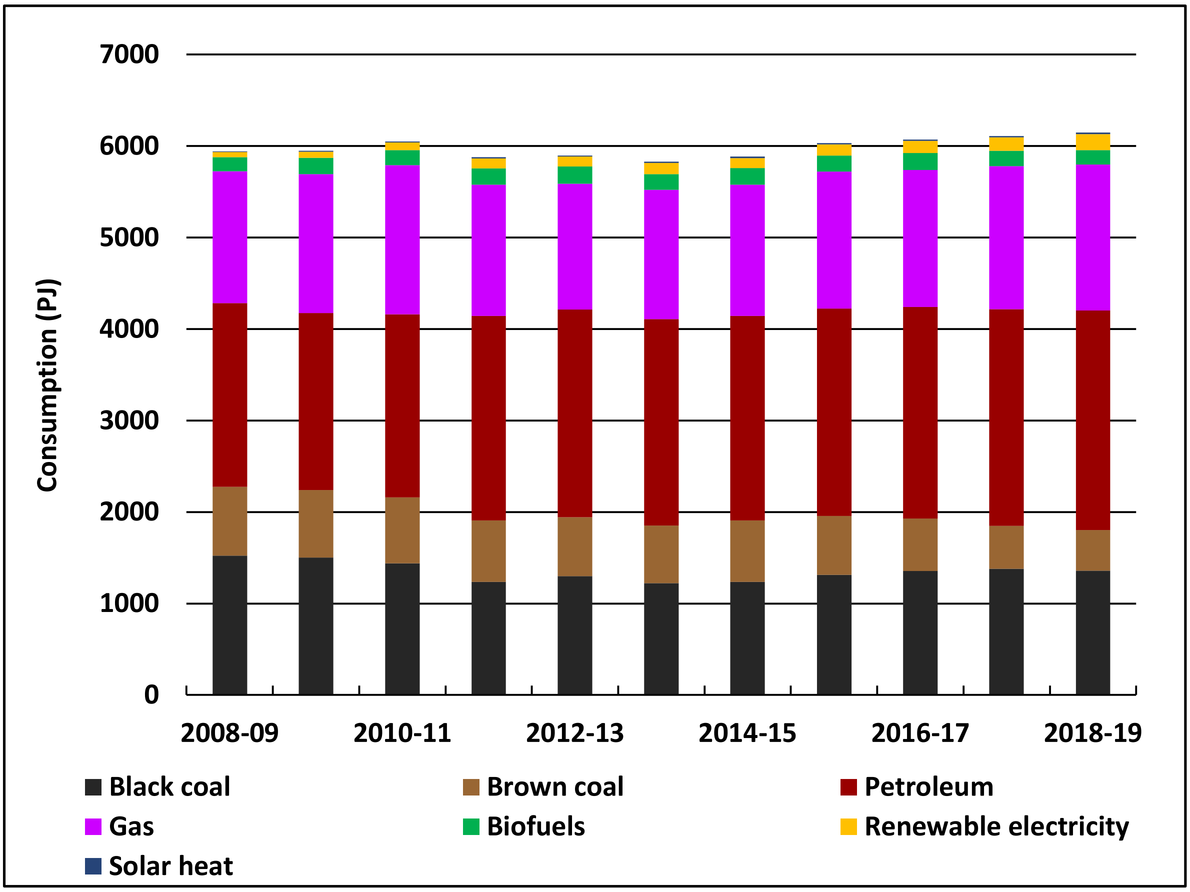
Coal consumption decreased as coal fired electricity generation was displaced by renewable wind and solar generation. Consumption of petroleum fuels increased, in line with the growth of energy used for transport and other mobile equipment. There was a smaller increase in gas consumption, almost all attributable to the LNG export industry.

4.1 Primary energy consumption by fuel type

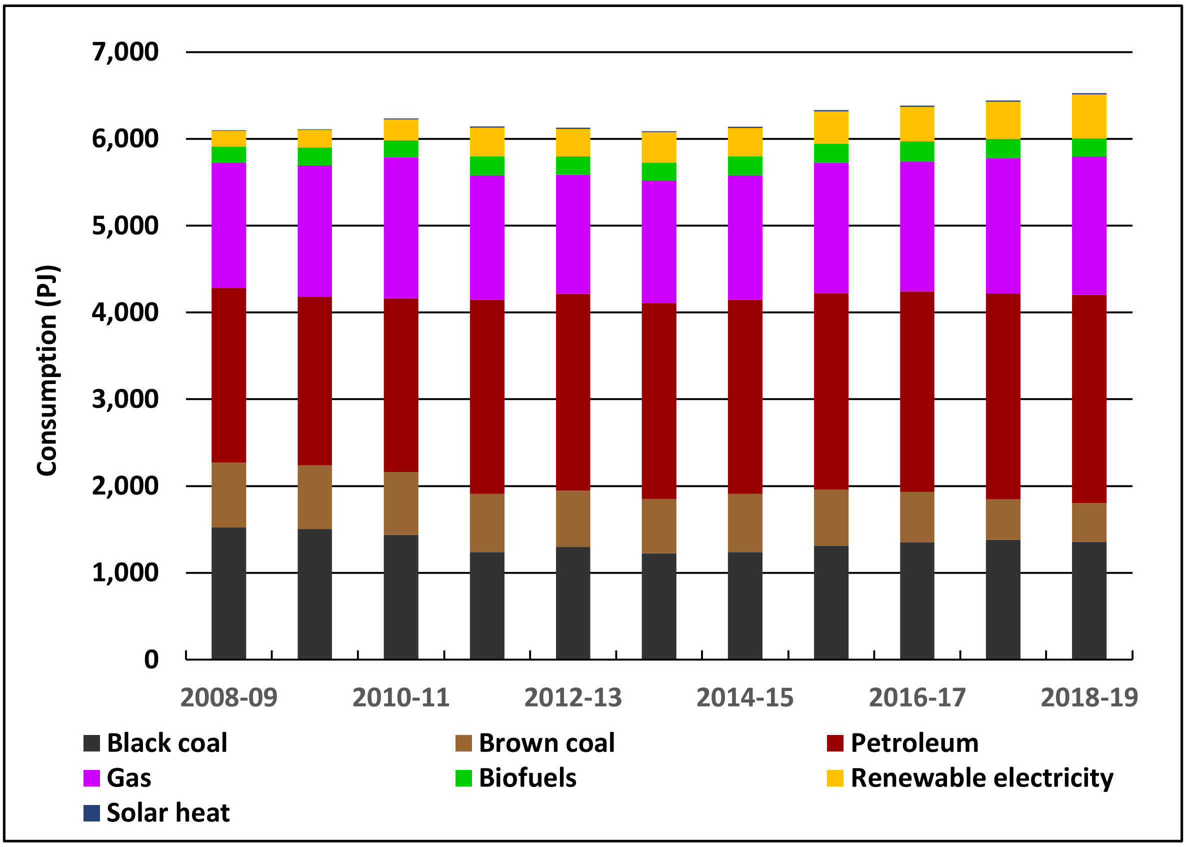
Primary energy consumption data are sourced from Table A of successive annual editions of *Australian Energy Statistics*. National average efficiency of thermal electricity generation, used in the substitution method for calculating the contribution of renewable electricity to primary energy supply, is calculated as the ratio of thermal electricity generated to total combustion fuels consumed in electricity generation, as reported in Table F of *Australian Energy Statistics.*

The time series presented extend back only to 2008-09. The reason for this limited time span is that there is a major discontinuity in the sectoral energy consumption data between 2007-08 and 2008-09. This discontinuity re-allocates estimated energy consumed in "behind the meter" generation of electricity at industrial and commercial facilities (in Australia, usually termed cogeneration) from the economic sector where the cogeneration occurs to the electricity generation sector, in conformity with IEA conventions for energy statistics. This change was made possible by the implementation of the National Greenhouse and Energy Reporting Scheme (NGERS), under which the corporate entities required to report (there is a fairly low minimum annual corporate energy consumption threshold for reporting) include all or virtually all the entities with cogeneration. One of the items required to be reported by those with cogeneration installations is an estimated allocation of total fuel (almost invariably gas) consumption used in cogeneration between electricity generated and useful thermal energy captured and used for other functions. The overall effect of the change is to reduce final energy consumption and increase energy used in conversion, relative to the values which would have been calculated using the previous convention.

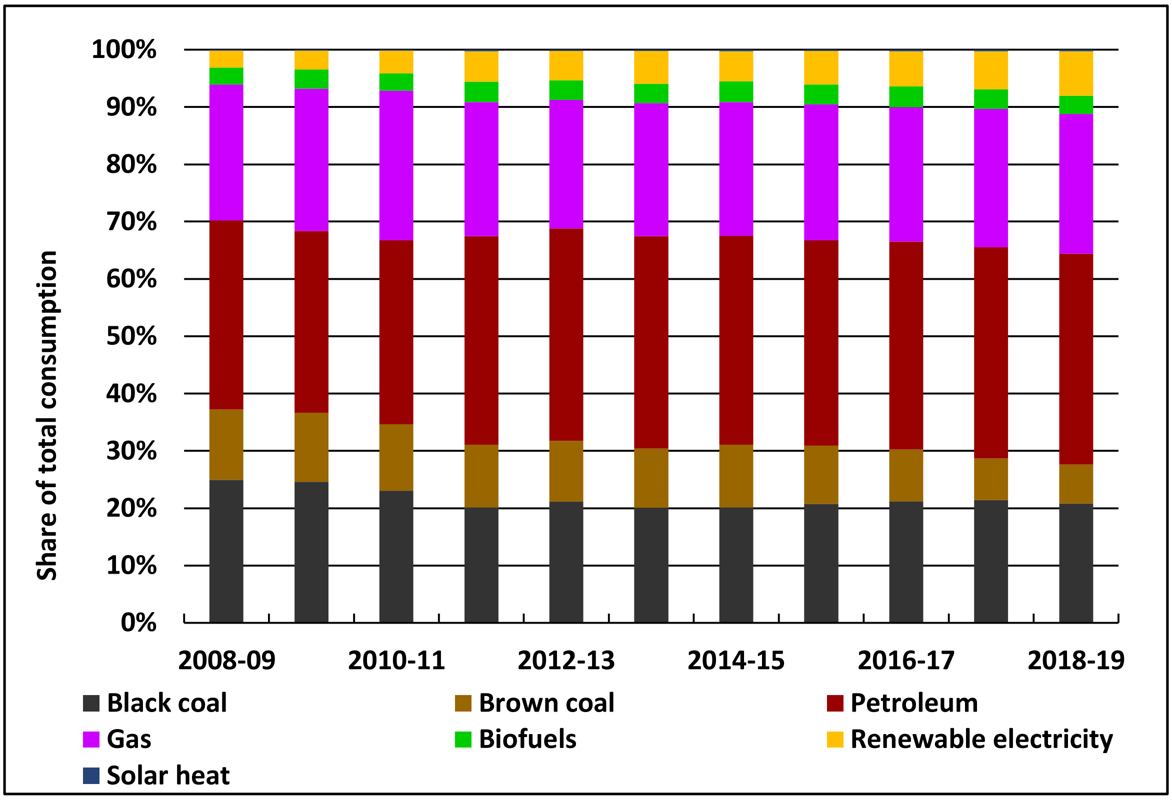
4.1.1 Primary energy consumption by fuel types – conventional calculation method for renewable fuels



4.1.2 Primary energy consumption by fuel types –substitution calculation method for renewable fuels



4.1.3 Shares of primary energy consumption by fuel types –substitution calculation method for renewable fuels



Commentary

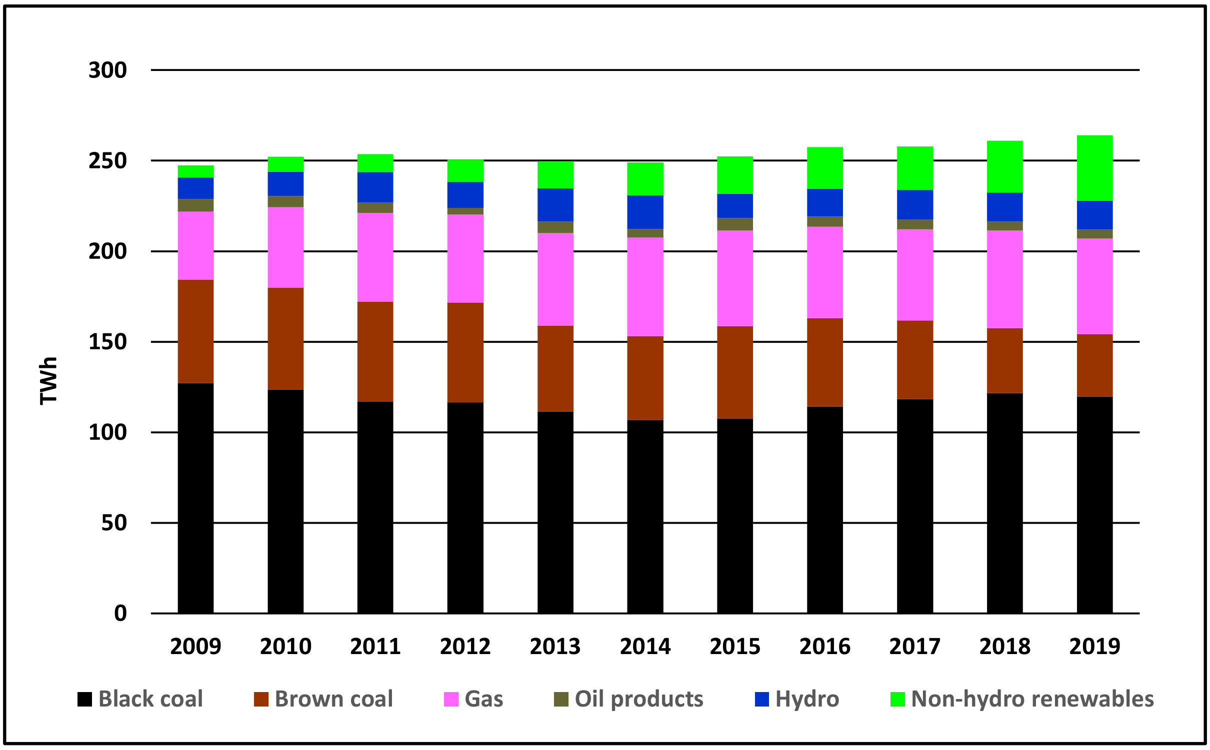
There are three components of primary renewable energy used in Australia. The most important and fastest growing is renewable electricity, generated from hydro, wind and solar radiation. When calculated in conventional terms, these sources contributed 2.8% of Australia's total primary energy supply in 2018-19. However, when the substitution calculation method is used, this share increases to 7.8%. The second source is biofuels, of which the most important are bagasse and woodwaste. These are waste products of the sugar milling and pulp and paper industries respectively, and are used, typically at rather low thermal efficiency, to generate process steam and electricity, mostly for use in the associated manufacturing processes. There are also small quantities of landfill gas and biogas from wastewater treatment, also used to generate electricity. The quantities of primary energy supplied by these sources has been roughly constant for many years and there is little or no prospect of any significant increase. The third, very small source of primary renewable energy is solar heat used by residential consumers for hot water supply. For a variety of technical and economic reasons, this technology has been largely superseded, and there is little prospect for significant growth. Note however, that this technology is quite distinct from large scale use of concentrated solar energy to supply process heat. While there is no industrial scale supply of solar thermal energy in Australia at present, it is a prospective technology for future application.

The rapid growth in solar and wind electricity generation, particularly over the past four or five years, has seen the renewable share of primary energy supply, calculated using the substitution method, increase from 6.2% in 2008-09 to 11.2% in 2018-19.

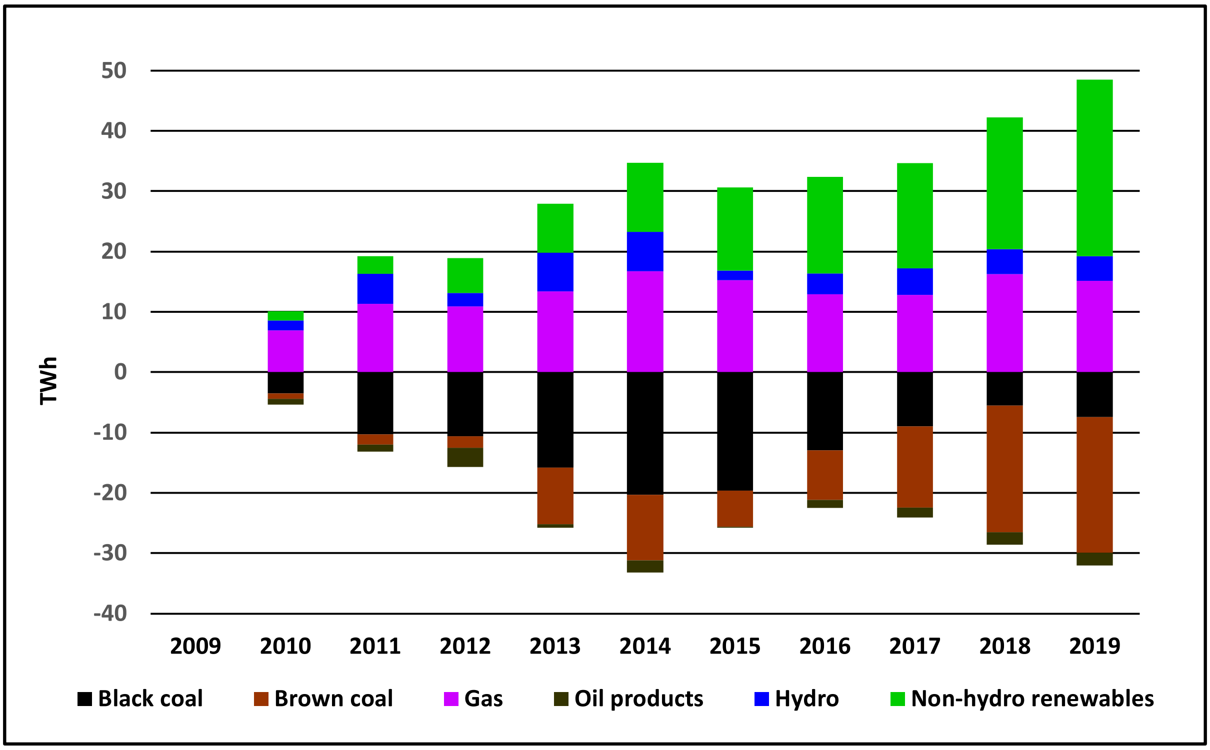
4.2 Electricity generated in Australia by source

Sectoral objective: Increase the share of electricity generated from zero emission primary energy sources

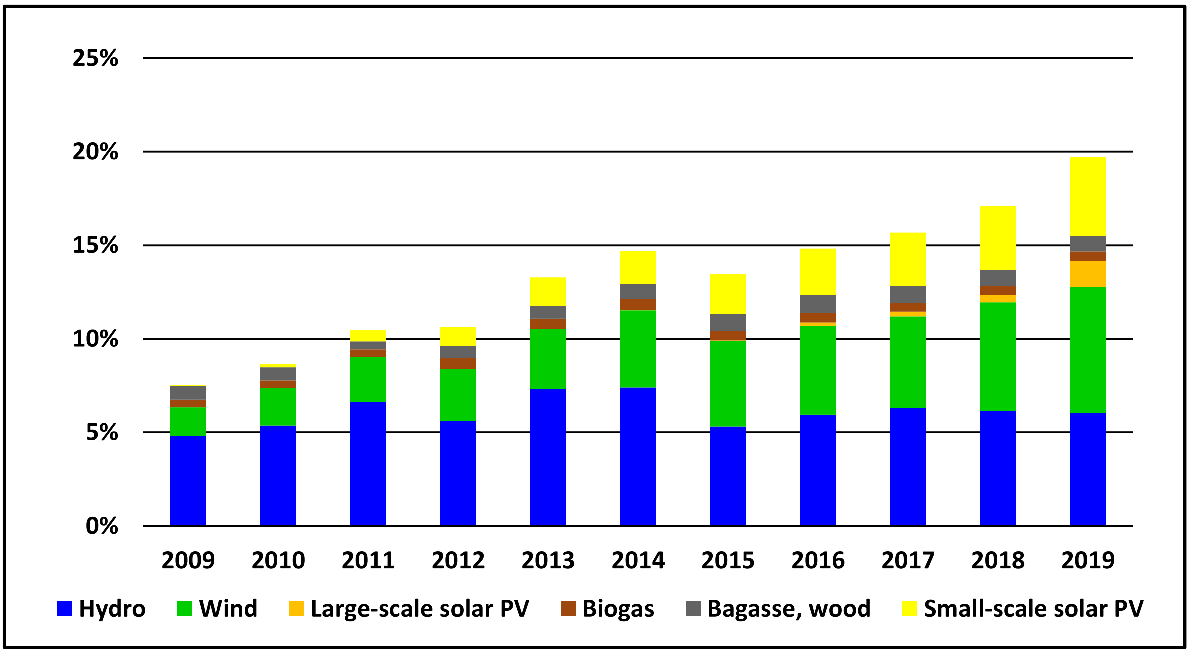
4.2.1 Total electricity generated by primary energy source, as-generated basis



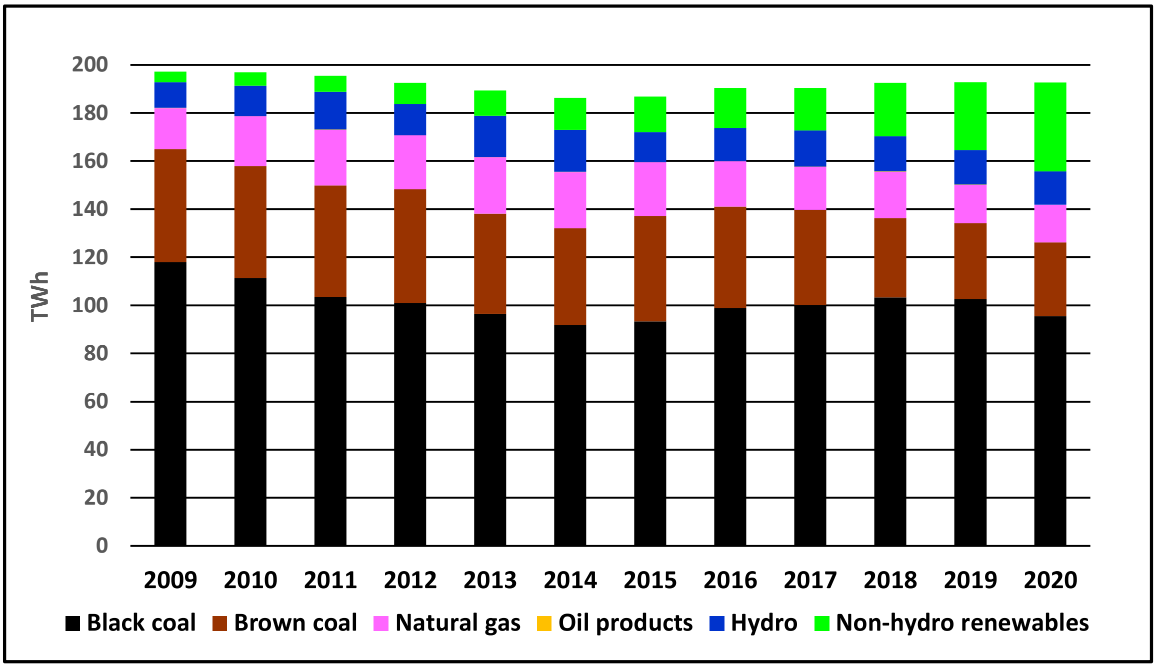
4.2.2 Changes in total electricity generated by source since 2009, as-generated basis



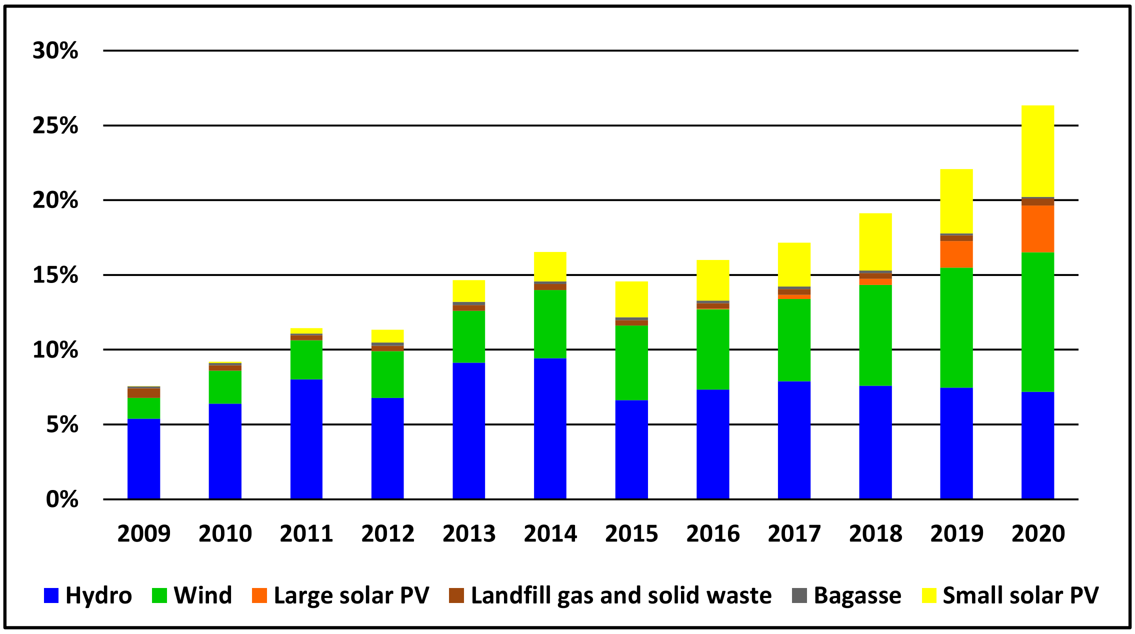
4.2.3 Shares of renewable electricity generation by source, as-generated basis



4.2.4 Electricity generation by primary energy source in the National Electricity Market, sent out basis



4.2.5 Shares of renewable electricity generation by primary energy source in the National Electricity Market, sent out basis



Commentary

The data shown in graphs 1 to 3 in this section includes electricity generation in Australia's largest grid system, the National Electricity Market (NEM), together with generation in smaller grid systems in Western Australia and the Northern Territory. In addition, the data include self-generation (also termed cogeneration) at a number of industrial sites, most notably Australia's ten liquefied natural gas (LNG) plants, and generation at a great many remotely located, off-grid locations, including both mine sites and remote communities.

Graphs 4 and 5 present data for generators which participate in the NEM, which is a wholesale electricity market, trading through a single grid covering almost all consumers in the states of New South Wales, Victoria, Queensland, South Australia and Tasmania. The data also include estimated output from several million small ("rooftop") solar photovoltaic systems, which supply into local distribution networks.

The national figures are calculated on an as-generated basis. This means that they include auxiliary loads, which are electricity consuming activities within power stations, such as pumps, blowers and conveyors. These loads are particularly large at coal-fired power stations; according to data published by the Australian Energy Market Operator (AEMO) they are between 5% and 10%, depending on the individual station. Auxiliary loads at hydro, wind and solar generators are less than 1%. Consequently, the data somewhat over-state the contribution of coal fired generation to total electricity supply. This is corrected in the data for the NEM only, which are expressed in terms of sent out generation. As-generated data for the NEM are not graphed, but have been used to calculate that the weighted average annual auxiliary load in the NEM has varied between 6.6% and 5.4% over the period covered by the graphs, gradually declining in recent years because of the decreasing share of coal generation.

The data have also been used to calculate that, in as-generated terms, the NEM share of total national generation has been gradually falling, from 85% in 2009 to 77% in 2019. This trend is largely attributable to the rapid growth in electricity consumption in Western Australia, while consumption in the NEM states has been almost constant.

Graph 4.2.1 shows that total electricity generation increased by 8.6% over the ten years from 2009 to 2019. Generation from renewable sources – mainly wind and solar – and gas increased over the period, while coal fired generation decreased. The decrease led to the closure of five black coal fuelled power station, most of which were in New South Wales, between 2010 and 2014, and five brown coal fuelled stations in Victoria and South Australia between 2011 and 2017. These changes caused the decrease in emissions from electricity generation, shown in graph 3.3.1.

Graph 4.2.3 shows that the growth in renewable generation has been almost entirely caused by growth in wind and small (rooftop) solar generation. More recently, there has been strong growth in large (grid scale) solar PV generation. Australia currently has no solar thermal generation. The sharp increase in hydro generation in 2013 and 2014 was the response of the two main hydro system operators to the short-lived price on CO_2 emissions from power stations. The political situation at the time made if likely that the price legislation would be repealed quite quickly, as indeed turned out to be the case. Each of the two large hydro generation businesses therefore decided, for sound commercial reasons, to generate at above the long-term sustainable level of their respective systems for the two years that the price was in place, then cut back sharply in 2015. Note also that 2009 and 2010 were drought years in south east Australia, where nearly all hydro capacity is located, with the consequence that hydro generation was below long term average levels in those years.

Comparing graph 4.2.3 with graph 4.2.5, it can be deduced that renewable generation has grown much further and faster in the NEM than outside the NEM. In 2019, the total share of renewable generation, as-generated, in the NEM was over 21%, whereas in the rest of Australia it was barely half that figure. By 2020, for which data are available through the Australian Energy Market

Operator, the total renewable share of NEM generation had increased to 25.3% as-generated and 26.4% sent out.

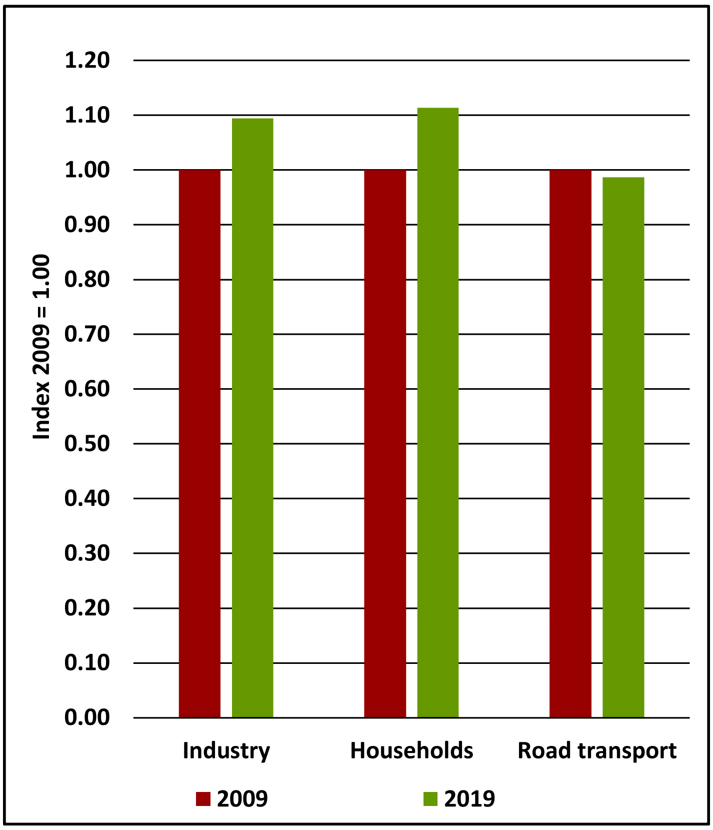
5 FINAL ENERGY CONSUMPTION

Objective: Reduce final energy consumption per capita and per dollar of Gross Domestic Product, by using energy more efficiently to deliver useful energy services

The sources of the annual consumption data reported here are Table A of successive issues of *Australian Energy Statistics*., together with Table F, which publishes the entire historic time series every year. Final energy use efficiency of industry is calculated as total energy consumption per dollar of real Gross Value Added. For this purpose, industry means all economic sectors other than the electricity and gas supply industries. Residential final energy use efficiency is calculated as total energy consumption per capita of national population. Population and Gross value added are sourced from the ABS series *National, state and territory population* and *Australian national accounts: National income, expenditure and product,* respectively.

Overview

5.0 Final energy consumption productivity in industry, households and road transport, 2009 and 2019, index numbers

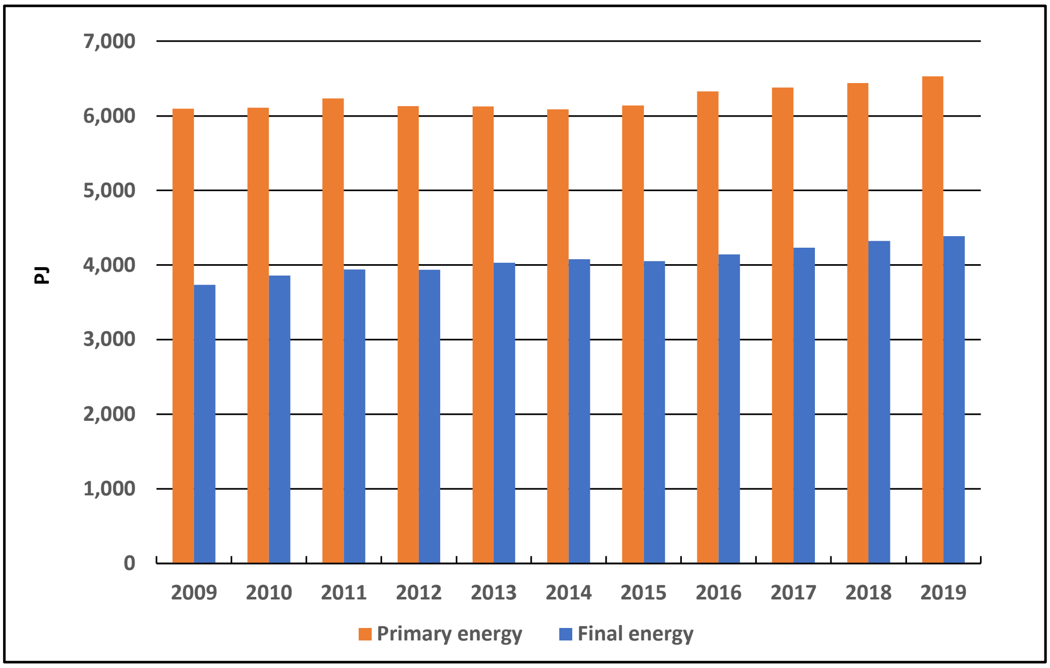


The productivity of energy used by industry is measured as constant value (real) $ Gross Value Added per unit of energy consumed. Energy consumed is calculated as total final energy consumption minus final energy consumption by the residential sector. The productivity of energy used by households is measured as the total number of households divided by the quantity of energy used for stationary functions in the residential sector, i.e. excluding fuel which households use for motor vehicles and recreational equipment. The productivity of road transport combines energy used for freight transport, which is also included in the calculation of energy productivity, and energy used for passenger transport, i.e. cars, the majority of which is not included in either of the other productivity indices. Productivity of freight transport is measured by tonne-kilometres transported, while the productivity of passenger transport is measured by total kilometres travelled by passenger vehicles, and the composite index weights each of these two components by its respective share of energy used in the base year.

All three indices are expressed as index numbers, comparing 2019 with 2009, except for road transport for which the years are 2007 and 2018, not 2009 and 2019, for reasons which are explained below. It can be seen that the industry and household energy productivity indices have each increased by roughly 11% over 10 years, i.e. approximately 1% per annum, whereas the road transport index has decreased by 1.4% over the period covered.

5.1 The relationship between primary and final energy consumption

5.1.1 Primary and final energy consumption – absolute levels

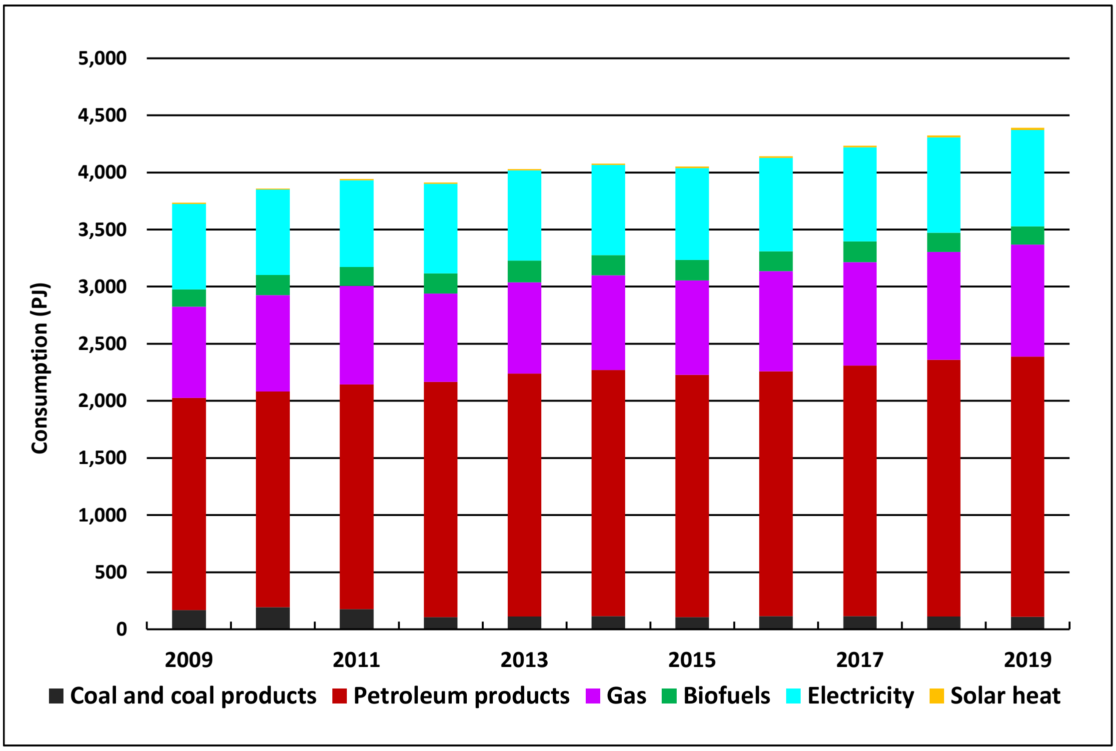


Commentary

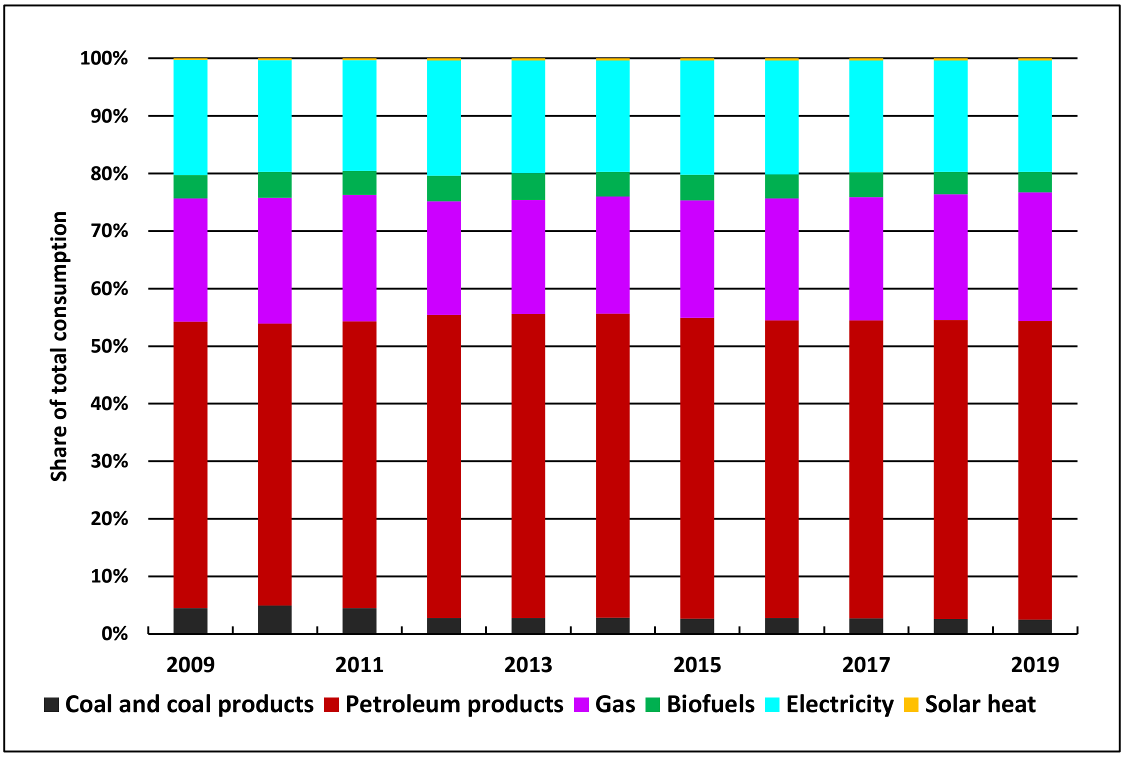
Most of the difference between primary and final energy consumption is accounted for by energy lost in the process of thermal electricity generation. Energy consumed by oil refineries accounts for a small and declining share, as Australian oil refineries are progressively closed. Primary energy consumption decreased slightly between 2009 and 2014, as a number of older, less efficient coal fired power stations were closed. In addition, the carbon price, in place during 2012-13 and 2013-14, had the effect of supporting output from hydro generators, at the expense of the least efficient coal fired power stations, and towards the end of this period two of Australia's then seven oil refineries closed. Since then, primary and final energy consumption have increased steadily, more or less in parallel, as use of the substitution calculation method for renewable generation has removed the statistical distortion which would otherwise be caused by the rapid growth of wind and solar generation, at the expense of coal and gas.

5.2 Final energy consumption by fuel type

5.2.1 Final energy consumption by fuel types



5.2.2 Shares of final energy consumption by fuel types



Commentary

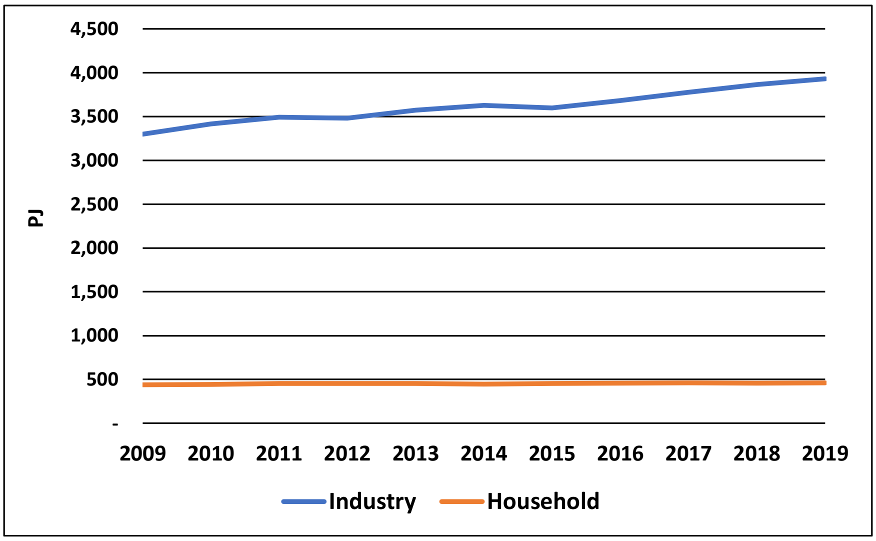
Over the ten years covered by these indicators, final energy consumption, i.e. energy used by consumers, has grown slowly but steadily. However, the shares of each major energy source (fuel type) have remained almost completely unchanged, other than a reduction of the already small share of coal, caused mainly by a halving of output at Port Kembla, Australia's largest steelworks. The relative sizes of the shares of petroleum fuels and electricity are particularly significant. As expressed in these statistics, petroleum products account for over half of total final energy consumption, while electricity contributes just under 20%. However, in most of the applications where these two fuel types are alternatives, which involve powering motors, electricity delivers up to four times as much useful energy output as a petroleum fuelled internal combustion engine would deliver. Similarly, where electricity and gas are alternative energy sources, most notably in space heating, an electric heat pump delivers four or more times as much useful heat as does a gas heater. It is because of these very large differences in end use efficiency that the basic energy consumption numbers, on which these indicators are based, are unavoidably misleading.

These differences in end use efficiency between electricity and other duels are also the reason that electrification of end uses is a fundamentally important component – essentially the second half, together with renewable electricity generation – of a comprehensive strategy to reduce greenhouse gas emissions from the energy system. The complementarity of renewable electricity and electrification of energy end uses forms the foundation of the comprehensive energy policy package recently announced by President Biden.

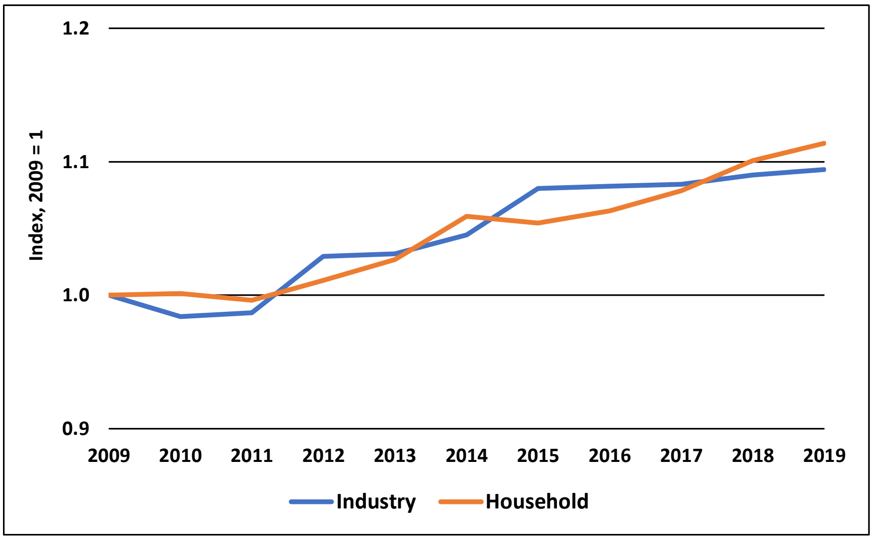
These indicators show that, In Australia, as distinct for the USA and many other countries, electrification is the missing half of energy policy. The next set of indicators examine separate energy consuming sectors of the economy, with the aim of seeing whether any individual sectors have made any progress with electrification.

5.3 Final energy consumption by economic sector

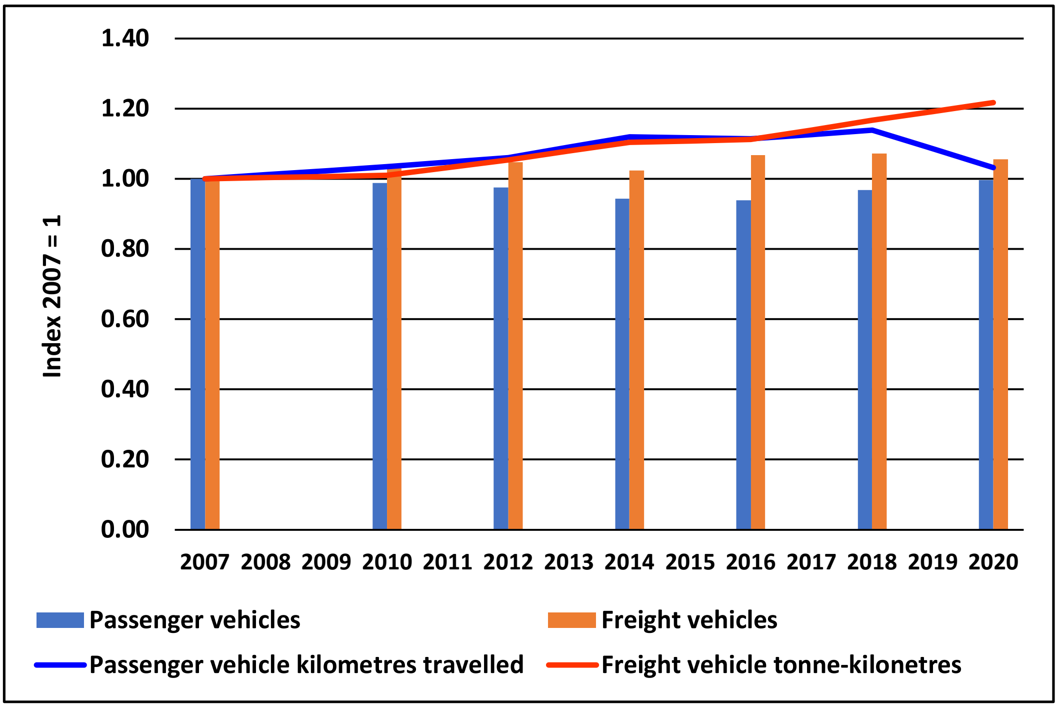
5.3.1 Final energy consumption: industry and households



5.3.2 Final energy use efficiency: industry and households



5.3.3 Final energy use efficiency, road transport



Commentary

It can be seen that the energy use efficiency of both industry, measured as gross value added per unit of energy consumed, and households, measured as the reciprocal of energy consumed per head of population, have been gradually increasing at about the same rate. It is notable that the rate of increase of industry energy use efficiency has decreased since 2014-15. More detailed analysis (Saddler, 2020) reveals that the main reason for this change has been the rapid growth of the very energy intensive LNG export industry. In other words, the change has mainly been caused by a change in the overall structure of the economy, not by a change in the rates of efficiency increase within individual economic sectors. That said, the detailed analysis shows that in some economic sectors, including some sectors of manufacturing and aviation, energy use productivity has increased.

Turning to residential energy consumption, it is certainly the case that many low income households use less energy than they would prefer, because they cannot afford to use more. If these households were not income constrained, total residential energy consumption would be higher. However, there is no clear evidence that the proportion of such households has increased in recent years. It is therefore reasonable to conclude that the observed reduction in consumption per capita is a real measure of increased energy use efficiency in the residential sector.

Finally, road transport is both one of the largest and the fast growing sources of fossil fuel energy combustion emissions in Australia. The graph shows why this is so. Both passenger and freight road transport activity, measured respectively as annual vehicle-kilometres travelled and annual tonne-kilometres transported, has been growing steadily. However, the energy intensity of road transport, i.e. fuel energy consumed per kilometre travelled or tonne-kilometre, has hardly changed.

Some caution should be applied in interpreting this graph. All the data are extracted from the ABS *Survey of Motor Vehicle Use*, which has been undertaken (at varying annual intervals) since 1976. The published Methodology document for the 2020 issue warns: "…….it should be noted the survey was designed to produce reliable estimates of key data items for a point in time, not for year-to-year changes. Estimates of movement over time are subject to high sampling error and care should be taken in drawing inferences from these comparisons." That said, estimates of CO_2 emissions, calculated from the ABS data, show an almost identical growth trend to the road transport emissions reported in the NGGI, though they are consistently around 4% lower than the NGGI estimates; some of this difference is explained by the fact that the NGGI data also include the not insignificant emissions of methane and nitrous oxide emanating from internal combustion engines. The trends in the efficiency graph are entirely consistent with observed trends in road transport since 2007, including the dip in passenger, but not freight transport, in 2019-20, caused by the pandemic lockdown and the consumer shift towards larger vehicles and diesel engines in the passenger vehicle fleet.

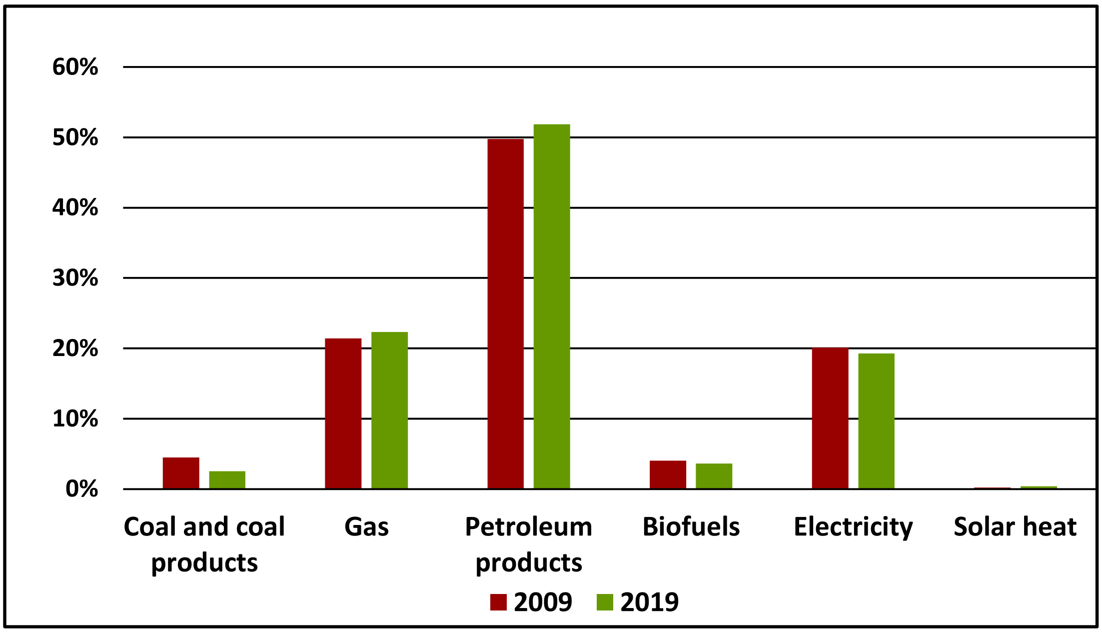
Finally, it should be noted that the ABS has announced the most recent (2020) edition of the *Survey of Motor Vehicle Use* will be the last. This paper has reported the very large and rapidly growing contribution of road transport to Australia's greenhouse gas emissions, caused in large part by its extremely poor productivity performance, and its almost complete reliance on petroleum fuels, which presents a major challenge to national energy security. It is therefore imperative that the *Survey of Motor Vehicle Use* is replaced by another statistical series, of similar scope and quality, in order to allow monitoring of Australia's progress towards a more efficient and lower emission transport system.

6 FUEL/TECHNOLOGY MIX OF ENERGY SERVICES

Overall objective: Increase the share of each energy service delivered by sources and processes other than fossil fuel combustion

Overview

6.0 Fuel shares in final energy consumption, 2009 and 2019



It is widely, if not universally agreed that decisive emissions reduction in the energy system will require widespread electrification of final energy consumption, meaning a shift away from direct consumption, by consumers, of petroleum products and gas and towards consumption of electricity. This imperative has been most recently and powerfully articulated by the IEA (2021). Electrification means in the immediate term replacing gas used to provide heat in buildings and manufacturing with electric technologies, such as heat pumps and induction heating, and replacing petrol and diesel in road transport with electric vehicles. In the longer term it means using hydrogen or zero emission synthetic fuels to replace gas and petroleum products in high temperature thermal manufacturing processes and heavy road vehicles and other types of mobile equipment.

Over the past ten years Australia's final energy consumption has, overall, de-electrified, moving slightly away from electricity and towards petroleum products and gas. The only positive change has been a lower share of coal and coal products, largely caused by reduced output from the steel industry.

6.1 Final energy consumption used for thermal processes, by fuel source

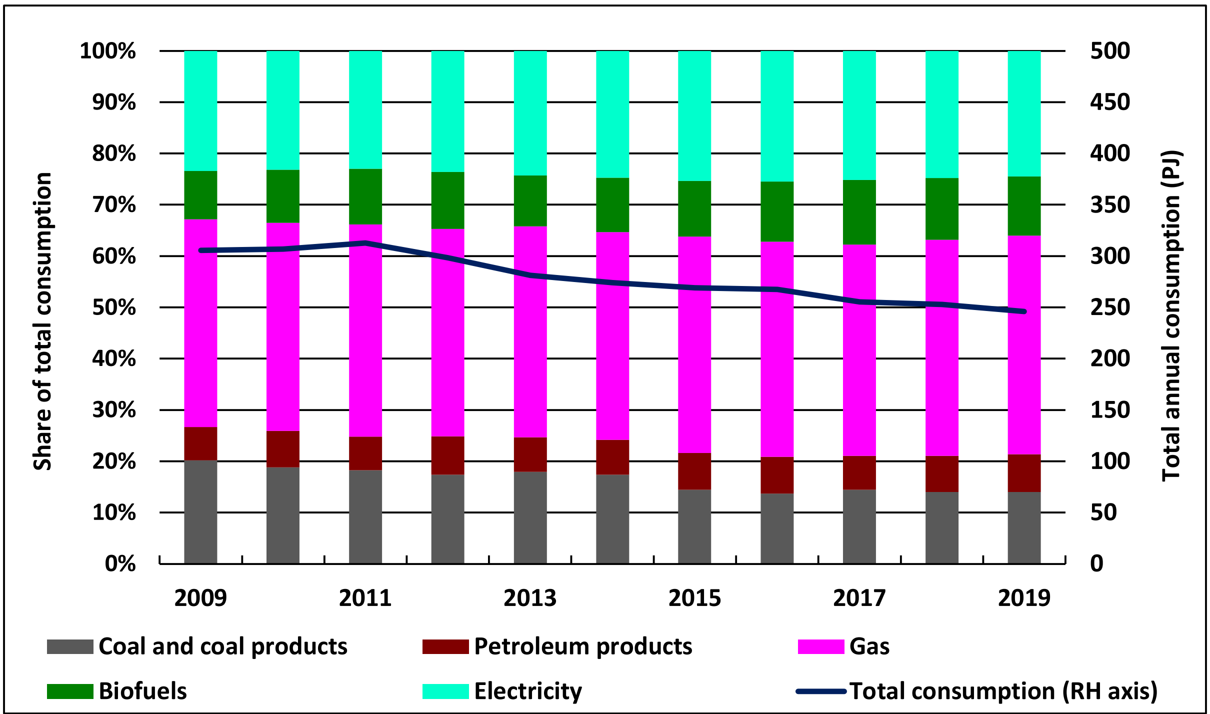
Sectoral objective: Reduce the share of energy for thermal processes sourced from direct combustion of fossil fuels.

As previously explained, two long established industries, sugar milling and pulp and paper, use large volumes of biomass waste materials as boiler fuels to produce process steam. In the residential sector, fuel wood has long been an important though steadily declining source of energy for space heating. However, there is no policy to encourage increased use of biomass fuels in other industries or sectors, and no prospect of it occurring in the absence of supportive policy. Indeed, a variety of environmental quality policies and regulations have the effect of constraining use of biomass fuels.

Consequently, as explained above, a shift in the final energy mix, away from gas and coal, and towards electricity, will be the key indicator of progress towards emissions reduction in thermal energy use. The main parts of economy in which thermal processes use large quantities of fossil fuels currently include many, though not all parts of manufacturing, the commercial and institutional sectors, and the residential sector.

6.1.1 Final energy supplied by fuel source in selected sectors of manufacturing

The manufacturing sectors included in this graph include food products, excluding sugar milling, textiles, clothing and footwear, wood products, pulp and paper, non-metallic mineral products (cement, ceramics, glass etc.), and all sectors of elaborately transformed manufacturing (fabricated metal products, machinery and equipment, furniture and all other manufacturing). In each of these sectors, electricity is used almost exclusively to provide motive power, while direct combustion of fuels is used in thermal processes, delivering heat energy either directly, or as steam. In the sectors of manufacturing which have been excluded (chemicals, primary metals), a large proportion of coal, petroleum products and gas consumption is in the form of petrochemical feedstocks or chemical reductants in metal smelting, while considerable quantities of electricity are used for electrolysis. Energy consumption statistics cannot therefore be used to estimate, even roughly, energy used in thermal processes.

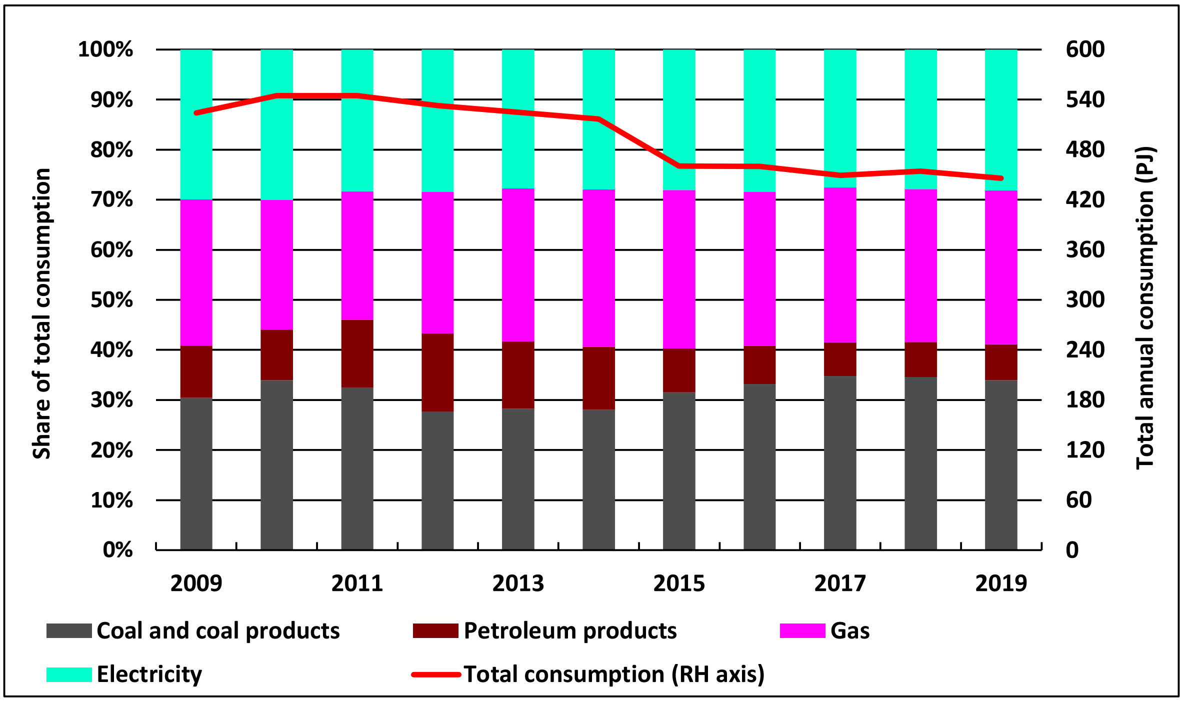


Commentary

The main trend in these parts of the economy is a gradual decline in the total volume of activity. There has been some displacement in coal consumption, mainly towards gas, which more detailed examination shows has been mainly confined to the cement and ceramics industries, where many older, smaller and less energy efficient coal fuelled kilns have been closed and partially replaced by larger, more energy efficient gas fuelled kilns. There is no obvious increase in the share of electricity consumption.

6.1.2 Final energy supplied by fuel source in the primary metals sector

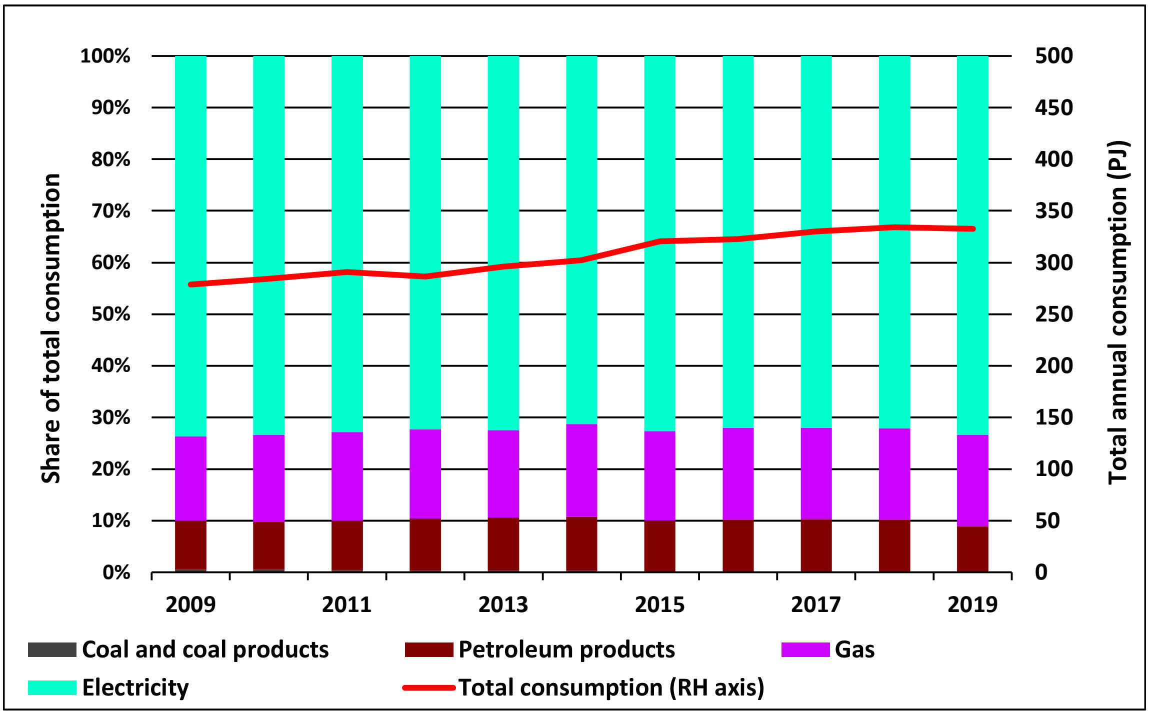
The primary metals sector includes the production of iron and steel and the production of a wide range of non-ferrous metals. In Australia, steel is produced from iron using the coke based blast furnace process at two integrated steelworks, and from scrap at several electric arc furnace mills. The more important non-ferrous metals include aluminium, copper, zinc, lead, silver, gold and nickel. Major production processes include digestion in steam heated aqueous solutions, high temperature thermal furnace processes and electrolysis. In total, the primary metals sector currently uses nearly 60% of total energy used in manufacturing in Australia, excluding the oil refining and chemicals sectors.



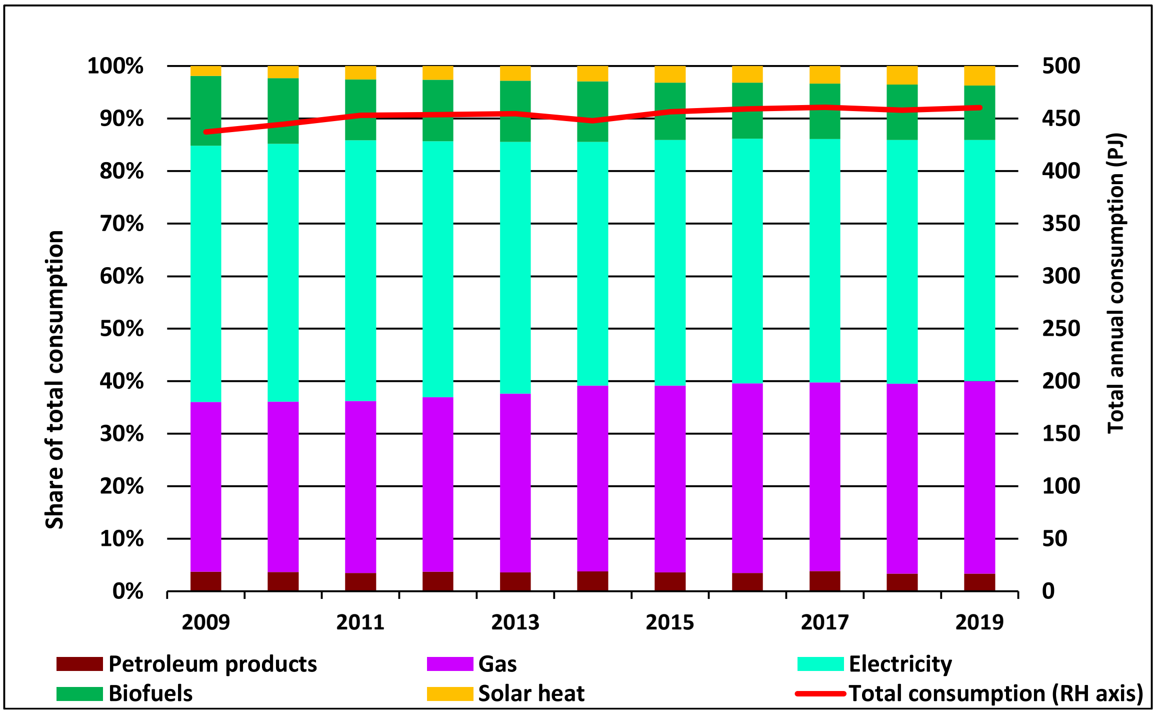
Commentary

Over the ten years covered by the graph, consumption of every fuel type has decreased, largely because of structural changes. Electricity consumption decreased following the closure of two of Australia's previously six aluminium smelters, in 2012 and 2014. Petroleum consumption decreased when the Gove Alumina plant was mothballed in 2014. Coal and coke consumption decreased when production was halved at Australia's largest integrated steelworks in late 2011. There have also been incremental changes in energy efficiency at many plants. However, the large size of individual plants means that any change in energy using technology is likely to involve investments of hundreds of millions of dollars. Unsurprisingly, given the importance of this sector for both Australia's energy consumption and emissions, not to mention its contribution to export income, many parties have been considering options for fundamentally new technologies, such as so-called green steel. So far, however, the only significant changes have been some power purchase agreements with wind and solar generators, which will reduce the overall emissions intensity of total electricity consumption at the relevant plants. One electrolytic zinc smelter, Sun Metals in Townsville, built and operates its own grid scale solar farm, adjacent to its refinery.

6.1.3 Final energy supplied by fuel source in the commercial and institutional sectors



6.1.4 Final energy supplied by fuel source in the residential sector



Commentary

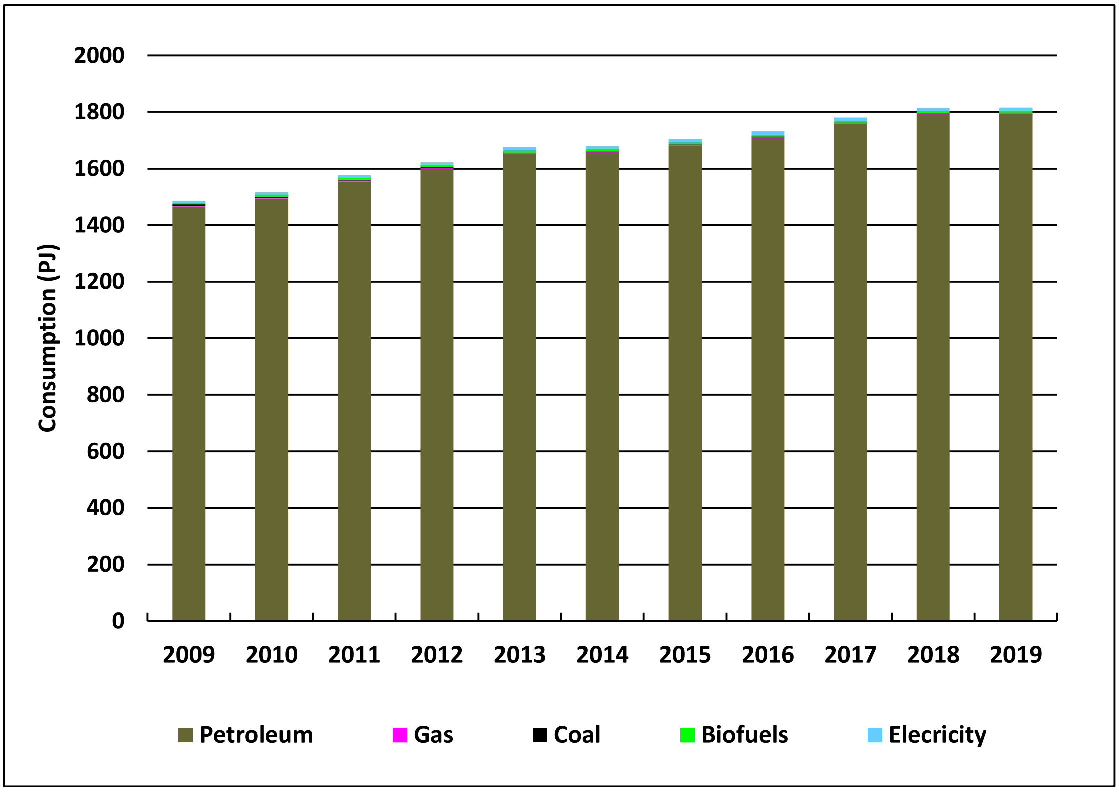
In both the commercial/institutional and the residential sectors, the main requirement for energy in the form of heat are space heating of buildings and water heating, both of which use heat at relatively low temperatures, well suited to heat pumps. Other data sources, less comprehensive but more detailed than *Australia Energy Statistics*, suggest that gas is the predominant fuel for space heating in the residential sector, while in the commercial/institutional sector reverse cycle air conditioning, powered by electric motors, is relatively more important. For many years, solar supplied thermal energy was almost the only option for low emission water heating, and it became quite popular in the residential sector. However, the emergence of low cost solar photovoltaics and low cost, high efficiency heat pumps in recent years has reduced the attractiveness of solar water heating in both technical and economic terms. In some circumstances, it is economically attractive for households with rooftop solar electricity to revert to using "old fashioned" electric resistance water heating as a sink for their surplus electricity generation.

Energy consumption data up to 2017-18 show no detectable fuel mix shift away from gas, towards electricity, in either the commercial/institutional or the residential sectors. On the contrary, the data show a clear shift towards gas in the residential sector up to about 2015-16, while in the commercial/institutional sector the fuel mix has remained very stable, despite the relatively rapid growth in total consumption. This growth undoubtedly reflects the ongoing structural change in the Australian economy, from manufacturing to services. As such, it is the obverse of the decline in total energy consumption by manufacturing, as seen in graph 6.1.1 above.

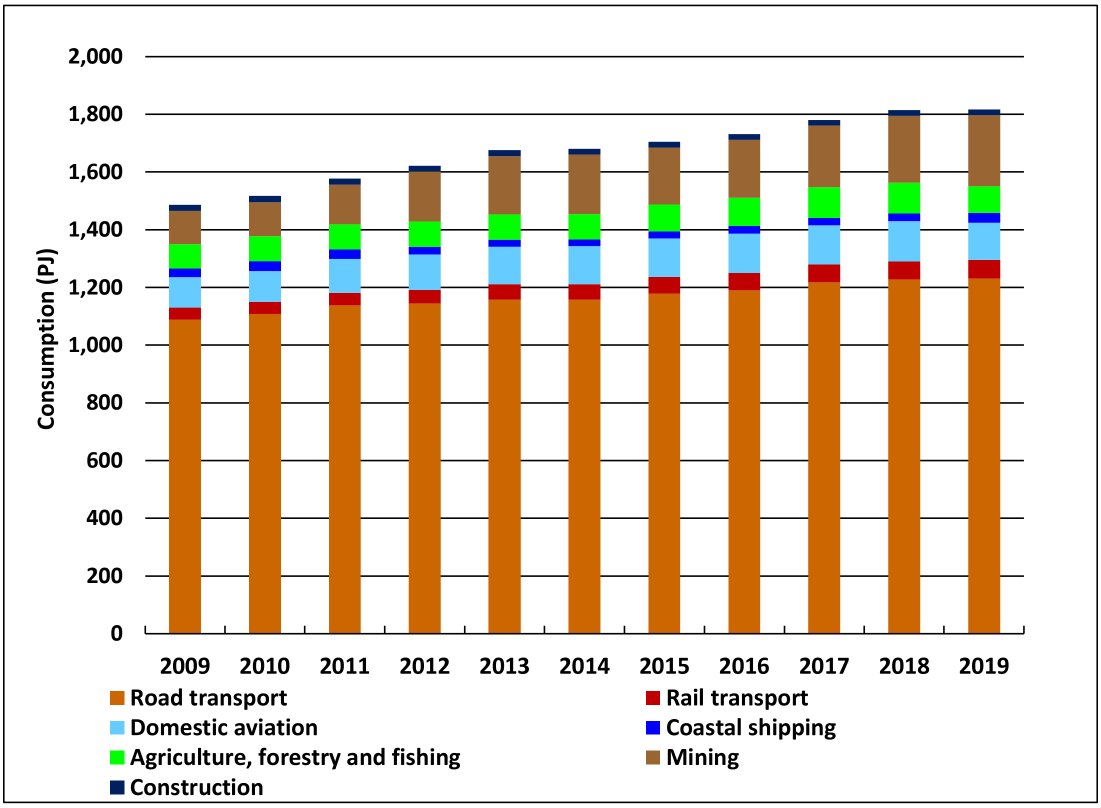
6.2 Final energy consumption used for transport, and by other types of mobile equipment, by sector and by fuel source

The data presented here have been extracted from *Australian Energy Statistics* on the basis of the definitions set out in the introduction to section 3.4. Mobile equipment includes road and rail transport, domestic aviation, and coastal shipping, plus diesel and auto gasoline used in agriculture, forestry and fishing, construction, and mining of coal and all other minerals except oil and gas. It does not include electricity and gas used to power pipeline transport of natural gas, water and other commodities. Nor does it include electricity and gas used in the agriculture and mining sectors, because these fuels are mainly used in stationary energy applications, such as intensive horticulture and animal rearing, coal washeries, and metal ore beneficiation.

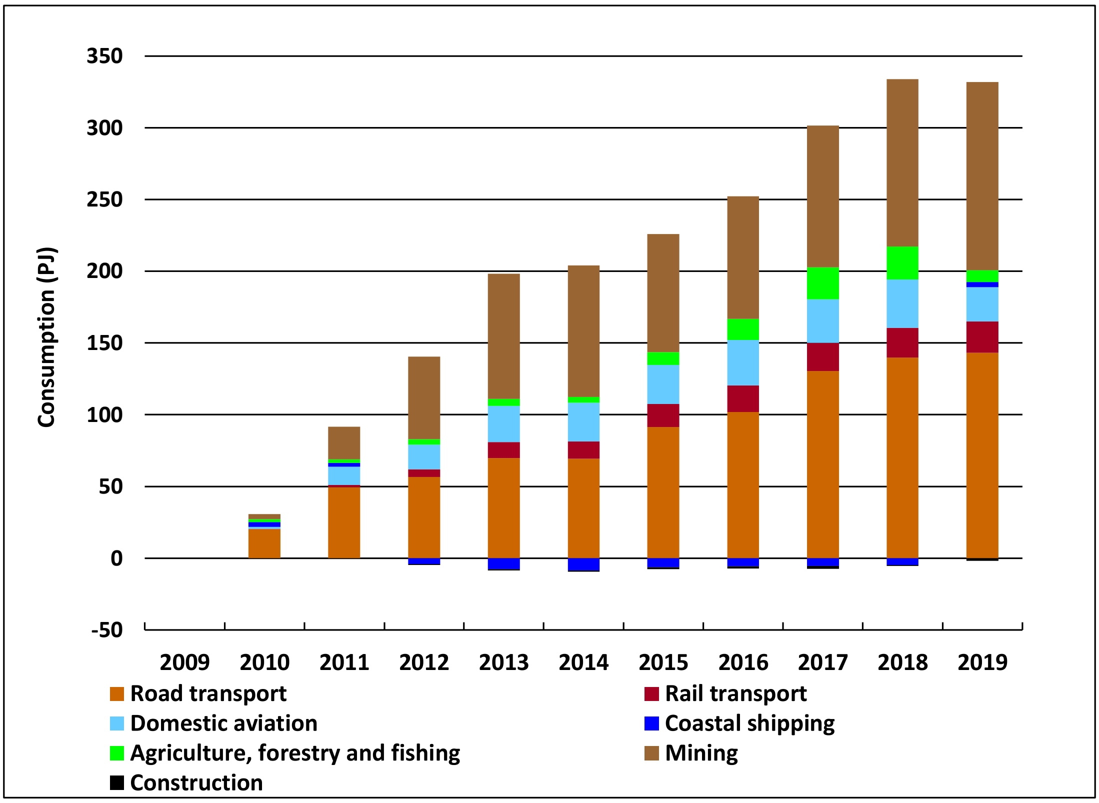
6.2.1 Final energy use, by fuel source, for transport and other mobile equipment



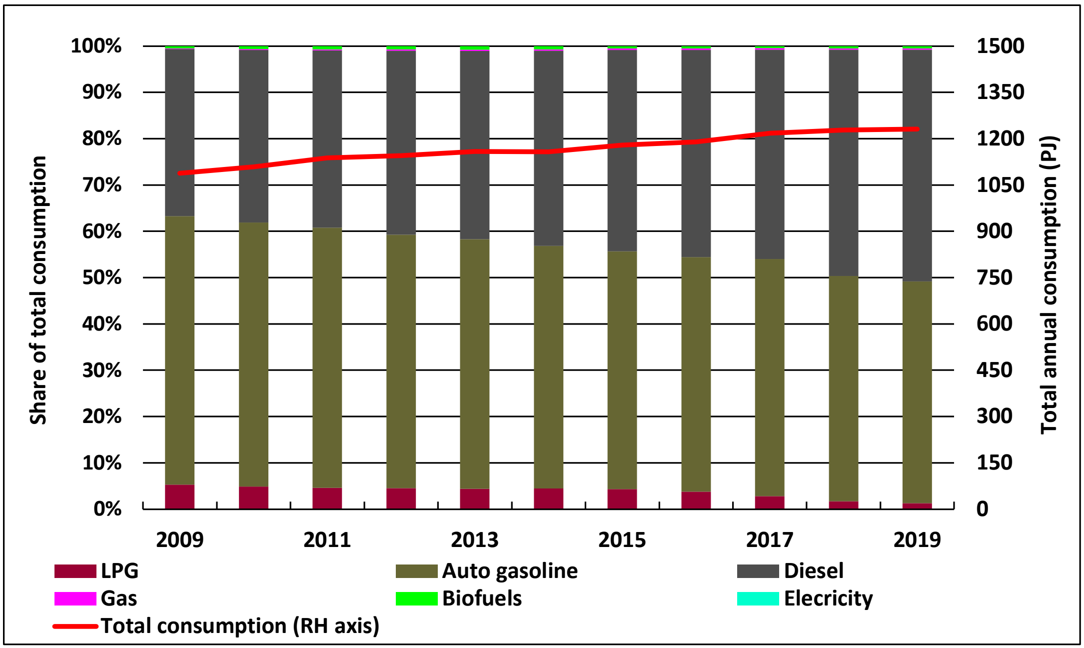
6.2.2 Final energy consumption by individual sectors of transport and other mobile equipment



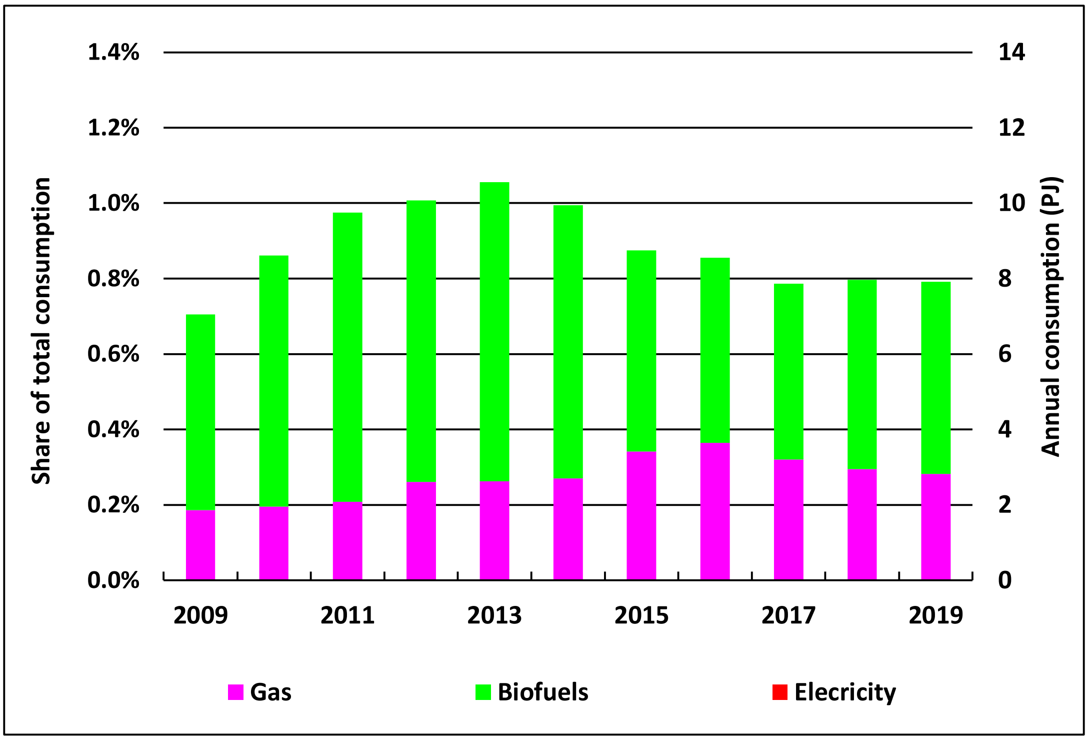
6.2.3 Changes since 2009 in final energy consumption by individual sectors of transport and other mobile equipment



6.2.4 Final energy supplied by fuel source in the road transport sector (all fuels)



6.2.5 Low and zero emission fuels in the road transport sector



Commentary

Graphs 6.2.1, 6.2.2 and 6.2.3 show that transport and mobile equipment is clearly both the fastest growing major component of Australia's final energy consumption, and also the component with the lowest shares of both renewable fuels and electricity use. Energy consumption has increased in every year, to reach its maximum level in 2019. The overwhelming majority of energy used (over 98% in every year) is sourced from petroleum products, mainly diesel, in all sectors, auto gasoline, in road transport, and jet fuel, in aviation. Most of the growth in energy consumption has come from two component sectors – road transport and mining. In addition, most of the growth in rail transport is linked to mining of coal, in New South Wales and Queensland, and iron ore, in Western Australia.

Clearly, no energy transition is occurring in the one third of final energy consumption and one third of energy combustion greenhouse gas emissions attributable to transport and other mobile equipment use. Emissions from this sector have been growing steadily – up from 27% in 2005 and 29% in 2009 of energy combustion emissions – while the other sources of energy combustion emissions examined in this paper have been declining. Graphs 6.2.5 and 6.2.5 show the negligible share of lower emissions energy sources being used in road transport. In 2019 electricity use was just 0.007% – far too small to be visible in either graph. Rail transport is the only sector where electricity contributes a significant share of energy used – just under a fifth in 2019 (though a larger fraction of motive energy supplied, because electric motors are very much more efficient than diesel engines). As previously explained, the extreme dependence of transport and mobile equipment on petroleum fuels has important energy supply security implications. In years past, oil supply security was a central concern of national energy policy; it has recently re-emerged as a rationale for extending large public operational subsidies to the two oil refineries which will remain operating after the end of 2022.

Before the emergence of electric vehicle technology, various policy incentives were introduced to support the uptake of ethanol blended auto gasoline for light road vehicles, natural gas for heavy road vehicles and biodiesel for both light and heavy vehicles. LPG was also sometimes promoted as a more environmentally friendly alternative, though its main attraction was always its lower cost. However, as graph 6.2.4 shows, the fuel mix has been moving away from all of these alternatives in recent years, and reverting to exclusive dependence on auto gasoline and diesel, albeit with a much higher share of diesel than in past years. This shift is one of the drivers of steadily growing road transport emissions.

It is now clear that electric vehicles will be the future of road transport – certainly for light vehicles and almost certainly for many heavy vehicles also. However, unlike many other countries, Australia has no worthwhile national policy and only fragmented state and territory level policies to stimulate uptake of electric vehicles. As noted above, electricity is estimated to have supplied only 0.007% of energy used for road transport in 2017-18. Other, incomplete data indicate that the share of electricity has increased since 2018, but is still extremely small. A clearer indicator of any transition towards electric vehicles would be numbers of registered vehicles. Unfortunately, however, only two of Australia's eight states and territories, New South Wales and Queensland, publish details of numbers of registered vehicles by vehicle type and fuel used. The table below shows the reported shares of electric vehicles in the population of relevant vehicle types (classified as light vehicles in New South Wales and cars in Queensland). It can be seen that growth has been very fast, but from an extremely low base, in both states.

NSW				
	Date	Dec-18	Dec-19	Dec-20
	Share of registered light vehicles	0.033%	0.063%	0.092%
Queensland				Jun-20
	Share of registered cars			0.060%

Data sources

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