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## Australia's Resource Use Trajectories

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### ABSTRACT

*Australia's export oriented large natural resources sectors of agriculture and mining, the ways in which large scale services such as nutrition, water, housing, transport and mobility, and energy are organized, as well as the consumption patterns of Australia's wealthy urban households, create a unique pattern of overall resource use in Australia. In an attempt to contribute to a new environmental information system compatible with economic accounts, we represent Australia's resource use by employing standard biophysical indicators for resource use developed within the OECD context. We are looking at the last three decades of resource use and the economic, social and environmental implications. We also discuss scenarios of future resource use patterns based on a stocks and flows model of the Australian economy. We argue that current extractive economic patterns have contributed to the recent economic boom in Australia but will eventually lead to negative social and environmental outcomes. While there is currently little evidence of political support for changing the economic focus on export-oriented agriculture and mining industries, there is significant potential for improvements in socio-technological systems, and room for more sustainable household consumption.*

Keywords: natural resources, resource use patterns and dynamics, physical accounting, resource productivity, social and environmental impacts of resource use, Australia

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## INTRODUCTION

Environmental reporting in Australia today tends to focus on the state of the environment, water quality, air and soils. In this paper we apply an approach for accounting for the use of natural resources in the Australian economy in an attempt to contribute to a top-down accounting system that is compatible with economic accounting and indicators. This shifts the focus away from the state and quality of natural resource assets, to economically-induced material and energy flows, and invites debate about the biophysical consequences of economic activities within an industrial metabolism concept (Ayres and Simonis, 1994).

Let us start with a simple comparison. In the year 2000, 50 thousand million tonnes of natural resources were used globally, or about 8.5 tonnes per capita (Schandl and Eisenmenger, 2006). OECD countries used about 20 thousand million tonnes or 17.5 tonnes per capita, i.e. twice as much as the global average and 40% of global natural resource use. In the same year, Australia's per capita material consumption, at 32 tonnes per capita, was twice as high as the OECD average.

In this article we analyze what is driving Australia's resource-intensive economy. We focus on three areas that influence overall resource use, namely export industries, infrastructure and the provision of large services such as food production and nutrition, construction and housing, and transport and mobility. We then ask whether the Australian resource boom can be sustained into the future, and if so, what might the social, economic and ecological consequences be.

This article starts by analyzing Australia's metabolic profile during the years 1970-2005. We report material and energy flows during this period. Then, we discuss the main environmental issues related to Australia's metabolic profile. Next, we look at economic and social issues. Then finally, we employ scenario analysis to

compare different resource use futures with regard to different assumptions on natural resource endowment. We summarize our findings in a concluding section.

## AUSTRALIA'S METABOLIC PROFILE

Resource use in Australia is different from other OECD countries, being dominated by two largely disconnected sectors, a large primary sector producing primary commodities for export, and an urban sector mainly based on tertiary economic activities and dominated by affluent urban consumers. While the primary sector is scattered across vast Australian landscapes, the urban population is concentrated along the east and southeast (Brisbane, Sydney, Melbourne and Adelaide) and southwest (Perth) coasts. Nine out of ten Australians live in large cities or in towns along the coastal fringe. About 60% of all people live in one of the five largest cities (ABS, 2006).

### *The Primary Sector*

Rural Australia is characterized by mining and agricultural activities. The mining sector, in the year 2004, contributed 6.0% of GDP and 1.1% of employment, about 103,000 jobs. Business profits and salaries in the mining sector are among the highest in the country, and 60% of export revenues come from primary commodities, a large part of these related to mining. Coal alone made up for 13.5% of export revenues in 2004, followed by iron ore, petroleum, natural gas, and gold and aluminum ores (ABS, 2006). During the past three and a half decades, mining activities have experienced a boom, tripling output from 278 million tonnes in 1970 to currently 965 million tonnes. The mining sites are often operated by large multinational companies such as Rio Tinto and BHP Billiton and depend on global capital and considerable foreign investment. As a consequence, many decisions are made outside Australia and not all revenues stay in the country. Despite these

international dependencies, the mining boom has created an economic up-swing in the Australian economy, creating a large number of secondary jobs delivering to the mining industry and providing high incomes to its workers. It remains to be seen whether the mining related boom will further overheat the Australian economy and contribute to rising inflation, low unemployment and rising interest rates. At the same time, Australia's mining production is bound by contracts to long-term delivery obligations. The major markets for Australian ore, coal, gas and oil exports include Japan, the Republic of Korea, China, India, the United Kingdom, Singapore and Taiwan. Japan was consistently the main destination for Australian minerals and oil, receiving about one fifth of total exports in 2004 (CSIRO, 2007).

Crop and livestock production are important economic activities in rural Australia. However, their contribution to overall GDP and employment are rather small. They were contributing 3.7% of GDP and 3.7% of employment, about 360,000 jobs, in 2004 (CSIRO, 2007). Australian agriculture, due to its extensive production systems, utilizes large amounts of natural resources by occupying 60% of total land area and consuming 70% of total stored water but more than 80% of all profits come from 10% of productive land (ABS, 2007). Because of Australia's highly variable climate, the production of crops and stock numbers fluctuate yearly, affected by events such as the 2002-03 drought. Until the late 1950s, agricultural products dominated exports by contributing 75-80% of export income (ABS, 2000). Although production has increased markedly since then, the relative importance of agriculture as a proportion of exports has declined, and is now around 8% of total export revenue (ABS, 2007). Considering total amounts, Australian agricultural products such as wheat, cotton, sugar, wool, beef and dairy as well as fruit, rice and flowers make an important contribution to the export sector. Despite the export orientation of

agriculture, there is obviously a closer connection between domestic urban consumers and agricultural activities, than is the case with mining products. Nevertheless, a large proportion of agricultural produce such as wheat and meat is delivered to the world market. The major destinations for Australian wheat include Indonesia, South Korea and Japan, as well as Iran, Egypt, and Iraq and to a lesser extent China and India (ABS, 2007).

While the manufacturing sector has declined in its contribution to GDP from around 20% to only 13% over the last three decades, the primary sector has consistently produced around 13% of overall GDP. Australia's economy is a rare case in the OECD, in that it has similar proportions of primary production and manufacturing activities in the GDP. This unusual situation has mainly been a result of Australian economic policy removing tariff protection for the manufacturing industry in the 1990s. In contrast, the mining sector, agriculture and forestry have received constant political support.

The scale of primary activities in Australia is reflected in the account of domestic extraction of materials, which at a per capita level is amongst the highest in the OECD countries.<sup>3</sup> As Figure 1 shows, Australia currently extracts around 60 tonnes of materials per capita – 4 times higher than the OECD average of around 17.5 tonnes per capita. The main contributors to overall materials extraction in Australia are the agriculture and livestock sector, responsible for about 12 tonnes per capita; construction activities contributing another 10 tonnes per capita; and mining of metal ores and coal each contributing above 15 tonnes per capita. However, Australia is not alone. Several other OECD countries, among them Canada, the US,

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<sup>3</sup> The accounting for Australia's resource use is based on standard material flow accounting methodology (see EUROSTAT, 2001). We use three main headline indicators, namely domestic material extraction (DE), physical trade balance (PTB) and domestic material consumption (DMC) and material breakdowns for those indicators.

and New Zealand, have high per capita extraction levels as well and thus these countries represent a similar metabolic profile (for more details see Krausmann et al. *Journal of Industrial Ecology* 12(5)).

*FIGURE 1 ABOUT HERE*

A large proportion of the extractive economic activities are export driven, and motivated by Australia's role in the world economy as a net exporter of materials. Figure 2 shows a physical trade balance for Australia. In 1970, only around 5 tonnes of materials per capita were exported, predominantly metal ores, coal and cereals. During the last three decades, net exports have grown about five-fold, driven by a boom in coal and in ore exports. The only net import during the last three decades has been crude oil but amounts were relatively small. The Australian physical trade pattern is outstandingly different because most OECD countries are net importers of materials and rely on resources from outside their local territory.

*FIGURE 2 ABOUT HERE*

The Australian trade pattern is characterized by primary commodities dominating exports, while final commodities play a dominant role in imports. In the year 2004, 60% of export incomes were derived from primary commodities, mostly coal, petroleum, natural gas, iron ore, aluminum, gold, bovine meat, and wheat. These 8 commodities alone accounted for 44.7% of export revenues. Only 16% of import expenditure related to primary commodities, mainly mineral fuels (2006). As a result, the unit value of imports to Australia in 2004 was \$2.44 per kg of material while the unit value of exports was as low as \$0.23 per kg. In other words, Australia buys high value finished products from the world market but mainly sells its primary



resources, with hardly any added value, at a relatively low price.<sup>4</sup> While the exploitation of Australia's vast resource endowment is boosting the economy today, it is important to explore whether such a difference in the balance of trade, in terms of unit value of traded goods, can be maintained in the long run.

Due largely to Australia's role as a resource provider, and the subsequent waste and emissions that occur at the extraction stage, domestic material consumption is twice as high as the OECD average. The primary activities that dominate domestic extraction are often waste- and emission-intensive processes, as reflected in the indicator domestic material consumption (DMC) that captures both intermediary and final uses of materials. Interpreted as domestic waste potential (Weisz et al., 2006), a high DMC also indicates higher pressure on the absorptive capacity of ecosystems in Australia. To give an example, most of the ores extracted have a low extraction ore grade causing considerable waste and emissions in the concentrating and smelting process. Since Australia exports metals and not ores these wastes and emissions remain within the Australian domestic environment. A similar effect can be observed with regard to exported livestock products, where the large amount of animal feed is part of domestic extraction, and related wastes and emissions again remain within Australia whereas the refined products – bovine meat and dairy products – are exported.

On the other hand, as Figure 3 shows, domestic material consumption has been stable at around 35 tonnes per capita for at least 30 years. This appears to be a cumulative effect of an increasing material standard of living, increased mining and agricultural activities, offset by a sharp decrease in the manufacturing sector.

*FIGURE 3 ABOUT HERE*

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<sup>4</sup> A similar pattern was found by Eisenmenger et al. (2007) for developing countries in Latin America.

In Figure 4 we compare the three main indicators, namely domestic extraction (DE), physical trade balance (PTB) and domestic material consumption (DMC)<sup>5</sup>, for the year 2000 for Australia, the US and the OECD average, and we find very different patterns. Australia had a per capita domestic materials extraction more than twice as high as the US and three times the OECD average. This is mainly due to extraordinarily high per capita figures for coal, ores and fodder crops as is shown in Table 1. Australia also consumes large quantities of construction minerals, but similar per-capita amounts can be found for the US. The OECD as a whole and also the US were net importers of materials; Australia was a large net exporter; again mainly attributable to coal and ores. The main difference between Australia and the US is that the US organizes most of the material intensive processes within its own territory and is therefore less dependent on trade than Australia. This plays out in different levels of domestic materials consumption of around 32 tonnes per capita in Australia as compared with 25 tonnes per capita for the US and 17 tonnes per capita in the OECD as a whole. In Australia's domestic material consumption figures, construction materials, fodder crops and coal stand out as being related to infrastructure requirements in a very sparsely populated country, to large scale livestock raising activities, and to coal used as the main source of primary energy.

*FIGURE 4 ABOUT HERE*

*TABLE 1 ABOUT HERE*

A standard way of comparing economic performance uses the concept of productivity as an indicator of international competitiveness. We compare resource productivity, based on output of international dollars per kilogram of resources used in economic activities since the 1980s. As shown in Figure 5, OECD countries on

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<sup>15</sup> For a definition of all indicators used in this study see (EUROSTAT 2001).

average, and particularly the US and Japan, have consistently improved their resource productivity over the last two decades. On average, OECD countries produce one dollar of added value for every kilogram of resource used. Australia, by comparison, does not even achieve half of the resource productivity of average OECD countries and is even further behind when compared to Japan and the US. This seems to be the common fate of extractive economies that most of the wealth created on the basis of resource use occurs elsewhere, outside their economies.

*FIGURE 5 ABOUT HERE*

*Supply Systems in Urban Environments*

Primary resource export industries are only one factor when trying to explain Australia's resource use dynamics. A second important factor is the way in which large supply systems including water, energy, mobility and transport, housing and nutrition are organized in Australia. These supply systems are based on a socio-technological solution bringing together a specific institutional and management system, a large infrastructure and a bulk resource flow (Geels, 2004). Once these systems are in place, it is hard to quickly change them because they are bound to longer investment cycles of about one generation.

The provision of energy in Australia is dominated by the abundance of coal and other fossil energy carriers. According to the International Energy Agency, Australia used 4,847 PJ of primary energy in the year 2004 (IEA, 2006), equal to 241 GJ per capita. Energy use was significantly above the OECD average of around 200 GJ per capita but well below the US level of 330 GJ per capita (Haberl et al., 2006). While energy use and GDP grew at similar rates between 1960 and 1985 there has been a decoupling between economic growth and energy use, as energy efficiency has increased. There are two main reasons for this decline in the energy intensity of

the Australian economy. Firstly, greater efficiency has been achieved through technological improvements and fuel switching, and secondly, the rapid growth in less energy-intensive service sector activities, that were offsetting energy use in the manufacturing, mining and agriculture industries. The main share of final energy – about three-quarters – was consumed by three major energy-consuming sectors, namely electricity generation, transport and manufacturing. Mining, residential, commercial and service sectors account for most of the remainder (ABARE, 2007).

As Table 2 shows, Australia has a remarkably high share of coal in its primary energy supply, twice as much as the OECD average. This is mainly explained by the use of coal as the main fuel for electricity generation. In the year 2001-02, coal accounted for 83% of the energy input into electricity production (ABS, 2002). The high amount of per capita energy use and primary energy composition in Australia resulted in the second largest per capita CO<sub>2</sub> emissions of 17.5 tonnes per capita in the year 2004, only surpassed by the US with per capita CO<sub>2</sub> emissions of 19.7 tonnes and slightly ahead of Canada (17.2 tonnes per capita). In terms of per capita CO<sub>2</sub> emissions from fossil fuel burning, these three countries are very distinct from other nations. Some of the energy pathways in Australia are very inefficient, for example, electricity production from brown coal used for aluminum smelting and space heating.

*TABLE 2 ABOUT HERE*

Resource use related to transport and mobility is dependent on the geographical make-up of a country. Australia's low average population density and the necessity to link people up over large distances and also in remote places creates a situation of high per-capita resource use for the mobility of people and the transport of commodities. At the same time, urban Australian's live in places of

higher density which should allow for a more sustainable organization of transport systems. The potential for such systems is complicated by the nature of Australian cities and their historical as well as current design (Taylor and Newton, 1985). Cities have been designed for private car use, with residential areas, shopping malls, recreation areas and commercial and business areas usually separated, and distances between them often considerable. The distances between certain urban functions and infrastructure, and a lack of public transport options, results in extensive use of private cars for commuting to work and for personal and recreational activities. As a result, energy use in the transport sector is mainly caused by road travel, accounting for around 80% of energy use. A further 15% of transport energy is consumed by air travel between the major urban centers (ABARE, 2007).

Another feature of Australian cities is poor housing infrastructure, not making use of the opportunities offered by the local climate and the latest technical standards of energy saving features. Many houses are badly insulated, the heating and cooling systems often not at the latest technical standard, and the use of solar energy and passive solar heat not common at all. Since land and housing prices have escalated during the last decade (TAFTF, 2007), households are often not in a position to invest in retrofitting their houses on top of already high mortgages that have to be repaid.

Another fundamental supply system closely linked to how land is used is the nutrition sector. In terms of what people eat, meat plays an important role in Australia's daily diet. Because a meat-based diet needs eight times as much area for agricultural production in comparison with a vegetarian diet (Foran et al., 2005),

pressure on local land use systems and the availability of water is a consequence of current dietary patterns.

In summary, the high per capita use of materials in Australia is a consequence of the export orientation of the country and of the way basic supply systems currently operate. While a more cautious use of primary resources for exports is not a favored political objective, the organization of bulk material flows related to large supply systems might be improved considerably if incentives and enabling conditions, as well as public investment, were to be directed differently.

#### *Patterns of Household Consumption*

What contributes further to the already material-intensive economy in Australia are the consumption patterns of wealthy urban dwellers, who gain their income from service sector activities but have a materialist approach in their daily lives (Hamilton and Denniss, 2005). The impact of high consumption on domestic resource use is, however, less than it could be, because most of the household appliances, durables and consumer goods bought in Australia are produced somewhere else, predominantly in China, because Australia's industries have been shrinking for three decades. By importing finished goods, the environmental burden related to the production processes is carried by the countries of origin, and resources are not used in Australia, nor do the waste and emissions of the production process occur in Australia.

#### *Summary*

The nature of Australia's resource intensive economy is linked to the experience of the vast Australian landscapes, the abundant stocks of natural capital and the comparatively low average population density. For many Australians, the country is still perceived as a place of natural cornucopia, despite high resource use levels.

The only exception is water, where resource shortages have become part of the daily experience of Australia's people. Australia is the driest inhabited continent, and climate and rainfall are extremely variable (2007). During the last ten years, Australia has experienced a situation of consistent drought, making water availability and security worse. Climate change and rainfall projections also point to a further worsening of these issues of water availability in Australia (CSIRO, 2007).

#### ENVIRONMENTAL ISSUES RELATED TO AUSTRALIA'S METABOLIC PROFILE

The Australian economy is characterized above as based to a large extent on resource intensive primary economic activities, subsequently reflected in material and energy flow indicators. Such an economic orientation has certain environmental costs, including the fast depletion of natural capital stock, increasing inputs of energy and water as well as other inputs for extraction, and the release of emissions and waste, in the case of non-renewable resources. For renewables, similar issues of stock depletion, such as in forestry and fisheries, as well as ecosystems degradation due to the intensity of use, occur.

The rate of extraction of natural capital including fossil fuels, metals and minerals in Australia might not be seen as an immediate problem since natural resources are still abundant. Table 3 shows that for bauxite, copper ore, and iron ore, despite their current high rate of extraction, production could go on for about 50-100 years at current levels of production of the economically-demonstrated resources. Similarly, black and brown coal reserves seem to have no current identified limits in their availability. For some metals and minerals, including diamonds, gold, silver, lead and zinc the natural stocks of economically-demonstrated resources are much closer to being exhausted but at the same time, investments for new explorations are high and the likelihood of finding new deposits

is considerable. The base metal mining industry appears to be well positioned for the future (Mudd, 2007a).

*TABLE 3 ABOUT HERE*

Mining industries create an economic advantage today but could be disadvantageous in the long run, because Australia's natural capital is being sold out quickly at a comparatively low price. A related issue is the magnitude of environmental impacts related to resource extraction in agriculture, forestry, fishing, mining and quarrying.

Agriculture has led to major environmental impacts in Australia from clearing of native vegetation, diversion of water for irrigation and the application of fertilizers, herbicides and pesticides. Over half of all agricultural land in Australia is affected by some form of land degradation (Conacher and Conacher, 2001). Major forms of land degradation relating to agricultural land use include soil erosion from wind, salinity from rising water tables, loss of biodiversity and dieback of native vegetation, and increases in animal pests and weeds (McTainish and Broughton, 1993; Dargavel, 1995; Mott and Tothill, 1994; Heatwole and Lowman, 1986).

For example, salinity is a major problem affecting both irrigated and non-irrigated (dry land) systems, and it has been the focus of a \$1.4 billion public investment in land remediation in the form of the National Action Plan for Salinity and Water Quality (COAG, 2000). Approximately two million hectares of broad acre farm land are affected by dry land salinity already, and six million hectares are estimated to be at risk from this threat (NLWRA, 2001a; ABS, 2002; Pannell and Ewing, 2006). It has been forecast that up to 17 million hectares of agricultural land are at risk of being salt affected by 2050 if no remedial action is taken (NLWRA, 2001a).



Agriculture has negative environmental impacts on water resources in terms of both water quality and quantity (Williams, 1999; Peck and Hatton, 2003). Water use for agriculture reduces the water available for environmental flows in rivers, which in turn causes damage to ecological habitat and biodiversity (TWG, 2002, 2003). Approximately a quarter of Australia's 325 identified surface water management areas are either over-used for agriculture or vulnerable to over-use. Furthermore, around a third of Australia's river basins are affected by problems with turbidity, nutrient or salinity levels (NLWRA, 2001b).

In contrast with agriculture, the environmental impacts of forestry have been dramatically reduced over recent decades in Australia due to conservation policies and declaration of world heritage listings for key forest areas, both for ecological and cultural reasons (Dargavel, 1995). However, Australia's fisheries continue to experience significant environmental impacts both in terms of effects on fish stocks themselves and also on the surrounding marine environment. Of 97 Australian fisheries assessed in 2006, 19 were classified as over-fished or subject to over-fishing and 51 were classified as uncertain, with only 27 classified as not over-fished (Larcombe and McLoughlin, 2007). Meanwhile, the impacts of trawling and dredging affect non-target species and damage the sea floor (Kaiser et al., 2002). In an international comparison of fishing impacts on the ocean floor, the largest negative impacts were found to be in Eastern Australia, followed by Northern Europe and North America (Collie et al., 2000).

Australia faces severe environmental impacts from mining due to the demand for deeper exploration, the milling of different ore types, solid waste management (tailings and waste rock), declining ore grades and energy, water and reagent consumption in mining as well as pollutant emissions. Solid waste burden will

continue to increase especially as open cut mining continues to expand. The resource intensity of metal production appears to follow inverse-exponential relationships: as ore grade declines the unit consumption or unit CO<sub>2</sub> emissions rate goes up (Mudd, 2007b).

## ECONOMIC AND SOCIAL ISSUES RELATED TO AUSTRALIA'S METABOLIC PROFILE

Australia's resource intensive pathway, in combination with the urbanized nature of its population, has an impact on the economic structure, the composition of the labor force, the education system and the ways in which people live their lives.

Australia's economy in 2004 was dominated by service sector activities, such as trade and transport, which contributed three quarters of GDP. During the last three decades the share of GDP from manufacturing has decreased from 20.9% in 1975 to 12.9% in 2005. Agriculture showed a decline from 4.6% to 3.6%, and mining went up from 5.4% to 6.2% (ABS 2006). Today, manufacturing is in the same range as primary industries (agriculture, forestry and mining) with regard to the revenue produced. Manufacturing has been considered to be unprofitable in Australia for quite some time, because of comparatively high labor costs that can't compete with Asian neighbors, and because the domestic market is too small to support local production industries. The decrease in employment in manufacturing is mirrored in the availability of vocational skills, which tend to be in short supply.

The mining boom, especially, is having severe social consequences in rural Australia. Mining activities directly compete for labor and skills in marginal areas where local businesses and agriculture cannot match the income level offered by mining companies. This results in a considerable outflow of labor from those

businesses into mining, leaving other businesses short of workers. Local rural communities are often ill-prepared to deal with the challenges going hand-in-hand with mining operations, resulting in shortages of both soft and hard infrastructure, when suddenly the local population increases. Additional social problems are introduced into communities by the inflow of well-paid male laborers who don't find appropriate facilities for spending their leisure time (Ivanova, Rolfe, and Lockie, 2005).

As a result of the mining boom, property prices and rental prices have increased in many local towns leading to a displacement of resident families because of a lack of affordable housing. Rural communities are concerned about skill shortages and the loss of their social identity and rural lifestyle, because of the speed of change. The situation is worsened by the fact that mining in a specific place is often an ephemeral phenomenon and governments are hesitant to put in infrastructure which might not be needed in the long run. A boom is often followed by a crash and communities quickly lose population once mining sites have been abandoned.

## POSSIBLE RESOURCE FUTURES IN AUSTRALIA

So far, we have analyzed the recent past and the current state of resource use in Australia. But what are the implications for possible resource futures? To inform our understanding of possible future pathways we employ a quantified scenario analysis based on the Australian Stock and Flows Framework (ASFF). ASFF is a highly disaggregated simulation framework that keeps track of all physically significant stocks and flows in the Australian socio-economic system. Stocks, in this framework include people, livestock, infrastructure, buildings, capital goods, and durable goods disaggregated according to their physical characteristics, age or vintage. We are

dealing with a national data set based on census data, resource use data and a simulation model consisting of 32 hierarchically connected modules (calculators) for physical processes related to demography, consumption, buildings, transport, construction, manufacturing, energy supply, agriculture, forestry, fishing, mining, land, water, air and international trade. The calculators are based on available scientific and technical understanding. The framework includes an input-output model for the transformation of raw materials into basic industrial commodities, such as steel, cement and electricity (see Gault et al., 1987; Foran and Poldy, 2004; Lennox et al., 2004).

We model three scenarios based on an historical upward trend with declining growth and three resource constraints. For mineral resources, a distinction is usually made between demonstrated and inferred resources, to identify the natural resource stock that might be available in the long run. For demonstrated resources it is important to know whether they are economic or sub-economic, based on the available technologies and resource prices. Such an assessment has been made for the major mineral and fossil resources of Australia for the year 2003 (Geoscience Australia, 2004). For some of the important export commodities including copper, gold, iron ore, lead, silver and zinc, today's economic resource stocks might be depleted within 25 to 50 years, assuming a yearly production at 2003 levels (see Table 3). Reserves of bauxite and coal seem to be available for many decades at current production rates.

For the three scenarios we assume different levels of mineral resource availability based on current levels of demonstrated resources (economic and sub-economic), and inferred resources. For agriculture, we assume moderate growth rates in production of crops and livestock, without taking into account production

limits imposed by the availability of land and water, and we ignore impacts of climate change on crop and animal production systems. The three scenarios show different possible pathways for the Australian primary sector and how they are conducted through the whole economy in physical terms.

As Figure 6 shows, primary materials extraction could grow further and even double within the next three decades without experiencing any resource limits. Only around 2035 do the scenarios diverge with regard to assumptions made about the amount of resources that would be economically viable and technologically feasible to extract, assuming today's technologies and price levels. The most aggressive scenario only shows a change in trend around 2050 when Australia's mining sector activities would be 2.5 times larger than today in terms of extracted materials. Eventually, the extraction would have to decrease but would only come down to today's levels in the lower scenarios.

*FIGURE 6 ABOUT HERE*

Figure 7 shows that the physical trade balance diverges around 10 years earlier with respect to the different scenario assumptions since increasing imports counterbalance growing exports in the less resource intensive scenarios. Assuming the lowest resource availability scenario, some resources have to be provided by imports since domestic supply is insufficient because of natural stock depletion. The highest scenario only shows a change in trend in around 60 years time, when Australia's physical trade would have reached around 30 tonnes of net exports per capita, twice as high as today.

*FIGURE 7 ABOUT HERE*

The modeling trends for domestic extraction and physical trade result in an increase in domestic material consumption in all three scenarios until about 2030, with related pressures on the domestic environment in terms of waste and emissions. Subsequently, domestic material consumption could drop to current levels by around 2070 if investment in explorations and related new resource demonstration was not pursued (see Figure 8).

*FIGURE 8 ABOUT HERE*

The modeling results suggest that Australia could continue its resource intensive path and could double its mineral extraction until around 2030, assuming that water availability, energy supply, or stricter international greenhouse emission standards do not curtail this activity earlier. Expanding the current resource boom into the future would accord with current political goals and long-term commitments with international trade partners and also would be in the economic interest of multinational mining companies. At the same time, due to the very specific structure of the Australian economy combining extractive activities with a large urban, service sector-oriented segment, this could result in short-term economic benefits as has already been the case during the last two decades.

However, there might be certain disadvantages in pursuing the resource intensive path, including insufficient infrastructure development, skill and labour shortages, a lock-in in terms of technology decisions and severe environmental and potential social consequences. The current mining boom also adds to the inflationary pressure in Australia (Economist, 2008). It has to be asked whether Australia's economy and society would be better off in the long term, if they tried to achieve longer value chains and reduced their dependency on extractive industries. A shift in economic orientation, however, will become more difficult in the future,

since pressure on resources is most likely to increase in the future, and resource rich countries will find even greater incentives to provide these highly demanded resources (Krausmann et al., 2008).

The current economic pathway being followed in Australia will have impacts in the larger global policy context of international political processes dealing with climate change and its potential mitigation. Despite the fact that the public's concern about climate change probably contributed to the change in Federal government in Australia in November 2007, and that the new Labor government signed the Kyoto protocol as one of its first actions in office, Australia seems likely to remain tied to extractive industries and materialist lifestyles making effective GHG control more difficult.

## CONCLUSIONS

This paper aimed to contribute to a paradigmatic shift in Australia's environmental reporting. Standard information and indicators for material flows and resource productivity are proposed in order to increase policy attention on natural resource use reporting. Australia's economy is demonstrated to be very different from OECD economies as a whole with regard to its resource use pattern. Australia's per capita resource use is three times higher while its resource productivity is less than half the OECD average. Essentially, there are three drivers of high resource intensity in Australia. The first is the primary resource export industry; the second is the inefficient way that large supply systems for water, energy, mobility and transport, housing and nutrition are organized, and the third is the material standard of living and related consumption patterns of Australia's wealthy urban consumers. Additionally, Australia's vast area and low population density, and abundant resources further support high resource intensity.

The three areas described as influential for resource use patterns in Australia require different policy attention and responses. Extraction activities prompt us to consider whether such a resource intensive path is favorable to a country, both in economic as well as in social and environmental terms. If they are to be pursued into the future, there is potential for technology improvements and efficiency gains as well as good management of resources and landscapes.

Infrastructure and larger socio-technological systems are often closely linked to government investments and require specific attention because they create lock-ins for about 30 years until an investment such as, for example, a particular electricity-generating technology has been amortized. We have shown that this is an area where Australia has great potential to improve its resource use performance.

Finally, consumption of individual households is linked to lifestyle decisions, the way in which households identify meaningful ways of living and how this translates into consumption habits. There might be considerable room for improvements in consumption-related resource use within the paradigm of sustainable consumption.

The unique combination of extractive and service sector activities created an economic boom in Australia with high incomes, low unemployment but also rapidly rising land and house prices and considerable inflation with related high interest rates. Primary industries create considerable environmental impacts such as stress on water supply, soil salinity and land degradation in agriculture and landscape change, toxic waste and emissions as well as natural resource depletion in the mining sector. The social impacts of the mining boom were found to be considerable as well, because of fast population growth in rural areas, lack of infrastructure and



affordable housing, leading to loss of cultural identity, social cohesion and replacement of rural residents, to name a few examples.

High resource intensity results in large amounts of waste and high emission levels. Due to the carbon intensive pattern of the Australian production and consumption system Australia is a large contributor to global CO<sub>2</sub> emissions creating a difficult international position when involved in climate change mitigation negotiations. While there is little evidence of political change with regard to the economic role of primary resource sectors, systems innovation of large socio-technical systems and sustainable household consumption have a great potential to contribute to more sustainable resource use in the future.

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Figure 1. Domestic extraction of natural resources in Australia, 1970-2005, tonnes per capita

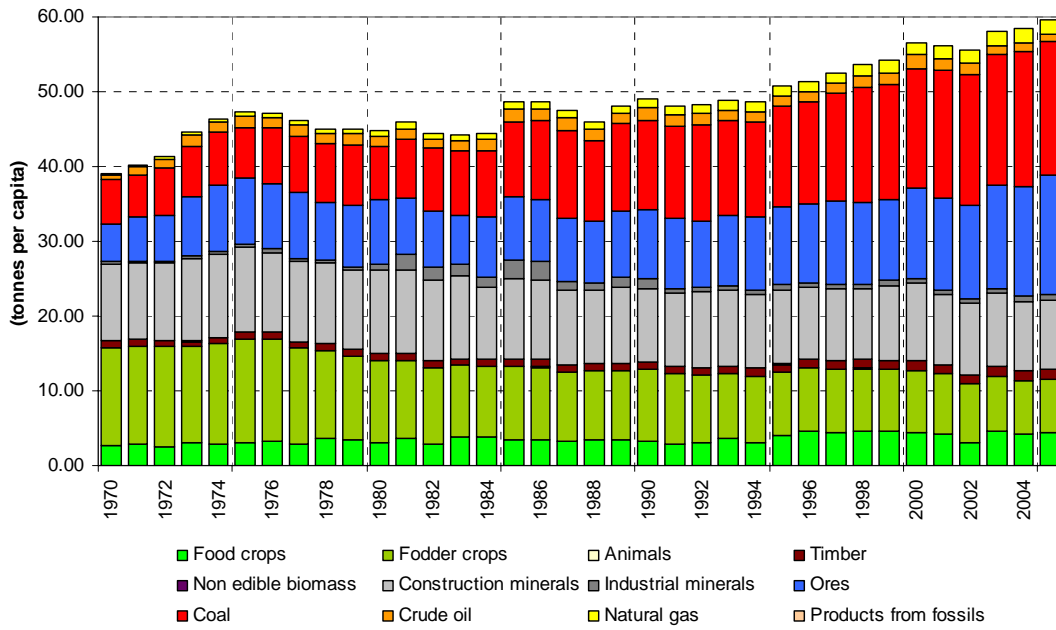


Figure 2. Australia's physical trade balance, 1970-2005, tonnes per capita

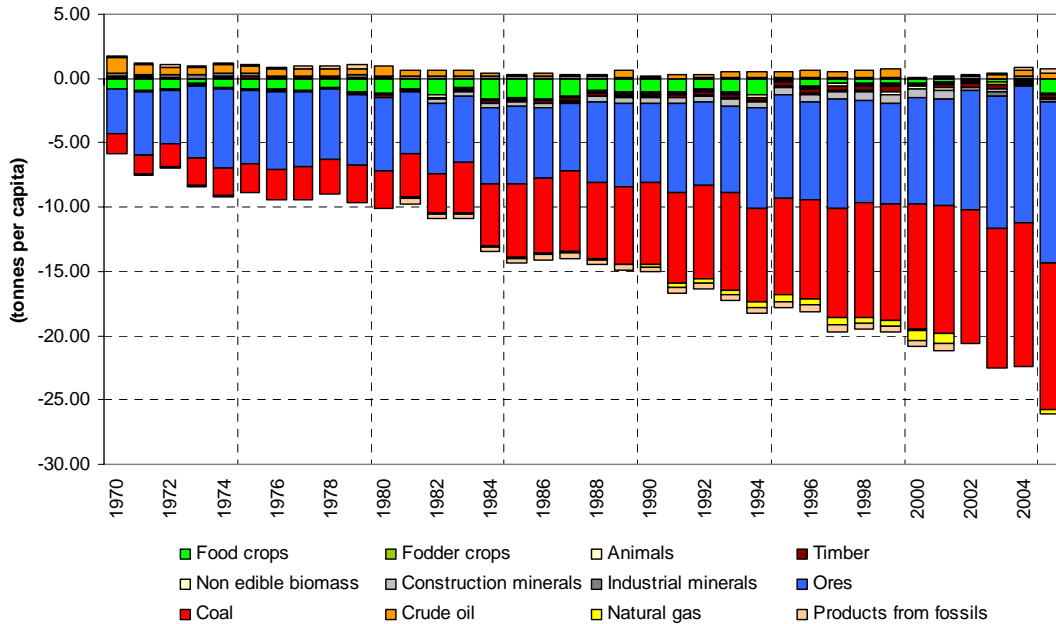


Figure 3. Domestic material consumption in Australia, 1970-2005, tonnes per capita

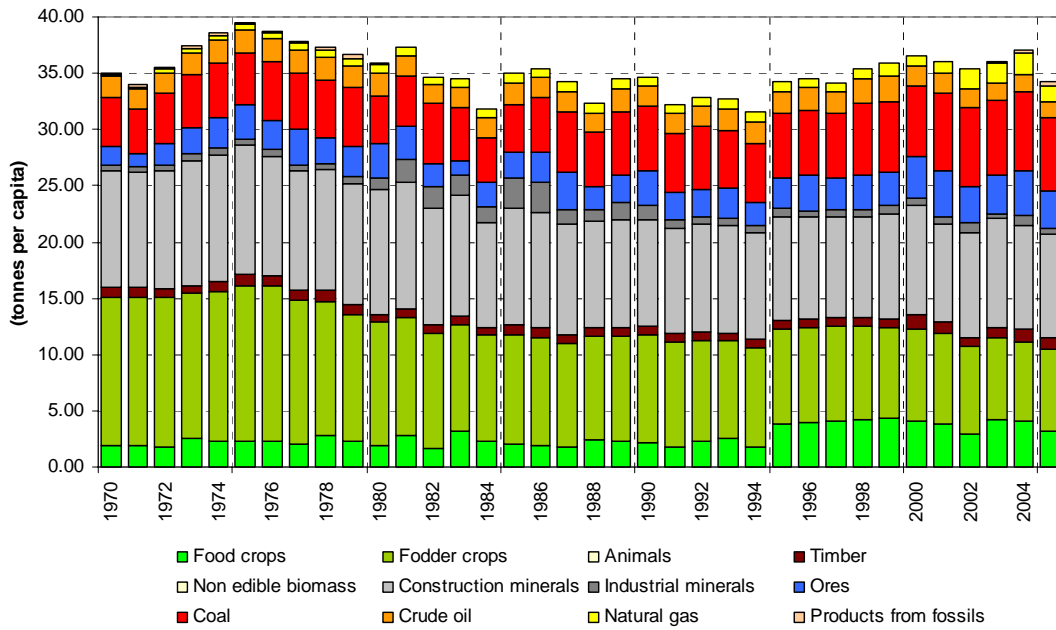


Figure 4. Comparing Australian, US and OECD resource use patterns, 2002, tonnes per capita

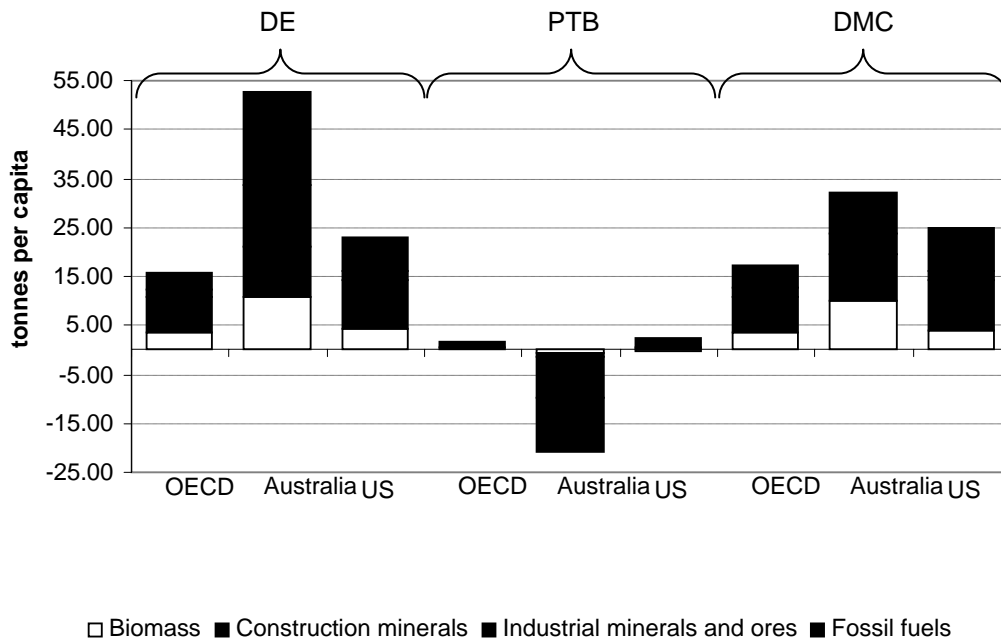


Figure 5. Resource productivity in Japan, US, OECD and Australia, 1980-2005. \$US 2000 prices PPP per kg

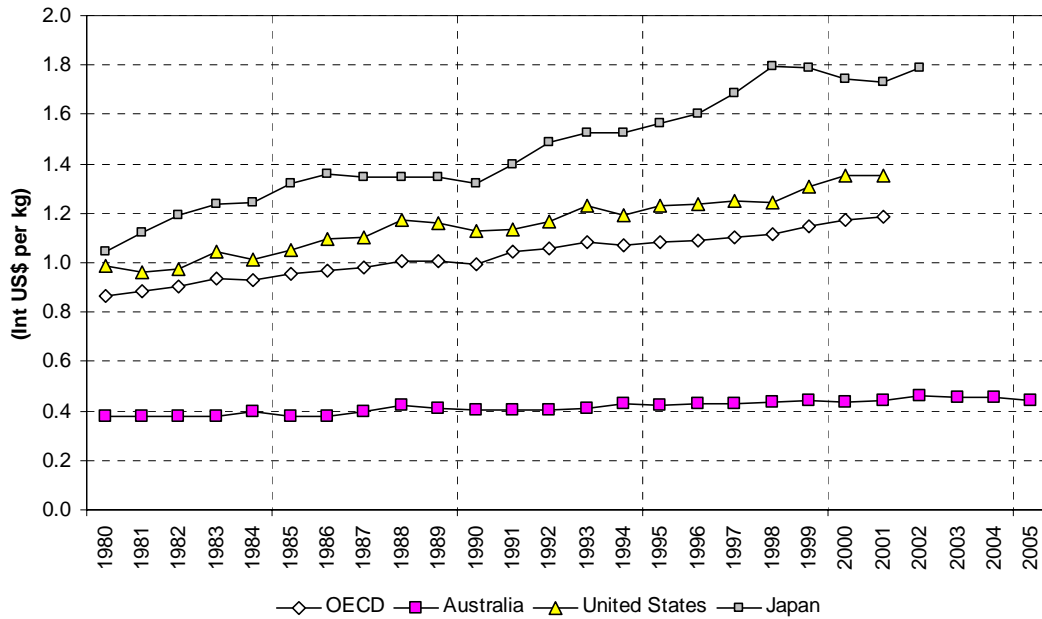


Figure 6. Domestic extraction of natural resources in Australia, 1946-2101, tonnes per capita

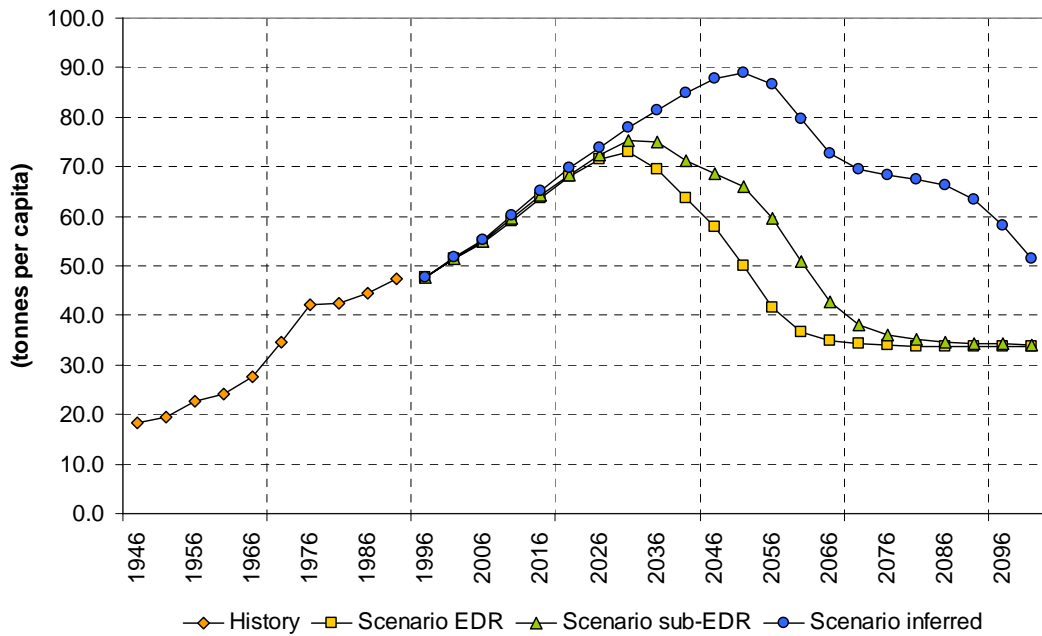


Figure 7. Australia's physical trade balance, 1946-2101, tonnes per capita

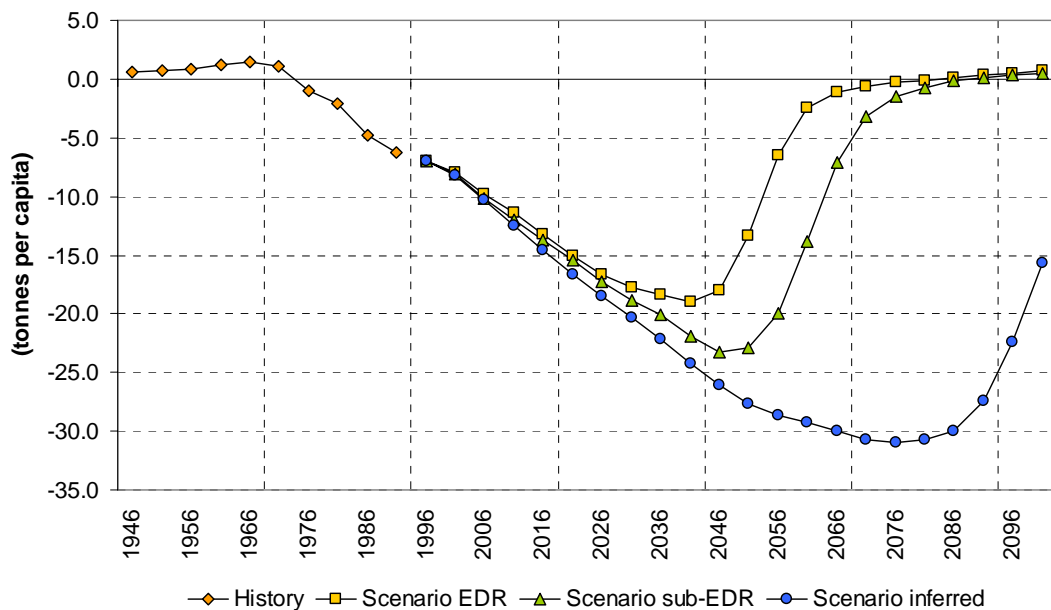


Figure 8. Domestic material consumption in Australia, 1946-2101, tonnes per capita

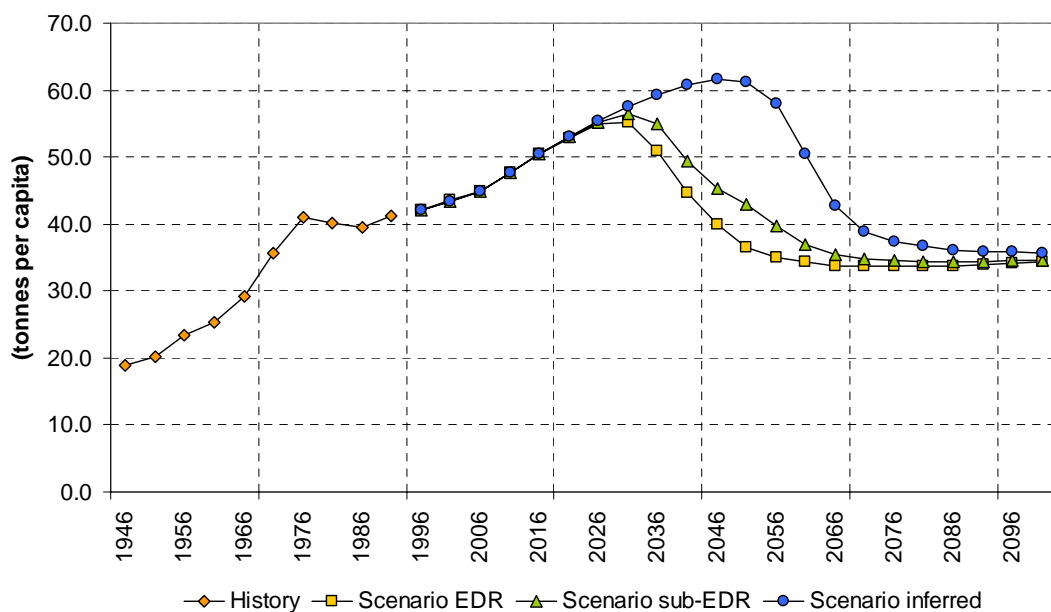




Table 1. Comparing Australian, US and OECD resource use patterns, 2002, tonnes per capita

	DE per capita			PTB per capita			DMC per capita		
	OECD	AUS	US	OECD	AUS	US	OECD	AUS	US
Food crops	1.44	2.45	2.15	-0.05	-0.34	-0.26	1.39	2.11	1.89
Fodder									
crops	1.22	7.07	0.82	0.02	-0.15	-0.07	1.24	6.92	0.75
Animals	0.03	0.01	0.02	0.00	-0.14	-0.01	0.02	-0.12	0.01
Timber	0.74	1.12	1.16	0.05	0.03	0.08	0.79	1.14	1.24
Non edible									
biomass	0.01	0.00	0.00	0.01	-0.17	-0.09	0.02	-0.17	-0.09
Construction									
minerals	7.48	10.35	10.09	0.01	-0.67	0.21	7.49	9.69	10.30
Industrial									
minerals	0.46	0.61	0.37	0.11	0.05	0.27	0.57	0.66	0.63
Ores	0.84	12.02	1.45	0.28	-8.32	-0.02	1.12	3.70	1.43
Coal	1.79	16.02	3.54	0.12	-9.76	-0.12	1.91	6.26	3.43
Crude oil	0.80	1.25	1.05	1.01	-0.09	1.92	1.80	1.15	2.97
Natural gas	1.03	1.98	2.16	0.07	-0.72	0.10	1.10	1.26	2.26
Products									
from fossils	0.01	0.00	0.00	-0.01	-0.50	-0.04	0.00	-0.50	-0.04
Total	15.84	52.87	22.81	1.60	-0.76	1.99	17.44	32.11	24.80

Table 2. Primary energy use by energy carrier in Australia, OECD and the World, 2004, percentage

	Australia	OECD	World
Coal	42.7%	20.5%	25.1%
Oil	32.0%	40.7%	34.3%
Natural gas	19.6%	21.7%	20.9%
Nuclear	0.0%	11.0%	6.5%
Hydro	1.2%	2.0%	2.2%
Combustibles, renewables and waste	4.3%	3.4%	10.6%
Geothermal, solar, wind, heat	0.1%	0.7%	0.4%

Source: IEA (2006)

Table 3. Australia's identified resources, current production and lifetime of natural stock, 2004

Commodity	Unit	EDR	Mine production	Years at current production
Bauxite	Gt	5.5	0.056	98.2
Black coal	Gt	92.9	0.385	241.3
Brown coal	Gt	79.2	0.068	1,164.7
Copper	Mt (Cu)	40.1	0.829	48.4
Diamond	Mc	147.3	31	4.8
Gold	t (Au)	5382	282	19.1
Iron ore	Gt	12.4	0.213	58.2
Lead	Mt (Pb)	19.3	0.688	28.1
Magnesite	Mt (MgCO <sub>3</sub> )	344	0.473	727.3
Manganese ore	Mt	124	2.55	48.6
Mineral sands	Mt	262.3	2.645	99.2
Nickel	Mt (Ni)	22.8	0.192	118.8
Phosphate rock	Mt	91	1.508	60.3
Silver	kt (Ag)	42.9	1.868	23.0
Zinc	Mt (Zn)	34.8	1.479	23.5

Source: Geoscience Australia (2004)