

# Implications of Australian Economic Growth for Environmental Sustainability

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RAND Justice, Infrastructure, and Environment

WR-1081

March, 2015

Prepared for and supported by the Australian Council of Learned Academies

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## **Australia's Comparative Advantage: Implications of Australian Economic Growth for Environmental Sustainability<sup>i</sup>**

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<sup>i</sup> This work was funded by the Australian Council of Learned Academies (ACOLA).



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**Abstract:** Australia’s economy has grown an average of 3.3 percent annually over the past 40 years, and there are concerns that growth has been accompanied by excessive natural resource use and declines in environmental quality. Economic growth can also stimulate demand for environmental quality—and thus environmental policy—by enabling the development and adoption of new technologies. Whether income growth is associated with increasing or decreasing environmental quality is an empirical question that varies across environmental quality measures and economies. We use decomposition and trend analysis to describe the drivers of environmental quality for six groups of metrics in Australia using time series data. We find that aggregate measures of ecosystem vitality and environmental health and indicators related to water use, nutrient balance, carbon monoxide, volatile organic carbons, and protected areas have been strongly decoupled from economic growth and show improving trends over the past several decades. Nitrogen oxides and sulfur oxides have only been weakly decoupled, in that intensity per unit output has decreased, but not enough to offset economic scale effects. Indicators of biodiversity as viewed by subject matter experts conflict with the optimistic view suggested by increases in protected areas. Carbon dioxide emissions have stabilized and slightly declined since 2008, suggesting that the relationship between economic growth and greenhouse gasses and may have reached a turning point, while solid waste has not been decoupled.

**JEL:** Q56, Q58, Q4, Q5

**Keywords:** growth and environment, environmental Kuznets curve, IPAT, scale, composition, technique, environmental policy

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## Table of Acronyms

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<b>CO</b>	Carbon monoxide
<b>CO<sub>2</sub></b>	Carbon dioxide
<b>EA15</b>	15 OECD countries that are part of the Euro area as of 2011
<b>EKC</b>	Environmental Kuznets Curve
<b>EPI</b>	Environmental performance index
<b>FOSS</b>	Fossil fuels
<b>GDP</b>	Gross domestic product
<b>GHG</b>	Greenhouse gas
<b>GVIA</b>	Gross value of irrigated agriculture
<b>IPAT</b>	Impact = Population time affluence
<b>NO<sub>x</sub></b>	Nitrogen oxides
<b>OECD</b>	Organisation for Economic Co-operation and Development
<b>PM10/2.5</b>	Particular matter 10 microns / 2.5 microns
<b>SO<sub>2</sub></b>	Sulfur dioxide
<b>SO<sub>x</sub></b>	Sulfur oxides
<b>TPES</b>	Total primary
<b>VOC</b>	Volatile organic compounds

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## **Introduction**

Australia's economy has been growing over the past 40 years at an average annual gross domestic product (GDP) growth rate of 3.3 percent, corresponding to an average annual GDP per capita growth rate of 1.3 percent (ABS, 2014). However, this growth has been accompanied by concern about the drawdown of natural capital stocks and growing environmental emissions. For example, A recent UNEP estimate suggests that approximately 37 percent of the value of Australia's capital stock base, including manufactured, natural, and human capital, can be attributed to environmental stocks, but the estimated value of natural capital declined by nine percent from 1990 to 2008 (UNEP, 2012). Other estimates vary significantly, with the World Bank reporting that natural capital values increased from 1995 to 2000 and then plateaued (World Bank, 2011), while estimates from the Australian government suggest increasing values of natural capital from 2000-2012 (ABS, 2013). As these estimates make clear, even when the underlying concept being valued is the same, the qualitative story of environmental degradation or appreciation over time may vary due to limited data or methodological differences.

To make matters more complicated, overall societal wealth depends not just on natural stocks but also the value of man-made capital, which is often a substitute. From a weak sustainability standpoint, if the overall value of the sum of man-made and natural capital stocks is declining over time, then the path of the economy is generally considered unsustainable, even as wealth increases. From 1990-2008, the value of man-made capital stocks per capita in Australia has increased by nearly 42 percent (ABS 2010), outpacing the estimated decline in natural capital stock value calculated by the United Nations. Despite this seemingly optimistic statistic, questions remain about the validity of the substitutability assumption and the ability to accurately measure the comprehensive value of all natural capital. When it comes to questions

about the ultimate relationships between economic growth and environmental quality, the answers are often elusive and contradictory.

Concern about whether sustainable economic development is possible can be traced back to the writings of Thomas Malthus in the eighteenth century, , continued through the publication of *Limits to Growth* (Meadows, et al., 1972), and the issue remains salient today. Analyses inspired by these ideas highlight the fact that as the scale of economic activity increases, environmental degradation (including increasing resource use and negative externalities) tends to increase as well.

On the other hand, empirical and theoretical work by econometricians starting in the early 1990s highlights the possibility that for some environmental pollutants there tends to be an inverted-U shaped development path with respect to income, as measured by GDP, such that pollution tends to increase at low levels of income but decreases after some switching point (Grossman and Krueger, 1991).<sup>3</sup> This relationship, termed the environmental Kuznets curve (EKC), could arise from demand-side pressures (environmental quality is a normal good) or supply-side pressures (technological and structural changes) (Selden and Song; 1995, Panayotou, 1997; Torras and Boyce 1998; Lopez and Mitra, 2000; Farzin and Bond, 2006; Kolstad, 2006).<sup>4</sup>

These stylized facts can be used to bound the possible relationships between environmental quality and economic growth. In what might be termed the “very pessimistic” view, carrying capacity constraints lead to environmental collapse in the presence of economic growth. The “very optimistic” view posits that growth will ultimately solve all environmental problems. However, mixed empirical evidence across pollutants, resources, and contexts

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<sup>3</sup> For environmental “goods”, the EKC relationship would be U-shaped.

<sup>4</sup> The conventional Kuznets curve suggests that as economic growth proceeds, income inequality first increases and then decreases (Kuznets, 1955).

suggests that neither extreme outcome is likely across all environmental indicators and for every economy. Rather, responses in policy and technology tend to decrease the negative influences of economic growth typically brought on by scale; the key empirical question is whether or not these responses will be sufficient to overcome the negative environmental effects associated with growth.

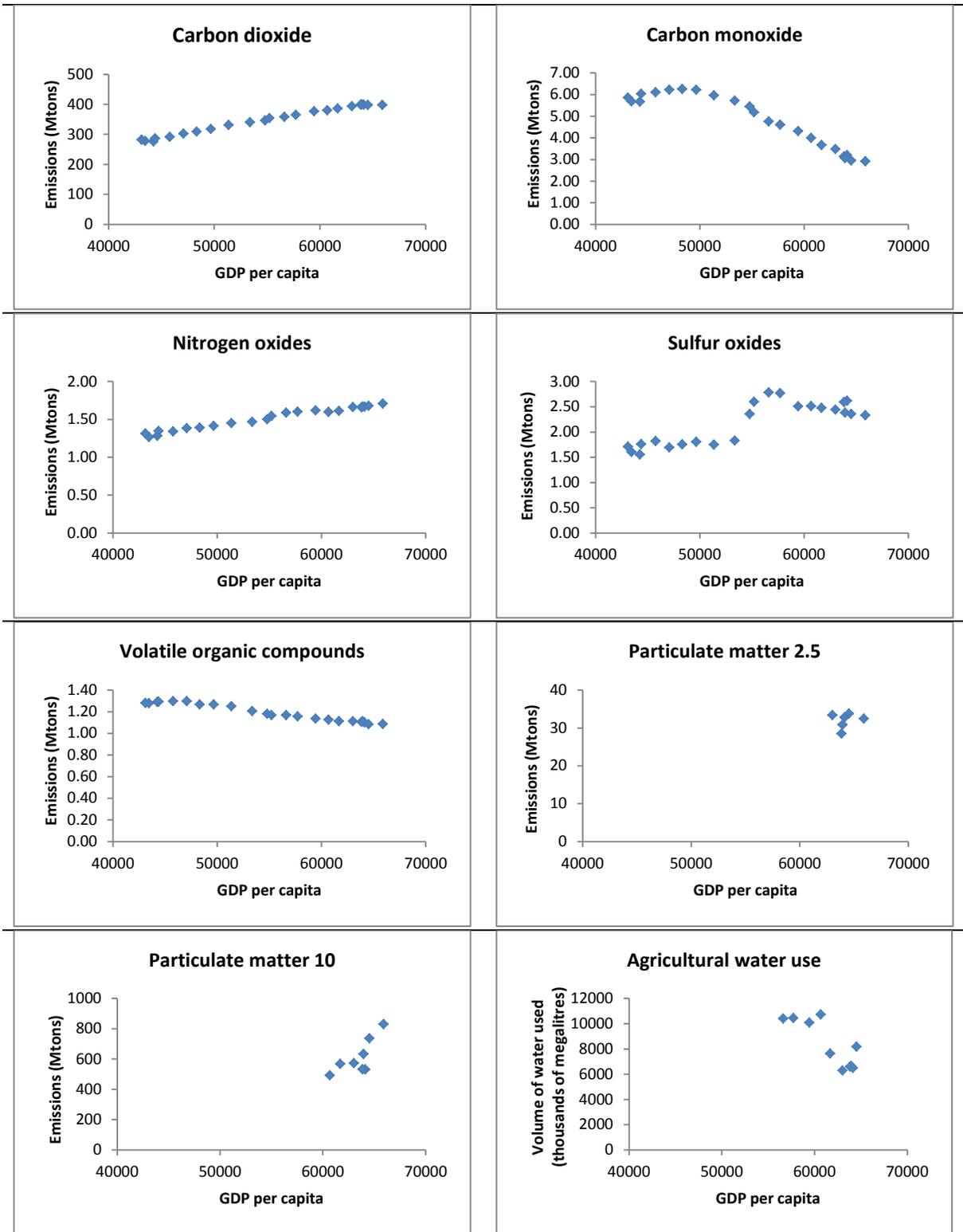
We focus on the relationship between GDP growth and environmental quality in Australia. Figure 1 presents the set of environmental quality indicators we consider in this paper, plotting each with respect to GDP per capita. Each graph describes how the level of environmental quality, such as amount of pollution or area of protected land) has changes as Australia's income has changed. Generally, moving from left to right on the graphs—increasing income per capita—mirrors moving forward in time, as incomes rise. The charts in Figure 1 are not meant to imply a causal relationship between income and the environment, but instead they show basic trends for a select set of indicators over the past two decades. Some of the indicators have fewer observations than other due to limited data availability (e.g., particulate matter and water use).

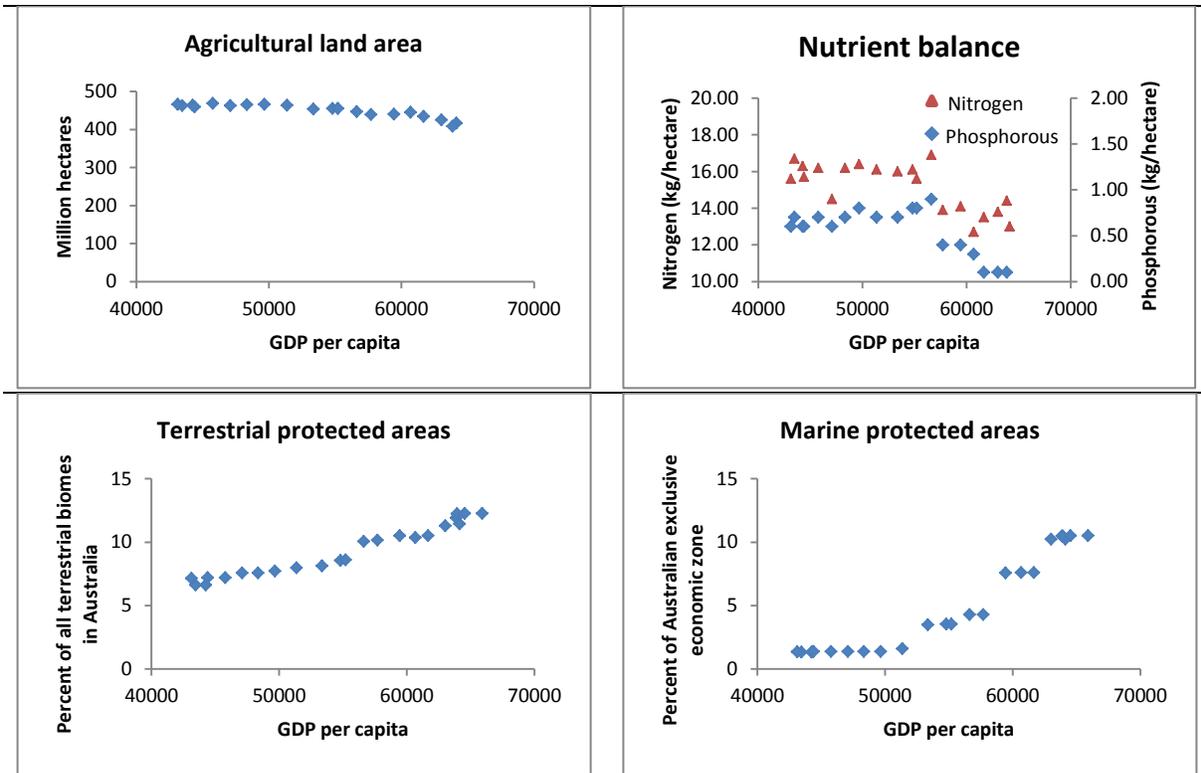
There are a number of patterns shown across indicators, suggesting complicated and context-dependent relationships between economic growth and environmental quality. In some cases, scale is dominant; in others, scale is overwhelmed by other forces. However, these unconditional relationships cannot tell us about the important trends in technologies, policies, and preferences at play behind basic trends.

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**Figure 1. Environmental Quality Indicators for Australia as a Function of GDP/Capita**

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Note: Data are for the time period 1990-2012.

Sources: Australian Bureau of Statistics (ABS); Australian Energy Statistics, Australian Bureau of Resources and Energy Economics (BREE); National Greenhouse Accounts, Australian Department of the Environment (ADE); National Pollutant Inventory, Australian Department of the Environment (ADE); Environmental Protection Index (EPI) Project; Organisation for Economic Co-operation and Development (OECD)

We use decomposition and trend analysis to provide some insight into the relationship between Australian environmental outcomes and economic growth. This technique allows us to identify environmental trends related to scale, technology, and in some cases, composition of economic activity, providing a link to the EKC literature and the dynamic models of resource economics. We use multiple environmental quality indicators, including criteria pollutant emissions, greenhouse gas emissions, measures linked to water pollution, natural resource use and biodiversity, and overall environmental indicators, to provide a degree of breadth in outcomes and the different possible relationships between growth and environmental quality. However, our analysis is constrained by limited data, especially for some indicators, and the concept of environmental quality is sufficiently broad that virtually no set of indicators can

comprehensively cover all relevant dynamics (ADE, 2011). Throughout, we identify key environmental policy dimensions and tradeoffs that might be of interest in the future.

The paper is organized as follows. We first discuss the interplay between scale, technique, and composition effects that drive the relationships between economic growth and environmental quality, including the empirical and theoretical evidence about these relationships. We then briefly discuss decomposition analysis, its relationship with the environmental Kuznets curve hypothesis, and the notion of decoupling. After a brief discussion of data sources, we present the results for several classes of environmental indicators. A final section concludes with a discussion of the implications of the analysis for Australia's future economic growth.

### **Environmental Quality and Economic Growth: Conflicting Evidence**

The environmental Kuznets curve concept—that environmental quality initially deteriorates with income but then improves after a point—offered a welcome alternative to the view the economic growth degrades the environment, but the EKC literature has been controversial. After early interpretations of empirical findings argued in favor of an inevitable improvement in environmental quality due to economic growth, researchers began to seriously re-examine the theoretical and empirical basis of the models used to argue for and against an EKC. Previous work has shown that many factors affect the estimated relationship between GDP and pollution, including technical details in econometric methods, an assumption that GDP and environmental quality follow identical patterns across countries of differing development levels and resource endowments,<sup>5</sup> and differing data sources and measures of environmental

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<sup>5</sup> Many studies have, however, attempted to control for heterogeneity across sites by using fixed or random effect specifications that allow for additive differences in pollution levels across space.

quality including, concentrations of pollutants vs. emissions, production-based emissions vs. consumption-based indicators<sup>6</sup> (Deacon and Norman, 2004).<sup>7</sup>

Several studies have used U.S. state-level data to test the EKC hypothesis, which reduces the amount of variability across levels of development. Carson, et al. (1997) found monotonically decreasing relationships between multiple sources of air pollution and per capita income in a cross-sectional specification, but they found no relationship using panel data after controlling for a time trend, a result that is consistent with generally improving technology. List and Gallet (1999) use a longer set of per capita sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) emissions and find heterogeneous relationships across states, while Aldy (2005) reports a similar finding for carbon dioxide (CO<sub>2</sub>).<sup>8</sup> Taken together, there are questions about the universality of the proposed EKC relationship across geographies and pollutants, and considerable evidence indicates that there is not an unambiguous causal relationship between income growth and decreasing pollution (Carson, 2010). Rather, outcomes and development paths appear to depend on context: the environmental indicator in question and the demand- and supply-side characteristics of the region.

Theoretical models can explain the conditions under which an EKC relationship might be likely, and there have been multiple theoretical relationships proposed to underpin the EKC concept and observational evidence. Two important lines of research emphasize the role of institutions (Jones and Manuelli, 1995; Farzin and Bond, 2006) and endogenous technological development (Stokey, 1998). In contrast, Andreoni and Levinson (2001) show that, in a static

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<sup>6</sup> Aldy (2005) defines *production-based* pollution as emissions from goods before they are traded, and *consumption-based* pollution as emissions to capture the effects of emissions associated with goods produced within a state from the emissions associated with goods traded across states.

<sup>7</sup> In fact, using the oft-use yet criticized GEMS/AIRS data for Australia, Deacon and Norman (2004) find monotonically decreasing relationships between GDP and SO<sub>2</sub> using a cross-section of countries..

<sup>8</sup> In a complementary result, Brock and Taylor (2005) suggest that longer-lived stock pollutants are more likely to be associated with heterogeneity in emissions-growth patterns than “flow”-type pollutants.

framework, increasing returns to scale in pollution control technologies can lead to economic growth, ultimately reducing environmental damage when the proportion of wealth spent on abatement is constant. This pathway requires no endogenous response from society's standpoint, instead it is a technical property of abatement technologies.<sup>9</sup>

Brock and Taylor's (2005; 2010) theoretical "green Solow" and learning-by-doing models suggests that factor endowments will result in differing pollution paths and abatement policies, with long run convergence. This model extends a standard Solow model with exogenous labor force growth and labor-augmenting technological progress by assuming that output generates pollution, but that resources can be extended to abate pollution according to a constant returns to scale process that exhibits diminishing marginal returns. Brock and Taylor further assume that technological progress augments the abatement process, making it more efficient, and depending on the parameterization, this model produces a cross-country EKC relationship without assuming a negative relationship between growth and environmental degradation.

While the green Solow model relies upon technological change coupled with diminishing marginal returns to explain a potential EKC relationship, it is agnostic as to the mechanisms through which technology actually changes. Smulders et al. (2011) attempt to explain this process through a growth model of endogenous technological change in which firms invest in technological development primarily to innovate on production costs and the ability to adapt to regulatory pressures. Unlike the model in Brock and Taylor (2010), the demand side of the economy is represented through the assumption that public policy responds to consumer preferences, since consumers are harmed by pollution, technological changes emerges from the

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<sup>9</sup> As noted by the authors, this does not necessarily imply that the absence of environmental policy is socially optimal, as marginal damages may still exceed the marginal benefits of pollution.

interplay of incentives faced by firms. However, like Brock and Taylor, the endogenous process does not necessarily predict an EKC for all pollutants in all cases.

The empirical and theoretical work cited above suggests a mixed story. Modeling how growth drives environmental quality is not straightforward, and, “long-run growth trends [in overall net welfare, including income and environmental quality] depend upon the growth of inputs, the rate and direction of technological change, and the elasticities of substitution among the different factors” (Nordhaus, 1992), as well as any potential policy responses (Smulders, et al. 2011). Regardless of the mechanism, increasing income without incurring adverse environmental effects depends on the adverse effects of growth being offset by reductions in the pollution intensity of the economy, defined as the pollution rate per unit income. In the following section we outline a practical way to break down these effects and use decomposed trends to assess the role of growth on Australia’s environment, without assuming an EKC relationship holds.

### **Scale, Composition, and Technique Effects**

The scale, composition, and technique framework, introduced in the context of the EKC literature by Grossman and Krueger (1991), offers a useful way to unpack the mechanisms by which growth affects the environment. As an economy grows, income rises and drives up both demand for natural resources and pollution associated with economic activity. If the environmental impact per unit of income is constant, then pollution increases with economic growth.<sup>10</sup> This is known as the scale effect, and it manifests through growth in GDP per capita and population.

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<sup>10</sup> We are concerned not only with environmental pollution but degrading environmental quality in general. This includes, for example, the degradation of the natural resource base, such as decreasing freshwater supplies. For

On the other hand, demand for a cleaner environment generally increases with income, operating through changing patterns of production and consumption or demand for stricter environmental regulation that affects production or consumption. At least in the wealthiest world economies, there has also been a tendency to move from an industrial-based economic structure to more of a service economy, which tends to be less pollution intensive.<sup>11</sup> Changes related to cleaner production technologies are generally known as technique effects, while changes in the structure of the economy are known as composition effects (Grossman and Krueger, 1991).<sup>12</sup>

The interplay of scale, composition, and technique effects ultimately determines the relationship between growth and environmental quality. If the scale effect is positively related to growth, then the sum of technique and composition effects must offset it in order for environmental quality to improve with income. If it does so totally, the economy achieves an absolute decoupling of the relationship between economic growth and environmental quality. If, instead the technique and composition effects only partially offset changes in scale, then growth and environmental quality are weakly decoupled. We will use the scale, composition, and technique framework to assess decoupling across environmental indicators in Australia.

## **Methodology**

Decomposition analysis is a family of non-parametric quantitative methods that relies on identities and historical data to lend insight into major drivers of indicators over time. With a long history in the energy efficiency and emissions literatures, decomposition analysis has been

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simplicity, we often refer to pollution when providing examples or explanation, but the concepts generalize unless otherwise noted.

<sup>11</sup> This is a potentially localized phenomenon, as there may simply be substitution from one location to another of the production of “dirty” or resource-intensive goods. Similarly, population pressures from immigration/emigration may exhibit similar substitutable properties.

<sup>12</sup> Although in this paper we focus on the tendency for technology to improve environmental outcomes, the opposite trend (i.e., the adoption of environmentally damaging technologies that enabled rapid post-WWII growth in the United States) was the focus of Commoner in the original IPAT discussions (Chertow, 2001).

used to identify the empirical scale, composition, and technique effects discussed in the EKC literature (see, e.g., Grossman and Krueger, 1991). This approach has also been used by the Intergovernmental Panel on Climate Change (IPCC), among others, to analyze the relationship between energy use and carbon emissions (IPCC, 2000).<sup>13</sup> Decomposition analysis is flexible across environmental indicators, sectors, and data availability, and it explicitly incorporates (an) identity relationship(s) involving economic activity and other drivers of environmental outcomes. Finally, it provides the opportunity to perform what-if scenario analysis.

The IPAT model provides a basis for decomposition analysis: *Impact* = *Population* times *Affluence* times *Technology*. IPAT, originally proposed and discussed by influential environmental thinkers Paul Ehrlich, John Holdren, and Barry Commoner (Chertow, 2001; Carson, 2010).<sup>14</sup> To illustrate, a basic identity between an environmental indicator *I*, economic activity in the form of Gross Domestic Product (GDP), and population *P* takes the form:

$$I = P \cdot \frac{GDP}{P} \cdot \frac{I}{GDP}. \quad (1)$$

The second term on the right-hand side gives a measure of per-capita income (affluence), while the third term represents the intensity of the indicator with respect to GDP (technology). Taking the total derivative with respect to time provides an equation that can decompose growth of the indicator into growth in its component parts, while scenario analysis can be performed by simulating the growth paths of each of the three driver terms.

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<sup>13</sup> Other examples include Burnett, et al. 2013; Duarte, et al., 2014; Agnolucci et al., 2009; and Pink, 2013.

<sup>14</sup> For a discussion about the history of the IPAT model in the environmental movement, including the arguments between Ehrlich and Holdren (who generally argued that population was largely responsible for environmental ills) and Commoner (who argued that technology was the pressing problem), the interested reader is referred to Chertow (2001). In addition, in this context, population is generally considered an input into the production of an economic bad (pollution); in more traditional macroeconomic models, population (labor) is considered a valuable input into the production of economic goods. The balance between benefits and costs, of course, is at the heart of the sustainability debate.

Assuming increasing GDP and population for a particular country or region (increasing scale) over time, an environmental Kuznets curve relationship between a public bad and material well-being is possible only through decreasing intensities of the public bad per unit income. Such a change could happen due to differences in production technologies, which can directly change emissions intensity (technique effects), or differences in the structure of production, which can indirectly change emissions intensity (composition effects). In some cases it may be possible to further decompose the relationship by sector or by decomposing terms further. For example, in the case of fossil fuel emissions, the link between energy and emissions has been explicitly incorporated into the decomposition (see, e.g., Roca and Alcantara, 2001; Burnett, et al., 2013). In particular, emissions intensity is driven by changes in energy intensity (energy consumed per unit GDP) and emissions intensity per unit energy.<sup>15</sup> Formally, we define  $\frac{I}{GDP} = \frac{I}{E} \cdot \frac{E}{GDP}$ , where  $E$  is energy consumed, and substitute this equation into (1). This is the Kaya identity (Kaya, 1989 as in Agnolucci, et al. 2009). Of course, this assumes a not necessarily fixed relationship between the environmental indicator and energy use. In our analysis below, we use the literature to guide us on the potential additional decompositions appropriate for each indicator.

It is important to understand that decomposition based on an identity is not the same as a dynamic structural model of the economy, which assumes specific functional relationships between variables and key economic parameters. For example, consider the case of implementing a new tax on energy consumption. Such a policy may reduce the quantity demanded of energy, which may decrease emissions intensity per unit GDP, assuming pollution per unit of energy remains constant. However, implementing a tax may also slow aggregate GDP growth, leading to increased pollution intensity and, holding population constant, lower GDP per

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<sup>15</sup> This has been termed the “carbonization index” (Roca and Alcantara, 2001).

capita, which tends to decrease emissions. The IPAT/Kaya model is thus reflective of the effect of environmental policy, but is ill-suited to model the effects of it.

## **Data Sources**

In this analysis we use data from publicly available sources, including the Australian Bureau of Statistics, the Australian Department of the Environment, Australian Bureau of Resources and Energy Economics, the Organisation for Economic Co-operation and Development (OECD), and other Australia-based and international sources. Where possible, we use data with as long as an interrupted time series as possible to capture long-term trends in environmental quality indicators and their drivers.<sup>16</sup> In some cases, we simply report analysis that has been done previously, while in others, we perform the analysis ourselves.

### ***Environmental data***

Environmental quality spans many different sub-dimensions, and there is generally disagreement among stakeholders about which indicators are most useful, the overall representativeness of given sets of indicators, and how they should be aggregated (de Sherbinin, et al. (2013) In general, however, key environmental indicators are split into those dealing with pollution and those dealing with the use and/or stock of natural resources (OECD, 2003), or alternatively into drivers of environmental problems (e.g., economic indicators), direct pressures on the environment (e.g., resource use or emissions), environmental conditions (e.g., concentrations of a pollutant), impacts of environmental conditions (e.g., health effects of pollutant concentrations), or effectiveness of policy responses (de Sherbinin, et al., 2013).

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<sup>16</sup> One exception is our use of the Australian Greenhouse Emissions Information System for greenhouse gasses, as opposed to the longer-term time series of the Carbon Dioxide Information Analysis Center ([http://cdiac.ornl.gov/trends/emis/meth\\_reg.html](http://cdiac.ornl.gov/trends/emis/meth_reg.html)), These estimates are based on the production of coal, brown coal, peat, and crude oil.

The indicator set considered in this paper span air and water pollution indicators and key stocks of natural resources, with a focus on direct pressures on the environment (i.e., emissions and resource use). We also present two of the more widely-cited and used aggregate indicators of environmental health. For pollutants, we do not generally cover environmental concentrations and the link to health, which is of key importance for applied welfare and benefit-cost analysis of pollution control strategies.<sup>17</sup> For natural resource stocks, our indicators typically report the state and/or trend related of the stock, though one of our measures is directly policy driven. Implicit in our conceptualization of the linkages between the economic and environmental system is that population pressures and economic activity (on the production side) tend to increase environmental damage, all else equal.

We collected data on six classes of environmental indicators, including criteria pollutant emissions, resource use indicators (e.g., water consumption), biodiversity, and individual and aggregate indicators of ecosystem health (e.g., the Environmental Performance Index and its subcomponents). The research team selected the final set of indicators on the basis of appearance in the literature and the categorization of various Australian government publications (e.g., Pink, 2013; ADE, 2011), the latter of which should be correlated with perceptions of the major environmental issues facing Australia.<sup>18</sup> Of course, the set was also chosen, in part, on data availability, though it should be noted that lack of measurability does not necessarily mean that a particular concept is unimportant. Table 1 provides additional detail.

While we strive to be comprehensive and use appropriate data, limitations on environmental outcome measures are often severe and necessarily limit the type of analysis that

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<sup>17</sup> This is predominantly due to a lack of data availability.

<sup>18</sup> For example, Pink (2013) presented chapters on water, energy, waste, greenhouse gas emissions, land and ecosystem accounting, and natural capital.

is possible (ADE, 2011). Even when metrics are available, they are often subject to considerable time lags, which explains our coverage through 2012 for many indicators. We chose our method primarily because of limited data, which generally precluded standard statistical analysis. This is especially true with respect to complex environmental measures such as biodiversity, which may not be adequately captured by simple, observable measures of habitat protection. For example, at best true biodiversity is positively correlated with habitat protection; at worse, the two are independent.

**Table 1. Indicators and Associated Sources used in the Analysis**

Indicator Group	Indicators Considered	Source
<b>Greenhouse gas (GHG) emissions</b>	CO <sub>2</sub> emissions, total GHG emissions	Australian Greenhouse Emissions Information System (ADE, 2014); OECD
<b>Criteria Air Pollutants</b>	NO <sub>x</sub> , SO <sub>x</sub> , VOCs, PM 2.5	OECD; Boys, et al. 2014 and Aaron van Donkelaar (submitted) via EPI project
<b>Water Used in Agriculture</b>	Irrigated Water Use	Australian Bureau of Statistics
<b>Applied Nutrients (Water Pollution)</b>	Nutrient Balances	OECD
<b>Protected Areas/ Biodiversity</b>	Fish Stocks, Trawling Catch, Marine Protected Areas, Terrestrial Protected Areas	Sea Around Us Project, University of British Columbia Fisheries Centre, 2013; IUCN; UNEP-WCMC via EPI project
	Terrestrial ecosystem extent and quality, plant species, and animals; aquatic species and ecosystems; marine species and ecosystems	Australian Department of the Environment (2011)
<b>Overall Ecosystem Health</b>	Environmental Protection Index (EPI)	Yale University; United Nations Environment Programme; International Human Dimensions Programme on global Environmental Change
	Ecological Footprint	Borucke, et al. (2013)

Notes: The EPI project (Hsu, et al., 2013) collects data from the sources indicated in the table.

### *Economic data*

The primary data source for GDP and population for Australia are the key aggregates of the Australian national accounts published by the Australian Bureau of Statistics (cat no.

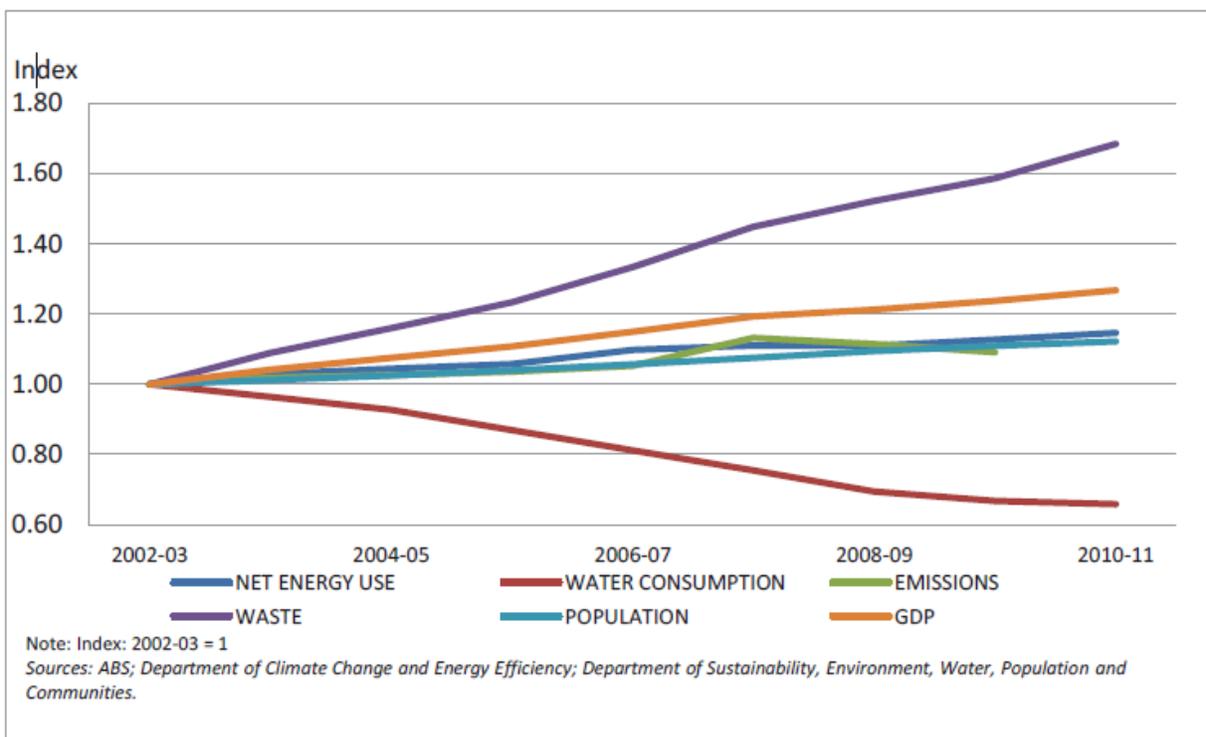
5206.0).<sup>19</sup> In some cases, we use other economic data as a measure of the potential scale effect (e.g., the amount of land in irrigated agriculture). In these cases, the source of the data is indicated with the relevant results.

## Results

### *Broad Measures of Air Pollution, Water Consumption, and Waste*

We begin by reproducing the results of an analysis recently performed by the Australian Bureau of Statistics (Pink, 2013), which compared GDP and population to a number of aggregate environmental indicators, including overall GHGs, water consumption, net energy use, and waste. Figure 2 shows the reproduced results.

**Figure 2. Selected Economic and Environmental Indicator Indices for Australia, 2002/03-2010/11**



Source: Reproduced from Pink (2013).

<sup>19</sup> Specifically, we use the Gross Domestic Product: Chain Volume measure, series ID A2304755F with population figures derived from this and the GDP per capita chain volume measure (A2305001C).

The data in the figure are derived from a number of public sources and agencies across Australia. Water consumption includes consumptive use by industry, government, and households across the country, and thus does not include return flows. Net energy use includes all energy consumed for final purposes (intermediate plus final demand) measured in terms of energy content (petajoules). Waste includes solid waste only, measured in tonnes, and defined as “discarded materials that are no longer required by the owner or user” (Pink, 2013, p. 34). Emissions are defined as total greenhouse gasses, including CO<sub>2</sub>, methane, NO<sub>x</sub>, and fluorinated gasses, but excluding changes due to land use and forestry.<sup>20</sup>

In Figure 2, with 2002/03 as the base year, any indicator that grows more slowly than GDP (in particular, net energy use, emissions, and water consumption) does so because intensity per unit GDP (which includes technique and composition effects) is declining. However, except for water consumption, this effect is dominated by the scale effect over the entire time period, as indicated by the upward slope of the indicator. In other words, there is a weak decoupling between economic growth and the environmental measure.

Not surprisingly, the net energy use and emissions series are highly correlated, with declining in intensity (use/unit GDP). For these indicators, Pink (2013) explains the decoupling as a combination of energy efficiency improvements due to technology and structural change due to continued movement towards a service-based economy. Price changes could have also played a role.

While the composition effect is likely to continue in the short to medium run, its effect will be limited in the long run due to the fact that even the service sector requires certain resources (energy and water, for example) to function. On the other hand, technological changes,

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<sup>20</sup> For more detailed variable definitions and additional decompositions (including some composition effects by sector and geographic stratifications), the reader is referred to Pink (2013) and additional references therein.

through developed or imported generation or abatement technologies, which may be driven by government policies, have no such theoretical limit. Nevertheless, the reliance of the Australian economy on fossil fuels (including coal) as primary energy sources suggests that in the absence of cost-competitive technological developments, further policy changes will be needed to decouple emissions from growth. We explore this issue further later in the paper.

In the case of waste, both scale and intensity are increasing over time, with hazardous waste generation doubling from 2002/03 to 2006/07 (EPHC, 2009). In an example of endogenous policy response, environmental ministers across Australia agreed to the National Waste Policy in 2009, which sets out sixteen strategies that promote best practices in waste recycling and disposal (EPHC, 2009). It remains to be seen if these programs will significantly affect the intensity of waste production in the future.

## ***Greenhouse Gas Emissions***

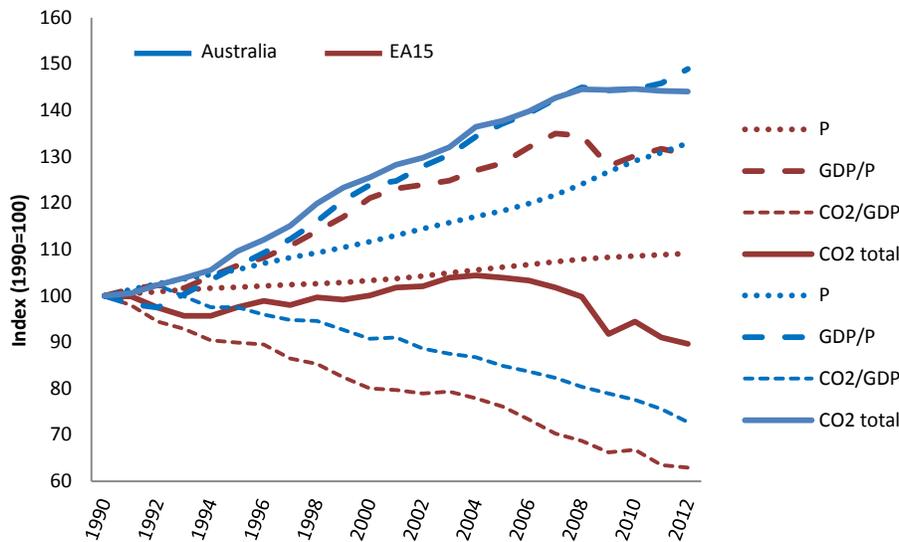
### *Carbon Dioxide*

The decomposition results in Figure 3 indicate that, since 1990, growth in CO<sub>2</sub> emissions in Australia has been driven by growth in income (GDP/P) and population (P), with growth in per-capita income outpacing that of population. Some of the growth in emissions is offset by reductions in carbon intensity (CO<sub>2</sub>/GDP), which captures technological efficiency and changes in the mix of energy (e.g., a shift toward more renewable fuels), as well as compositional shifts across the economy (i.e., a continued movement towards a service economy). Overall, CO<sub>2</sub> emissions have been consistently higher than 1990 levels, though emissions have plateaued since 2008, stabilizing at approximately 44 percent (121 Mtons) above 1990 levels (397 Mtons in 2012 compared with 276 Mtons in 1990). Although Figure 3 suggests that the lack of growth in CO<sub>2</sub> emissions since 2008 was due to a combination of zero growth in GDP/capita for several years

coupled with continued decoupling through decreased intensity, preliminary estimates of annual emissions from 2013-2014 show a 1.4 percent decline in 2013 and a 2.1 percent decline in 2014 (year to September) relative to 2012 levels (Department of the Environment, 2014c).

Trends in the drivers of CO<sub>2</sub> emissions in the EA15 countries (the 15 OECD countries that are part of the Euro area as of 2011) are qualitatively similar to those in Australia, at least until about 2008. That is, growth in income is the primary driver of growth in emissions, with population playing a smaller role. However, the EA15 differs from Australia in that overall population and per capital GDP growth was smaller, and that larger proportional carbon intensity reductions in EA15 countries offset much of the impact from income and population, resulting in lower overall CO<sub>2</sub> emissions as compared with 1990. The trend in emissions intensity is mirrored since 2008 by changes in GDP per capita growth, which is close to zero since peak carbon emissions. In the EA-15, continuing declines in CO<sub>2</sub> emissions since 2008 have corresponded to a relatively flat GDP/capita trend.

**Figure 3. Decomposition of Australian and EA15 Carbon Dioxide Emissions, 1990 - 2012**



Sources:  
 Australia data sources: Australian Greenhouse Emissions Information System (ADE, 2014); Australian Bureau of Statistics (ABS, 2014)  
 OECD data sources: StatExtracts, Organisation for Economic Co-operation and Development (OECD, 2014)

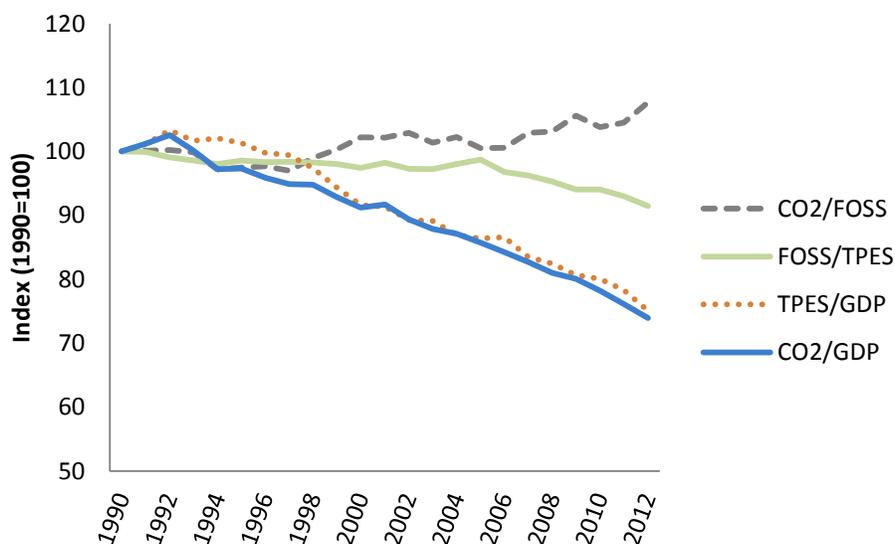
We also constructed a more detailed decomposition of the carbon intensity term as follows:

$$\frac{CO_2}{GDP} = \frac{CO_2}{Fossil\ fuels} \times \frac{Fossil\ fuels}{Primary\ energy\ supply} \times \frac{Primary\ energy\ supply}{GDP} = \frac{CO_2}{FOSS} \times \frac{FOSS}{TPES} \times \frac{TPES}{GDP}$$

Fossil fuels (FOSS) include energy from coal, natural gas, and oil. Total primary energy supply (TPES) is used as a proxy for domestic energy consumption, and includes energy from fossil fuels and renewable sources.

Results, shown in Figure 4, indicate that the reduction in carbon intensity (CO<sub>2</sub> emissions per unit GDP) is primarily due to reductions in energy intensity (TPES/GDP)—that is, the amount of energy consumed has decreased for every unit of GDP. The carbon content of fuels has increased (CO<sub>2</sub>/FOSS), possibly due to Australia’s recent booms in coal mining and gas production. Some of this is offset by decreases in the amount of fossil fuels consumed as a proportion of total energy consumed (FOSS/TPES), which is consistent with policies like the mandatory renewable energy targets that increase the share of low-carbon electricity supply.

**Figure 4. Carbon Dioxide Emissions Intensity and Composition, Australia, 1990-2012**



Sources: Australian Greenhouse Emissions Information System (ADE, 2014); Australian Bureau of Statistics (ABS, 2014); Australian Energy Statistics (BREE, 2014)

Australian government instituted a carbon tax in 2012/13 that applied directly to large CO<sub>2</sub> emitters and indirectly on other businesses (Australian Department of the Environment, 2014b). Carbon pricing was a core part of the Clean Energy Future initiative that aimed to “trigger a broad transformation of the economy by breaking the link between emissions and economic growth” (Pink, 2013, p. 43). However, the tax was unpopular among certain segments of the population, and was repealed in the winter of 2014. In the September 2014 quarter (the first quarter after elimination of the carbon tax), emissions increased by 0.3 percent as compared with the June 2014 quarter (Department of the Environment, 2014c).<sup>21</sup> It is too early to tell if repealing the carbon tax will result in a reversion to previous emissions trends, but after steady or declining emissions from 2008 through mid-2014 without a commensurate decrease in GDP per capita, it appears that a strong decoupling of CO<sub>2</sub> emissions and economic growth may be technologically feasible for Australia.

### *Criteria Air Pollutants*

Concentrations of criteria pollutants are indicators of air quality and are particularly important for human health.<sup>22</sup> Criteria pollutants are generally byproducts of fossil fuel combustion, motor vehicle emissions, and other industrial processes. We decompose emissions of criteria pollutants (1990-2012) into two components: income (GDP) and emissions intensity (E/GDP), as illustrated in Figure 5.

Overall emissions for carbon monoxide (CO) and volatile organic compounds (VOC) have decreased, an absolute decoupling, but sulfur oxides (SO<sub>x</sub>) and nitrogen oxides (NO<sub>x</sub>) have

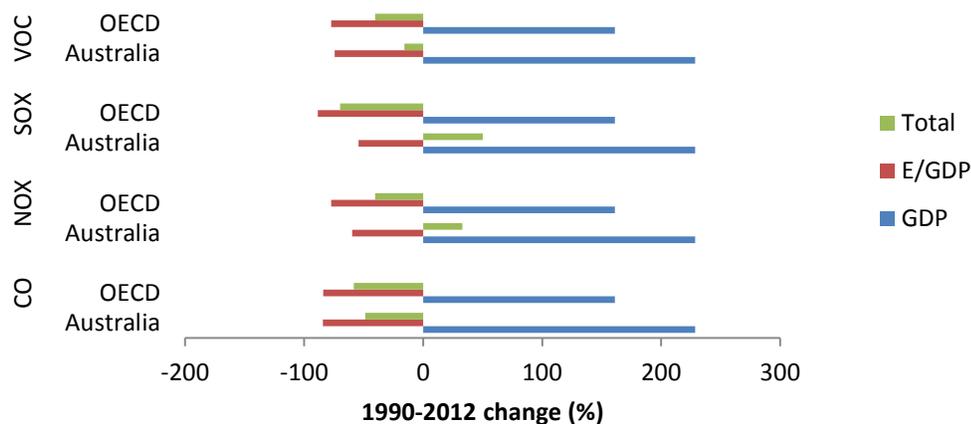
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<sup>21</sup> This figure is seasonally adjusted and weather normalized.

<sup>22</sup> The term “criteria pollutants” is used by the United States Environmental Protection Agency to describe ozone, particulate matter, lead, carbon monoxide, sulfur oxides, and nitrogen oxides, for which EPA sets Federal standards through the Clean Air Act. We also include volatile organic compounds in this analysis. See <http://www.epa.gov/oaqps001/urbanair/> for more information.

increased. Major sources of increases in SO<sub>x</sub> and NO<sub>x</sub> include metal manufacturing, electricity generation, burning (prescribed burning or wildfires), and motor vehicles (Australian Department of the Environment, 2015). Decreases in VOC and CO may be attributable to national implementation of vehicle emissions and fuel quality standards for new vehicles (Australian Department of Infrastructure and Regional Development, 2015/n.d.). For instance, beginning in the early 2000s, Australia aligned its performance standards for new vehicles (Australian Design Rule certification) with those of the Euro categories (e.g., Euro 5 adoption in 2013, and Euro 6 adoption in 2017 for light petrol vehicles).

**Figure 5: Decomposition of Australian and OECD Criteria Pollutant Emissions, Change from 1990-2012**



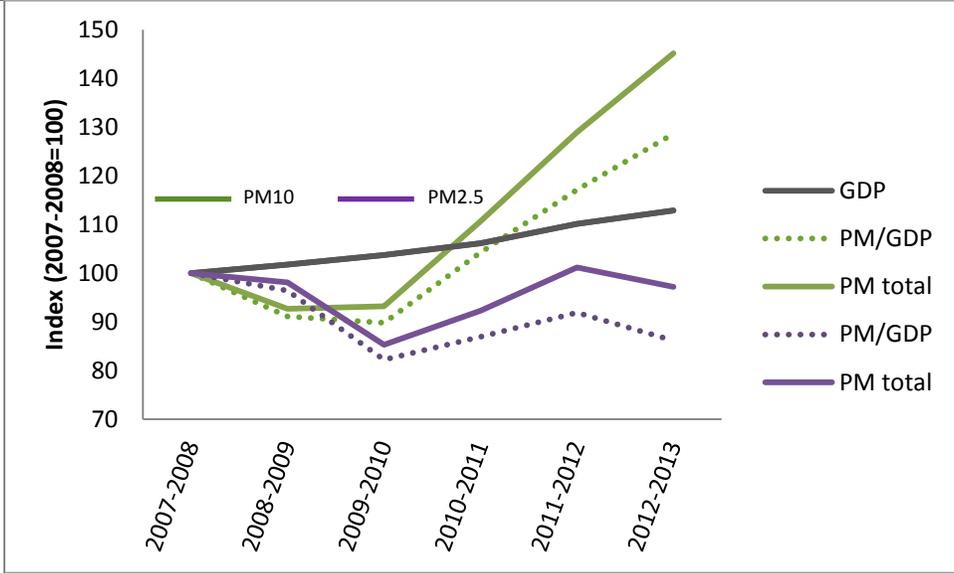
Sources: OECD. Abbreviations: CO=carbon monoxide; NO<sub>x</sub>=nitrogen oxides; PM<sub>2.5</sub> (particulate matter 2.5µm); SO<sub>x</sub>=sulfur oxides; VOC=volatile organic compounds

Particulate matter (PM) is a pollutant that causes serious health problems, including respiratory conditions, when found in high concentrations. Figure 6 shows the approximate amount of PM<sub>10</sub> and PM<sub>2.5</sub> emitted annually relative to 2007/2008.<sup>23</sup> Emissions of PM<sub>10</sub>

<sup>23</sup> PM<sub>10</sub> is particulate matter smaller than 10 micrometers (microns); PM<sub>2.5</sub> is smaller than 2.5 microns.

increased significantly starting in 2009-2010, largely driven by higher emissions intensity. Sources of particulate matter include industrial processes, vehicle emissions (e.g., fuel combustion from diesel-powered vehicles), biomass burning (both wildfires and prescribed burning), and mining, with biomass burning more prevalent in south-east Australia and mining an increasingly significant emissions source in Western Australia (OECD, 2008).

**Figure 6: Decomposition of Particulate Matter Emissions in Australia**



Sources: OECD

Abbreviations: PM2.5 (particulate matter 2.5µm); PM10 (particulate matter 10µm).

### ***Resource Use***

In this subsection, we shift our attention away from air pollution and towards indicators of resource use, including water quantity and quality, and the provision of protected areas.

#### ***Water Used in Agriculture***

With the exception of Antarctica, Australia is the world's driest continent (ABS, 2012), and the use of freshwater resources is an important natural resource indicator. Irrigated agriculture accounts for between 50 and 65 percent of Australia's water consumption, and just

under 30 percent of the overall value of Australian agriculture.<sup>24</sup> Of total irrigation-based water use, approximately half is used in the Murray-Darling Basin in the southeast, which is a major contributor to the agricultural sector of the economy (National Water Commission, 2012). Countrywide, household use constitutes around 12-14 percent of total water consumption (Australian Bureau of Meteorology, 2014). The remainder is for industrial and other uses. Freshwater management has been identified as a key challenge for Australia, especially in the face of a changing climate (ADE, 2011).

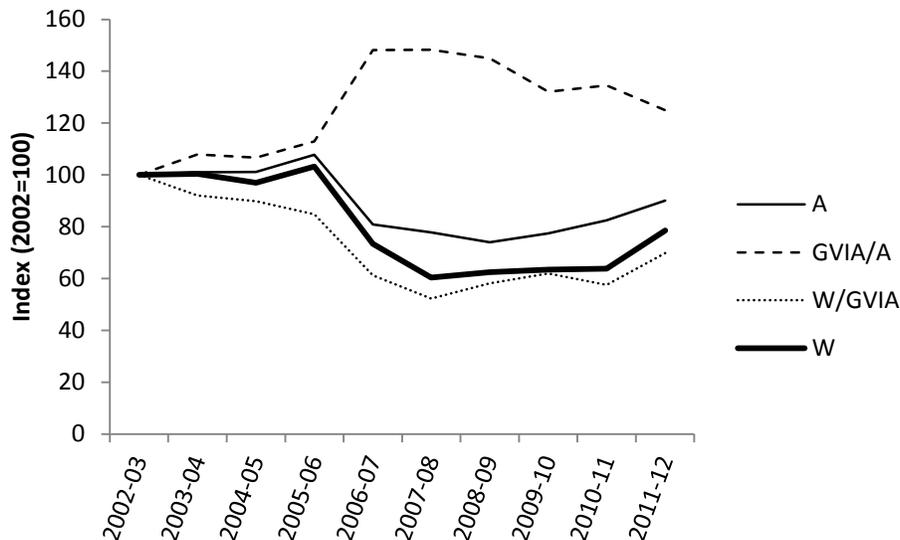
Given that agriculture is the largest water-using sector of the economy, we decompose the volume of water applied to irrigated agricultural production using the identity

$$W = A \cdot \frac{GVIA}{A} \cdot \frac{W}{GVIA},$$

where  $W$  is total water applied,  $A$  is irrigated acreage, and  $GVIA$  is the real

gross value of irrigated agricultural production. Figure 7 reports the results.

**Figure 7. Decomposition of Water Use in Agriculture**



Source Data: Australian Bureau of Statistics, Water Use on Australia Farms (cat. no. 4618) and Gross Value of Irrigated Agricultural Production (cat. no. 4610), various years.

<sup>24</sup> Does not include aquaculture, forestry, and fishing. Source: Australian Bureau of Statistics Water Account Australia 2012-13, cat. no. 4610DO001.

Irrigated Australian agriculture has become more efficient, with both greater output values per acre of irrigated land and less water intensity per dollar value of production. However, much of the value gains may be driven by output price increases associated with a severe drought from 2005/06 through 2009/10, which reduced both acreage and water use. Since 2002/03, aggregate water applied for agricultural purposes has declined by approximately 20 percent, though acreage slightly increased and efficiency (measured as W/GVIA) slightly declined from the mid-2000s, likely as a result of improving environmental conditions in the form of water availability. Irrigated acreage in 2012/13 was similar to that of 2002/03.

The major policy challenge related to freshwater use is increased demand for instream flows in the face of system that may be over-allocated, especially in dry years. In the early 2010's, the Murray-Darling Basin Authority approved a plan to manage resources in the basin, which will likely impact irrigators more heavily than municipalities, and the Australian government has committed to a program to purchase water from willing suppliers in that region (NWC, 2012). The management plan involves trading within the Murray-Darling as well, which has had positive economic and environmental effects (NWC, 2000). Continued technological development and deployment of efficient irrigation technologies, in addition to incentive policies such as trading schemes, will be necessary to increase environmental flows, maintain agricultural production, and meet residential and other industrial demand for water.

### *Urban Water and Desalinization*

In the past two decades Australia has experienced both technological and policy responses with respect to urban water. The drought from the late 1990s through 2010 spurred a considerable amount of investment in developing substitutes for over-allocated surface water and groundwater via desalination (ABM, 2014. p. 8). For example, projects in Adelaide (Port

Stanvac), Melbourne (Wonthaggi), and Perth (Southern and Perth Seawater Desalination Plants) could supply between 40 and 50 percent of urban water needs in each city when at full capacity (ABM, 2014).<sup>25</sup>

This evidence suggests several important points relating to the nature of the relationship between economic growth and the environment. First, in some cases, technological innovation may change the nature of environmental and resource allocation problems. In the case of urban water, this is taking the form of developing a substitute to natural surface and groundwater, which functionally relaxes the supply constraint facing both urban and rural areas.

Second, these types of processes can change how we interpret certain indicators. For example, in the context of a fixed quantity of a resource, demand-side indicators (such as water use) may indicate increasing environmental pressures from economic activity; however, if supply can be augmented, then increasing water use may not pose as much of an environmental threat with respect to water availability as might be implied by a constant technological regime. Thus, how an environmental indicator maps onto the stress placed on the environment needs to be understood in the context of technological and economic conditions that currently exist and that may prevail in the future.

Finally, the desalination process, which is energy intensive, may place additional pressures on indicators other than water availability (i.e., greenhouse gas emissions). This may not always be true; more general advances in technologies could spill over and serve as complements in abatement, rather than substitutes. Thus, technological advances to address one particular environmental issue may improve or exacerbate environmental quality as a whole.

### *Applied Nutrients*

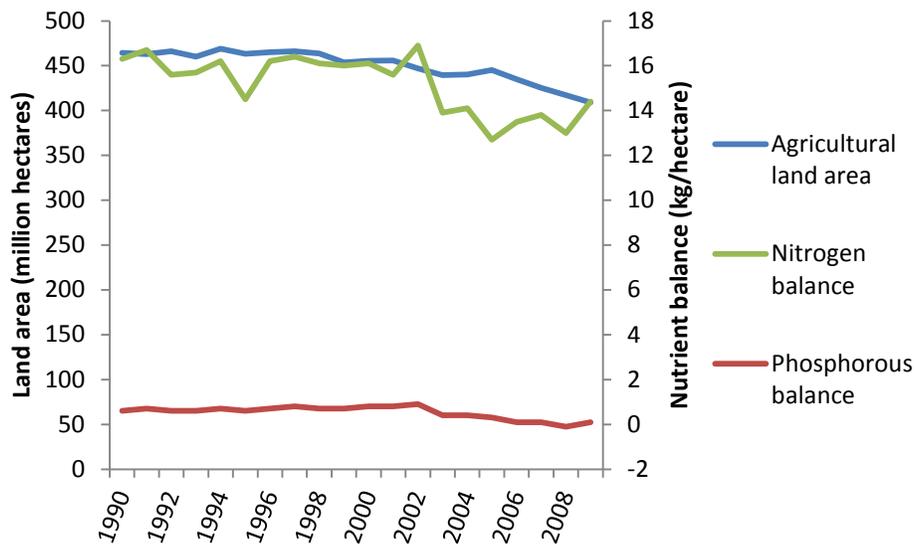
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<sup>25</sup> This list is not a comprehensive accounting of all desalination facilities in Australia, but rather the most recently developed facilities.

Applied nutrients to agricultural production systems, such as nitrogen and phosphorus, are not direct indicators of water quality, but they can describe pressures due to run-off and leaching processes, which can drive down water quality. Agriculture uses nearly 52 percent of Australia’s land area and about the same share of national water consumption (2009/2010) (ABS, 2012). Roughly three quarters of agricultural land is used for grazing, with a small share (approximately three percent) used for crops (Tisdell, 2007).

The difference between nutrients applied (via chemical fertilizers and manure) and uptake, or nutrient balance, is an indicator that can help understand both soil condition and water and air pollution pressures (OECD, 2013). The OECD estimates nutrient balances over time for two macronutrients, nitrogen and phosphorus, for primary agricultural production. Because these indicators apply primarily to the agricultural sector, we present nutrient balances per unit of land in production per year as a measure of intensity in Figure 8.

**Figure 8. Nitrogen (N) and Phosphorus (P) Nutrient Balances**



Source data: OECD.

Figure 8 shows that land used in agricultural production decreased by about 12 percent from 1990-2009, with most of the decrease occurring from the late 1990s forward. This is

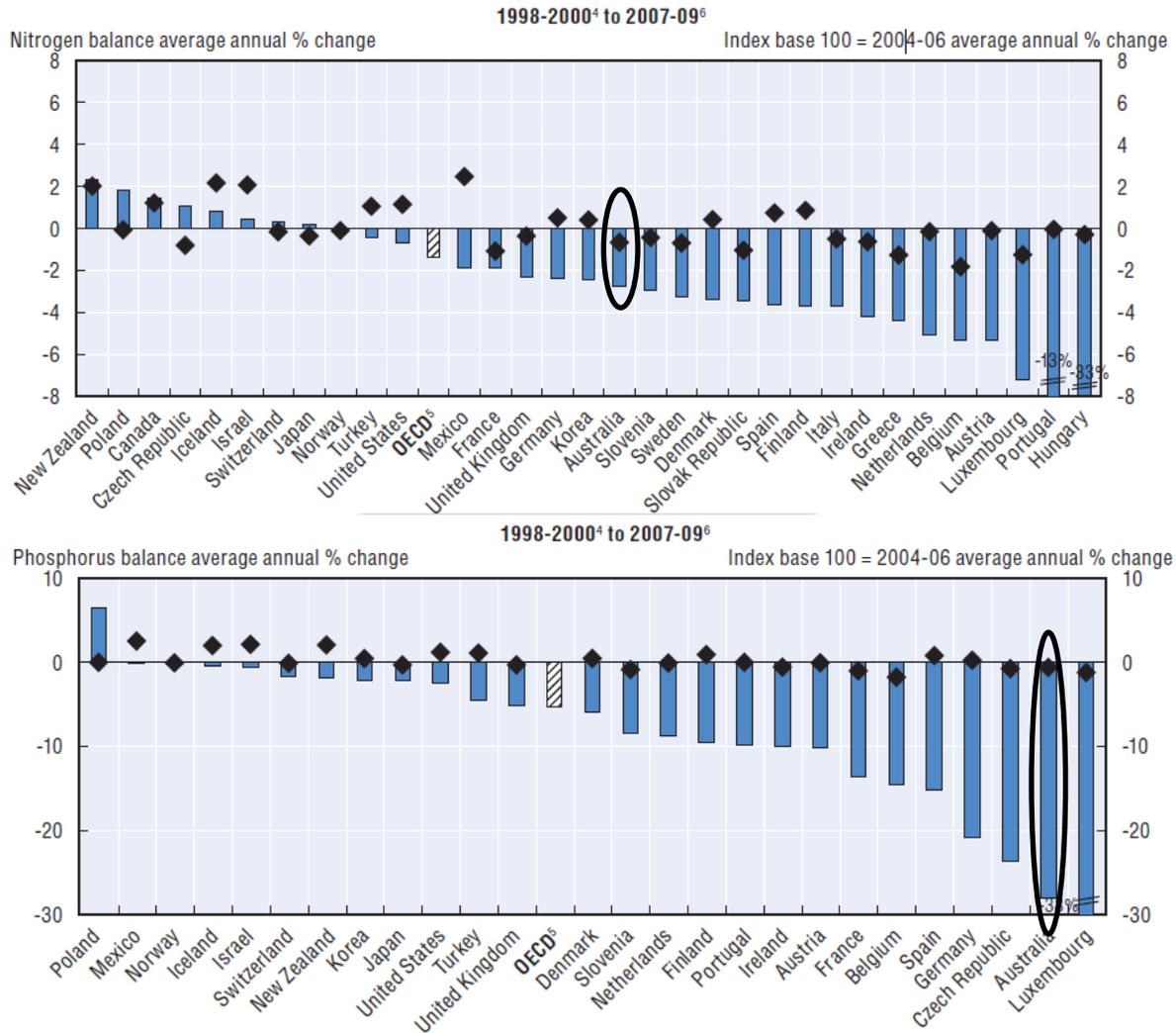
consistent with the general trend of declining relative importance of agriculture for the economy as a whole (Tisdell, 2007). Coupled with reductions in positive nutrient balances of about 12 percent for nitrogen and over 80 percent for phosphorus (from a much smaller base), the environmental pressures associated with modern agricultural production appear to have decreased across Australia over the past few decades due to both scale and technology changes. This generally mirrors the trends in other OECD countries, which have experienced overall and per hectare declines. For nitrogen, the average annual percentage change is slightly greater in absolute value than the OECD average, while the average annual per-hectare decline is smaller. Average annual percentage phosphorus balance declines, on the other hand, were much larger than average.

In addition, as shown in Figure 9 (reproduced from OECD, 2012), the average annual declines in nutrient balance have been accomplished without a proportional decrease in agricultural production, suggesting an absolute decoupling of this particular environmental pressure and agricultural production.<sup>26</sup>

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<sup>26</sup> The agricultural production index used in the figures is formed from a price-weighted quantity index that excludes quantities for food and seed as calculated by the Food and Agriculture Organisation of the United Nations (FAO).

**Figure 9: Nitrogen and Phosphorus Balance (bars) and Agricultural Production Volume (diamonds), 1998-2000 to 2007-2009, OECD Countries, Australia Circled**



Source: OECD, 2012 (Figure 4.6 and Figure 4.7 in original). Blue/hatched bars indicate average annual change in nutrient balance. Black diamonds represent average annual change in in price-weighted quantity index of agricultural production from FAO.

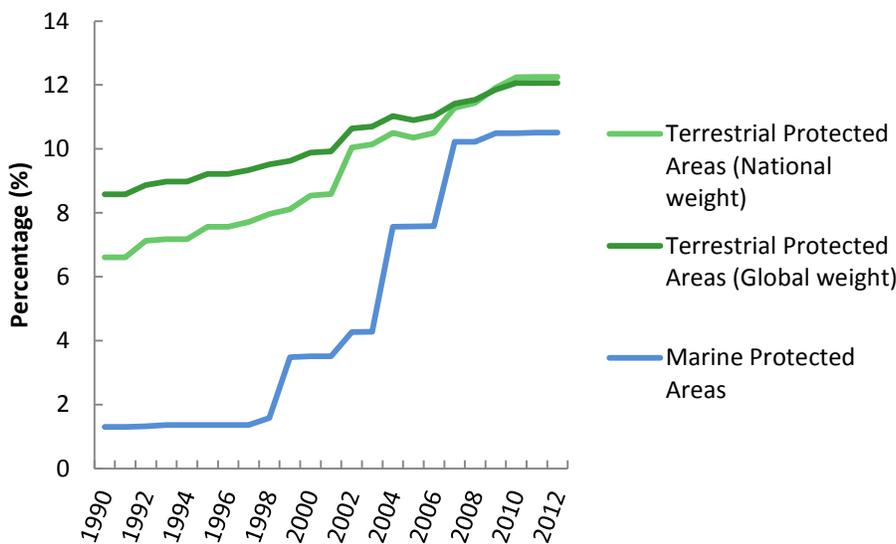
Although we cannot say definitively what is causing the declines in Figure 9, there were some relevant policy changes during this time period. In 2002-2003, the Australian National Heritage Trust’s 23 agricultural programs were reformed into four programs that generally encouraged “sustainable” farm practices and improvements in water quality and ecosystems (Vojtech, 2010). These were replaced in 2008 by a Caring for our Country initiative focused on healthy ecosystem services and resilience (Vojtech, 2010). Coupled with regulatory

requirements, including mandating buffer strips around water sources, and spending on technical assistance, these policy efforts may have contributed to the de-intensification of agricultural production with respect to the environment. Of course, there may have been other forces at work that contributed to the decline.

*Protected Areas and Biodiversity*

The percentage of protected areas, both terrestrial and marine, has increased in Australia since 1990, as seen in Figure 10. Following the 1992 Rio Earth Summit, Australia ratified and signed the Convention on Biological Diversity and established a national strategy for biodiversity conservation and system of protected areas. Spending on protected areas increased substantially in the following years. In 1998, the Australian government established a separate system for marine protected areas, the result of which can be seen by relatively flat percentage of protected areas, followed by a step increase starting in 1998 and thereafter.

**Figure 10. Trends in Protected Areas, Australia, 1990-2012**



Note: Terrestrial protected areas are measured as a proportion of the abundance of all terrestrial areas in Australia (national weight) or globally (global weight). Marine protected areas are measured as a proportion of Australia’s exclusive economic zone.  
 Source: EPI (2015).

While this particular indicator of biodiversity protection suggests a positive policy response to threats to biodiversity and genetic resources, it likely paints an incomplete picture of the state of biodiversity resources in Australia. First, aggregate metrics like *area protected* are appealing because they are simple and measurable, but they may not reflect genuine conservation in the sense that the areas set aside may not be under immediate development threat or be suitable habitat for valuable biodiversity resources. Second, meaningful metrics related to biodiversity are extremely difficult to measure and construct. For example, the *Sustainable Australia Report 2013* reports that “[i]nformation on Australia’s biodiversity is limited and suffers from a lack of consistent national reporting. In general, the ability to report on trends in the conservation status of species and ecological communities is poor...” (NSC, 2013, p. 182).

To illustrate the conflict, the *2011 State of the Environment* report (ADE, 2011) presents indicators of biodiversity that are at odds with the positive view painted by the increase in protected areas. Recognizing a lack of data, subject matter experts were consulted about a range of biodiversity issues, “report cards” of status and trends were produced, and the results were peer reviewed (NSC, 2013). Table 2 summarizes the results, though it should be cautioned that the results are based on limited evidence.

**Table 2. Biodiversity Indicators from 2011 State of the Environment**

	Grade in 2011		
	Very Poor	Poor	Good
<b>Terrestrial Ecosystem (native vegetation) extent</b>			
North and Central Australia			Stable
Southern, Eastern, and South-Western Australia		Deteriorating	
<b>Terrestrial Ecosystem (native vegetation) quality</b>			
Remote areas			Deteriorating
Agricultural regions & around urban development		Deteriorating	
<b>Terrestrial plant species</b>			

High altitude, remote, and very dry	Stable
Areas most suitable for development or agriculture	Deteriorating
<b>Terrestrial animals - mammals</b>	Deteriorating
<b>Terrestrial animals - birds</b>	Deteriorating
<b>Terrestrial animals - reptiles</b>	Deteriorating
<b>Terrestrial animals - amphibians</b>	Deteriorating
<b>Aquatic Species and Ecosystems</b>	
North and Central Australia	Stable
Southern, Eastern, and South-Western Australia	Deteriorating
<b>Marine Species and Ecosystems</b>	
Overall	Stable
In a few areas	Deteriorating

Source: 2011 State of the Environment report (ADE, 2011). Table entries show trend, while column position shows state as of the 2011 report. Based on limited quantitative data and subject-matter expert opinion.

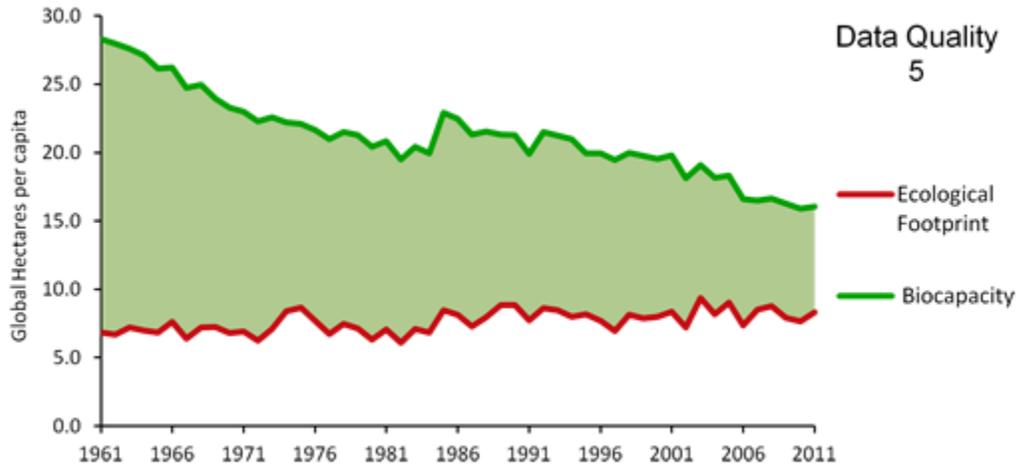
Overall, the indicators concerning biodiversity are inconclusive. While protected areas have increased, subject matter experts tend to take a generally pessimistic view of both the state and trend of these genetic resources, the degradation of which may be irreversible. Severe data gaps remain that limit our ability to quantitatively measure the biodiversity dimensions of the status quo and the overall trend in the stock of natural capital.

### ***Ecosystem Health***

Although traditional EKC analysis focuses on individual air or water pollution indicators, several authors have examined aggregate indicators of ecosystem health or non-emissions measures of environmental quality (Strong, 2013; Hsu, et al., 2013). Aggregate environmental indicators, such as the Ecological Footprint, have also become popular due to their stated ability to quickly and succinctly summarize the state or trend of environmental quality or pressures. Figure 11 displays both estimates of Australia’s ecological footprint, as well as its biocapacity. The latter represents biologically productive land, while the Ecological Footprint is a demand-side measure representing the land area required to provide the renewable resources used by a

country and absorb wastes. By both metrics, environmental pressures caused by reduction of environmental supply and increased demands are increasing.<sup>27</sup>

**Figure 11. Estimated Ecological Footprint, Australia, 1961-2011**



Source: Global Footprint Network, <http://www.footprintnetwork.org/en/index.php/GFN/page/trends/australia/>

A prominent aggregate indicator is the Environmental Performance Index (EPI), developed by a partnership of the Yale Center for Environmental Law & Policy, the Center for International Earth Science Information Network at Columbia University, and the World Economic Forum. EPI was developed to provide policy-relevant environmental information across two major dimensions: environmental public health and ecosystem vitality (Hsu, et al., 2013). Within these broad categories, the 20 individual indicators are weighted to create scores in environmental health impacts, air quality, water and sanitation, water resources, agriculture, forests, fisheries, biodiversity and habitat, and climate and energy (Hsu, et al., 2013). EPI's

<sup>27</sup> The Ecological Footprint claims to calculate the “demand on nature” from economic activity by comparing consumption for a nation to its biocapacity. Australia’s 2008 footprint was estimated at 6.68 global hectares per capita, placing it 8<sup>th</sup> in the world, and increased by 13.4 percent from 2007 to 2008. For reference, the United States had a footprint of 7.19 and ranked 6<sup>th</sup>. Details of the methodology are available in Borucke, et al. (2013), but the specific time series data are not publicly available. However, this graphical representation is available from <http://www.footprintnetwork.org/en/index.php/GFN/page/trends/australia/>.

developers state that it “provide[s] a gauge of a country’s performance toward policy goals” in the environmental dimension, using a “proximity-to-target” methodology based on prominent national or international policy goals (Hsu, et al., 2013, p. 5, EPI, 2015). In essence, this methodology provides a means of converting observable metrics to a 0 – 100 scale, where a score of 0 indicates a country has the lowest rank, and a score of 100 indicates a country has met standards (see Appendix A). All measures are normalized and transformed such that a higher number corresponds to better performance.<sup>28</sup>

Figure 12 presents the overall EPI and major subcategory indices (environmental public health and ecosystem vitality) for Australia from 2002-2012 in panel A, and the non-constant subindices within each major subcategory in panel B.<sup>29</sup> The overall EPI increased by 2.3 percent over the 10 year period, with increases in ecosystem vitality scores about twice those of environmental health scores. By these measures, then, Australia has been relatively successful in moving towards environmental policy goals, although these constitute an imperfect and incomplete picture of the state of the environment across Australia, with the ecosystem vitality indicator at odds with the subject-matter expert-derived indicators of biodiversity discussed in the previous subsection.

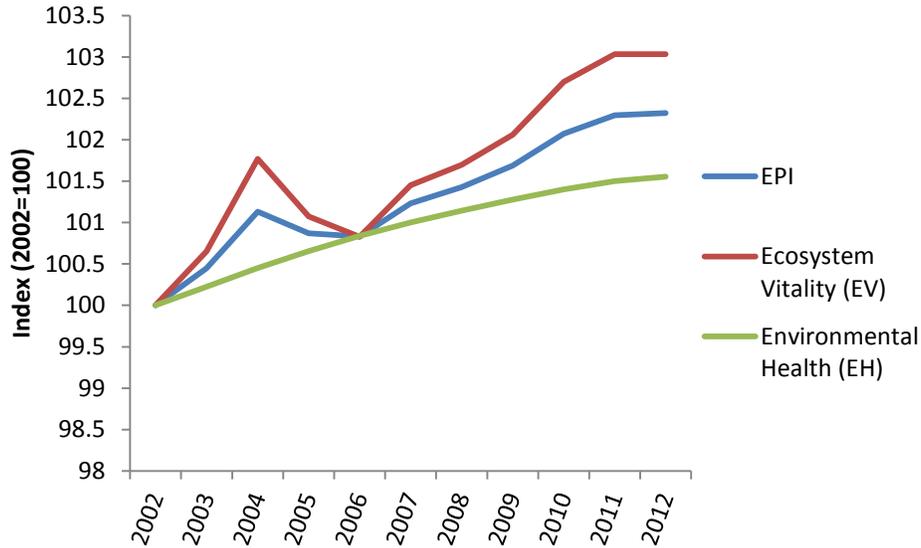
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<sup>28</sup> See Appendix A of Hsu, et al. (2013), or EPI (2015) for more details.

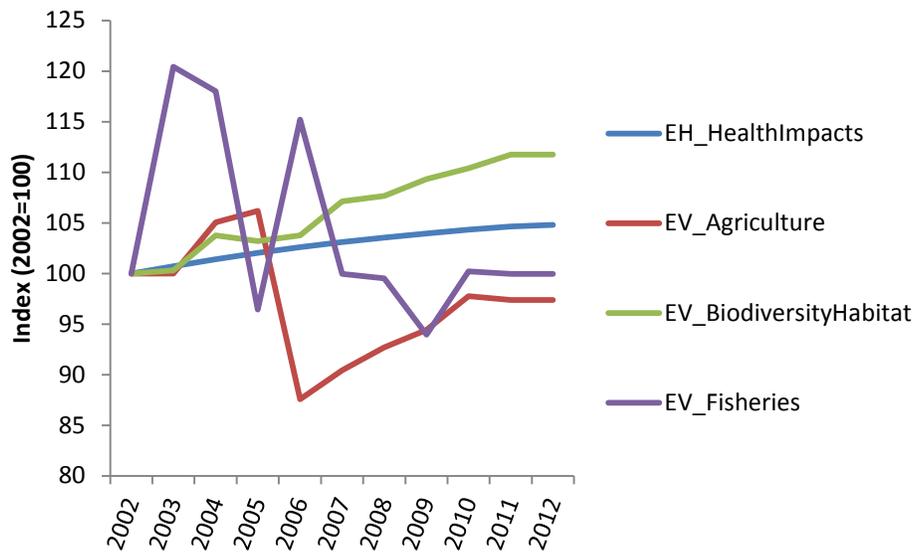
<sup>29</sup> Subindices for air quality and water and sanitation were constant within environmental health, and subindices for climate and energy, forests, and water resources were constant within ecosystem vitality.

**Figure 12. Environmental Performance Index and Components for Australia, 2002-2012**

**A**



**B**



Source: EPI (2015). Abbreviations: EH = Environmental Health, EV = Ecosystem Vitality. Default weights for indicators within each subindex are used in the figure. Only non-constant subindices are included in panel b).

Panel B shows the subindices within each major category that drive the overall results. At this disaggregated level, the indices tend to exhibit slightly more variance. Health impacts, as measured by child mortality, and biodiversity and habitat protection, which is reflected by protected terrestrial, marine, and critical habitat areas (see Figure 11), tend on increase between

most years between 2002 and 2012. The biodiversity and habitat indicator increase of almost 12 percent is a policy response enabled in part by increased demand for protection services. As previously discussed, however, protection of land is not necessarily the same as preservation of biodiversity, and other metrics related to biodiversity across Australia have suggested deteriorating performance.

Measures related to agriculture and fisheries both declined slightly from 2002 to 2012, though trends were less regular. The agricultural subindex, includes agricultural subsidies<sup>30</sup> and pesticide regulation, while the fisheries subindex included measures of catch from trawling and dredging and the percentage of fish populations that are overexploited or collapsed. In the agricultural index, the decline in 2006 is attributable to subsidy activity (calculated based on price differences with world prices rather than measured budget expenditure), with pesticide regulation staying constant after a discrete increase in stringency in 2004. For fisheries, which declined less than 1 percent over the ten-year period, the trawling and dredging indicator increased by just over 5 percent, but this was offset by a 3.1 percent decrease in endangered stocks.

The EPI data suggest Australia's environment is improving due to increases in health and biodiversity/habitat, while fisheries conditions were essentially stable and agricultural policy was declining. These conclusions, however, are quite specific to the indicators collected, as shown by the conflicting results related to biodiversity pressures. Given the multidimensional nature of environmental quality, and the ability of indicators claiming to represent the same or similar dimensions of it to measure qualitatively different trends, a key policy recommendation would be

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<sup>30</sup> The indicator related to agricultural subsidies is calculated via price differentials between world and local prices; as such, policy mechanisms and/or other market distortions not related to direct subsidization are likely captured in the measure.

for the Australian government to continue to invest in data collection, understanding that multiple measures may be necessary to fully paint a complete picture of the state of the environment.

## **Conclusions**

We focus on the question of whether continued economic development inevitably and irretrievably degrades the environment to an unacceptable level, or if technological progress and public policy pressure can help mitigate or even alleviate environmental damage, leading to so-called sustainable development. Our goal is to help understand the growth-environment relationship in Australia, analyzing recent trends and assessing what those trends suggest for the future.

There is considerable evidence in the literature that for some—though not all—pollutants and resources, environmental quality is increasing with economic growth after a certain point in the development process, contrary to a “scale only” story in which limits to growth are binding. Though far from universal, this relationship is often strongest for those issues for which there is a strong policy response, and for which technological solutions, in terms of abatement, can be found (Carson, 2010). For economic growth to drive improved environmental quality, environmental intensity (e.g., emissions per unit GDP) must be decreasing due to composition or technique effects. The literature has not broadly resolved what mechanisms cause environmental intensity to change and whether or not that change is inevitable, but current research suggests a combination of increasing returns to scale in abatement technologies and demand-side pressures to implement environmental policy play a role.

In Australia, there is mixed evidence regarding the decoupling of environmental outcomes and economic growth. The subindices contained in the EPI, as well as indicators

related to water use, nutrient balance, carbon monoxide and volatile organic compounds, and protected areas suggest that economic growth is not associated in all cases with a decline in environmental indicators, as might be suggested by a rigid IPAT-type model that holds technology constant and does not include endogenous policy response to environmental pressures. However, our analysis of other components of the EPI, biodiversity, nitrogen oxides, large particulate matter, and (to a lesser degree) sulfur oxides suggest that economic growth does not lead to unambiguously positive environmental quality trends. In still other cases, such as CO<sub>2</sub>, there is limited evidence that an absolute decoupling may currently be underway. Table 3 provides a summary.

**Table 3. Summary of Environmental Indicator Decoupling in Australia**

<p><b>Environmental Improvement</b></p> <ul style="list-style-type: none"> <li>• Carbon Monoxide (CO)</li> <li>• Volatile Organic Compounds (VOC)</li> <li>• Applied Nutrients (Water Pollution)</li> </ul>
<p><b>Mixed Outcomes</b></p> <ul style="list-style-type: none"> <li>• Carbon Dioxide (CO<sub>2</sub>)</li> <li>• Particulate Matter 2.5 (PM2.5)</li> <li>• Water used in agriculture</li> </ul>
<p><b>Environmental Deterioration</b></p> <ul style="list-style-type: none"> <li>• Particulate Matter 10 (PM10)</li> <li>• Waste</li> <li>• Nitrogen Oxides (NO<sub>x</sub>)</li> <li>• Sulphur Oxides (SO<sub>x</sub>)</li> </ul>
<p><b>Inconclusive Impact</b></p> <ul style="list-style-type: none"> <li>• Protected Areas / Biodiversity</li> </ul>

*Source:* Authors' analysis. "Improvement" indicates strong decoupling and declining environmental impact; "mixed" indicates some evidence of strong decoupling along with evidence of weak decoupling (declining environmental intensity); "deterioration" indicates not evidence of decoupling.

Our analysis uses decomposition methods to understand what underlying growth factors are associated with observed trends in environmental quality over the past two decades. The role of population and economic growth on the environment—and the extent to which negative effects can be mitigated through technological change—is important in light of Australia’s expected growth patterns. The 2015 Intergenerational Report predicts that by 2055 Australia’s population will grow by 66 percent, to approximately 40 million, and real per capita GDP will grow by 1.5 percent annually (Australian Department of the Treasury, 2015). Although we urge caution interpreting predictions, based on these growth projects and our analysis Australia will see continued growth in nitrogen oxide emissions over the next 40 years if there are no significant policy or technology changes, since the population and GDP per capita drivers overwhelm reductions in emissions intensity. Continued mining activities using current technology will likely increase large particulate matter emissions, waste is likely to continue to increase, and pressure on biological resources is likely to continue given a lack of available technological substitutes for the habitat fracturing and land and marine disturbances associated with resource extraction. At least to date, these indicators have not been decoupled from economic growth. To do so, based on these projections, would require a reduction in the impact intensity of GDP of just over two percent per year in order for impact to remain constant.

In contrast, for some criteria pollutants such as carbon monoxide and volatile organic compounds, declines in emissions intensity between 1990 and 2012 were sufficient to dominate increased emissions related to output, and we would expect this trend to continue if Australia’s economy continues to grow at rate comparable to the past 20 years. This absolute decoupling likely happened due to a combination in changes in technology, policy, and demand-side pressures that accompanied the growth process.

Still other indicators of environmental quality fall somewhere in between. For example, since 2008, CO<sub>2</sub> emissions in Australia have been stable or declining, at least in part due to the anticipation and implementation of a carbon tax which was subsequently abandoned after two years. Only time will tell if the technological, economic, and policy conditions necessary to maintain this trend will persist into the future as energy demand naturally grows with economic activity, and Australia continues to exploit its considerable fossil fuel resources.

The coupled human-natural system in Australia is a series of complex relationships between the resource- and service-providing natural world, the endowments, institutions, and preferences of Australian society, and technologies that transform labor and capital into valuable goods and services. These relationships are varied and interrelated, a point reinforced by our analysis and much of the recent literature growth and the environment (Brock and Taylor, 2005). It is difficult, if not impossible, to forecast future economic/environmental development paths. However, we do know that the effect of growth on the environment is not pre-ordained, rather it is at least partially controllable through policy choices that would ideally balance the benefits of growth in economic activity with the potential damages caused by pressures placed on the ecosystem through human interactions.

Although we know of no single guiding document for policies to manage the environment-growth relationship, the OECD (2012) provides insights that are relevant to Australia. The report, “Towards a Green Investment Policy Framework,” is designed to help governments implement policies to achieve both growth and improved environmental quality. Another OECD report from 2010 sets out a framework for developing regulatory policy targeted at sustainable growth and provides a review of regulatory policies of the 15 EU member states

(OECD 2010). These documents may provide useful insight for the Australian government as it develops and revises policies to manage the growth-environmental quality relationship.

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## **Appendix A. Development and Components of the EPI Indicators**

Chapter 6 in Hsu, et al. (2013) documents the “proximity to target” methodology as used in the 2012 EPI. According to this document, there were five major types of sources used in the

index to establish the relevant policy goals: treaties or other internationally agreed-upon goals, standards or recommendations set by international organizations, leading natural regulatory requirements, expert judgment from scientific consensus, and ranges of values observed in the data over time (Hsu, et al., 2013, p. 56). To normalize, the “worst-performing country usually established the low performance benchmark” of zero for a particular indicator, while the high-level score of 100 was typically based on international standards (Hsu, et al., 2013, p. 56). This allowed the creators to normalize across countries on a bounded scale.

The following outline, drawn from Figure 6.2 in Hsu, et al. (2013), describes the objectives, policy categories, and indicators of the 2012 EPI.

#### **Environmental Health** (Objective)

- ***Environmental Health*** (Policy Category)
  - Child Mortality (Indicator)
- ***Air: Effects on Human Health*** (Policy Category)
  - Particulate Matter (Indicator)
  - Indoor Air Pollution (Indicator)
- ***Water: Effects on Human Health*** (Policy Category)
  - Access to Sanitation (Indicator)
  - Access to Drinking Water (Indicator)

#### **Ecosystem Vitality** (Objective)

- ***Air: Ecosystem Effects***(Policy Category)
  - SO<sub>2</sub> per Capita (Indicator)
  - SO<sub>2</sub> per \$ GDP (Indicator)
- ***Water Resources: Ecosystem Effects*** (Policy Category)

- Change in Water Quantity (Indicator)
- ***Biodiversity and Habitat*** (Policy Category)
  - Critical Habitat Protection (Indicator)
  - Biome Protection (Indicator)
  - Marine Protected Areas (Indicator)
- ***Agriculture*** (Policy Category)
  - Agricultural Subsidies (Indicator)
  - Pesticide Regulation (Indicator)
- ***Forests*** (Policy Category)
  - Forest Growing Stock (Indicator)
  - Change in Forest Cover (Indicator)
  - Forest Loss (Indicator)
- ***Fisheries*** (Policy Category)
  - Coastal Shelf Fishing Pressure (Indicator)
  - Fish Stocks Overexploited (Indicator)
- ***Climate Change and Energy*** (Policy Category)
  - CO<sub>2</sub> per Capita (Indicator)
  - CO<sub>2</sub> per \$ GDP (Indicator)
  - CO<sub>2</sub> per KWH (Indicator)
  - Renewable Electricity (Indicator)

Examination of the indicators that comprise the EPI shows that many of the same elements used in decomposition analysis appear in the index, including measures of intensity for carbon dioxide and sulfur dioxide. In addition, some indicators directly related to policy (such as

the habitat protection indicators) may move in opposite directions as more biologically-based indicators (such as overexploited fish stocks).