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EMISSIONS ABATEMENT OPTIONS FOR AUSTRALIA:

ASSESSMENTS AGAINST CRITERIA OF MAGNITUDE, COST AND QUALITY

APRIL 2014

ANU Climate Change Institute
ANU Energy Change Institute

Emissions abatement options for Australia: assessments against criteria of magnitude, cost and quality

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April 2014

Table of Contents

Summary

It is widely agreed that reductions in greenhouse gas emissions cannot be achieved effectively and efficiently by preselecting a few preferred abatement options. Rather, a broad suite of strategies is needed.

This report reviews the criteria for effective abatement, and their implications for the policy frameworks (including carbon pricing and complementary measures) that will allow the best options to emerge dynamically through economic, environmental and social forces.

It is critical that abatement options and policies be consistent with the multi-decadal and global nature of the climate-change challenge. Just as important as meeting the 2020 target is ensuring that policies from now to 2020 build a strong base for meeting the more ambitious targets needed in subsequent decades.

We consider a range of abatement activities in different sectors against three broad criteria: the *magnitude*, *cost* and *quality* of potential abatement. Of these, magnitude and cost are conventional metrics, but the "quality" of an abatement activity is a less widely used concept. Quality incorporates seven key attributes: verifiability, permanence, additionality, legal accountability, lead time, longevity, and ancillary benefits/costs. All of these bear significantly on the actual climate change abatement outcome of any proposed activity.

The power, transport, buildings and industry sectors offer significant opportunities that also deliver high-quality abatement against most or all of the above attributes. There are major opportunities through demand reduction, driven by energy efficiency. By contrast, abatement options through soil carbon and land management have significant quality problems, centred on verifiability, permanence and additionality. These land-sector options are unlikely to be long-term major contributors to climate-change mitigation in Australia and therefore cannot replace abatement options in the power, transport, buildings and industry sectors. Geological carbon capture and storage can be discounted on cost, risk and feasibility grounds.

An assessment of abatement options carries policy implications. First, a well-designed price on carbon is essential; a subsidy scheme alone such as "Direct Action" is likely to produce considerably inferior outcomes. Second, complementary policy measures alongside a carbon price are also essential, including (a) support for longer-term, high-quality supply-side abatement (through the Renewable Energy Target and by other means); (b) support for demand-side energy efficiency, through regulation, performance standards and incentives; (c) support for enabling R&D; (d) public consultation and information provision.

1 Introduction

This short report assesses a number of abatement sectors and options against criteria of magnitude, cost and especially quality (encompassing verifiability, permanence, additionality, legal accountability, lead time, longevity, and ancillary benefits/costs). As well as these criteria we focus on the policy frameworks that will allow the best options to emerge dynamically.

The origin of the report was a request in November 2013 from the Minister for the Environment, the Hon Greg Hunt MP, for a brief assessment of emission abatement options to meet the emissions reduction target of the Australian Government. target of a 5% emissions reduction by 2020, referenced to 2000.

Section 2 of the report provides a short overview of the abatement challenge; Section 3 establishes criteria and assesses abatement sectors and options; Section 4 places the options into the context of abatement policy; Section 5 considers key examples; and Section 6 offers conclusions

2 The abatement challenge

Emissions reductions to mitigate against dangerous climate change are a long-term, multi-decadal challenge. There is a near-proportional relationship between cumulative anthropogenic emissions of carbon dioxide (CO_2) emissions and global warming (IPCC 2013, Meinshausen *et al.* 2009, Raupach 2013). This means that there is a global cap or quota on the total amount of CO_2 that can be emitted to the atmosphere if climate change is to be limited to any given warming threshold, such as 2 degrees Centigrade since 1850 (Schellnhuber *et al.* 2006). For a 2-degree threshold, more than half of the quota has already been used (Figure 1). To stay within this emissions quota, steep reductions in global emissions of CO_2 and other greenhouse gases are required through the 21st century, at rates of 3% per year or more (Raupach *et al.* 2011). The required rate of mitigation increases rapidly with any delay in starting the global mitigation effort.

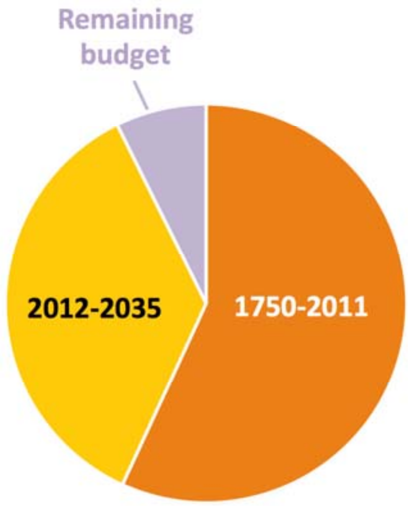

Figure 1: The global carbon quota or "carbon budget" to limit warming to 2 degrees Centigrade from pre-industrial times. More than half the quota has been used already; business-as-usual emissions (with continued emissions growth) would see almost all of the remainder used by 2035. Source: IEA (2013a).

Australia has set a target for greenhouse gas (GHG) emissions of a 5% reduction by 2020, referenced to 2000. This is a very modest aspiration in comparison with the requirement for developed countries: a higher target (15-25%) would be more consistent with a global 2-degree threshold (Climate Change Authority 2013). The importance of the long-term nature of the emissions reduction challenge is that 5% by 2020 is only the start of the effort: just as important as meeting the 2020 target is that policies from now to 2020 build a strong base for meeting the necessary more ambitious targets in subsequent decades.

Australia's annual GHG emissions increased from 1990 to 2012 by 33% when the Land Use Change and Forestry sector (LUCF, the sum of deforestation and afforestation) is excluded. When LUCF is included, total emissions are higher but the increase over 1990-2012 is much smaller because of a large decrease in LUCF emissions over that period – the reason that Australia has been able to meet its Kyoto Protocol target.

The Australian emissions inventory (Commonwealth of Australia 2013b) breaks total emissions into nine inventory sectors. In 2012-13, their shares of total emissions were: electricity (32%), transport (16%), other stationary energy (16%), agriculture (16%), deforestation (9%), fugitive emissions (8%), industry (5%), waste (2%), afforestation (–4%). Over the five years 2008-2013 there have been declines in electricity and deforestation emissions, offset by increases in fugitive, transport and other stationary energy emissions (Figure 2).

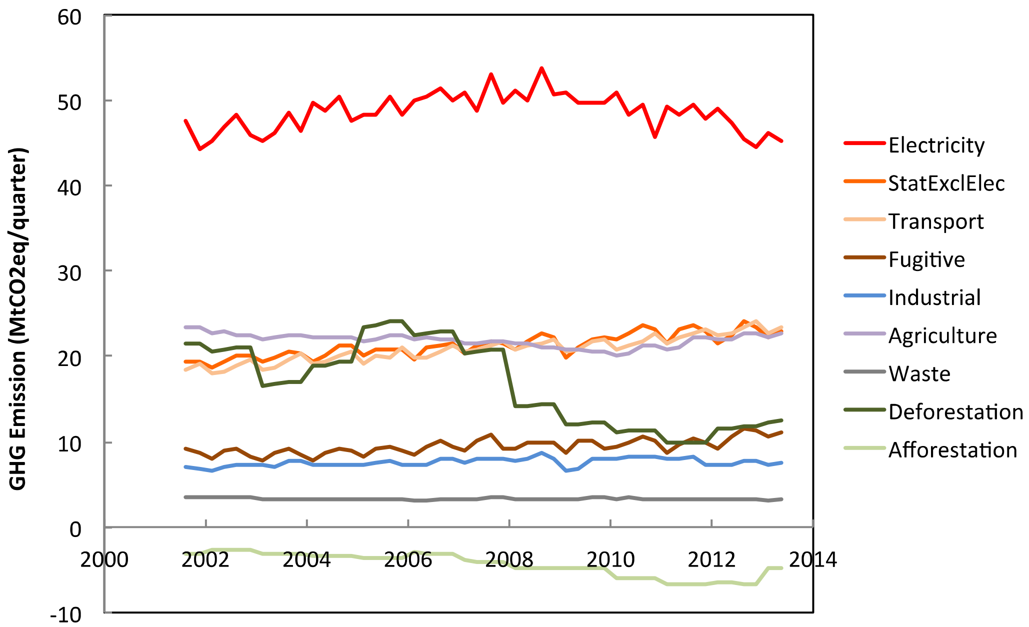

Figure 2. Quarterly greenhouse gas emissions for Australia for September 2001 to June 2013, for the following sectors: electricity, stationary energy excluding electricity (StatExcElec), transport, fugitive emissions, industrial, agriculture, waste, deforestation and afforestation. LUCF is the sum of deforestation and afforestation. "Original" data from Commonwealth of Australia 2013b.

The latest estimates of Australia's abatement task, given a 2020 target of a 5% emissions reduction, are as follows (from Commonwealth of Australia 2013c): emissions in 2000 (including LUCF) were 586 $MtCO_2e/y$, implying a 2020 target of 555 $MtCO_2e/y$. Actual emissions in 2012-13 were 545 $MtCO_2e/y$. Under a business-as-usual (BAU) scenario for economic growth and emissions increase, projected emissions in 2020 would be 685 $MtCO_2e/y$, implying an abatement requirement of 130 (= 685 – 555) $MtCO_2e/y$ in 2020. When the abatement requirements of earlier years are also included, the cumulative abatement requirement for 2014-2020 is 431 $MtCO_2e/y$.

3 Potential abatement activities

3.1 Scope and criteria

Table 1 lists over 30 broad abatement options, grouped into seven major abatement sectors: power, transport, buildings, industry, waste, agriculture, and forestry. We have excluded geological carbon sequestration, which is by now has been widely ruled out due to high cost and risks (IEA 2013a). The abatement sectors in Table 1 differ from emissions-inventory sectors (Figure 2) because the inclusion of both supply-side options (such as power generation technologies) and consumption-side options (such as efficiency measures) in the abatement portfolio; by contrast, inventory sectors are linked to the sites of actual emissions. In global emissions budgets there is a similar distinction between territory-based and consumption-based budgets (Le Quéré *et al.* 2013, Peters *et al.* 2011).

Solar PV: distributed	**Solar PV: large-scale**	**Concentrated Solar Thermal**	**Wind**
Cogeneration (combined heat and power)	**IGCC, other enhanced coal technologies**	**Fuel substitution**	**Bioenergy for electricity**
Off-grid electricity efficiency	**Geothermal**	**Nuclear**	
Solar hot water	**Efficient building heating, cooling**	**Efficient appliances**	
Energy, GHG efficiency industrial processes	**Energy, GHG efficiency in chemical processes**	**Removal of fuel subsidies**	
Transport demand management	**Fuel consumption standards**	**Transport fuel substitution (hydrids, LNG, biofuel)**	**Incentives for hybrid, electric drives**
Recycling	**Capping landfills**	**Waste gas recovery from landfills**	**Limit fugitive emissions**
Avoided deforestation	**Afforestation**	**Forest management**	**Fire management**
Managing soil carbon in croplands, rangelands	**Anti-methane-emission treatments for livestock**		

Table 1: Listing of some broad abatement activities. PV = photovoltaic, IGCC = Integrated gasification combined cycle. Colours denote abatement sectors: power (orange), buildings (yellow), industry (pink), transport (grey), waste (violet), forestry (green), agriculture (aqua).

There are three broad criteria for assessing abatement options: the *magnitude*, *cost* and *quality* of potential abatement. Of these, magnitude and cost are conventional metrics that have formed the basis of many published abatement cost curves (for example McKinsey&Company 2008, ClimateWorks 2011). However, the concept of abatement quality is not yet widely used. An abatement of 1 tonne of CO_2e does not achieve the same result for the atmosphere and the climate, irrespective of the abatement activity.

"Abatement quality" is determined by the attributes of an abatement activity that bear on its long-term mitigation outcome. The following seven attributes are important.

1. *Verifiability* is the confidence with which emissions or sequestration, and therefore abatement, can be measured for a particular activity. Verifiability is a biophysical attribute, and does not include uncertainties around BAU emissions. For instance, verifiability is usually good for

emissions and abatement in the power sector because of effective inventory practices. Conversely, it is poor for many land-based activities because of measurement problems associated with variations of processes with location, time, management practices and natural influences on carbon turnover in landscapes.

2. *Permanence* is the extent to which GHGs removed from the atmosphere by abatement will stay out of the atmosphere in future, and not physically leak back. Permanence is an issue for abatement activities based on CO_2 sequestration, either biological or geological. Indicatively, good permanence would keep CO_2 out of the atmosphere for hundreds of years, poor permanence for few years.
3. *Additionality* is the extent to which an abatement activity yields emissions reductions additional to what would have occurred in its absence. Thus, the activity must produce reductions beyond those due to either natural processes (such as the natural land carbon sink) or normal technological improvements (such as continuation of past improving trends in emissions intensities). Difficulties in defining BAU trajectories cause problems with identifying and assuring the additionality of many abatement options.
4. *Legal accountability* is the extent to which an abatement activity can be accounted under existing and future legal governance of emissions reduction activities, both national and international.
5. *Lead time* is the start-up time required for an abatement activity.
6. *Longevity* or lifespan is the time over which an action now will continue to be effective before replacement or renewal (such as the turnover time of energy generation plant). Indicatively, a good lifespan would be 50 years or more, a poor lifespan would be less than a decade.
7. *Ancillary benefits/costs* refer to economic, social and environmental benefits or costs of an abatement action, beyond its direct GHG impacts. These arise through the close nexus between climate, energy, water, food, ecosystems and human wellbeing (PMSEIC 2010, Pittock 2011).

All of these attributes bear significantly on the actual abatement outcome of an activity, measured through its overall mitigating effect on climate change. Adequate abatement quality, and therefore the success of the overall abatement effort, is assured by an adequate regulatory framework for the governance of abatement policy. This is one reason why the financial mechanisms supporting abatement (such as carbon pricing) need to be complemented by appropriate regulation.

3.2 Broad sectoral patterns

Although there is wide variation in the above criteria among specific abatement activities (Table 1), some broad patterns are evident at sectoral level.

1. *Power (including electricity generation, heat and other stationary energy generation):* Abatement opportunities in the power sector are often large in magnitude because of the large shares in Australia's GHG emissions inventory from electricity (32%) and other stationary energy (16%). These activities deliver high-quality abatement against most or all attributes, through leading-edge renewable energy and other near-zero-carbon technologies such as nuclear power. Abatement in the power sector is absolutely essential for the sustainable, long-term reductions in emissions that are necessary if Australia is to play its part in meeting global climate goals and emissions reduction targets (Section 2). Assessments of Australia's energy future show that a mix of technologies will be required, including major contributions from renewables (Wright and Hearps 2010, Graham *et al.* 2013), and that many of these technologies are available at increasingly competitive costs (BREE 2012, BREE 2013).

2. *Transport (private and public, personal and commercial):* Representing 16% of Australia's emissions inventory, the transport sector offers large-magnitude abatement opportunities at low to moderate cost through fuel efficiency improvements, alternative drivetrains, fuel switching and encouragement of use of lower-carbon transport modes. High-quality abatement against most or all attributes is available.
3. *Buildings (residential and commercial, including heating, cooling and appliance use):* There are large, low-cost abatement opportunities in the building sector through reduction in power demand, because this sector incorporates much of the consumption side of the energy supplied by the power sector. Potential (and readily achievable) magnitudes in this sector therefore tend to be high. Costs also tend to be low, because of numerous energy efficiency opportunities with rapid return on investment. Further, opportunities in the building sector deliver high-quality abatement on most quality attributes, provided that they are undertaken rapidly enough to significantly exceed historic rates of efficiency improvement.
4. *Industry (resource extraction, manufacturing):* Direct emissions from industrial processes represent 5% of Australia's inventory, but opportunities in this sector are large because of two factors: first, industrial activities embody the consumption side of a substantial part of the energy produced in the power sector, so there are low-cost and high-quality abatement opportunities through demand reduction by energy and GHG efficiency improvements. Second, fugitive emissions from extraction of coal, natural gas and coal seam gas are a significant (8%) and increasing part of Australia's inventory (Figure 2). As in the building sector, many abatement opportunities in this sector tend to be of low to moderate cost and high quality, provided they exceed historic rates of efficiency improvement.
5. *Waste (processing, storage):* Waste emissions, mainly from landfills, represent 2% of Australia's inventory. There are abatement opportunities in this sector at low to moderate cost, and with moderate to high quality on most attributes.
6. *Agriculture (soil carbon, land management, livestock methane, fertiliser emissions):* The agriculture sector accounts for 16% of Australia's inventory, with significant contributions through non-CO_2 emissions (methane from livestock and nitrous oxide emissions associated with fertiliser use). There are substantial abatement opportunities from reducing these non-CO_2 emissions, at low to moderate cost and with high quality by most quality attributes. By contrast, abatement options through soil carbon and land management have significant problems with many of the attributes of abatement quality, as discussed below in more detail.
7. *Forestry (reduced deforestation, afforestation, forestry management):* Deforestation accounted for 9% of Australia's emissions in 2012-13, having declined from fractions as high as 20% around 1990. Afforestation was –4% of 2012-13 emissions (negative because afforestation leads to net CO_2 removal from the atmosphere). Thus LUCF (deforestation + afforestation) accounted for a modest net 5% of Australia's emissions in 2012. There are some abatement opportunities in this sector through afforestation and continued reduction of deforestation. However, like soil carbon and land management in the agriculture sector, these opportunities have significant problems in abatement quality through many of its component attributes, further discussed below.

4 Enabling abatement

An evaluation of abatement options necessarily carries implications for the policy framework that these options inhabit. There are four key dimensions: financing abatement, incentives, regulation and public participation.

1. Financing abatement – subsidies versus carbon prices: There is a strong consensus among economists and international organisations that a broad pricing mechanism which is well designed and focused on creating long term carbon prices is the best policy for reducing greenhouse gas emissions (OECD 2013b, OECD 2013a, McKibbin 2012, Jotzo 2012). A gradually increasing carbon price would see Australia transition to a low-carbon economy at low economic cost.

Carbon trading markets and carbon taxes are not new ideas. The practical design of carbon trading and tax systems cover a wide spectrum of options, debated by McKibbin and Wilcoxen (2002), Nordhaus (2006), Pizer (2002), Pezzey (2003), and Pezzey and Jotzo (2012), among others.

By generating a credible future carbon price, the key objective of carbon pricing is to encourage the abatement of carbon emissions through changes in practices, deployment of existing technologies to reduce emissions, and development of new technologies. In addition, the markets created need to be well designed with appropriate institutions for monitoring and enforcement. The policy should also create constituencies throughout the economy that reinforce the existence of the framework.

So far the record of carbon pricing mechanisms has been disappointing in a number of cases, in particular with regard to ambition and durability of schemes. The political failure of Australia's carbon pricing mechanism and the current problems in the European trading system demonstrate how faulty design due to political rather than economic considerations can destroy many of the benefits of carbon pricing versus other approaches to carbon abatement policy. Policy uncertainty due to anticipated changes in policy can further reduce effectiveness and impede investment (Jotzo *et al.* 2012). Nonetheless the evidence is clear that carbon pricing, if well designed, is a much lower cost policy than the alternative of subsidies (McKibbin *et al.* 2011). If market participants have a reliable expectation of future carbon prices, they will implement the cheapest ways of reducing emissions.

Burke (2014) argues that from an economic perspective, a subsidy scheme for carbon abatement such as the Emissions Reduction Fund (Commonwealth of Australia 2013a) is unambiguously inferior to carbon pricing. This is so for at least twelve reasons: (1) it is not least-cost; (2) BAU baselines are impossible to estimate reliably; (3) genuine emissions reductions cannot be identified (that is, the additionality requirement cannot be assured); (4) leakage is inevitable without a cap on total emissions; (5) there are time-frame problems with a five-year scheme that may discriminate against essential long-term projects, and may lead to emissions rebounding after project completion; (6) it invites a "subsidy culture"; (7) it imposes a fiscal burden on the Commonwealth; (8) it is administratively very complex; (9) it perpetuates uncertainty; (10) it sets a bad precedent to subsidise negative externalities, creating perverse incentives; (11) it is not scalable upward to address the long-term policy challenge of climate change; (12) it sends a strongly adverse international signal to other mitigation efforts around the world.

2. The role of incentives: In order to drive abatement more rapidly (or in the case of market failure to ensure that abatement occurs at all) incentives and performance standards, backed up by regulation, are needed to complement carbon price-based mechanisms. An important case in point is the Renewable Energy Target (RET), which mandates a goal for the share of renewable energy contribution, and drives this through the provision of tradeable certificates to act as an incentive to investors. Without this incentive, the reduced pace of investment would seriously compromise the prospects of reaching the 5% emissions reduction target by 2020.

At the same time, the learning rate for renewable energy capital costs is more rapid compared to fossil fuel generation, and as shown in the Australian Energy Technology Assessment (AETA) (BREE 2012, BREE 2013) will eventually enable the Levelised Cost of Electricity (LCOE) produced by renewables to supplant carbon-based sources. The use of regulation to provide incentives and performance standards will not only increase the rate of abatement, but will also accelerate the production rate of renewables and shift the price more rapidly down the learning curve. The AETA also demonstrates that substitution of carbon-based energy by renewables occurs more rapidly under a carbon price. In addition, this favours lower-carbon fuel substitution (e.g. natural gas for coal) as well as other forms of zero-carbon energy production such as nuclear power; see the CSIRO eFutures project (Graham *et al.* 2013).

3. The role of regulation: A major role for regulation is to underpin a well-designed carbon price with institutions for monitoring and enforcement, reinforced by connections with constituencies throughout the economy. One important component of this role is to ensure that abatement quality (as defined by the seven attributes above) is monitored and maintained. This is essential to ensure that the overall abatement project achieves its climate-change mitigation goals.

4. The role of public consultation and information provision: In addition to technical, financial and regulatory dimensions, the uptake of abatement options depends on public acceptance and participation, and therefore on the building of essential social capital (Fischer *et al.* 2012, Raupach *et al.* 2013). This requires public consultation, negotiation and the provision of reliable information. A large percentage of Australian businesses have reported that a lack of skills and lack of relevant and reliable information are significant barriers to identifying and implementing energy efficiency opportunities (AIG 2012).

5 Two key examples

Here we discuss two examples of abatement options. The first, energy efficiency allied with electricity market reform, demonstrates the close linkages between carbon pricing and complementary measures including regulation, performance standards and incentives. This example shows the great opportunities that can be created.

The second example, the LUCF sector and carbon farming, carries an opposite implication: it demonstrates the need for caution in reliance on some abatement options because of difficulties with abatement quality. This example reinforces and the need for abatement quality to be safeguarded through an adequate regulatory framework.

5.1 Energy efficiency and electricity market reform

This example shows that that complementary policy measures, well designed and purposefully pursued, can achieve remarkable results. In California, electricity demand management policies for electricity utilities, combined with energy efficiency policies, have effectively flattened electricity demand and emissions from the electricity sector since the early 1980s (Rosenfeld 2008). The California Energy Commission estimates that building and appliance efficiency standards have saved a total of more than $56 billion in electricity and natural gas costs, equivalent to net savings of more than $1,000 per household; these savings go back into California's economy (Bernstein *et al.* 2000). By 2013, these measures are expected to save an additional $23 billion. This has been achieved whilst creating nearly 1.5 million jobs from 1977 to 2007 (Roland-Holst 2008).

Australia's energy and carbon efficiencies improved over the last decade more slowly than in most other developed countries (Figure 3). This shows that Australia could greatly benefit from (1) policy reform in the national electricity market to better incentivise investment in energy efficiency, and (2) demand management to meet peak electricity demand more cost effectively. It is possible to reduce annual peak electricity demand costs by $3-12 billion per annum in Australia through reform of the national electricity market (Dunstan *et al.* 2008), with associated emissions abatement.

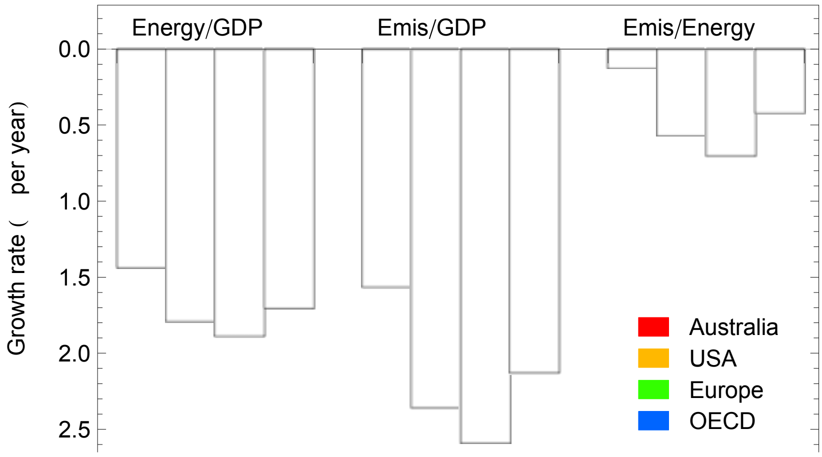

Figure 3: Comparison of rates of improvement over the decade 2003-12 of the energy intensity of the economy (GDP/Energy), the CO_2 emissions intensity of the economy (Emis/GDP) and the CO_2 emissions intensity of energy (Emis/Energy) for Australia, the USA, Europe and all OECD countries combined. The more negative the growth rate for each ratio, the more rapid is the rate of improvement. For all ratios, Australia has a less rapid rate of improvement than the other countries or regions shown. Calculation method follows Raupach *et al.* (2007), using updated data from IEA (2013b).

Performance standards also play a major part. It is significant that, at no extra cost to Australia, minimum energy-performance standards, as well as bans on the most energy-inefficient products, can positively influence the energy efficiency standards of both products used in Australia and also around the world. For instance, the Australian ban on inefficient incandescent light bulbs, commencing in 2007, was rapidly adopted by many countries and resulted within a few years in a virtual global ban. This contributed to changes in the manufacturing of lighting globally, reducing investment in the manufacturing of incandescent light bulbs and increasing investment in more energy-efficient models. This global ban of inefficient lighting has had significant flow-on effects by driving a change among lighting manufacturers in China to focus on more energy-efficient lighting products. This seemingly simple regulatory change in Australia could potentially result in net global GHG emissions reductions that exceed Australia's domestic emissions.

5.2 Abatement quality in the LUCF sector and carbon farming

Abatement in the LUCF sector and through carbon farming is widely cited as a major component of the climate policies of successive governments, through the Carbon Farming Initiative and in other ways. This has been motivated partly by assessments based on extensions of modelling tools used in plantation forestry (CSIRO 2009), which provide upper bounds for abatement potential. However, for most LUCF options there are significant issues with attributes of abatement quality.

Despite the success of the National Carbon Accounting System in tracking land clearing, *verifiability* remains a problem for below-ground carbon stocks including soil carbon and root biomass carbon, and also for above-ground biomass carbon in rangelands. *Permanence* is a key issue because terrestrial carbon is in continual exchange with the atmosphere on time scales of a few years, being lost from terrestrial carbon stocks to the atmosphere during droughts and regained in wet periods. These two-way natural exchanges of carbon are massive, exceeding the whole of Australia's accounted greenhouse gas emissions (Haverd *et al.* 2013a, Haverd *et al.* 2013b). The magnitude of these natural exchanges creates problems for verifiability because of the superposition of a small signal on enormous background fluctuations. There are also implications for *additionality*, because in lightly managed landscapes such as rangelands, much of the net uptake of carbon to terrestrial stocks is part of the natural terrestrial carbon sink that removes roughly 25% of all anthropogenic CO_2 emissions to the atmosphere each year (about another 25% being removed by the natural ocean sink – Le Quéré *et al.* 2009). *Legal accountability* is an issue because many of the abatement mechanisms in the Carbon Farming Initiative, including soil carbon, are not currently part of international protocols for emissions accounting.

Finally, there are major concerns with *ancillary benefits/costs* for some LUCF and carbon farming options. First, afforestation and reforestation strongly reduce water flows in catchments, so that reforestation in mid-to-high-rainfall areas (where sequestration potentials are highest) carries the downside that it significantly reduces water flows in rivers (Herron *et al.* 2002, van Dijk and Keenan 2007). This creates a “climate-energy-water nexus” with significant governance implications (Pittock 2011, Hussey and Pittock 2012, Pittock *et al.* 2013). Second, building up soil carbon also requires that other nutrients (nitrogen and phosphorus) be entrained in soil organic matter; without a supply of these other nutrients in farming systems, soil carbon cannot build up. Such a nutrient supply carries significant costs, and in some systems may not be available.

For all these reasons, abatement through LUCF and carbon farming activities is not as attractive as some policy views have maintained. In appropriate circumstances, afforestation, reforestation and building up soil organic matter are highly desirable land management practices for reasons to do with agricultural and forest production, and/or with ecosystem health. When undertaken for these reasons they may bring ancillary abatement benefits (bearing in mind the issues of verifiability, permanence and additionality), but it is not sustainable to rely on them as major components of Australia’s suite of abatement options to 2020 or beyond.

6 Conclusions

1. A well-designed scheme that places a price on carbon is essential in order to enable market forces to drive abatement.
2. This market mechanism needs to be supplemented by regulation, performance standards and incentives – such as provided under the Renewable Energy Target – in order to accelerate (or in cases of market failure to ensure) abatement.
3. There are good grounds for caution in investing in abatement options in the land sector through land-based carbon sequestration. Geological carbon capture and storage can be discounted on cost, risk and feasibility grounds.
4. The most significant abatement opportunities lie in the following sectors: electricity substitution with low/zero carbon sources, transport, buildings, industry and non-CO_2 agricultural emissions.

Appendix: Author profiles

Professor Michael Raupach, Director of the ANU Climate Change Institute, Fellow of the Australian Academy of Science, the Australian Academy of Technological Sciences and Engineering, and the American Geophysical Union; Chair of the "Australia 2050" project of the Australian Academy of Science.

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