A Framework for Economic Analysis of Greenhouse Abatement Options

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Abstract

Economic analysis has been central to the development of greenhouse abatement policy in Australia. Current Australian policy is to remain outside the Kyoto Protocol, while still attempting to meet the emission targets established under the Protocol. Australia's failure to ratify the Protocol has incurred international criticism; it is therefore appropriate to examine the validity of the economic analysis used to support this policy position. This paper reviews approaches to economic analysis that have been prominent in the greenhouse policy debate in Australia, including computable general equilibrium modelling, bottom-up energy sector modelling and policy-specific cost benefit analysis. Alternative approaches that have received less attention in Australia are also reviewed. Flaws in existing economic analyses include a failure to consider the net cost to society of greenhouse abatement measures, a tendency to exclude abatement benefits, inadequate consideration of ethical and moral issues, a lack of accessibility and the assumption that economic systems are in an optimal equilibrium state.

In response to these flaws, an alternative approach to economic analysis termed 'integrated abatement planning' is developed. Integrated abatement planning draws on the principles of least cost planning and integrated resource planning to identify least cost greenhouse abatement measures. A primary tool is the marginal abatement cost curve, which plots abatement measures according to their total abatement over a specified time period and the marginal cost of abatement. The approach is based on an explicit ethical position that values inter-generational and intra-generational equity. Integrated abatement planning is intended as a simple, practical approach that can be used by policy makers to explore the balance between long- and short-term objectives, to test the impact of varying assumptions, and to identify a robust set of measures for meeting politically determined greenhouse reduction targets. It draws on evolutionary economic theory, notably the insight that selected policies will always be sub-optimal but will provide opportunities for learning and continual improvement of policy. Integrated abatement planning offers a way to move beyond arguments about whether greenhouse abatement is required and to focus, more productively, on the best ways to achieve abatement.

1. Introduction

Economics has been defined as 'the study of how societies use scarce resources to produce valuable commodities and distribute them among different people' (Samuelson and Nordhaus, 2001, p.4). Consistent with this definition, economic analysis of climate change response focuses on how much, if any, of society's scarce resources should be dedicated to greenhouse abatement. This, in turn, depends on the value placed on avoiding the future impacts of climate change, or how valuable a commodity greenhouse abatement is perceived to be.

As the future impacts of climate change are uncertain, the value of greenhouse abatement is uncertain. Economic analysis of climate change must therefore address uncertainty. It must also address distributional issues, as the costs and benefits of greenhouse abatement are unevenly distributed over space and time. Economic approaches that fail to deal adequately with issues of uncertainty and distribution have little value in guiding the human response to climate change.

Unfortunately, most economic analyses of climate change take a narrow approach to uncertainty that fails to adequately address surprise events and catastrophes (Spash, 2002, p.19). Treatment of distributional issues is also poor. Temporal distribution of costs and benefits is addressed primarily by discounting future costs and benefits, which biases economic assessment towards the needs and wants of present generations. Inequity in the spatial distribution of costs and benefits is assumed to be a political concern that is beyond the scope of economic analysis (Spash, 2002). Diesendorf (1998) examines economic models of greenhouse abatement in Australia, and finds other fundamental flaws, including a tendency to estimate costs without benefits and a lack of transparency in model assumptions and structure.

Despite the evident flaws in existing approaches to economic analysis of climate change, policy positions have been developed and defended using economic arguments. Australia and the United States, in particular, have elected not to participate in the Kyoto Protocol partially on the basis that greenhouse abatement will harm their economies. It is appropriate to examine the validity of the economic analysis that supports these policy positions.

This paper briefly reviews the role of economic analysis in Australian greenhouse policy formation. Problems are identified with existing approaches to economic analysis of greenhouse abatement, and an alternative approach is developed in an attempt to address some of these problems. The alternative approach applies the principles of integrated resource planning to the task of achieving least cost greenhouse abatement, and could be termed integrated abatement planning.

2. Greenhouse Economics and Australian Policy Development

In Australia, economic models of greenhouse abatement have played a key role in shaping greenhouse policy; see Diesendorf (1998), Hamilton (2001) and Henman (2002) for a more detailed discussion of this role. This section reviews three common economic approaches used to assist policy development in Australia and two additional approaches that have not yet been widely applied in Australia.

2.1. Computable General Equilibrium Models

The most prominent models in Australian greenhouse policy development are top-down computable general equilibrium (CGE) models of the world economy, including:

- GTEM, developed by the Australian Bureau of Agricultural and Resource Economics (ABARE);
- G-Cubed, developed by the McKibbin Software Group; and
- MMRF-Green, developed by the Centre of Policy Studies at Monash University.

CGE models are used to estimate a future carbon penalty (in $/tonne) and/or the future impact on economic activity of specified levels of greenhouse abatement. They consider the aggregated behaviour of the whole economy and do not consider specific technologies. The models put a price on greenhouse gas (GHG) emissions and use an assumed price elasticity of energy demand to determine the degree of greenhouse abatement (Diesendorf, 1998).

To date, much of the focus of CGE modelling has been on the cost of Australian involvement in the Kyoto Protocol under varying assumptions about involvement by other countries, future commitments and the operation of emission trading regimes; see for example ABARE (2002), Jakeman et al. (2002) and McKibbin (2002). The MMRF-Green model focuses in more detail on regional impacts within Australia and has been used for a wider variety of applications, including modelling regional employment impacts of renewable energy promotion (The Allen Consulting Group, 2003).

2.2. Bottom-Up Models

Another type of economic model used in the greenhouse policy debate is the bottom-up model, typified by ABARE’s modified version of the MARKAL model; see Naughten (2003) for documentation and an application of MARKAL. The MARKAL model selects from a database the least cost mix of demand and supply side technologies to meet an externally specified demand for energy. In contrast with CGE models, specific technologies are explicitly included. Least cost abatement options for the energy sector are identified by running the model with imposed constraints on GHG emissions (Diesendorf, 1998). The results depend heavily on the quality of the database of energy technologies, particularly the assumptions made about the costs of different technologies and how those costs will change over time. MARKAL can model market constraints within the energy sector, but does not model the wider economic impacts of changes within the energy sector (Naughten, 2003).

2.3. Policy-Specific Cost Benefit Analysis

A third type of analysis used to assess the economic impact of greenhouse abatement in Australia is detailed cost benefit analysis (CBA). The economic analyses prepared to assess the impact of new or revised Minimum Energy Performance Standards (MEPS) for electrical appliances typify this approach; see for example GWA

(2000) and GWA (2001b). The total costs and benefits of the policy proposal are estimated and a benefit-cost ratio is calculated. A positive ratio indicates that the policy proposal will have a net benefit. CBA often relies on spreadsheet models to assess policy-specific economic impacts but can incorporate results from more complex models.

2.4. Hybrid Models

Hybrid models have been developed internationally that combine aspects of the top-down CGE models and bottom-up models. An example is the Prospective Outlook on Long-Term Energy Systems (POLES) model developed by researchers in the European Union. The POLES model is a world simulation model for the energy sector that divides the world into regions, one of which comprises Australia and New Zealand. As for top-down models, energy prices play a key role in the adjustment of the model. However, the degree of detail with which technologies are treated is more consistent with bottom-up models (Criqui, 2001).

Hybrid models are commonly used to construct marginal abatement cost curves (MACCs) on a regional basis, which can then be used to estimate international emission permit prices and total abatement costs (Klepper and Peterson, 2003). Hybrid models have not yet been prominent in the development of Australian greenhouse policy but could play a greater role in the future.

2.5. Evolutionary Economics

Evolutionary economic theory is concerned with economic change and is a response to the neo-classical economic focus on comparing different equilibria, usually within a static framework (Mulder and van den Bergh, 2001). The evolutionary approach ‘focuses attention on irreversible, path-dependent change and long-run mutual selection of environmental and economic processes and systems’ (Mulder and van den Bergh, 2001, p.110). Such an approach is ideally suited to economic analysis of greenhouse abatement, a task that will require adaptive action over a long period of time.

An evolutionary approach acknowledges that abatement policies will be sub-optimal and therefore focuses on ongoing adaptation and learning through policy innovation and experimentation. It also encourages a diversity of policy responses and energy technologies, as a way of improving the resilience and flexibility of the energy system (Ring, 1997). The application of evolutionary economic theory to climate change policy is still largely at a theoretical stage but shows promise for the future.

3. Problems with Existing Economic Approaches to Greenhouse Policy

3.1. Consideration of Total Cost to Society

Bottom-up models and CBA rely on estimation of the cost of specific greenhouse abatement technologies and/or policies. The choice of costs to include often lacks a strong theoretical basis, which can result in inaccurate estimation of the total cost to society of an abatement option. As an example, the Regulatory Impact Statement (RIS) on revised MEPS for small electric storage water heaters, released by the AGO in 2001, identifies the main benefit of revised MEPS as ‘the value of the electricity saved’ (GWA, 2001a, Chapter 4). The RIS then goes on to estimate this benefit and uses it to calculate a benefit-cost ratio to assist in determining whether revised MEPS should be introduced.

The RIS fails to note that a reduction in electricity consumption will also reduce the revenue received by electricity suppliers. The cost of the revenue foregone by suppliers is equal to the benefit received by customers and the net benefit to society is zero; there is simply a transfer of wealth from electricity suppliers to electricity customers. The real economic benefit of a reduction in electricity demand is the avoided marginal cost of supplying that demand, which comprises the operating cost of electricity supply and any cost associated with augmenting the electricity supply system. This confused approach to CBA of greenhouse abatement programs is also evident in other RISs released by the AGO. A ‘whole of society’ cost framework is essential to determine the true costs and benefits of greenhouse abatement programs.

3.2. Exclusion of Benefits from Economic Analysis

Most economic analyses of climate change conducted in Australia consider the cost of greenhouse abatement but ignore the benefits. The primary benefit of a greenhouse abatement program is a reduction in the severity of climate change impacts. However, greenhouse abatement programs can also stimulate employment and regional investment (MacGill and Watt, 2002, Watt and MacGill, 2002) while helping to drive innovation, establishing new industries with strong export potential, reducing fossil fuel imports and providing other environmental and health benefits (Diesendorf, 1998). The exclusion of these benefits from economic modelling distorts the true cost of abatement programs by focusing on the negative impacts and ignoring the positive. Economic arguments characterised by this unbalanced perspective are frequently used to justify a lack of strong action on climate change.

3.3. Approach to Ethical and Moral Issues

A common justification for exclusion of benefits from economic analyses of greenhouse abatement is the difficulty of valuing climate change impacts in monetary terms. This justification has some merit; the exact impacts of climate change, and their distribution across regions and economic sectors, are uncertain. It is likely that the impacts will include loss of human life, forced human migration, and diminished biodiversity. Valuation of such impacts is controversial (Spash, 2002) and introduces ethical concerns to economic analysis. What is the value of a human life, or the existence of another species? Does the value remain the same in different parts of the world? Contingent valuation can give a monetary value in response to such questions but does not remove the controversy.

The uneven temporal distribution of the costs and benefits of greenhouse abatement introduces related ethical concerns. In most economic analyses of greenhouse abatement, future values are discounted at a constant rate. The theoretical justification for discounting is the higher value placed on a given sum that is available in the present, relative to the same sum that is available in the future. The rationale is that a sum that is available in the present can be invested at the prevailing rate of return and will therefore be worth more in the future. In purely economic terms, this is a rational approach to comparison of values over time.

However, as most of the costs of climate change will be experienced in the future, while many of the costs of abatement fall closer to the present, the choice of discount rate implies an ethical decision about intergenerational equity. If intergenerational equity is taken seriously, future generations have as much right to inherit a stable climate as current generations. Devaluing the future costs of climate change unfairly shifts the burden of abatement to future generations.

There is an argument that future generations will be better placed to reduce the costs of climate change, as technological development will have provided cheaper abatement options than those available today. However, this argument fails to consider the lag in the response of the climate system to current GHG emissions. By the time the costs of climate change are felt, it is too late to abate the emissions that caused them. On this basis, ‘the use of discounting to reduce distant values asymptotically to zero appears morally vacuous’ (Spash, 2002, p.19).

Existing approaches to economic analysis of greenhouse abatement in Australia provide no real guidance on how to address the ethical and moral concerns introduced here and, in most cases, do not even acknowledge that such concerns exist.

3.4. Accessibility of Models

Many CGE, bottom-up and hybrid models are characterised by a high degree of complexity and a large number of assumptions. Both of these characteristics make it difficult for policy-makers to interpret modelling results with full confidence. Interpretation is even more difficult for the general public. The problem is exacerbated by a tendency not to clearly state all modelling assumptions and to provide limited detail about the operation of the model (Diesendorf, 1998).

Henman examines the interactions between computer models and greenhouse policy in Australia and argues that the growing complexity of the models ‘constrains the capacity for the conduct of democratic politics’ (Henman, 2002, p.161). The lack of transparency in model assumptions makes it difficult to publicly contest model results and facilitates the use of models to construct partisan political views. This points to a need to develop simple accessible tools for policy development that do not constrain wider involvement in policy debate. Such approaches should be fully transparent and accessible to a wider range of stakeholders.

3.5. Value for Policy Design

CGE models and hybrid models, which focus on price-based mechanisms to achieve greenhouse abatement, have little value for design of specific greenhouse abatement measures. Bottom-up models focus purely on technological options and tend to ignore the role of institutional change and other non-technical factors in achieving successful greenhouse abatement. CBA approaches are the most useful for considering the role of institutional change in promoting greenhouse abatement. However, CBA focuses on specific policy proposals and therefore needs to be embedded in a wider framework if least cost abatement measures are to be identified.

3.6. Assumption of Economic Equilibrium

Existing neo-classical economic models are fixated on equilibrium conditions (Nelson and Winter, 2002). They neglect to consider that the current system may not be optimal due to lock-in of technologies as a result of historical conditions, and provide no guidance on how to move away from a locked-in system (Mulder and van den Bergh, 2001). The dominance of fossil fuels in the energy sector is a clear example of lock-in (Unruh, 2000). Neo-classical economic models also systematically underestimate potential double dividends associated with environmental tax reform because such changes are non-marginal (Mulder and van den Bergh, 2001, p.127). For example, they deal poorly with the distribution of carbon tax revenue to decrease tax burdens in other areas. Greenhouse abatement requires a fundamental shift in technological systems, and is more consistent with evolutionary economic approaches than equilibrium approaches.

3.7. Developing an Alternative Approach

The remainder of this paper develops a simple, practical approach to economic analysis of greenhouse abatement options that attempts to address the problems discussed above. The focus throughout is on greenhouse abatement in the energy sector, however the approach should be equally applicable to other sectors. The approach is based on a ‘whole of society’ cost framework, and gives consideration to the benefits of greenhouse abatement. An ethical position is developed to guide the analysis and assumptions are clearly stated.

The proposed method is related to least cost planning and integrated resource planning; see Swisher et al. (1997) for an overview of these techniques. As the focus is not on the yield of a specific resource, such as energy or water, but on greenhouse abatement, a more appropriate term is integrated abatement planning (IAP).

The proposed IAP approach uses total abatement costs for different greenhouse abatement programs to develop marginal abatement cost curves (MACCs), which can be used as a tool for policy development. Temporal distribution of benefits and costs is treated explicitly when formulating MACCs. A range of MACCs can be developed to assess different assumptions under different scenarios. MACCs developed using detailed hybrid models could be compared to MACCs developed through IAP as a means of validating the results.

The IAP approach incorporates some of the important insights from evolutionary economic theory. In particular, it recognises that the selected policies will be sub-optimal but will provide opportunities for learning and continual improvement of policy.

4. Incorporating Ethics

An ethical principle that can guide the human response to climate change is the precautionary principle. The future costs of climate change are uncertain, as the effect of interfering with the operation of atmospheric cycles is unpredictable. In the absence of evidence that GHG emissions are safe, the precautionary principle requires present generations to reduce emissions to levels that are known to be safe. This would require global emission reductions of greater than 60 per cent (Watson, et al., 1990).

The next ethical problem is to determine how the burden of emission reduction should be distributed. Singer (2002) discusses the ethics of climate change in detail. He considers four separate ethical principles and concludes, after applying each of these principles, that developed nations have an ethical duty to reduce per capita GHG emissions to much lower levels. The economic advantages of the developed countries have been achieved, in part, through an uncompensated expropriation of the atmospheric resource that belongs equally to all of humanity. Singer proposes that nations should be allocated:

> equal per capita future entitlements to a share of the capacity of the atmospheric sink, tied to the current United Nations projections of population growth per country in 2050 (Singer, 2002, p.43).

This is a variant of the well-known ‘contraction and convergence’ approach, developed by Aubrey Meyer, in which all nations are required to reduce per capita emissions to an equal level by a target year (Meyer, 2000). The level to which emissions should be reduced, and the target year, is open to debate. However, principles of intergenerational equity provide some guidance. If the current generation is to pass on a stable climate to future generations, then immediate global emission reductions of greater than 60 per cent are needed (Watson, et al., 1990). Accepting that an immediate reduction of this magnitude is not feasible, many have called for a 60 per cent reduction in global emissions by 2050. This seems to strike a reasonable balance between the needs of present and future generations.

The idea that people have equal rights to the atmospheric sink is strongly defensible on ethical grounds, and the contraction and convergence approach has the advantages of simplicity and a strong potential to achieve support from developing nations. When combined with emissions trading, such an approach can reduce economic inequity between developed and developing nations by providing developing nations with a valuable resource: emission permits.

To determine what sort of economic burden this ethical approach might place on Australia, it is instructive to consider the results of CGE modelling conducted for the AGO. Despite the CGE model flaws discussed in Section 3, which tend to inflate predicted costs, the Kyoto Protocol is predicted to reduce GNP by a maximum of 0.51 per cent by 2020 (ABARE, 2002, McKibbin, 2002). Considering that the models set economic growth at around 3.7 per cent per year, these falls in GNP are insignificant compared to total projected growth in GNP of more than 100 per cent over the next two decades. It seems ethically indefensible to use a small fall in economic growth in a developed country to argue against greenhouse abatement when many in the developing world live below the poverty line.

If the notion that developed nations have an ethical duty to reduce per capita emissions to much lower levels is accepted, then the role of economic analysis in determining whether to allocate scarce resources to greenhouse abatement is diminished. The decision to pursue greenhouse abatement becomes, properly, an ethical decision. The role of economics, then, is to identify the least cost options to achieve a desired level of abatement. This is the purpose of IAP.

5. A ‘Whole of Society’ Cost Framework

This section develops a framework for identifying the total costs and benefits of a greenhouse abatement option. A clear framework is needed to avoid the confused approach to costs and benefits described in Section 3.1 and ensure that the costs and benefits to all stakeholders are considered.

For analyses focused on energy or water (or some other resource), the term ‘total resource cost’ (TRC) is often used (White and Howe, 1998). The TRC is the net cost to all stakeholders, on a ‘whole of society’ basis, of providing the resource. As the focus here is on greenhouse abatement, an equivalent term is the ‘total abatement cost’ (TAC). Any given abatement measure will have a stream of costs over time, so a more precise term is TAC_t, which is the net cost of a greenhouse abatement measure in year t. This stream of costs over time can be discounted, at discount rate r, to give a net present value (NPV) for TAC, as shown in Equation 1. When combined with a metric of the total abatement achieved by the measure, as discussed in Section 6.1, $\mathrm{TAC}_{\mathrm{NPV}}$ provides a fair basis to compare the cost of different abatement measures.

Equation 1:

$$TAC_{NPV} = \sum \frac{TAC_t}{(1+r)^t}$$

In determining the components of the TRC for water, White and Howe (1998) identify the stakeholders involved in water service provision as water service providers and customers. Their assumption is that the water service provider is a vertically integrated, state-owned organisation. This assumption does not hold for the energy sector, where deregulation and privatisation of the electricity and gas industries has split most of the vertically integrated energy utilities into numerous entities. Different organisations are responsible for electricity generation, energy transmission, energy distribution and retailing. These organisations include private companies and state-owned corporations and are subject to varying degrees of regulation.

Table 1 extends the analysis by White and Howe to the stakeholder groups affected by greenhouse abatement in the Australian energy sector. The table summarises the NPV costs and benefits potentially experienced by each stakeholder group when a greenhouse abatement measure is implemented. Each stakeholder group comprises multiple organisations or individuals that are amalgamated for convenience. A chain of energy generators, transmission network service providers (TNSPs), distribution network service providers (DNSPs) and energy retailers replaces the single service provider used by White and Howe. Equipment manufacturers are also included, as some abatement measures (e.g. appliance efficiency standards) will impact them.

The TAC will be the sum of all the costs and benefits (negative costs) listed in Table 1. Each type of cost or benefit is discussed in more detail below.

Table 1. NPV costs and benefits experienced by stakeholder groups affected by greenhouse abatement in the energy sector.

Parameter	***Stakeholder Group***						
	Government	***Generator***	***TNSP***	***DNSP***	***Retailer***	***Energy Customer***	***Equipment Manufacturer***
Costs	PC_{Gov}	PC_{Gen} FR_{Gen}	PC_T FR_T	PC_D FR_D	PC_R FR_R	PC_C	PC_M
	WEC						
Benefits	PB_{Gov}	PB_{Gen} AC_{Gen} AT_{Gen} AD_{Gen}	PB_T AC_T	PB_D AC_D AT_D	PB_R AC_R AG_R AT_R AD_R	PB_C AG_C AT_C AD_C AR_C	PB_M
	WEB ACOCC						

KEY

PC	Program Costs
PB	Program Benefits
FR	Foregone Revenue
AC	Avoided Cost (of energy supply)
AG	Avoided Generator Charges
AT	Avoided Transmission Charges
AD	Avoided Distribution Charges
AR	Avoided Retail Charges
WEC	Wider Economic Cost
WEB	Wider Economic Benefit
ACOCC	Avoided Cost of Climate Change

NOTES

$FR_{Gen} = AG_R + AG_C$
$FR_T = AT_{Gen} + AT_D + AT_R + AT_C$
$FR_D = AD_{Gen} + AD_R + AD_C$
$FR_R = AR_C$

5.1. Program Costs and Benefits

Program costs (PC) are the direct or indirect costs associated with the implementation of a greenhouse abatement program. Typical program costs include capital and recurrent expenditure on technology, program administration and staffing costs, costs associated with changes to the taxation regime, increases in customer energy bills and manufacturing costs, and the costs of any feasibility studies, regulatory assessments or evaluations required for the program. Program costs are not solely the cost of an abatement technology, but also the costs of any institutional changes required to smooth adoption of the technology. All of the stakeholder groups may potentially initiate a greenhouse abatement program or share in the cost of its implementation.

Most greenhouse abatement programs will not only have program costs, but also program benefits (PB). For example, the existing Mandatory Renewable Energy Target (MRET) scheme provides an increased revenue stream for generators through sales of Renewable Energy Certificates (RECs). Similarly, changes to the taxation regime will generally benefit either specific taxpayers or the government. Any of the stakeholder groups could potentially experience program benefits depending on the design of the abatement program.

Program costs and benefits are specific to a particular abatement program and are estimated by analysing the components and expected operation of the program. Capital and operating costs can be readily estimated; estimation of costs associated with changes in taxation regimes, manufacturing processes and energy prices may require a more detailed analysis.

5.2. Foregone Revenue and Avoided Charges

Customers buy energy either directly from generators (if they are large industrial customers) or through retailers that buy the energy from generators and package it for customers. If a greenhouse abatement program reduces customer demand for energy, for example by improving the efficiency of appliances and equipment, then generators and retailers will sell less energy than they would if the greenhouse abatement program were not implemented. This foregone revenue (FR) is a cost to the generator and/or retailer. Similarly, if less energy is transmitted and distributed through networks, then TNSPs and DNSPs will receive less revenue from the provision of network services.

Foregone revenue is defined as the difference between baseline sales (of energy, network services etc) and sales that would occur if the greenhouse abatement program were implemented. The baseline against which foregone revenue should be measured is discussed in more detail below.

The revenue received by each stakeholder is equal to the charges that each stakeholder imposes on other stakeholders. For example, generators charge retailers and/or customers for the supply of energy. If the generator foregoes revenue due to decreased energy sales, then the retailers and/or customers will not have to pay for as much energy as they otherwise would. The cost to the generator is equal to the sum of the benefits to retailers and customers.

The relationship between foregone revenue and avoided charges for each stakeholder is shown under 'Notes' in Table 1. Revenue received by TNSPs comprises charges to generators, DNSPs, retailers and large customers for use of the transmission system. Revenue received by DNSPs comprises charges to generators (embedded in the distribution system), retailers and large customers for use of the distribution system. Revenue received by retailers comprises charges to customers for energy purchased.

As the revenue foregone by one stakeholder is equal to the sum of the reduction in charges to other stakeholders, the foregone revenue and avoided charges have no net effect on the TAC. These transactions are transfer payments from one stakeholder to one or more other stakeholders. While the foregone revenue and avoided charges do not need to be estimated as part of the TAC, they are important for identifying stakeholders that will be negatively impacted by particular abatement programs. Foregone revenue can be estimated by multiplying an assumed price for energy services by the quantity of energy services that are foregone.

5.3. Avoided Cost of Energy Supply

The energy system is a dynamic system in which infrastructure is constantly retired, replaced or built. Maintaining the level of service provided by the energy system requires ongoing injection of funds. Current projections (e.g. Dickson et al. (2001)) show significant growth in energy demand in Australia over at least the next two decades, in response to increasing population and increasing economic activity. This means that, beyond the cost of maintaining and operating the energy system, there will be significant costs associated with expansion of the energy system. These costs include the costs of new power stations, gas and petroleum processing facilities, and electricity and gas networks.

If a greenhouse abatement program reduces energy demand (e.g. through energy efficiency improvements) or supplies energy (e.g. using renewable energy sources) then the cost of supplying that quantity of energy by alternative means will be avoided. To calculate the avoided cost associated with a greenhouse abatement program, the stream of energy supplied or conserved by the program over time must be known. The avoided cost will be the marginal cost of supplying the same stream of energy using a defined baseline energy infrastructure. Marginal cost and the choice of a baseline are considered in more detail below.

Marginal Cost of Supply

In determining the marginal cost of supply, a distinction is drawn between the short run marginal cost (SRMC) and the long run marginal cost (LRMC). The SRMC is the cost of delivering an additional unit of energy using the existing system, and is also known as the average production cost of supply (Fane and White, 2003). The SRMC does not include any capital costs, as it assumes that the additional supply is generated by the existing system, without the need for any augmentation of the system. This implies that the SRMC is only relevant when the energy system has spare generating or network capacity and additional capital investment is not required.

The LRMC is the cost of delivering an additional unit of energy when a share of the capital cost of the infrastructure needed for delivering the additional energy is included. The LRMC is also called the marginal cost of supply (Fane and White, 2003), and is the appropriate measure of the avoided cost of supply in a dynamic system.

Most of the costs of a base load power station are capital costs, and a portion of the operating costs are fixed costs that do not vary with quantity of electricity generated. The only cost in increasing generation from the power station, assuming it is not at maximum capacity, is the portion of the operating costs that is directly related to generation levels, mainly fuel costs. Thus, the SRMC is not much more than the cost of fuel. Similarly, the major costs associated with the transmission and distribution networks are capital costs. Transmitting or distributing an additional quantity of energy through existing networks costs very little, so SRMC is low. The LRMC can be significantly higher than the SRMC, as recovery of capital costs is included.

While there is general agreement that the LRMC is the appropriate measure of avoided cost, there is less agreement over the method that should be used to calculate it. Fane and White (2003) review methods and adopt the average incremental cost (AIC) method described by Mann et al. (1980). The same method is used here, which gives Equation 2 for AIC. C_t is the capital and operating cost in year *t* required to meet estimated additional demand, and E_t is the additional energy output in year *t*. The discount rate is *r*, and the numerator and denominator are the net present values of the stream of additional costs and energy over time, respectively.

Equation 2:

$$AIC = \frac{\sum C_t / (1+r)^t}{\sum E_t / (1+r)^t}$$

Choice of Baseline

The AIC gives an estimate of the LRMC. As noted by Fane and White, this estimate depends on the projected baseline demand for energy. Estimates will differ when differing timeframes and demand projections are used. The biannual Australian energy projections developed by ABARE provide a standard energy sector baseline for Australia. These projections give annual estimates of energy consumption and fuel mix through to 2019-20 under assumptions of business as usual in the energy sector (Dickson, et al., 2001). Short-term projections of baseline energy demand are also available for particular jurisdictions, such as the National Electricity Market (NEMMCO, 2002). These projections are less comprehensive, but more detailed, than the ABARE projections and can be used to supplement them.

Unfortunately, ABARE's projections lack sufficiently fine detail to assess the avoided cost and abatement potential of many greenhouse abatement programs. For example, to estimate the energy conserved by implementing MEPS for an appliance, it is necessary to compare appliance energy consumption after MEPS is implemented with the baseline appliance energy consumption. ABARE's projections provide estimates of the energy content of each fuel consumed in a particular sector, but do not break energy use down further into end uses. This means that the baseline appliance energy consumption is unknown.

Existing projections can be extended to cover specific end uses by making various assumptions about present and future patterns of energy consumption within a sector. However, this introduces additional sources of error into the projections. An alternative approach is to use a frozen efficiency baseline. A frozen efficiency baseline assumes that energy efficiency and fuel mix are frozen at the levels that prevail at the starting point of the analysis. Total demand may still follow ABARE's projections, but there is no fuel substitution or technological improvement. Every new unit of energy is supplied by a proportional increase in the magnitude of the energy system, without a change in average structure.

This greatly simplifies the estimation of the avoided cost and abatement potential of abatement programs, particularly demand-side programs, as the energy consumed by specific end uses can be more easily estimated. With a frozen efficiency baseline, there is no need to assume a pattern of energy consumption within a particular sector. Instead, the consumption associated with a particular end use can be specified using only assumptions about population, economic growth and demand for energy services. By reducing the number of assumptions, the potential sources of error are reduced.

The disadvantage of a frozen efficiency baseline is that it bears no relation to reality. It is a purely theoretical construct, so abatement costs that relate to a frozen efficiency baseline are not real. This disadvantage can potentially be addressed by estimating the cost of ABARE's baseline compared to the frozen efficiency baseline. Costs derived using the frozen efficiency baseline can then be adjusted relative to the baseline cost. This would ensure that the costs are related to a real baseline, while avoiding the problem of the lack of detail in the modelled baseline.

Estimating LRMC

When a frozen efficiency baseline is used, a constant mix of energy supply technologies will meet increased demand. The marginal demand for each type of energy supply technology is therefore known. This can be well represented by assuming construction of a typical energy supply plant (e.g. a coal-fired power station) is completed each time the marginal demand for that type of plant reaches the typical plant size. This will give a stream of capital and operating costs over time that can be used in Equation 2.

The timing of network capacity augmentation is more difficult to estimate, as it is related to power consumption (e.g. MW) rather than energy consumption (e.g. kWh). However, the ACCC and state regulatory authorities cap the revenue that TNSPs and DNSPs can earn. The regulatory decisions on allowable revenue are available, and include estimates of future capital and operating costs. These costs can be used to develop an estimate of AIC. Alternatively, data on the historical relationship between supply augmentation and network augmentation could be used to link future network capital costs to supply capital costs.

The LRMC of additional retail activity is the most difficult to determine due to the paucity of data on the components of retailing cost (BurnVoir Partners, 2001). Most retail costs will be fixed; marginal energy supply will have little direct influence on total cost. Administration costs may increase as the number of customers increases, but this is not necessarily related to growth in energy sales. The LRMC of retailing will therefore approach the SRMC; SRMC will give a reasonable (and conservative) estimate of LRMC for retailing.

5.4. Avoided Cost of Climate Change

As well as avoiding the cost of energy system augmentation, greenhouse abatement programs will reduce greenhouse emissions and therefore contribute to a reduction in the eventual impact of climate change. This is the major benefit of greenhouse abatement programs and the one that is most often excluded from economic analysis.

As discussed earlier, valuation of the impacts of climate change, which will include loss of human life, forced human migration, and diminished biodiversity, is controversial. There is an ethical argument that these values are irreplaceable and should not be traded for present gain. Despite this, numerous authors have attempted to estimate the cost of climate change. Estimates vary over at least an order of magnitude, depending on the assumptions made and the timeframe considered.

None of the estimates claim to be comprehensive, and none can include the cost of unexpected future events that may occur as a result of climate change. As discussed earlier, ethical principles indicate that present generations should be less concerned with refining economic analysis of something that can never be accurately estimated, and more concerned with passing on a stable climate to future generations. On this basis, the avoided cost of climate change is irrelevant; action should be taken for ethical reasons. Although it may not be possible to include the avoided cost of climate change in the TAC due to valuation problems, it is included in Table 1 as a reminder of the benefits associated with greenhouse abatement.

If the avoided cost of climate change is not included in the estimate of TAC, then the TAC is really a relative ranking of greenhouse abatement programs according to cost, rather than an absolute measure of the total cost or benefit of the programs.

5.5. Wider Economic Costs and Benefits

As well as economic costs and benefits experienced directly by the stakeholders listed in Table 1, there are wider economic impacts associated with greenhouse abatement. For example, greenhouse abatement programs may alter Australia's balance of payments due to changes in import and export of fuels and energy technologies. Greenhouse abatement will also require diversion of funds from other sectors of the economy, and this may have a positive or negative economic impact, depending on whether greenhouse abatement is a more economically efficient use of scarce resources.

The costs and benefits of these wider economic impacts are represented by the wider economic cost (WEC) and wider economic benefit (WEB) in Table 1. Like the avoided cost of climate change, WEC and WEB are not allocated to any specific stakeholder group, but are borne by society as a whole. They are difficult to estimate because they depend heavily on how the structure of the energy sector, and the economy as a whole, evolves over time. They also depend on what greenhouse abatement action other nations are taking. If all nations take action to reduce GHG emissions, then Australian exports of fossil fuels will fall. This may be balanced by a reduction in oil imports and increased exports of sustainable energy technology. However, predictions of how the future might unfold are speculative.

There is evidence that the wider economic impacts of greenhouse abatement will be positive. The existing fossil fuel-based energy sector receives significant perverse public subsidies (Riedy, 2003, Riedy and Diesendorf, 2003). Diversion of these subsidies to greenhouse abatement should have a positive impact in terms of economic efficiency. There is also evidence that the sustainable energy sector is more labour intensive than the fossil fuel sector (Renner, et al., 2000, Australia Institute, 2001), which means that greenhouse abatement will have a net employment benefit.

It is recognised that the shift to a carbon-constrained economy represents a substantial structural change for modern economies. This change carries significant potential for disruption, but also opportunities for innovation. There is no reason why, with careful planning, the shift to a carbon-constrained economy cannot bring wider economic benefits. In the absence of strong evidence to the contrary, it is assumed here that the wider economic cost of greenhouse abatement is neutral (WEC equals WEB).

5.6. Total Abatement Cost

Summing the costs and benefits (negative costs) for each stakeholder group in Table 1 gives the net cost of an abatement program as perceived by that stakeholder. Summing the costs and benefits for all stakeholders gives the TAC on a ‘whole of society’ basis. The net stakeholder costs and TAC are given in Table 2. While the TAC is of the most interest in assessing and ranking greenhouse abatement programs, stakeholder costs are also of interest as they indicate which stakeholders are likely to resist implementation of a specific abatement program. The distribution of stakeholder costs can point to a need to redesign the program to more evenly share costs and benefits. The avoided cost of climate change and the wider economic costs and benefits are excluded from specific stakeholder costs but included in the TAC.

Table 2. Net cost experienced by each stakeholder group.

Stakeholder Group	***Net Cost***
Government	$PC_{Gov} - PB_{Gov}$
Generator	$PC_{Gen} - PB_{Gen} + FR_{Gen} - AC_{Gen} - AT_{Gen} - AD_{Gen}$
TNSP	$PC_T - PB_T + FR_T - AC_T$
DNSP	$PC_D - PB_D + FR_D - AC_D - AT_D$
Retailer	$PC_R - PB_R + FR_R - AC_R - AG_R - AT_R - AD_R$
Energy user (customer)	$PC_C - PB_C - AG_C - AT_C - AD_C - AR_C$
Manufacturer	$PC_M - PB_M$
SOCIETY (TAC)	$\mathbf{PC_{Gov} + PC_{Gen} + PC_T + PC_D + PC_R + PC_C + PC_M - PB_{Gov} - PB_{Gen} - PB_T - PB_D - PB_R - PB_C - PB_M - AC_{Gen} - AC_T - AC_D - AC_R - ACOCC + WEC - WEB}$
	$\mathbf{PC_{Total} - PB_{Total} - AC_{Total} - ACOCC}$

Essentially, for each stakeholder, the net cost is their share of the program cost, minus any program benefits, plus any foregone revenue, minus the avoided cost of providing the displaced energy service, minus the avoided charges from other energy service providers. As the revenue received by each stakeholder is equal to the charges by other stakeholders, these terms cancel out in the TAC. As shown in Equation 3, the TAC is simply the total program cost (the sum of the program costs for each stakeholder), minus the total program benefit, minus the avoided costs of augmenting the energy system and of climate change. Wider economic costs could be added to the TAC if later modelling confirms that greenhouse abatement has negative impacts across the wider economy.

Equation 3: $$TAC = PC_{Total} - PB_{Total} - AC_{Total} - ACOCC$$

6. Integrated Abatement Planning

The objective of integrated abatement planning is to identify the least cost greenhouse abatement options to meet specified GHG reduction targets. To achieve this objective, a metric is needed that can be used to compare options on an equivalent basis. In integrated resource planning for the energy sector, the metric used is the cost of conserved energy (CCE). The CCE is a unit cost of conserved energy (measured in cents/kWh for example), which allows fair comparison of options with different yields.

As well as considering differing yields, it is necessary to consider how to represent abatement costs and yields that vary over time. Stoft (1995) provides the theoretical basis for dealing with temporal variation and calculating CCE. Following Stoft's approach, an equivalent metric for IAP is derived below, termed the unit abatement cost (UAC).

6.1. Unit Abatement Cost

The unit abatement cost is defined as shown in Equation 4, where TAC_t is the total abatement cost in year *t* (as defined previously), ΔQ_t is the greenhouse abatement in year *t*, r_1 is the discount rate for TAC_t, r_2 is the discount rate for ΔQ_t and t_0 is the starting year for the analysis. Greenhouse abatement is defined relative to the baseline greenhouse gas emissions in any year, Q_t.

Equation 4: $$UAC = \frac{\sum TAC_t \big/ (1+r_1)^{t-t_0}}{\sum \Delta Q_t \big/ (1+r_2)^{t-t_0}}$$

Following Stoft, the definition of UAC uses not just the present value of the stream of costs associated with an abatement measure, but also the present value of the stream of abatement associated with the measure. Hence, the denominator in Equation 4 is the NPV of the stream of abatement over time, as shown in Equation 5. The choice of discount rate for greenhouse abatement programs is controversial, as discussed previously. This issue is considered in more detail below.

Equation 5: $$\Delta Q_{NPV} = \sum \frac{\Delta Q_t}{(1+r_2)^{t-t_0}}$$

6.2. Choice of Discount Rate

The choice of appropriate discount rates has been the subject of extensive debate. The discount rate is used to represent the time preference for money. It is based on the theory that a rational person would prefer to have a given amount of money now, rather than in the future. This is due to the fact that money that is available now can be invested and will earn more money over time. In NPV calculations, the discount rate is used to reduce the value of future streams of costs and benefits. The higher the discount rate, the greater the value placed on the present relative to the future.

In calculating CCE, Stoft uses a single discount rate (e.g. 8%) for both program costs and the flow of conserved energy. While discounting monetary costs is accepted economic practice, discounting a flow of energy is controversial. However, discounting is appropriate if we note that the stream of energy is not actually a physical quantity, but a measure of satisfied demand, or utility. Discounting this quantity over time is reasonable to account for a consumer's time preference for consumption (Fane and White, 2003). It is also consistent with the observation that a quantity of energy that is available now can be used to do something, and can therefore create more value.

The validity of this approach is less clear when applied to greenhouse abatement, as the time preference for abatement is not as obvious. A tonne of greenhouse abatement that is available in the present cannot be used to create more abatement, so the rationale for discounting is less clear. It could be argued that a tonne of abatement achieved in the present is more valuable than a tonne of abatement achieved in the future, as the present abatement will keep atmospheric GHG concentrations lower over a longer period of time (relative to a specified future date) than the future abatement. Delaying abatement would allow more GHGs to accumulate in the atmosphere over the time period leading up to the abatement and is an undesirable result. This argument could be used to justify a positive discount rate.

However, the scale of greenhouse abatement required is such that it cannot possibly be achieved over a short time period, and must be seen as a long-term project. Abatement will likely need to continue throughout this century and total abatement will need to exceed 60% of current global emissions, and perhaps 90% of current emissions in Australia (due to Australia's high per capita emissions; see Turton and Hamilton (2002)). If a positive discount rate is used, the value of future greenhouse abatement is diminished. As a result, abatement options that favour short-term abatement over long-term abatement would be favoured.

This would not be a problem if the energy system retained the flexibility to allow continual changes in the choice of the best short-term abatement options to meet progressively tighter abatement targets. Unfortunately, many short-term options, such as increased use of natural gas, tend to lock the energy system into a particular type of technology and stifle the development of options that can provide the long-term abatement that is required (Unruh, 2000). The marginal abatement provided from pursuit of a natural gas-based energy system would rapidly diminish over time as the system becomes dominated by natural gas.

To avoid any bias towards short-term abatement options, compared to long-term abatement options, a zero discount rate could be justified for the stream of abatement over time. A positive discount rate would be retained for the stream of costs over time. This would effectively mean that an option is judged on the unit cost of the total greenhouse abatement it provides over time, with each tonne of abatement valued equally. The best approach may be to use several different discount rates to calculate UAC and compare the results. The discount rate could be varied between zero and the rate chosen for the cost stream, and the results could be used as a tool to determine trade offs between long and short-term objectives. Abatement options that have a low UAC across several discount rates would be particularly attractive.

6.3. Marginal Abatement Cost Curves

In integrated resource planning for energy, the CCE is commonly used to plot a 'conservation supply curve' (CSC). A CSC is a visual tool used to compare energy conservation and energy supply options on a common basis. An equivalent tool for IAP is the 'marginal abatement cost curve' (MACC). MACCs have been used in recent years to analyse the impacts of the Kyoto Protocol and emissions trading and have been developed for both countries and regions (Klepper and Peterson, 2003).

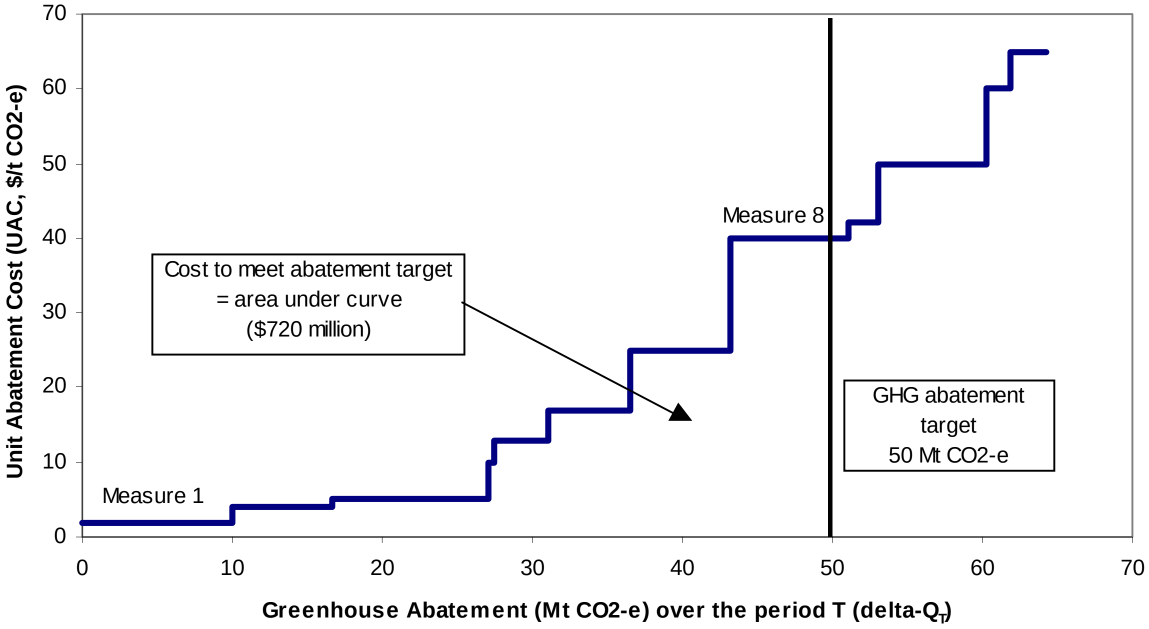
MACCs plot the greenhouse abatement achieved by a measure over a specified timeframe T (ΔQ_T, horizontal axis) against the UAC (vertical axis). Both ΔQ_T and the UAC are measured as changes from a baseline scenario, as discussed earlier; they are the marginal abatement and marginal abatement cost, respectively. Typical units are Mt CO_2-e for ΔQ_T and \$/t CO_2-e for UAC. Construction of a MACC starts with the least cost abatement measure in the bottom left of the curve and progressively adds higher cost measures to achieve greater abatement. Each point on the curve corresponds to the cumulative unit cost of achieving a specified level of abatement. An example MACC is provided in Figure 1. The costs and abatement shown are for illustration only and are not intended as estimates of the real cost of abatement.

The value of ΔQ_T is not necessarily equal to ΔQ_{NPV} from Equation 5, as the timeframe T used to construct the MACC may not coincide with the total life of an abatement measure. The timeframe will depend on the purpose for which the MACC is being developed. If a policy maker is interested in comparing abatement options on the basis of the total abatement they can achieve, and a zero discount rate is used, then $\Delta Q_T = \Delta Q_{NPV}$. More commonly, a policy maker will be interested in choosing the least cost options to meet a GHG reduction target set for a specific year or group of years. An example is the Kyoto Protocol target for the first commitment period, over the years 2008 to 2012. In this case, ΔQ_T would more usefully be defined as the total (or annual average) abatement achieved over 2008 to 2012.

Various definitions of ΔQ_T can be used to derive different MACCs. Whatever definition of ΔQ_T is used to plot MACCs, the UAC should still be derived using ΔQ_{NPV}, as this provides the only economically rational basis for comparing the costs of different options. This means that the ranking of options will not change, but the number of options selected to achieve the target abatement will change. The risk with this approach is that there will be over-selection of options; because some of the best options in terms of TAC will have most of their benefits in the long-term, they will add little to the achievement of the short-term target.

This points to the need to balance achievement of short-term targets against long-term targets. If the options selected to achieve a short-term target would cause a later target to be very easily met, then there may need to be some further analysis done to determine the best balance between short-term and long-term options. In practice, as targets are expected to get steadily more challenging, this problem may not arise. Additionally, achieving a long-term target easily would be a desirable result for the environment.

Figure 1. An example of a marginal abatement cost curve (MACC).



6.4. The Role of MACCs

CSCs are most commonly used to divide a series of energy conservation measures into those that are economic (providing conservation at a positive NPV) and those that are uneconomic. This is achieved by comparing the cumulative cost of the measures to the prevailing electricity price. It is assumed that price is equal to LRMC. A horizontal line on the CSC is used to represent the electricity price; all measures below the line are judged competitive and above the line are uncompetitive (Stoft, 1995). A CSC therefore identifies those demand-side measures that are more economically attractive than supply-side measures to meet growth in the demand for energy services.

Theoretically, a MACC could be used in a similar way. Instead of comparing plotted measures to the energy price, measures would be compared to a line representing the long run marginal cost of climate change (ACOCC would need to be excluded from the definition of TAC in Table 2). It would be economically rational to continue to implement abatement measures until the cost of abating a tonne of GHG is greater than the cost imposed by emitting the GHG. All measures below the line would therefore be implemented.

However, as was discussed earlier, it is not possible to satisfactorily value the cost of climate change. A better approach, based on ethics, is to undertake emission reductions sufficient to ensure that a stable climate is passed to future generations. This is equivalent to adopting an extremely high value for the cost of climate change, so that essentially all options plotted on a MACC would be considered economically competitive when compared to the cost of climate change. As technically feasible options are already available to reduce emissions by 60% or more without economic hardship (Turton, et al., 2002), this does not place an undue burden on current generations.

The role of a MACC, therefore, is not to determine which options are competitive, but to determine which options can achieve established greenhouse abatement targets at the least cost. Greenhouse abatement targets would need to be set through a separate process of public debate, based on the value that the public places on a future world that is not adversely impacted by climate change. A MACC can help determine how best to reach a target, but should not be used to set the target.

The example MACC in Figure 1 shows that a greenhouse abatement target of 50 Mt CO_2-e over the target period could be met by implementing Measures 1 to 8. If failure to meet the target has serious consequences, additional measures might be pursued to provide a safety margin. This would ensure that the target is still met if some of the measures fail or are optimistic in their abatement estimates. The total cost of meeting the target would be the area under the curve, up to the end of Measure 8.

A secondary role of a MACC, and the one that has received the most attention in the literature, is to identify the point at which a particular nation should turn to Kyoto Protocol emissions trading, rather than trying to achieve domestic abatement; see for example Klepper and Peterson (2003). Once the UAC in a country rises above the world market price for emission permits, it would be rational to purchase permits to meet GHG reduction targets. The market price for emission permits can be plotted on the MACC and used to identify which domestic abatement options are competitive.

7. Conclusions

Economic analysis appears to have been dominated by the continual refinement and use of models to try and determine the ‘optimal’ level and type of greenhouse abatement that society should pursue. The availability of increasingly refined and complex economic models does little to assist the process of policy formation. At best, it adds to the complexity that policy makers must cope with when making decisions. At worst, it serves to perpetuate business as usual approaches and discourage any actions that might reduce economic growth, regardless of their impact on present and future quality of life.

The bewildering array of assumptions incorporated into most models means that they will never accurately predict what will actually happen in the future. While many models are concerned with identifying the optimal economic solution, it is not possible for any model or decision-making process to identify an optimal solution in the face of an uncertain future. As Anderson (2002) points out, in the absence of complete information about future developments, human decisions are necessarily sub-optimal.

This is not a cause for concern, as long at it is recognised. Once it is recognised, the value of using simple, practical economic analysis tools, like integrated abatement planning, increases. Such tools can be readily understood by policy makers and can be easily adapted to changing circumstances. While these tools cannot identify optimal greenhouse abatement programs, they can indicate which programs are likely to achieve the most robust greenhouse abatement results under a range of assumptions, at close to the least cost. They are also well suited to an evolutionary approach that sees policy making as a process of continual iteration based on the successes and failures of the past.

Rather than using economic analysis to decide whether greenhouse abatement is required, the approach described here recognises that this decision is properly an ethical one. Greenhouse abatement can be justified by principles of inter-generational and intra-generational equity. The focus of economic models can then shift, appropriately and productively, to identification of the least cost abatement programs to pursue.

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