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Incorporating GHG Emission Costs in the Economic Appraisal of Projects Supported by State Development Agencies*

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Abstract: This paper sets out a methodology for updating an economic appraisal model to ensure that it takes appropriate account of costs arising from greenhouse gas emissions. While the analysis is based on the appraisal model used in Ireland, it should be broadly applicable to circumstances in any EU Member State; indeed, many features will be relevant in any jurisdiction subject to a carbon tax or participating in a carbon permit trading system.

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1. INTRODUCTION

Ireland's industrial development agencies use a cost-benefit analysis model as part of the process for evaluating whether particular projects merit state support. This model has evolved over the years due to changes in the Irish economy and government industrial policy. This paper considers how an economic appraisal model such as the one used in Ireland could be updated to ensure that it takes appropriate account of costs to Ireland due to greenhouse gas (GHG) emissions, specifically in the context of Ireland's commitments under the Kyoto Protocol and the EU proposals for emission targets for 2020, and in the context of the domestic carbon tax currently being studied by the Commission on Taxation. This analysis should be broadly applicable to circumstances in any EU Member State; indeed, many features will be relevant in any jurisdiction subject to a carbon tax or participating in a carbon permit trading system.

This paper is structured as follows. We start with a discussion of how greenhouse gas (GHG) emissions may affect the economics of publicly supported projects and how evaluations of such projects could be extended to take account of the cost of emissions to Ireland. Section 3 focuses on options for predicting the cost of CO_2 emissions to Ireland, the key parameter in making such an assessment. Since there are other GHG emissions than of CO_2, we consider in Section 4 how other gases might be accommodated. Section 5 provides a brief review of how some international organisations incorporate GHG emissions costs in evaluations, and we conclude the paper in Section 6.

2. EXTENDING ECONOMIC APPRAISAL MODELS TO TAKE EXPLICIT ACCOUNT OF GHG EFFECTS

Many projects supported by industrial development agencies affect total greenhouse gas emissions. Most projects increase emissions, and this implies that emission reduction elsewhere should increase or that more emission permits should be imported. A few projects would decrease emissions (e.g., investment in renewable energy), and this implies that emission reduction elsewhere would decrease or that less permits would be imported. These emissions should be valued at the social shadow price of carbon dioxide emission reduction.[1]

There are two main channels through which costs of GHG emissions are likely to affect the attractiveness of a proposed project.[2] First, GHG emissions associated with the project will impose costs on Ireland by raising its overall emissions level relative to target levels (and in particular, those imposed under the Kyoto Protocol). We will refer to this as the social cost of emissions, but it is also equal to the expected marginal cost borne by the Irish exchequer.

The second channel through which GHG emissions should enter project evaluations is by increasing the private costs to the project developer. To the extent that the project has to buy permits or pay taxes in respect of its GHG emissions, the project may be less profitable than if emissions were free. Profitability is included among the benefit parameters, so such costs would have the effect of reducing estimated benefits. However, if the project bears some or all of the costs of its emissions directly, it should be given credit for this expenditure when calculating the social costs of the emissions. This is probably best done by reducing the estimated social costs by an amount equal to the private costs.

For example, if a project was being undertaken by a firm that is subject to a carbon tax, and the tax was equal to the price of emission permits on the European market, the net cost of the emissions to Ireland would be fully borne by the project. No further social costs should be charged to this project when it is being evaluated. To the extent that a project that does not bear the full cost of its GHG emissions, either because it is not subject to a tax or permit scheme or because it receives grandparented permits, the excess of social cost over private cost should be charged to the project in the evaluation.

Estimating the social and private costs of emissions by a project requires that the appraisal model include a range of new parameters. These may be divided into project-specific

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[1] The shadow price of carbon dioxide is the true cost to society if emissions were increased by a small amount. The shadow price of a good equals its market price only if there is a perfect market. The market for greenhouse gas emissions is imperfect..

[2] We also recognise that some projects may give rise to benefits by reducing GHG emissions, for example by directly supporting innovation in emission-reducing technologies or by substituting for existing (more GHG-intensive) production methods. However, it is likely to be more efficient to take such benefits into account on a case-by-case basis rather than requiring them to be assessed for all projects.

parameters and economic parameters that should apply across all projects. Project parameters include:

Annual forecasts of the quantity of each greenhouse gas that the project is expected to produce. Only incremental emissions should be included: project extensions should include only emissions associated with the extension, not the original project. These forecasts might be obtained through the evaluation process in the same way as other cost items, such as electricity costs. Projects for which energy costs are substantial are likely to have estimates of expected energy use and price by energy type (even if the economic appraisal requires only that total electricity costs be included). Emission factors can be obtained from http://www.sei.ie/index.asp?locID=72&docID=-1. Emissions of other greenhouse gas require an IPPC license and should be estimated anyway, although these would be zero for many projects.

An indicator will be needed for whether a project falls within the European Emission Trading Scheme (EU-ETS), or not. If it is in the ETS, data will be required on the number or share of permits that will be provided to the project through grandparenting arrangements, these factors will be needed to calculate the private cost borne by the project.

Similarly, an indicator should be included as to whether any carbon tax applies, and if so, the amounts expected to be paid in each year of the project evaluation period. While there is currently no carbon tax in Ireland, this feature will provide flexibility against the possibility that such a measure might be in place in the future.

A variable should be included to incorporate energy related emissions arising from a project. As well as direct process emission of GHGs, many projects will give rise to indirect emissions through the use of electricity and transport services. At present, predicted annual energy costs are entered into the model in nominal terms, with no indication of the assumed quantities and prices of energy that underlie them. This is problematic, because for a given project it is difficult to know whether the assumed prices include likely future costs of GHG emissions or not. In order to incorporate these sources of emissions into the model, we could either impute a GHG quantity based on assumed future price movements and the average sectoral GHG content of energy used, or we could require that expected quantities of different types of energy used be reported for each project (e.g. electricity, gas, etc.). In principle, the same could be done for emissions caused by use of transport services, but these are likely to be less significant for most projects seeking support from the industrial development agencies.

Economic parameters should include:

- The marginal cost to Ireland if a unit (say, a tonne) of CO_2 is emitted in a given year. At present, the government purchases carbon dioxide emission allowances so as to offset Ireland's excess emissions. The shadow price of emissions therefore equals the price of such allowances. Also in the future, emission reduction abroad is likely to be cheaper than domestic emission reduction, so that the price of imported allowances will continue to set the shadow price of emission reduction in Ireland. These emissions "prices" will be required for each year covered by an evaluation model, so at any given time, predictions will be needed covering the next 7-10 years. Possible sources for these data are discussed in Section 3 below.
- A consistent way to arrive at "prices" for emission of non-CO_2 greenhouse gases will also be required. Methods for calculating these are discussed in Section 4 below.

It is also worth noting that climate policy puts constraints on investment options. At the moment, such constraints are restricted to power generation (e.g., the renewables target) and to transport (e.g., the biofuels target). However, at present any such constraints on a project seeking support could probably be handled in the qualitative elements of the appraisal.

We anticipate that these parameters will enter the cost-benefit appraisal formula by reducing profits, increasing energy costs and through a new cost item that might be described as the net social cost of CO2 emissions (*S*). In year *t*, this would be equal to:

$$(5) \qquad S_t = \alpha_t \left(1 - \beta_t - \tau_t\right)\left(C_t + \sum_i W_i G_{it}\right)$$

where

α is the marginal price of CO_2 emission faced by Ireland

C is the projected quantity of CO_2 emissions by the project

G_i is the projected quantity of emissions by the project of non-CO_2 greenhouse gas i

W is the relative cost for non-CO_2 greenhouse gas i (e.g., the GWP)

β is the share of emissions that the project is allocated for free

τ is the average tax rate applicable to emissions by the project

In the remaining sections of this paper, we focus on options available for obtaining GHG emissions price estimates to be used in the model. We return to the issue of how the model should be extended in the concluding section, where we classify several types of projects by the way they would be captured under the model.

3. PREDICTING THE PRICE OF CARBON DIOXIDE EMISSIONS

There are various methods for pricing carbon dioxide emissions. Some approach the task from a private perspective, and others from a social perspective. Some methods are very complicated, but some of the simpler methods may be misleading. In this chapter, we discuss the various options, their advantages and disadvantages, and their appropriateness for evaluating investment decisions in Ireland. We divide the methods into those based on the marginal damage cost of carbon dioxide; spot and futures prices in GHG permit markets; financial econometrics and option pricing models; and methods based on climate change models.

3.1 The marginal damage cost of carbon dioxide

The impacts of climate change on the economy and human welfare has been quantified in monetary terms. The welfare loss due a small increase in emission is often called the marginal damage cost of CO_2 or the social cost of carbon. In economic jargon, this is the Pigou tax, and it equals the net present value of the damage done by an infinitesimally small increase in emissions along the optimal emission trajectory. From a global, social perspective, carbon dioxide should be priced at a rate that corrects for the negative externalities it causes – that is, its Pigou tax. However, not only are current estimates of the social costs of carbon controversial and uncertain – Tol (2005) surveys the literature and finds a range of -$4/tC to $1,666/tC – a private investor would align the price of carbon to *actual* climate policy rather than to some *idealised* climate policy.

Nonetheless, the marginal damage cost estimate gives some guidance. Cost-benefit analysis is one of the main guides to policy in the European Union, and cost-benefit analysis says that the marginal costs of emission reduction (that is, the price of carbon permits, or the carbon tax) should equal the marginal damage costs. The marginal damage costs are therefore an indication of whether actual climate policy is too lenient or too strict, and may help to predict in which direction climate policy is moving. The World Bank and HM Treasury use estimates of the marginal damage costs as indicative of carbon prices (see section 5).

Although the marginal damage cost is theoretically appealing, its practical usefulness is limited. Figure 1 shows a probability density function of published estimates of the marginal damage costs of carbon dioxide emissions, indicating the range of estimates that exist. The uncertainty is very large. This is partly because future emissions and climate change are so uncertain; the latest report of the Intergovernmental Panel on Climate Change (IPCC) states that warming may be anywhere in between 1.1˚C and 6.4˚C by 2100.

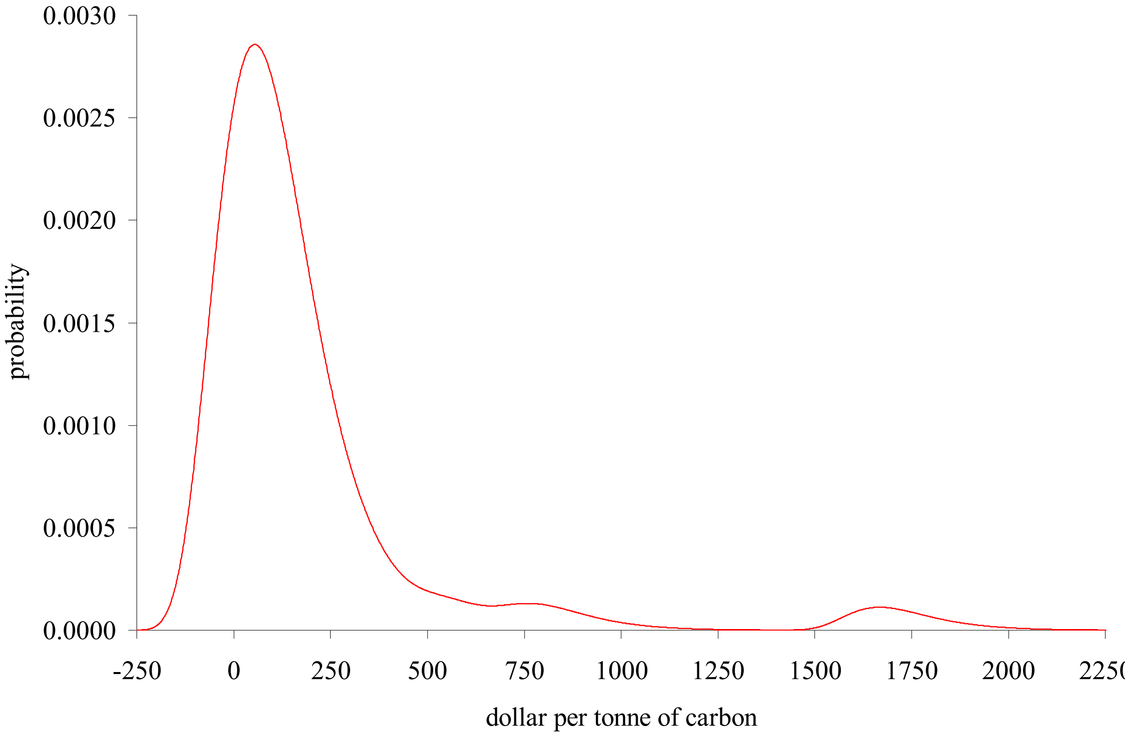

Figure 1: The range of estimates of the marginal damage cost of carbon dioxide[3]

Estimates of the impacts of climate change add a further layer of uncertainty. Impact estimates are incomplete, and different studies include different impacts while some studies add an arbitrary provision for "missing impacts". Furthermore, impact estimates depend

[3] Figure 1 shows the probability density function (PDF) of the marginal damage costs of climate change. The PDF is a kernel-density of the 210 estimates of Tol (submitted). The kernel imputes a Fisher-Tippett PDF for each observation, using the best guess of each study as the mode, and the standard deviation of all studies at the standard deviation. These PDFs are aggregated using the author-quality weights defined in Tol (2005).

strongly on quasi-empirical, quasi-ethical parameters, particularly the rates of time preference, risk aversion, and inequity aversion. That is, the impacts of climate change will occur in the distant future, are very uncertain, and will largely fall on faraway lands. The empirical evidence on how much people and governments care about such matters is ambiguous.

3.2 The current price of carbon permits

A more attractive option is to use the valuation of carbon dioxide emissions as revealed in market information. This should have the advantage of combining the information and preferences from large numbers of firms with a strong interest in accurate pricing. This sub-section and the following one set out market-based methods.

With the establishment of the European Trading System (EU-ETS) for carbon dioxide emission permits , a price for carbon emissions was created. The EU-ETS began trading on 1 January 2005. Prices in this market have been highly volatile – ranging from a high of over €30 to a low of one cent and back up to the current value of €26 per tonne of carbon dioxide emitted (spot-price). See Figure 2. The deep trough in prices was apparently due to a market perception that the permit allocations were generous relative to the expected emissions. Indeed, recent academic studies (Ellerman and Buchner, 2006; Kettner et al., 2007) also point to over-allocation of emission allowances.

Figure 2: Spot price of carbon dioxide emission allowances in the European Trading System – from www.eex.com

One could use current market price or the average over a recent period to price carbon emissions. This measure is simple and transparent, but as the ETS is a spot market, it does not take expectations of the future into account. We will therefore need some other method for obtaining values for the seven- to ten-year term of a project evaluation.

3.3 The future price of carbon permits

There is also a futures market for ETS permits. Expectations are that the permit price will rise to €29/tCO_2 in 2012 (www.eex.com, 30th May 2008). Using the future price of carbon according to the market is simple and transparent, and it includes expectations up to 2012.

Figure 3: Derivatives price (Second Period European Carbon Futures – 2008) – from www.eex.com

Figure 4: Derivatives price (Second Period European Carbon Futures – 2012) – from www.eex.com

Another market for carbon-based derivatives has emerged on foot of the Kyoto Protocol: a market for Certified Emissions Reductions (CERs), where each CER is equivalent to one metric tonne of CO_2 reduction.

Under the terms of the Kyoto Protocol any Annex I signatory (developed nations) has three principal options in its efforts to meet its emission commitments. First, the country can implement projects within its own borders to either reduce greenhouse gas emissions or provide a sink for existing greenhouse gases.[4] This can often be inefficient, as projects abroad may reduce emissions by the same amount at a lower cost. The second option, allowed by Article 6 of the Kyoto Protocol, allows for Annex I countries to engage bilaterally with each other in order to undertake an emission-reducing (or greenhouse gas sink) project in either country under a process called Joint Implementation (JI). Ostensibly, JI acts to improve efficiency, as a project designed to reduce emissions (or create a sink) might be more easily – and cheaply – implemented in one of the countries. Third, under Article 12 of the protocol, Annex I countries can invest in projects in Annex II countries (developing nations) under a process called the Clean Development Mechanism (CDM).

In order to verify the additionality associated with each project, a regulatory body (the CDM Executive Board) must confirm that the project would not have proceeded without the involvement of the contracted Annex I country's involvement. Since only approved JI/CDM reductions may be used to offset national carbon emissions under Kyoto, this certification process confers value on CERs.

Recently, it was reported that the mid-April Asia Carbon Exchange auction of 700,000 CERs saw them change hands at €10.40/tCO_2 for a hydro project at the validation stage[5] in China (www.carbonpositive.net). Prices of CERs generally follow those of allowances traded under the EU-ETS, with issued CERs 'selling at about 80 per cent of the EU-ETS allowance Dec 08 price, or about €12 to €13 per tonne of CO_2 this year (ibid. – note that the price of EU-ETS permits at this time were around €18) – reflecting the higher risk associated with some JI/CDM projects (see note 5).

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[4] Note that the EU is a signatory to the Kyoto Protocol. Therefore, emissions trade between EU member states is considered to be a "domestic" affair.

[5] At the validation stage of a project, it is still to achieve registration by the CDM executive board and some way off having CERs actually issued, therefore there is a degree of risk of non-delivery and prices for CERs are consequently lower.

However, CERs are traded as bundles (in projects) rather than in units; the administrative costs are high; and regulatory approval is cumbersome. Therefore, the CER market has not seen many transactions, and price data is therefore scarce and difficult to interpret.

3.4 Financial econometrics and option pricing models

As discussed earlier, the futures market for ETS carbon permits currently extends only to 2012. Since project assessments extend for seven to ten years, we are left with the question of how to arrive at price estimates beyond this date.

There are two main methods for making forecasts of this kind: financial time-series econometrics, which essentially involves extrapolating from historical information, and model-based estimation. In this sub-section, we consider the first of these approaches.

Financial time-series econometric techniques use information about past behaviour of an asset's spot and futures prices to predict future price levels and volatility. These tools are highly developed and are widely used to analyse price movements in a diverse range of asset markets, including those for equities, bonds, currencies and commodities.

The basic premise behind these techniques is that the price of a particular asset can be characterised in statistical terms, normally as a "stochastic" process (i.e. one made up of a mixture of random and deterministic components). If this process can be identified and its parameters measured accurately, a modeller should be able to predict the expected price of the asset at a given point in the future with a specified level of confidence, based on the asset's current price level and recent price movements.

Option pricing theory takes this type of analysis a step further. Again assuming that the stochastic process associated with an asset's price has been properly characterised, option pricing models allow the modeller to calculate the expected cost of purchasing a guarantee as to the price of the asset at a specific future point in time. For example, this approach might in principle be used to estimate the cost of ensuring that the carbon permit price faced by a project would not exceed a pre-set ceiling during the project's life.

There is active academic research internationally into the appropriate way to model carbon permit prices.[6] While research to date has revealed some of the statistical properties of carbon price series, there is as yet no consensus on the best specification to use for modelling these prices. It is clear that ETS carbon permit prices are influenced both by "market fundamentals" such as the relative prices of different fuels and changes in marginal cost of emissions within member countries[7] and by policy factors such as decisions on the future quantity and distribution of permits, as well as on the penalty for non-compliance (€40/tCO_2 in 2007, €100/tCO_2 in 2008-2012). These drivers are analogous to the determinants of prices for other economic pollution control instruments such as tradable SO_2 permits, but quite different from the determinants of prices for financial assets like equities and bonds (Daskalakis *et al.*, 2006, p.12).

Most research thus far suggests that the most appropriate statistical representation of carbon permit prices similarly involves a two-component approach. In essence, price movements tend to move in line with a particular statistical process most of the time, but there are occasional "jumps", or changes in state, that may be very extreme, happen only occasionally and seem to follow a different statistical pattern from normal period-to-period movements. The precise choice of models to best represent the state-switching process and the "normal" process are still under debate.

Ultimately, our purpose here is to determine whether this approach offers the best way to predict future carbon permit prices for use in project evaluation. Financial time-series econometrics and option pricing models work best for assets in well-established and highly liquid markets, for which significant historical data are available. Where these conditions do not hold, it is difficult to be confident that such models (dependent as they are on the assumption that historical patterns will continue) can accurately predict future values. This problem is likely to be acute in the case of carbon permit markets, where markets are relatively new, illiquid (trading is "virtually zero" on some days)[8] and heavily influenced by policy changes. Although financial econometric models can accommodate variables that lead

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6 See Lin and Lin, submitted, p.6, for a concise recent survey.

7 Paolella and Taschini, 2006, pp.11-12.

8 Uhrig-Homberg and Wagner (2006, p.6). However, there are suggestions that the liquidity of these markets is likely to rise over time: Paolella and Taschini, 2006, p.11.

to periodic sudden changes in pricing behaviour such as political shifts, they must still include assumptions on the statistical patterns behind such changes. There is little international research into the statistical properties of environmental public policy decisions.

A further problem with using financial econometric models in this setting is that, even in well-established markets, econometric models tend to predict accurately for only a relatively short time horizon. In the case of carbon permits, the longest-term out-of-sample forecasts tested to date have been around three months (see Benz and Trűck, submitted; Lin and Lin, submitted). Since project evaluations require that expected costs be forecast seven to ten years into the future, it is likely that financial time-series forecasts would carry unacceptably high error margins.

Given these shortcomings and the complexity associated with financial econometrics models, we consider that full-scale econometric models are not currently practical for use as multi-year evaluation models. If an extrapolative model is preferred, the most practical option would be to use a very simple formulation. For example, one might assume that the best estimate of the price in a future period is the actual price in the previous period.

3.5 Climate change models

Model-based estimation is probably the most practical option for deriving price estimates for emissions beyond 2012.

We suggest that the model used to inform policy should ideally be relevant, credible, robust, transparent and up-to-date. By **relevant**, we mean that the model should forecast the measures in which we are interested, or at least quantities closely correlated to those measures. In this case, that means the price of permits to emit CO_2 after 2012. A **credible** model is one that has undergone rigorous external review, perhaps also being employed by other governments or supranational organisations. In principle, we can only really know how **robust** a model is to changing market conditions after the fact, but the likelihood of robustness may be augmented by averaging results from a set of models based on different assumptions or methods of estimation. **Transparency** is not an essential characteristic for a model to have *per se*, but it is desirable insofar as it increases one's understanding of its predictions and confidence that the model has been constructed with appropriate care. Some very good models are the result of one-off exercises. However, since project evaluations are a continuing activity, it might be better to select a model that may be at least occasionally **updated**.

In the remainder of this section we describe the main models that might be used to produce multi-year carbon price forecasts for project evaluations.

The Intergovernmental Panel on Climate Change (IPCC) reviews the literature every six years or so. The IPCC is a joint venture of the World Meteorological Organization (a UN agency) and the United Nations Environment Programme. The latest published assessment (Barker and Bashmakov, 2007) argues that the price of carbon in 2030 would be between \$20/tC and \$50/tCO_2 if atmospheric carbon is to be kept below a density of 550 parts-per-million (ppm). This falls to between \$6/tC and \$50/tCO_2 for 650ppm.. Without international permit trade, carbon prices would be anywhere in between \$70/tCO_2 and \$2000/tCO_2. Hourcade and Shukla (2001) show that the permit price of carbon grows at about the same rate as the rate of discount.

Although it reviews the entire literature, the IPCC typically relies heavily on the ensemble of models gathered by Stanford University's Energy Modeling Forum[9] (e.g., Weyant *et al.*, 2006).

The most recent EMF working group – EMF21 – used the ESRI's FUND model (Tol, 2006) and eighteen other greenhouse gas mitigation models from working groups around the world to investigate the topic of 'multigas mitigation and climate policy'. Each of these models presents permit prices for both CO_2-only and multigas scenarios that extend as far as 2150. Interestingly, in all the models 'the inclusion of non-CO_2 greenhouse gases (in addition to CO_2)…decreases the marginal costs through the century of meeting the stabilization target[10]' (Weyant *et al.,* 2006, 24) – indicating that a multi-gas emission reduction policy is more beneficial than regulating CO_2 only. With regards to the forecasted prices from these models

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[9] T The Energy Modeling Forum operates as a 'forum for discussion and evaluation of important energy and environmental issues' (Weyant et al., 2006). As part of "EMF-21" 19 modelling teams looked at the issue of 'multigas mitigation and climate policy'. Further details on each of these models can be found in Weyant *et al*. (2006).

[10] The stabilisation target set in EMF-21 was defined as 'stabilising radiative forcing by 4.5Wm^{-2} (Watts per square meter) relative to pre-industrial times by 2150 using CO_2-only mitigation. This forcing level corresponds to a temperature level of 3.0˚C, for a 2.5˚C per CO_2 doubling climate sensitivity' (Weyant et al., 2006, 7)

in EMF21, the price of a carbon permit (without other gases being priced) in the scenarios ranges from $3/tCe to $482/tCe for the year 2025, with an average of $100/tCe (at 2000 prices).

As noted above, EMF findings heavily influence the IPCC, and this lends the necessary credibility, transparency and visibility to the EMF results. Besides, the EMF has been active since the early 1970s and is organised by one of the leading universities in the world (Stanford). Note that the EMF is very international; in recent rounds, the number of models from Europe was larger than the number of models from the USA; while participation from Australia and Japan has been substantial for a long time, there is increasing involvement by researchers from Brazil, China and India. The EMF is more regularly updated (every two to three years) than the IPCC (every six years).

The Innovation Modelling Comparison Project (IMCP) is a consortium with similar aims to the EMF, but it is a much more recent development and the models assembled by the IMCP have less scientific pedigree. The IMCP has completed only one model comparison exercise. Barker *et al.* (2006) summarise the results. A trajectory that aims at stabilisation of carbon dioxide at 550 ppm would imply a carbon price of less than $55/tC in 2030 (EMF21 has $100/tC in 2025 for a similar target), while 450 ppm would imply less than $185/tC. A target of 450 ppm CO_2 would achieve the EU's 2 degree target with 50% chance. The carbon prices of IMCP are lower than those of EMF because the IMCP models make substantially more optimistic assumptions about technological change.

Other model-based options exist for determining future price levels for emissions permits/credits. The European Commission uses a suite of models consisting of the GEM-E3[11] (Capros *et al.*, 1998), POLES[12] (Criqui, 2001) and PRIMES[13] (Criqui *et al.*, 2006) models for this purpose, while the Irish government has used the ESRI's HERMES model (Fitz Gerald *et al.*, 2002). These models are discussed below.

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11 GEM-E3 stands for General Equilibrium Model for Energy, Environment and Economy

12 POLES stands for Prospective Outlook on Long-term Energy Systems

13 PRIMES stands for PaRtial equIlibrium Model for the European energy System

The European Commission: GEM-E3/POLES/PRIMES.

In 1997 The European Council of Ministers announced its intention to limit emissions of greenhouse gases in 2010 to 15% below the level at which they were recorded in 1990. In order to analyse the implications of this decision for the EU, Capros *et al.* (1998) used three models: PRIMES, a model of the European energy system; POLES, a world energy system model; and GEM-E3, a model that 'integrates the energy system with the rest of the (European) economy, including several policy instruments for the environment, such as taxes and pollution targets' (Capros *et al.*, 1998). Among other results, the models employed by Capros *et al*. (ibid) found that a shadow tax of $180/tC would keep emissions in 2010 at 1990 levels.

More recently, an official communication of the European Commission (2005) explained that:

> "In the POLES projections, the global carbon price per tonne of CO_2 reaches €37 by 2020 and €64 by 2030. Costs, as a result of investments in low carbon technologies, are estimated at less than 0.5% of global annual GDP until 2030. Reduction targets of up to 30% in 2020 and 50% in 2030 would trigger carbon trading, achieving cost-effective emission reductions on a global scale."

The modelling process used by the European Commission is complex (comprising 3 separate models for different parts of the process, but no integrated model) but narrow (a single system of models), and updates are irregular.

The Irish Government: HERMES.

The HERMES macroeconomic model was first developed as part of an EU-wide research programme in the 1980s to allow analysis of the interaction of the macro-economy with various sectors of the economy including energy. The model has been further developed in recent years to incorporate a section explaining emissions of CO_2. HERMES connects the price of energy to the price of carbon. The results are reproduced in Table 1. HERMES is focused only on emissions from Ireland, and it predicts quantities of emissions rather than prices for permits (which are ultimately set in an international market). However, experiments with the model suggest that a €10/tCO_2 carbon tax would reduce carbon dioxide emissions by 3-4% from the baseline.[14]

From this analysis, it has emerged that one of the advantages of using a (good) model is that the crucial drivers of future price developments are all included – as well as the prices themselves being endogenously determined. One crucial disadvantage of all these models is their lack of transparency, as they often appear to be a 'black box' that produces unexplained results. This is common to each of the model-based methods described above, and is an unfortunate side effect of using such a method.

Of the three models considered here, however, it would appear that the IPCC or EMF method offers the most in terms of credibility, robustness, transparency, and regularity of updating for determining emission permit prices in the medium term – and particularly beyond the 2012 trading period for the EU-ETS.

Table 1: Change (%) in energy prices due to a carbon tax of €10/tCO_2, 2001 (Fitz Gerald *et al.*, 2002)

	Coal	**Oil**	**Gas**	**Electricity**	**Peat**	**All energy**
Households	10.3	5.9	4.8	5.1	19.4	7.2
Industrial	38.1	7.9	11.8	5.8		16.8
Commercial						5.6
Transport		2.9				
Electricity	55.1	30.4	15.4		45.8	33.1

4. PREDICTING THE PRICES OF OTHER GHG EMISSIONS

The Kyoto Protocol regulates the emissions of six "gases". Besides carbon dioxide (CO_2), there is methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The last two are classes of gases. Table 2 shows the emissions for Ireland for 2005. There are a number of methods of comparing the effects and impacts of greenhouse gases. Four of these are outlined below.

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[14] Ireland's emissions have been growing by some 2.5% per year over the last 15 years, and in 2004 were 43% above 1990 levels. With a €10/tCO_2 tax, 2004 emissions would have been some 40% above 1990 while the Kyoto target is 13% by 2012. Therefore, emission reduction in Ireland is expensive, and it is cheaper to import emission certificates from abroad.

Global Warming Potential. The Kyoto Protocol establishes the equivalence between the other gases and carbon dioxide, namely the 100-year Global Warming Potential (GWP) as reported in the Second Assessment Report of the IPCC (Schimel *et al.*, 1996). With this, it is trivial to calculate the price of, say, methane. The GWP of methane is 21, so the price per tonne of methane is 21 times the price per tonne of carbon dioxide.

However, the Third Assessment Report of the IPCC (Ramaswamy *et al.*, 2001) raised the GWP of methane to 23, and the Fourth Assessment Report (Forster *et al.*, 2007) raises it to 25. The GWP values of many other greenhouse gases have changed too. Presumably, international regulations will be updated as well, possibly in the second commitment period of the Kyoto Protocol, but perhaps also before 2012.

Furthermore, there are a growing number of academic papers that argue that the GWP is numerically and conceptually wrong – from a natural science (Shine *et al.*, 2005; Smith and Wigley, 2000a,b) as well as from an economic perspective (Kandlikar, 1995; Manne and Richels, 2001). Below, we briefly survey the various arguments, and assess if and when European climate policy may shift to an alternative metric. As the Fourth Assessment Report of the IPCC is largely silent on this matter, a policy shift is highly unlikely before 2012.

The GWP is defined as a ratio of two time integrals of radiative forcing[15]; the numerator is the radiative forcing from an infinitesimally small pulse of the greenhouse gas under consideration; the denominator is the same for carbon dioxide. The GWP of carbon dioxide is therefore unity by definition.

The natural scientific critiques of GWP are twofold. Smith and Wigley (2000a,b) argue that relative radiative forcing depends on assumptions about future greenhouse gas emissions and concentrations. The GWP, however, is not sensitive to such assumptions. Or rather, the GWP assumes that future concentrations are equal to today's concentrations. Although future concentrations are uncertain, it is very unlikely that they will be like today's. This implies the GWPs as used by the IPCC are biased. The alternative would be to use a GWP that is

[15] Radiative forcing is the per area change in the energy balance of the atmosphere, that is, the difference between the incoming radiation energy and the outgoing radiation energy in a given climate system. A positive forcing (more incoming energy) tends to warm the system.

probability-weighted average over all scenarios, but this has yet to be calculated as probabilistic scenarios are rare.

Global Temperature Potential. Shine *et al.* (2005) have a more profound critique of GWP: Policy is not concerned with radiative forcing. Indeed, most people would not know what radiative forcing is.. For emissions with a long life-time in the atmosphere, the equilibrium temperature change is proportional to radiative forcing. For short-lived emissions, such as aerosols, there is no simple relationship between radiative forcing and temperature. Besides, it is the actual temperature that matters, rather than the equilibrium temperature that may never be reached or only in century's time. They therefore propose to use a global *temperature* potential (GTP), and suggest that the temperature should be evaluated at the target point (e.g., the two degrees target of the European Union). This particularly affects methane, for which the GTP is much smaller than the GWP.

Global Cost Potential. Manne and Richels (2001) raise the same issue as Shine *et al.* (2005), but argue that it is not only the relative contribution of various greenhouse gases to meeting the target that matters, but also the relative costs of emission reduction. They construct an index dubbed the global *cost* potential (GCP). The GCP and GTP are roughly the same if the target is remote, and start deviating as the target is approached (Tol *et al.*, in preparation). For investment projects in the near future, GCP and GTP are similar, therefore. The GCP and GTP for methane are about 1 in 2007 – their minimum value as CH_4 degrades to CO_2 in the atmosphere.

Global Damage Potential. Schmalensee (1993) raises another fundamental concern about the global warming potential. In the social optimum, the trade-off between the emissions of different greenhouse gases would be determined by the ratio of the marginal damage costs, discussed in sub-section 3.1. Kandlikar (1995) calls this the global *damage* potential (GDP). GDP and GWP are equal only if climate change impacts are proportional to radiative forcing, an unsupported assumption, and if the discount rate is zero, which is inconsistent with existing investment policy. Estimates of the GDP are sensitive to all the things that marginal damage costs are sensitive to (see above). Furthermore, the GDP (and by implication, the GWP) assumes that climate policy is driven by cost-benefit analysis – while both the UN

Framework Convention on Climate Change and European climate policy are explicitly phrased in a cost-effectiveness framework.[16] Therefore, the GTP and GCP may be more appropriate.

For the moment, however, it would be advisable to use the official exchange rates between gases, that is, the 100-year global warming potentials of the Second Assessment Report of the IPCC. As the differences between GWP and the other methods outlined above are largest for methane, it may be worth doing a sensitivity analysis on the GWP for those projects that emit a lot of methane.

Table 2: Emissions in 2005 (in Gg CO_2eq), sources and GWPs (http://coe.epa.ie/ghg/)

Gas	**Emissions**	**Main sources**	**GWP**
CO_2	44,635	Energy; manufacturing; transport	1
CH_4	13,102	Agriculture; waste	21
N_2O	8,850	Agriculture; energy	310
HFC-23	3	Fire extinguishers; semiconductor manufacture	11,700
HFC-32	2	Refrigeration and air conditioning equipment	650
HFC-125	55	Refrigeration and air conditioning equipment; foam blowing	2,800
HFC-134a	286	Refrigeration and air conditioning equipment; foam blowing; aerosols / metered dose inhalers	1,300
HFC-152a	1	Refrigeration and air conditioning equipment; aerosols / metered dose inhalers	140
HFC-143a	70	Refrigeration and air conditioning equipment; foam blowing	3,800
HFC-227ea	13	Fire extinguishers; aerosols / metered dose inhalers	2,900
CF_4	3	Semiconductor manufacture	6,500
C_2F_6	34	Semiconductor manufacture	9,200
c-C_4F_8	2	Semiconductor manufacture	8,700
SF_6	96	Semiconductor manufacture; electrical equipment; medical applications; sporting goods; double-glazed windows	23,900

[16] A cost-effectiveness finds the cheapest way to reach a given target. A cost-benefit analysis finds the optimal target as well as the cheapest way to reach that target.

5. PRACTICE IN OTHER JURISDICTIONS

Analysing investment options using environmentally-adjusted cost-benefit analysis is undertaken in many ways by financing institutions worldwide, but as yet there is no clear 'best-practice'. To illustrate some of the available variants, in this section we briefly refer to the methods employed by the World Bank, the European Investment Bank, the UK Treasury and the European Commission.

5.1 The World Bank

The work of Samuel Fankhauser (1994, 1995) has significantly influenced the decision criteria employed by the World Bank in its assessment of investment projects (Hamilton, 2002). Fankhauser (1995) conducted an analysis that gave the following results:

"damage per tonne of emissions is rising over time, from about $20/tC between 1991 and 2000 to about $28/tC in the decade 2021-30."

Three issues must be borne in mind when employing these results. First, as is discussed in Section 4 above, the methods used to calculate the effects of greenhouse gases have changed since Fankhauser calculated the costs of CO_2 emissions. Second, inflation and the changing value of the dollar mean that a re-estimation is required before a contemporary value can be calculated. Third, as Fankhauser noted when presenting his results, discounting the future value of the potential costs of climate change is essentially arbitrary depending on the assumptions employed by the analyst – and 'catastrophic events' can significantly influence the damage cost estimates that are reached (1994, 68-9).

Nevertheless, the World Bank continues to draw on this analysis for project appraisal.[17] In describing the World Bank's current approach to evaluating the environmental impact of potential projects (with a particular focus on resource extraction), Hamilton (2002) notes that:

"[With regards to] pollution damages, these should ideally reflect emissions and exposure data for the full range of local regional and global pollutants. In practice, there are no

[17] It should be noted that this is distinct from the World Bank's other role as market operator in the market for carbon credits. For this purpose, it was one of the fore-runners in establishing markets for carbon credits, and 'has set up a bank-wide pricing committee, and through that and dialogue with fund participants and host countries, and its own market research the World Bank has developed an approach by which it will seek to establish transparent, fair and consistent pricing' (worldbank.org).

comprehensive data on local and regional pollutants. As a ‘place-holder’ for other pollutants, therefore, damages from carbon dioxide emissions are included…using a figure of $20 per ton of carbon derived from Fankhauser (1995) and widely available data on CO_2 emissions from industrial sources.”

5.2 The European Investment Bank

The EIB has adopted a rather different approach to the valuation of carbon emissions that relies on prices derived from markets for carbon. The Multilateral Carbon Credit Fund allows companies and other agencies in transition/developing nations, who are seeking assistance from the EIB and the European Bank for Reconstruction and Development (EBRD), to offset polluting emissions from their proposals by purchasing carbon credits on an open market. Prices for these credits are largely exogenously determined, and are based on the EU-ETS, Joint Implementation (JI) and Clean Development Mechanism (CDM) trading schemes.

5.3 UK Treasury

Like the World Bank, HM Treasury bases the price of carbon on estimates of the marginal damage costs. Clarkson and Deyes (2002) conducted a review that recommended a damage cost estimate of £70/tC (2000 prices; $100/tC), with upper and lower bounds of £35/tC and £140/tC for sensitivity analyses. This paper was critiqued by Pearce (2003), who recommended a price of £3-6/tC, drawing inter alia on Nordhaus and Boyer (2000). In response, HM Treasury commissioned another review by Downing and Watkiss (2004), who recommended a lower bound of £35/tC but could not specify a best estimate for an upper bound.

This analysis has been superseded by the Stern Review on the Economics of Climate Change, another study by HM Treasury. Stern *et al.* (2006) recommended a carbon tax of around $85/t$CO_2$, or $315/tC. The Stern Review is hotly disputed in academic circles (Dasgupta, 2006; Mendelsohn, 2006; Nordhaus, forthcoming; Tol, 2006; Tol and Yohe, 2006, 2007; Yohe and Tol, 2007; Weitzman, forthcoming), but seems to be broadly accepted among UK policymakers. It is therefore expected that the UK will increase its carbon price (as recommended by Stern *et al.*, 2006) rather than decrease it (as recommended by Downing and Watkiss, 2004).

5.4 The European Commission

The European Commission has a dual approach to valuing carbon dioxide emissions. On the one hand, it has commissioned a series of studies on marginal damage costs. The ExternE series is best known (Eyre *et al.*, 1999; Friedrich and Bickel, 2001; Bickel and Friedrich, 2005), and this work is currently being updated in the Commission-sponsored MethodEx (http://www.methodex.org/) and NEEDS (http://www.needs-project.org/) projects. On the other hand, there are emission reduction targets for both the short- and the long-run – and these targets imply marginal emission abatement costs; see Section 3.5. As the current emission targets are not based on a cost-benefit analysis, the marginal abatement costs are the more appropriate way of pricing emissions, but we are not aware of an official EU policy on this matter.

6. CONCLUSIONS

Above, we outline three choices that need to be made in order to include the costs of greenhouse gas emissions in the economic appraisal model used to evaluate investments in projects in the Republic of Ireland. This section sets out our suggested approach. The first sub-section discusses the three options, and the second sub-section summarises how the model would affect six types of projects.

6.1 Recommended methodology and data sources

For projects with substantial energy use, **carbon dioxide emissions** should be estimated on the basis of the expected energy use and the SEI's emission factors (http://www.sei.ie/index.asp?locID=72&docID=-1). **Emissions of other greenhouse gases** should be taken from IPPC license applications.

The **private costs of energy** assumed to be borne by each project should be increased by a proportion that depends on the expected price of carbon dioxide (see Table 3). This is an approximation of the actual increase in energy costs, but a more accurate estimate of the increase in energy costs would require substantial additional detail on energy use and energy prices, and it would involve significantly more maintenance work for those using the model. We recommend that the option of employing a more detailed treatment of these costs be deferred until the next major revision of the economic appraisal model.

The **social cost of carbon dioxide emissions** should be set equal to the future price of carbon dioxide emission permit as traded on the European Energy Exchange. This represents the opportunity cost to "Ireland Inc" of having to import additional emission allowances to offset the increase in emissions. There is no futures market after 2012, and we have provided two options as to how to predict prices in years after this date.

First, the carbon price from 2013 may be interpolated between the futures prices in 2012 and the model-based price in 2030 according to the IPCC for the scenario towards 550 ppm (roughly the long-term EU target). The IPCC states "that carbon prices in the range 20-50 US$/t$CO_2$ reached globally by 2020-2030 […] would deliver deep emission reductions by mid Century consistent with stabilisation around 550ppm CO_2-eq"; we use \$50/tCO_2 for 2030.

Second, the expected carbon prices for periods when futures are not available may be held constant at the latest futures price available. Table 3 below sets out the current carbon prices resulting from both of these methods.

Table 3: Recommended carbon prices and associated price increases for electricity and fuels.

	Carbon price Constant after 2012	Carbon price IPCC-based after 2012	Price increase Industry fuel	power	Services fuel	power
	€/tCO_2	€/tCO_2	%	%	%	%
2008	26.06	26.06	8.9	43.8	8.6	12.0
2009	26.64	26.64	9.1	44.8	8.8	12.3
2010	27.21	27.21	9.3	45.7	9.0	12.6
2011	27.91	27.91	9.6	46.9	9.2	12.9
2012	28.87	28.87	9.9	48.5	9.6	13.3
2013	28.87	29.28	10.0	49.2	9.7	13.5
2014	28.87	29.69	10.2	49.9	9.8	13.7
2015	28.87	30.11	10.3	50.6	10.0	13.9
2016	28.87	30.53	10.5	51.3	10.1	14.1
2017	28.87	30.96	10.6	52.0	10.3	14.3
2018	28.87	31.4	10.8	52.8	10.4	14.5
2019	28.87	31.84	10.9	53.5	10.5	14.7
2020	28.87	32.29	11.1	54.2	10.7	14.9
2021	28.87	32.74	11.2	55.0	10.8	15.1
2022	28.87	33.2	11.4	55.8	11.0	15.3
2023	28.87	33.67	11.6	56.6	11.2	15.5
2024	28.87	34.14	11.7	57.4	11.3	15.8
2025	28.87	34.62	11.9	58.2	11.5	16.0
2026	28.87	35.11	12.0	59.0	11.6	16.2
2027	28.87	35.6	12.2	59.8	11.8	16.4
2028	28.87	36.1	12.4	60.6	12.0	16.7
2029	28.87	36.61	12.6	61.5	12.1	16.9
2030	28.87	37.12	12.7	62.4	12.3	17.1

The future prices should be updated at least once a year, using http://www.eex.com/en/. The model-based carbon prices should be updated every six years, using http://www.ipcc.ch/.

The **social cost of other greenhouse gas emissions** may be set equal to the social cost of carbon times the 100-year Global Warming Potential according to the Second Assessment Report of the Intergovernmental Panel on Climate Change. The current numbers are given in Table 2.[18]

[18] If a project is expected to emit a substantial amount of methane, it is recommended to conduct a sensitivity analysis with a GWP of 2.1. Methane emissions typically result from coal mining, natural gas transport, paddy rice cultivation, livestock, and organic waste processing.

6.2 Summary of how the proposed approach would apply to different project types

To help cast light on the administrative processes that might be required to apply the proposed model, this section describes the model's broad data requirements and implications for a range of possible project types.

1. **Project obtaining all its energy by purchasing electricity from an external supplier (i.e. across the national grid) and generating no process emissions**

No net social cost of emissions would arise in this case. Purchases of electricity from an external ETS-participant supplier would be deemed to have had their carbon emissions paid for by the supplier (with the cost potentially passed on in the price of electricity). Since no other emissions are anticipated, it would not be necessary to collect information on such emissions, ETS participation or grandparenting. Many service sector projects are likely to fall under this heading.

2. **Project generating its own energy, participating in the ETS, *not* receiving grandparented permits, and without other process emissions.**

Here too, there would be no net social cost of emissions. While the project would generate incremental emissions due to energy generation, it would have to purchase ETS permits to cover these emissions on the open market. Its private costs would fully offset the relevant social costs.

3. **Project generating its own energy, participating in the ETS and receiving grandparented permits (e.g. from the New Entrant Reserve), but without other process emissions.**

This project would give rise to a net social cost in respect of the gases emitted as a result of its energy generation. The share of such emissions covered by grandparenting would not be offset by a private cost to the firm. To calculate these costs, the model would require information for each year of the evaluation on the quantity of emissions and the share of emissions covered by grandparenting.

4. **Project generating its own energy, but not participating in the ETS or giving rise to other process emissions.**

This would probably be a small plant that was under the threshold for ETS participation. Its emissions would give rise to a net social cost, with no offsetting private cost. To calculate these costs, the model would require information on the quantity of emissions during each year modelled. This should be a relatively straightforward function of the fuel type and boiler capacity.

5. Project generating its own energy, not participating in the ETS, not giving rise to other process emissions, but subject to a (currently hypothetical) carbon tax

This project might give rise to a net social cost, depending upon the level of the carbon tax relative to the cost of carbon. To calculate these costs, the model would require information on the quantity of emissions and the level of the carbon tax during each year modelled.

6. Project giving rise to process emissions other than CO_2

At present, emissions of GHGs other than CO_2 are outside the ETS and are not taxed, so projects of this kind will not currently face a private cost for these emissions. The project would therefore give rise to a net social cost. Calculating it would require the expected emissions of each gas for each year, which should be available from the IPPC licence application that such a project must make to the EPA. The model would multiply these emissions by the relevant GWPs to arrive at the total cost. If a particular gas is made subject to the ETS or taxed at some point in the future, the model has the flexibility to take this into account.

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