AGE Analysis of the Impact of a Carbon Energy Tax on the Irish Economy

Wiepke Wissema*[1] and Rob Dellink[2]

[1]*Department of Economics, Trinity College Dublin, Dublin, Ireland and* [2]*Environmental Economics and Natural Resources Group, Wageningen University, Wageningen, The Netherlands*

ABSTRACT

A computable general equilibrium model with specific detail in taxation and energy use is developed in this paper to quantify the impact of the implementation of energy taxation to reduce carbon dioxide emissions in Ireland. We find that the reduction target for energy related CO_2 emissions in Ireland of 25.8 percent compared to 1998 levels can be achieved with a carbon energy tax of 10-15 euro per tonne of CO_2. Though fuel switching is important in meeting the target, this result is more sensitive to the possibilities for producers to substitute away from energy use. Welfare would fall but only by small percentages. Production and consumption patterns would change more significantly, with a shift in demand from fuels with a high emission factor to energy sources with a lower carbon-intensity and from energy to other commodities. This paper confirms that a carbon energy tax leads to greater emission reductions than an equivalent uniform energy tax. The latter has a stronger negative impact on the less polluting energy sectors whereas the carbon tax greatly stimulates the use of renewable energy and reduces the use of peat and coal. This paper contributes to a better informed debate on environmental policy in Ireland.

JEL classification: D58; H23; Q43; Q48

Keywords: Applied general equilibrium; Climate change; Energy taxes; Ireland

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[*] Corresponding author. Email address: wissemaw@tcd.ie. We gratefully acknowledge funding by the EPA ERTDI.

1. INTRODUCTION

Currently climate change is at the top of the environmental agenda in the European Union (EU). It is caused by the accumulation of greenhouse gases (GHGs) in the Earth's atmosphere. Global political efforts to reduce this problem led to the agreement of the Kyoto Protocol in 1997. The Protocol sets targets to reduce the anthropogenic emissions of GHGs. As part of the EU burden-sharing agreement, Ireland has to limit average annual emissions in the period 2008-2012 to 13 percent above 1990 levels. Due to strong economic development in Ireland in the 1990s, emissions are already well past this target and Ireland has the highest per capita emissions in Europe. Ireland also faces one of the widest gaps (nearly 18 percent) between forecasted emissions under a business-as-usual scenario and the target (Indecon, 2003). To meet the target, specific government policy is required and the economy will have to undergo structural changes. The government of Ireland has published a National Climate Change Strategy (NCCS) that sets sectoral targets and proposes both sectoral and cross-sectoral measures. The aim of the strategy is to meet the targets and to minimise the costs of implementation for the economy as a whole (DoE, 2000). Key measures in the Strategy are

- to gradually introduce taxation from 2002, prioritising taxes aimed at CO_2 emissions;
- to participate in the pilot EU emissions trading scheme and in international emissions trading.

The Minister for Finance indicated in his Budget speech for 2003 that the government was proposing to introduce a carbon tax in 2004. In 2005, however, the tax was still not implemented and this proposal was abandoned altogether due to fears for its impact on competitiveness. Oil prices were already increasing strongly. Since January 2005, the 109 installations emitting most CO_2 have been participating in the EU emissions trading scheme. The price of permits has varied but recently hovers around 20 euro per tonne of CO_2.

Clinch and Dunne (2006) examined the social impediments to environmental tax reform (ETR) in Ireland. From their interviews with businesses and policy makers and from discussions in focus groups with members of the general public it is clear that awareness and understanding of the concept of ETR is very low. The main problem with its introduction appears to be that there is insufficient trust that the government will keep its promise to recycle the revenue from the tax by lowering other taxes. Some of the other problems mentioned are: concern for competitiveness and inequity between sectors, the perception that an energy tax would need to be very high ('punitive', p. 959) to have an impact and would further worsen existing fuel poverty.

In 1992, Fitz Gerald and McCoy carried out the first empirical work assessing the macro-economic effects of imposing a carbon tax on the Irish economy. The findings were that a tax of 30 euro per tonne of CO_2 in 2002 prices[1] would increase tax revenue by almost 2 percent of GNP. The overall implications for the economy depended on how the revenue from the tax was spent. The model they used was the ESRI macro-economic Medium Term Model (HERMES) supplemented by an energy sub-model, which has a fixed fuels mix and does not incorporate explicit energy consumption by households or the services sector (Fitz Gerald and McCoy, 1992).

Conniffe et al. (1997) estimated the cost of abatement through changes in technology. They found that the electricity sector could achieve significant reductions by switching to gas

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[1] At the time, the proposed EC carbon tax was equivalent to $10 per barrel of oil or IEP7.47 per tonne of CO_2.

firing, but once the possibilities were exhausted, abatement costs for this sector would rise sharply.

Bergin et al. (2002) used an improved version of HERMES and found that a carbon tax of 20 euro per tonne of CO_2 would cost the Irish economy relatively little. However, this tax would not lead to the required emission reduction and the additional measures suggested in the NCCS would need to be fully implemented along with an early implementation of the tax. They simulated four ways to use the revenue and concluded that (1) with reduced taxes on labour a welfare improvement is possible; (2) reducing VAT has less attractive macro-economic results but distributional advantages; (3) a lump sum payment to households could have very adverse competitiveness effects and lead to loss of output, which in the long term would affect income levels and employment and (4) a lump sum payment to firms would lead to the biggest loss in GNP. Only the first two instruments lead to lower prices and lower wage rates which would offset the negative impact of the carbon tax on competitiveness.

Scott and Eakins (2002) analysed the implications of this tax for the incomes of different household groups. If all households received an average compensation of 247 euro per year, all household groups gained, on average, from the reform. But many individual households in low-income brackets would be worse off. They recommended a more integrated analysis of the tax and welfare system.

As the next section will indicate, applied general equilibrium (AGE) models provide the most appropriate methodology for analysing the impact of a carbon tax on an economy. So far, only one AGE study on climate change policy focused specifically on Ireland (Indecon, 2003). The AGE model used was based on GEM-E3, the General Equilibrium Model for Energy-Economy-Environment interactions used for European policy analysis (Capros *et al.*, 1997). The Indecon analysis was limited to the impact of emissions trading on manufacturing sectors. The carbon tax and the impact on the agricultural, services and residential sectors were not considered.

This paper focuses on CO_2 emissions from the use and production of energy. The climate change policy debate in Ireland focuses, with regard to fiscal instruments, on the introduction of a carbon tax, while in the European context more experience has been gained with uniform energy taxation. In order to properly evaluate environmental taxation in Ireland, it is important to systematically compare the impact of the different types of taxation. Thus, this paper contributes by addressing the "distinct lack of objective research [into environmental taxes] on which the [Irish] government […] can draw" (Clinch and Dunne, 2006, p. 957).

The aim is to answer the following research questions.

1. In what range would a carbon energy tax need to lie in order to meet the Irish Kyoto target for energy-related emissions of CO_2?
2. What would be the impact of such a carbon tax compared to an undifferentiated (uniform) energy tax on the Irish economy, welfare and emissions?
3. How would this carbon tax affect sectoral output, household consumption patterns and demand for the various energy commodities?

Emissions trading is not assessed in this paper. But the conclusions may be generalised on the basis that theoretically, a system for emissions trading that is limited to CO_2 emissions provides the same economic incentives as the carbon energy tax and, in perfectly functioning markets, leads to the same abatement results when the carbon tax level equals the price of permits (which equals the marginal abatement costs at the levels of emissions that corresponds to the same abatement target). The next section motivates the choice of methodology and describes the model applied. First it briefly summarises relevant discussions in the international literature on this topic.

2. METHODOLOGY

2.1 Literature

Pempetzoglou and Karagianni (2002) review carbon taxation models that have been developed to quantify the impact of the imposition of an energy tax on competitiveness. They conclude that the most suitable types of models for this purpose are dynamic general equilibrium models and sectoral macro-econometric models. For macro-econometric models the data requirement limits the extent of disaggregation. Time-series data is needed to estimate the econometric equations for each sector. General equilibrium models use elasticities of substitution that should ideally be estimated econometrically but if that is not practicable, they can be taken from the literature. In the latter type of models it is thus feasible to have a far more detailed breakdown of the production sectors. Therefore it was decided to use a general equilibrium model in this paper.

General equilibrium models are based on the micro-economic behaviour of producers and consumers and are most suitable for the analysis of policy measures that lead to indirect as well as direct effects because they include all sectors in the economy and consist of a closed cycle. They can include a detailed representation of substitution possibilities between energy sources as well as between energy on one hand and production factors on the other hand.

Internationally, many applied general equilibrium (AGE) models have been developed to analyse energy policy options, ranging from the early Hudson-Jorgenson (1974) model to recent contributions such as Dissou (2005). Bhattacharyya (1996) carried out a survey of AGE models for energy studies, most of them applied to climate change policy analysis, and points out nine issues the modeller should keep in mind, the most relevant being (Bhattacharyya, 1996, p. 159-161): (i) the robustness of the results depends on parameter values, especially elasticity values; (ii) existing inefficiencies are implicitly incorporated in the specification of technology through parameter estimation; (iii) results depend on specification of functional forms in the model[2]; (iv) models incorporate the limitations of underlying theories; (v) the optimal level of disaggregation depends on the objective of the study, constraints on cost, time and other factors.

Devarajan and Robinson (2002) advise modellers to use the simplest model adequate to the task at hand. They recommend structural, applied (or ‘computable’) general equilibrium models because “the experience of the past twenty years seems to demonstrate that it is better to have a good structural model capturing the relevant behaviour of economic actors and their links across markets, even if the parameters are imperfectly estimated, because the domain of applicability of such models makes them far more useful for policy analysis” (Devarajan and Robinson, 2002, p. 3-4) than stylised models.

More recent overviews of AGE models for climate change and energy issues are given in Conrad (1999), Harrison *et al*. (2000), Weyant (2004) and Dellink (2005).

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[2] For instance, Jaforullah (1992) compares three Johansen-type models with production functions of varying flexibility and recommends incorporating both inter-factor and inter-fuel substitution possibilities.

2.2 The Irish Energy-Environment Model

This paper introduces the first energy-environment-AGE model for Ireland with specific detail in the area of taxation. It is a structural, real, static model of a small open economy with seven energy commodities, 19 other commodities, a government, an investment agent, a foreign agent and a single representative household. It incorporates energy flows among producers and between producers and consumers. The sectors and commodities are described in Appendix A; Appendix B contains a complete overview of the equations of the model.[3]

2.2.1 General Features

The standard assumptions of GE models apply: market clearing in all markets, goods and services as well as production factors, zero excess profits[4] and a balanced budget for each agent (*cf*. Ginsburgh and Keyzer, 1997). The model is calibrated to benchmark data.

A less common feature is the separation of industries and commodities in the model, creating the option of joint production (*cf*. Lofgren *et al.*, 2001). Also, the model accommodates the possibility that imported commodities are exported as explained in Section 2.2.3. It is assumed that the economy is in equilibrium in the benchmark. A policy simulation is implemented as a 'counter-factual' scenario, which consists of an exogenous shock or set of shocks to the system. The model output shows the state of the economy after all markets have reached a new equilibrium, *i.e.*, we conduct a comparative-static analysis[5].

2.2.2 Production

A firm can choose how much to produce of each of the commodities it can produce. The output is divided among the produced commodities with a CET[6] function, where the elasticity of transformation is equal to zero for all industries. This perfectly inelastic function ensures that the shares of commodities produced, in terms of quantity, remain the same during all simulations. The production process is represented by a nested production function as depicted in Figure 1 below[7]. The electricity producer has a separate production function (shown in the second panel). In the figures, the Allen elasticities of substitution are indicated with 's: ' and are the same for each industry. The top-level function is a Leontief function (s:0) that determines the producer's demand for the aggregate factor input of labour, capital and energy *LKE* and each of the intermediate (non-energy) inputs *IO(i)*. CES[8] functions are applied for levels two to six of the production function. The elasticities of substitution between labour *L* and composite capital and energy, *KE*, and between aggregate energy *E* and capital *K* are taken from Kemfert (1998)[9].

Elasticities for the *E*, *FOS* and *LIQ* nests are taken from GTAP-EG (Rutherford & Paltsev, 2000). Peat and coal form *SOL* with an elasticity larger than unity because they are good, but

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[3] The model code is available upon request.

[4] It is possible to incorporate imperfect competition in the model, but this is not within the scope of this project.

[5] Dellink (2005) shows how the modelling framework can be expanded to a fully dynamic analysis and discusses the validity of the comparative-static approach as an approximation. A good example of a dynamic multi-regional model for climate policy is given in Böhringer and Welsch (2004).

[6] CET = Constant Elasticity of Transformation.

[7] The choice for the L-KE nesting structure is based on Kemfert (1998), who concludes that this fits the German industry best overall. GTAP-EG (Rutherford & Paltsev, 2000) inspired the remainder.

[8] CES = Constant Elasticity of Substitution.

[9] Kemfert (1998) econometrically estimates L-KE and K-E elasticities for German industry overall to be 0.846 and 0.653, respectively. It is assumed that the Irish economy has equal flexibility to German industry.

not perfect substitutes. Finally, crude oil and oil products are aggregated in a Leontief function, because crude oil is only used in the oil refinery and there should not be any substitution between these two fuels.

Irish security of energy supply policy prevents a major drop in peat consumption by the electricity generation sector. This situation is approximated by fixing the input of peat per unit of electricity produced in the Leontief function in the top level of the production tree. Since 'RNEW' is defined as electricity produced from renewable resources, substitution is only limited by a lack of capacity in the renewables industry. It is assumed that capacity can be increased and therefore, the elasticity is set fairly high, at 10.

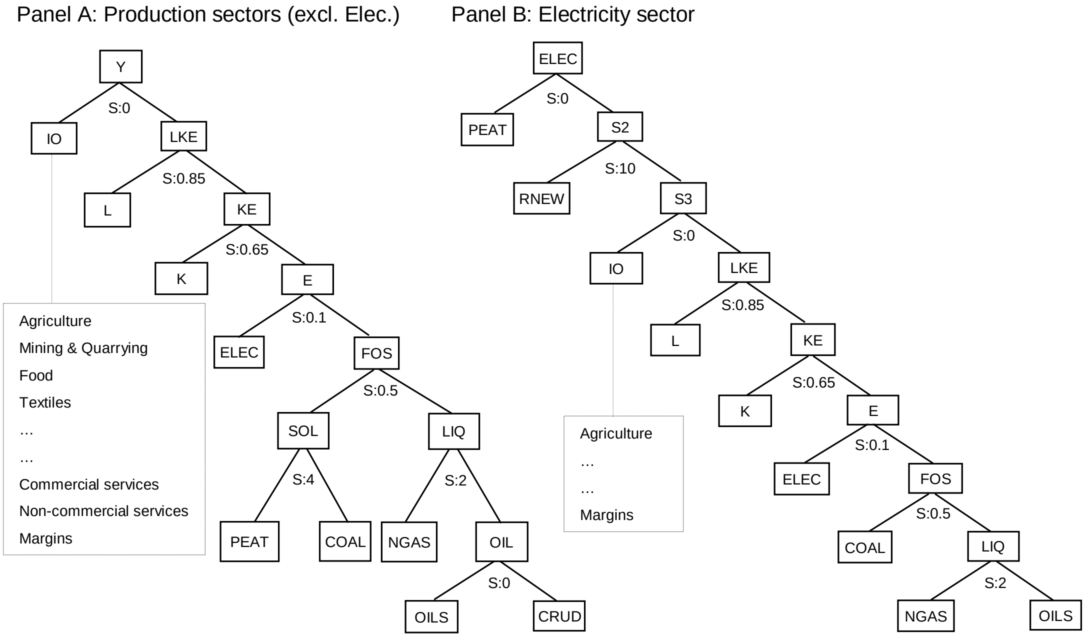

Figure 1. Nesting Structure of the Production Functions

2.2.3 International Trade

The Armington assumption[10] is applied in combining domestic production *Y* and imports *M*, using a CES function. The resulting homogeneous 'Armington commodities' (quantity *A* valued at price *pa*) are either sold in Ireland or exported. A CET function determines the scope for choice between domestic supply (quantity *D* valued at price *pd*) and export (quantity *E* valued at price *px*). Exports are traded for foreign exchange *pfx*, which is used to pay for imports. The elasticity of substitution between Irish made products and imports (the Armington elasticity in the CES function) as well as the elasticity of transformation between domestic sales and exports in the CET function, are set equal to 4. This creates substantial flexibility in choices about the destination and source of commodities.

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[10] The assumption is that imported and domestically produced commodities are substitutes of each other, but not perfect substitutes. This solves the problem that the same kind of good is found to be both exported and imported in actual trade data which is inconsistent with the Heckscher-Ohlin model under perfect competition (Armington, 1969).

2.2.4 Consumption

Total domestic supply of each commodity is assumed to exactly meet demand (market clearing). Total demand is made up of intermediate demand and final demand, including household and government consumption, investment and exports. Intermediate demand is dealt with in the discussion of production. Household and government consumption as well as investment are driven by the maximisation of a Cobb-Douglas utility function subject to a budget constraint. This means that domestic agents respond to price incentives but keep the share of their budget spent on each commodity fixed. The household sector is represented by a single Representative Agent (RA).

2.2.5 Taxation

One of the main distinctive features of the model is its relatively detailed modelling of taxation. Three taxes are modelled:

1. indirect taxes less subsidies on products;
2. taxes less subsidies on production;
3. a counter-factual carbon energy tax or uniform energy tax.

Indirect taxes on products, net of subsidies, are paid by all users. Even the government has to pay itself some tax. In the case of exports, subsidies on products generally exceed their taxes. The second tax is a net production tax levied on the value of output, regardless whether exported or sold in Ireland. Its rate is fixed, but it is different for each industry. In some cases it is negative, indicating that subsidies are greater than taxes for that industry.

The energy tax is introduced as a counter-factual scenario. In the carbon tax simulation, both firms and households have to pay a tax on energy if their use of the energy commodity causes emissions of CO_2. The tax rate is different for each fuel, according to its carbon content. The uniform energy tax is levied on all energy sources. Section 4 has more details on these tax simulations. All tax revenue is collected by the government. The government spends all revenue (net of subsidies) on the aggregate commodity *G* and endogenous transfers keeping its budget surplus fixed. The closure rule is discussed in Section 2.2.7.

2.2.6 Factors of Production and Savings

The RA owns all factors of production, *i.e.*, labour *L* and capital *K*. The RA's income is made up of income from the supply of labour (quantity *LS* valued at price *pl*) and from the rental of capital (capital supply *KS* valued at price *pk*). Household savings are exogenously fixed and equal to the sum of the government's budget surplus and the balance of trade surplus less investments and the value of increases in stock. This ensures that the financial cycle is closed.

2.2.7 Closure and Welfare Measurement

The choice of exogenous variables is the closure rule of the model. In the model, the price of aggregate private consumption, the consumer price index, is chosen as the numéraire, the price relative to which all price changes are evaluated[11]. This price being fixed at unity, the total quantity of consumption equals the total value of consumption at all times. A change in total household consumption therefore equates a welfare change as measured by Hicksian equivalent variation (EV).

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[11] Absolute price levels are undetermined in the model and only relative prices can be assessed. Fixing the consumer price index implies that inflation cannot occur.

The government intended to implement the carbon energy tax as an equal yield policy. This means that total tax revenue remains unchanged. The tax revenue from the new tax must therefore be matched by a reduction in revenue from another tax or an increase in transfers to households. Government spending as well as the budget surplus are fixed. With world prices fixed, the market for foreign exchange is cleared by fluctuations in the exchange rate. Even though Ireland is in the euro-zone, two of her main trading partners are the United Kingdom and the United States, both of which have different currencies. Labour and capital supply are exogenously fixed. Markets for labour and capital are cleared by endogenous factor prices. Since the model is static, the output of the model must be interpreted as the new equilibrium reached after the economy has had time to adjust, but changes in factor supply have not (yet) occurred.

3. DATA

3.1 The Aggregated Social Accounting Matrix

In this paper, a new Social Accounting Matrix (SAM) was created for the base year 1998. This is the most recent year for which the Central Statistics Office (CSO) has produced Supply and Use Tables (GoI, 2004), the main data source for the SAM. Some of the sectors/products in the CSO Tables were aggregated in the SAM in order to reduce the dimensions of the model. The SAM is disaggregated to create separate energy industries and commodities in Section 3.2. Appendix A lists the acronyms with their full descriptions. Emissions are discussed in Section 3.3.

The CSO Supply Table (CSO T1) provides the matrix which maps industries to their products, *MAKE(j,i)*, valued at *basic prices*, and then adds imports, trade margins and taxes on commodities and deducts subsidies on commodities in order to arrive at the same totals for each commodity as in the Use Table, at *purchaser's prices* (CSO T2). In the SAM, the index for the 26 commodities is *i*, and *j* indicates the 26 industries. Imports are valued at *c.i.f.* prices and import duties are included with product taxes *TY(j)* in the industry columns. The commodity rows in the SAM, which show intermediate demand *ID(i,j)* and final demand *FD(i,f)*, valued at *basic prices*, are created by adding corresponding cells in an unpublished Use Table at *basic prices* (T7), the imports table (T3) and an unpublished table with estimates of margins on all commodities paid by all industries (T9). Labour and capital costs *L(j)* and *K(j)* as well as taxes and subsidies on products *TID(j*) and production taxes and subsidies *TY(j)* are published as part of CSO T2. The transfers between agents appearing in the section in the SAM beneath the commodity rows and in the columns for final demand are taken from the CSO tax table (T8); savings are calculated as residual income for each agent to balance their budgets.

3.2 Disaggregation of Energy in the SAM

In order to simulate climate change policies in relation to energy-related carbon dioxide emissions, it is imperative to first adequately model the following features:

- energy flows among industries (intermediate demand);
- energy flows between industries and consumers (final demand including exports);
- tax paid on energy products;
- imports of energy sources;
- the cost structure of energy producing industries.

Seven energy sources and industries (crude oil, oil products, coal, peat, electricity, renewables and natural gas) are distinguished separately in the model, and thus also in the SAM. This disaggregated SAM will henceforth be referred to as the energy-SAM (ESAM). The rows and columns in the SAM (partially) pertaining to energy sources[12] were initially disaggregated proportionally, using value shares. Using quantity shares would lead to incorrect results. The disaggregation methodology and the data sources used are described in Wissema (2006). The data manipulations culminate in Table 1 below, which shows an alternative energy balance in monetary units based on Irish energy data (IEA, 2000) and prices from the Economic and Social Research Institute (ESRI, 2003). Import values in Table 1 are derived from the CSO Trade Statistics (CSO, 2000a).

Table 1. Energy Use, Imports and Domestic Production, Ireland, 1998 (thousand euro, at basic prices)

	CRUDE OIL	REFINED OIL	COAL	PEAT	GAS	ELECTRICITY	RENEWABLES
Agriculture	-	71 143	-	-	-	-	-
Mining and Quarrying	-	5 382	-	-	2 095	14 921	-
Crude oil							
Coal industry	-	-	-	-	-	3 345	-
Peat briquetting	-	730	566	3 347	-	-	-
Food and Tobacco	-	28 708	2 236	-	25 763	91 120	-
Textile and Leather	-	5 852	-	-	-	20 019	-
Wood and Wood Products	-	2 521	-	-	-	20 921	-
Chemical	-	19 036	-	-	94 449	47 169	-
Petrochemical	-	1 215	-	-	6 029	3 011	-
Other Non-Metallic Minerals	-	20 774	4 362	-	8 033	30 904	-
Iron and Steel and Non-Ferrous Metals	-	45 705	-	-	3 064	33 559	-
Transport Equipment and Machinery	-	12 408	-	-	-	49 436	-
Non-specified (Industry)	-	9 440	-	-	6 750	62 393	-
Oil refinery	269 218	6 891	-	-	-	1 646	-
Gas extraction and distribution	-	-	-	-	3 271	-	-
Electricity generation and distribution	-	76 686	79 808	56 638	138 553	169 655	76 295
Renewables							
Construction	-	-	-	-	-	2 867	-
Trade							
Hotels, Restaurants and Bars	-	15 206	-	115	2 805	31 870	-
Road, Rail and Water Transport	-	842 341	-	-	-	2 347	-
Air Transport	-	84 939	-	-	-	-	-
Other Commercial Services	-	127 901	-	968	23 595	268 059	-
Non-Commercial Services	-	65 200	-	494	12 028	136 649	-
Residential	-	215 129	91 142	108 852	125 174	595 662	-
Government							
Exports (1)	-	108 563	-	38 854	2 666	635	-
Investment							
Stock							

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[12] These rows (commodities) and columns (industries) are Mining and quarrying (coal and peat), Other manufacturing (oil products, refining) and Electricity and gas (electricity including renewables and natural gas).

	CRUDE OIL	REFINED OIL	COAL	PEAT	GAS	ELECTRICITY	RENEWABLES
Total demand	269 218	1 765 770	178 113	209 268	454 277	1 586 187	76 295
Imports (1)	269 218	467 103	128 323	1 571	139 544	2 286	-
Production (2)	-	1 298 667	49 790	207 698	314 732	1 583 902	76 295

Note 1. Import and export figures from CSO Trade Statistics.
Note 2. Domestic production calculated as total demand less imports.

Disaggregating each cell in a row or column using the initial aggregate shares would necessarily lead to the correct totals. However, this would not be realistic for most industries and in some cases far more data was available to refine this disaggregation. With value shares calculated from CIP data (CSO, 2000b, with a supplemental energy breakdown), the energy rows in intermediate demand of manufacturing industries and the utilities sector were disaggregated in considerable detail. Furthermore, the disaggregation of the electricity and gas industries were refined using the CIP data (CSO, 2000b, T1). Wissema (2006) details this further disaggregation process and presents the ESAM.

3.3 Emissions

Emissions data was calculated by multiplying the energy volume data with emission factors of Table C.2 in the Appendix. Table 2 shows the results, disaggregated by fuel and user. Total emissions of CO_2 for 1998 are estimated at some 39.7 million tonnes by the ESRI and 40.0 million tonnes in the National Climate Change Strategy (DoE, 2000). The ESRI estimates that CO_2 emissions from the use of energy amount to 37.4 million tonnes. Total emissions in Table 2 are slightly higher, at almost 37.8 million tonnes. This is due to the fact that revised IEA data was used here. Emissions of CO_2 due to the use of energy are quite important in Irelnad, as they represent nearly 60 percent of total greenhouse gases emitted in 1998, as measured in CO_2-equivalent units (calculated from data used for the NCCS).

Table 2. Emissions of CO_2 in Ireland, 1998 (million tonnes)

	AGFF	MINE	PEAT	FOOD	TEXT	WOOD	CHEM	RBPL	NMIN	METL	MTPR
COAL			0.04	0.10					0.19		
PEAT											
OILS	0.75	0.09	0.03	0.48	0.10	0.04	0.32	0.0	0.35	0.76	0.21
NGAS		0.03		0.35			1.28	0.08	0.11	0.04	

(cont.)	OMAN	OILS	NGAS	ELEC	LDCT	TRNS	AIRT	SVCC	SVCN	MARG	HOU
COAL				5.29					0.97		
PEAT				2.73					1.63		
OILS	0.16	0.30		3.46	0.16	8.72	1.35	0.69	2.41	0.16	0.30
NGAS	0.09		0.07	3.10	0.04		0.32	0.16	0.78	0.09	

4. ENERGY TAX SIMULATIONS

Two types of energy taxes are compared in this section. The first type, the *carbon tax*, is differentiated according to the emission factor of each energy source. The second type is a *uniform energy tax*, where all energy sources are taxed at the same rate. In the model, both taxes are implemented as an *ad valorem* tax. The emission factors in Table C.2 in the

Appendix are divided by user-specific 1998 prices of the energy commodities and multiplied by a chosen tax level to obtain the matrix of *ad valorem* carbon tax rates. The uniform tax rates are equivalent to the carbon tax rates in the sense that they would raise an equal amount of tax revenue in the benchmark[13]. Thus, both taxes can directly be compared on their performance in terms of welfare impacts and emission reduction.

A series of increasing tax levels are simulated for each tax type. For the carbon tax, the rates applied correspond to tax levels ranging from 0 to 30 euro per tonne of CO_2. The model closure is as described in Section 2.2.7, with endogenous transfers to households to recycle the net revenue from the energy tax.

Figure 2 shows that the emission reduction target of 25.8 percent compared to 1998 levels is achieved with a carbon tax at a tax level between 10 and 15 euro per tonne of CO_2. The uniform energy tax only achieves the abatement target when the tax level lies between 40 and 45 euro. It is obvious that the carbon tax is much more effective at reducing emissions, especially at lower tax rates. While both tax types provide incentives to reduce the use of energy and to change the sectoral structure of the economy towards less energy-intensive production, the carbon tax also motivates the substitution of emission-intensive fuels for energy sources with a low or zero carbon-intensity. The carbon tax results in this switching behaviour because it changes user prices of different fuels to reflect their impact in terms of CO_2 emissions (see Figure 5). Therefore, in order to meet the target of 25.8 percent emission reduction, the uniform tax rate would need to be higher (just over 35 euro per tonne of CO_2 in the benchmark) than the carbon tax (just over 10 euro per tonne of CO_2).

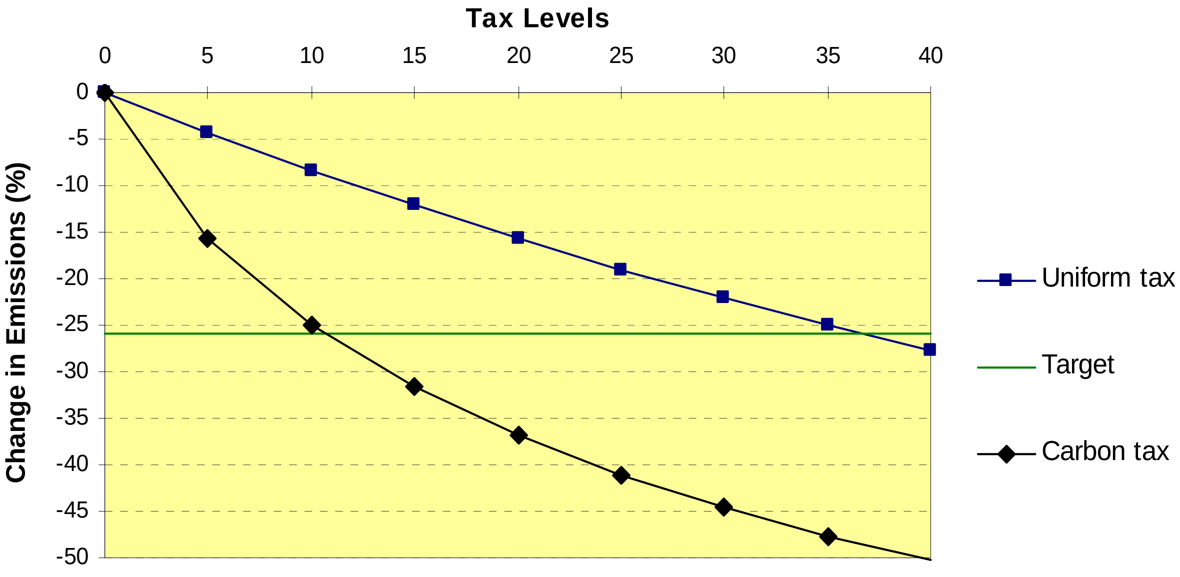

Figure 2. Changes in Emissions due to a Carbon Tax at Tax Levels from 0 to 40 euro per tonne of CO_2 and an equivalent Uniform Energy Tax, compared with the Kyoto target CO_2.

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[13] In the counter-factual equilibria, the revenue from the uniform tax no longer equals that of the carbon tax because the emission-intensity of total energy use changes, so the uniform tax can, strictly speaking, not be expressed in euro per tonne of CO_2. We can express the uniform tax in euro per tonne of CO_2 in the benchmark; for ease of notation and to stress the equivalence between the uniform and carbon taxes, we denote this simply as euro per tonne of CO_2.

Welfare changes are depicted, for both simulated scenarios, in Figure 3. Both taxes make the overall tax system less efficient, causing welfare to fall. But welfare decreases by less than 1.3 percent, even at the highest tax level simulated. At any given tax level, the carbon tax distorts the economy more because it is a differentiated tax, which leads to more changes in behaviour than a uniform energy tax. In Figure 3, the drop in welfare at the level of tax that reaches the emission reduction target is marked with a box for either tax simulated. As the tax rate that meets the emission target is higher for the uniform tax than for the carbon tax, welfare costs of achieving the target are higher for a uniform energy tax than for a carbon tax. The uniform energy tax rate that meets the target would cause welfare to fall by about 0.9 percent whereas the carbon tax at a sufficiently high level would only cause welfare to decrease by about 0.3 percent. It needs to be stressed that these welfare impacts do not include the positive effect of improved air quality and reduced climate change; the benefits of the policy are not taken into account, and therefore the reported welfare impacts represent only the cost side of the policy implementation.

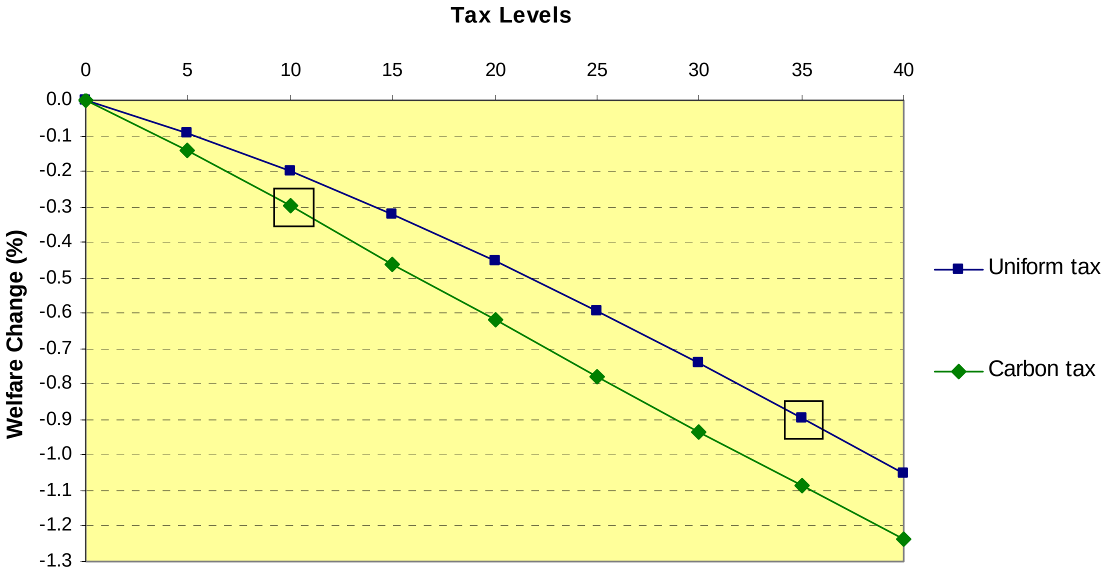

Figure 3. Changes in Welfare due to a Carbon Tax and a Uniform Energy Tax at Tax Levels from 0 to 40 euro per tonne of CO_2.

While overall economic indicators change only moderately, changes in output levels are quite significant for a number of industries. Results of a simulation with a carbon tax at 10 euro per tonne, at which the abatement target is nearly met, and a simulation with an equivalent uniform energy tax are presented in Figure 4. Figure 4 shows that the carbon tax mostly reduces domestic production levels in the industries Peat, Electricity, Basic metals and Transport by road and water. The large reduction in peat production is due to the fact that its output is taxed at the highest rate when not used in electricity generation – and even there at the one but highest rate (after coal); this is due to a combination of a high emission intensity of peat and a low price compared to other fuels. Electricity, Basic Metals and Transport suffer this much from the higher costs of their energy inputs because they are highly energy-intensive. Emissions from fuel combustion in transport by air are not taxed, because the sector consists mostly of international aviation, which is not covered by the Kyoto Protocol.

The renewables industry strongly increases its output level, because renewable energy is used as a substitute for taxed energy inputs in electricity generation. The Services, Metal products, Chemical and Textiles sectors also increase their output levels, but only moderately. They are less energy-intensive and some of them are also relatively capital-intensive sectors that benefit, in relative terms, from the fact that the price of capital drops a bit more than the price of labour. The shares of capital in total production costs of Commercial services and Chemicals are 37.9 and 37.5 percent, respectively.

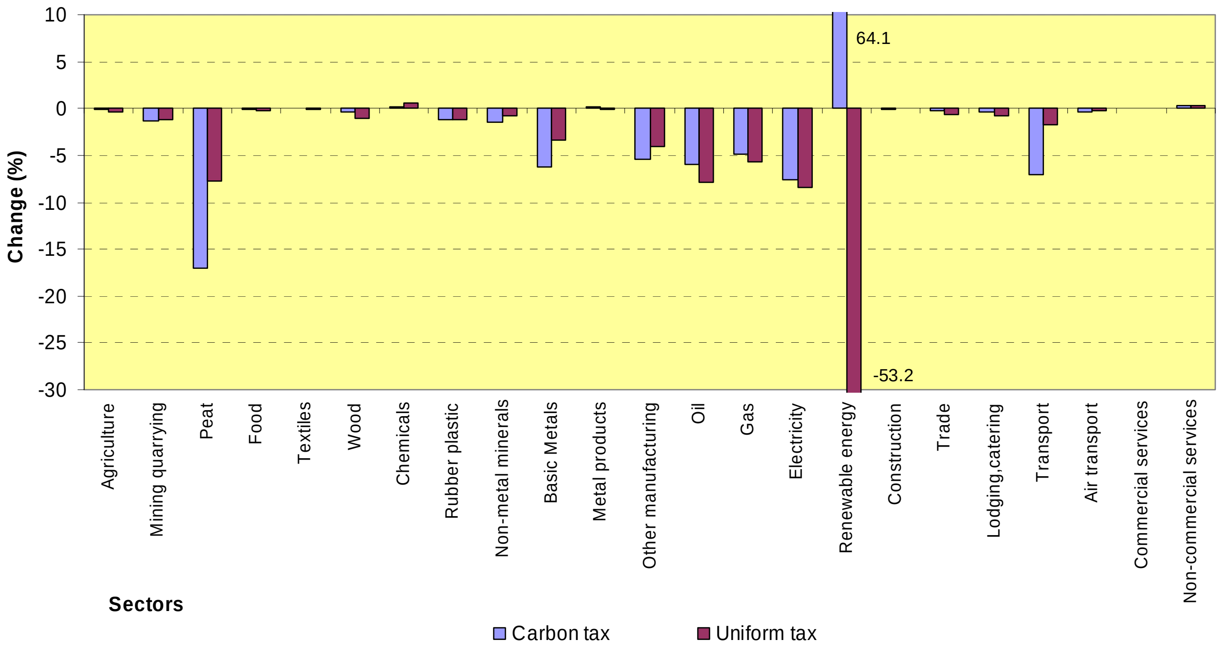

Figure 4. Changes in Domestic Sectoral Output Levels (Y) due to a Carbon Energy Tax of 10 euro per tonne of CO_2 and an equivalent Uniform Energy Tax.

In the simulation of a uniform energy tax, the renewable energy sector declines most strongly because renewable energy is taxed at the same rate as other energy inputs in electricity generation, but the possibility to substitute away from renewables is much larger (see Figure 1). This result is related to the way renewables are modelled: renewables are defined as green electricity and not used directly by other sectors or consumers. Clearly, a wider approach to renewables, as adopted in for example the EPPA model (Babiker et al, 2001, McFarland et al, 2004), would have substantial effects on the results for renewables. The decline in Road and water transport and in Basic metals is less marked than with the carbon tax, because the uniform tax rate on oil products is lower than the corresponding carbon tax rates.

Figure 5 shows how the carbon tax increases Irish energy prices. Firms pass on these cost increases to customers in the form of higher output prices. Each price increase leads to a drop in demand for the corresponding commodity, forcing its production levels down. After an adjustment process that involves relative scarcity on all markets, a new set of equilibrium prices emerges. Clearly, the more emission-intensive fuels are taxed more heavily than fuels such as natural gas. Electricity is not taxed because its use does not cause emissions. Similarly, crude oil is not taxed as it is only used to produce oil products; this approach avoids double-taxing of commodities. Tax-exclusive prices fall a little due to reduced demand.

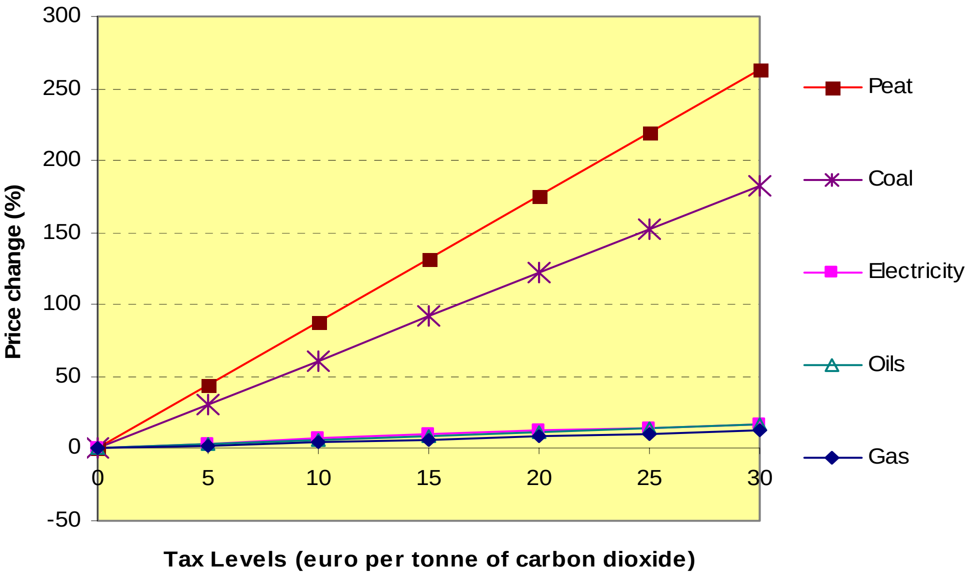

Figure 5. Price Changes (inclusive of carbon tax) of Domestically Supplied Energy Commodities due to Carbon Tax Levels from 0 to 30 euro per tonne of CO_2.

The Cobb-Douglas utility function adopted in the model implies that the Representative Agent still spends the same share of income on each commodity, but due to the price changes, less is bought of Peat, Coal, Electricity, Refined oils, Natural gas and Transport. Figure 6 shows changes in consumption levels by commodity due to a 10 euro per tonne carbon tax.

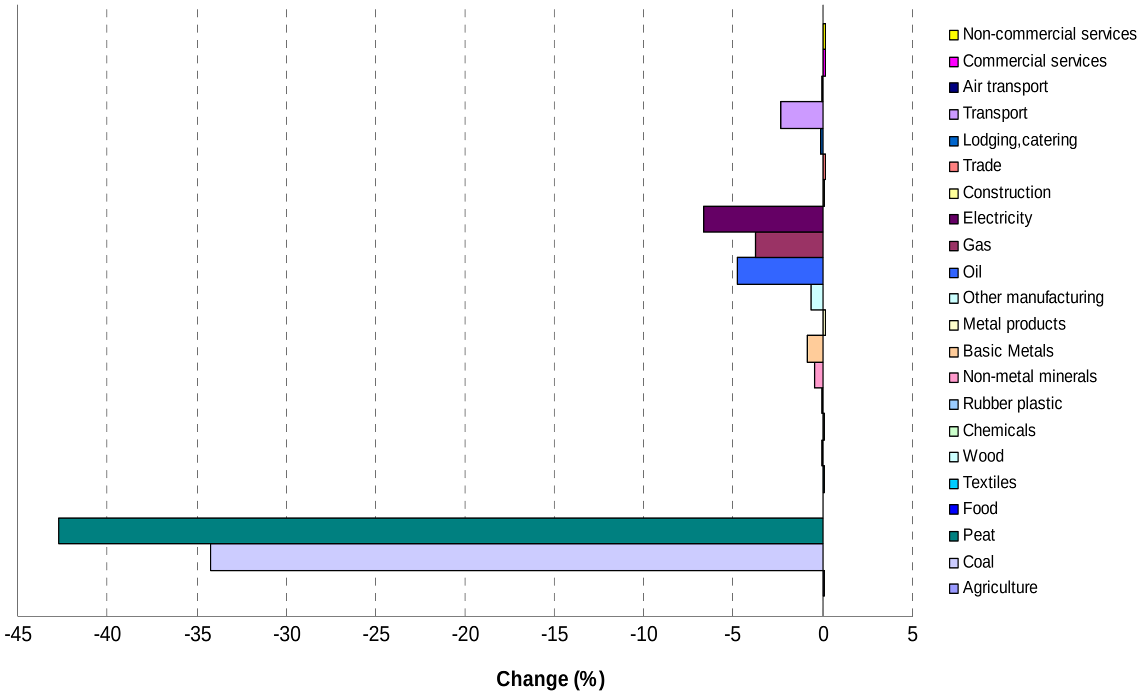

Figure 6. Changes in Consumption Levels due to a Carbon Energy Tax of 10 euro per tonne of CO_2.

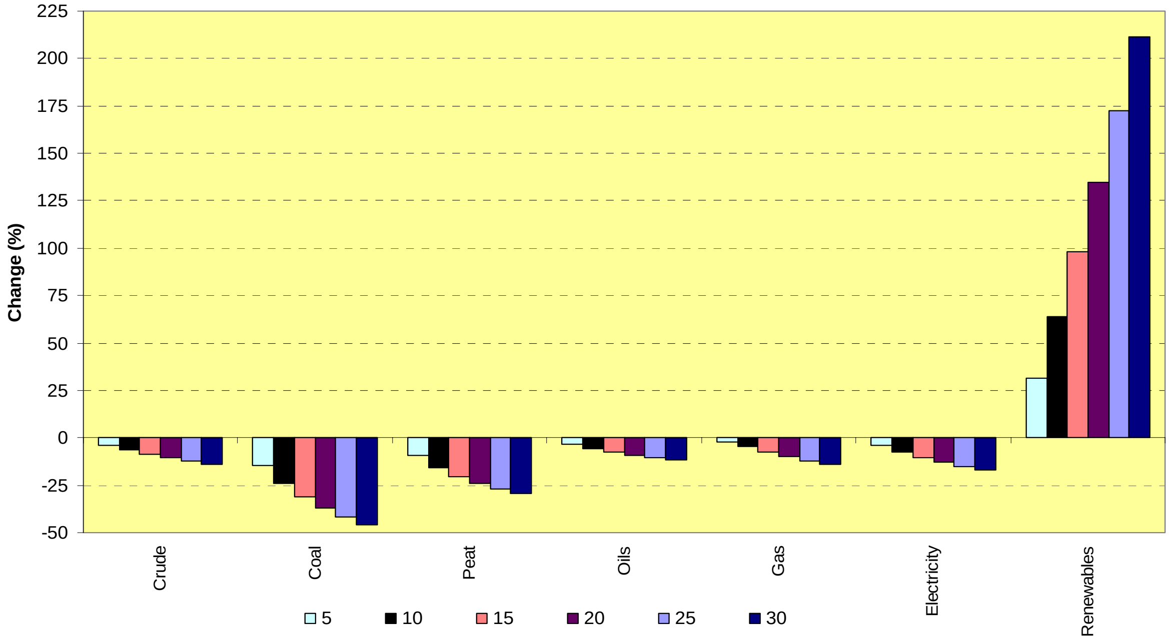

Figure 7. Changes in the Use of Different Energy Commodities due to Carbon Tax Levels from 5 to 30 euro per tonne of CO_2.

Energy consumption is reduced more at higher tax levels, as can be seen for the case of the carbon tax in Figure 7. Only the use of renewable energy increases. This is because untaxed renewables are used more and more to replace conventional energy inputs in electricity generation. The uniform energy tax (the results of which are not presented in Figure 7) makes the use of Coal and Peat drop less, the use of Gas drop more and the use of Renewables fall by 53 percent at the tax level equivalent to 10 euro per tonne of CO_2. Total emissions drop by less as well, as shown in Figure 2.

5. SENSITIVITY ANALYSIS

Table 3 compares some of the results presented in the previous section with those obtained when the elasticities of substitution are either halved or doubled, one by one. This comparison is shown for simulations of a carbon tax of 10 euro per tonne of CO_2.

Table 3. Welfare changes resulting from changes in individual elasticities for carbon tax of 10 euro per tonne of CO_2 (percent changes compared to the benchmark)

Elasticity	Default Value	Low Elasticities (%)	Default Elasticities (%)	High Elasticities (%)
S Top level*	0	n/a	-0.30	-0.32
S2 (in electricity tree)	10	-0.30	-0.30	-0.29
S3 (in electricity tree)*	0	n/a	-0.30	-0.30
sLKE (L–KE)	0.846	-0.32	-0.30	-0.28
sKE (K–E)	0.653	-0.26	-0.30	-0.38
sE (ELEC–FOS)	0.1	-0.30	-0.30	-0.30
sFOS (LIQ–SOL)	0.5	-0.30	-0.30	-0.30
sSOL (COAL–PEAT)	4	-0.30	-0.30	-0.30
sLIQ (NGAS–OILS)	2	-0.30	-0.30	-0.30

* These Leontief functions have an elasticity of substitution of zero. This has been changed to 1, creating Cobb-Douglas functions, in the 'High elasticities' column.

At lower tax levels the model appears to be quite robust. At higher taxes, some elasticities have a significant impact on the results. The results in terms of welfare changes are most affected by changes in the elasticity of substitution between capital and energy (K–E). Also significant are the values of the elasticities of substitution at the top level and between labour and the capital-energy composite (L–KE). Thus, it seems that the main determinant of the welfare cost of the carbon tax is the possibility to substitute away from energy, rather than the possibilities to substitute between the different fuels.

Emissions are reduced more strongly with higher elasticities. In the simulation used for Table 3, emissions fall by 32.3 percent (as opposed to the 25 percent cut obtained with 'normal' elasticities), when the 'K–E' elasticity is doubled (result not reported in Table 3). Doubling the elasticity of substitution between natural gas and oils or changing the function in the top level into a Cobb-Douglas (*sTOP*=1) leads to a reduction in emissions of 27 percent in the same simulation. When the 'L–KE' elasticity is doubled in the same simulation, emissions fall by 26.3 percent. Changes in the other elasticities have little effect on changes in emissions.

Because both welfare and emissions results react most strongly to changes in the 'K–E' elasticity, this parameter is subject to further analysis. Its value is varied from 0.3 to 1.0 to test how sensitive the results are to the value of this parameter. The results for welfare and emissions of a 10 euro per tonne of CO_2 carbon tax are shown in Figure 8 below.

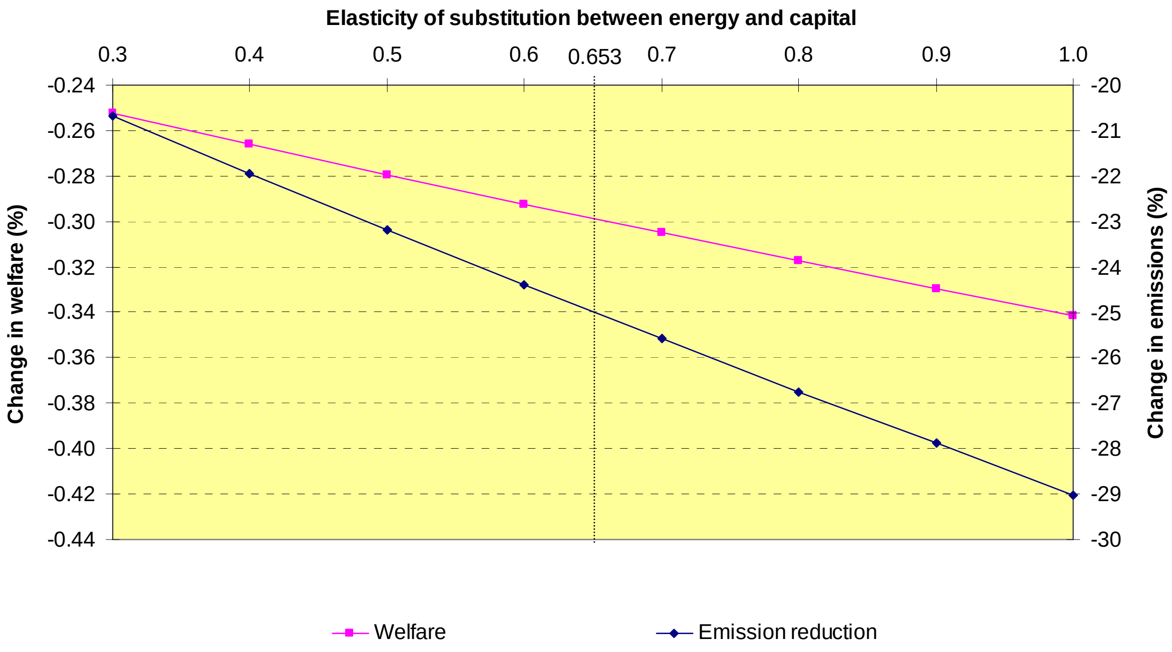

Figure 8. Sensitivity of Welfare and Emissions Changes to the Value of the Elasticity of Substitution between Capital and Energy (sKE) in case of a Carbon Tax of 10 euro per tonne of CO_2.

The left axis measures the change in welfare and the right axis the change in emissions. The default value for this elasticity is 0.653, which is in the middle of the graph where welfare drops by 0.30 percent and emissions are reduced by 25 percent. Increasing the value means that substitution away from energy is easier and this leads to a stronger drop in energy use and emissions but also to a higher level of distortion of the economy and therefore to a larger decrease in welfare. A greater elasticity of substitution means that, *ceteris paribus*, the demand for energy is more price elastic. Tax theory shows that the dead weight loss of a tax is higher when demand for the taxed commodity is more price elastic.[14]However, with higher elasticities, a lower tax level is required in order to meet the abatement target. For instance, when the 'K–E' elasticity is doubled, the emission target is met at a tax level of just 7 euro per tonne of CO_2 and in that case welfare only decreases by 0.26 percent.

6. CONCLUSIONS AND RECOMMENDATIONS

Policy makers have to make some tough decisions about environmental policies that will have a far-reaching impact. It is important that they are well informed about the possible effects of the implementation of various policy packages or sets of measures. A computable general equilibrium model with specific detail in taxation and energy use is the most suitable methodology to quantify both the direct and indirect effects of a change in energy taxation.

Given the limitations and assumptions of the present model and data as described in Sections 2 and 3, the following conclusions can be drawn. First, the reduction target for energy related CO_2 emissions in Ireland of 25.8 percent compared to 1998 levels can be achieved with a carbon energy tax of between 10 and 15 euro per tonne of CO_2. Though fuel switching is an important part of achieving the target, the sensitivity analysis shows that this result is sensitive to the possibilities for producers to substitute away from energy use. Greater substitution possibilities make emissions respond more strongly to a given tax level, so that the target can be reached with lower tax levels. In comparison, a uniform tax on energy, as currently adopted by many countries, needs to be much higher to achieve the same emission reduction target.

Secondly, the macroeconomic impact of the carbon tax would not be very strong. Welfare would be affected downwards[15] but only by less than 1 percent even at a tax level of 30 euro per tonne of CO_2. A uniform energy tax at a rate high enough to meet the emission abatement target would lead to three times greater welfare decreases, because its rate would have to be much higher than the tax rate of the effective carbon tax. These results arise from the implementation of an energy tax in Ireland alone. The macroeconomic changes may be expected to be even lower if the analysis included carbon taxation in Ireland's trading partners as well.

Thirdly, consumption patterns would change due to changes in relative prices. There would be a shift in demand from fuels with a high emission factor to energy sources with a lower carbon-intensity and from energy to other commodities. Structural changes would also occur on the production side. Relatively 'dirty' sectors, *i.e.*, sectors with a high CO_2 emission intensity, would suffer substantially from cost increases and decreased demand. The Services, Metal Products, Chemical and Textiles sectors, however, appear to consistently benefit in relative terms from the implementation of the carbon energy tax. The production of renewable energy would increase quite strongly. Sectoral impacts are much less pronounced, and in some cases even reversed, when a uniform energy tax is imposed.

Regarding the equivalence of the carbon tax with the emissions trading scheme, it may be concluded that if the emissions trading scheme were extended to include all firms and

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[14] The taxes investigated in this paper are introduced in a second-best situation and they will interact with existing distortionary taxes, so the rationale given above is only a partial explanation.

[15] Note that the benefits of meeting the abatement target are not measured in this paper. Apart from the environmental benefits of pollution abatement (reductions in the future pace of climate change and lower emissions of related local and regional pollutants that cause smog and acidification, for instance), the avoided penalties for non-compliance must be taken into account.

consumers (the way the carbon tax applies to all energy users in the model), the price of permits may come down by over 25 percent. However, that would require certain assumptions to hold, such as perfect information and zero transaction costs, conditions that are not realistically expected to be achieved. The NCCS included introducing a carbon tax for all those energy users who do not take part in the emissions trading scheme. This would be a good compromise between the ideal and the possible.

Low-income households need special attention because a carbon energy tax may push certain households into poverty and enhance the existing problems with fuel-poverty (Healy, 2003). This paper uses a single representative household and therefore does not offer this kind of insight. Thus, it is important to assess more accurately the impact of different combinations of policy measures on income distribution in general and on the welfare of households of different income groups in particular. This can be achieved by separately distinguishing different income groups and modelling the relevant linkages between these household groups and the rest of the economy, including the government, in more detail.

Other possible improvements to the model include further disaggregation of indirect taxes, and the introduction of unemployment and endogenous labour supply. The representation of the energy industry can be enhanced by disaggregating renewable energy commodities and by introducing imperfect competition; a feature that is especially relevant in the energy markets. The representation of demand for energy can be improved by modelling the use of renewable energy sources such as solar energy by households. Since climate change is a long term problem, the introduction of intertemporal dynamics is recommended. The introduction of bottom-up technologies to abate emissions of greenhouse gases would make the model more realistic and more credible, though this is less essential for CO_2 than for other greenhouse gases. It is further recommended to introduce emissions trading and to model foreign energy policies. Finally, it is possible and desirable to include other greenhouse gases than carbon dioxide and even to incorporate other environmental problems and solutions. Different environmental problems and their solutions tend to interact and are best analysed in an integrated manner (Dellink, 2005; Dellink and Van Ierland, 2006).

Notwithstanding these options for further research, this paper shows that a carbon energy tax, *i.e.*, a specific energy tax related to emissions of carbon dioxide from energy use leads to greater emission reductions than an equivalent uniform energy tax. The model tells us that the impact of both types of energy tax on overall welfare is small at the effective level, even when parameter values are changed. Changes in the patterns of sectoral production and aggregate consumption can be clearly observed. The carbon tax achieves the emission reduction target at a lower welfare cost than the uniform energy tax. The uniform energy tax has a stronger negative impact on the less polluting energy sectors whereas the carbon tax greatly stimulates the use of renewable energy and reduces the use of peat and coal.

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APPENDIX A SECTORS AND COMMODITIES IN THE ESAM

The sectors and commodities have the same acronyms, because each commodity is produced mainly by one corresponding sector. Each industry can thus be regarded as the main producer or manufacturer of the product with the same acronym. Table A.1 therefore gives descriptions of commodities only.

Table A.1. Commodities in the ESAM and the Model

Model Acronyms	Descriptions
AGFF	Agriculture, forestry and fishing
MINE	Mining and quarrying products
CRUD	Crude oil
COAL	Coal
PEAT	Peat
FOOD	Food, beverages and tobacco products
TEXT	Textiles, wearing apparel, leather and leather products
WOOD	Wood and wood products (excl furniture), pulp, paper and print
CHEM	Chemical products and man-made fibres
RBPL	Rubber and plastics
NMIN	Other non-metallic mineral products (glass, concrete, stone)
METL	Basic metals
MTPR	Fabricated metal products, machinery and equipment
OMAN	Furniture and other manufactured goods n.e.c.
OILS	Oil products
NGAS	Natural gas
ELEC	Electricity
RNEW	Renewable energy (electricity from)
CONS	Construction work
TRAD	Wholesale and retail trade
LDCT	Lodging and catering (includes bars)
TRNS	Transport services by land and water
AIRT	Air transport services
SVCC	Services – Commercial
SVCN	Services – Non-commercial
MARG	Margins

APPENDIX B MODEL EQUATIONS

Indices

en	energy commodities	CRUD, COAL, PEAT, OILS, NGAS, ELEC, RNEW
f	agents	HOU, GOV, INV, EXP
i	commodities	1, …, 26 (see Appendix A)
j	industries	1, …, 26 (see Appendix A)

Variables

A_i	Armington supply of commodity i
$BoPdef$	Balance of international payments deficit
C	Aggregate household consumption
CD_i	Household demand for commodity i
D_i	Domestic demand for commodity i
E	Aggregate exports
ED_i	Export demand for commodity i
G	Aggregate public good
GD_i	Government demand for commodity i
$GovSur$	Government budget surplus
$HouSav$	Household savings
I	Aggregate investment
ID_i	Investment demand for commodity i
$IO_{i,j}$	Intermediate demand for commodity i by industry j
K_j	Capital demand industry j
L_j	Labour demand industry j
$lsum$	Lump sum tax rebatement multiplier
M_i	Imports of commodity i
SD_i	Stock additions of commodity i
$transfer$	Lump sum transfer from government to household
$Welfare$	Total utility for measuring Hicksian equivalent variation
$\mathrm{Y}_{\mathrm{j},i}$	Production of commodity i by industry j

Parameters

KS	Capital supply
LS	Labour supply
te_i	Carbon energy tax on commodity i, where $i = en$
tfd_f	Indirect tax on commodities consumed by agents
tid_j	Indirect tax on commodities used in industry j
ty_j	Production tax industry j

Equations

Production functions:

$$Y_{j,i} = CES(IO_{1,j},\ldots, IO_{26,j}, L_j, K_j) \quad \forall j$$

Zero-profit in production

$0 = (1- ty_j) \cdot \Sigma_i (py_i \cdot Y_{j,i}) - \Sigma_i (1+tid_j+te_i) \cdot pd_i \cdot IO_{i,j} - pl \cdot L_j - pk \cdot K_j \quad \forall j$

Household
$Welfare = C = Cobb\text{-}Douglas(CD_1, \ldots, CD_{26})$
$pc \cdot C = \Sigma_i (1+tfd_{HOU}+te_i) \cdot pd_i \cdot CD_i$
$\Sigma_j (pl \cdot L_j + pk \cdot K_j) + lsum \cdot transfer = pc \cdot C + HouSav$

Government
$G = Leontief(GD_1, \ldots, GD_{26})$
$\Sigma_j (ty_j \cdot Y_j + \Sigma_i (tid_j \cdot IO_{i,j})) +$
$\quad \Sigma_i (tfd_{HOU} \cdot CD_i + tfd_{GOV} \cdot GD_i + tfd_{INV} \cdot ID_i + tfd_{EXP} \cdot ED_i) +$
$\quad \Sigma_{en,j} (te_{en} \cdot IO_{en,j}) + \Sigma_i (te_{en} \cdot CD_{en})$
$\quad = \Sigma_i (1 + tfd_{GOV}) \cdot GD_i + GovSur$;   where $en \in i$
$G = G$ (fixed quantity);   determines $lsum$

Rest of the World
$E = Cobb\text{-}Douglas(ED_1, \ldots, ED_{26})$

Investment
$I = Cobb\text{-}Douglas(ID_1, \ldots, ID_{26})$
$\Sigma_i (1+tid_j+te_i) \cdot pd_i \cdot ID_i + \Sigma_i SD_i = HouSav + GovSur + BoPdef$

International trade
$A_i = CES(M_i, \Sigma_j (Y_{j,i}); \sigma=4)$
$A_i = CET(D_i, ED_i; \sigma=4)$

Market clearing
$M_i + \Sigma_j (Y_{j,i}) = A_i = D_i + ED_i$
$D_i = \Sigma_j (IO_{i,j}) + CD_i + GD_i + ID_i + SD_i$
$\Sigma_j L_j = LS$ (fixed);   determines pl
$\Sigma_j K_j = KS$ (fixed);   determines pk
$\Sigma_i (pm_i \cdot M_i - pfx \cdot (1 + tfd_{EXP}) \cdot px_i \cdot ED_i) = BoPdef$ (changes at same rate as C);   determines pfx

APPENDIX C EMISSIONS DATA AND REDUCTION TARGET

In the model the target is implemented as a percentage change in emissions, not as an absolute reduction. The benchmark is the 1998 level of emissions. The NCCS provides absolute abatement targets for each broad sector expressed in million tonnes of CO_2 or million tonnes of CO_2-equivalent. These targets equal the reductions in 1998 emission levels required to achieve the annually allowed emission levels in the commitment period.

Based on the descriptions of the abatement measures and the units used it can be derived which emissions are concerned: CO_2 or other greenhouse gases, emissions related to energy or other emissions. Levels of energy-related CO_2 emissions by broad sector in 1998, thus derived, are shown in the second column in Table C.1 below. In the third column, the reduction targets of emissions that are related to the production or use of energy are shown. In column four, the reduction percentages are calculated as 100 x {abatement target}/{baseline emissions}.

Table C.1. Sectoral Energy-related CO_2 Emissions and Targets

Broad Sector	**Baseline Emissions** (million tonnes of CO_2) [1]	**Abatement Target** (million tonnes of CO_2) [2]	**Emission Reduction Target** 100*[2]/[1]
Energy Sector	15.047	5.65	37.5%
Residential Sector	6.447	0.25	3.9%
Transport Sector	8.768	2.67	30.5%
Industrial Sector	3.917	1	25.5%
Commercial Sector	2.775	0.175	6.3%
Agricultural Sector	0.752	0	0.0%
Total energy CO_2	**37.706**	**9.745**	**25.8%**

Only the overall target is used in this paper, as it does not matter which sectors reduce their emissions as long as the national target is met. The emission factors used are shown in Table C.2.

Table C.2. Emission Factors for each Fuel, User-specific (tonne of CO_2 per TOE)

Energy Commodity	**Emission Factor**
Oil products for Electricity Generation	3.18
Oil products for Transport*	3.001
Oil products for other purposes	3.05
Coal	3.586
Peat for for Electricity Generation	4.83
Peat for other purposes	4.14
Natural gas	2.30
Electricity	0.0
Renewable electricity	0.0

*Calculated as a weighted average of emission factor of oil products used in private and public transport. Emissions from air transport are not calculated, because emissions from international air transport are excluded from the Kyoto Protocol. Domestic air transport is negligible.

Source: ESRI.