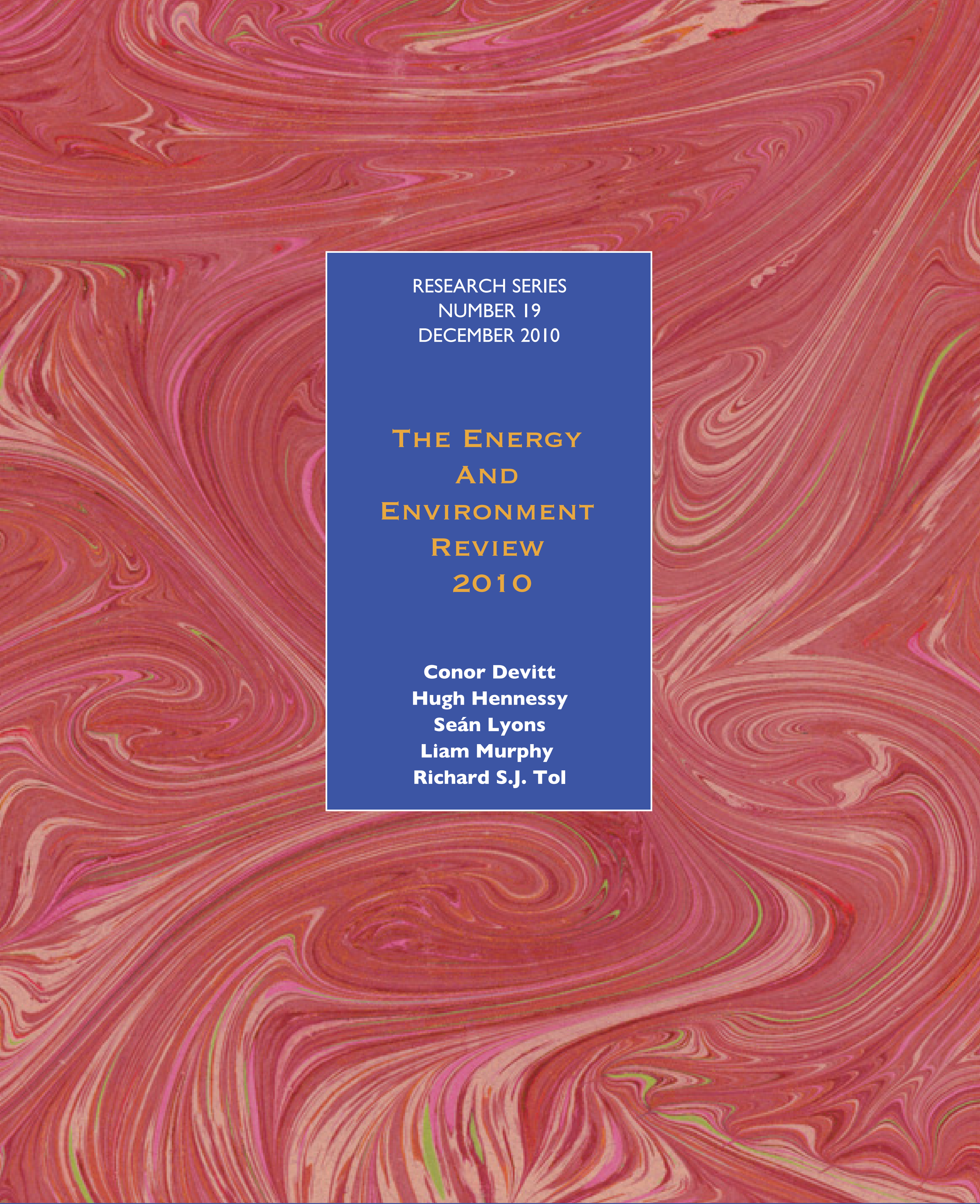

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CONTENTS

1. INTRODUCTION

The Energy and Environment Review 2010 reviews trends in energy use and emissions to the environment for the period 1990-2008 and projects these trends for the period 2009-2025. We show results for two alternative scenarios of how the Irish economy may develop in the future. In the two baseline scenarios, we include current energy and environmental policies, and likely changes in these policies. In a number of cases, we discuss alternative policy developments.

Building scenarios of future developments is always fraught with uncertainty. Uncertainties are particularly large at present because of the state of the Irish banking sector and the government budget. The latter may imply drastic reform in the energy and transport sectors (Allard *et al.* 2010). Furthermore, when dealing with energy and the environment in a small country, single decisions can have a large effect. We illustrate this below with the cases of the Poolbeg incinerator and the Moneypoint power plant. Because single decisions are hard to predict, the future may well be very different from what our scenarios suggest – and in some cases we highlight the need for policy changes to avoid a future as projected here. We present a limited number of sensitivity analyses to further underline the uncertainty about the future. We alternate between the two alternative scenarios of economic development as both are equally likely.

In this edition of the *Energy and Environment Review*, we focus on power generation, private car use, landfilled waste, persistent organic pollutants and corporate expenditures on environmental protection. The selection of topics is a mixture of issues that are high on the policy agenda and issues that have received little attention to date, perhaps because data were unavailable until recently. The full set of results can be found at: http://www.esri.ie/research/research_areas/environment/isus/

This is the third *Energy and Environment Review* published by the Economic and Social Research Institute. The first two editions (Bergin *et al.*, 2009; Fitz Gerald *et al.*, 2008) were part of larger publications. This review is published in a stand-alone format, reflecting the importance of energy and the environment in Irish society and policy.

The *Energy and Environment Review* is not the only source of scenarios for energy and the environment. The Sustainable Energy Authority of Ireland (SEAI) regularly publishes its outlook on future energy use (*SEI,* 2009),[1]

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[1] There are several differences between this study and the one published by the SEAI on 10 December 2010 (after this report went to press). We calibrate to the 2008 energy balance while SEAI uses the provisional energy balance for 2009. We use different scenarios for energy prices, particularly oil. We use different assumptions for investment in power generation. We use a different model for agriculture and transport. We do not

and the Environmental Protection Agency (EPA) does the same for greenhouse gas emissions (*EPA*, 2010). The *Energy and Environment Review* has several distinguishing features. First, our scenarios include an analysis of the impact of policies where policy instruments are clearly identified. However, we ignore government targets unless they are supported by measures to achieve them or arguments explaining how they can be achieved (Scott and McCarthy, 2008). Second, we report on both energy and the environment because the two topics are so closely linked. Third, we take a more inclusive approach to the environment, considering issues beside climate change. In that sense, the *Energy and Environment Review* is closer in coverage to *Ireland's Environment* (*EPA*, 2008).

The report continues as follows. Section 2 briefly reviews the trends in the economy (Bergin *et al.,* 2010). Section 3 presents the results for energy, with a particular focus on private car transport and power generation. Section 4 discusses the environment, emphasising greenhouse gas emissions, waste, persistent organic pollution and corporate expenditures on environmental protection. Section 5 concludes.

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incorporate any expert adjustments to the model results. We do not impose policy targets unless policy instruments are in place.

2. TRENDS IN THE ECONOMY

The second revision of the *Medium-Term Review* (Bergin *et al.,* 2010) explores a number of scenarios for future economic recovery and considers the implications of these scenarios for policy, in particular fiscal policy. We here use the two main scenarios: *High Growth* and *Low Growth*.

Table 1 shows the key assumptions made in the projections – which date back to July 2010.[2] The main difference between the two scenarios is the assumed response of the Irish economy to growth elsewhere. The scenarios assume a modest economic recovery, as it will take time to restore balance sheets. Sovereign borrowing would be higher in the *Low Growth* scenario, and the risk premium on Irish bonds would be higher as a result. The price of peat is projected to stay constant, while the prices of coal and gas will rise modestly with growing demand in the period to 2025. The prices of oil and carbon rise much faster, reflecting tightness in the market and stringent emission reduction targets, respectively.

If the Irish economy responds to world economic growth and changes in competitiveness in the same way as it has done over the last twenty years there could be a vigorous recovery over the period 2012 to 2015, as set out in the *High Growth* scenario. Such a recovery would gradually move the economy back towards full employment.

On the other hand, the Irish economy could record lower rates of growth over the medium term for a number of reasons; for example, if the export sector has suffered long-term damage, if a continuing high interest premium seriously affects future investment or if structural unemployment remains high due to a failure of labour market policy. While under such a *Low Growth* scenario there would still be significant growth over the period 2012-2015, it would not be rapid enough to return the economy to full employment.

Table 2 shows the key macroeconomic and demographic figures used in this report. We show levels for 2008, and rates of changes for the periods 1990-2008, 2008-2012, 2012-2020, and 2020-2025. 2008 is the most recent year with complete observations. The ESRI Environmental Accounts start in 1990, the base year of the Kyoto Protocol of the UN

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[2] The economic outlook has changed since the summer. It has not been possible, however, to build new scenarios of economic development (and any attempt to do so would have been overtaken by events). For the latest assessment of the economic situation, see Fitz Gerald *et al.* (2010).

Framework Convention on Climate Change. 2008-2012 is the compliance period under the Kyoto Protocol, and covers the severe recession in the Irish economy. The compliance period for the EU climate and energy package is 2012-2020. The forecast horizon for the Hermes model is 2025.

Table 1: Key Assumptions in the Economic Scenarios

Growth	**2010**	**2011-2015**	**2016-2020**
USA	2.9%	2.8%	2.3%
UK	1.0%	2.8%	2.7%
Eurozone	1.2%	2.2%	2.5%
World	3.9%	4.1%	3.8%
Budget*		**2011-2014**	
Adjustment		-€7.5 bln	
Risk premium	**2010**	**2015**	**2020**
High growth	2.0%	0.8%	0.5%
Low growth	2.0%	1.3%	1.0%
Energy	**2010**	**2015**	**2020**
Coal	€7.2/MWh	€8.7/MWh	€10.2/MWh
Oil	€26.5/MWh	€41.5/MWh	€51.6/MWh
Gas	€17.7/MWh	€21.3/MWh	€26.2/MWh
Peat	€12.0/MWh	€12.0/MWh	€12.0/MWh
Carbon dioxide	2010	2015	2020
ETS permit**	€13.9/tCO$_2$	€19.9/tCO$_2$	€29.5/tCO$_2$

* The budget adjustment is given in nominal euros. All other items are real.
** Carbon dioxide emission permit in the EU Emission Trading System
Source: Bergin *et al.* (2010).

We use gross output as the best indicator of the volume of industrial activity, driving resource use and emissions. For services, however, we use gross value added (as gross output was not available). It would therefore be meaningless to show a total for the economy.

The period 2008-2012 is dominated by the severe recession.[3] Construction takes the hardest hit, but leads in the recovery (as the capital stock is built-up). The transport sector also shrinks between 2008 and 2012, but bounces back after that. Agriculture, too, contracts during the severe recession, and grows only slowly after 2012. Industry and services grow during 2008-2012. Industry is projected to continue to grow relatively rapidly until 2020 in both scenarios, after which growth slows down. Services show modest growth over the entire projection period in both scenarios.

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[3] GDP fell by eight quarters in a row (2007Q4-2009Q4) for a cumulative total of -14.5 per cent. See http://www.cso.ie/releasespublications/documents/economy/current/qna.pdf

Table 2: Gross Economic Output, Gross Value Added and Population as Observed and as Projected*

	Observed		*Low Growth*			*High Growth*		
	2008	**1990-2008 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**
			Real Change Per Year					
Agriculture	4.4	1.6	-0.8	1.0	0.0	-0.8	1.0	0.0
Industry	111.4	8.2	3.1	3.8	0.5	4.8	5.9	1.8
Construction	13.2	4.7	-15.9	6.8	2.4	15.5	7.2	2.9
Services	81.2	5.2	0.2	1.9	1.6	0.6	2.8	2.5
Transport	4.4	6.3	-1.1	3.4	2.3	-0.3	4.4	3.0
Population	4,418	1.3	0.1	0.8	0.9	0.1	0.8	0.9

*The numbers for agriculture, industry and construction are gross output; for services and transport, gross value added is given. Nominal values are in billions of Euros with the exception of Population (thousands).

Source: Bergin *et al.* (2010).

3. ENERGY

3.1 Power Generation

We use IDEM to generate scenarios of power generation. IDEM is a standard dispatch model which explicitly represents every plant on the island, and has a stylised representation of plants in Great Britain (Diffney et al., 2009). The model has a half-hourly resolution, matching supply to demand. Table 3 shows the key assumptions and details on the model are given in Appendix 2.

Table 3: Key Assumptions in IDEM

Plant*	Year	Commissioned	Year	Decommissioned
Aghada CCGT	2010	432 MW		
Whitegate CCGT	2010	445 MW		
Edenderry OCGT	2010	111 MW		
Dublin WtE	2013	72 MW		
Meath WtE	2011	17 MW		
Nore OCGT	2011	98 MW		
Cuileen OCGT	2012	98 MW		
Suir OCGT	2013	98 MW		
Moneypoint	2025	1000 MW		
Poolbeg 1&2			2010	219 MW
Great Island			2012	216 MW
Tarbert			2012	590 MW
	2010	2015	2020	2025
Interconnection	400 MW	900 MW	900 MW	1400 MW
Wind	2050 MW	4300 MW	6100 MW	6100 MW

MW = Megawatt; CCGT = Closed-cycle gas turbine; OCGT = Open-cycle gas turbine; WtE = Waste-to-energy.
Source: after (EirGrid, 2009) and this study.

Table 4 shows the primary energy used to generate electricity. In 2008, gas was by far the largest input, followed by coal, peat, oil and renewables. Over the last two decades, the use of gas and wind to generate electricity has grown rapidly, while peat and coal use has fallen. Transformation efficiency, the energy contained in the electricity relative to the energy used to generate that electricity, improved steadily as modern plants replaced older ones.

Table 4: Primary Energy Used (in thousand tonnes of oil equivalent; KTOE) in Power Generation by Fuel, Electricity Generation, Transformation Efficiency (TfEff), and Wholesale Price as Observed and as Projected

	Observed		*Low Growth*			*High Growth*		
	2008	**1990-2008 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**
	KTOE				*change per year*			
Coal	1,046	-1.0	-6.7	-5.6	15.5	-6.7	-5.2	14.9
Peat	565	-0.4	1.9	-24.8	37.0	1.9	-24.0	35.0
Gas	2,810	6.9	3.8	2.0	1.0	3.8	2.3	1.1
Oil	335	0.0	-37.3	0.0	0.0	-37.3	0.0	0.0
Renewables	332	9.7	14.8	7.0	0.2	14.8	7.1	0.2
Total	5,088	2.8	1.0	0.3	3.3	1.0	0.6	3.3
Electricity	2,294	4.6	0.4%	-0.2%	0.2	0.3	0.2	0.3
Tf Eff	54.1%	1.7	0.4	0.3	-3.8	0.3	0.3	-3.7
Price	6*	n/a	-7.8	4.6	3.7	-7.8	4.6	3.8

* The wholesale price of electricity is given in cent per kilowatt hour.
Source: ESRI Environmental Accounts and IDEM.

In the period 2008-2012, the use of oil-fired power generators will decline substantially. The use of renewables accelerates while gas use expands too. This is primarily at the expense of coal, which is affected most by climate policy. Peat use grows too as it enjoys "priority dispatch" status.[4] The wholesale price of electricity, which reflects only fuel and operating costs, falls because of the increased penetration of wind and the falling price of gas.

Priority dispatch ends in 2015 for one peat plant and in 2019 for the rest. On the basis of the fuel and carbon price assumptions used here (Table 1), peat will be pushed out of the market by 2020. Coal use would also fall as climate policy is likely to become more stringent. As electricity demand grows only modestly, the expansion of gas-fired and renewable power slows down. Nonetheless, as more wind is put on the system, transformation efficiency rises.[5] The wholesale price of electricity rises because the price of carbon goes up, and because Ireland will be a net exporter of electricity from 2014 onwards.[6] Exports reach 3,000 GWh in 2020 in the *High Growth* scenario, and 3,500 GWh in the *Low Growth* scenario.

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[4] Priority dispatch means that peat-fired power plants are deployed when available, regardless of the price they charge for their electricity. Note that the growth rate of peat reflects extensive maintenance in 2008.

[5] This is because the energy input and energy output of wind generation are defined as being the same.

[6] Export implies reduced domestic supply, which drives up the price.

Trends reverse after 2020. Wind power will have reached its assumed maximum of 6,000 MW by 2020 (DCENR and DETINI, 2008). We assume that Moneypoint will be replaced by a coal-fired power plant (without carbon capture and storage). See below. We further assume that no new gas plant will be built after 2013. Coal returns to the fuel mix, therefore. Capacity is tight after 2020 and peat too returns to the fuel mix. The wholesale price of electricity rises further. Because the increasing demand for electricity is met by ageing peat stations and the reintroduction of coal, transformation efficiency falls.

The results in Table 4 are based on a large number of assumptions. We assume that there will be no capacity crunch in Great Britain. If there is a realistic prospect that the necessary investment will be delayed in planning, investors may opt for adding capacity in Ireland and building more interconnection.

We assume here that wind will continue to expand rapidly until it reaches 6,000 MW in 2020 at which point concerns about the operation of the power system call a halt to the expansion of wind power. It may be that financing problems would decelerate the expansion of wind, or that advances in volatility regulation permit a greater share of wind power. It may of course also be that the power system cannot accommodate 6,000 MW of wind power.

We assume that the prices of oil and gas remain linked (cf. Table 1), although this assumption becomes ever more tenuous as shale gas and LNG expand. In that case, the price of gas would fall and investors may decide to build additional gas plant.

We assume that no new gas plant will be built after 2013, because investors are deterred by the high cost of capital, by the uncertainty about the Moneypoint replacement, and by the uncertain prospects for demand growth because of the economic outlook and the government's emphasis on energy efficiency improvement. It may of course be that these concerns are alleviated by the middle of the decade so that new gas plant would come online around 2020 (when capacity is indeed tight).

We also assume that Moneypoint will be replaced by a coal plant without carbon capture and storage. Carbon capture and storage is a technology that has yet to be demonstrated. As demonstration plans around the world have been delayed and postponed, we wonder whether it is advisable for Ireland to accept the technological and financial risks of early adoption. We re-ran the model with a "clean coal" plant. Emissions fall by 2.6 million tonnes of carbon dioxide. Such a new coal plant, however, could not compete with existing plant. Its fuel and operating costs would be too high. The plant would be idle, therefore.[7] In order to meet electricity demand, the model predicts an increase in the use of wind (1 per cent), peat (4 per cent) and gas (14-15 per cent). Furthermore, less electricity (54 per cent) is exported over the interconnector.

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[7] Note that this holds for the first year of operation only. Higher prices for oil, gas and carbon would subsequently make a clean coal plant commercially viable.

3.2 Transport

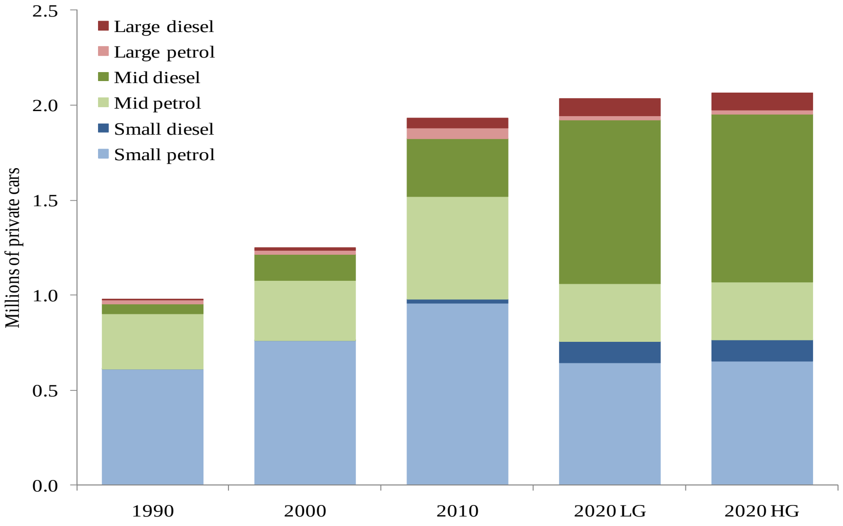
Transport uses a substantial amount of energy. We focus here on private transport by cars. Figure 1 shows the composition of the stock of private cars for selected years. The number of cars has almost doubled between 1990 and 2010, from slightly less than one million to almost two million vehicles. We expect that the number of cars will fall slightly until 2015 and gradually rise thereafter – in line with the projections for the number of households and disposable income. The projected number of cars in 2020 is somewhat greater than two million in both scenarios.

The number of small cars (<1.4 litre) has grown slowly (60 per cent in the last 20 years), while the number of mid-sized and big cars (>2.0 litre) has grown much more rapidly (150 per cent and 330 per cent, respectively). These trends will be different in the future. The number of small cars will fall (as many people are rich enough to switch from small to mid-sized cars in both scenarios), and the number of large cars will grow only slightly (as very rapid economic growth will not return in either scenario, and taxes favour smaller cars). The number of mid-sized cars will make up the difference and account for most of the projected growth.

In 1990, diesel cars accounted for about 5 per cent of all private cars. This grew to 20 per cent in 2010. We expect that this trend will accelerate primarily because of the tax reforms of 2008. Vehicle registration and motor tax were changed, and a carbon tax was introduced. Each component of the tax reform shifts the balance in favour of diesel engines, but the change in the vehicle registration tax is the most important reform (see Section 3.3). In both scenarios, the share of diesel increases to about 52 per cent. The diesel share is slightly higher (0.2 per cent) in the *High Growth* scenario because richer people can afford bigger cars and diesel engines are more attractive for bigger cars.

There are four main uncertainties in the projections. First, we assume that the tax regime will continue to favour diesel over petrol engines. The post-2008 tax regime, however, implies a substantial shortfall of revenue compared to the pre-2008 taxes. It is, therefore, likely that tax rates will be adjusted again in the foreseeable future. The other main uncertainty is that commuting patterns will persist as they are today. Settlement patterns will not change much in a decade, and rail-based public transport is unlikely to expand rapidly given budget constraints and the time required for building tracks. However, liberalisation of bus services and bicycle safety can be achieved much faster and could lead to a shift away from urban commuting by car. A third uncertainty is the rate of progress in fuel efficiency. Between 1990 and 2010, the fuel efficiency of *new cars* improved by 0.8 per cent per year; we project this to fall by 0.6 per cent per year for 2010-2025 as the shift to diesel also implies a shift to heavier cars. It may be, however, that policies abroad would lead to faster improvements in fuel efficiency. The fuel efficiency of the *car stock* increased by an annual 0.5 per cent between 1990 and 2010; this accelerates to 1.2 per cent for 2010-2025 as older cars are retired. Section 3.3 discusses the fourth uncertainty: electrification of transport. We suggest that this is unlikely, as the technology is too immature for the mass market and as supply constraints and car stock turnover would, in any event, slow down deployment.

Figure 1: The Number of Private Cars by Engine Size and Fuel Type as Observed and as Projected According to the *Low Growth* (*LG*) and *High Growth* (*HG*) scenarios



Source: ESRI Environmental Accounts and ISus.

3.3 The Effect of Policy on Private Cars and Carbon Dioxide Emissions

The results above assume that the vehicle registration (VRT) and motor tax (MT) rates remain as they are today; that the carbon tax will rise with the price of carbon dioxide emission permits; and that the targets for electric vehicles are extremely challenging and hence it is assumed that they will not be met. These are baseline assumptions. This section explores alternative policy assumptions.

Figure 2 shows fuel use in transport with VRT and MT as they are and as they were. The tax reform of 2008 has made diesel cars considerably more attractive, particularly for people who prefer large cars and who drive long distances. However, Figure 2 also shows that the tax reforms reinforced and accelerated the ongoing trend.[8] It is unlikely that the tax rates will remain as they are. Hennessy and Tol (2010b) show that, by 2020, the Exchequer would forego half a billion euro in VRT and MT per year compared to the previous tax regime. VRT and MT rates may therefore need to be increased, and the relative after-tax retail prices of diesel and petrol cars will probably change again.

The government hopes that 10 per cent of the private car stock in 2020 will be all-electric vehicles. Current support is generous: taxes are waived and fuel is free if a public charger is used. Such generosity is unlikely to be maintained given current and expected future pressures on the budget, particularly if the sales of all-electric vehicles reach substantial numbers. It is an open question whether current support is sufficiently generous to persuade people to buy all-electric vehicles in large numbers. The models that will come on to the market in the foreseeable future serve the niche market for second cars for urban driving. According to the Census 2006, 22 per cent of households are urban and own more than one car, while 20

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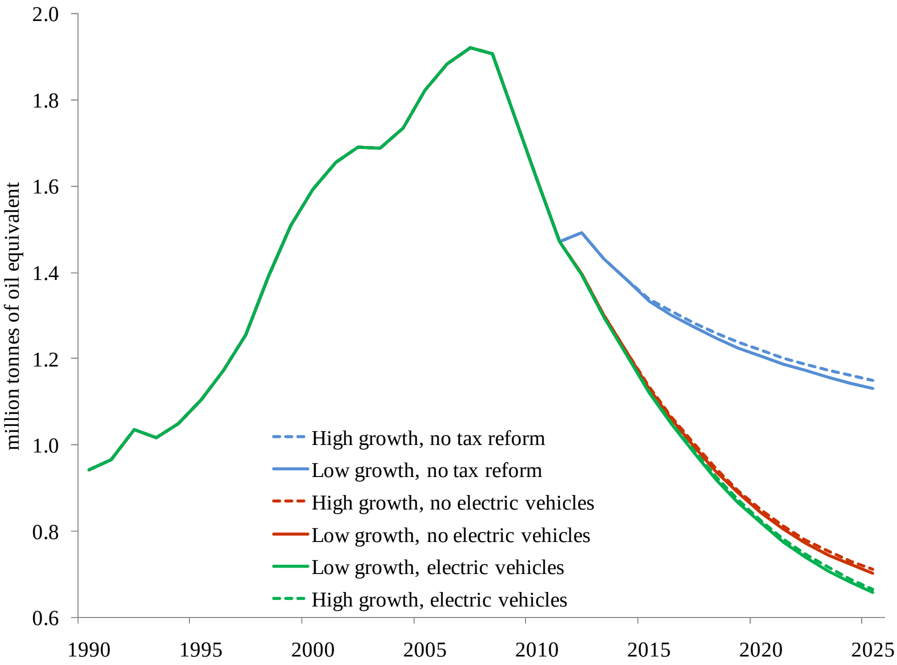
[8] There is a blip in petrol use in 2012, as transport demand grows rapidly after a period of low car sales.

per cent of cars are second cars owned by urban households. This implies that the government's 10 per cent target translates into a 50 per cent penetration of the relevant niche market. It is also uncertain whether production capacity will expand sufficiently fast to supply over 200,000 all-electric cars to Ireland. We therefore treat this target as aspirational in the baseline scenarios.

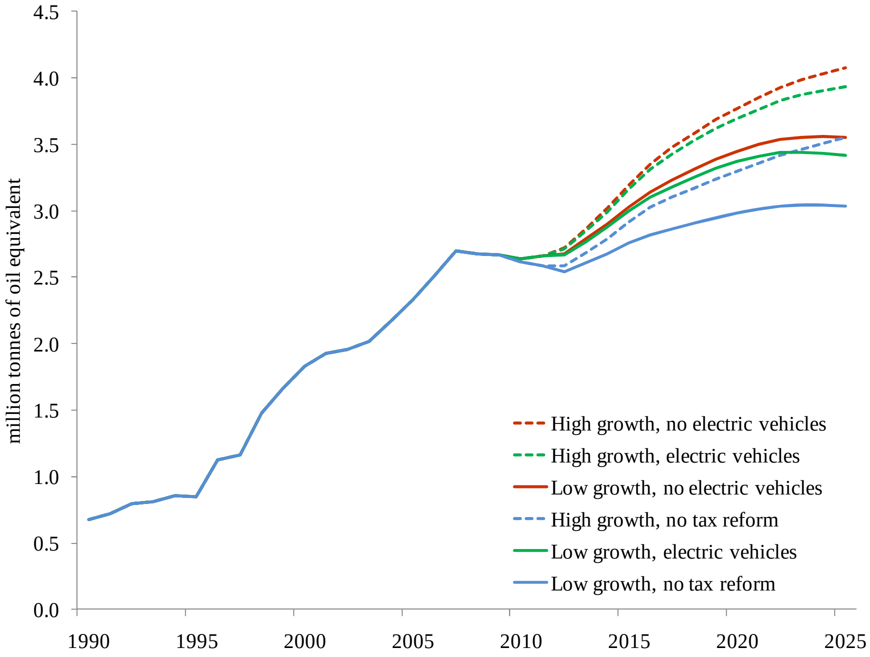
Figures 2 (petrol) and 3 (diesel) show what would happen if the target of 10 per cent of cars being all-electric by 2020 is met (Hennessy and Tol, 2010a). Diesel use in 2020 would fall by some 2 per cent and petrol use by some 3 per cent. This is because all-electric vehicles would primarily displace small cars with a low mileage. The impact of electric vehicles is small compared to the impact of economic growth. Carbon dioxide emissions from private transport would fall by 2 per cent if 10 per cent of cars were to be all-electric. Electricity use would increase by 3-4 per cent depending on the scenario. Carbon dioxide emissions from electricity would rise by 0.4 per cent. This is less than the increase in electricity use because we assume that car batteries will be recharged at night, so that base load power can be used more efficiently. Carbon dioxide emissions from private transport and power generation would together fall by 1 per cent; the drop in total greenhouse gas emissions is therefore negligible. In sum, this analysis suggests that the target to have 10 per cent of cars all electric by 2020 is unrealistic. Furthermore, if it were met, the effect on carbon dioxide emissions would be minimal.

Figure 2: Petrol Used in Transport as Observed and as Projected for Six Alternative Scenarios: Low and High Growth, With and Without Electric Vehicles (but With Tax Reform), and With and Without tax Reform (but Without Electric Vehicles)



Source: ESRI Environmental Accounts and ISus.

Figure 3: Diesel Used in Transport as Observed and as Projected for Six Alternative Scenarios: Low and High Growth, With and Without Electric Vehicles (but With Tax Reform), and With and Without Tax Reform (but Without Electric Vehicles).



Source: ESRI Environmental Accounts and ISus.

3.4 Energy Use

Table 5 shows final energy use as observed and as projected per fuel and per sector. We use the Hermes energy model for these projections (Fitz Gerald *et al.,* 2002).[9] Oil products contribute most to energy use, followed by electricity and gas. Transport is the largest user, followed by households and industry. Final energy use grew by 3.5 per cent per year between 1990 and 2008. Coal and particularly peat use fell, and gas use grew particularly rapidly.

Energy use falls with economic activity. For the period 2008-2012, we expect an annual drop in energy use of 1.1-1.3 per cent. This is particularly pronounced for total energy use in construction and for coal use across the economy. For 2012-2020, assuming the *Low Growth* scenario, we expect that energy efficiency improvement and structural change would largely offset economic growth. Energy use would rise slightly, by 0.2 per cent per year. For the *High Growth* scenario, energy use would grow at 0.9 per cent, a much slower rate than the economy would grow. The shift away from coal and peat continues in both scenarios. Oil use grows are slowly (0.7 per cent per year) in the *Low Growth* scenario as freight transport growth is muted and people buy smaller cars; in the *High Growth* scenario, the annual growth rate is 1.2 per cent. The service sector is likely to see the highest growth

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[9] Note that the Hermes energy model was reprogrammed in Matlab, the same language as the ISus model. The two model versions produce identical results when estimated with the same data and the run with same scenarios. For this report, we estimated the parameters with data up to 2008, and drive the model with the assumptions set out in Tables 1 and 2.

rate for energy use while industrial energy use would fall slightly in the *High Growth* scenario but fall rapidly in the *Low Growth* scenario.

Table 5: Final Energy Use (in Thousand Tonnes of Oil Equivalent; KTOE) as Observed and as Projected Per Sector and Per Fuel

	Observed		*Low Growth*			*High Growth*		
	2008	**1990-2008 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**
	KTOE				*change per year*			
Coal	419	-3.8	-9.9	-2.9	-1.1	-10.1	-3.2	-1.4
Peat	280	-5.4	-4.9	-6.4	-5.5	-4.9	-6.3	-5.4
Gas	1,660	6.1	5.3	1.2	0.2	6.9	2.9	0.5
Oil	7,603	4.2	-3.2	0.7	0.2	-3.1	1.2	0.7
Renewables	253	4.9	5.9	0.5	0.8	5.6	0.8	1.2
Electricity	2,294	4.4	0.2	-0.5	0.0	0.1	-0.1	0.0
Agriculture	299	1.0	0.5	1.2	0.4	0.5	1.1	0.4
Industry*	2,316	2.1	0.2	-2.5	-3.4	1.1	-0.6	-2.8
Construction*	748	3.1	-17.3	1.3	0.5	-17.8	1.0	0.0
Services*	1,582	3.3	1.4	1.4	1.9	1.5	1.9	2.2
Transport**	4,682	5.9	-2.9	0.8	0.0	-2.6	1.5	0.8
Residential	3,184	1.9	1.0	0.5	1.0	1.0	0.7	1.1
Total	12,811	3.3	-1.3	0.2	0.1	-1.1	0.9	0.5

* Note that cement production (an industry) and construction (a service) are here listed together as construction.

** Excluding international aviation.

Source: ESRI Environmental Accounts and ISus.

3.5 Energy Efficiency

The European Union has the aspiration to increase primary energy efficiency by 20 per cent from what it otherwise would have been in 2020 (CEC, 2008).[10] This target is not binding. The government's draft climate bill does not have a target for energy efficiency (DEHLG, 2010), but the Oireachtas' draft does (OJCCES, 2010). Figure 4 shows the observed and the projected energy intensity (the inverse of efficiency), and relates the latter to the EU target. The EU target is relative to a baseline, which is unobserved and undefined. We constructed a baseline from a simple extrapolation of the trend between 1990 and 2008.

Over the last 20 years, Ireland's energy efficiency has improved rapidly (Cahill and O Gallachoir, 2010). In fact, Ireland's progress was extraordinary compared with other developed economies (Diakoulaki and Mandaraka, 2007). We project that this trend will continue until 2015 or so. In the *Low Growth* scenario, energy efficiency improvements will be "on target" while the rate of progress exceeds the target in the *High Growth*

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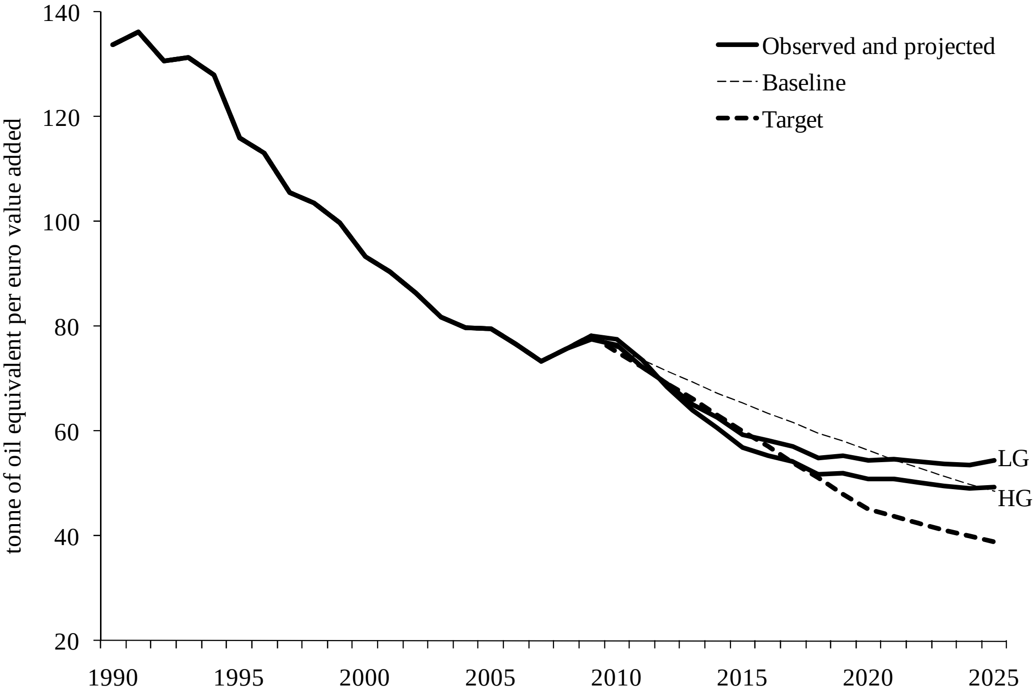
[10] Note that the EU defines primary energy efficiency relative to Gross Domestic Product, while we here use Gross Output. This does not matter as long as GDP and output change at the same rate.

scenario. After 2015, however, energy efficiency improvements slow down in the *High Growth* scenario, and come to a halt in the *Low Growth* scenario. This is partly because the sectoral composition of economic growth changes in favour of those sectors where energy efficiency improvement is slowest, partly because transformation efficiency in power generation falls and electricity exports rise (see above). As a result, the energy efficiency target for 2020 is not achieved in either scenario.

Figure 4: Primary Energy Intensity as Observed and as Projected According to the High Growth (HG) and Low Growth (LG) Scenarios



Note: The graph also displays a simple extrapolation (baseline) and the EU target.
Source: ESRI Environmental Accounts and ISus.

The projections for energy efficiency are derived from detailed models for power generation and private transport. Other energy uses are modelled in a simpler way. Among those, home heating is the only substantial energy use for which there is a material policy (Dineen and O Gallachoir, 2011). The Warmer Homes Scheme does not appear to affect energy use according to research commissioned by the SEAI (Social Market Research 2009). The SEAI also commissioned an evaluation of the Home Energy Savings Scheme but, while finished, this is unfortunately still unpublished. Building regulations have been tightened, but this is likely to have a limited impact as few new houses will be built in the immediate future. We assume that these policies are included in the trend.

3.6 Renewable Energy

The European Union has set binding targets for the share of renewables in total final energy use[11] and in transport energy use; for Ireland, these targets are 16 per cent and 10 per cent, respectively (European Parliament and Council of the European Union, 2009). There is no target for other sectors. Figure 5 compares the targets to the projected out-turn under the *High Growth* scenario.

If the market share of biofuels grows at its historical rate, renewable fuels would cover less than 2 per cent of the market in 2020, well below the target. However, there is mandatory blending of biofuels and conventional fuels since July 2010. We impose this blend, and keep the mandate at its current level throughout the projection period. For home heating, the current policy focus is on insulation. Consequently, we do not expect much growth in renewable home heating either. Wind power for electricity, on the other hand, is likely to continue to expand rapidly. Some 38-39 per cent of electricity is forecast to be renewable in 2020 (see above). This is not enough, however, to make up for the trend in the other energy uses. We therefore expect that Ireland will fall well short of its renewables targets, and will have to purchase renewable certificates from other Member States.

Biofuels are a proven technology, and there would be no technical difficulties in meeting the renewables target for transport (Smyth *et al.*, 2010). A three-fold increase of biofuels in the mandated blend of petrol and ethanol and diesel and biodiesel would suffice. However, as the first generation of biofuels are not particularly climate-friendly while competing with food production and increasing deforestation, and as the second generation is not ready for mass production, we expect that the current renewables target for transport will not be complied with or the target will be changed.

The cost of meeting the renewables targets in other EU countries are likely to be very high. This issue is attracting increasing concern in the UK. The cost of meeting their target through offshore wind could be exceptionally high and, given the financial difficulties, there is quite likely to be a rethink. As these costs become apparent elsewhere there is the possibility that majority opinion within the EU could see a change in the target. Thus, policy in Ireland should take account of the possibility that EU policy may change in the future. Where compliance will incur major costs there is the possibility that this investment could be "stranded" in the future.

Our projections for renewables in industry, services and homes extrapolate past trends. The Greener Homes Scheme supports renewable home heating. In 2006, 1,338 (subsidised) devices were installed. This rapidly rose to 8,384 in 2007 and 9,643 in 2008. However, installations fell to 7,311 in 2009 and to 2,259 in the first nine months of 2010. Solar is the most popular technology (60 per cent), followed by heat pumps (20 per cent) and bioenergy (20 per cent).[12] Unfortunately, the Irish climate is not optimal for either solar or heat pumps. The probable reasons for the drop

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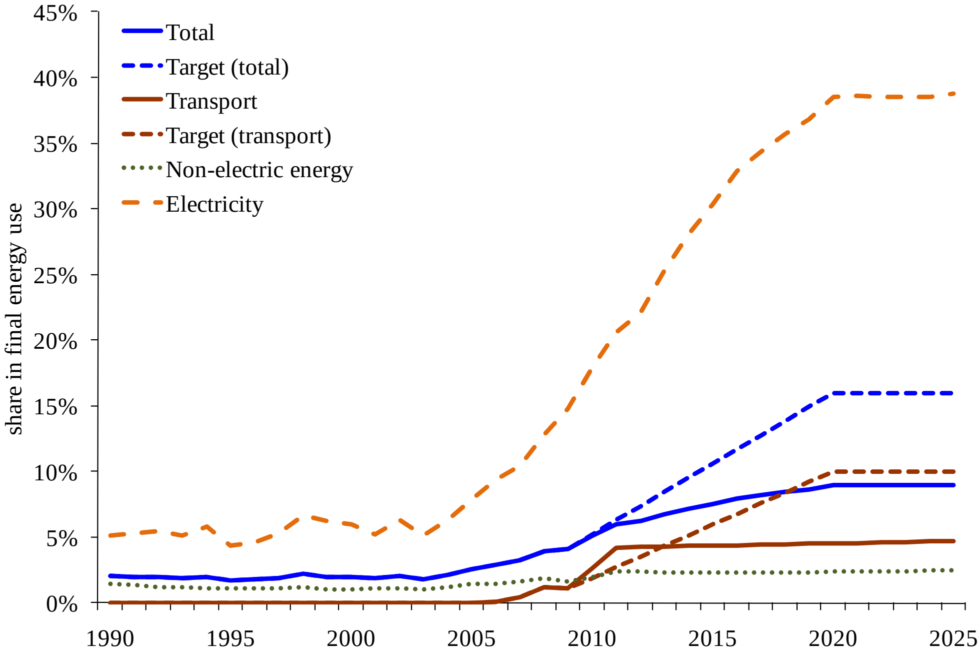
[11] Note that it would make more sense to define a target in primary energy use.

[12] http://www.seai.ie/Grants/GreenerHomes/Scheme_Statistics/

in installations are that the niche market of environmentally friendly households is saturated while the severe recession implies that people postpone, perhaps indefinitely, home improvements even if part-funded by the government. Furthermore, the grant was lowered and eligibility narrowed. We therefore project only a modest expansion of renewable heating.

Figure 5: The Share of Renewables in Electric and Non-electric Final Energy Use, in Transport Energy (Target Also Shown) and in Total Final Energy Use (Target Also Shown) as Observed (1990-2008) and as Projected (2009-2025) for the High Growth scenario



Source: ESRI Environmental Accounts and ISus.

4. ENVIRONMENT

4.1 Greenhouse Gas Emissions

Climate change continues to top the environmental policy agenda. Table 6 shows greenhouse gas emissions, per gas and per sector, for 2008, the observed trend for 1990-2008, and the projected trends until 2025.

Combustion of fossil fuels was the largest source (68 per cent) of greenhouse emissions in 2008. Some 27 per cent was regulated under the EU Emissions Trading System.[13] Methane emissions followed at 19 per cent and nitrous oxide emissions at 10 per cent. Process emissions of carbon dioxide – largely from cement production – stood at 3 per cent, and industrial gases at 1 per cent. Recently, Ireland has become a sink for carbon dioxide in soil and vegetation, primarily because of an increase in the size of trees (McGettigan *et al.*, 2010).

Agriculture contributed most (28 per cent) to greenhouse gas emissions in 2008, followed by transport (21 per cent) and power generation (21 per cent). Households were directly responsible for 11 per cent of emissions. Construction (including cement production) and other industry each contributed 7 per cent, and services 6 per cent.

Over the last two decades, emissions of industrial gases grew the fastest at 18 per cent per year, although the growth rate was only 2 per cent since 2000. Non-ETS carbon dioxide emissions (primarily from transport and home heating) grew at 2.6 per cent per year. Energy-related ETS emissions grew at 1.6 per cent per year, and process carbon dioxide at 0.5 per cent. Emissions of methane and particularly nitrous oxide fell by 0.3 per cent and 1.5 per cent per year. Overall, greenhouse gas emissions grew by just 1 per cent per year between 1990 and 2008, a remarkably low rate relative to the economic expansion.

In the period 2008-2012, we expect emissions to fall. The construction sector, and hence process carbon dioxide, falls the most. Other emissions fall too, but not as fast. Transport volumes are down, and the introduction of biofuels further reduces emissions. Emissions of industrial gases and nitrous oxide, on the other hand, rise. Total greenhouse emissions from industry, households, and agriculture rise, while emissions from other sectors fall.

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[13] Note that we allocate economic sectors to the ETS rather than activities and installations.

Table 6: Greenhouse Gas Emissions as Observed and as Projected Per Gas and Per Sector*

	Observed		*Low Growth*			*High Growth*		
	2008	**1990-2008 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**
	*			*change per year*				
CO2, energy, ETS	17.6	1.6	-2.3	-1.8	4.6	-2.1	-1.2	4.3
CO2, energy, non-ETS	27.4	2.6	-2.0	0.3	0.2	-1.8	1.0	0.6
CO2, process	2.4	0.5	-12.9	9.2	5.0	-12.9	9.2	5.0
CO2, land use	-1.5	Na	-1.1	7.6	3.9	-1.1	7.6	3.9
CH4**	12.7	-0.3	0.0	-0.3	0.2	0.0	-0.3	0.2
N2O	7.2	-1.5	0.6	-0.9	-0.1	0.6	-0.9	-0.1
F-gases	0.7	17.8%	9.2	7.8	3.7	9.2	7.8	3.7
Agriculture	18.4	-0.4	0.5	-0.4	0.0	0.5	-0.4	0.0
Industry***	4.6	0.1	1.2	0.5	-0.7	2.4	2.1	-0.6
Construction***	4.9	1.6	-15.8	6.4	4.0	-16.1	6.2	3.9
Services***	4.1	0.8	-1.2	0.4	1.9	-1.1	0.7	2.1
Transport	14.3	5.8	-3.6	0.8	-0.1	-3.3	1.6	0.8
Power	14.1	1.3	-1.0	-2.4	5.6	-1.0	-2.0	5.4
Residential	7.6	0.2	1.0	0.2	0.9	1.0	0.4	1.0
Total	66.6	1.0	-1.6	-0.3	1.4	-1.5	0.1	1.5

* Levels are in million metric tonnes of carbon dioxide equivalent, using the IPCC AR2 global warming potentials; CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; F-gases = HFC23, HFC32, HFC34a, HFC125, HFC143a, HFC152a, HFC227ea, CF_4, C_2F_6, cC_4F_8 and SF_6; ETS = EU Emissions Trading System.

** Note that methane emissions from landfill reported here differ from the official statistics.

*** Note that cement production (an industry) and construction (a service) are here listed together as construction.

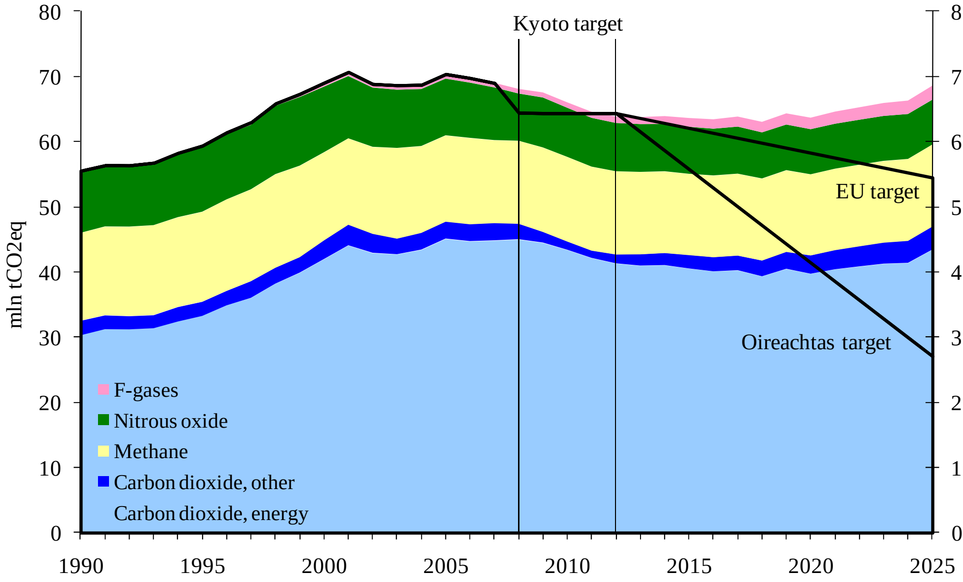
Source: ESRI Environmental Accounts and ISus.

Between 2012 and 2020, there is forecast to be a recovery in the construction sector but in other sectors energy efficiency improvements balance out economic growth. Emissions grow only modestly or fall. In power generation, emissions fall with the expansion of wind power (see above). Overall, emissions rise by an annual 0.1 per cent in the *High Growth* scenario and fall by 0.3 per cent per year in the *Low Growth* scenario.

After 2020, emissions start to grow again, between 1.4-1.5 per cent per year. This is partly due to structural change in the economy. An important component of this is the replacement of Moneypoint. We assume this is a coal-fired power plant without carbon capture and storage, as Ireland may not be in a position to finance the additional costs and may not be prepared to bear the technological risk.

Figure 6 shows greenhouse gas emissions by gas for the *Low Growth* scenario. The pattern for the *High Growth* scenario is similar. Because of the severe economic recession, Ireland is likely to meet or come close to its emissions target under the Kyoto Protocol. We assume that the ETS price and the carbon tax rise over time to €30/tCO_2, but the EU targets for 2020 are out of domestic reach – if current policy is continued. That would imply that permits will need to be imported from abroad (Gorecki *et al.*,, 2010; Tol, 2009a; Tol, 2009b).[14]

Figure 6: Greenhouse Gas Emissions by Gas According to the Low Growth Scenario



Note: The graph also shows the agreed target under the Kyoto Protocol for 2008-2012, the agreed target under EU policy for 2020, and the maximum 2020 target proposed by the Oireachtas Joint Committee on Climate Change and Energy Security.
Source: ESRI Environmental Accounts and ISus.

The draft Climate Bill (OJCCES, 2010) states that "…the overall target reduction in greenhouse gas emissions by 2020 shall be between 20 per cent to 30 per cent" (Article 4(2)(c)) but opt in Article 6(2)(i)(c) for "at least 30 per cent". Figure 6 therefore also shows the 30 per cent target, which would be even harder to achieve.

We discuss energy policy above. Climate policy is closely related to energy policy (Legge and Scott, 2009). We assume that the carbon tax rises with the price for emission permits in the EU ETS. The carbon tax would have to increase much faster in order to reduce emissions substantially (Conefrey *et al.,* 2008). We think that this is unlikely.[15] The current subsidies for energy efficiency and renewable energy have a limited effect (see

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[14] Note that there are ongoing discussions about accounting for land use emissions for EU policy. We here follow the reporting conventions under the UN Framework Convention on Climate Change rather than its Kyoto Protocol. This implies that our estimate of the distance to target could be out by 1-2 mln tCO_2 depending on the approach taken.

[15] Indeed, the recent four year plan proposes a doubling of the carbon tax (Government of Ireland 2010), which is not sufficient for meeting the targets.

above), and a decrease is more likely than an increase in such subsidies, given the fiscal position of the government.

In our projections, we assume little change in agricultural policy which would imply a modest decline of the beef herd and a modest growth of the dairy herd. Of course, reform of the Common Agricultural Policy would affect emissions. We further assume that there will be no technological breakthrough that would reduce methane emissions per animal. While progress has been made for sheep through immunisation against rumen methanogens (Wright *et al.*, 2004), the same is not true for cattle. Therefore, a rapid decline in methane emissions from agriculture can only be achieved through a reduction in the size of the herd. Such a reduction is unlikely for political reasons and would in any event be futile, from a global emissions perspective, unless there is a concomitant change in meat and dairy consumption, which is unlikely (Leahy *et al.,* 2010).

4.2 Alternative Projections of Carbon Dioxide Emissions from Energy Use

In the baseline projections, we use the ISus model for private car transport, the Hermes model for energy demand in other sectors, and the IDEM model for power generation. The ISus model is then used to compute carbon dioxide emissions from energy use. These models are designed for medium-term projections.

Short-term projections would require a different model structure. Generation of short-term projections is further hampered by the release schedule of data. In our model, energy use results from economic activity. However, energy data are available before data on the output of economic sectors, while migration statistics are preliminary in between Census. This implies that our short-term energy forecast is driven by other forecasts and data that are subject to revision. There are many possible causes for a failure to accurately predict energy use and carbon dioxide emissions.

For 2009, the Hermes-IDEM-ISus model predicts a drop in carbon dioxide emissions from fossil fuel of 1.9 per cent compared to 2008. The preliminary estimates of emissions by the EPA indicate that emissions fell by 11 per cent..[16] The short-term forecast is clearly wrong, essentially because the model assumes that there is a lot of momentum in the energy sector. While this is a generally accepted and adequate modelling strategy for times of economic growth, the model does not behave well in the short term during a severe recession.

There are two alternative ways to project emissions besides the structural Hermes-IDEM-ISus model (cf. Appendix 3). We can extrapolate trends in energy intensity by sector, and derive emissions from energy use (ISus Energy); and we can extrapolate trends in emission intensity by sector (ISus Emissions). Extrapolation ignores energy prices, vehicle taxes, plant closures and so on. We therefore prefer not to use these methods.

Figure 7 compares carbon dioxide emissions from fossil fuel combustion according to the three alternative models for the *Low Growth*

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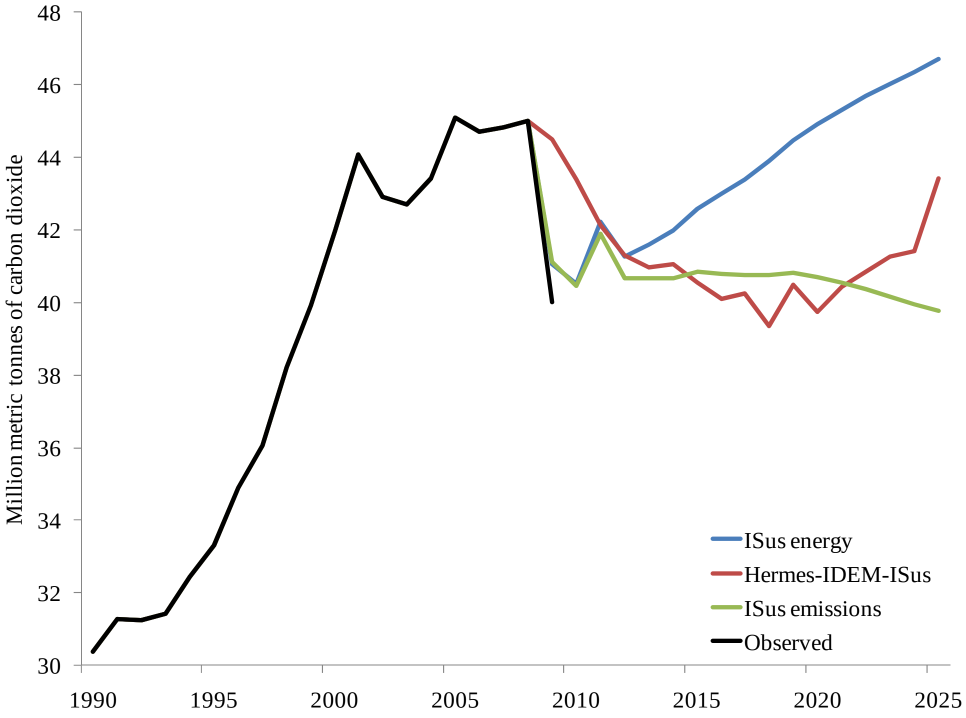
[16] http://www.epa.ie/news/pr/2010/name,30406,en.html

scenario. The ISus Energy model has a drop in emissions of 4.4 mln tCO_2 and the ISus Emissions model a drop of 3.9 mln tCO_2. This compares to a drop of 0.9 mln tCO_2 according to Hermes-IDEM-ISus, and a drop of 5.0 mln tCO_2 according to the EPA. The simple models also reasonably reproduce the sectoral pattern of the preliminary data (results not shown).

Figure 7 also compares the medium-term results of the three models. The simple models essentially project past trends into the future. The result is either a steady increase of emissions (ISus energy) or a stabilisation (ISus emissions). The structural Hermes-IDEM-ISus has a richer pattern, reflecting investment decisions and expected changes in the prices of energy and carbon prices.

Figure 7: Carbon Dioxide Emissions from Fossil Fuel Combustion as Observed and as Projected by Three Alternative Models for the Low Growth Scenario



Note: The Hermes-IDEM-ISus model is used in the rest of the report.

For short-term forecasts, the simple models clearly outperform the structural model. However, as the simple models ignore changes in policy and economic conditions, the structural model is better suited for projections in the medium term.

4.3 Waste

The ESRI Environmental Accounts have been further refined for waste. While previously we distinguished between three types of waste (hazardous, biodegradable municipal and other) and four destinations (recycling, incineration, landfill and unattributed), we now have five destinations (landfill, recycling, incineration, use as fuel and unattributed) and three types of waste (hazardous, soil and stones and other waste). We plan to add a fourth category, bio-waste, in the near future. In addition, we have added a secondary waste category: incinerator ash. These accounting categories can be re-aggregated into additional categories of policy interest; in particular, biodegradable municipal waste (BMW), municipal solid waste (MSW), construction and demolition and industrial. The current waste classification reflects both regulatory and reporting requirements. More details of the categories are given in the Appendices.

In the remainder of this section, we provide projections of future waste generation based on two macroeconomic scenarios. These are baseline projections, in the sense that we assume that policies applied in the base year (2008) are continued throughout. This is not to say that we consider that no significant new policies will be implemented after that date (indeed, some are already in train). However, some proposed policies are still subject to consultation by the government and may or may not ultimately be implemented. Other policy measures have been enacted but not yet implemented fully. Particularly, there is a range of (proposed) policies that aim to divert waste from landfill, but without providing an alternative. We use landfill here as the default way to dispose of waste. Still other measures affecting waste generation (e.g. increases in income tax or VAT) may be applied to help address Ireland's fiscal difficulties but have not yet been announced. There is relatively little published research into the likely net effects of the various policies that are in place or being considered for the waste sector in Ireland. This is an area we plan to develop in future research. Those wishing to use our projections to inform forecasts of waste growth or disposition can of course form their own views as to the likely effects of current or planned policies.

Table 7: Waste Arisings as Observed and as Projected for Municipal Solid Waste (MSW), Biodegradable Municipal Waste (BMW), Hazardous Waste, Construction and Demolition Waste (C&D) and Industrial Waste

	Observed		*Low Growth*			*High Growth*		
	2008	**2001- 2008 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**
	Tonnes	*change per year*						
MSW	3,250	3.6	-0.1	2.2	1.6	0.1	2.7	2.3
BMW	2,092	5.5	-0.1	2.1	1.6	0.1	2.7	2.3
Hazardous	812	n/a	-8.1	4.9	0.8	-7.1	6.4	1.8
C&D	13,449	n/a	-18.7	6.7	1.3	-18.5	7.1	1.8
Industrial	6,126	n/a	-1.1	3.0	0.8	-0.3	4.1	1.5

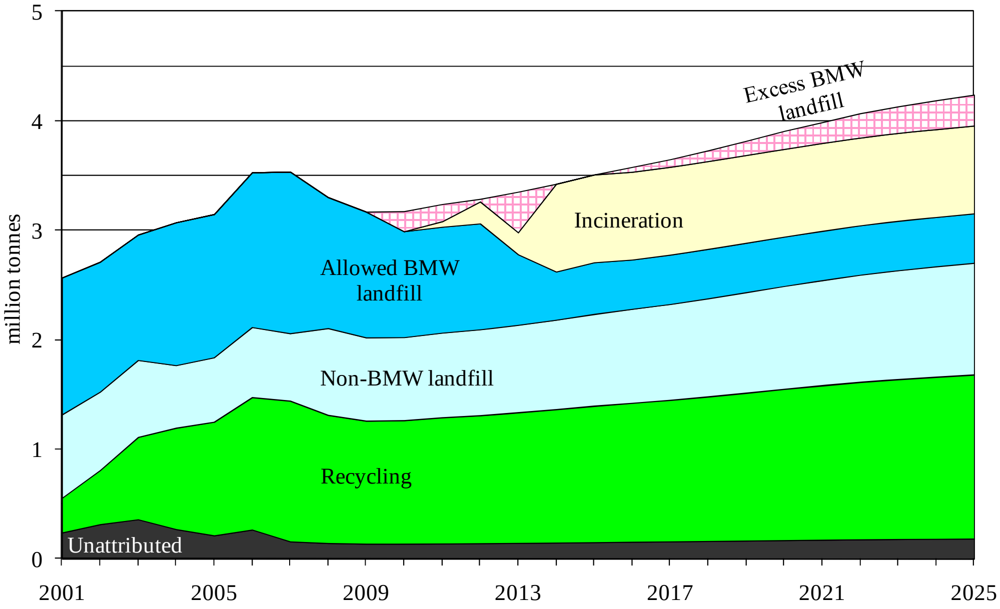
Source: ESRI Environmental Accounts and ISus.

Table 7 shows the waste arisings in 2008 (the most recent reporting year), past trends, and baseline projections for the future. Construction and demolition waste is the largest waste stream by weight. We expect a very steep decrease over the period of the severe recession, but with a substantial recovery as the economy recovers. After 2020, construction (and hence its waste) slows down again. The pattern is the same in both the *Low Growth* and the *High Growth* scenario, but more pronounced in the latter. Hazardous waste, the smallest type (by weight), follows the same pattern, but is more modest. Industrial waste, the second largest type, follows the same pattern but is more muted still.

The bulk of municipal solid waste is biodegradable and the bulk of biodegradable waste is municipal.[17] Waste arisings are expected to be flat through the severe recession, but start rising again after 2012 but at a much slower rate than during the boom years. Projected growth after 2012 is significantly slower than we had previously predicted, mainly because the forecast growth rates for real disposable income per capita are much lower in current macroeconomic forecasts than they were previously (1.1 per cent per annum in the current *high growth* scenario, compared to 2.9 per cent per annum in the central projection from (Bergin *et al.*, 2009).

Projecting the destinations to which waste streams go is subject to greater policy uncertainty than waste generation, because disposition of waste is more readily influenced by public policy. Figure 8 shows baseline projections of municipal solid waste by destination. Note that this baseline does not assume any change to recycling rates; measures such as the EPA pre-treatment guidelines (EPA, 2009) and the Waste Management (Food Waste) Regulations 2009 (DEHLG, 2009) should lead to increased recycling. As explained earlier, we have not attempted to model the net effects of such measures. Other market developments that might limit the expansion of recycling facilities, such as continuing difficulties in the financial sector and the effects of policy uncertainty on firms' investment plans, should also in be taken into account in forming a view as to future waste disposition.

Figure 8: Municipal Solid Waste by Destination as Observed (2001-2008) and as Projected (2009-2025) Under the Low Growth Scenario



Source: ESRI Environmental Accounts and ISus.

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[17] Municipal waste is waste from households and commercial sources.

Landfill Directive limits for the amount of biodegradable municipal waste that can be landfilled entered into force in July 2010 and will gradually tighten until 2016. If the two incinerators that currently have planning permission are put into service, [18] Ireland should be capable of meeting the Landfill Directive limits for several years at least – if we, somewhat optimistically, assume that exclusively BMW would be incinerated. However, in both the *high* and the *Low Growth* scenarios, implementation of improvements in collection arrangements or new post-collection processing capacity will be required to ensure sustained compliance.

4.4 Methane Emissions from Landfill

A substantial amount of methane is emitted by waste decaying in landfills. This is a slow process, with methane being emitted for 20 years or more after waste disposal. Methane is the second-most important anthropogenic greenhouse gas. Emission reduction targets are formulated relative to 1990. This implies that waste data going back to 1969 are needed to estimate methane emissions from landfill in 1990.[19] Such data do not exist for Ireland: actual waste data are only available for 1987, 1995, 1998 and annually from 2001 onwards – and data quality and classifications have changed over time. We therefore use the ISus model to fill in the gaps.

In its past submissions to the UN Framework Convention on Climate Change (McGettigan *et al.,* 2008), the EPA Office for Climate, Licensing and Resource Use also developed a model (here referred to as EPA08). Our model is identical to theirs, except for the amount of waste disposed. EPA08 assumes that waste per capita equals one kilogramme per person per day between 1969 and 1984 (except in leap years, when there was 365/366 kg/p/d). After 1984, per capita waste rises linearly to the levels observed in 1995 and 1998. The ISus Waste model distinguishes between waste from households and small businesses. Waste is sensitive to the size of the service sector, the size of the population, per capita income, and the price of disposal.

Figure 9 shows the total waste generation as predicted by ISus and EPA08. Because both models are based on recent data and predict earlier values, the figures converge in recent times. Waste projections according to ISus are consistently lower than the EPA08 estimates. Figure 9 also shows the waste sent to landfill. Our estimates are first lower than those of EPA08, then higher, and the series converge in recent times. ISus exactly reproduces the data in the National Waste Report of the EPA Office for Environmental Assessment (McCoole *et al.,* 2008), while the EPA08 results are close.

Recently, the EPA changed its model of methane emitted by landfills (McGettigan *et al.,* 2010). We refer to this new model as EPA10. Specifically, where the old model (EPA08) uses a generic representation of an "average" landfill, EPA10 has a specific representation of each landfill in the country. The new model also uses recently collected data on flaring and utilisation of landfill gas (Fehily Timony & Co.Ltd., 2009).

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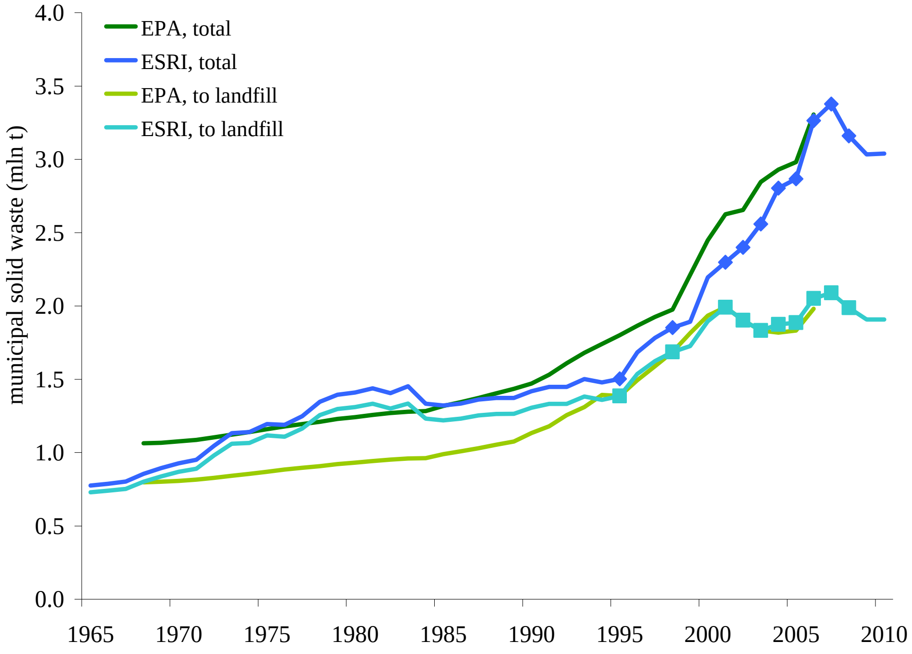
[18] Note that there is substantial uncertainty about the future of the Poolbeg incinerator.

[19] Alternatively, the content of existing landfill can be examined and characterised.

Figure 9: Municipal Solid Waste (Total and Landfill) According to ISus and EPA08 Models (Lines) and EPA Data (Symbols)



Source: Lyons *et al.* (2010).

Figure 10 contrasts estimates of methane emissions according to ISus with those of EPA08 and EPA10.[20] EPA08 and EPA10 use the same numbers for the amount and composition of waste, but different emission models; ISus uses different numbers of waste, but the same emission model as EPA08. The three historical series show a dip in 1996-7 as flaring and biogas exploitation are introduced, and another dip in 2007-8 as flaring is expanded. However, the series are remarkably different in every other aspect. The ISus record starts at the highest point, but gradually falls between 1990 and 2008. The EPA08 record starts lower but rises over time. The EPA10 record starts lowest and falls. The differences between ISus and EPA08 are due to the differences in the historic reconstruction of landfilled waste. The differences between EPA08 and EPA10 are due to updates of the emissions model. The differences between ISus and EPA10 are due to differences in both the historic reconstruction and the emissions model.

The emissions targets for 2008-2012 (Kyoto) and for 2020 (EU) are formulated relative to 1990 and 2005 emissions, respectively. The targets are different, therefore, for the three alternative reconstructions of history.[21] The Kyoto targets are achieved for the EPA08 estimates without additional policy. Ireland overcomplies according to the EPA10 and ISus estimates. If the EPA had updated its emissions model as well as its waste

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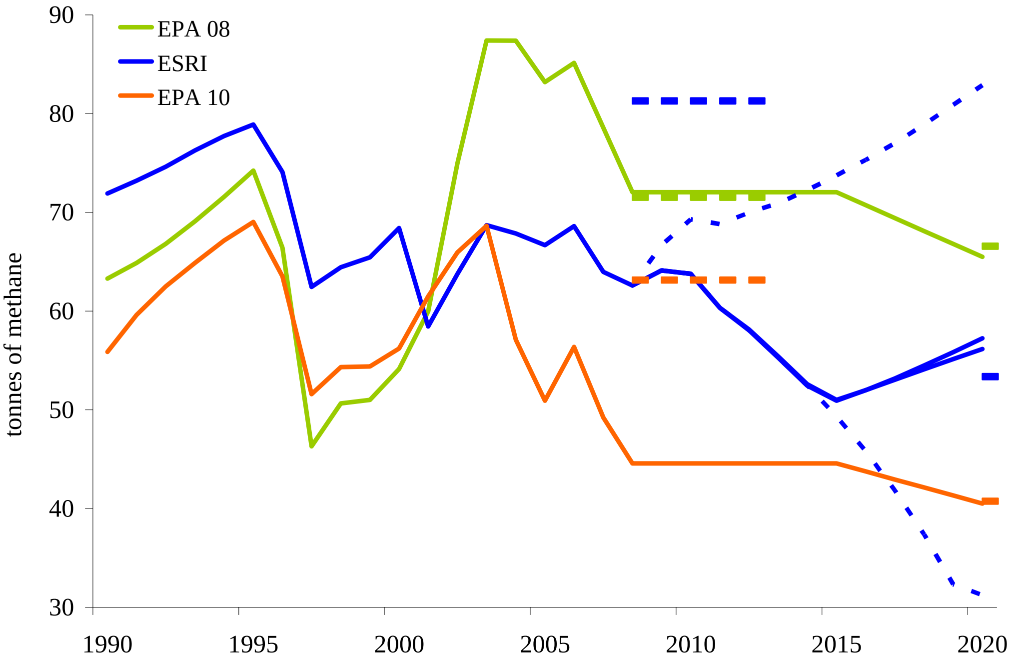
[20] The EPA08 record ends in 2006. We extrapolated it using the same growth rate as the EPA10 record.

[21] Note that the targets are for total greenhouse gas emissions. We here assume that the same targets for methane, that is +13 per cent wrt 1990 for 2008-2012, -20 per cent wrt 2005 for 2020. While this assumption is academic, it illustrates the implications of alternative reconstructions of the historic emissions record.

arisings model,[22] then the gap between target and outturn would have been even greater.

Figure 10: Methane Emissions from Landfill According to ISus, EPA08 and EPA10



Note: ISus and EPA08 use the same emission model, and that EPA08 and EPA10 use the same waste data. The solid, blue lines represent the *High* and *Low Growth* scenarios according to ISus. The dotted lines show a sensitivity analysis around the *High Growth* scenarios, keeping the share of methane flaring at current (2008) practice and increasing that share to current best practice.
Source: Lyons *et al.* (2010).

For 2020, the scenario matters as well. We use the growth rate of the latest "with measures" scenario of the EPA to project the historical reconstructions of EPA08 and EPA10 into the future. For ISus, we show results for both the *High Growth* and the *Low Growth* scenario, and a sensitivity analysis on flaring around the *High Growth* scenario. We assume that the use of landfill gas will grow at its historic rate between 1996 and 2008.

According to EPA08 and EPA10, methane emissions from landfill will be flat until 2015.[23] Emissions over this period are largely driven by waste already landfilled, so EPA08 and EPA10 assume more flaring and utilisation (75 per cent in 2020). We let flaring grow at the historical rate, and emissions fall as a result. The difference that is due to alternative assumptions about economic growth is minimal. However, if we keep the rate of methane flaring as it was in 2008, emissions grow rapidly.

According to EPA08 and EPA10, emissions will start to fall after 2015, presumably because the projections assume that the targets for diverting

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[22] Note that the ESRI developed its waste model with EPA funding.

[23] Note that the EPA projections of greenhouse gas emissions are not reported with an annual resolution, and are poorly documented.

waste from landfill will be met.[24] The ISus projections suggest that the landfill targets will be missed because there is no policy in place which would achieve such a change in behaviour. If we keep the rate of flaring at its 2008 level (36 per cent), methane emissions continue to grow after 2015. If we assume that flaring grows at its historical rate until it reaches best current practice (76 per cent, close to the EPA assumption), then methane emissions continue to fall rapidly (and substantially below the EPA projections). If we cap flaring at 56 per cent – halfway between current practice and best current practice – methane emissions start to rise again after 2015.

According to the EPA08 and EPA10 projections, Ireland will meet its "EU emission targets" for 2020 for methane from landfill. According to the ISus projections, Ireland may miss these targets unless flaring and utilisation are expanded. This highlights the importance of model uncertainty. This is of particular concern in this case, as the "data" on methane emissions from landfill are model results rather than observations.

4.5

The Impact of Policy on Landfilled Biodegradable Municipal Waste

The EU has placed limits on the amount of biodegradable, municipal waste (BMW) that can be landfilled. The projections in the main text show that Ireland is likely to miss these targets, which would likely result in fines.

The baseline projections, however, assume that policy will remain as it is today. The main impact of the policies currently out for consultation by the government would be to limit the expansion of incineration. Waste generation would not be affected much. In the short term, the current policy uncertainty provides disincentives to potential developers of all alternatives to landfill that requires capital investment.

The ISus model, however, can evaluate hypothetical policy changes too (Curtis *et al.,* 2009). Estimates show that increasing the landfill levy from €30 per tonne to €75, without increasing pay-by-use charging or construction of new post-collection processing, would reduce the amount of BMW landfilled by only about 1 per cent. A minority of households face effective pay-by-use charges for waste services (EPA, 2008) which reduces the effectiveness of such a measure. A nation-wide roll-out of a three-bin waste collection system would cut landfilled BMW by roughly 17 per cent. Nation-wide weight-based charging could reduce landfilled BMW by 25 per cent.

So, it would be feasible to meet the landfill targets, but only with a departure from current waste policy.

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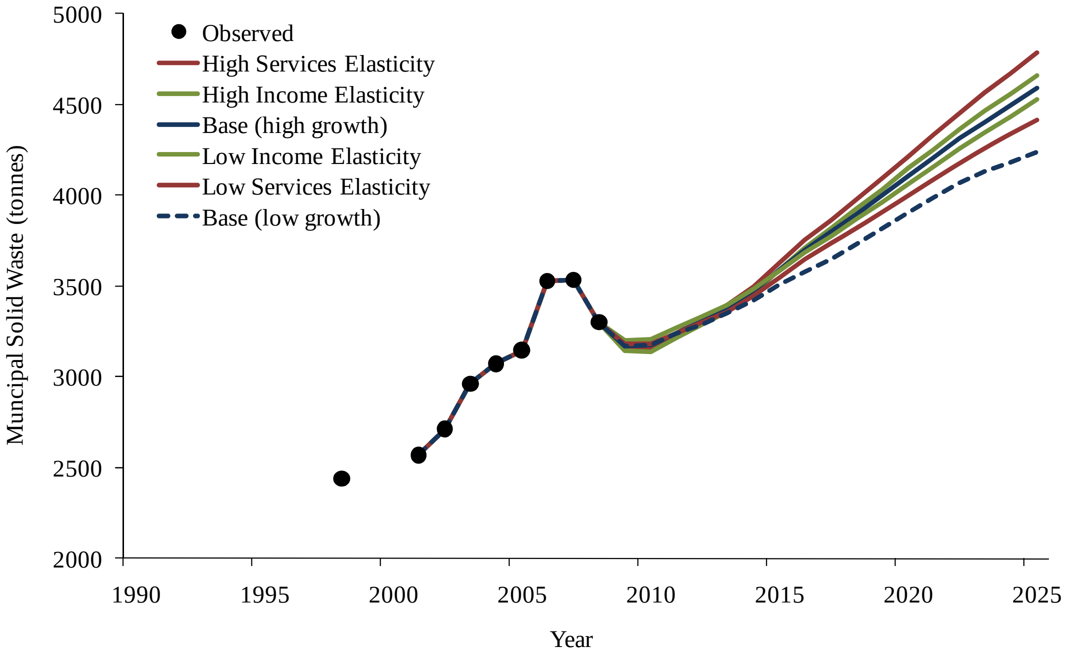
[24] The EPA projections are based on international guidelines.

4.6 Sensitivity Analysis of Waste Projections

Forecasts of future developments are uncertain. Above, we focus on one particular aspect of that uncertainty, namely, economic growth. Here we focus on parameter uncertainty. In the ISus baseline, we assume that household waste generation per household is directly proportional to real per capita income (plus an effect from the number of persons per household). We also assume that commercial waste is directly proportional to the output of that the service sector. Figure 11 shows what happens if we set these parameters at 0.7 or 1.3 instead.[25] The lower value would imply a move towards the level of response found in most other countries; the higher value is drawn from recent empirical evidence for Ireland (Curtis *et al.,* 2009).

Obviously, if growth in waste arisings is more (less) than proportional to economic growth, waste grows faster (more slowly) when the economy is expanding. Municipal solid waste is more sensitive to the growth of the service sector than to per capita income. The sensitivity analysis in Figure 11 is around the *High Growth* scenario, but it also includes the base results for the *Low Growth* scenario. The assumptions about economic growth are more important than parameter uncertainty.

Figure 11: Municipal Solid Waste Arisings as Observed and as Projected for the Base Model with High and Low Growth, and for Alternative Parameter Choices for the High Growth Scenario



Source: ESRI Environmental Accounts and ISus.

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[25] For example, a value of 0.7 would imply that only 70 per cent of any change in real household incomes will be reflected in waste growth rates; this is sometimes referred to as 'partial decoupling'.

4.7 Dioxins and Persistent Organic Pollutants

Initially, the ESRI Environmental Accounts focused on energy, waste, and greenhouse gas emissions. There are other environmental problems too. Based on (Creedon *et al.,* 2010),[26] we have extended the ESRI Environmental Accounts to include emissions of polychlorinated dibenzo-p-dioxins and dibenzofurans (dioxins; to air, land and water), polychlorinated biphenyls (PCBs; to air and land), hexachlorobenzene (HCB or C_6Cl_6; to air, land and water), benzo(a)pyrene ($C_{20}H_{12}$; to air), benzo(b)fluoranthene ($C_{20}H_{12}$; to air), benzo(k)fluoranthene ($C_{20}H_{12}$; to air), and indeno(1,2,3-cd)pyrene (to air). These substances are persistent, bioaccumulative and toxic, and many are carcinogenic and mutagenic. Table 8 shows current emissions, past trends, and future projections.

The projection method is straightforward. We compute the emission intensity per pollutant per sector for the period 1990-2008, and the annual change in emission intensity. We assume that future changes in emission intensity equal the median of past changes. Emissions follow from the projected change in sectoral output and emission intensity.

Table 8: Persistent Organic Pollutions by Type and Medium as Observed and as Projected

	Observed		*Low Growth*			*High Growth*		
	2008	**1990-2008 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**	**2008-2012 %**	**2012-2020 %**	**2020-2025 %**
	Kg				*change per year*			
Dioxin (air)	0.023	-1.1	-1.8	0.4	0.0	-1.7	0.6	0.1
Dioxin (land)	0.058	1.4	-2.4	0.6	0.3	-2.3	1.0	0.7
Dioxin (water)	0.001	-2.2	-3.8	-1.7	-2.0	-3.5	-1.0	-1.2
PCB (air)	41	-2.6	-1.4	1.3	0.8	-1.3	1.5	1.0
PCB (land)	150	-1.7	-2.2	-3.7	-7.5	0.0	-1.3	-6.0
HCB (air)	1.44	-16.9	4.0	6.0	5.0	4.0	6.0	5.0
HCB (water)	0.02	11.9	4.1	6.1	5.0	4.1	6.0	5.0
HCB (land)	0.58	11.9	4.1	6.1	5.0	4.1	6.0	5.0
Benzo(b)pyrene (air)	1294	-5.9	0.6	-1.8	-1.0	0.6	-2.0	-1.3
Benzo(b)fluoranthene (air)	328	-4.9	-0.9	-0.8	-0.8	-0.7	-0.6	-0.8
Benzo(k)fluoranthene (air)	150	-6.6	-1.5	-0.1	-0.2	-1.3	0.1	-0.1
Indeno(1,2,3-cd)pyrene (air)	838	-6.1	0.6	-2.1	-1.3	0.6	-2.3	-1.6

Source: ESRI Environmental Accounts and ISus.

Dioxins primarily originate from combustion by households and in the cement and services sector. Emissions to air have fallen slightly over the last 20 years. Emissions to land have grown. We project a slight increase of dioxin emissions to air and a more pronounced increase of emissions to land. Most of the increase comes from the residential sector.

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[26] Note that emission estimates are particularly uncertain. The estimates used here are the latest, and differ considerably from earlier estimates (Hayes and Marnane, 2003).

PCB emissions too have fallen over the last two decades. Emissions to air have fallen because of technological progress and stricter regulation but also because steel production ceased in 2002. Household emissions have risen and households are now the dominant source. We expect that household emissions will rise further in the future. PCB emissions to air from the electrical goods sector have fallen rapidly, but emissions to land have declined much less. We expect that these emissions will fall, despite the projected expansion of the electrical goods sector, because of regulation (Council of the European Union 1996; DELG ,1998).

HCB emissions to air have fallen dramatically since the use of hexachlorethane was banned in 1996. HCB emissions to air, land, and water from agriculture have grown steadily and agriculture is now the predominant source. We project that emissions will continue to increase, consistent with past trends.

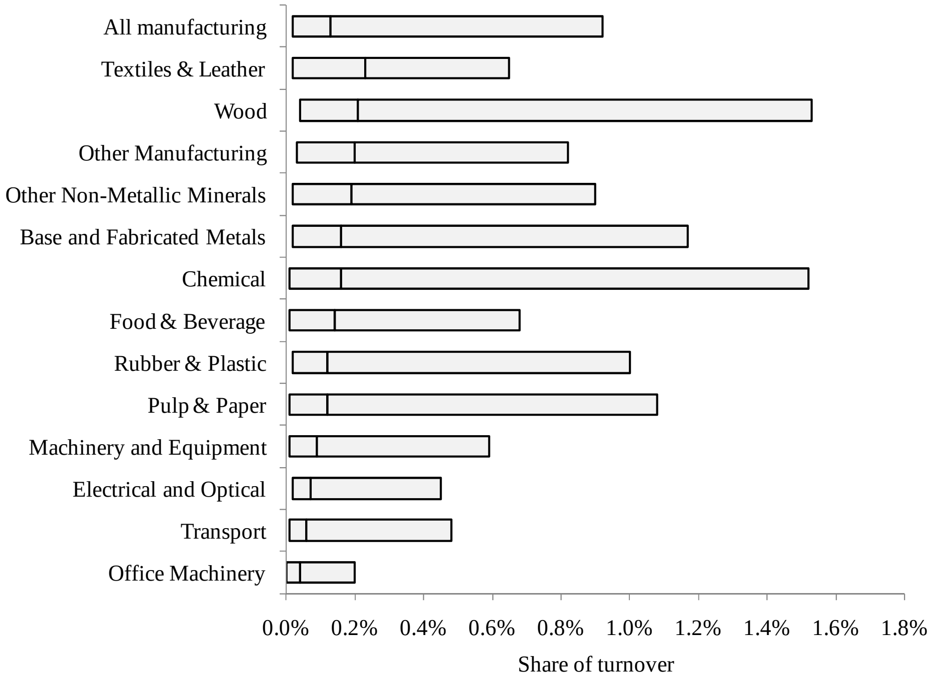
Emissions of pyrenes and fluoranthenes have steadily decreased over the last 20 years. The main sources are fuel burning by households and transport. We expect that emissions will continue to fall as combustion technology improves.

4.8 Environmental Expenditure and Investments

Over the years, the government has imposed ever stricter environmental regulations on firms, and many companies now strive for a green image. Until recently, however, it was poorly understood what this meant to businesses. The Central Statistics Office (CSO) annually conducts the Census of Industrial Production (CIP). Since 2006, the CIP gathers information on current environmental expenditure and on capital investments in equipment for pollution control for firms with 20 employees or more. The survey probably under reports the cost of environmental protection, as environmental features that are integrated into purchases and investment are not recorded. Only 22.5 per cent of firms report positive environmental expenditure in 2007 and the share of firms that invest in equipment for pollution control is even smaller at 4.5 per cent. Overall mean expenditure on the environment was €23,000 in 2007; among firms that spend, it was €105,000.

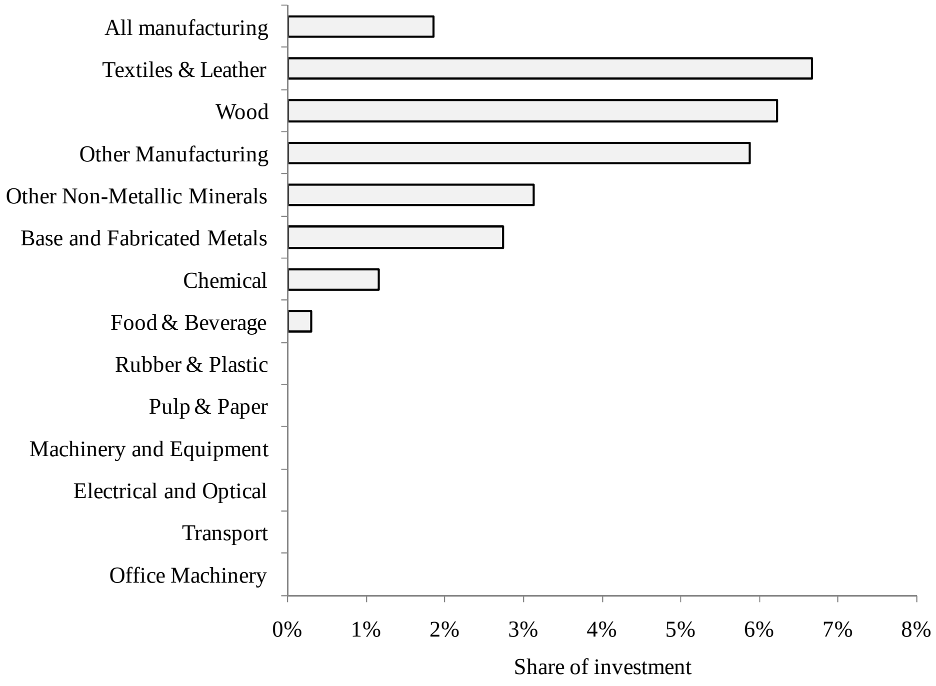
There is variation across industries, with firms in the chemicals, non-metallic minerals and food, beverages and tobacco sectors reporting the largest expenditures. The share of environmental expenditure in turnover is small – an average of 0.3 per cent. The chemicals sector reports the largest share. Companies in the machinery and equipment, office and data machinery, electrical instruments and transport goods sectors spend least. Figure 12 shows that the variation is large, with the firm at the 95th percentile of the sector often spending over 1 per cent of turnover. Mean capital investment in equipment for pollution control is €23,000 for all firms and €523,000 for those that report positive investments. Again the chemicals sector is prominent, as well as food, beverages and tobacco and machinery and equipment. Relative to total capital investment in the sector, sector-wide investment in equipment for pollution control is highest in the wood and transport goods sectors (see Figure 13). Variation between firms is large. While the vast majority of firms do not invest at all in environmental protection, some firms invest up to 7 per cent.

Figure 12: Expenditures on Environmental Protection as a Share of Turnover by Industry



Note: the graph shows the 5 percentile, median and 95 percentile; sectors are ordered according to median expenditure.
Source: Haller and Murphy (2010).

Figure 13: Investments in Environmental Protection as a Share of Total Investment



Note: the graph shows the 5 percentile, median and 95 percentile; sectors are ordered according to maximum expenditure; note that the 5 percentile and median are zero.
Source: Haller and Murphy (2010).

A more detailed analysis (Haller and Murphy, 2010) reveals that larger, exporting firms and firms subject to the Integrated Pollution Prevention and Control directive are more likely to spend money on environmental protection, while larger firms, firms that are foreign-owned, and firms that report low shares of water and refuse charges in turnover have higher absolute levels of environmental expenditure. Energy intensive and exporting firms are more likely to invest in environmental protection, while firms that report high water and refuse charges invest more.

5. DISCUSSION AND CONCLUSION

The *Energy and Environment Review 2010* covers a broad range of topics. We discuss current energy use, emissions and waste, past trends, future projections and the impact of policy. Although the current report is wide-ranging, the full set of results is even broader. We highlight here those areas which are either of particular interest to current policy making or where significant advances in understanding have been made.

Recent research has significantly improved the data on emissions of persistent organic pollutants, which cause a range of health problems for animals and humans. We expect a decline in the emissions of most of these substances. However, dioxins (to air and land) and PCBs (to air) gently trend upwards while our scenarios, based on the extrapolation of past trends, show a sharp increase in emissions of hexachlorocarbons to air, land, and water. A tightening of policy is called for.

We highlight the uncertainty about the methane emitted by landfills, and indicate that the EPA may overestimate the emission reduction requirement.

We also looked, for the first time, at corporate expenditures and investments in environmental protection. Less than a quarter of firms spend money on environmental protection, and fewer still invest. Average expenditure is 0.3 per cent of turnover and average investment is 0.7 per cent of investment. However, there are marked differences between and within sectors, with some firms spending 1.5 per cent of turnover and other firms investing 7 per cent of total investment in environmental protection. Foreign-owned and exporting firms spend more on environmental care than do other firms.

In power generation, we project a steady increase in the share of renewables, particularly wind, until 2020 even though a number of gas-fired power plants will be built. We expect that Ireland will become a net exporter of electricity to Great Britain. After 2020, much depends on the decision as to what type of plant would replace Moneypoint. A coal-fired power plant with carbon capture and storage would be technically risky and can perhaps not be financed; with the prices assumed here, such a plant would not be able to compete in the market. We, therefore, assume that Moneypoint will be replaced with a conventional coal plant which will provide for the baseload demand in electricity.

We project a steady increase of the number of diesel cars at the expense of petrol cars, largely as a result of the tax reforms of 2009. Carbon dioxide emissions fall, but so do tax revenues. There are few electric cars in the baseline projections, because the current generation of electric vehicles serve a small niche market only and current government support is unlikely to be maintained for budgetary reasons. Even if the government target of 10 per cent of all cars by 2020 were met, it would have a minimal impact on emissions as all-electric cars would disproportionally displace small cars that are driven short distances.

The primary energy efficiency of the economy has improved rapidly over the last 20 years. The government aims to accelerate this trend, but with unchanged policies a deceleration is likely, because economic growth is faster in those sectors in which technological progress in energy use is slow, and because electricity is exported.

Wind power will be the source of an increasing share of Ireland's electricity. Biofuels can easily deliver 10 per cent or more of transport energy, but this may not be desirable from an economic or environmental perspective. In other sectors, renewable energy is less likely to make a significant contribution. It seems likely, therefore, that Ireland will have to purchase renewable certificates from abroad unless so many Member States have difficulty meeting their renewables targets that the directive will not be enforced.

Because of the severe recession, Ireland is likely to meet its greenhouse gas emission reduction targets under the Kyoto Protocol. However, we project a slight increase of emissions after 2012 so that the 2020 target will be missed domestically and emission permits will have to be imported. The reason is that current policies effectively reduce the growth rate of emissions, but are insufficient to reduce the absolute level of emissions. Subsidies for emission reduction are more likely to go down than up for budgetary reasons. The carbon tax is tied to the ETS permit price, for good reason, and therefore unlikely to have a large impact on emissions.

There are targets for diverting waste from landfill but no effective policies to back them up. On the contrary, public policy has created so much uncertainty over waste that crucial investment in alternatives to landfill has been postponed. As a result, Ireland is likely to miss its landfill targets in the short term. Although expansion of incineration capacity would bring Ireland back into compliance in the medium term, we will be again in breach of the EU Landfill Directive in the long term unless policy is reformed. An increase in the landfill levy would only have a substantial impact if three-bin waste collection and weight-based charging are widespread.

APPENDIX 1: THE ESRI ENVIRONMENTAL ACCOUNTS

A1.1 An Overview of the ESRI Environmental Accounts

The national accounting framework, including such key concepts as Gross National Product, is a vital input to economic decision making. However, the standard national accounting framework does not take account of the pressure or damage to the environment caused by the economic activity. Thus, similar levels of GNP might involve quite different environmental damage, with implications for both current and future welfare and economic activity. Environmental accounts are now constructed in many countries to take account of these concerns, building on initial research by Nordhaus and Tobin (1972) and agreed international standards (United Nations *et al.*, 2003). Environmental accounts build on the well-established and coherent national accounting framework, but add to this with what are termed "satellite accounts" dealing with environmental issues, in a way which allows for them to be integrated and measured in a more comprehensive framework. This provides an increasingly sound basis for decision making on the environment.

A recent paper (Lyons *et al*,, 2009) presents the ESRI Environmental Accounts for the Republic of Ireland for the period 1990-2005. The paper describes the principles of environmental accounts, and illustrates their use by discussing trends in emissions and resource use in Ireland, by comparing the trend in carbon dioxide emissions in Ireland to other countries, and by attributing emissions to consumption.

There are four parts to the environmental accounts: (1) emissions and waste, (2) resource use, (3) expenditures on environmental protection, and (4) economic value. Data are given by economic sector. The ESRI Environmental Accounts are the most extensive accounts for Ireland, and the only ones that adhere to the internationally agreed standards. There are 79 "substances" (27 emissions to air, 5 emissions to water, 3 emissions to land, 19 types of waste, and 25 resources; see Table A1) for 20 sectors (19 production sectors plus households; see Table A2) for the period 1990-2008. The data come primarily from the Central Statistics Office (CSO), the Environmental Protection Agency (EPA) and Sustainable Energy Authority of Ireland (SEAI). Data on expenditures on environmental protection have recently been added. Data on the economic value of the environment is scattered and inconsistent. While the amount of data on emissions and resource use is impressive at first sight, the ESRI Environmental Accounts are skewed towards climate, acidification, persistent organic pollutants, energy, and waste. The use of land, water, and materials is largely omitted. Large groups of chemicals, including many potentially harmful ones, have to be ignored because of the lack of suitable data.

The ESRI Environmental Accounts are proper satellite accounts of the National Accounts. We can therefore readily integrate economic and environmental data. This allows us to interpret trends and, for example, allocate responsibility for particular emissions to the relevant sectors of activity.

The data can be found at:
http://www.esri.ie/irish_economy/environmental_accounts/

Table A1: ESRI Environmental Accounts for the Republic of Ireland, by Substance, Version 0.0 to 0.5

Substance	v0.0	v0.1	v0.2	v0.3	v0.4	v0.5
Emissions (air)						
CO_2	1994-2004; CSO	1994-2004; CSO	1990-2006; EPA	1990-2006; EPA	-	-
Fossil CO_2	-	-	-	-	1990-2006; EPA	1990-2008; EPA
Other CO_2	-	-	-	-	1990-2006; EPA	1990-2008; EPA
N_2O	1994-2004; CSO	1994-2004; CSO	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
CH_4	1994-2004; CSO	1994-2004; CSO	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
SO_2	1994-2004; CSO	1994-2004; CSO	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
NO_x	1994-2004; CSO	1994-2004; CSO	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
NH_3	1994-2004; CSO	1994-2004; CSO	1990-2005; CSO	1990-2006; CSO	1990-2006; CSO	1990-2008; CSO
CO	1990-2004; EPA	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
VOCs	1990-2004; EPA	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA

Substance	**v0.0**	**v0.1**	**v0.2**	**v0.3**	**v0.4**	**v0.5**
HFCs	1990-2004; EPA	-	-	-	-	
HFC23	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
HFC32	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
HFC125	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
HFC134a	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
HFC143a	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
HFC152a	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
HFC227ea	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2008; EPA
PFCs	1990-2004; EPA	-	-	-	-	-
CF_4	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA
C_2F_6	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA
cC_4F_8	-	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA
SF_6	1990-2004; EPA	1990-2004; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA	1990-2006; EPA
Dioxins	-	-	2000; H&M	2000; H&M	2000; H&M	1990-2008; Creedon *et al.*
PCB	-	-	-	-	-	1990-2008; Creedon *et al.*
HCB	-	-	-	-	-	1990-2008; Creedon *et al.*
Benzo(b)pyrene	-	-	-	-	-	1990-

Substance	v0.0	v0.1	v0.2	v0.3	v0.4	v0.5
						2008; Creedon *et al*.
Benzo(b)fluoranthene	-	-	-	-	-	1990-2008; Creedon *et al*.
Benzo(k)fluoranthene	-	-	-	-	-	1990-2008; Creedon *et al*.
Indeno(1,2,3-cd)pyrene	-	-	-	-	-	1990-2008; Creedon *et al*.
Emissions (water)						
BOD	1994; ESRI	1990-2000; ESRI, WRI	1990-2000; ESRI, WRI	1990-2007; ESRI, WRI	1990-2007; ESRI, WRI	1990-2008; ESRI, WRI
N	1994; ESRI	1994; ESRI	1994; ESRI	1994; ESRI	1994; ESRI	1994; ESRI
P	1994; ESRI	1994; ESRI	1994; ESRI	1994; ESRI	1994; ESRI	1994; ESRI
Dioxins	-	-	2000; H&M	2000; H&M	2000; H&M	1990-2008; Creedon *et al*.
HCB	-	-	-	-	-	1990-2008; Creedon *et al.*
Emissions (land)						
Dioxins	-	-	2000; H&M	2000; H&M	2000; H&M	1990-2008; Creedon *et al.*
PCBs	-	-	-	-	-	1990-2008; Creedon *et al*.
HCB	-	-	-	-	-	1990-2008; Creedon *et al*.
Resources						
Fungicides	-	1992-2003; EuroStat	1992-2003; EuroStat	1990-2007; EuroStat; ESRI	1990-2007; EuroStat; ESRI	1990-2008; EuroStat; ESRI
Herbicides	-	1992-	1992-	1990-	1990-	1990-

Substance	**v0.0**	**v0.1**	**v0.2**	**v0.3**	**v0.4**	**v0.5**
		2003; EuroStat	2003; EuroStat	2007; EuroStat; ESRI	2007; EuroStat; ESRI	2008; EuroStat; ESRI
Insecticides	-	1992-2003; EuroStat	1992-2003; EuroStat	1990-2007; EuroStat; ESRI	1990-2007; EuroStat; ESRI	1990-2008; EuroStat; ESRI
Other pesticides	-	1997-2003; EuroStat	1992-2003; EuroStat	1990-2007; EuroStat; ESRI	1990-2007; EuroStat; ESRI	1990-2008; EuroStat; ESRI
Nitrogenous fertilizer	-	1997-2001; EuroStat	1990-2006; Dept. Ag	1990-2006; Dept. Ag	1990-2008; Dept. Ag	1990-2008; Dept. Ag
Phosphate fertilizer	-	1997-2001; EuroStat	1990-2006; Dept. Ag	1990-2006; Dept. Ag	1990-2008; Dept. Ag	1990-2008; Dept. Ag
Potash fertilizer	-	1997-2001; EuroStat	1990-2006; Dept. Ag	1990-2006; Dept. Ag	1990-2008; Dept. Ag	1990-2008; Dept. Ag
Water	2001; ESRI	2001; ESRI	2001; ESRI	2001; ESRI	2001; ESRI	2001; ESRI
Coal	-	1990-2005; SEI	1990-2006; SEI	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Peat	-	1990-2005; SEI	1990-2006; SEI	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Oil	-	1990-2005; SEI	1990-2006; SEI	-	-	-
Crude Oil	-	-	-	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Gasoline	-	-	-	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Diesel	-	-	-	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Kerosene	-	-	-	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Fuel Oil	-	-	-	-	1990-2007; SEI	1990-2008; SEI
LPG	-	-	-	-	1990-2007; SEI	1990-2008; SEI

Substance	**v0.0**	**v0.1**	**v0.2**	**v0.3**	**v0.4**	**v0.5**
Other Oil	-	-	-	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Natural Gas	-	1990-2005; SEI	1990-2006; SEI	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Renewables	-	1990-2005; SEI	1990-2006; SEI	1990-2007; SEI	-	-
Hydro	-	-	-	-	1990-2007; SEI	1990-2008; SEI
Wind	-	-	-	-	1990-2007; SEI	1990-2008; SEI
Biomass	-	-	-	-	1990-2007; SEI	1990-2008; SEI
Landfill Gas	-	-	-	-	1990-2007; SEI	1990-2008; SEI
Biogas	-	-	-	-	1990-2007; SEI	1990-2008; SEI
Other renewables	-	-	-	-	1990-2007; SEI	1990-2008; SEI
Electricity	-	1990-2005; SEI	1990-2006; SEI	1990-2007; SEI	1990-2007; SEI	1990-2008; SEI
Waste						
Solid waste	1995, 1998, 2001; EPA	-	-	-	-	-
Hazardous waste, incinerated	-	2001, 2004; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006, 2008; EPA
Hazardous waste, as fuel	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Hazardous waste, landfilled	-	2001, 2004; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006, 2008; EPA
Hazardous waste,	-	2001,	-	-	-	-

Substance	v0.0	v0.1	v0.2	v0.3	v0.4	v0.5
spread		2004; EPA				
Hazardous waste, recycled	-	2001, 2004; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006, 2008; EPA
Hazardous waste, unknown	-	2001, 2004; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006, 2008; EPA
Biodegradable municipal waste, incinerated	-	-	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	-
Biodegradable municipal waste, landfilled	-	-	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	-
Biodegradable municipal waste, recycled	-	-	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	-
Biodegradable municipal waste, unknown	-	-	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	-
Biowaste, incinerated	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Biowaste, as fuel	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Biowaste, landfilled	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Biowaste, recycled	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Biowaste, unknown	-	-	-	-	-	2001, 2004, 2006, 2008; EPA

Substance	v0.0	v0.1	v0.2	v0.3	v0.4	v0.5
Soil and stones, landfilled	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Soil and stones, recycled	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Soil and stones, unknown	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Incinerator ash, unknown	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Other waste, incinerated	-	2001, 2004; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006, 2008; EPA
Other waste, as fuel	-	-	-	-	-	2001, 2004, 2006, 2008; EPA
Other waste, landfilled	-	2001, 2004; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006, 2008; EPA
Other waste, spread	-	2001, 2004; EPA	-	-	-	-
Other waste, recycled	-	2001, 2004; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006, 2008; EPA
Other waste, unknown	-	2001, 2004; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006; EPA	2001, 2004, 2006, 2008; EPA

Table A2: ESRI Environmental Accounts for the Republic of Ireland, by Sector

Code	Category	NACE	Hermes
1	Agriculture, fishing, forestry	1-5	Agriculture
2	Coal, peat, petroleum, metal ores, quarrying	10-14	Traditional manufacturing (“Mining, quarrying”)
3	Food beverage and tobacco	15-16	NACE 151-158 is Food processing NACE 159 and 16 is Traditional manufacturing
4	Textiles, clothing, leather and footwear	17-19	Traditional manufacturing
5	Wood and wood products	20	Traditional manufacturing
6	Pulp, paper and print production	21-22	Traditional manufacturing
7	Chemical production	24	High-technology manufacturing
8	Rubber and plastic production	25	Traditional manufacturing
9	Non-metallic mineral production	26	Building
10	Metal prod. Excl. machinery and transport equipment	27-28	High-technology manufacturing
11	Agriculture and industrial machinery	29	High-technology manufacturing
12	Office and data process machines	30	High-technology manufacturing
13	Electrical goods	31-33	High-technology manufacturing
14	Transport equipment	34-35	High-technology manufacturing
15	Other manufacturing	23,36-37	Traditional manufacturing
16	Fuel, power, water	40,41	Utilities
17	Construction	45	Building
18	Services, excl. transport	50-55,64-95	Distribution, other market services and non-market services
19	Transport	60-63	Transport and communications
20	Households	-	Households

A1.2 Revised Structure of Waste Accounts

This version of ISus includes a different set of waste accounts than previous versions. Up to now, we have used 12 categories (4x3). These were made up of four dispositions (landfilled, recycled, incinerated and unattributed) for three substances (hazardous, biodegradable municipal waste "BMW", and other non-hazardous, non-BMW). We now have five dispositions for four substances, plus one emissions category for a secondary material that is not yet being generated and for which the eventual disposition is not known. However, we omit two combinations of emissions and dispositions that are not operative due to the nature of the material. Table A3 has the new matrix, with "X" denoting combinations that are present in our accounts.

Table A3: Waste Types and Dispositions

	Primary Materials				Secondary Materials
Dispositions	**Hazardous**	**Bio-waste**	**Soil and Stones**	**Other**	**Incinerator Ash**
Landfilled	X	X	X	X	
Recycled	X	X	X	X	
Incinerated	X	X		X	
Used as fuel	X	X		X	
Unattributed					X

In addition, the ISus model reports five summary waste emission categories that are of policy interest: BMW, municipal solid waste (MSW), construction and demolition (C&D), and industrial waste. These totals are calculated by selecting relevant sectors and materials from the basic set of accounts.

As in previous versions of ISus, emissions for 19 production sectors plus residential are reported for each material/disposition.

CONTENT OF NEW WASTE CATEGORIES

Bio-waste

This new waste category is not fully implemented in ISus, but we plan to include it as soon as the data permit. The bio-waste emission category was introduced in the 2008 Waste Framework Directive (European Parliament and Council of the European Union 2008), which defined it as "…biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants." Although there is no settled definition of this category in Irish waste statistics at present, we plan to calculate it as the sum of the organic component of BMW and the component of industrial waste tagged with the European Waste Catalogue (EWC) codes or EWC-STAT codes listed in Table A4 below. The main sectoral sources are households, commercial enterprises and the food processing sector.

Bio-waste emission categories are included in our latest environmental accounts, but the figures in them are not correct. The difficulty is that the 2008 NWR did not separate out the quantities of organic BMW by source (household/commercial) and disposition, so we will need to impute these components before we can calculate correct totals for bio-waste. Until we can do so, the bio-waste totals reported in the accounts are placeholders only and should not be used.

Table A4: EWC and EWC-STAT Codes Used to Identify Bio-waste

EWC Code	Description
02 02 01	sludges from washing and cleaning
02 02 02	animal-tissue waste
02 02 03	materials unsuitable for consumption or processing
02 03 01	sludges from washing, cleaning, peeling, centrifuging and separation
02 03 02	wastes from preserving agents
02 03 04	materials unsuitable for consumption or processing
02 05 01	materials unsuitable for consumption or processing
02 06 01	materials unsuitable for consumption or processing
20 01 08	biodegradable kitchen and canteen waste
20 01 08 01	
20 01 25	edible oil and fat
20 01 25 01	
20 01 25 03	
20 02 01	biodegradable waste

EWC-STAT code	Description
9	Animal and vegetal wastes
9.11	Animal waste of food preparation and products
9.12	Vegetal waste of food preparation and products
9.13	Mixed waste of food preparation and products
9.2	Green wastes
9.21	Green wastes

Used as fuel

Only industrial sectors dispose of waste in the class "used as fuel". This class is used for waste flows that are tagged with D/R code "R1" by the EPA. There is a regulatory distinction between this form of treatment and incineration, which is tagged with code D10.

Soil and stones (non-hazardous component)

This material, attributed to the construction sector, is separately identified in EPA National Waste Reports so we have given it a separate accounting category. It should be added to "Other" and "Hazardous" waste emissions from the construction sector to arrive at total C&D waste.

Incinerator bottom ash

We describe this as a secondary material, because it results from material already counted as incinerated. Incinerator ash should not simply be added to other emission categories, because this could lead to double-counting of some material in mass-balance terms.

Base year values

The ESRI Environmental Accounts for waste are based on data collected for, and in some cases reported in, the EPA *National Waste Reports*. However, the waste categories and sectors we use are sometimes cut differently from those reported by the EPA. Below we outline how some of the aggregates we report are constituted, making reference to McCoole *et al.* (2008), which we refer to as NWR08.

Hazardous waste

We include both contaminated soil and other hazardous waste; the total given is equal to the sum of the totals in NWR Tables 29 and 34.

MSW

This category in our model only approximately equates to the regulatory category of the same name. To the MSW figure in Table 2 of NWR08 we add estimated uncollected household waste (p.18, NWR08) and sewage sludge (for which the data relates to 2007 and which we treat as largely attributable to the household and commercial sectors).

C&D and Industrial

The totals listed under these headings relate to non-hazardous waste from these sources. The industrial waste data are drawn from the database used to construct NWR08 Table 23, and the C&D figures are for soil and stones and other C&D waste, including both materials with reported (NWR08 Tables 21-22) and unreported (NWR08 p.29) dispositions.

APPENDIX 2: IRELAND'S DISPATCH OF ELECTRICITY MODEL (IDEM)

IDEM determines projections for energy use in electricity generation. It is a bottom up model, in the sense that it starts from detailed information on the plants available on the electricity system on the island of Ireland and in Great Britain,[27] determines the expected fuel use by plant and aggregates them to define energy used in electricity generation in each jurisdiction (Northern Ireland and the Republic of Ireland). The All-Island market was established in November 2007. It is a wholesale market for electricity that is formed by a compulsory pool system with capacity payments. Any generator with a capacity greater than 10 MW has to bid their generation in a common pool and all buyers have to buy from that common pool. Generators are remunerated by the system marginal cost, determined by supply and demand in each half hour, and by capacity payments. Capacity payments are designed to cover the capital costs of investing in new generating plants.

This model stacks all the plants in the All-Island market according to their bid price in each half hour of the year, to build a merit order curve, such as the one displayed in Figure A1, which reflects installed capacity and fuel prices at the end of 2007.[28] The merit order varies as fuel prices or the cost of carbon changes and plants are commissioned or decommissioned. If coal becomes more expensive there will be a coal price for which coal plants will be dispatched after natural gas plants and will move to the right in Figure A1. Wind generation is assumed to have a bid price of 0, since wind itself is free. IDEM takes electricity demand as given for every single year. Electricity demand varies over time in response to changes in economic growth rates.

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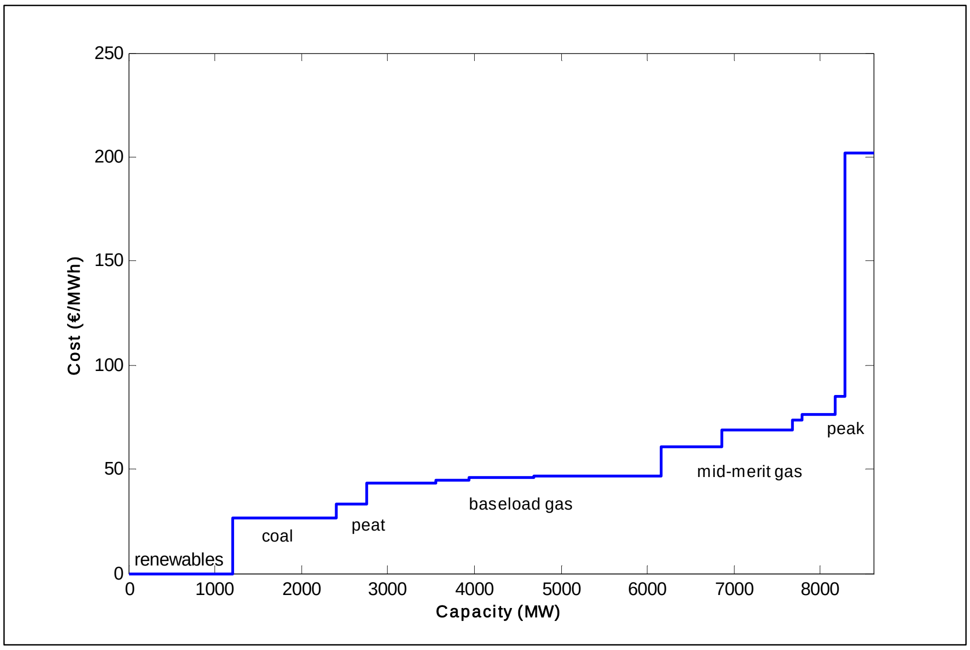
[27] The level of detail used for GB is somewhat less as plants are grouped by fuel use and efficiency band.

[28] At the end of 2007 the price of carbon in the EU Emissions Trading System was essentially.

Figure A1: Merit Order Cispatch curve for the Island of Ireland, End of 2007



IDEM determines the least costly way to meet demand in each half hour. The most expensive plant needed to meet demand sets the marginal price, which is paid out to all generators producing electricity during that period. The marginal price essentially reflects the cost of fuel and carbon needed to generate the most expensive MWh of electricity. IDEM also calculates the level of capacity payments.

Electricity is provided to final consumers through a grid of regional transmission and local distribution lines. As electricity flows through the lines there are electricity losses. In practice this means that more electricity needs to be generated than the sum of electricity consumed. In this model transmission and distribution losses are set at 8.3 per cent of total generation.

Ireland is interconnected to Great Britain by an existing electricity cable between Northern Ireland and Scotland. A second cable is in its planning phase and will run between the Republic of Ireland and Wales. In this study we assume that there will be a third interconnector in place by 2025, bringing the total interconnection between Ireland and Great Britain to 1,400 MW. In order to determine the price of electricity at each node of the interconnector the model also calculates a system marginal price for Great Britain, assuming that the market in Great Britain is also set up as a mandatory pool market. The dispatch model for Great Britain is similar to the one for Ireland, albeit less detailed. Generating plants that use the same type of fuel (e.g. coal or natural gas) are aggregated into a few large plants.

The model takes into account key features of the electricity system in Ireland. It gives details of all the plants generating electricity, their size, the type of fuel they use, their yearly availability (accounting for typical maintenance schedules) and how efficient they are at converting fuel into electricity. The model abstracts from some more detailed engineering constraints, such as the time needed (and the costs incurred) to turn a power plant on or off and to increase or decrease output. IDEM assumes that there are no transmission constraints within Ireland, which yields a single wholesale price of electricity within the jurisdiction.

Model results are aggregated to give yearly fuel use, yearly power generation by fuel and yearly electricity prices. The price of electricity then affects demand for electricity in the economy.

APPENDIX 3: IRELAND'S SUSTAINABLE DEVELOPMENT MODEL (ISUS)

A3.1 An Overview of ISus

ISus is a simulation model. It combines behavioural equations and data on state variables in period *t* to predict the state variables at time *t*+1. The current version of the model uses data for the period 1990-2008 (the period covered by the ESRI Environmental Accounts) to calibrate the model and estimate relationship, while projections are generated for the period 2009-2025 (the period covered by Hermes).

Figure A2 shows the relationship between ISus and other models. Three models are used for the international context: NiGEM, FAPRI and HTM. NiGEM is used for scenarios on the overall macroeconomic situation, while FAPRI and HTM zoom in on agriculture and tourism, respectively. The ICPop generates scenarios of the population of Ireland and its structure. The Hermes model takes output from NiGEM and HTM as given, and it interacts with IDEM and ICPop (on migration) to build scenarios of the macroeconomy of Ireland. IDEM takes world energy prices from NiGEM and the demand for electricity from Hermes to generate scenario of power supply; IDEM and Hermes iterate on electricity supply.

ISus takes population for ICPop, energy use in the electricity sector from IDEM, world market prices and demand for Irish agricultural exports from FAPRI, and macroeconomic variables from Hermes.

Figure A3 shows the internal structure of ISus. The model is split between consumption and production, and production is split into power generation, other energy, transport, agriculture and other production. These six inputs are used to generate resource use, emissions, and waste from 20 sectors. An input-output model is then used to attribute emissions etc. from production to the components of final demand.

Further documentation and the model code can be found at:
http://www.esri.ie/research/research_areas/environment/isus/

Figure A2 ISus and Its Relationship to Other Models

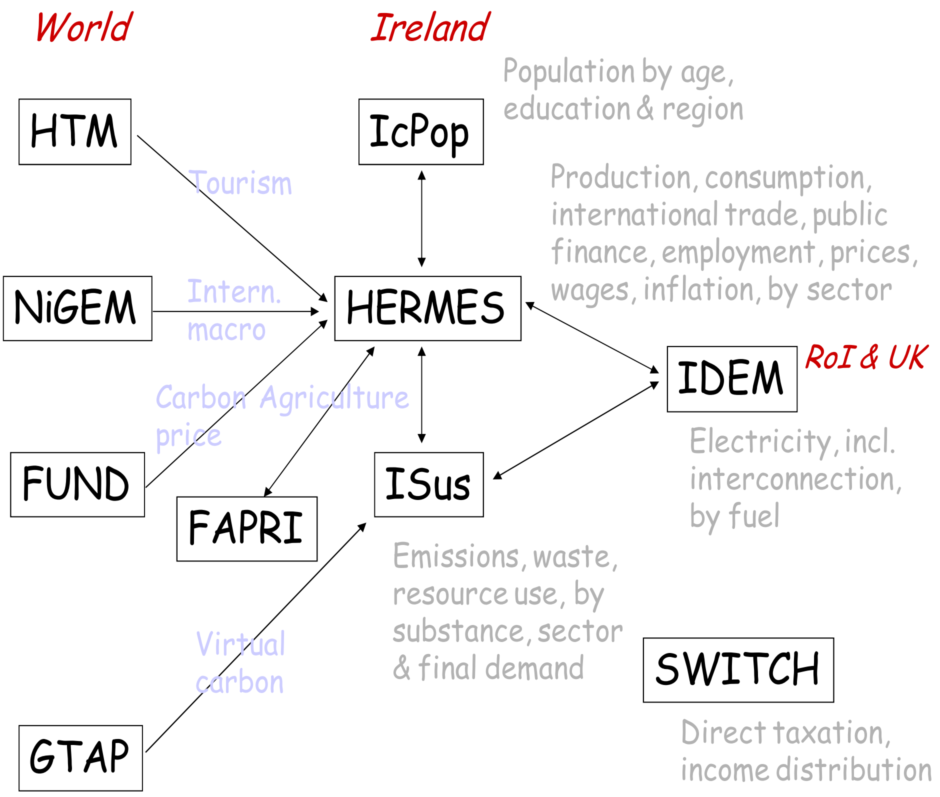
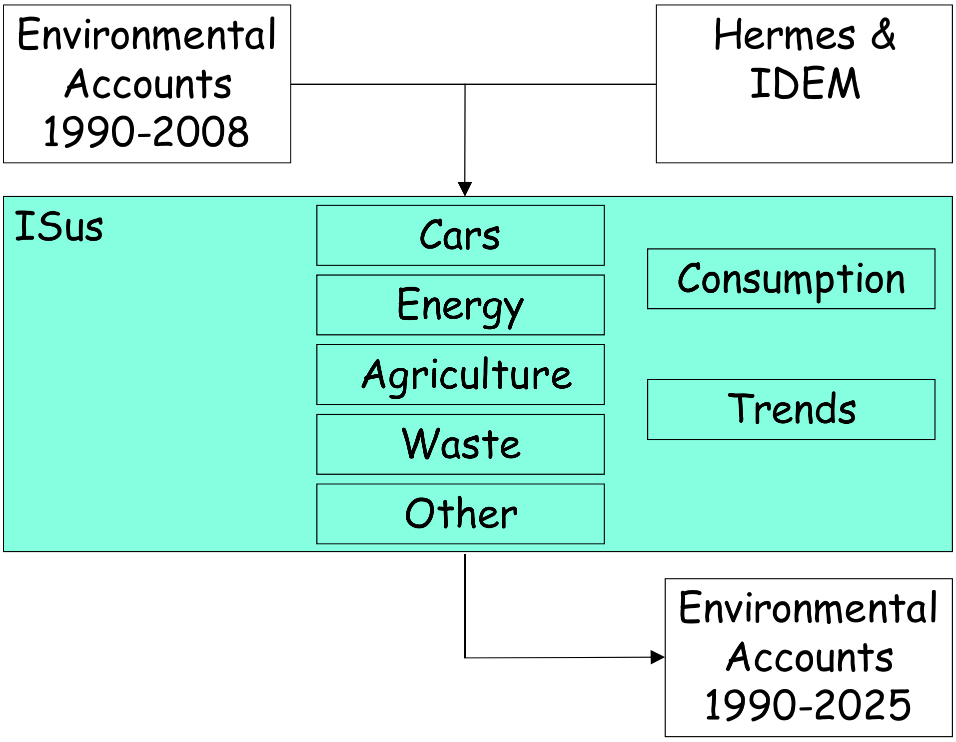


Figure A3: Flowchart of ISus



A3.2 Agricultural Activity

The agricultural sub-model is an iterative parametric model that runs in Microsoft Excel. The full model description can be found in Tol *et al.* (2009).

A3.3 Energy Use and Related Emissions

The energy use model was developed in a previous ESRI project for the EPA. The equations have not changed, but the model was re-estimated using more recent data. Emissions follow by multiplying energy use with the appropriate emission coefficients. The full model description can be found in Fitz Gerald *et al.* (2002).

A3.4 Waste Arisings and Disposition

The waste sub-models project future volumes based on output, income, other behavioural drivers and some supply effects, together with elasticity assumptions.

Waste volumes from agriculture are projected from historical values based on the elasticity of waste with respect to the agriculture sector output. The equation used is $Q_t = Q_{(t-1)}\left(1+\varepsilon Y_t\right)$ for each forecast period t, where Y is the percentage change in agricultural output. The elasticity in this model is currently set to one. Disposition is deemed to be "Recycled" for this waste stream, because it is dominated by landspreading of organic waste from farm animals.

Hazardous agricultural waste is projected in proportion to agricultural activity. It is assigned to unknown disposition.

Waste quantities from the construction sector are projected based on technological parameters relating the waste emissions to the level of construction activity. We divide construction into four sub-sectors (residential, private non-residential, social infrastructure and productive infrastructure), and each of these sub-sectors is in turn divided into new construction and repair/maintenance. Emissions from residential construction depend upon the number of properties built, while the other sub-sectors depend upon the predicted real value of construction activity. Shares for each disposition – landfill, recovery and unknown – are held constant at their base year values for soil and stones and other materials, but these materials are aggregated for reporting from ISus.

For each disposition j, the quantity emitted $Q_{jt} = \left(Q_{j(t-1)} \Big/ \sum_j Q_{j(t-1)} \right) \sum_i \left(Y_{it} C_i \right)$ for each sub-activity i, technical conversion factor C_i and forecast period t, where Y_{it} is the level of real activity (either in volume or value terms) for the relevant sub-activity. Disposition of each of these waste types is divided between landfill, recovery (including recycling) and unknown.

Hazardous waste from C&D is projected on the same basis as soil and stones, because most hazardous C&D waste is contaminated soil. No BMW is generated by this sector.

Waste volumes for the industrial sectors are projected using a simple constant-elasticity demand model. There is a separate model for each disposition – landfill, incineration, recovery and unknown – in which changes in volumes are driven by forecast movements in the relevant sector's turnover and number of employees (and for some dispositions) by landfill and recovery prices.

The basic equation is $Q_{ijt} = Q_{ij(t-1)}\left(1+\varepsilon E_{it} + \delta Y_{it} + \alpha P_{jt} + \beta X_t\right)$ for each sector *i*, disposition *j* and forecast period *t*, where *E*, *Y*, *P* and *X* are the percentage changes in employment, turnover, price of disposition *j* and price of alternative disposition. Disposition of each of these waste types is divided between landfill, recovery (including recycling), incineration and unknown. No BMW is generated by these sectors.

We model waste from households and services together because in some cases the waste they generate is combined at the disposition stage. Emissions of hazardous, BMW and other non-BMW, non-hazardous waste are included. Waste generation is projected using a simple constant-elasticity demand model for each broad disposition: disposal (landfill/incineration), recovery and unknown. For unknown disposition, only activity drivers such as the number of households or sectoral output are taken into account. The recycling and disposal models also include own-price and cross-price effects. Once we have projected volumes for disposal, these are further disaggregated into landfill and incineration quantities based on the available incineration capacity net of ash fraction. Quantities sent to landfill are also assumed to include the fraction of waste that is not combustible. We assume that BMW is incinerated first and non-BMW is incinerated if any capacity remains, while household and services waste are allocated for incineration pro rata. Generation of hazardous household waste is projected on the same basis as other waste intended for disposal (i.e. black bin waste), but we assign it to unknown disposition.

Projections for waste oil, oil filters and batteries (which are hazardous waste) are based on variations in the predicted car stock compared to its base year value, while End of Life Vehicle waste is similarly based on predicted car scrapping rates.

Waste that lacks a sectoral assignment is held constant over the forecast period at base year values.

Values and sources of static parameters used in the waste sub-models are given below.

Table A5: Household and Services (Commercial) Waste Parameters

Parameter	Value	Source
Elasticity of weight per household w.r.t. Persons/household	0.486	Scott & Watson (2006), pp. 57 and 62. Coef/mean of Y
Elasticity of weight per household to real personal disposable income per capita	1.08	Curtis, Lyons & O'Callaghan-Platt (2009)
Volume-based charging black bin price elasticity of demand	-0.15	Scott & Watson (2006), p.9
Weight-based charging black bin price elasticity of demand	-0.27	Scott & Watson (2006), p.28
Volume-based charging (VBC) green bin x-price elasticity of demand	0.22	Kinnaman & Fullerton (2000)
Weight-based charging (WBC) green bin x-price elasticity of demand	0.22	Kinnaman & Fullerton (2000)
Diversion from landfill to recycling after switch from flat rate to VBC	0.2	For illustration
Diversion from landfill to recycling after switch from flat rate to WBC	0.45	Scott & Watson (2006), p.37
Diversion from landfill to recycling after switch from VBC to WBC	0.25	For illustration
Elasticity of services waste w.r.t. real output from services	1	Default assumption
Disposal elasticity w.r.t. price of disposal – commercial	-0.29	Jenkins (1993), p.11
Combustible fraction - BMW	100.0%	Calculated based on materials shares in MSW, *Source*: EPA NWR 2007
Combustible fraction - municipal, non-biodegradable waste	44.0%	Calculated based on materials shares in MSW, Source: EPA NWR 2007
Ash fraction resulting from incineration of combustible waste	25.0%	http://www.raceagainstwaste.ie/learn/incineration/

Sources: Curtis *et al.* (2009); Jenkins (1993); Kinnaman and Fullerton (2000); le Bolloch *et al.* (2009); Scott and Watson (2006).

Table A6: Construction and Demolition Waste Parameters

Parameter	Value	Source
Waste (kg per m2 floor area constructed)		
New residential	70.27	Kelly & Hanahoe (2007), p.163
New private non-residential	86.82	Kelly & Hanahoe (2007), p.163
New social infrastructure	138.94	Kelly & Hanahoe (2007), p.163
New productive infrastructure	48.48	Kelly & Hanahoe (2007), p.163
Residential R&M	322	EPA (2001), Table 1
Private non-residential R&M	422	EPA (2001), Table 1
Social infrastructure R&M	422	EPA (2001), Table 1
Productive infrastructure R&M	422	EPA (2001), Table 1
Investment (€m, nominal, 2001)		
New private non-residential	3,119.1	DoE. (2001), Table A3.1
New social infrastructure	1,118.3	DoE, Table A3.1
New productive infrastructure	3,265.1	DoE, (2001), Table A3.1
Residential R&M	3,528.4	DoE, (2001), Table A3.1
Private non-residential R&M	591.0	DoE, (2001), Table A3.1
Social infrastructure R&M	408.5	DoE, (2001), Table A3.1
Productive infrastructure R&M	608.1	DoE, (2001), Table A3.1
Area (m2, 2001)		
New private non-residential	3,610,557	EPA, (2001), Table 1
New social infrastructure	1,276,278	EPA, (2001), Table 1
New productive infrastructure	2,163,864	EPA, (2001), Table 1
Residential R&M	3,458,670	EPA, (2001), Table 1
Private non-residential R&M	696,327	EPA, (2001), Table 1
Social infrastructure R&M	466,277	EPA, (2001), Table 1
Productive infrastructure R&M	373,832	EPA, (2001), Table 1
Value (€m, nominal, 2007)		
Private non-residential construction	6,644.7	DKM (2007), Table A2.1
Social infrastructure construction	1,896.4	DKM (2007), Table A2.1
Productive infrastructure construction	4,581.4	DKM (2007), Table A2.1
Residential R&M	4,945.9	DKM (2007), Table A2.1
Private non-residential R&M (2007 €m)	997.7	DKM (2007), Table A2.1
Social infrastructure R&M (2007 €m)	440.9	DKM (2007), Table A2.1
Productive infrastructure R&M (2007 €m)	1,183.8	DKM (2007), Table A2.1

Note: R&M = Repair and maintenance

Sources: DKM (2007); DoE (2001); EPA (2001); Kelly and Hanahoe (2007).

Estimated industrial waste parameters

These regressions are estimated using OLS; standard errors allow for clustering at county level because landfill charges are county averages. Waste variables are firm level estimates from IPPC licence returns. We believe these estimates may be significantly improved upon by allowing for sectoral heterogeneity once additional IPPC data are available.

Elasticity of total industrial waste w.r.t. landfill charge

	Coef.	Std. Err.	t	P>|t|
lnlandfchg	-.434	0.126	-3.44	0.002

Elasticity of landfill share of industrial waste disposition w.r.t. landfill charge

	Coef.	Std. Err.	t	P>|t|
lnlandfchg	-0.0787	0.0338	-2.33	0.029

Elasticity of recycling share of industrial waste disposition w.r.t. landfill charge

	Coef.	Std. Err.	t	P>|t|
lnlandfchg	0.0619	0.0326`	1.90	0.070

Elasticity of incineration share of industrial waste disposition w.r.t. landfill charge

	Coef.	Std. Err.	t	P>|t|
lnlandfchg	0.0167	0.00495	3.38	0.003

Table A7: Other Waste Parameters

Parameter	Value	Source
Elasticity of agricultural waste w.r.t. real output from agriculture	1	Default assumption
Elasticity of hazardous industrial waste w.r.t. real output of sector	1	Default assumption
Elasticity of non-hazardous industrial waste w.r.t. real output of sector	1	Default assumption

A3.5 Methane from Landfill

The model used is a so-called Tier II model (McGettigan *et al.* 2008). Emissions follow from

(A1) $E_t = A_t(1-F_t-G_t)$

where

- E_t are emissions of methane from landfill at time t;
- t is the time index;
- A_t are "actual emissions";
- F_t is the fraction of "actual emissions" that is flared; and
- G_t is the fraction of "actual emissions" that is combusted (as landfill gas).

"Actual emissions" follow from

(A2) $A_t = \Sigma_s c_s P_{t-s}$

where

- P_t are "potential emissions" at time t;
- c_s are emission coefficients at delay s; and
- s is the delay index, $s = 1, 2, \ldots, 20$. See Table 3.

"Potential emissions" are taken from Table A9 for 1968-2008. For 2009-2025, "potential emissions" follow from

(A3) $P_t = P_{t-1}\, BMW_t \,/\, BMW_{t-1}$

where

- BMW_t is landfilled biodegradable municipal waste at time t.

That is, “potential emissions” are scaled with landfilled waste according to the waste model in ISus. For 2009-2025, we also assume

(A4) $F_t = F_{t-1}$

(A5) $G_t = G_{t-1}$

Table A8: Emission Coefficients

Age	Coefficient
(year)	(fraction)
20	0.0100
19	0.0100
18	0.0130
17	0.0170
16	0.0230
15	0.0260
14	0.0290
13	0.0340
12	0.0340
11	0.0340
10	0.0390
9	0.0440
8	0.0440
7	0.0490
6	0.0550
5	0.0560
4	0.0790
3	0.1810
2	0.1640
1	0.0600

Source: McGettigan *et al.* (2008).

Table A9: Emissions of Methane from Landfill (Metric Tonne of CH4)

Year	Potential	Actual	Emissions	Landfill gas	Flared
1968	46977				
1969	47186				
1970	47585				
1971	48492				
1972	49701				
1973	50965				
1974	52282				
1975	53654				
1976	54997				
1977	56243				
1978	57468				
1979	58917				
1980	60005				
1981	61274				
1982	62451				
1983	63412				
1984	64188				
1985	66822				
1986	68163				
1987	70063				
1988	71693				
1989	74973				
1990	79236	63431	63431	0	0
1991	81746	65021	65021	0	0
1992	86863	66952	66952	0	0
1993	89917	69249	69249	0	0
1994	94326	71736	71736	0	0
1995	95037	74400	74400	0	0
1996	102446	77296	71419	5342	535
1997	108543	80070	61715	16789	1565
1998	120842	82905	65273	16026	1606
1999	133198	86271	66954	17552	1765
2000	150369	90843	71025	18316	1503
2001	150480	96636	63279	18316	15042
2002	145894	104041	71283	14500	18258
2003	147989	111929	78046	12210	21672
2004	152412	118147	77844	15263	25040
2005	159698	121787	76998	19079	25711
2006	172523	125220	79168	19616	26435
2007	175739	129752	74741	18527	36485
2008	167175	135452	73518	20070	41863

Source: McGettigan *et al*. (2008).

A3.6 Emissions from Other Production

There are four ways to project emissions from and resource use by economic production:

1. Output elasticities.
2. Intensity trends.
3. Output elasticities and intensity trends.
4. Frozen technologies (diagnostic scenario only).

This option is set in the dialogue box when the model is initialised. The default option is intensity trends, and that is indeed the method used in this report.

If output elasticities are used, emissions $E_{s,t}$ of sector s at time t are equal to

$$\text{(A5)} \qquad E_{s,t} = E_{s,t-1}\left(\frac{Y_{s,t}}{Y_{s,t-1}}\right)^{\varepsilon_s} \Leftrightarrow E_{s,t} = \alpha_s Y_{s,t}^{\ \varepsilon_s}$$

where $Y_{s,t}$ is the output of sector s at time t, and ε_s is the output elasticity of emission.

The output elasticity is estimated by ordinary least squares for the equation

$$\text{(A6)} \qquad \ln E_{s,t} = \ln\alpha_s + \varepsilon_s \ln Y_{s,t} + u_{s,t}$$

where $u_{s,t}$ is the error term. See Tol *et al.* (2009) for the results.

By default, emissions from economic production are projected on the basis of an exogenous trend in emission intensities. The trend extrapolates the observed trend. The median trend, rather than the average trend, is used for robustness. In some small or clunky sectors, discrete events dominate the average, but not the median trend.

Emissions $E_{s,t}$ of sector s at time t are equal to

$$\text{(A7)} \qquad E_{s,t} = \varphi_{s,t} Y_{s,t}$$

where $Y_{s,t}$ is the output of sector s at time t, and $\varphi_{s,t}$ is its emission intensity. Equation (A7) is an identity.

Emissions are projected on the basis of:

$$\text{(A8)} \qquad \varphi_{s,t} = \alpha_s \varphi_{s,t-1}$$

where

$$\text{(A9)} \qquad \alpha_s = \text{Median}\left(\frac{\varphi_{s,2}}{\varphi_{s,1}}, \frac{\varphi_{s,3}}{\varphi_{s,2}}, \ldots, \frac{\varphi_{s,T}}{\varphi_{s,T\text{-}1}}\right)$$

where T is the most recent year of observation. See Table A10 for the results.

It is also possible to project emissions from economic production on the basis of output elasticities and technological progress.
Emission intensities $EI_{s,t}$ of sector s at time t are equal to

$$\text{(A10)} \qquad EI_{s,t} = \left(1 + \tau_s + \varepsilon_s \frac{Y_{s,t} - Y_{s,t-1}}{Y_{s,t-1}}\right) EI_{s,t-1}$$

where $Y_{s,t}$ is the output of sector s at time t, τ_s is the autonomous changes in emission intensities and ε_s is the output elasticity of emissions.

Emissions $E_{s,t}$ readily follow from inverting the definition of emission intensity:

(A11) $E_{s,t} = EI_{s,t} Y_{s,t}$

The technological change parameter and the output elasticity are estimated by ordinary least squares for the equation:

(A12) $\frac{EI_{s,t} - EI_{s,t-1}}{EI_{s,t-1}} = \tau_s + \varepsilon_s \frac{Y_{s,t} - Y_{s,t-1}}{Y_{s,t-1}} + u_{s,t}$

where $u_{s,t}$ is the error term.

As a diagnostic, emissions from economic production can be projected on the basis of fixed emission intensities, equal to the most recent observation.

Emissions $E_{s,t}$ of sector s at time t are equal to

(A13) $E_{s,t} = \varphi_{s,t} Y_{s,t}$

where $Y_{s,t}$ is the output of sector s at time t, and $\varphi_{s,t}$ is its emission intensity. Equation (A13) is an identity.

Emissions are projected on the basis of:

(A14) $\varphi_{s,t} = \varphi_{s,T}; t > T$

where T is the most recent year of observation.

Table A10: Estimated Trends in Emission and Resource Use Intensity by Sector and Substance, and Income Elasticities for Sector 20 (Households)

Substance\sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
CO2 fossil	-0.2	-1.8%	-3.4	na	0.5	-5.0%	-5.0	0.5	-1.4	5.0	-3.2	-5.0	-5.0	na	0.0	-5.0	-4.3	-4.3	-0.9	0.1
CO2 other	na	na	na	na	na	na	-5.0	na	2.7	na	na	na	na	na	na	na	na	na	na	na
CH4	-0.8	na	-5.0	4.7	3.7	na	-5.0	3.6	na	5.0	-2.4	-5.0	-5.0	-2.4	-1.4	na	na	-1.5	-5.0	-0.5
N2O	-1.3	na	-4.9	na	2.2	-5.0	-5.0	-1.0	-2.6	3.1	-3.2	-5.0	-5.0	-3.6	na	-5.0	-5.0	-5.0	-4.2	-0.4
HFC23	na	na	na	na	na	na	na	na	na	na	5.0	na	5.0	na	na	na	na	na	na	na
HFC32	na	na	na	na	na	na	na	na	na	na	na	na	1.7	na	na	na	na	na	na	na
HFC134a	na	na	na	na	na	na	2.2	na	na	na	na	na	5.0	na	na	na	na	na	na	na
HFC125	na	na	na	na	na	na	na	na	na	na	na	na	1.8	na	na	na	na	na	na	na
HFC143a	na	na	na	na	na	na	na	na	na	na	na	na	2.2	na	na	na	na	na	na	na
HFC152a	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
HFC227ea	na	na	na	na	na	na	na	na	na	na	5.0	na	na	na	na	na	na	na	na	na
CF4	na	na	na	na	na	na	na	na	na	na	na	na	5.0	na	na	na	na	na	na	na
C2F6	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
cC4F8	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
SF6	na	na	na	na	na	na	-5.0	na	na	na	na	na	2.1	na	na	na	-5.0	-5.0	na	na
SO2	-3.5	na	-4.7	-4.6	na	-5.0	-5.0	-5.0	-5.0	na	-5.0	-5.0	-5.0	-5.0	1.4	-5.0	-5.0	-5.0	-5.0	-1.0
NOx	-0.2	na	-0.1	na	4.1	-5.0	-5.0	1.8	na	5.0	na	-5.0	-5.0	-3.0	1.0	-5.0	-4.7	-4.7	-5.0	0.0
CO	-0.2	na	na	na	1.8	-5.0	-5.0	4.8	na	5.0	na	-3.4	-5.0	1.0	na	-5.0	na	na	-5.0	-1.1
NMVOC	-0.2	na	na	na	5.0	na	-5.0	2.2	na	5.0	-1.5	-3.4	-5.0	-0.5	4.3	-5.0	-3.7	-5.0	-5.0	-0.9
NH3	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
BOD	-2.1	na	-2.1	-2.1	na	na	-2.1	na	na	na	na	na	na	na	na	na	na	-2.1	na	na
Fungicides	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Herbicides	0.9	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Insecticides	5.0	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Other Pesticides	1.3	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Nitrogen fertilisers	-1.8	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Phosporus fertilisers	-3.6	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Potassium fertilisers	-3.1	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Coal	na	na	na	1.8	na	na	na	na	4.3	na	na	-5.0	na	na	na	-5.0	na	na	na	-1.0

Table A10: Estimated Trends in Emission and Resource Use Intensity by Sector and Substance, Contd

Peat	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	-5.0	-5.0	-5.0	na	-1.2
Gas	na	na	-1.6	-4.8	na	-5.0	-5.0	2.4	-3.0	na	-2.9	-5.0	-5.0	-1.5	-5.0	-4.7	0.6	0.6	na	1.6
Crude Oil	na	na	na	na	na	na	na	na	na	na	na	na	na	na	2.2	na	na	na	na	na
Gasoline	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	-3.1	na
Kerosene	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	-0.6	na
Diesel	-0.2	1.9	-2.7	3.3	na	-5.0	-5.0	-4.0	1.4	5.0	-1.1	na	na	na	na	na	-4.4	-4.4	1.3	0.2
Fuel Oil	na	na	-4.8	-2.7	-3.9	-5.0	-5.0	-1.5	-2.9	-2.3	-5.0	-5.0	-5.0	-5.0	-1.7	-4.0	-5.0	-5.0	-5.0	na
LPG	na	-3.1	na	4.1	na	-5.0	na	na	-4.9	1.4	na	na	na	na	na	na	-4.1	-4.1	-5.0	0.2
Other Oil	na	na	2.4	5.0	5.0	-1.2	-3.2	na	0.4	5.0	1.9	2.7	5.0	-4.7	0.6	na	na	na	na	2.2
Hydro power	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	-3.4	na	na	na	na
Wind power	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	5.0	na	na	na	na
Biomass	na	na	na	na	-1.3	na	na	na	na	na	na	na	na	na	na	-4.7	na	na	na	-0.9
Landfill Gas	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Biogas	na	na	-2.4	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Other Renewables	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	2.5
Electricity	na	4.7	-2.0	5.0	na	-5.0	-5.0	na	1.8	na	0.2	na	na	na	na	-3.8	0.4	0.4	na	0.7
Dioxin (air)	0.9	na	-4.8	na	na	-5.0	-5.0	na	-2.6	-5.0	na	na	-5.0	na	3.7	-5.0	na	-4.6	-5.0	0.2
Dioxin (land)	na	na	na	1.9	na	na	na	na	na	na	na	na	na	na	na	na	na	-4.0	na	na
Dioxin (water)	na	na	4.9	na	na	na	na	na	na	-5.0	na	na	-5.0	na	na	-5.0	na	-5.0	na	1.1
PCB (air)	0.9	na	-3.8	na	na	na	-5.0	-3.5	2.6	-5.0	na	na	-5.0	na	3.0	-5.0	na	-5.0	-5.0	0.8
PCB (land)	na	na	na	na	na	na	na	na	na	na	na	na	-7.8	na	na	na	na	na	na	na
HCB (air)	5.0	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	-5.0	na	na
HCB (water)	5.0	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
HCB (land)	5.0	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Benzo(b)pyrene (air)	0.9	na	-4.1	na	na	na	-5.0	-4.2	3.1	-1.3	na	na	na	na	4.0	-5.0	na	na	-5.0	-1.1
Benzo(b)fluoranthene (air)	0.9	na	-5.0	na	na	na	-5.0	-2.4	na	-1.5	na	na	na	na	4.0	-5.0	na	-5.0	-5.0	-0.7
Benzo(k)fluoranthene (air)	0.9	na	-5.0	na	na	na	-5.0	-0.9	2.9	-1.5	na	na	na	na	3.9	-5.0	na	-5.0	-5.0	-0.5
Indeno(1,2,3-cd)pyrene (air)	0.9	na	-5.0	na	na	na	-5.0	-1.7	3.1	-1.5	na	na	na	na	3.9	-5.0	na	-4.8	-5.0	-1.2

A3.7 Residential Emissions

Projections of residential emissions and resource use are on the basis of income elasticities, which are estimated using data for 1990 to 2008. See Table A10.

A3.8 Emission Adjustments

Emission adjustments in ISus are defined as ad hoc adjustments to the system, for instance due to identified technological change in a sector. The default value of the emissions adjustment variables is 1, i.e. no exogenous changes are made.

For example, the introduction of flue gas desulfurisation at Moneypoint is indicated by an emission adjustment factor of 0.73 for the years 2006 and 2007 for emissions of SO_2 and NO_x.

A3.9 Indirect Emissions and Resource Use

An input-output model is used to attribute the emissions that arise during production, to final demand and its constituents. This module is not used in this report. Details can be found in Tol et al. (2009).

A 3.10 Decomposition of Trends

ISus shows emissions and resource use per sector, as well as total emissions. In order to help interpret changes in total emissions, we use logarithmic mean Divisia index decomposition. This module is not used in this report. Details can be found in Tol *et al.* (2009).

A3.11 Private Car Stock Model

Prevalence of Car Ownership

The model for private cars has a number of components. The first is the number of cars. Countries where average income is growing tend to have a growing car ownership rate. At some point car ownership rates are bound to stop increasing. This point is defined as the saturation point. Beyond the saturation point, changes in the total car stock are directly proportional to the changes in the population or its demographic components. We assume that car ownership saturation is reached at 0.8 cars per adult (where adults are defined as residents between the ages of 15 and 64 years), the level in Germany.[29] Car ownership also depends on the number of adults and on the level of disposable income in the economy.

Taking all these variables into account allows the model to project the stock of private cars out to 2025. The specific equation used for this is as follows

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[29] Germany has a high rate of car ownership and has been a high-income country for several decades.

$$\text{(A15)}\quad \Delta \ln \frac{0.8}{C_t / P_t \text{-} 1} = \alpha + \beta \frac{Y_t}{P_t}$$

where Y is the level of disposable income, C is the number of cars and P is the population between 15 and 64.

Type of Car

Once the future level of car ownership is defined, we estimate the share of the total stock by engine size. We disaggregate all cars into 9 engine size categories (and two fuels: petrol and diesel). We then use the income elasticity of demand for each engine category (see Table A11) estimated using the 2004/2005 Household Budget Survey (CSO, 2008). These income elasticities, together with information on future disposable income levels are used to project the number of cars per engine size.

Table A11: Income Semi-elasticities of Demand for Cars by Engine Size*

Engine Size	Income Semi-elasticity	
<900 cc	-0.3301	(0.0934)
900-1000 cc	-0.3301	(0.0934)
1301-1400 cc	-0.0898	(0.0808)
1401-1500 cc	-0.0640	(0.1029)
1501-1600 cc	0.4114	(0.0874)
1601-2000 cc	0.5691	(0.0861)
2001-2400 cc	0.7287	(0.1220)
>2400 cc	1.1377	(0.1938)

* Standard deviations between brackets.

Stock Demographics

The car demographic model distinguishes 9 engine sizes and 25 age classes. The dynamic equations are

$$\text{(A16a)}\quad C_{t,1,s,f} = S_{t,1,s,f}$$

$$\text{(A16b)}\quad C_{t,a,s,f} = (1 - \rho_a) C_{t-1,a-1,s,f} \qquad a = 2,3,....25$$

where $C_{t,a,s,f}$ is the stock of private cars in year t, of age a, of engine size s and of fuel f; S is the sales, and ϱ_a denotes the scrappage rate.

The probability of scrapping a car is constant over time for every car of age a, independent of engine size and fuel. Cars are assumed to be scrapped at the end of 25 years.

Distance Model

The CSO provides information on average distance travelled by type of car. For the distance driven per year, we account for the impact of change in the composition of the car stock. Specifically, distance $D_{i,j,t}$ is given by:

$$\text{(A17)} \quad D_{i,j,t+1} = \left(1 + \varepsilon\left(1 - \frac{P_{i,j,t+1}}{P_{i,j,t}}\right)\right) D_{i,j,t} \Delta \frac{C_{i,j,t}}{C_t}$$

where $C_{i,j,t}$ is the number of cars of size *i* and fuel *j* at time *t*; ε=-0.23 is the price elasticity of distance travelled (Hayashi et al. 2001). In theory, this elasticity should be lower for higher engine sizes as the higher incomes associated with larger cars make the owners more inelastic in the consumption patterns. Conversely, the elasticity estimates are higher for small cars. This is indeed the case with elasticities on the 2 largest engine sizes not being statistically different from zero. We calibrated Equation (A17) against data on distance travelled from the years 2000-2008. Thus, Equation (A17) estimates distance driven by engine size and is driven by elasticity estimates and the change in the relative price.

Carbon dioxide emissions

To convert distance travelled to carbon dioxide emissions, we need to compute how many litres of each fuel type are consumed. As we have approximated the composition of the car stock and the distance travelled, we need the fuel efficiency for each representative car.

We use fuel efficiency estimates calculated by SEAI for the Republic of Ireland (Howley *et al.,* 2007). Fuel efficiency has historically increased over time (for each engine size), so we extrapolate the trend out to 2025. This, combined with our earlier data, gives a fuel efficiency estimate of each car by its engine size, age and fuel type. We also assume that there is no depreciation of cars in terms of fuel efficiency over their lifetime and that any significant effects of age on efficiency will result in scrappage. One litre of diesel fuel has greater CO_2 emissions than one litre of its petrol substitute. The conversion factors are as in Howley *et al.* (2007). Note that diesel cars consume less per kilometre, so emissions per kilometre travelled are lower for diesel cars (compared to petrol cars of equivalent size).

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