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Irish Sustainable Development Model (ISus)
Literature Review, Data Availability and Model Design

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1. Introduction

Economic growth can increase pressure on the environment. See, for example, the growth in carbon dioxide emissions in Ireland. However, when economic activity is properly managed, the associated environmental pressure can be reduced or even eliminated at low costs. Proper management requires information. Where do emissions originate? How would emissions develop over time if policy were unchanged? How would emissions respond to changes in policy? What are the interactions between different environmental policies? Is stringent environmental policy compatible with vigorous economic growth?

Answering these questions requires data and models. While the availability and quality of data on the environment in Ireland have improved markedly in the last 15 years, model development is still in an early stage. Therefore, the Environmental Protection Agency (EPA) has commissioned the Economic and Social Research Institute (ESRI) to develop a sustainable development research model for Ireland: *Irish Sustainable Development Model (ISus)*. The model will be capable of linking economic and social developments to their related environmental impacts to provide a tool for policy-makers to assess the implications of different growth paths for national objectives on sustainable development,[1] and will be used to project emissions and resources until 2025.

It was suggested in the ESRI's tender for the ISus project that to be successful, any modelling framework needs to fulfil two criteria. Firstly, it needs to be useful to and used by key policy-makers. Secondly, it should build on models and research that are already available.

This document fulfils the second of these requirements and in so doing provides a review of the relevant literature and data sources for a sustainable development model.

Having introduced the study in this section, section two presents an analysis of six processes that currently impact on Ireland's environment.

Section three presents an overview of existing economic models that have been used in relation to environment-economy interactions, as well as a dedicated discussion of land use modelling.

Section four presents an analysis of evaluation techniques.

Section five presents the data and indicators currently available in Ireland.

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[1] The Brundtland Commission (1987) defines sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs.'

Section six presents an overview of similar projects elsewhere, as well as the proposed design for the ISus model in terms of its scope, structure and applications.

The concluding section draws inferences from each of the previous sections in order to critically assess the parameters that constrain the development of a sustainable research model for Ireland.

2. Environmental Processes

The first step in the construction of the ISus model will be to determine what forcings are important in an Irish context, and thus what emissions should be analysed and what data should be collated. As such, this section will examine the issues surrounding six processes that impact on the environment, the effect they can have, how they can be prevented or mitigated, and – perhaps most importantly with a view to constructing the ISus model – how each of these is relevant in Ireland. The environmental processes discussed below are eutrophication, climate change, acidification, air quality, resource use and waste.

2.1 Eutrophication

2.1.1 Issue

Eutrophication involves the enrichment of an ecosystem with chemical nutrients, typically compounds containing nitrogen (N) and phosphorus (P). A certain amount of eutrophication occurs naturally, particularly in aquatic environments, but this process can be accentuated by human behaviour.

2.1.2 Effect

Eutrophication can have the following effects (from Carpenter *et al.*, 1998; Smith, 1998):

- Increased biomass of phytoplankton
- Toxic or inedible phytoplankton species
- Increases in blooms of gelatinous zooplankton
- Increased biomass of benthic and epiphytic algae
- Changes in macrophyte species composition and biomass
- Decreases in water transparency
- Taste, odour, and water treatment problems
- Dissolved oxygen depletion
- Increased incidence of fish kills
- Loss of desirable fish species
- Reductions in harvestable fish and shellfish
- Decreases in perceived aesthetic value of the water body

2.1.3 Prevention and mitigation

Sources of P and N that contribute to eutrophication include wastewater effluent, agriculture (particularly fertiliser application and intensive animal husbandry), irrigation and waste disposal sites. Measures to counter this problem can involve technical measures (e.g., treatment of manure and sewage), management changes (e.g., application of fertilizers) and structural changes (e.g., extensification of agriculture).

2.1.4 Situation in Ireland

In Ireland, water quality is not a significant problem. However, the problems that do exist in this area are generally due to eutrophication. In 2005 the European Environment Agency noted that:

> ‘Ireland's water quality overall remains of a high standard. Serious pollution in rivers and streams has been reduced to just 0.6 % of river channel, its lowest level since the early 1990s. Eutrophication of rivers, lakes and tidal waters continues to be the main threat to surface waters with agricultural run-off and municipal discharges being the key contributors.’

2.2 Climate change

2.2.1 Issue

Climate change refers to the variation in the global climate, or in regional or national climates, over time. It can be caused by both natural factors (e.g., glaciation and plate tectonics) and human factors (e.g., emissions of greenhouse gases and aerosols, and land use changes). The ‘main greenhouse gases’ observed by the United Nations Framework Convention on Climate Change (UNFCCC) are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Perfluorocarbons (PFCs), Hydrofluorocarbons (HFCs) and Sulphur hexafluoride (SF_6) (UNFCCC, 2006).

2.2.2 Effect

The effects of climate change are most notably manifest in varying weather conditions. In a special report, The Economist noted that ‘over the past 100 years [net temperatures] have gone up by about 0.6°C’ (2006a).

This rise in temperatures is predicted to accelerate by most commentators, who foresee global temperatures increasing by between 1°C and 6°C in the coming century (IPCC, 2006, 11). The effects on the environment of such a change could be significant. Rising sea levels would increase the risk of flooding and raise sea levels, placing many of the world’s low-lying areas at risk of being submerged. Declining crop yields and increased risk of disease could also affect many of the world’s warmest regions.

There are also mechanisms that act to amplify the effect of a given forcing. For example, melting ice caps can accelerate the process of further melting as the Earth’s surface absorbs more of the Sun’s heat.

2.2.3 Prevention and mitigation

The view that anthropogenic factors contribute significantly to climate change has become more popular in recent years (The Economist, 2006). Mitigation of forecasted climate change is thus in many respects a human responsibility.

Two recent studies recommend action now to curb GHG emissions in the future. The Economist special report on climate change and the Stern Review on the economics of climate change differ markedly in their assessment of the costs that global warming could impose on humankind.[2] However, both reports recommend that action should begin now in order to minimise the effects of climate change before its effects become irreversible.

Using traditional methods, the economic evidence in favour of mitigation is relatively weak. Cost-benefit analysis generally uses a discount rate that values costs and benefits now over the future. With mitigation of climate change, a certain amount of outlay now may lead to uncertain benefits in the future. Indeed, the very fact that these benefits are uncertain counts against action on climate change according to Bjorn Lomborg, the self-titled "sceptical environmentalist". In their survey, The Economist poses a similar question:

> 'Is it really worth using public resources now to avert an uncertain, distant risk?…If the risk is big enough, yes. Governments do it all the time. They spend a small slice of tax revenue on keeping standing armies not because they think their countries are in imminent danger of invasion but because, if it happened, the consequences would be catastrophic' (2005, 15).

In any event, Ireland is committed to greenhouse gas emission reduction until 2012 under the Kyoto Protocol, and after that date under EU climate policy.

2.2.4 Situation in Ireland

A report by McGrath *et al.* for the EPA in 2005 sought to model the effects of climate change in Ireland. A regional climate model 'was used to simulate the future climate for the period 2021-2060' (McGrath, 2005, 1). The results of their research are summarised as follows:

> 'Projected temperature changes from the model output show a general warming in the future period with mean monthly temperatures increasing typically between 1.25 and 1.5°C. The largest increases are seen in the southeast and east, with the greatest warming occurring in July.
>
> For precipitation, the most significant changes occur in the months of June and December; June values show a decrease of about 10% compared with the current climate, noticeably in the southern half of the country; December values show increases ranging between 10% in the south-east and 25% in the north-west. There is also some evidence of an increase in the frequency of extreme precipitation events (i.e. events which exceed 20 mm or more per day) in the north-west.
>
> In the future scenario, the frequency of intense cyclones (storms) over the North Atlantic area in the vicinity of Ireland is increased by about 15% compared with the current climate' (ibid, vii)

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[2] The Stern Review notes that 'the total cost of 'business as usual' climate change is the equivalent of around a 20% reduction in consumption per head, now and into the future'. The Economist report cites two other papers that report a range of, in the first instance, 0.1% of global output per year (Mendelsohn, 2000), and in the second instance, 2% of global output (Nordhaus, 2000) as the costs of climate change.

The baseline scenario used in the above model assumes 'business as usual' behaviour by economic actors throughout the world. The reality for Ireland is that, as a small country, domestic policies to prevent climate change will have little impact if the rest of the world continues along its 'business as usual' path.

Efforts to alter this path by reducing worldwide emissions of GHGs culminated in the agreement of the Kyoto protocol in 1997.[3]

Ireland is committed to the protocol under international law as a signatory to the Marrakech Accords – an agreement that divided the EU's commitment to reduce overall emissions by 8% between its 25 members. Because of its recent economic growth, Ireland is permitted a 13% *rise* in emissions from 1990 levels. However, Ireland's emissions are currently 10% above this allowance (23% above 1990 levels) and the government plans to buy emission permits from abroad to meet the obligations under the Kyoto Protocol (The Irish Times, 2006).

Ireland's failure to reduce its emissions in line with its Kyoto commitments is ostensibly in conflict with government policy; the National Climate Change Strategy (NCCS) was published in October 2000 in order to provide 'a framework for achieving greenhouse gas emissions reductions' (DEHLG, 2000, 2).

2.3 Acidification

2.3.1 Issue

Acidification refers to 'the process whereby air pollution – mainly ammonia (NH_3), Sulphur Dioxide (SO_2) and Nitrogen Oxides (NOx) – is converted into acidic substances' (EEA, 2006). The term 'acid rain' is often used to describe the process by which these harmful substances can affect ecosystems – particularly lakes and rivers – once they have resettled back on the Earth's surface.[4]

Sources for emissions of these substances can be both natural and anthropogenic. Park notes:

> 'There are three main natural sources. Most comes from the seas and oceans (in sea salt and gases), and much smaller total amounts come from volcanic eruptions and from natural soil processes (via the decay of organic matter). Although volcanoes contribute relatively little overall, individual eruptions can emit vast quantities over short time-periods in limited areas…[Manmade emissions can derive from] the burning of coal, the burning of petroleum products…and various industrial processes' (1987, 33-34).

2.3.2 Effect

Acid ran has been shown to have adverse impacts on freshwater ecosystems, forests, soils, buildings and possibly on human health also.

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[3] The Kyoto Protocol came into force in February 2006 and – as of October 2006 – 166 countries and other entities have ratified the treaty. Notably, neither the United States nor Australia has ratified the treaty.

[4] 'Acid rain' is perhaps something of a misnomer, and the terms 'acid precipitation' and 'acid deposition' more accurately describe how acidic substances can fall to the Earth, or how they can be carried in cloud water and fog droplets and directly deposited.

Some aquatic species cannot survive at reduced PH levels. The biggest impact of acidification on such species is due to heavy metals being leached from soil as a result of increased acidity.

The acidification of soil and freshwater are closely related. Some soils are naturally more able to ‘buffer’ (absorb) acid without having an adverse effect on vegetation and animal species that rely on the soil.[5] However, increased levels of acid are more commonly negative, and can lead to ‘significant changes in soil structure and productivity, and in turn on vegetation’ (ibid, 93).

Fig 2.1. Effects of acid rain on a forest and a sculpture

It is thus not surprising that forests can be affected by acidification – as they are under threat from above (due to acidic clouds and fog) and below (due to acidic soil and groundwater). However, perhaps the most visible evidence of the impact of acid rain is its effect on the corrosion of buildings and monuments, as limestone structures are slowly corroded by acid.[6]

2.3.3 Prevention and mitigation

It is clear that air pollution has been recognised as a problem in relation to industrial facilities for some time, but measures to mitigate this problem should be implemented with caution, so as not to shift it elsewhere.[7]

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[5] Indeed, at low levels of acidification, the soil can be enriched and many plant species can thrive in this improved environment.

[6] This is also perhaps the longest-observed phenomenon associated with acid rain. As far back as 1852, Robert Smith commented: ‘It has often been observed that the stones and bricks of buildings, especially under projecting parts, crumble more readily in large towns, where much coal is burnt, than elsewhere…I was led to attribute this effect to the slow but constant action of the acid rain.’

[7] For example, early problems of localised air pollution from industrial facilities were resolved in many countries by the introduction of high chimneystacks from the middle of the twentieth century. This has had the effect of lifting polluting emissions to a higher altitude, where they are transported longer distances with the prevailing wind.

It would be very difficult – if not impossible – to alleviate acidifying emissions from natural sources. However, anthropogenic emissions can ostensibly be reduced, either by using substitutes (e.g., renewable energy and hydrogen powered) or technological solutions (e.g., fluegas desulphurisation and low-sulphur petrol).

Park notes that ‘neither winds nor acids respect political boundaries, so pollutants are often carried across state and national frontiers’ (1987, xii). As a result, the difficulties in implementing the methods of prevention mentioned above are mainly political. This situation brought about the 1979 Convention on Lang Range Transboundary Air Pollution, as well as its subsequent protocols[8] – the most recent of which led the United Nations Economic Commission for Europe (UNECE) to observe that ‘once the Protocol is implemented, the area in Europe with excessive levels of acidification will shrink from 93 million hectares in 1990 to 15 million hectares’ (UNECE, 2006).

2.3.4 Situation in Ireland

McCoy (1991) observed that ‘the problem of acid rain is an important issue in North America and Europe but it is a less significant problem for Ireland’. He concluded that ‘the same impacts for the European environment could be achieved at much lower costs to the Irish economy by a direct transfer of funds to Eastern Europe,’ though he provided the caveat that ‘many important issues have been ignored in making this decision’ (ibid, 101). As noted above, Ireland never did sign or ratify the Helsinki protocol, and only joined the 1979 convention through the National Emissions Ceiling Directive (see note 8).

In 2004, the EPA detailed trends and abatement measures for emissions of SO_2, NOx, VOCs and NH_3. The generally downward trend in emissions of these substances has been achieved with little economic impact, but future targets ‘are environmentally ambitious and economically challenging in the light of sustained rapid economic growth and potential impacts of emission control measures on the major source sectors [energy production and transport]’ (EPA, 2004, 259). One proposed measure to reduce Ireland’s production of acidifying gases is the cessation of coal-burning at Moneypoint power plant in county Clare. This was proposed by Bowman and McGettigan in 1994, and is also part of the National Climate Change Strategy (DEHLG, 2000).

2.4 Air quality

2.4.1 Issue

Poor air quality (air pollution) results from the emission of chemical, particulate or biological agents that modify the natural characteristics of the atmosphere.

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[8] The 1979 Convention has had eight protocols appended to it – including the 1985 ‘Helsinki Protocol’ (an agreement to provide for a 30% reduction in sulphur emissions or transboundary fluxes by 1993 over 1980 levels. Its signatories did not include the United States or the United Kingdom) and the 1999 ‘Gothenburg Protocol’ (which sets emission ceilings for 2010 for four pollutants: sulphur, NOx, VOCs and ammonia. It is enforced in the EU through the National Emissions Ceiling Directive – Directive 2001/81/EC – and has been ratified by the United States, the United Kingdom and the EC).

These pollutants are classified as either directly released or formed by subsequent chemical reactions.[9] Although the most recognisable sources of air pollution are large stationary facilities such as power plants, incinerators, mines and quarries, the greatest source of emissions are motor vehicles. As such, urbanised areas are most affected by air pollution. Natural sources also exist, such as dust-storms, radioactive decay and volcanic activity, though compared to anthropogenic sources these contribute little overall.

2.4.2 Effect

Air pollution can have a detrimental effect on the environment and ecosystems, as well as cause acid rain, eutrophication, particulate matter and other environmental problems. Further, in 2004 the World Health Organisation estimated that 3 million people die annually as a result of air pollution.[10]

2.4.3 Prevention and mitigation

Monitoring and assessment of air quality has been a priority for environmental agencies in the last quarter-century (EPA, 2004, 26-28). However, this is only the first step towards mitigating and preventing air pollution.

By way of prevention, a number of technical control measures exist that can limit emissions of polluting materials to the air, such as catalytic converters, filters, flares and carbon adsorption techniques. Non-technical measures also exist, such as changing the fuel used for combustion in power plants.

It is usually not in a polluter's interests to implement such measures unless there is a legal requirement or financial incentive to do so. Such requirements exist under many of the international agreements discussed above under 'acid rain', which have proven to be effective at improving air quality, particularly in developed countries. Further, national standards exist in many countries that set numerical limits on the concentrations of air pollutants and provide reporting and enforcement mechanisms, as well as banning outright the combustion of certain materials in specific areas.

2.4.4 Situation in Ireland

Enfo reports that 'Ireland as a whole is relatively free of air pollution, when compared with other more industrialised countries' (Enfo, 2006). However, public concern for air pollution, and the number of legislative controls over monitoring, emissions and fuel types have increased in recent decades.

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[9] A direct release air pollutant is one that is emitted directly from a given source, such as carbon monoxide or sulfur dioxide, which are byproducts of combustion. A subsequent air pollutant is formed in the atmosphere through chemical reactions involving direct release pollutants. The formation of ozone is an example of a subsequent air pollutant. Other air pollutants include gases such as benzene, carbon monoxide (CO) and oxides of nitrogen (NOx), as well as lead and other heavy metals.

[10] BBC, 2004; and see Lave and Seskin, 1970; Bascom, 1996; and Künzli *et al.*, 2000.

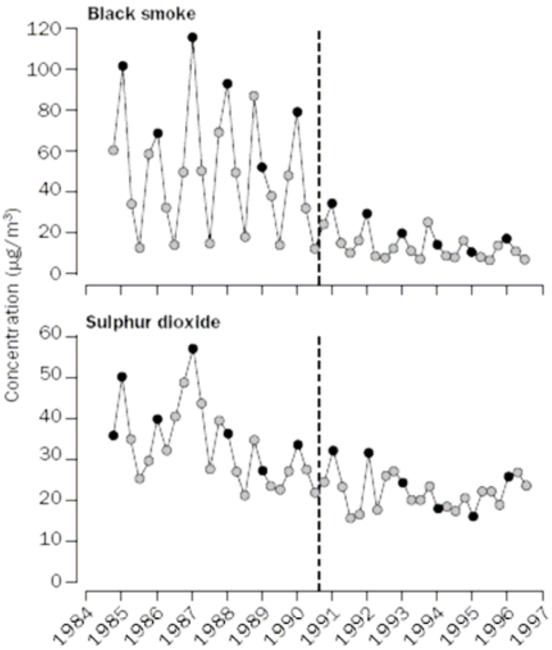

Fig 2.2. Seasonal mean black smoke (upper) and sulphur dioxide (lower) concentrations, September 1984-96. Vertical line shows date bituminous coal was banned in Dublin County Borough. Black circles represent winter data. Source: Clancy *et al.*, 2002, 1211

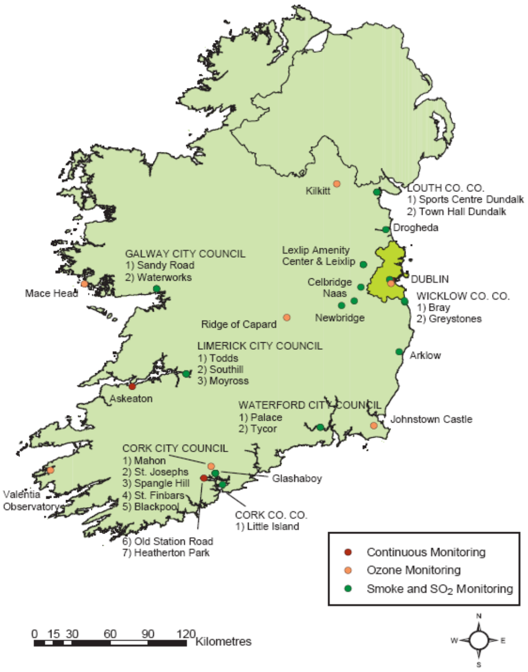

Fig 2.3. Fixed air monitoring stations in Ireland. Source: EPA, 2004, 28

Since 1990 a ban on the marketing, sale and distribution of bituminous ('smoky') coal has been in place in Dublin. This has proven particularly effective at combating winter smog in the Dublin area, and the scheme has been extended to other parts of the country.[11] A study by Clancy *et al.* (2002) calculated that 'respiratory and cardiovascular death rates fell coincident with the ban on coal sales' (1210). The fact that this ban has been introduced locally is indicative of the decentralised nature of decision making in the area of environmental regulation in Ireland. The 1987 Air Pollution Act requires local authorities to issue licences for industrial emissions to air, and make provision for suitable monitoring of environmental air quality. Fig 2.3 shows the locations of air quality monitoring stations in Ireland.

There is still a lot that can be done in Ireland to improve tropospheric air quality. For example, it was mentioned above that the government's National Climate Change Strategy allows for the cessation of coal-burning at Moneypoint. However, concentrating efforts on industrial point sources may be missing the true problem, as the EPA notes:

> 'It is now emissions from traffic that pose any threat to good air quality…The implementation of pollution abatement measures would be much more difficult than the application of the smoke control legislation that previously eradicated winter smog. The introduction of

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[11] Similar bans have been introduced in Cork in 1995, Arklow, Drogheda, Dundalk, Limerick and Wexford in 1998, Celbridge, Galway, Leixlip, Naas and Waterford in 2000, and in Bray, Kilkenny, Sligo and Tralee in 2003.

> such measures, in the form of air quality management plans or short-term actions entailing restrictions on traffic, would represent a major new challenge for local authorities in Ireland' (ibid, 36).

2.5 Resource use[12]

2.5.1 Issue

When referring to natural resources, it is essential to distinguish between those that are renewable and those that are not. Fossil fuels, metals and fossil groundwater are non-renewable. Stocks of these are finite and, *ceteris paribus*, they will run out if we continue to use them. Food and timber – from crops, livestock and trees – are renewable because, when carefully managed, quantities of these resources can be maintained.

However, the usage of non-renewable resources does not take place *ceteris paribus*. Previous predictions that resource depletion would lead to extinction have proven to be false alarms.[13]

2.5.2 Effect

One of the principal impacts of resource depletion is in relation to biodiversity[14]. Research by Pimm *et al.* showed that 'recent extinction rates are 100 to 1000 times their pre-human levels' (1995, 347). Their conclusion is that there is 'unambiguous evidence of human impact on extinction' (ibid, 348). Such a loss of biodiversity is caused by, and leads to, resource depletion by humans. On the one hand, changes in land use brought about by agriculture, mining and industrial development can have adverse effects on ecosystems due to processes such as eutrophication, air pollution and climate change. On the other hand, a significant proportion of the Earth's biomass[15] is tied up in only the few species that represent humans, our livestock and crops (BBC, 2006).

The most poignant example of the potential impact of resource depletion is in relation to fossil fuels, particularly oil. Without mitigation, the impacts of 'peak oil'[16] will be evident – in the short term – with shortages and higher prices. In the long term it will impact on transport (by road, rail, shipping and aviation), industrial production of oil derivatives (such as plastics and paints) and other downstream goods and services.

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[12] In the context in which it is discussed here, resource use is considered separately from land use, which is discussed below in section 3.2 (land use models).

[13] For example, Tietenberg notes that 'the chief geologist of the U.S. Geological Survey reported in 1920 that only 7 billion barrels of petroleum remained to be recovered with existing techniques. He predicted that, at the contemporary annual rate of consumption of a half-billion barrels, American oil resources would be exhausted in 14 years' (1996, 4). Changes in technology and new discoveries had not been factored into the calculations of remaining oil reserves.

[14] Unlike resource use, humans do not consciously 'use' biodiversity. Its depletion is a bi-product, possibly several steps removed, from other activities.

[15] Biomass is defined as the amount of living matter in a given habitat, expressed either as the weight of organisms per unit area or as the volume of organisms per unit volume of habitat.

[16] The Earth's known reserves of oil – after growing for the past hundred years or so as exploration has increased and technology has improved – are now reaching a point – peak oil – where stocks will fall and scarcity becomes a concern. Indeed, many believe that this point has already been passed (see Simmons, 2005).

Similar problems may exist for natural gas, coal, fissionable materials, and – in many parts of the world – freshwater reservoirs.

2.5.3 Prevention and mitigation

Analyses have suggested that actions can be taken to limit resource depletion – or at least offset its effects – without harming economic growth significantly.

To use the example of peak oil, a report in The Economist concluded that ‘it is wrong to imagine that the world’s addiction to oil will end soon, as a result of genuine scarcity’ (2006b). This is based on the evidence of recent technological developments, which have forced many traditional oil companies to become manufacturers of substitutes for traditional petroleum such as diesel formed from natural gas, biodiesel, ethanol, fuel from tar sands and shale oil, and coal liquefaction (ibid).

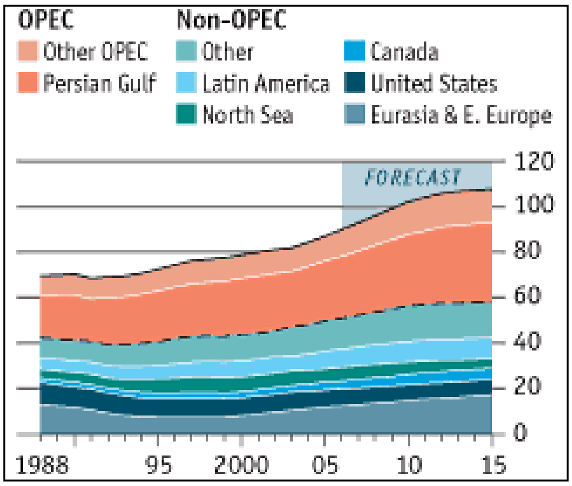

Fig. 2.4. World oil production capacity, million barrels per day. Source: The Economist (2006b)

Further, the development of renewable energy sources such as wind-, hydro-, tidal-, geothermal- and wave-energy, as well as nuclear fission and, perhaps, fusion technologies, may further offset the global peak in fossil fuel production such that ‘the metaphor of a peak [may become] misleading: the right picture is of an undulating plateau’ (ibid – see Fig. 2.4).

In the case of renewable resources, the European Commission’s *Thematic Strategy on the Sustainable Use of Natural Resources in Europe* is a policy proposal that would unite European nations in an effort to protect ecosystems and resources for the next 25 years. Its central premise is that ‘environment policy needs to move beyond emissions and waste control’ (2005, 5). The objective of proposing the strategy is therefore ‘to reduce the negative environmental impacts generated by the use of natural resources in a growing economy – a concept referred to as decoupling’ (ibid).

2.5.4 Situation in Ireland

Commercial natural gas fields exist off the coasts of Mayo and Cork. Other resources include peat, which has been used as a fuel in Ireland for centuries and is still used in energy production. Coal has not been mined commercially in Ireland since the mid 1980s, when the mine at Arigna, Co. Roscommon was closed.

In relation to resource depletion, three issues are of interest in Ireland.

Firstly, Ireland’s biodiversity – as elsewhere in the world – is under threat if resource depletion continues to impact on ecosystems.[17]

Secondly, James Nix has observed that ‘Ireland is already the most car-dependent country in the world’.[18] This leaves Ireland particularly vulnerable to changes in the

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[17] In 2004 the EPA noted that ‘some flora and fauna, and their habitats, are under threat from a variety of sources including agricultural practices, forestry, peat extraction, eutrophication of waters, climate change, invasive alien species, land clearance and development’ (2004, 97).

price of oil, as we have no sources of oil of our own, and no 'strategic reserves' in the event of a large price change such as occurred twice in the 1970s (Earthtrends, 2005).

Thirdly, concern has been raised in recent years over the possibility of water shortages in Dublin as it expands and becomes ever more populous.[19] The idea that Ireland – one of the wettest countries in Europe – could be faced with drought is counterintuitive. However, as Dublin expands out of proportion to the rest of the country, this will become a very real threat to a natural resource (water) that has always been taken for granted in this country.

2.6 Waste

2.6.1 Issue

'Waste is something which is produced as an undesired joint product[20]; as such, it has no economic value. If this waste is disposed of into the environment, it may constitute a source of pollution' (Bisson and Proops, 2002, 5). Bisson and Proops' definition of waste implies that it is a 'public bad', and shares the common ownership problems associated with other public property – namely, the existence of free riders and the determination of an optimal level of production. The optimal solution to the problem of waste must thus involve such measures as regulation, public ownership, Pigouvian taxation and tradable permits.

So why not simply stop waste at its source and produce no waste? By applying the principles of thermodynamics, Baumgärtner notes that 'the occurrence of waste appears as an *unavoidable necessity* of industrial production' (2002, 13 – italics from original).

2.6.2 Effect

Barata observes that 'worldwide, enormous amounts of residues are being produced, which need to be managed in an economical way, while not compromising the environment and public health' (2002, 117). Indirectly, he has recognised the problems currently associated with waste; that a lot of waste is produced, that it is not managed efficiently, and that it currently harms both the environment and human health.

Different forms of waste – for example, toxic waste – present a different set of problems. Adeola observes that: 'hazardous wastes are ubiquitous in our society…generally people are concerned about hazardous waste sites, accidental releases of toxic substances, expensive clean-up costs, property values depreciation,

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[18] Nix observes that 'we drive 24,400km per year [in Ireland] compared to the US average of 19,000km, the UK at 16,100km, France at 14,100km, and Germany at 12,700km.' This is based on a study by Banister and Berechman entitled 'Transport investment and economic development' (The Irish Times, 2003; Banister and Berechman, 2000).

[19] In October 2006, the Irish Independent reported that the 'thirsty capital could soon be drinking from the Shannon' (Irish Independent, 12/10/06). This was with reference to a plan to expand Dublin's water network such that it incorporated either a source over 100km away at Lough Rea, or a desalination plant on the East coast.

[20] Faber *et al.* (1998) note that 'all production is joint production' – that is, with the production of desirable, low entropy products there must come undesirable, high entropy products such as excess heat and physical waste.

stigma and other social and psychological costs, adverse ecological effects, and human health diminution' (2002, 146).

2.6.3 Prevention and mitigation

Two courses of action can prevent the accumulation of waste products within a given area. Firstly, a simple solution is to export waste material. This occurs particularly in relation to nuclear waste and recyclables, the treatment of which is made more economical with scale.

The second solution is to accord priority to certain methods of waste treatment, such as to minimise its impact on the environment. The waste hierarchy is shown in Fig. 2.5.

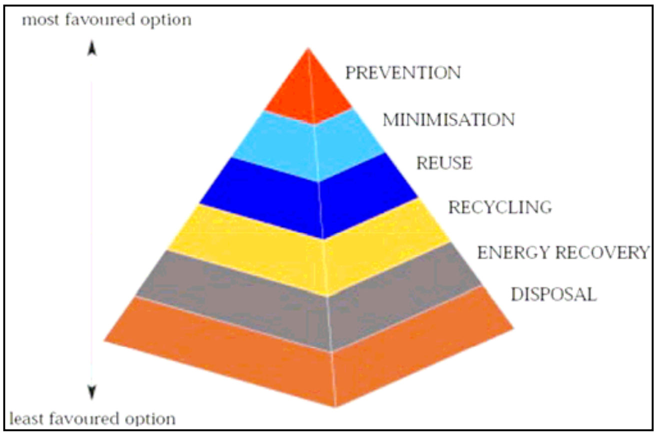

Fig. 2.5. The waste hierarchy. Source: DEHLG, 2004, 3

2.6.4 Situation in Ireland

The EPA notes that 'waste generation and resource use are at unsustainably high levels in Ireland and the EU, and have increased in tandem with economic growth' (2004, 226). Agriculture accounts for the majority of waste produced in Ireland (76%), while municipal waste – the most common conception of the problems associated with waste – accounts for only 4% of the total.

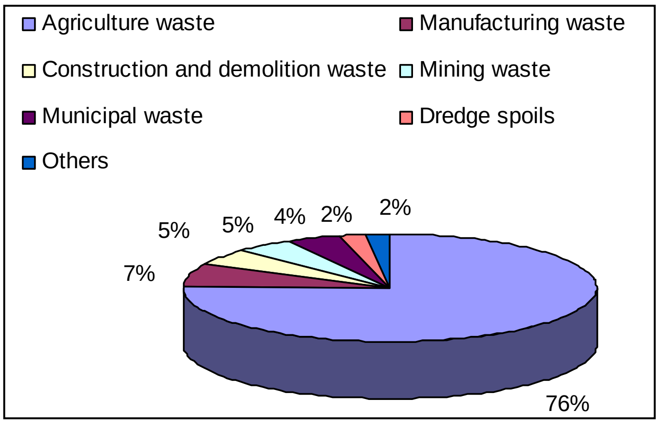

Fig. 2.6. Waste generation in Ireland and principal sources – 2001. Total tonnes in 2001 were 74,071,634 Source: EPA, 2004, 229

By way of legislation, systems of registration and licensing of treatment centres/landfill sites are monitored by the EPA and local authorities under various acts that have been passed since 1998.[21] However, the EPA has suggested that more action is required if we are to meet the targets outlined above:

> 'Indigenous recycling enterprises should be given every opportunity to develop. Waste management costs should be internalised and public-sector collection and disposal services should be funded wholly by charges made for those services. Environmental service charges should similarly be ring-fenced for environmental initiatives' (EPA, 2004).

In relation to landfill, The Department of the Environment, Heritage and Local Government has set targets for the quantities of waste to be diverted from landfill (ibid, 229).[22] However, even if these targets are met, the large increase in the total quantity of waste generated means that the quantity of waste sent to landfill is likely

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[21] These are the Waste Management (Permit) Regulations (1998), the Waste Management (Collection Permit) Regulations (2001) and the Waste Management (Licensing) Regulations (2000).

[22] These targets are a diversion of 50% of household waste from landfill, minimum 65% reduction in biodegradable wastes consigned to landfill, recycling of 35% of municipal waste, and recycling of 85% of construction and demolition waste (a 50% rate was achieved in 2003).

to increase. The challenge, it would seem, is to decouple waste generation from economic growth.

2.7 Conclusion

This section has examined the issues surrounding six processes that impact on the environment, the effect they can have, how they can be prevented or mitigated, and how each of these is relevant in Ireland.

This analysis has revealed two important distinctions among environmental processes that currently impact on Ireland. Firstly, the processes discussed above have varying impacts on the environment in this country. Secondly, each of the above processes can be placed on a scale – ranging from low to high – of the effectiveness of domestic policy in mitigating and preventing that problem. These are shown graphically in Fig. 2.7, which is largely subjective and merely designed for the purpose of illustration.

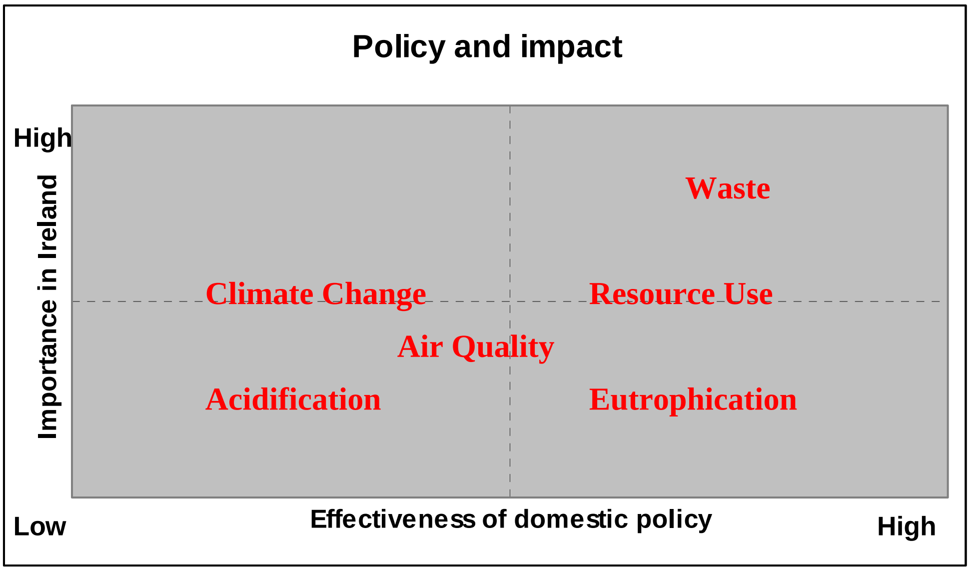

Fig. 2.7. Impact of policy on – and relative importance of – environmental problems

This form of analysis is the first step towards formulating effective policy decisions; action in a given area can have a much greater impact on the environment – without the economic pressures of acting in another area.

The information gleaned from the above section will assist in choosing the most suitable method (or methods) for the construction of the ISus model from those discussed in the next section; this will discuss various methods for modelling economy/environment relationships in Ireland.

3. Modelling the environment

Little of the overall body of research in relation to environmental economic models focuses on Ireland.[23] In analysing the body of literature in this area it is thus of little value to focus on those studies that are limited to this country.

As such, what follows is an analysis of environmental economic models, which are herein broadly grouped into seven categories: Input-output models, environmental Kuznets curve analyses, decomposition models, computable general equilibrium models, econometric models, optimisation models and a final category of ‘hybrid’ models, a relatively recent phenomenon that seeks a union between the social and physical sciences.

This section concludes with an analysis of land use models.

3.1 Emission models

3.1.1 Decomposition

Index decomposition analysis requires the modeller to deduce the energy intensity of a given sector of the economy, and how this is determined by industrial production across the economy.[24] Comparing this to a base year then allows the modeller to analyse any changes that have occurred in that sector, and over the economy as a whole. This methodology was popularised following the world oil crisis of 1973-74, as ‘energy researchers began to look for ways to quantify the impact of structural shifts in industrial production on total industrial energy demand in order to have a better understanding of the mechanisms of change in energy use in industry’ (Ang and Zhang, 2000, 1149; Greening *et al.*, 1997; Ang, 1999). However, Ang notes that ‘more recently, with the growing concern about global warming and air pollution, a number of studies using the methodology to study energy-induced emissions of CO_2 and other gases have been reported’ (1999, 1146-7).

In a review of literature on decomposition models in environmental and energy economics, Ang and Zhang recognise 124 studies over a twenty-two year period to

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[23] In Ireland, the relationship between greenhouse gas emissions and the economy has been modelled by Conniffe *et al.* (1997), Bergin *et al.* (2002) and Fitz Gerald (2004). Teagasc has modelled the impact of agriculture on greenhouse gas emissions (Behan and McQuinn, 2002). Work on the impact of economic activity on the generation of solid waste is described by Barrett and Lawlor (1995). The state of research on the link between economic activity on water use and emissions to water is described by Scott (see Scott *et al.*, 2001 and Scott, 2004). Finally, a range of different types of research on transport has been carried out for Ireland (See, Department of Public Enterprise, 2000), and a simplified model of the transport sector is already incorporated into the ESRI’s HERMES model of the Irish economy.

[24] Sectoral energy intensity is ‘a better measure of energy efficiency than the aggregate energy intensity, [and] is the amount of energy consumption that is required to yield a given level of output at the sectoral level’ (Ang and Zhang, 2000, 1149-50).

2000 (2000, 1150). It is interesting to note that only four of these include Ireland in their analyses.[25]

Two broad schools of decomposition methods are recognised by Ang (1999). These differ by the way in which the energy intensity from a given sector is compared to energy intensities in a base year.

1. The *Laspeyres index* method 'follows the Laspeyres price and quantity indices in economics by isolating the impact of a variable through letting that specific variable change while holding the other variables at their respective base year values' (Ang and Zhang, 2000, 1157). By comparing the production share of a particular industry at a particular time with its energy intensity and production share in a base year, the modeller can derive the estimated impact of structural change in the economy over the period. Similarly, by comparing the energy intensity of a particular industry at a particular time with its energy intensity and production share in a base year, the modeller can derive the sectoral intensity of that sector over the period, and see changes in this regard.
2. The *Arithmetic mean Divisia index* method is noted to be 'more robust, exhibiting a smaller residual term with less variation' (Greening, 2004, 4). The Divisia index compares the relative energy intensities of an industry to a base year in a multiplicative form such that a Divisia index of 1 would mean that the energy intensity in the year under analysis is the same as in the base year.

For mathematical descriptions of both the Laspeyres index method and the Arithmetic Mean Divisia index method see the appendix.

Greening *et al.* compare the two as follows:

> 'The Laspeyres [method] compares each of the components of energy usage patterns with a fixed base year, while holding the other components constant. As a result, this index does not have the time or factor reversal properties of an ideal price index (see Fisher, 1972[26]). The other main method previously used is the sample average Divisia method (Boyd *et al.*, 1987, 1988; Torvanger, 1991). As opposed to the Laspeyres index, the Divisia index…does have the time reversal property but does not have the factor reversal property' (1997, 376).

Ang notes some faults with both Laspeyres Index decomposition and Divisia index decomposition (1999, 1159-61). These are presented below:

1. Difficulties in selecting a method – It is often unclear which decomposition method is most appropriate for a given situation. Ang (1994) suggested three methods of selection: (a) whether or not the assumptions associated with the chosen method meet the study objective, (b) ease of use, and (c) magnitude of the residual.
2. Large residuals – Ang recognises that 'when changes in the data between the decomposition years are drastic, the performance of the conventional and the adaptive weighting divisia methods can be shown to deteriorate and give a

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[25] These are Eichhammer and Mannsbart, 1997; Morovic *et al.*, 1989; Morovic *et al.*, 1987; and Sun and Malaska, 1998.

[26] Fisher's Ideal price index is the geometric mean of the Laspeyres and Paasche price indices.

large residual term. This situation can arise when decomposition is carried out using highly disaggregated data or on the aggregate intensity for a specific fuel' (1999).

3. Zero values in the data set – The arithmetic mean Divisia index formulae have logarithmic terms (see equations (17) and (18) in the appendix). This could 'lead to computational problems when zero values appear in the data set' (Ang and Zhang, 2000, 1163).[27]

However, these problems have been overcome by the refined divisia index decomposition method, the details of which are introduced and explained in Ang and Choi (1997).

Finally, the accuracy of decomposition models can be improved by using either a rolling base year or an annually changing weighting system. Greening *et al.* explain that:

> 'although computationally more intensive and requiring more data, time series methods capture more information about changes in the underlying effects over time or how energy consumption has evolved over time. These methods include the Adaptive Weighting Divisia (AWD) and the simple average Divisia method with a rolling base year. The AWD allows for changing weights or parameter values through time in response to changing energy inputs or outputs' (ibid).

It is evident that the accuracy and applicability of decomposition models have improved over the last three decades. However, it is still uncertain which method might be most applicable in the case of Ireland. Further, the lack of prior research using this country in its analysis increases the risks associated with using a decomposition model to construct the Isus model, as there are few bases for comparison of any results the model might produce.

3.1.2 Environmental Kuznets Curve (EKC) analysis

Stern explains that:

> 'the environmental Kuznets curve (EKC) is a hypothesized relationship between various indicators of environmental degradation and income per capita. In the early stages of economic growth degradation and pollution increase, but beyond some level of income per capita, which will vary for different indicators, the trend reverses, so that at high income levels economic growth leads to environmental improvement. This implies that the environmental impact indicator is an inverted U-shaped function of income per capita.

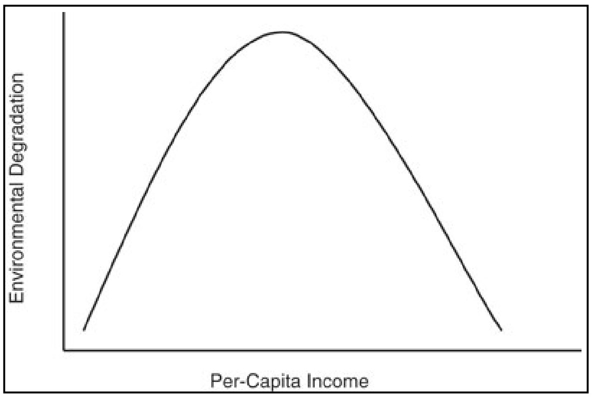

Fig. 3.1. Typical shape of the Environmental Kuznets Curve

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[27] Ang and Zhang observe that 'in industrial energy demand analysis, the problem [of zero values in the data set] arises when a certain type of fuel begins or ceases to be used in an industrial sector' (2000, 1163).

> Typically, the logarithm of the indicator is modelled as a quadratic function of the logarithm of income…The EKC is named for Kuznets (1955) who hypothesized that income inequality first rises and then falls as economic development proceeds' (2004, 1419).

The evidence for such a relationship is mixed, however. Harbaugh *et al.* (2001) and Stern (2004) are critical of the existing literature in support of a consistent relationship between environmental indicators and national wealth.

Although ostensibly an academic curiosity, EKC analysis has important policy implications. For instance, a developing nation with rising levels of pollution can justify potentially harmful policies on the grounds 'that developing countries will *automatically* become cleaner as their economies grow' (Harbaugh *et al.*, 2001, 541).

Beckerman goes so far as to claim that 'the best – and probably the only – way to attain a decent environment in most countries is to become rich' (1992, 482). Stern finds fault with analyses such as Beckerman's on two levels. Firstly, EKC analyses generally include assumptions in relation to constant returns to scale and consistency in technology and both the input and output mix of growing economies. Yet Stern notes that 'though any actual change in the level of pollution must be a result of change in one of the proximate variables, those variables may be driven by changes in underlying variables that also vary over the course of economic development' (2004, 1422).

Secondly, Stern conducts an econometric critique of EKC analysis, and notes the following criticisms:

- Heteroskedasticity – smaller residuals can be associated with countries with higher total GDP and population, although feasible generalised least squares (GLS) can be employed to resolve this problem.
- Omitted variables bias – Stern observes that in some cases the regressors that underlie a given relationship (between, say, pollution and GDP) may be correlated with variables that are omitted from the analysis. Further, he finds significant differences between the turning points for OECD and non-OECD countries. Finally, he concludes that serial correlation is present in these analyses.
- Cointegration – Stern finds that in some cases, though not all, the series that underlie EKC curves have stochastic trends (ibid, 1429).

However, despite the assessments of both Harbaugh *et al.* and Stern, the development of models similar to those provided by EKC analysis will be important in the construction of the ISus model. The dynamic relationship between economic growth and the ecological impact of the policies that encourage this growth will be an important consideration when modelling the effects of policy choices. Yet, one must be careful in so doing to avoid the pitfalls of previous EKC analyses.

3.1.3 Input-Output models

According to its founder, Wassily Leontief,

> 'input-output analysis describes and explains the level of input of each sector of a given national economy in terms of its relationships to the corresponding levels of activities in all the other sectors' (1970, 262).

Essentially, this involves a matrix representation of the economy in order to predict the effect of changes in one industry on others, while at the same time modelling the effect of this interaction on consumers, the government and foreign suppliers.

The first effort to model the effect of these interactions on the environment was undertaken by Leontief himself, when in 1970 he sought to account for pollution and a new industry aggregation – the anti-pollution industry – within a hypothesised two-sector, two-good economy.

However, Van den Bergh and Hofkes note that 'the most important recent study [in input-output environment modelling] is by Duchin and Lange (1994)' (1999, 1114). Their ambitious model involves a detailed input-output model of the world economy, covering the dynamics of trade in sixteen regions and fifty sectors. This study sought to test the Brundtland Commission's statement that growth and sustainable development could go hand in hand, and concluded that this is not the case.[28]

A common issue in relation to input-output models is that these models 'are structurally fixed in the sense that sectoral classification and disaggregation, and assumed technologies, cannot change endogenously' (van den Bergh and Hofkes, 1999, 1115).

One effort to overcome these problems is the Regional and Welsh Appraisal of Resource Productivity and Development (REWARD) project in the UK (see Ravetz, *et al.*, 2003). The project distinguishes different regions of the UK and thus further subdivides the standard input-output modelling framework to create a Regional Economy-Environment Input-Output (REEIO) model. The REWARD project was designed with the specific intention of modelling policy options in the UK and as such may prove valuable as a comparative tool in constructing the Isus model.

Input-output models are generally considered to be a useful tool for short-term and static analyses. As a result, they can be less accurate than more dynamic methods in modelling over the medium- and long-term. Further, they focus on the production side of the economy and as such may be weak when modelling sectors such as households and international trade. However, the data and other information required to build an input-output model, as well as the 'regionalisation' that has been developed in a model such as REWARD, may prove useful in constructing the ISus model. As such, the development of an environmental input-output model has proven to be a useful first step this project.

3.1.4 Computable General Equilibrium (CGE) models

Computable (or applied) general equilibrium models are the principal analytical tools of applied economic policy analysis. Conrad explains that 'models of this type are a computer representation of a national economy or a region of national economies, each of which consists of consumers, producers and the government' (1990, 1060), although these aggregations are further broken down as more powerful models simulate the economy with ever-greater accuracy.

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[28] Dellink *et al.* (1999) extend a computable general equilibrium (CGE) model to environment-economy relationships in the Netherlands up to 2030. Their principal conclusion – 'that economic growth can be reconciled with a reduction in environmental pressure…[if] there is improved environmental efficiency combined with a significant restructuring of the economy' (ibid, 153), counters that of Duchin and Lange. CGE models are discussed below.

Conrad notes that as ‘the practice of model-building itself has become increasingly systemised’ (1999, 1060) the variety of approaches in using these models to predict the effects of a chosen policy on the environment has grown, such that:

> ‘from a pragmatic point of view…[it has] become more and more difficult to understand why a carbon dioxide reduction target of 10 per cent calls for a CO_2 tax rate of, for example, \$20 by one model builder, but \$300 by another’ (ibid).

In an investigation of eighteen distinct E3-CGE (energy-economy-environment computable general equilibrium) models that have been developed since 1998, Böhringer and Löschel (2006) investigate the coverage of both environmental and economic indicators in each of these models. They conclude that: ‘Operational versions of E3–CGE models have a good coverage of central economic indicators, whereas environmental indicators with complex natural science backgrounds and — in particular — social indicators are hardly represented’ (ibid, 61). In other words, CGE models are good at answering economic questions with regard to emissions and emission reduction for global and continental environmental problems. For local problems (e.g., urban air quality) or environmental problems that cannot be reduced to emissions (e.g., biodiversity), CGE models are less appropriate. Similarly, CGE models are not suitable for analysing the social dimension of sustainable development.

Perhaps the most prominent developments in CGE modelling of the environment have been the calculations of a sustainable national income (SNI) for The Netherlands.

SNI is a concept that was popularised by Hueting in the 1970s. Verbruggen *et al.* explain that:

> ‘According to Hueting, the objective to construct a SNI boils down to a correction of national income for environmental losses. With environmental losses is meant the foregone use of the environment due to competition between the different functions the environment performs to sustain economic activities and human life. As national income is recorded in market prices, the correction for environmental losses should be in comparable terms. Hence, ideally, shadow prices have to be found on the basis of demand and supply curves for environmental functions. Then, environmental losses can be expressed in market prices and deducted from national income to arrive at SNI’ (2001, 276).

Hueting makes a number of assumptions when defining SNI, among them that shares of imports and exports are constant (as opposed to an assumption of constant relative prices on the world market) and that the final figure for SNI is expressed in new equilibrium prices (as opposed to relative prices of a given base situation). However, Verbruggen *et al.* broaden this analysis. Because ‘no decisive preference can be given to one of the two assumptions on foreign trade as well as on the use of old or equilibrium prices, four SNI variants are calculated’ (ibid, 284). These are shown in Table 3.1 along with the calculated impact of implementing SNI under each set of assumptions.

Assumptions of the model	Calculated impact of SNI
Constant relative prices on the world market and SNI expressed in relative prices of the base situation	All sustainability standards are met National income is 45-47% lower
Constant relative prices on the world market, but SNI expressed in new equilibrium prices	
Constant share of imports and exports and SNI expressed in relative prices of the base situation	Some indicators still below sustainable standards National income is 64-66% lower
Constant share of imports and exports, but SNI expressed in new equilibrium prices	

Table 3.1. Four models for calculating SNI. Source: from Verbruggen *et al.*, 2001, 284-95

In a different study that attempts to model SNI in the Netherlands, Gerlagh *et al.* (2002) use a model that 'combines the advantages of a top-down approach with the information of a bottom-up approach' (ibid, 157). Top-down models have a consistent representation of the economy, the behaviour of producers and consumers, and the costs of emission reduction. Unfortunately, top-down models lack detail; bottom-up models provide such detail, but at the expense of internal consistency. See Tol (2000) for a further discussion.

The type of model used by Gerlagh *et al.* (2002) could be considered a 'hybrid model' (discussed below). The conclusion reached is that 'in 1990 Dutch SNI is about 50 per cent below net national income' (ibid), similar to the results reached in the study by Verbruggen *et al.* the previous year.

Verbruggen *et al.* recognise that one of the deficiencies of calculating SNI is that 'the modelling of international trade needs more attention' (2001, 303). An effort to remedy this defect was undertaken by Steininger (1999), who posed the following questions:

- 'Which countries export goods the production of which is pollution-intensive?
- Can a country introduce an energy or CO_2 tax without significant implications for its trade flows or for industry migration?
- How does trade liberalisation affect the environment? (1999, 416)

Among other conclusions, Steininger notes that 'the significance of geographical distance in trade theory and policy has been largely neglected', backing up the assertions of Verbruggen *et al.* that CGE models need to accord greater significance to international trade flows as well as environmental endowments.

The specification of a particular CGE model is very important in regard to the results that it provides. The complexity of a model – whether it incorporates international trade or real prices, for example – as well as the relative bias it accords to economic and environmental indicators, can impact significantly on the policy recommendations that may be adopted based on a particular model.

3.1.5 Econometric models

By its nature, an econometric model is an economic model formulated so that its parameters can be estimated if one makes the assumption that the model is correct. As such, formulating an econometric model of the environment requires some degree of prior knowledge about the likely inputs and outputs that affect both the environment and economy of a chosen system. Therefore, models of this kind are often actually hybrid models that seek firstly to estimate the likely parameters of the environment-economy relationship, and secondly to test the nature of that relationship by using econometric methods.

For example, although E3ME (short for Energy-Environment-Economy Model of Europe) – a pan-European environmental modelling project using econometrics – claims to ‘provide a one-model approach in which the detailed industry analysis is consistent with the macro analysis’, in reality it ‘combines the features of an annual short- and medium-term sectoral model estimated by formal econometric methods with the detail and some of the methods of the CGE models’ (Cambridge Econometrics, 2006). Nevertheless, the E3ME model is capable of being recalibrated to produce predictions and policy alternatives (Barker, 2000).

Don (2004) has noted that in the absence of a hybrid model ‘the interaction between the policy-maker and the model-cum-expert system then takes the form of an iterative trial-and-error procedure’ (25). Far from being a fault in econometric modelling of policy choices, this procedure can help to simulate the estimation of parameters – such as a welfare function – that would otherwise be arrived at by a system of ‘prior knowledge’ that may or may not involve another form of model (ibid).

In an Irish context, there are currently two significant models of the economy – the Central Bank’s model and the ESRI’s HERMES model.[29]

The Central Bank’s model has been in existence since 1999, and has recently been updated and recalibrated (see McQuinn *et al.*, 2005). Although it can be used as a ‘stand-alone’ model, it has also been included in ‘linked mode simulations with other country models to generate euro area projections and responses to shocks’ (ibid, 3). In a domestic context, the model is regularly used to model medium- and long-term forecasts of the national economy, and has been used to test the economy’s readiness for ‘shocks’ such as oil price increases and a correction in the construction sector (ibid).

The ESRI’s medium-term economic model was developed in similar circumstances, as part of a Europe-wide effort to coordinate national macroeconomic modelling under a project entitled HERMES in the early 1980s. Of the national models developed at this time, the Irish model is one of the few that is still in existence[30], and

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[29] Other much smaller models are available as part of the EU QUEST project, and the UK NIESR NiGEM model. In the past, general equilibrium models have been developed by University College Dublin and Trinity College, Dublin, but they have not been developed or maintained on a continuous basis.

[30] Bossier *et al.* (2000 and 2002) have used the Belgian version of the HERMES econometric model – in conjunction with an input-output model – to model CO_2 emissions in Belgium. In other countries, pure econometric models have been replaced with models that are a hybrid between econometric models and computable general equilibrium models. See Bray *et al.* (1995) for a review of the situation in the UK.

has developed and evolved during the last twenty years. The model is structured as follows:

> 'The ESRI economic model of the Irish economy focuses initially on the output (or production) relationships [between actors in the economy], and examines the downstream expenditure and income consequences. The key mechanisms within the model are:
>
> 1. The exposed sector is driven by world demand, elements of domestic demand, and cost competitiveness.
> 2. The sheltered market sector (services and building) is driven by domestic demand.
> 3. The public sector is policy-driven, with treatment of borrowing and debt accumulation
> 4. Wages are determined in a bargaining model, and influenced by the factors that affect the supply and demand for labour – e.g. prices, taxes and unemployment.
> 5. The labour market is open and influenced by conditions in the UK labour market.' (Bergin *et al.*, 2003)

Macro-econometric models are particularly useful in the medium term. For short-term forecasting, other model types (particularly decomposition and input-output models) can be more accurate.

It is thus perhaps not surprising that in order to analyse the economic impacts of the 1997 EU energy tax in the short-, medium- and long-term, Jansen and Klaassen (2000) employed three different types of models. As the authors explain:

> 'Three different macroeconomic models were employed to assess the economic impacts of the directive: HERMES (Harmonised European Research for Macrosectoral and Energy Systems), GEM-E3 (General Equilibrium Model for Economy-Energy- Environment), and E3ME (Energy-Environment-Economy Model for Europe). While having a number of points in common, these models cover a broad scope of economic modelling approaches, thus allowing insights into the robustness of the models involved' (ibid, 183).

As such, the authors employ input-output, Computable General Equilibrium and econometric models in the same framework.

In constructing the ISus model it may be advisable to build on existing models such as those discussed in this section, as forecasts are required for the medium- and long-term, but not necessarily for the short-term.

3.1.6 Optimisation models

Optimisation models consist of an intertemporal objective that must be optimised subject to a set of constraints (on time, money, resources, etc.).

Feenstra *et al.* explain that:

> 'optimal control theory originated as a mathematical tool to solve problems of dynamic optimisation. Applying it to economic problems allows the explicit consideration of time. This makes it suitable for

> analysing the intertemporal trade-off between current consumption and future pollution or exhaustion of natural resources that is inherent in many environmental problems' (1999, 1099).

The Dynamic Integrated Climate-Economy (DICE) model of the economics of global warming presents just such a situation. Nordhaus explains that it was developed to provide input to the Intergovernmental Panel on Climate Change (IPCC), the World Climate Conferences and the United Nations Conference on Environment and Development (the Earth Summit).

One difficulty that Nordhaus recognised was that the DICE model 'must take into account, above all, the long time lags between actions or policies and responses. Nations must take steps now in order to slow climate change over the coming centuries' (1992, 4). The DICE model adopted the following format:

> 'The basic approach is to use the Ramsey growth model[31] of optimal economic growth with certain adjustments and to calculate the optimal path for both capital accumulation and GHG-emission reductions. The resulting trajectory can be interpreted as either the most efficient path for slowing climate change given initial endowments or as the competitive equilibrium among market economies where the externalities are internalised using the appropriate social shadow prices for GHGs' (ibid).

By 2000, Nordhaus and Boyer had updated the DICE model and the closely related RICE – the Regional Integrated model of Climate and the Economy. They note that 'the purpose [of the updated RICE model] is to integrate scientific knowledge of the dynamics of climate change with understanding of the economic aspects of emissions of greenhouse gases and damages from climate change' (2000). As such, it could be classified as a hybrid model (see below), as it encompasses elements of natural science modelling in order to derive a more accurate estimation of climate change. That it derives from DICE, and that its results are used as a basis of comparison for this model (and vice-versa), means that it is more prudent to discuss it here. Indeed, its economic basis is from optimisation modelling; as the model's designers note: 'the basic approach taken in analysing the economics of climate change is to consider the trade-off between consumption today and consumption in the future' (ibid).

The RICE model has unearthed three 'major results':

- Firstly, Nordhaus and Boyer note that an emissions growth path 'that limits CO_2 concentrations to no more than doubling of pre-industrial levels is close to the "optimal" or efficient policy'. By contrast, current approaches, such as the Kyoto Protocol, are highly inefficient, with abatement costs approximately ten times their benefit in reduced damages' (ibid).
- Secondly, according to the RICE model, 'the optimal carbon price in the near term is in the \$5 to \$10 per ton range' (ibid).[32]

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[31] The Ramsey growth model is a neo-classical model of economic growth. Unlike the Solow model, the Ramsey growth model, does not incorporate an endogenous saving rate. As a result, the saving rate in general is not constant and the convergence of the economy to its steady state is not uniform.

[32] On Jan 2, 2007, the price was €6.55/tCO_2 according to www.pointcarbon.com

- Thirdly, the RICE model is far less pessimistic about future trends in climate change than previous and subsequent models have been. It predicts a baseline scenario of uncontrolled warming of 2°C by 2100, compared to 'at least a 50% risk of exceeding 5°C global average temperature change' predicted in the Stern Review on the economics of climate change (2006, iv), and the 3.3°C predicted in the original DICE model (Nordhaus and Boyer, 1999).

Fankhauser and Tol (2005) present another example of optimisation models in environmental economics. They employ the basic tenets of the DICE model, allowing for a focus on changes in 'dynamic interlinkages' (how climate change may affect welfare in the future), capital accumulation and savings behaviour as climate change affects the economy and vice versa. Their analysis concludes that 'climate change will always have a negative effect on the capital stock…[and] net savings will always be reduced. These results hold independent of the choice of discount rate' (ibid, 12). This result is significant because, as the authors explain, 'the traditional enumerative studies [econometric, decomposition, input-output models] of climate change impacts underestimate the true costs of climate change' (ibid).

However, Fankhauser and Tol are also keen to point out two limitations of optimisation models. Firstly, in their own model and others, savings and capital accumulation are not the only ways in which climate change can affect economic growth, although their model could be expanded to account for more parameters, as well as international trade effects (the model assumes a closed economy). Secondly, they note some theoretical problems with their model. They have largely ignored the interaction between a changing environment and health effects, and have assumed that welfare maximisation is the rational choice for society (2005, 13).

Finally, in another example of a hybrid model of environment-economy relationships, Klaassen *et al.* (1999) link the MARKAL optimisation model[33] with an input-output model. The authors explain that:

> 'The linkage between MARKAL and the IO model is established through two interfaces. The first interface transforms and re-allocates energy costs associated with MARKAL technologies to comply with the structure of the IO model. The second interface uses the results from the model to calculate the induced changes in useful energy demand level for MARKAL. This procedure is iteratively repeated until the model results of MARKAL and IO converge and a new optimal solution is found'(ibid, 1).

Another extension of optimisation modelling has been undertaken by the International Institute for Applied Systems Analysis (IIASA). The MESSAGE model is 'a systems engineering optimization model used for medium- to long-term energy system planning, energy policy analysis, and scenario development' (IIASA, 2006). MESSAGE provides the framework for analysing energy systems from resource extraction to usage across eleven world regions. It has been used to assess mitigation strategies for carbon dioxide (Riahi and Roehrl, 2000a) and other greenhouse gases (Riahi and Roehrl, 2000b), as well as for deriving scenario analyses for the

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[33] MARKAL (MARKet ALlocation) 'is a generic model tailored by the input data to represent the evolution over a period of usually 40 to 50 years of a specific energy system at the national, regional, state or province, or community level' (IEA, 2006).

Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic, 2000). The model is constantly extended, and is now the first to include emissions of black and organic carbon their abatement (Rao, personal communication, 2006).

IIASA has also developed the Regional Air Pollution Information and Simulation (RAINS) model, and its extension, the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model. Both of these are optimisation models, but whereas RAINS addresses threats to human health and the environment that are posed by acidification, GAINS uses scientific methods to analyse the synergies that occur between various pollutants in the atmosphere, and – separately or jointly – how they cause a variety of environmental effects at the local, regional and global levels. The models' designers explain that 'The RAINS model framework makes it possible to estimate, for a given energy and agricultural scenario, the costs and environmental effects of user-specified emission control policies' (Amann *et al.*, 2004). As such, it qualifies as an optimization model.

Optimization models have also been applied to find least-cost solutions to meeting targets for eutrophication, for the Rhine basin (van der Veeren and Tol, 2001), for the Baltic sea catchment (Gren *et al.*, 1997), and even for the whole of Europe (Warren and ApSimon, 2000). The last study appropriately includes the interactions between acidification and eutrophication policies.

It is apparent that optimisation models are widely used in environmental economic modelling. However, the experience and research of Bray *et al.* advocates a careful approach to the use of such models that requires the ongoing participation of the eventual policy maker.

3.1.7 Hybrid models

Tol explains that:

> 'Hybrid models are economic models with a detailed representation of the supply side of energy, including transformation technologies and reserves of energy carriers. Prime examples are MERGE, CETA, SGM, GTEM, and MS-MRT. Unlike top down models, which rely on aggregate production functions, hybrid models cannot burn more gas than there is, distinguish between nuclear power and biomass as alternatives to fossil fuels, and explicitly treat the changes in relative prices between alternative energy carriers. Hybrid models are thus considerably more realistic and offer substantially more insight than traditional top-down models. Hybrid models also have better economics than bottom-up models' (2000, 3).

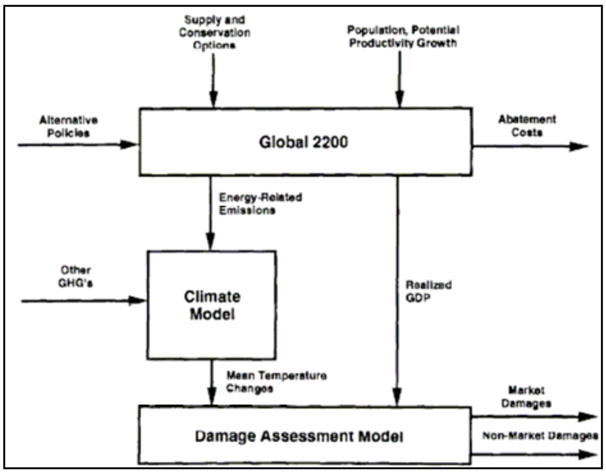

Fig. 3.2. Overview of the MERGE model. Source: Manne *et al.* (1995, 18)

MERGE and CETA are optimization models, resembling DICE and RICE in principle but with much detail added. SGM, GTEM and MS-MRT are computable general equilibrium models, but selected production functions were replaced with engineering detail.

Each of the models identified by Tol is discussed below.

- MERGE (Model for Evaluating Regional and Global Effects of GHG reductions) 'consists of a series of linked modules representing the major processes of interest' (Manne *et al.*, 1995, 18). These modules represent the cost of reducing emissions, the reactions of natural systems to these emissions, and the reaction of human and natural systems to changes in the atmospheric/climate system (ibid). This is achieved by integrating three submodels: Global 2200 (an applied general equilibrium model for assessing the costs of emissions out to the year 2200), a climate submodel (which models 'the relationship between man-made emissions and atmospheric concentrations and the resulting impact on temperature'), and a damage assessment submodel (that values the environmental impact of climate changes) (Manne and Richels, 1999, 4).
- The CETA (Carbon Emissions Trajectory Assessment) model is structurally based on the Global 2100 model (the fore-runner to the Global 2200 model that forms the basis of MERGE – see above), but incorporates an energy submodel, a production submodel and a warming submodel (Peck and Teisberg, 1992). As such, it is quite similar to the MERGE model (Peck and Teisberg, 1999, 368).

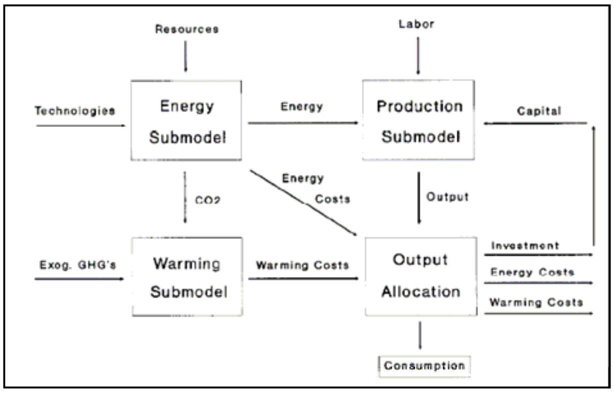

Fig. 3.3. Overview of the CETA model. Source: Peck and Teisberg, 1992, 58

- SGM (Second Generation Model) builds on the GCAM (Global Change Assessment Model), a model developed in the US in the early 1990s. It is 'a computable general equilibrium model that projects economic activity, energy consumption, and carbon emissions for twelve world regions' (MacCracken *et al.*, 1999, 27). The model is outlined in Fig. 3.4. Edmonds *et al.* explain the diagram:

  'On the left hand side of Fig. 3.4 are two sectors that create final demands for new net goods and services production in the economy, the household and government sectors. On the right hand side of Fig. 3.4 are the sectors of the economy that produce new final goods and services, the energy production and transformation, agricultural, transportation, and industrial and services sectors. In addition to the production and consumption of goods and services, Fig. 3.4 indicates that the release of greenhouse related emissions to the atmosphere are tracked by the point of release' (Edmonds *et al.*, 2004, 9-10).

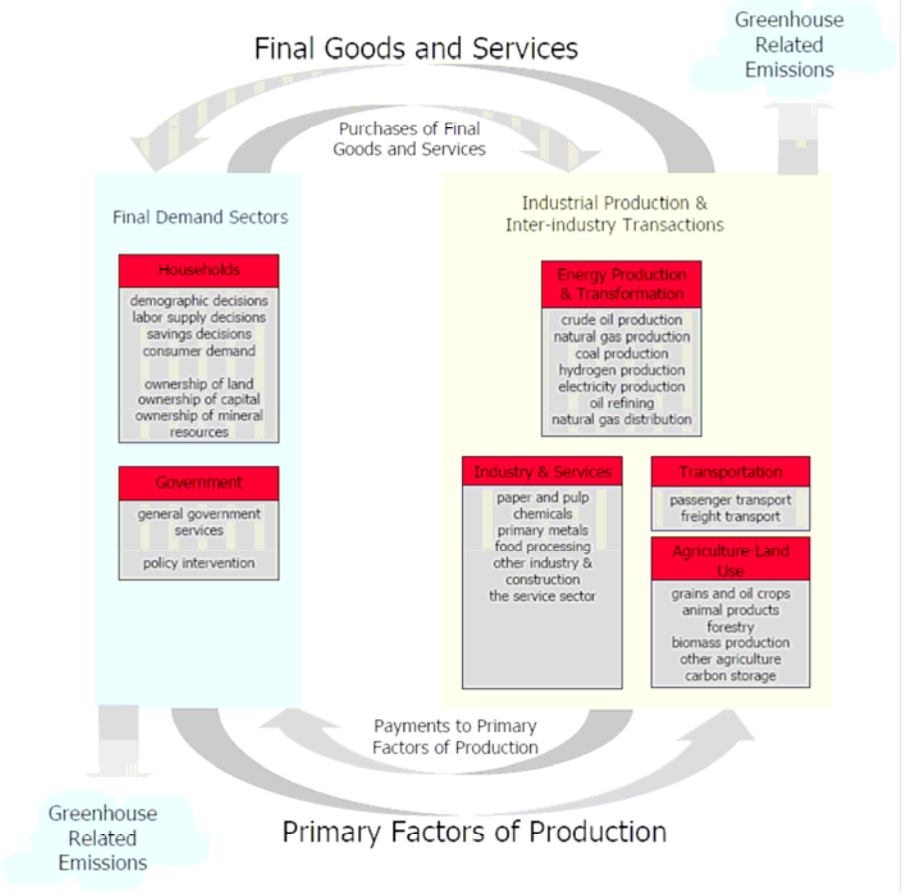

Fig. 3.4. Overview of the SGM model. Source: Edmonds *et al.*, 2004, 10

- GTEM (Global Trade and Environment Model) is a recursive dynamic general equilibrium model of the world economy developed by the Australian Bureau of Agricultural and Resources Economics 'specifically to address policy issues with long term global dimensions' (Pant, 2002). The regional coverage includes detail for only 5 EU countries: Denmark, Finland, Germany, Sweden, and the United Kingdom. The greenhouse gas coverage in GTEM includes carbon dioxide, methane and nitrous oxide, as well as removals by forest sinks. Viguier *et al.* note that 'the GTEM model has been used to analyze the economic impacts of the Kyoto Protocol on different regions, such as developing countries and European countries' (2003, 464; and see Tulpulé *et al.*, 1999).

- The MS-MRT (Multi-Sector Multi-Region Trade) model adopts a similarly disaggregated depiction of the world economy as is portrayed in the MERGE model. According to the consultancy CRAI, MS-MRT is capable of analysing 'differences in energy intensities across countries and differences in the composition of industries' as it 'includes Social Accounting Matrices and bilateral trade flows for 55 countries/regions and 8 industries' (CRAI, 2006). Otherwise, it is similarly structured to MERGE, such that it adopts its 'business as usual' scenario from that model, while allowing policy changes and

> changes in production, trade and technology/productivity to be modelled in MS-MRT.

The hybrid models above are extended economic models. Tol (2000) also recognises another form of hybrid models: extended engineering models. In explaining these he notes that:

> 'The novel aspect is that these models, like new growth models[34], endogenise technological progress based, unlike new growth models, on learning by doing, implying that the average costs fall if volume increases, not because of economies of scale, but because of experience gained' (ibid, 4).

As Tol notes, it is possible for these models to better describe the economy (than earlier engineering models might), but their assumptions and parameterisations may undermine any result.

A project was launched in 2002 by the Alliance for Global Sustainability involving two separate research groups[35] to assess the role of technological change in transportation systems, and their environmental impact (see Krzyzanowski *et al.*, 2004). The authors explain that:

> 'While the first group [MIT] was concerned with linking the general-equilibrium top-down and the bottom-up, energy-systems (MARKAL) approach, the focus of the second group was the integration of technological learning by doing (LBD) in transportation technologies in the "bottom-up" component of the modelling system. MIT has successfully completed the link between the three models (without endogenous technological learning components) in a consistent framework (Schafer and Jacoby, 2003), while PSI [the Paul Scherrer Institute] has contributed to the introduction of LBD in the context of the MARKAL model and of a stand-alone simplified transportation model' (ibid).

Essentially, hybrid models of this kind look outside the traditional disciplines of the social sciences and engage the natural sciences, particularly models associated with engineering systems. As such, they can have a better understanding of technological change and how it can impact on the environment.

The word 'hybrid' can thus describe two types of environmental economic model; one with a detailed representation of energy supply; or one that builds on new growth models, but with a more complex description of technological change. Whereas the latter is a developing area of research that has only recently been applied to environmental modelling, the former is something of a necessity in building advanced – particularly econometric – models.

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[34] New growth models (or 'endogenous growth models') are distinguished by their treatment of technological development. They rely on 'virtuous cycles', wherein new technologies are 'produced' and importance is thus given to human capital. Some of the knowledge associated with the innovation "spills over" to other economic actors, which increases those actors' ability to innovate.

[35] The two research groups are the Center for Technology, Policy & Industrial Development, Massachusetts Institute of Technology (MIT) (H. Jacobi and A. Schäfer) and the Energy Economics Group of the Paul Scherrer Institute (PSI) in Switzerland (S. Kypreos, L. Gutzwiller, D.A. Krzyzanowski and L. Barreto).

3.2 Land Use Models

3.2.1 Land use in economics

The root of the word economics is in the Greek for 'laws of the household' – particularly referring to the traditional farm, for which subsistence and barter were more important than trade.[36] The first systematic economists, the Physiocrats, argued that agriculture was the primary sector, and that land was the only true source of value. The Classical economists similarly placed substantial emphasis on agriculture and land. David Ricardo's (1815) notion that land rents reflect land quality is hotly debated today (Mendelsohn *et al.*, 1994; Darwin, 1999; Schlenker *et al.*, 2005, Timmins, 2006). Economic textbooks still explain decreasing returns to scale with the example of additional farmhands on a field using Turgot's (1793) intensive margin.[37] Steuart's (1767) extensive margin,[38] another source of decreasing returns to scale, similarly seeks to explain land use patterns. Further, externalities are often introduced with the example of the beekeeper and the farmer.[39] However, as agriculture is a minor economic sector in industrialized countries nowadays, it is the vertically integrated manufacturing sector that serves as the canvas upon which much of modern economic theory is painted.[40]

Land *use* has attracted even less attention. In the Classical literature, there is Von Thuenen's (1826) model of farm specialization as a function of the distance to town, and Zipf's Law on the relative size of cities (e.g., Duranton, 2006).[41] In economic geography, there are the location analysis of Weber (1909) and the central-place theory of Christaller (1966) and Loesch (1964). But land use plays a minimal role in current economic theory. Partly, this may be because land is a minor problem. The built environment, and hence more than 95% of the world economy, occupies less than 1% of the land surface (Gruebler, 1994). Distance matters, of course, but can be parameterized (e.g., as in Samuelson's iceberg model[42]) without an explicit two-dimensional model of the land surface. Krugman (1998b) offers another explanation: City formation can only be explained by a combination of congestion and agglomeration externalities. As agglomeration implies increasing returns to scale, city formation resisted rigorous analysis until the monopolistic competition revolution (Dixit and Stiglitz, 1977).

This has now changed (Krugman, 1991; Fujita *et al.*, 1999; Brakman *et al.*, 2001). New economic geography offers micro-founded, general equilibrium models of activity location (Krugman, 1998a). See Martin (1999) and Henderson (1974) for a defence of the "old" economic geography of Isard (1956). New international economics has its roots in the monopolistic revolution too. Rossi-Hansberg (2005) shows that, in a spatial model, tariffs and transport costs are different – tariffs are step

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[36] The word "economics" is from the Greek words οικος [oikos], meaning "family, household, estate," and νομος [nomos], "custom, or law".

[37] Intensive margin refers to the degree (intensity) to which a factor of production is utilized or applied.

[38] Extensive margin refers to the range to which a factor of production is utilized or applied.

[39] Meade (1952) described how an apiary next to an orchard causes a positive externality. For a summary, see Maskin (1994, 333-4).

[40] See Hubacek and van der Bergh (2006) for more historical perspective.

[41] Zipf (1935) specified the functional form, but only applied it to the relative frequency of words.

[42] Samuelson (1954) described how a moving iceberg loses mass as it drifts. This is analogous to goods being lost in transport, which can be difficult to model.

changes, whereas transport costs are continuous. Bioeconomics is also adopting spatial analyses (Sanchirico and Wilen, 1999), particularly in the investigation of marine protected areas (Smith and Wilen, 2003). General equilibrium models of ecosystems are now emerging (Tschirhart, 2000, Finnoff and Tschirhart, 2003) and have recently been extended to include land – as a factor of production, not for humans but for plants (Eichner and Pethig, 2006). As promising and exciting as these developments may be, this is theory only (Neary, 2001) – with a few empirical tests (see Brakman *et al.*, 2006). Although this work is increasingly applied (e.g., Stelder, 2005), practical applications cannot be expected in the near future – at least, not in the sense of a calibrated global model that can be used for numerical questions on climate policy. Empirical analysis and operational models particularly suffer from lack of data. Nordhaus (2006) is a first step towards spatially explicit economic data.

Recent developments in land use modelling have hardly been revolutionary, applying established methods, and relying instead on a break-through on the data front in order to be distinguished. Only now do we have access to globally consistent databases of land use, coupled with data on the physical characteristics of land and the environment.

3.2.2 Geographic models of land use

Geographers obviously have a keen interest in land use. Most geographic models are small-scale, often limited to a small part of a country, and cannot be generalized; indeed, many geographers resist generalization and large-scale research, and mathematical analysis and numerical models are not core tools for much of this work. Nonetheless, there are a few large-scale models of land use. Heistermann *et al.* (2006) distinguish between statistical models and rule-based models.

CLUE is a prominent example of a statistical model (Veldkamp and Fresco, 1996). Most of the equations in the model are estimated by multiple regression, but the model is completed by rule-based competition and transition. The largest scale applications of CLUE are for China (Verburg *et al.*, 1999) and for tropical South America (Wassenaar *et al.*, forthcoming). The latter model works at the impressive resolution of 3x3 km.

SALU and IMAGE are examples of rule-based models. In both of these models demand-driven expansion of agricultural production is met on the basis of a suitability ranking, based on soil, climate, distance and so on. The trade-off between infra- and extra-marginal expansion is modelled in a similar way. The SALU model (Stephenne and Lambin, 2001, 2004) is restricted to the Sahel, but the IMAGE model (Alcamo *et al.*, 1998) is global with a spatial resolution of 0.5°x0.5°.

In ACCELERATES (Rounsevell *et al.*, 2003) and KLUM (Ronneberger *et al.*, 2005), the rules are derived from profit maximization. In both cases, a risk-averse farmer maximizes profits given prices of inputs and outputs, and a probability distribution of yields.

3.2.3 Economic models of land use

Partial equilibrium models are based on the same optimization principles as KLUM, but include the response of prices to changes in production and consumption. Examples are IMPACT (Rosegrant *et al.*, 2002) and WATSIM (Kuhn, 2003) for agriculture; GTM (Sohngen *et al.*, 1999) for forestry; and AgLU (Sands and Leimbach, 2003) and FASOM (McCarl, 2004; Adams *et al.*, 2005) for both agriculture and forestry. The distinct advantage of partial equilibrium models is that they are more flexible and less computationally intensive than general equilibrium models. Further, their data needs are less at any given level of spatial and sectoral resolution. As a result, partial equilibrium models often have substantial spatial and crop detail.

The disadvantage of partial equilibrium models is that the rest of the economy is ignored. General equilibrium models do not have this problem. The first global computable general equilibrium model with land use disaggregated by physical characteristics is the FARM model by Darwin *et al.* (1995). Land, a non-tradable endowment in a CGE model (perhaps as part of an aggregate endowment), is split into a number of different categories, distinguished by productivity. Land endowment by category is an aggregate taken from a spatially explicit bioclimatic model. The model has been used to estimate the impacts of climate change (Darwin, 1999, 2004; Darwin and Kennedy, 2000), of sea level rise (Darwin and Tol, 2001), and of nature conservation (Lewandrowski *et al.*, 1999) – each of which changes the relative land endowments.

Note that changes in demand for land were met, in the spatially-explicit biophysical model, on the basis of rules, rather than on the basis of optimal behaviour. That is, Darwin *et al.* (1995) brought biophysical realism into their economic model, but they did not bring economic realism into their biophysical model.

GTAP-L (Burniaux and Truong, 2002) extends the work of Darwin *et al.* (1995) through the introduction of the transformation of land (from one crop to another), thus introducing competition between alternative land uses. The input data were imperfect, however. The GTAP-AEZ model (Hertel *et al.*, 2006) combines the theoretical and empirical strengths of FARM and GTAP-L.

3.3 Conclusion

A number of modelling methods have been discussed in the above section. It is likely that in the construction of the ISus model many of these methods will have to be employed, particularly in relation to the construction of 'sub-models' (see section 6, below). For example, the prototype ISus model developed by O'Doherty and Tol (2007) took the form of an environmental input-output model, while in its final incarnation the model will link with the ESRI's HERMES model – an econometric model of the Irish economy. Land use models are likely to be important also.

All of the models noted above rely to some degree on price information and valuation of the environment. As such, this will be discussed in the next section.

4 Environmental valuation

Recreational resources such as forest parks, river activities or hiking are often the victims of commercial, agricultural or residential development. These environmental amenities are open to public use and can often be appreciated at no cost. However, the preservation of these sites from development depends on their perceived value. The absence of a market for these goods does not imply that they have no value. Indeed, as they impart a social benefit on their users (through recreation) a monetary value can be attributed to them – and this monetary value can be used to demonstrate the worth of nature conservation. The values of environmental amenities can be divided into two main groups — use values and non-use values.

Use values are those that are derived from an individual's direct enjoyment of the environment. For a fisherman, the use value of a fully stocked river is very high. On the other hand, non-use values do not require that any utility be derived from the use of the resource. The utility an individual gains from the environmental good is intrinsic. For instance, for someone living in Ireland, the use value of an elephant in Zambia is minimal. Nevertheless, individuals still associate the possibility of being able to someday potentially see that elephant with a value — an *option value*. Individuals can also improve their utility just by knowing that elephant exists, this is the *existence value* of an environmental amenity or that their children may one day benefit from its existence, this is the *bequest value*.

The sum of these values is the Total Economic Value (TEV). The development of techniques that allow economists to calculate these values has been relatively recent and these methods are still being improved, although not all take into account use and non-use values. Nevertheless taking into account the TEV of an environmental amenity when addressing environmental policy is crucial. The following techniques are those most commonly used in practice.

3.4 Valuation theory

Valuation methods are commonly divided into *revealed preference* and *stated preference* techniques. Revealed preference techniques derive the value of environmental amenities from market prices, while stated preference techniques ask individuals directly how much they value a specific quality level of an environmental amenity. While certain techniques are more applicable to certain types of environmental resources than others, all results from these projects should be taken purely as orders of magnitude and guidelines. Revealed preference methods are largely limited to use values, while stated preference methods can estimate both use and non-use values; revealed preference methods are more reliable, however, and less subject to bias.

4.2.1 Hedonic pricing

The hedonic pricing method is a revealed preference technique. This is a regression method that links the prices of goods such as property values or wages (whose separate characteristics can be analysed) to environmental attributes. By decomposing a market good into separate characteristics, these can then be used to estimate how much the price varies in relation to each of the characteristics. First, Willingness-To-

Pay (WTP) for a good with certain attributes is estimated, then the demand function for a change in an environmental amenity is formulated and the associated consumer surplus can be estimated. Individual consumer surpluses are then aggregated to obtain the total value of a change in the environmental amenity. The hedonic pricing technique can be difficult to implement in practice due to the amount of variables and data required for it to be feasible. Moreover, it does not take into account non-use values or households' future expectations, both of which are further limitations of the hedonic pricing technique.

4.1.2 The Travel Cost Method

The travel cost method (TCM) is another revealed preference method of estimation. The costs incurred by a person when visiting a site, such as entry fees, accommodation costs and the time and nuisance costs of travel, can be used to infer the value attributed by that person to a visit. The value of the site can be derived from the demand function estimated by observing users' behaviour in relation to costs sustained per number of visits. Degradation or amelioration in site quality can then be valued in monetary terms. There are two types of TCM, the Zonal Travel Cost Method (ZTCM) and the Individual Travel Cost Method (ITCM). The former takes into account the frequency rate for different zones, while the latter examines the behaviour of a single user.

Although the method is frequently used, there are a number of problems. First, as surveys are usually conducted on site there can be a sample bias, as non-visitors are not taken into account. Secondly, the likelihood of a person being sampled will depend on how often that person visits the site; this is the problem of endogenous stratification. Moreover, the technique does not take into account the fact that trips may be multi-purpose and that different sites, although they comprise the same amenity, can be quite distinct.

4.1.3 Contingent valuation techniques

Contingent valuation methods are a type of stated preference technique, which can assess use and non-use values. Individuals are asked directly how much they would be willing-to-pay for an increase in the quality of an environmental amenity or how much they would be willing-to-accept in compensation for a decrease in the quality of an environmental good. From these questions it is possible to infer the willingness-to-pay (WTP) or willingness-to-accept (WTA) for a unit change in the quality of an environmental amenity and consequently construct a hypothetical market for that amenity and put a monetary value on the good. In practice, this is achieved by asking individuals a series of questions. They can be in an open-ended referendum format, i.e. of the type "how much would you be willing-to-pay to conserve this area of forest?" There are also dichotomous questions such as "would you be willing-to-pay €5 for an increase in the quality of this good?" Finally, questions can form part of an iterative bidding process, e.g. "Would you be willing-to-pay €10? If yes, then would you be willing-to-pay €15? If no, then would you be willing-to-pay €5?", etc.

As with any of these techniques there are problems relating to data collection and the model. First, it has been argued that results can vary a great deal depending on the type of question asked. Moreover, it would seem that respondents have difficulty conceptualising an inexistent market (hypothetical market bias) and may overstate their WTP or may answer strategically instead of truthfully. Finally, results can be biased, as some respondents will have a tendency to free-ride. In order to avoid these problems, the payment vehicle and amount will have to be made clear to respondents before they reply to questions.

4.1.4 Choice modelling

Choice modelling comprises choice experiments, contingent ranking and contingent rating, which are all stated preference methods. Respondents are given a choice of scenarios which comprise different characteristics at different levels and are asked, depending on the method, to respectively choose their most preferred scenario, to rank them from their most to least preferred, or to rate all scenarios on a scale of 1 to 10. One of the characteristics will tend to be a monetary option. If a monetary characteristic is included, the values attributed by individuals to a one-unit change in a particular characteristic can be inferred. In this case, the individuals' WTP are implicit in their answers.

These methods consequently avoid the problems associated with contingent valuation, where respondents can over- or under-state their WTP. Nevertheless, there are also problems with these methods. The scenarios presented tend to include a status quo option which respondents will be drawn to. This is a version of the hypothetical scenario bias; individuals will choose the status quo, as they cannot visualize the real effect of any other option on their welfare. There are also problems with econometric model specifications and design issues that may bias results.

The following section will take a look at what applications of these techniques have been made in Ireland and in relation to which areas.

3.5 In practice – Valuation studies conducted in Ireland

Few environmental valuation studies have been conducted in Ireland and the ones presented here are all relatively recent. The use of the travel cost method, choice experiments and contingent valuation to evaluate Irish amenities are examined by environmental area and the results of these studies are summarised.

4.2.1 Rivers, water and recreation

Hynes and Hanley (2004) use the *Travel Cost Model (TCM)* to estimate the mean WTP of kayakers to use the Roughty river in Co. Kerry and as such the kayaking demand function. The conflict between commercial interests and recreational activities is often the precursor to such studies. The object of this study was to compare the value of preserving wild river assets versus developing them with hydro-electric power plants. In order to do so, the value of non-market benefits accruing from the preservation of the rivers – in this case the value of the river flows to recreationists – must be estimated. The interesting methodological advance of this study is the avoidance of endogenous stratification by pooling two sources of data, an on-site survey and an internet survey. There are also no problems relating to distinct sites and multi-purpose journeys as the visitors only travel to the site to go kayaking. The study reveals a consumer surplus per trip of €83.30 with 2.83 average trips per year. The WTP for the whole sample of 144 kayakers was then of €33,711 per year. A lower bound estimate of the total white-water kayaking population in Ireland is 5,000 kayakers. The results of this study were then further examined to determine whether kayakers with different skill levels had different valuations of the river. In order for figures to be more accurate, lost non-use values such as the scenic or cultural significance and the impact on the biodiversity of the rivers could be added to the study.

Curtis (2002) also uses count data and the TCM, this time to estimate the demand function for salmon angling in Ireland using 1992 data. He hopes that determining this function will allow fishery managers to identify key factors that can attract anglers to their sites. Furthermore, he hopes that a comparison of recreational and commercial values can also be inferred from the results of the study. The survey was only conducted on-site and hence in this sense the data is biased. The author also finds evidence of over-dispersion. The results indicate a mean consumer surplus of £675.70 (€882.84) per trip, with trips lasting an average of 4.9 days. This implies a mean consumer surplus of £138.60 (€181.09) per day. As WTP was found to be £206 (€269.15) per day, and travel costs only £68 (€88.84) per day there is a considerable benefit to anglers.[43]

4.2.2 Agriculture

Cambell, Hutchinson and Scarpa (2006) conducted two choice experiments and derived WTP estimates at an individual level for landscape improvements under agri-environmental schemes. Their data is from the Rural Environment Protection (REP) scheme. This scheme was launched in Ireland in 1994 and paid farmers to conduct their farming activities in an environmentally friendly manner and preserve the rural landscape. The benefits of the REP were then an improvement in the rural landscape, recreational amenities, preservation of native wildlife, etc. The authors wanted to measure the extent of these benefits. The experiments were designed to elicit willingness to pay (WTP) estimates for farm landscape improvement measures. Eight attributes were chosen; wildlife habitats, rivers and lakes, hedgerows, pastures, mountain land, stone walls, farmyard tidiness and cultural heritage, each with three levels of action to conserve or improve them; i.e. a lot of action, some action and no action. The results reveal that the scheme had positively contributed to the state of the rural landscapes and that the range of the values attached to the improvements varied significantly but were for the most part higher than the cost of the scheme. The results for the first choice experiment are summarized in Table 4.1. This valuation was then further used for other papers investigating some of the potential biases associated with choice experiments such as lexicographic preferences.

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[43] All £/€ conversions are based on IEP£1 at 1992 prices being equivalent to €1.307 on 1 February 2007 (According to fxtop.com).

	Mean WTP (€/year)
Wildlife Habitats - A lot	258.99
Wildlife Habitats - Some	186.46
Rivers and Lakes - A lot	547.85
Rivers and Lakes - Some	343.46
Hedgerows - A lot	160.66
Hedgerows - Some	85.06
Pastures - A lot	251.44
Pastures - Some	235.26

Table 4.1. Summary of results from choice experiments. Source: Cambell, Hutchinson and Scarpa (2006)

Hynes, Buckley and van Rensburg (2006) also investigate the value of agricultural land from a non-commercial perspective. Once again this paper was conducted because of a desire to observe the conflict between commercial farming activity and recreational activities. As countries become more and more urbanized, the value individuals place on the countryside and its associated activities increases. Using a TCM, the study estimates the mean WTP of individuals using a farm commonage site in Co. Galway. The authors aimed to find the first farmland recreation demand function for Ireland. Because of over-dispersion and on site data collection, traditional models could not be used and endogenous stratification and truncation were corrected. The gross economic value of the site as a recreational resource is also estimated and it is determined that Irish farmlands have a high recreational value. The mean number of trips per year to the Commonage area was found to be 3.51 trips with a travel cost of €9.67. Total consumer surplus per individual per year was €113.20. The annual recreation value of the commonage area for the sample was €27,280 per year and the site itself has a non-market value of €1.4 million per annum. Unfortunately, it is impossible to know what this represents in relation to the size of the site. Finally, mean WTP of the average individual using the site was €41.92. Once again the recreational value of a site is very high even without taking into account non-use values.

4.2.3 Forests

The effect of the creation of nature reserves in public woodlands on the WTP of individuals for recreational visits to forests was investigated in a paper in 1992 by Scarpa, Chilton, Hutchinson and Buongiorno. The creation of nature reserves in forests was thought to increase visitors' WTP as it preserves biodiversity and confers social benefits on visitors. A face-to-face contingent valuation survey was conducted in 26 forests with 13 sites in Northern Ireland and 13 in the Republic of Ireland and over 9,400 interviewees. The study underlines the impact of new nature reserves on economic welfare, which amounts to £0.5 million (€0.65m) a year. This is before taking into account the non-use values of the sites. The addition of a nature reserve to woodlands would result in an increase of WTP of between 22 and 56 pence (29-73¢). The total yearly welfare increase from the creation of nature reserves across all the sites surveyed in the Republic of Ireland is £318,042 (€415,538). There are other characteristics not examined here that will also have a positive influence on WTP, such as the size of the forest, the number of other visitors, or the age and type of trees.

In 1996, the Irish government announced its new long-term strategy regarding forests. Between 1996 and 2030, it aimed to increase forest cover from 8% to 18%. Funding to tree-planting schemes was to be extended. In order to value the benefits of this expansion, Clinch and Matthews (2001) – in the context of a contingent valuation study – conducted a survey in order to elicit the WTP for more or fewer forests. Finally, a report by Fitzpatrick Associates for Coillte in 2005 concentrated on the economic value of forest trails in Ireland. 3,000 households were questioned through a postal survey and 640 trail users were interviewed at 15 site locations. Using the contingent valuation method the WTP of respondents was calculated for both samples. The results show quite a wide range of figures; individual sites displayed varying levels of WTP, which ranged from €3 (Slish Woods in County Sligo) to €8 (Lough Key Forest Park in County Roscommon). This divergence could be due to different levels of activities available at the site or varying site quality or size. The average WTP for an individual site visit for postal respondents was €3.64. Those interviewed on site had a WTP of €5.42. This discrepancy is probably due to the fact that the sample of individuals surveyed by post probably do not use forest trails as much as those interviewed on site. Moreover, the latter, having just experienced the site, may have been more likely to approve of a higher monetary outlay. From this study the total non-market value of forest trails in Ireland was estimated at €95 million.

3.6 Conclusion

In the context of Ireland's increasing economic and urban development, being able to put a monetary value on the recreational and non-use value of its resources will be helpful in resolving the conflict often observed between commercial and environmental interests. Although there seems to have been recent growth in interest in the area, valuation studies of Irish environmental amenities are few and far between. Valuation of Irish nature assets will therefore have to be done by benefit transfer, using the few primary studies for Ireland as validity checks.

5 Indicators and data

Raw data on the environment can be difficult to accommodate in economic models. As such, methods of aggregation and simplification have emerged that allow indicators from environmental accounts[44] to represent natural phenomena such as resource depletion, CO_2 emissions or capital formation due to natural resources.

The System of National Accounts (SNA-1993) 'provides the worldwide macroeconomic accounting standards…but is too restricted with respect to environmental research questions' (Pedersen and de Haan, 2006, 20). In order to remedy this situation, the System of Environment and Economic Accounting (SEEA-2003) has been developed as a *satellite accounting system* to SNA-1993 to provide an objective system for analysing the effect of the economy on the environment and vice versa. Pedersen and de Haan observe that:

> 'Because SEEA-2003 is a satellite accounting system it is based on national accounts definitions…certain production and consumption activities carried out by resident units [economic actors in the economy], including their environmental consequences, may, however, appear outside the national territory…in contrast to this, conventional environment statistics, especially emissions inventories, often take a geographic view of the boundaries, irrespective of the kind of economic activity that lies behind them' (2006, 29).

This has two distinct advantages. Firstly, all emissions can be associated with the economies of individual countries – including international transport and other emissions that can be difficult to pin down to an individual economy. Secondly, environmental indicators are consistent with macroeconomic indicators such as GDP and growth per capita, and as a result, macroeconomic models that are based on these indicators.

The process of constructing indicators necessarily requires the aggregation of data in order to simplify its usage. The 'aggregation pyramid' and the 'information pyramid' are shown in Fig. 5.1. Commenting on this representation of environmental accounting, Pedersen and de Haan note that it demonstrates how SEEA-2003 observes both vertical consistency[45] and horizontal consistency[46].

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[44] Environmental accounts are designed to 'measure objectively and consistently how environmental functions contribute to the economy and, subsequently, how the economy exerts pressures on the environment' (Pedersen and de Haan, 2006, 20).

[45] Vertical consistency ensures that the 'definitions and identities of the accounts contribute to binding information at various levels together. The accounts provide users with the possibility of going deeper into the data structure underlying indicators targeting driving forces, pressures and responses' (Pedersen and de Haan, 2006, 30).

[46] Horizontal consistency ensures 'that it is meaningful to compare, for example, indicators for the economy with indicators for the environment' (Pedersen and de Haan, 2006, 30).

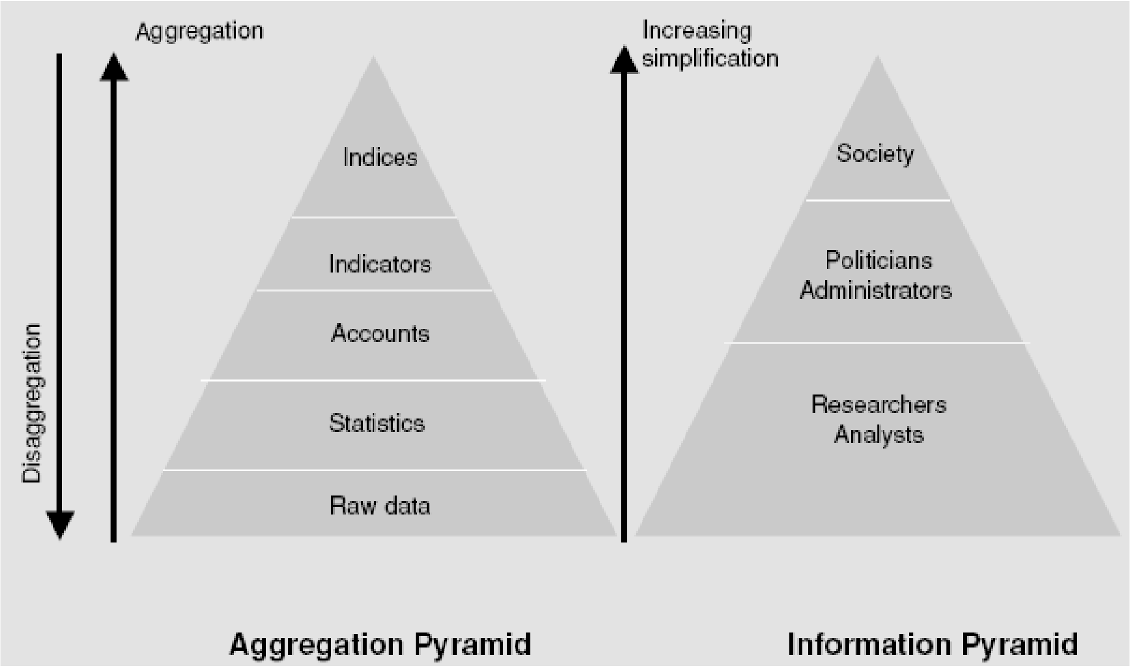

Fig. 5.1. Aggregation and information pyramids. Source, Pedersen and de Haan, 2006, 31

As a result of the principal of vertical consistency, physical and monetary indicators of the environment and the economy are comparable, and, when taken a step further, can be presented in the same set of accounts[47].

It is these accounts that have been used to assemble the dataset presented in Table 5.1. However, the environmental accounts for Ireland are limited to the emissions to air of six substances. This is a limited set compared to that of other European countries, as can be seen from Table 5.2. It should be noted, however, that many countries have no environmental accounts whatsoever. This is true for the USA, which has extensive and well-considered plans, but stopped collecting data in 1994 (Nordhaus, 1999a,b; Nordhaus and Kokkelenberg, 1999b). The EuroStat NAMEA has only threee gases. Nonetheless, it is clear that Ireland could achieve more in terms of its collection and dissemination of data.

Table 5.1 complements the environmental accounts of the CSO (2006) with data from various sources, particularly reports published by or for the EPA. Table 5.1 is restricted to data that is readily found in the public domain. This data was used for the prototype, ISus0.0 (O'Doherty and Tol, 2007).

In the second phase of the project, more extensive data will be collected. We may produce a pilot extension of the CSO's environmental accounts – noting that the ESRI is currently not equipped to take up a data collection role. Data sources include the following. Data on energy use can be sourced from Sustainable Energy Ireland. Data on land use can be found at the CSO and Teagasc. This data will substantially extend the resource accounts. Data on emissions from agriculture will be part of the development of the agricultural submodel. Fertilizer and pesticide use can be had

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[47] The acronym NAMEA – standing for National Accounting Matrix including Environmental Accounts – is often used for tables that 'combine monetary information from the national accounts consistently with selected parts of the physical supply and use tables for natural resources, products and residuals' (Pedersen and de Haan, 2006, 34).

from EuroStat. Additional waste data can be found at the EPA and IBEC. EuroStat holds data on total environmental tax revenue, but unfortunately not on a sectoral basis. The prime source for additional data, however, will be the EPA. Based on the EPER and IPPC, we will be able to cover emissions from large industrial sources. Current research (sponsored) by the EPA may allow us to extend the analysis to a range of industrial and pharmaceutical chemicals. The EPA-sponsored project on ecological footprints and material flow analysis of *EnviroConsult* may also be a source of useful data.

There is clearly a trade-off between comprehensiveness in data collection on the one hand, and data quality and the ability to understand, interpret and analyse data on the other. We will design the databases such that new data can be added at any time, and the model design will allow for data extensions too (see below). We will also introduce a system of flags, reflecting different levels of confidence in the data.

Table 5.1. Environmental data for the Republic of Ireland.

Substance	Medium	Theme	Period	Sector	Region	Source
CO_2	Air	Climate change	1994-2004	NACE (19)	Ireland	CSO (2006)
N_2O	Air	Climate change	1994-2004	NACE (19)	Ireland	CSO (2006)
CH_4	Air	Climate change	1994-2004	NACE (19)	Ireland	CSO (2006)
SO_2	Air	Acidification, air quality, climate change	1994-2004	NACE (19)	Ireland	CSO (2006)
NO_x	Air	Acidification, air quality, climate change	1994-2004	NACE (19)	Ireland	CSO (2006)
NH_3	Air	Acidification, eutrophication	1994-2004	NACE (19)	Ireland	CSO (2006)
CO_2	Air	Climate change	1990-2004	26	Ireland	EPA (no date)
N_2O	Air	Climate change	1990-2004	26	Ireland	EPA (no date)
CH_4	Air	Climate change	1990-2004	26	Ireland	EPA (no date)
NO_x	Air	Acidification, air quality, climate change	1990-2004	26	Ireland	EPA (no date)
CO	Air	Air quality, climate change	1990-2004	26	Ireland	EPA (no date)
VOCs	Air	Air quality, climate change	1990-2004	26	Ireland	EPA (no date)
SO_2	Air	Acidification, air quality, climate change	1990-2004	26	Ireland	EPA (no date)
HFCs	Air	Climate change	1990-2004	10	Ireland	EPA (no date)
PFCs	Air	Climate change	1990-2004	10	Ireland	EPA (no date)
SF_6	Air	Climate change	1990-2004	10	Ireland	EPA (no date)
BOD	Water	Eutrophication	1994	NACE (19)	Ireland	Scott (1999)
N	Water	Eutrophication	1994	NACE (19)	Ireland	Scott (1999)
P	Water	Eutrophication	1994	NACE (19)	Ireland	Scott (1999)
Water use	Water	Resource use	2001	NACE (10)	River basins	Camp *et al.* (2004)
Solid waste	Land	Waste	1995	NACE (19)	Ireland	Scott (1999)
Solid waste	Land	Waste	2004	NACE (19)	Ireland	EPA (2005)
Solid waste	Land	Waste	1995, 1998, 2001	NACE (2)	County	EPA (2003)

Table 5.2. Comparison of the environmental accounts of selected countries.

Country	Emissions	Resource use	Waste	Economics	Source
Ireland	CO_2, N_2O, CH_4, SO_2, NO_x, NH_3	None	None	None	CSO (2006)
Brazil	CO_2	Energy	None	None	Lenzen and Schaeffer (2004)
China	CO_2, NO_x, SO_x, NH_3	Energy	Industrial waste	None	Ike (1999)
Japan	CO_2, N_2O, CH_4, HFCs, PFCs, CFCs, SF_6, SO_x, NO_x, NMVOC, NH_3, N, P	Energy	Industrial waste	None	Ike (1999)
Germany	CO_2, CO, SO_2, NO_x, PM, CH_4, N_2O, NMVOC	None	None	None	Tjahajdi *et al.* (1999)
Netherlands	CO_2, N_2O, CFCs, NO_x, SO_2, NH_3, P, N	Energy	Waste, wastewater	Environmental protection expenditures, taxes	Keuning *et al.* (1999)
Sweden	CO_2, SO_2, NO_x, NMVOC, NH_3, N, P	Energy	Industry, household, hazardous; landfilled, incinerated, recovery	Environmental protection expenditures	Hellsten *et al.* (1999)
UK	CO_2, N_2O, CFCs, HFCs, NO_x, SO_2, NH_3, black smoke, CO, NMVOC, Benzene, Lead	Energy	None	Environmental taxes	Vaze (1999)

6. The Sustainable Development Research Model: Design Issues

The EPA and the ESRI are not unique in developing a sustainable development model such as the ISus model. The next section will demonstrate that projects similar to the ISus model have been – or are being – conducted elsewhere. The section then concludes with a discussion of the proposed specification and stages of development for the Isus model.

3.7 Activities in other countries

6.1.1 UK

The UK's Sustainable Development Commission is the government's independent sustainable development watchdog. In 2006 it produced a report titled 'I will if you will' which plans to develop 'a working economic model to track the links between national income, consumption growth and resources, by 2008'. This would use the Resource Energy and Analysis Programme (REAP; Weidmann et al, 2004).

DEFRA, the government department responsible for environment, food and rural affairs, has no overarching model, but has developed smaller models in relation to the EU chemicals strategy, fisheries and GHGs.

The England & Wales Environment Agency seeks 'to understand the relationship between economic development and the environment, and the ways in which economic incentives interact with environmental policy and regulation'. In achieving this, it produces reports based on a 'modelling framework' of environment/economy relationships that encompasses data and sector-level models based on the research topic in question. The most recent scenario report (Burdett *et al.*, 2006) is limited to socio-economic scenarios. The Scottish Environment Protection Agency has a project in place to develop scenarios, but no tangible results have been published. The Northern Ireland Department of the Environment and the Northern Ireland Environment and Heritage Service are not involved in any scenario activity.

The UK Government's Sustainable Development Unit produces a set of 'National Sustainable Development Indicators', which provide more of a monitoring than a forecasting role in relation to policy development.

Environment is not part of the research agenda of the National Institute of Economic and Social Research, which is responsible for forecasting the UK economy.

6.1.2 The Netherlands

The Netherlands has an Environment and Nature Planning Bureau (MNP), that grew out of the RIVM, the State Institute for Health and Environment. While RIVM implements and monitors, MNP projects and gives policy advice. The designation "planning bureau" implies that the MNP has to be consulted before any major decision by the government.[48] Every year, the MNP produces the Environmental Accounts and the Nature Accounts. Every four years, the MNP publishes the Environment and Nature Exploration. The latest, MNP (2006), projects emissions of CO2, NOx, PM10, SO2, NH3 and nitrates, concentrations of the same, as well as land use up to 2040. Two alternative socio-economic scenarios are used. Projections are compared to policy goals, and the costs of meeting existing policies are estimated. There is no unifying model. Instead, a set of different models are used with coordinated scenarios. Most of the models are from the MNP, but the MNP relies on its sister institute for economics (CPB), energy (ECN) and agriculture (LEI).

6.1.3 Switzerland

Switzerland has a Federal Office for the Environment (FOEN) which is the federal government's centre of environmental expertise and research and is part of the Federal Department of the Environment, Transport, Energy and Communication. In collaboration with the Federal Office of Statistics and the Federal Office of Territorial Development, the FOEN produced in 2003 a system of sustainable development indicators called MONET (MOnitoring der Nachhaltigen EnTwicklung). MONET is not a predictive model but rather aims to present the state of the country at regular intervals using 100 indicators of development. The system includes general economic indicators (e.g. house prices and work productivity), social indicators (e.g. gender inequalities in the workplace) as well as environmental indicators (e.g. energy efficiency in the transport sector, water and air quality indicators and the state of the natural environment).

6.1.4 France

The Institut Français de l'Environnement (The French Environment Institut or IFEN) is responsible for the collection and analysis of data on the environment as well as natural and technological disasters. It is directly related to the French Ministry of Ecology and Sustainable Development. The IFEN has based its research on the NAMEA (National Accounts Matrix with Environmental Accounts) which combines national input-output tables and environmental pressure indicators. The objectives and limitations of the model were outlined in 2006 and NAMEA was used to analyse energy use and the main air pollutants in France. An extension of the analysis to the waste production sector and water pollution is planned. It should be noted, however, that IFEN's analyses are used primarily as a monitoring instrument, rather than for developing predictions.

6.1.5 Germany

The German Federal Environment Agency (UBA) is an agency of Federal Ministry of Environment, Nature Protection, and Nuclear Safety. The UBA publishes an annual Environment Report, which combines past data and future goals. The UBA does not systematically project emissions or resource use. Systematic collection of environmental data is done by the Federal Statistics Agency (SBA), covering

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[48] The Netherlands has three planning bureaus. The economic one, the CPB is the oldest, and was founded at a time when economists still believed in central planning. There is also a socio-cultural planning bureau.

emissions, waste, water use, land use, water quality, air quality, biodiversity, and expenditures on environmental protection.

6.1.6 Belgium

The National Statistics Institute collects data on emissions to air and water, air and water quality, waste, land use, biodiversity, and expenditures on environmental protection. The Federal Planning Bureau produces biannual Federal Reports on Sustainable Development, in preparation for a Federal Plan on Sustainable Development that is yet to emerge. The latest report (FPB, 2005) is conceptually strong -- developing indicators for sustainable development in 20 domains of social, economic and environmental capital -- and contains a critical evaluation of the procedural aspects of environmental policy. There are plans to build future scenarios (Bernheim, 2004), but these have yet to reach fruition.

6.1.7 European Union

The European Environment Agency publishes its flagship report "The European Environment – State and Outlook" every five years. As their title suggests, the reports mix data on past and present with projections of the future. The latest report (EEA, 2005a) covers essentially all environmental themes, from coastal erosion to persistent organic pollutants. Reporting is done for all EEA member countries, and various aggregates.

Future projections are limited to a select set of indicators and themes only, viz. climate change, air pollution, agriculture, water shortage, water quality, waste, and material flows. A range of models is used, driven by a single scenario of developments in the population and the economy (EEA, 2005b). The models are maintained by teams from Germany, Greece, France and the Netherlands. Consistency across models may be an issue. Because the assessment is done at the European scale, projections for individual countries need not be realistic, particularly for small countries.

The Institute for Prospective Technological Studies, a part of the EU's Joint Research Centre, produces many partial scenario studies, also on environmental issues, but no comprehensive one. The European Commission's Forward Studies Unit produced 'Scenarios Europe 2010' in 1999. Designed as a tool for assessing proposed policies of the EU in certain policy areas, including the environment, the Commission's scenarios were based largely on qualitative analysis (Bertrand *et al.*, 1999). This unit is now part of the Bureau of European Policy Advisors. Environment is not on the agenda.

6.1.8 OECD and IEA

The environment is only a minor part of the agenda of the OECD. Although the OECD does project the economic development of its member states, these projections do not include environmental indicators. The projections of the International Energy Agency are limited to energy use and carbon dioxide (IEA, 2006).

6.1.8 United Nations

The United Nations Environment Programme (UNEP) has produced a series of 'Global Environmental Outlook – GEO' reports that seek to 'analyse environmental change, causes, impacts, and policy responses' as well as support policy-making on a global scale. The most recent report – GEO year book 2007 – is available from http://www.unep.org. It does not contain any future projections.

The Intergovernmental Panel on Climate Change published its Special Report on Emissions Scenarios in 2001 (Nakicenovic and Swart, 2001). It has six alternative groups of scenarios, each run with several models. The scenarios are limited to emissions of climate-change substances. This was the second set of emissions scenarios published by the IPCC, but it has decided that there will not be a third set.

3.8 Model Design

O'Doherty and Tol (2006) present a prototype (version 0.0) of the Irish Sustainable Development Model, *ISus*0.0. The model links 37 emissions (Table 6.1) and 1 resource (Table 6.2) to a national (Table 6.3) model with 19 production sectors (Table 6.4). Data are from the *Central Statistics Office* (CSO) supplemented with data from the *Environmental Protection Agency* (EPA). Emissions are linked to consumption via an input-output model, but emissions of and resource uses by households are omitted. Scenarios for productions are taken from the *HERMES* model. Emission coefficients are assumed to be constant or follow a simple time trend based on past experience (Table 6.5). The prototype includes emissions, and damage costs (Table 6.6).

The next versions of the ISus model will be based on the same structure, but with more detail added. The prototype and its documentation were completed in January 2007. Version 1.0 is scheduled for February 2008, and Version 2.0 for February 2009.[49]

With regard to emissions, the prototype model already has an extensive range of emissions to air. We will seek to add particulate matter, however. A finer disaggregation of types and destinations of waste is probably possible and certainly desirable. It may be possible to get data on emissions of pharmaceutical and medicines to waste water. This would require the inclusion of transformation coefficients between the waste water stream and surface, ground and coastal water. Agricultural emissions (pesticides etc.) to water will be part of the agricultural submodel, to be included in version 2.0. See Section 5 for further discussion.

With regard to resource use, the prototype only includes water. Data from *Sustainable Energy Ireland* (SEI) allow for a ready extension to energy use. Material use data may be found in the material flow analysis and ecological footprint estimates conducted by *EnviroConsult*. Land use will be part of the agricultural submodel. See Section 5 for further discussion.

We will develop a system of flags for the model output. These flags will reproduce the data flags (see Section 5), but we will add a separate flag for the level of confidence in the model projection.

The prototype model is national, and the same will be true for *ISus*1.0. In version 2.0, we will seek to regionalize the relevant parts of the model, particularly emissions to water, emissions of particulate matter to air, and land and water use. This will not be straightforward, as subnational economic data are scarce, and being collected on the

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[49] Note that for reasons of quality control on model development, there will be intermediate versions as well. Quality control also dictates that many of the steps in building, updating and extending the model will be automated.

basis of different spatial units that do not necessarily make sense from an environmental perspective.

At the same time, we will seek to include the emissions to air for international environmental problems (particularly climate change) associated with imported goods and services. This is important, because off-shoring (on-shoring) energy intensive production would look good (bad) in the environmental accounts of Ireland but would hardly affect climate change.

The model prototype is based on the 19 economic sectors identified in the *Environmental Accounts* of the *CSO*. This leads to some counterintuitive results – for example, the high methane contents of intermediate deliveries to the pulp and paper industry – and inaccuracies in the projections – HFC emissions, for example, come from very specific industrial activities. Therefore, we will switch to the maximum economic resolution of 57 sectors. Note that *EPA* and *SEI* data allow this for most emissions. Other emission coefficients will be interpolated.

Agriculture is one of the sectors in the prototype model. In *ISus*2.0, a submodel will cover agriculture.

The prototype omits emissions by households. This will be rectified in *ISus*1.0.

The projections with the prototype model assume constant emission coefficients, or simply extrapolate past trends in emission coefficients. We will replace this with emission coefficients that are a function of prices, income, and technological change; and allow for the introduction or sharpening of caps on emissions or emission intensities. Other policy instruments will be introduced in *ISus*2.0.

*ISus*0.0 has emissions and selected damage costs of emissions. Predicting emissions will be the core purpose of the *Isus* model, but where feasible concentrations and impacts will be included. This will apply particularly for water quality, where there is more data on loads than on discharges. Impacts will only be included in cases where simple dose-response relationships are readily available and uncontroversial. Similarly, monetization of impacts will only be undertaken where this is straightforward.

Table 6.1. Emissions in ISus.

Version	Emissions	Remarks
V 0.0	CO_2, N_2O, CH_4, HFC-23, HFC-32, HFC-41, HFC-43-10mee, HFC-125, HFC-134, HFC-134a, HFC-143, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-245ca, CF_4, C_2F_6, C_3F_8, C_4F_{10}, c-C_4F_8, C_5F_{12}, C_6F_{14}, SF_6, CO, NMVOC, SO_2, NO_x, NH_3, Agricultural waste, Hazardous industrial waste (not-recycled), Hazardous industrial waste (recycled), Non-hazardous industrial waste (not-recycled), Non-hazardous industrial waste (recycled), BOD, N, P.	
V 1.0	Same, but with a finer distinction for waste, and particulate matter and pharmaceuticals added.	If data available
V 2.0	Same, plus range of agricultural emissions.	Agricultural submodel

Table 6.2. Resource use in ISus.

Version	Resources	Remarks
V 0.0	Water	
V 1.0	Same, plus energy and materials	Materials from EnviroConsult.
V 2.0	Same, plus land use	Agricultural submodel.

Table 6.3. Spatial resolution in ISus.

Version	Spatial resolution	Remarks
V 0.0	National	
V 1.0	National plus imports	
V 2.0	NUTS II or county for demographic and economic data; river basins for water quality and quantity; county for waste; urban centres for air quality	Economic data at regional level may be hard to get, and will not match environmental regions.

Table 6.4. Sectoral resolution in ISus.

Version	Sectoral resolution	Remarks
V 0.0	19 production sectors	
V 1.0	57 production sectors, consumption	Some emissions and resource use will have to be interpolated to the sectors.
V 2.0	As above	

Table 6.5. Emission and resource use coefficients in ISus.

Version	Coefficients	Remarks
V 0.0	Constant plus trend extrapolation in selected cases	
V 1.0	Income and price elasticities; technological change; price and quantity instruments	
V 2.0	Same, plus other instruments	

Table 6.6. Scope of ISus.

Version	Scope	Remarks
V 0.0	Emissions, selected damage costs	
V 1.0	Emissions, selected concentrations, selected impacts, selected damage costs	Concentrations and impacts depend on the availability of environmental models.
V 2.0	Emissions, selected concentrations, selected impacts, selected damage costs	Concentrations and impacts depend on the availability of environmental models.

Table 6.7. ISus Output compared to the EPA Environmental Indicators.

EPA Indicator	Nature	ISus 0.0	ISus 1.0	ISus 2.0
Population and environment				
Population	Number	-	Number	Number
Pop. Dens.	$\#/km^2$	-	$\#/km^2$	$\#/km^2$
GDP/cap	Euro	-	Euro	Euro
Unemployment	%	-	%	%
Air quality				
Black smoke	Conc	-	-	-
PM_{10}	Conc	-	-	-
SO_2	Conc	Em	Em	Em
NO_x	Conc	Em	Em	Em
O_3	Conc	-	-	-
SO_2	Em	Em	Em	Em
NO_x	Em	Em	Em	Em
VOC	Em	Em	Em	Em
NH_3	Em	Em	Em	Em
CO_{2eq}	Em	Em	Em	Em
Temperature	Degree	-	-	-
Precipitation	Amount	-	-	-
Water quality				
River water	Class, length	-	-	-
Lake water	Class, number	-	-	-
	Class, area	-	-	-
Coastal water	Class, area	-	-	-
Bathing water	Share	-	-	-
Groundwater	Conc	-	-	-
Drinking water	Conc	-	-	-
Fish kills	Number	-	-	-
Waste water	Share	-	-	-

Surface water	Class, share	-	-	-
Waste				
Municipal waste	Weight	-	Weight	Weight
	Share	-	Share	Share
Packaging waste	Share		Share	Share
Bring banks	Number	-	-	-
Processing	Class, number	-	-	-
Land cover				
Land cover	Class, area	-	-	Class, area
Urbanisation	Class, area	-	-	Class, area
Protected area	Share	-	-	Share
Protected species	Class, number	-	-	-
Protected birds	Class, number	-	-	-
Birds	Number	-	-	-
Transport				
Vehicles	Number	-	-	Number
	Size	-	-	Size
	Compliance	-	-	-
	Age	-	-	Age
Freight	Mode, weight	-	-	Mode, weight
CO_2	Em	Em	Em	Em
NO_x	Em	Em	Em	Em
VOC	Em	Em	Em	Em
Public transport	Number	-	-	Number
	Mode, share	-	-	Mode, share
Industry				
Production	Sector, index	Sector, index	Sector, index	Sector, index
Waste	Weight	Weight	Weight	Weight

	Share	Share	Share	Share
Hazardous waste	Weight	Weight	Weight	Weight
Energy use	Type, amount	-	Type, amount	Type, amount
Licensing	Number	-	-	-
Energy				
Primary	Type, amount	-	Type, amount	Type, amount
Final	Type, amount	-	Type, amount	Type, amount
Renewables	Type, share	-	Type, share	Type, share
Electricity efficiency	Ratio	-	Ratio	Ratio
Agriculture				
Land use	Type, area	-	-	Type, area
Livestock	Type, number	-	-	Type, number
Fertilizer	Type, weight	-	-	Type, weight
CO_{2eq}	Em	Em	Em	Em
Organic farming	Share	-	-	Share
REPS	Area	-	-	-
Forestry				
Land use	Type, area	-	-	Type, area
Species	Share	-	-	Share
Fisheries				
Fish stock	Species, index	-	-	-
Landings	Species, share	-	-	-
Aquaculture	Species, weight	-	-	-
Shellfish quality	Class, share	-	-	-

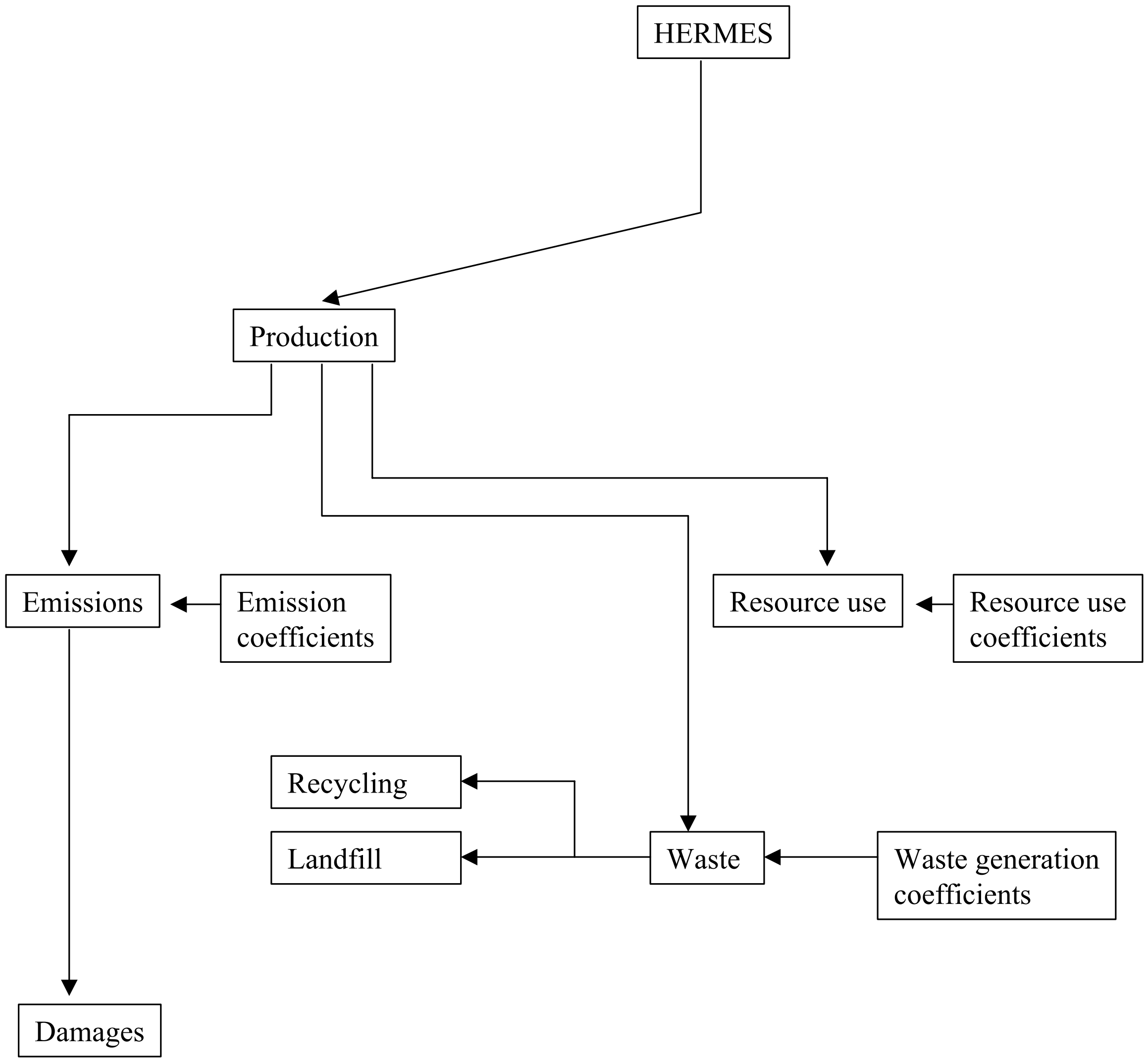

Figure 6.1. Structure of *ISus*0.0.

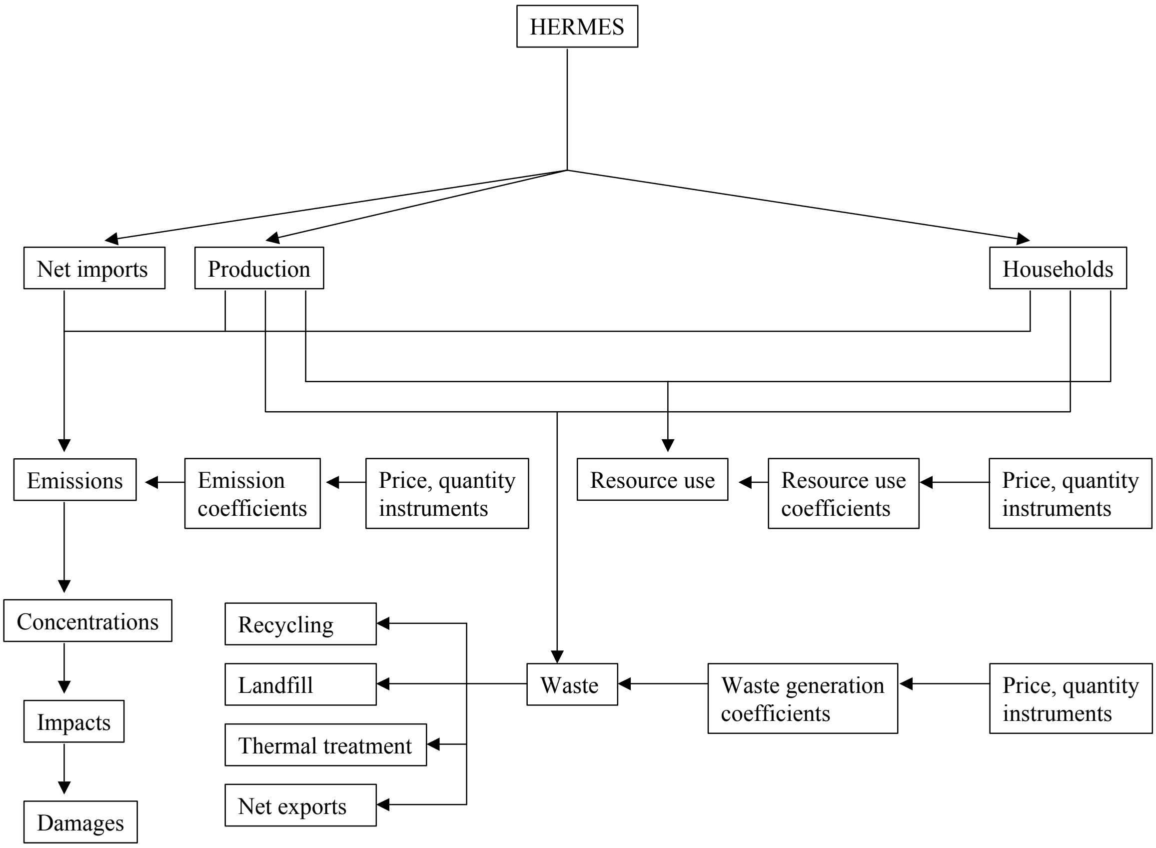

Figure 6.2. Structure of *ISus*1.0.

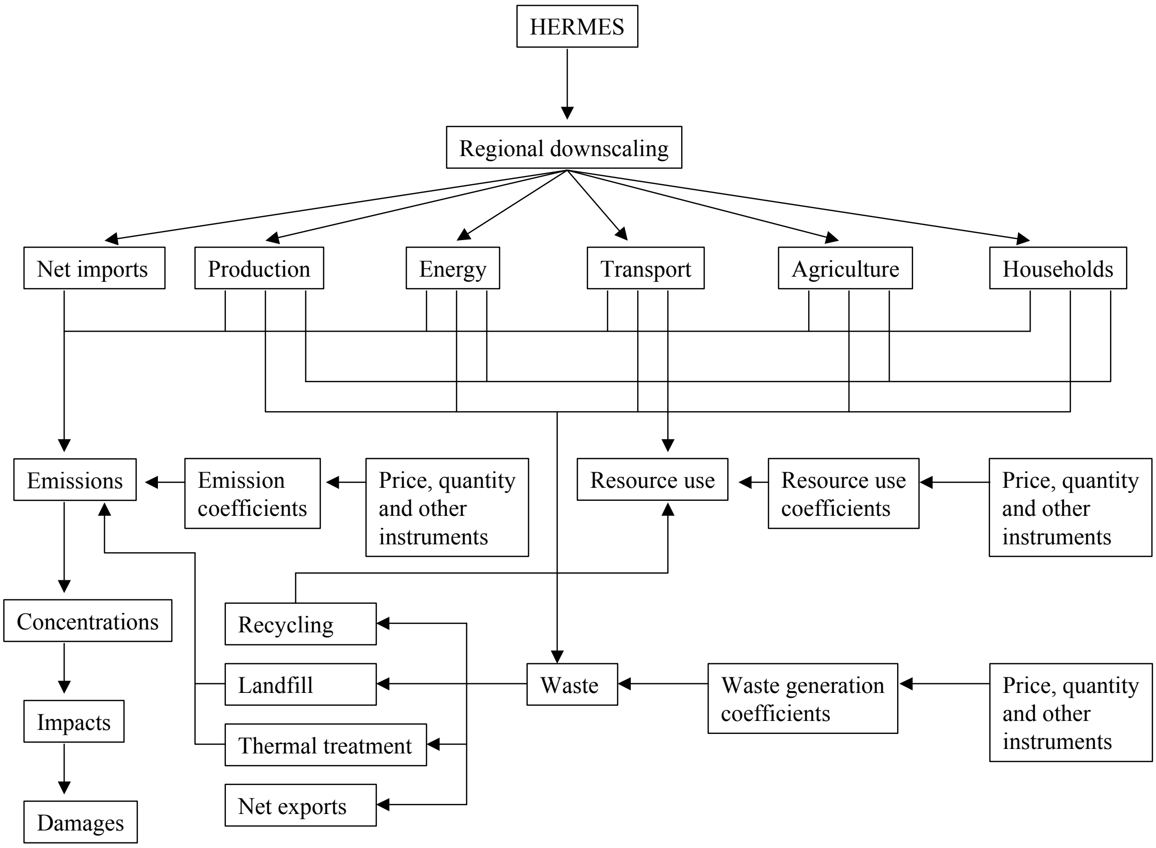

Figure 6.3. Structure of *ISus*2.0.

7. Conclusion

This project will develop an Irish Sustainable Development Model (ISus). The model will be capable of linking economic and social developments to their related environmental impacts to provide a tool for policy makers to assess the implications of different growth paths for national objectives on sustainable development. Thus, the eventual purpose of this project is to improve the understanding of economy–environment relationships in Ireland and, in so doing, improve the effectiveness of policy formulation.

As a first step towards the construction of the ISus, this review analysed the state of existing work in this area.

Having introduced the study in Section 1, Section 2 examines the issues surrounding six processes that impact on the environment in Ireland, the effect they can have, how they can be prevented or mitigated, and – perhaps most importantly with a view to constructing the ISus – how each of these is relevant in Ireland.

We establish that these processes have varying impacts on the environment in this country, with waste coming out as a particular concern. Waste is also an area where domestic policy can have significant impact, as opposed to, say, climate change and acidification, where international cooperation is the best solution.

Section 3 presents an overview of existing economic models that have been used in relation to environment-economy interactions, as well as a dedicated discussion of land use modelling. The construction of the ISus will most likely involve many of the methods discussed in this section. For example, the prototype ISus developed by O'Doherty and Tol (2007) took the form of an environmental input-output model, while in its final incarnation the model will link with the ESRI's HERMES model – an econometric model of the Irish economy. Land use models and scenario analyses are likely to be important also.

All economic models discussed rely to some degree on price information and valuation of the environment. Therefore, Section 4 briefly reviews monetisation methods and their application to environmental resources in Ireland. It was established that valuation studies are few and far between in Ireland. However, a core of literature exists such that validity checks will be available for valuation techniques when they are required in the ISus.

Section 5 presents the data and indicators currently available in Ireland. Ireland could achieve more in terms of its collection of data, but particularly in the organisation and dissemination of data. Although sufficient data existed for O'Doherty and Tol (2007) to construct the prototype ISus for Ireland (*ISus*0.0), the intention – as outlined in Section 6 - is to expand both the depth and breadth of the model, and thus its data requirements also.

Section 6 examines similar models elsewhere, and also outlines the stages through which the model must progress in order to reach its final specification. An intermediate model (*ISus*1.0) will provide a finer distinction for waste, add particulate matter and pharmaceuticals emissions, expand the number of resources and sectors analysed by the model, and generally broaden its scope. It is envisaged that the final model (*ISus*2.0) will be regionalised. It will contain sub-models for agriculture, energy and transport.

In conclusion, this review has sought to provide an overview and analysis of existing literature in the area of environmental economics, with a particular focus on those areas that help towards the construction of the ISus, as well as outlining the proposed design for such a model.

It is feasible to construct such a model, and many important insights will be gained from its application. However, the quality of the projections will stand or fall with the quality of the input data.

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8. Appendix

Index decomposition – mathematical notation

From Ang and Zhang (2000, 1156-59)

Assume that the aggregate energy consumption in industry is the sum of consumption in *m* different sectors (e.g. food, textiles, metal products, etc.). Define the following variables for time *t* that are normally measured on an annual basis. Energy consumption is measured in an energy unit and industrial output in a monetary unit.

E_t = Total industrial energy consumption

$E_{i,t}$ = Energy consumption in industrial sector *i*

Y_t = Total industrial production

$Y_{i,t}$ = Production of industrial sector *i*

$S_{i,t}$ = Production share of sector *i* ($=Y_{i,t}/Y_t$)

I_t = Aggregate energy intensity ($=E_t/Y_{i,t}$)

$I_{i,t}$ = Energy intensity of sector *i* ($=E_{i,t}/Y_{i,t}$)

Express the aggregate energy intensity as a summation of the sectoral data:

$$I_t = \sum_i S_{i,t} I_{i,t} \qquad (1)$$

where the summation is taken over the *m* sectors. The aggregate energy intensity is expressed in terms of production structure and sectoral energy intensity.

Suppose the aggregate energy intensity varies from I_0 in time 0 to I_T in time *T*. Such a change may be expressed in two ways: $D_{tot} = \frac{I_T}{I_0}$ and $\Delta I_{tot} = I_T - I_0$. We refer to the first as *multiplicative decomposition*:

$$D_{tot} = \frac{I_t}{I_0} = D_{str} D_{\text{int}} \qquad (2)$$

where D_{str} and D_{int} respectively give the estimated impacts of structural change and sectoral intensity. The second way is called *additive decomposition* where the differential change is decomposed into contributions from the same two effects but they appear in the additive form:

$$\Delta I_{tot} = I_T - I_0 = \Delta I_{str} + \Delta I_{\text{int}} \tag{3}$$

The above techniques can be applied to decompose changes in total industrial energy consumption. In such a case Eq. (1) is replaced by $E_t = \sum_i Y_i S_{i,t} I_{i,t}$, where multiplicative decomposition takes the form of $D_{tot} = \frac{E_T}{E_0}$ and additive decomposition the form of $\Delta E_{tot} = E_T - E_0$. The concept is basically the same except that there is an additional term related to the impact of total production Y_t, which is known as the production effect in index decomposition terminology.

Laspeyres index method

The Laspeyres index method follows the Laspeyres price and quantity indices in economics by isolating the impact of a variable through letting that specific variable change while holding the other variables at their respective base year values. With reference to Eqs. (1) and (2), the formulae for multiplicative decomposition are:

$$D_{str} = \frac{\sum_i S_{i,T} I_{i,0}}{\sum_i S_{i,0} I_{i,0}} \tag{4}$$

$$= \frac{\sum_i \begin{pmatrix} \text{Production share} \\ \text{of } i \text{ at time T} \end{pmatrix} \begin{pmatrix} \text{Energy intensity of} \\ i \text{ in the base year} \end{pmatrix}}{\sum_i \begin{pmatrix} \text{Production share} \\ \text{of } i \text{ in the base year} \end{pmatrix} \begin{pmatrix} \text{Energy intensity of} \\ i \text{ in the base year} \end{pmatrix}}$$

$$D_{\text{int}} = \frac{\sum_i S_{i,0} I_{i,T}}{\sum_i S_{i,0} I_{i,0}} \tag{5}$$

$$= \frac{\sum_i \begin{pmatrix} \text{Production share} \\ \text{of } i \text{ in the base year} \end{pmatrix} \begin{pmatrix} \text{Energy intensity} \\ \text{of } i \text{ at time T} \end{pmatrix}}{\sum_i \begin{pmatrix} \text{Production share} \\ \text{of } i \text{ in the base year} \end{pmatrix} \begin{pmatrix} \text{Energy intensity of} \\ i \text{ in the base year} \end{pmatrix}}$$

$$D_{rsd} = \frac{D_{tot}}{(D_{str} D_{\text{int}})} \tag{6}$$

The residual term D_{rsd} denotes the part of D_{tot} that is left unexplained. In additive decomposition and with reference to Eqs. (1) and (3), the formulae are:

$$\Delta I_{str} = \sum_i S_{i,T} I_{i,0} - \sum_i S_{i,0} I_{i,0} \tag{7}$$

$$\Delta I_{\text{int}} = \sum_i S_{i,0} I_T - \sum_i S_{i,0} I_{i,0} \tag{8}$$

$$\Delta I_{rsd} = \Delta I_{tot} - \Delta I_{str} - \Delta I_{\text{int}} \tag{9}$$

For additive decomposition, some researchers use the concept of percentage change (e.g. Golove and Schipper, 1996; Schipper *et al.*, 1997; and Farla *et al.*, 1998). This is obtained by dividing both sides of Eqs. (7)-(9) by I_0:

$$\frac{(\Delta I_{str})}{I_0} = \frac{\sum_i S_{i,T} I_{i,0}}{\sum_i S_{i,0} I_{i,0}} - 1 = D_{str} - 1 \tag{10}$$

$$\frac{(\Delta I_{str})}{I_0} = \frac{\sum_i S_{i,T} I_{i,0}}{\sum_i S_{i,0} I_{i,0}} - 1 = D_{str} - 1 \tag{11}$$

$$\frac{(\Delta I_{rsd})}{I_0} = \frac{\Delta I_{tot}}{I_0} - \frac{(\Delta I_{str})}{I_0} - \frac{(\Delta I_{\text{int}})}{I_0} \tag{12}$$

Arithmetic mean Divisia index method

The Divisia index is an integral index number introduced by Divisia (1973). More details about this index number can be found in Hulten (1973) and Diewert (1980). Applying the theorem of instantaneous growth rate to Eq. (1) leads to:

$$\frac{\mathrm{d}\ln(I_t)}{\mathrm{d}t} = \sum_i \omega_i \left[\frac{\mathrm{d}\ln(S_{i,t})}{\mathrm{d}t} + \frac{\mathrm{d}\ln(I_{i,t})}{\mathrm{d}t} \right] \tag{13}$$

where $\omega_i = \frac{E_{i,t}}{E_t}$ is the sector share of energy consumption and is known as the weight for sector *i* in the summation. Integrating over time from 0 to *T* and rearranging the terms gives:

$$\ln\left(\frac{I_t}{I_0}\right) = \int_0^T \sum \omega_i \left[\frac{\mathrm{d}\ln(\mathrm{S}_{i,t})}{\mathrm{d}t} \right] + \int_0^T \sum \omega_i \left[\frac{\mathrm{d}\ln(I_{i,t})}{\mathrm{d}t} \right] \tag{14}$$

Exponentiating, Eq. (14) can be expressed in the multiplicative form $D_{tot} = D_{str} D_{\mathrm{int}}$ where:

$$D_{str} = \exp\left\{ \int_0^T \sum_i \omega_i \left[\frac{\mathrm{d} \ln(\mathrm{S}_{i,t})}{\mathrm{d}t} \right] \right\} \tag{15}$$

$$D_{\mathrm{int}} = \exp\left\{ \int_0^T \sum_i \omega_i \left[\frac{\mathrm{d} \ln(\mathrm{I}_{i,t})}{\mathrm{d}t} \right] \right\} \tag{16}$$

Since only discrete data are available in empirical studies, the weight function is often approximated by the arithmetic mean of the weights for year 0 and year *T*:

$$D_{str} = \exp\left\{ \sum_i \frac{(\omega_{i,T} + \omega_{i,0})}{2} \ln\left(\frac{S_{i,T}}{S_{i,0}} \right) \right\} \tag{17}$$

$$D_{\mathrm{int}} = \exp\left\{ \sum_i \frac{(\omega_{i,T} + \omega_{i,0})}{2} \ln\left(\frac{I_{i,T}}{I_{i,0}} \right) \right\} \tag{18}$$

As a result of this approximation (which is also called the Törnqvist formula), the product of Eqs. (17) and (18) is not equal to D_{tot} and we may write $D_{tot} = D_{str} D_{\mathrm{int}} D_{rsd}$. The additive Divisia index method can be derived in the same manner. The formulae are:

$$\Delta I_{str} = \sum_i \frac{\left(\frac{E_{i,T}}{Y_t} + \frac{E_{i,0}}{Y_0} \right)}{2} \ln\left(\frac{S_{i,T}}{S_{i,0}} \right) \tag{19}$$

$$\Delta I_{\mathrm{int}} = \sum_i \frac{\left(\frac{E_{i,T}}{Y_t} + \frac{E_{i,0}}{Y_0} \right)}{2} \ln\left(\frac{I_{i,T}}{I_{i,0}} \right) \tag{20}$$

and $\Delta I_{tot} = \Delta I_{str} + \Delta I_{\mathrm{int}} + \Delta I_{rsd}$

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3.15 Appendix

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