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Decomposition of Ireland's carbon emissions from 1990-2010: an extended Kaya identity

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Abstract

In recent decades, Ireland has been an important example of a development pathway where rapid economic growth was accompanied by rising energy demand and increasing carbon emissions. Understanding the driving forces of carbon emissions is necessary for policy formulation and decomposition analysis is widely used for this purpose. This study uses an extended Kaya identity as the scheme and applies the log mean Divisia index (LMDI I) as the decomposition technique. Change in carbon emissions is decomposed from 1990 – 2010 and includes a measure of the effect of renewable energy penetration. Results illustrate that scale effects of affluence and population growth act to increase emissions and are countered primarily by energy intensity and fossil fuel substitution. Renewable energy penetration has a minor effect but has been increasing in recent years. Policy will need to significantly reduce intensity and increase renewables if applicable targets are to be reached. This requires not only a comprehensive suite of policies and measures but emphasis on the development path and 'non-technical' change for optimal outcomes.

Keywords: Carbon emissions, Ireland, Decomposition analysis,

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1. Introduction

The Republic of Ireland is an Annex I nation under the Kyoto protocol and subject to emissions limitation obligations. Despite a relatively small contribution to absolute global greenhouse gas (GHG) emissions, per capita emissions ranked 2nd in the European Union (EU) and 18th in the world in 2008 (UNSTATS, 2010).[1] Energy-related carbon emissions are a significant contributor to national GHG emissions.[2] Ireland experienced unprecedented economic growth from 1990 to 2007 as Gross Domestic Product (GDP) increased by 175.23 per cent, and was lauded internationally as an example of economic progress before the arrival of recession in 2008. This represented a period of profound change in Ireland. Development progress was underpinned by rapid economic growth, expanding population, an evolving technological profile and social and cultural changes that accompanied modernisation. Growing energy demand from rising production and consumption led to increasing total primary energy requirement (TPER), change in the associated fuel shares (Fig. 1.) and a substantial increase in associated carbon emissions. Carbon emissions based on TPER increased to a peak in 2008 of 48.12 $MtCO_2$, 54.09 per cent higher than 1990 (Fig. 2).

Apart from economic growth, from an emissions perspective, the example of Ireland is interesting due to a number of characteristics. There are limited indigenous fossil fuels, abundant potential renewables in the form of wind (OECD/ IEA, 2007), a benign temperate climate and a small dispersed population which sprawled into rural and low density locations over the last two decades (EEA, 2006). The relatively large

[1] Although GHG emissions in Ireland have declined somewhat since the 2008 economic recession, this is the latest year with collated data for emissions per capita (UNSTATS, 2010). This source measures emissions in $MtCO_2$ eq. excluding LULUCF/ LUCF.
[2] While agriculture is an important contributor to total GHG emissions in Ireland, and partly explains the relatively high per capita emissions, energy accounted for 66.1 per cent of GHG's in 2010, with carbon emissions 96.7 per cent of this (Duffy *et al.*, 2012).

proportion of GHG emissions attributable to agriculture places additional pressure on reduction of energy-related carbon emissions to meet future mitigation commitments.

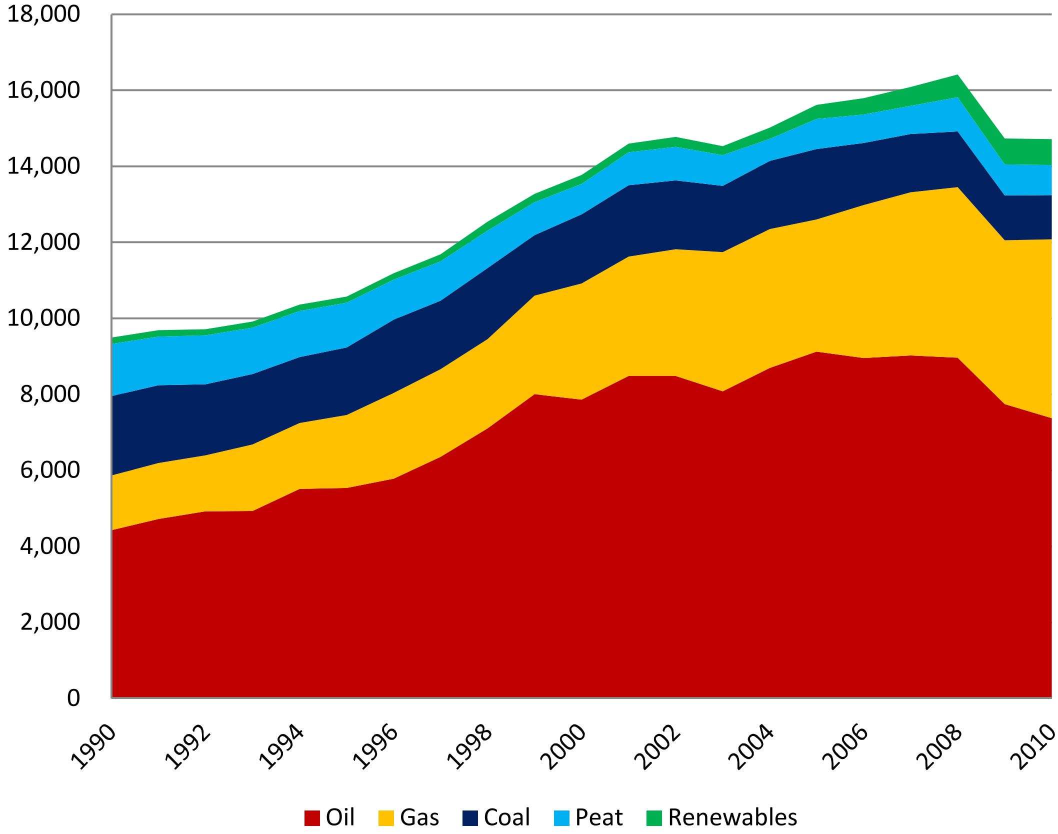

Fig. 1. Ireland's TPER 1990 – 2010 in kilo tonnes of oil equivalent (ktoe). Data source: Sustainable Energy Authority of Ireland (2011).

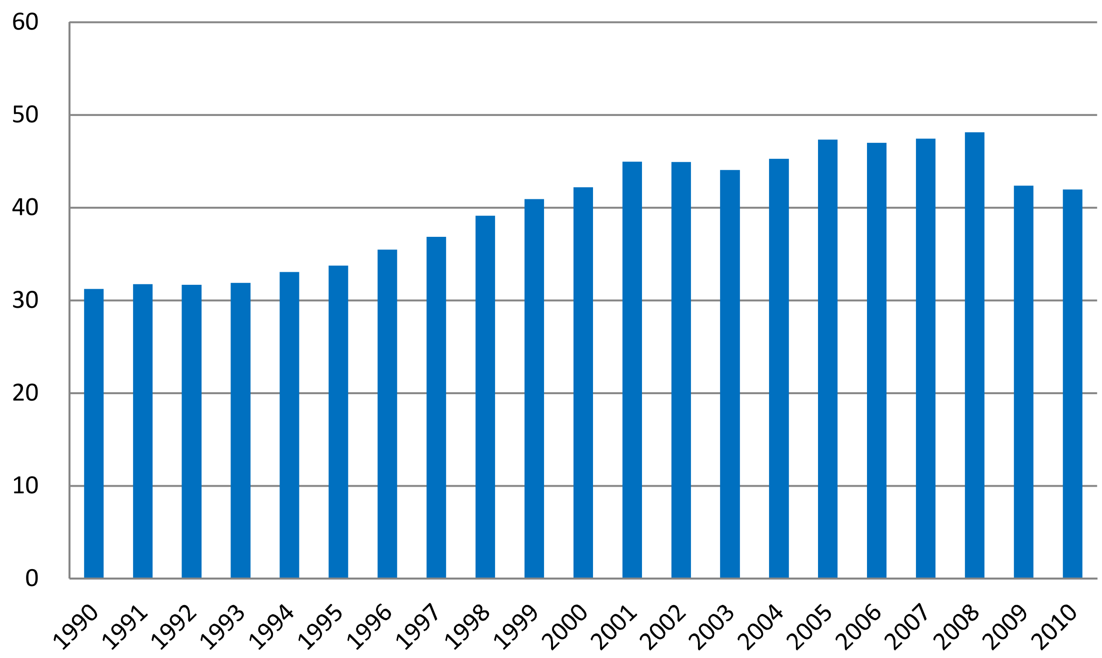

Fig.2. Total energy-related carbon emissions in Ireland from 1990 – 2010 in mega tonnes of carbon ($MtCO_2$). Data source: Sustainable Energy Authority of Ireland (2011).

Given the relative growth in the economy, some decoupling from growth in carbon emissions has been evident since 1990. The resumption of absolute increases in emissions once the economy recovers is incompatible with mitigation requirements. Ireland is an important example of a development pathway because of the pattern of high economic growth and emissions. While increased penetration of renewable energy has been central to Irish mitigation plans its effect on reducing carbon emissions has not been well understood. Understanding the driving forces of carbon emissions is not only of interest to national policy, but given the somewhat unique recent history of Ireland, may be of much interest to economies in transition and developing countries seeking accelerated economic growth.

Tools for analysis of driving forces have evolved in the field of decomposition analysis, including the framework for sustainability known as IPAT of Commoner (1972) and Ehrlich and Holdren (1972), to the specific application with energy and CO_2

in the Kaya identity (Kaya, 1990). The decomposition of changes in an aggregate environmental impact to its driving forces has become popular in disentangling the relationship of society and economy with the environment. Similar conceptual underpinnings can be found in the field of index decomposition analysis (IDA). With the arrival of the world oil crisis in 1973 and 1974, considerable attention was placed on industry energy use among policy-makers, as industrial energy constituted the largest share of primary energy demand in most countries. Research began to focus on the mechanisms of change in industrial energy use. This new area of research emerged to quantify the impact of a structural shift in industrial production on total energy demand. These initial studies showed a significant impact of structural change on energy demand trends and the need to identify and quantify this became an imperative for policy-making. This line of research has since expanded substantially in terms of methodology and application, and is now a widely accepted analytical tool for policymaking on energy and environmental issues (Ang, 2004). It is particularly useful given the analysis of contributing factors such as energy intensity and structural change. The decomposition of a pre-defined set of factors helps to understand the progression of driving forces, the impact of major processes occurring and policy dimensions tied to these processes (Steenhof *et al*., 2006). The scope of application of IDA has expanded beyond industrial energy demand to energy and environmental analysis across countries and sectors. Ma and Stern (2008) recommend decomposition analysis to determine the most important factors in driving change in emissions and to indicate where policy levers might exist. At the Dublin workshop of the United Nations Framework Convention on Climate Change (UNFCCC) in 2004, participants noted particular interest in the decomposition analysis approach reported in the In-Depth Review of Germany from analysis in studies such as Schleich *et al.* (2001). This technique could be used to explain problems and success stories allowing quantitative assessment to separate effects on emissions from improvements in energy efficiency, changes in the energy supply mix, and growth in population and GDP (UNFCCC, 2004). The development of policy and the reporting and monitoring of progress is contingent on appropriate analytical tools, and IDA has been advanced for this purpose.

Recent studies have sought to improve knowledge of driving forces in Ireland. O' Mahony *et al*. (2012) used decomposition analysis on driving forces of carbon emissions in eleven final consumption sectors from 1990 to 2007, O' Mahony (2010) developed a set of exploratory scenarios to 2020 using scenario driving forces on both the supply and demand side, Jennings *et al*. (2013) decomposed Irish passenger transport energy, Cahill and Ó Gallachóir (2009) decomposed energy efficiency improvements in Irish industry, O' Doherty and Tol (2007) applied an environmental input-output model to the year 2000 and a projection to 2020 for the economic sectors and transport. A number of pan-European studies have applied decomposition analysis to Ireland in international comparison (Kaivo-Oja and Luukkanen, 2004; Diakoulaki and Mandaraka, 2007; Tapio *et al*., 2007). This study extends further the decomposition literature to Ireland, and aims to identify, quantify and explain major driving forces acting to change energy-related carbon emissions. It is the first decomposition analysis of Ireland at this macro level similar to that of Schleich *et al*. (2001), and the first such study to measure the impact of renewable energy on carbon emissions. The paper is organised as follows. Section 2 details the decomposition methodology applied. Section 3 describes the data used. Section 4 presents and discusses the results of the decomposition analysis. Section 5 discusses the policy implications and some concluding remarks are presented in the final section.

2. Decomposition methodology

In conducting an IDA, the analysis begins by defining a governing function relating the aggregate to be decomposed to a number of predefined factors. These ‘drivers’ or ‘effects’ leading to observed change in total energy-related CO_2 are often expressed through the Kaya identity (Kaya, 1990). An extended Kaya identity has been applied using LMDI I in a number of studies (Zhang and Ang, 2001; Wang *et al.,* 2005; Ma and Stern, 2008). The objective of this study is a macro-oriented analysis and policy application of the drivers of energy-related carbon emissions in Ireland similar to these precedents. The identity proposed by Zhang and Ang (2001) is instructive to decompose changes in energy-related carbon emissions top-down at the national level and uses the following variables:

E = Total Primary Energy Requirement (TPER) of all fuel types

E_i = TPER of fuel type i

C = Total CO_2 emissions from all fuel types

C_i = CO_2 emissions from fuel type i

Y = GDP

P = Population

This leads to the following identity

$$C=\Sigma_i C_i=\Sigma_i (E_i/E)(C_i/E_i)(E/Y)(Y/P)P \quad (1)$$

However, function 1 does not represent the effect of change in CO_2 resulting specifically from the increased penetration of renewable or carbon-free energy. The identity decomposes CO_2, and as emissions from renewables are theoretically zero[3] the effect of renewables is not measured. In order to overcome this Ma and Stern (2008) and Wang *et al.* (2005) proposed an extended Kaya identity that also accounts for change resulting from increased penetration of renewables. Renewable energy is particularly important in Ireland because it is central to national mitigation efforts, nuclear generation is prohibited, and there is strong growth potential particularly for on-shore wind (OECD/ IEA, 2007). The term "negawatt" was coined by Lovins (1990) for avoided energy consumption due to energy efficiency. A similar term could be described as "negacarbon" or carbon emissions avoided through increasing the penetration of renewable energies and replacement of fossil fuels. The following variables are described for Ireland, as an extended Kaya identity:

E = Total Primary Energy Requirement (TPER) of all fuel types

FF_i = TPER of fossil fuel type i

FF = TPER of all fossil fuels

[3] Theoretically the carbon emissions from renewables are zero as fossil fuels are not combusted during the generation of electricity (when used in energy supply) or in the delivering of energy services (when used in final consumption). Some carbon emissions can be embedded in all energy sources in the production and decommissioning of hardware, but these life-cycle emissions are not relevant to this study.

C = Total CO_2 emissions from all fossil fuel types

C_i = CO_2 emissions from fossil fuel type i

Y = GDP

P = Population

Within this scheme i denotes fuel type (coal, oil, peat, gas, renewables). The CO_2 emissions using this approach can be written as the following extended Kaya identity;

$$C = \Sigma_i C_i = \Sigma_i (C_i/FF_i)(FF_i/FF)(FF/E)(E/Y)(Y/P)P = \Sigma_i F_1 S_1 S_2 IGP \quad (2)$$

Within this scheme the following nomenclature is applied;

$F_1 = C_i/FF_i$ the CO_2 emission coefficient for fossil fuel type i

$S_1 = FF_i/FF$ is the share of fossil fuel type i, in total fossil fuels

$S_2 = FF/E$ is the share of fossil fuels, in total fuels

$I = E/Y$ the aggregate energy intensity

$G = Y/P$ the GDP per capita or affluence

P = population

The decomposition of an observed change in C associated with these factors, are referred to as, the emission coefficient effect (ΔC_{emc}), the fossil fuel substitution effect (ΔC_{ffse}), the renewable energy penetration effect (ΔC_{repe}), the intensity effect (ΔC_{int}), the affluence effect (ΔC_{ypc}) and the population effect (ΔC_{pop}). The index of annual change in total CO_2 emissions (C_{tot}) can be expressed in the multiplicative form as follows;

$$C_{tot} = C_t/C_0 = C_{emc}C_{ffse}C_{repe}C_{int}C_{ypc}C_{pop} \tag{3}$$

Index decomposition analysis (IDA) is then applied as the method to decompose function (3). A range of techniques have been established under the umbrella of IDA but the Log Mean Divisia Index (LMDI I) has increasingly become the preferred approach (Ang, 2004; Ang *et al.,* 2003). This is due to a number of desirable properties of the *Divisia index* including perfect decomposition, consistency in aggregation, path independency and an ability to handle zero values. From Ang and Liu (2001), the following LMDI I formulae apply to each of the effects;

$$C_{emc}\text{: } \exp\left(\sum_i \frac{\left(C_i^T - C_i^0\right)/\left(\ln C_i^T - \ln C_i^0\right)}{\left(C^T - C^0\right)/\left(\ln C^T - \ln C^0\right)} \ln\left(\frac{F_1^T}{F_1^0}\right)\right)$$

$$C_{ffse}\text{: } \exp\left(\sum_i \frac{\left(C_i^T - C_i^0\right)/\left(\ln C_i^T - \ln C_i^0\right)}{\left(C^T - C^0\right)/\left(\ln C^T - \ln C^0\right)} \ln\left(\frac{S_1^T}{S_1^0}\right)\right)$$

$$C_{repe}\text{: } \exp\left(\sum_i \frac{\left(C_i^T - C_i^0\right)/\left(\ln C_i^T - \ln C_i^0\right)}{\left(C^T - C^0\right)/\left(\ln C^T - \ln C^0\right)} \ln\left(\frac{S_2^T}{S_2^0}\right)\right)$$

$$C_{int}: \exp\left(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{I^T}{I^0}\right)\right)$$

$$C_{ypc}: \exp\left(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{G^T}{G^0}\right)\right)$$

$$C_{pop}: \exp\left(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{P^T}{P^0}\right)\right) \quad (4)$$

Zero values in the data set are handled in accordance with Ang (2005) proposing the substitution of a small positive constant (e.g. between 10^{-10} and 10^{-20}). Negative values do not arise in the data set used in this study.

An IDA can be conducted in two forms either additive or multiplicative (Ang, 2005) to explore absolute or ratio of change respectively. While in LMDI I the two forms are linked through a simple mathematical relationship (Ang, 2005), the choice of form depends on considerations such as the purposes of the study, the existence of negative changes in the data set, and ease of application. In this study the Divisia index is employed in multiplicative form chain-linked year-by-year. This allows for annual analysis that can also be aggregated by sub-period and over the entire period. Results are reported as index change in effects annually and also grouped by period in both index and percentage annual change. An explanation of the effects measured in the decomposition analysis is provided in Table 1.

Table 1 Effects measured in the decomposition analysis

Effect	Type	Description of determinant effect
C_{ypc}	Scale	Change in average GDP per capita, or affluence.
C_{pop}	Scale	Change in number of inhabitants, or total population.
C_{emc}	Intensity	Change in carbon content per unit fossil fuel: coal, peat, oil and gas, attributable to fuel quality and potentially also to abatement technologies.
C_{int}	Intensity	Change in energy requirement per unit GDP due to the structure and efficiency of the economy and energy system, technological choices and socio-economic behaviour and lifestyle.
C_{repe}	Structure	Renewable energy penetration including; hydro, wind, biomass, biofuel, solar, geothermal etc.
C_{ffse}	Structure	Substitution or fuel switching of fossil fuel types (coal, oil, peat and gas) in total fossil fuels, a technological effect.
C_{tot}	Aggregate	Total change in carbon emissions aggregating the determinant effects.
C_{rsd}	Residual	Residual from the attribution of change to determinant effects above. This should be zero as LMDI I gives perfect decomposition.

3. Data

This study covers the period from 1990 to 2010 for which validated data for both energy and carbon emissions in Ireland are available. Energy data is compiled by the Sustainable Energy Authority of Ireland Energy Policy Statistical Support Unit (SEAI EPSSU), the official national source for reporting to EUROSTAT and the International Energy Agency (IEA). Energy data is reported in annual energy balance sheets that have been compiled using the currently applied format since 1990. The data includes Total Primary Energy Requirement (TPER) by fuel type, including renewables. This establishes the supply-side profile and consequently includes kerosene used in international aviation and stock changes (SEAI, 2011). The data used consists of sub-fuel types aggregated as kilo tonnes of oil equivalent (ktoe) of coal, oil, peat, gas and renewables. The data set also includes linked energy carbon emissions calculated by SEAI using the Intergovernmental Panel on Climate Change sectoral methodology (IPCC, 1997).

The activity data used in the IDA includes economic and population data compiled by the Central Statistics Office (CSO). The economic data (CSO, 2011a) is measured by GDP in million €, calculated at constant market prices. The data set blends 1990 to 1995 chain-linked and referenced to 2008, with data from 1996 to 2010 chain-linked and referenced to 2009. Pre-1995 data excludes Financial Intermediation Services Indirectly Measured (FISIM) and the data set must be blended in order to overcome this limitation. FISIM is an estimated service charge in respect of non-invoiced services in the case of banks and similar businesses.

The use of economic indicators such as GDP comes with many caveats. Such measurements of human welfare are limited in scope and exclude social and environmental dimensions. These indicators were not originally designed for the purposes of measuring human welfare or well-being (Kuznets, 1934) and are a gross tally of everything produced good and bad. They obscure equality and the disparity in income and welfare, the cost of pollution damage is calculated as positive, there is a failure to account for the lost value from depleted natural resources or the unpaid costs of environmental harm and the non-formal economy is excluded. It could be argued that measurements such as GDP evolved in an epoch where discourse and analysis of these social and environmental dimensions had not been sufficiently resolved or mainstreamed. The use of such measures can potentially compound undesirable phenomena as an intrinsic part of the epistemic culture in which the problem at hand arose. Conventional wisdom holds that driving GDP higher is desirable and decisionmakers seek to maximise this trajectory and avoid policies that could lead to reductions. Problems occur when the use of this indicator expands beyond its function in understanding income and production growth to measurement and perceptions of development progress. Through a myopic development focus on GDP, production and consumerism can be valued above human welfare or environmental quality, and perceptions of affluence can potentially be misguided, as costs are offset to future generations. Where the environmental and social underpinnings of well-being and economic development are undermined this could be described as a ´growth illusion´ (Douthwaite, 1992) and is particularly salient in the case of Ireland. Even from a solely economic perspective, growth historically was unsustainable and the resultant housing bubble saw the future mortgaged for present gain.

These conflicts could be reconciled by applying concepts and principles related to sustainable development as the decision-making framework, or as a platform for the selection of a broader set of development indicators, rather than a limited focus on GDP growth (Halsnaes *et al.*, 2007). Such critiques have led to the creation of alternative development indicators to reflect broader concerns of social and environmental welfare such as Green GDP, Genuine Progress Indicator (GPI) and the standard global Human Development Index (HDI). Yet these indicators are not used in most energy models due to the ubiquity of traditional economic output measures. While it would be a valuable exercise to apply alternative development indicators in a future study, as this is the first national scale decomposition of Ireland the traditional measure of GDP has been utilised.

In the case of population, estimates are published annually by the Central Statistics office (CSO, 2011b). Population estimates from 2006 onwards are based on the usual residence concept, while previous periods employ the de facto concept. The estimates have not yet been revised for the national 2011 census results at the time of this study.

4. Results

The complete time-series decomposition results for the macro LMDI are presented Appendix A. The accumulated effects by period are available as index change in Table 2 and as percentage change in Table 3. The accumulated effects over the entire period (Fig. 3) illustrate that the dominant positive effect is the affluence effect (C_{ypc}), as is often identified in other studies. The population effect (C_{pop}) as a scale effect, also had a positive but relatively minor effect on emissions while the emissions coefficient effect (C_{emc}) had a small positive effect also. The energy intensity effect (C_{int}) was the most significant negative effect on emissions, followed by the substitution effect among fossil fuels (C_{ffse}) and the renewable energy penetration effect (C_{repe}). The total negative effects are heavily outweighed by the total positive effects, which resulted in the increase in carbon emissions. These results are summarised as follows:

1. The scale effects (C_{ypc}, C_{pop}) are the dominant drivers in Ireland. Population contributes to growth in emissions, but this is dwarfed by the affluence effect (Table 2.).
2. The intensity effect (C_{int}) reducing the intensity of energy per unit economic output, is the most significant factor in limiting growth in carbon emissions.
3. The fossil fuel substitution effect (C_{ffse}) and the renewable energy penetration effect (C_{repe}) both contribute to decreasing emissions, but these effects combined are limited and minor in the case of (C_{repe}).

4. The accumulated effects reducing emissions are more than offset by drivers increasing emissions, leading to a significant increase in total energy-related carbon emissions (C_{tot}).

5. The analysis illustrates four distinct periods in development trends (Table 1 and Table 2) a.) the pre-economic boom period 1990-1993 with a small increase in total emissions, b.) 1993-2001 boom period of significant increase, c.) 2001-2007 period of moderated growth where emissions continue to increase at a slower rate, and d.) 2008-2010 as emissions fall during the Irish economic recession.

6. Carbon emissions began to drop dramatically in 2008. This is attributable to the declining economy. Continued progress is evident in technological change through renewable energy (C_{repe}), and fuel substitution (C_{ffse}) exerted a minor negative effect. The intensity of the economy increased during the economic downturn, while population (C_{pop}) continued a positive effect. Increasing intensity can be attributed to an increasing proportion of non-economic energy consumption in total consumption which makes the overall economy more intense.[4]

[4] The declining economy increased the relative proportion of energy consumption from non-economically productive sources, including the residential and transport sectors. This acts to increase intensity when it is measured as energy per unit GDP. Energy demand is aggregated across economic and non-economic sources and yet the activity indicator only measures change in the economy. Howley *et al.* (2011) cited loss of economies of scale and colder weather in 2008 and 2010.

Table 2 Decomposition of Ireland's energy CO_2 from 1990 - 2010

	ΔC_{tot}	ΔC_{ffse}	ΔC_{repe}	ΔC_{int}	ΔC_{ypc}	ΔC_{pop}	ΔC_{emc}
1990-1993	1.0058	0.9882	1.0005	0.9974	1.0175	1.0055	0.9970
1993-2001	1.4109	0.9462	1.0002	0.7751	1.7647	1.0764	1.0126
2001-2007	1.0551	0.9728	0.9851	0.8194	1.1923	1.1278	0.9993
2007-2010	0.8845	0.9871	0.9840	1.0178	0.8721	1.0303	0.9956
1990-2010	1.3435	0.8867	0.9710	0.6265	1.9387	1.2751	1.0075

Table 3 Decomposition of Ireland's energy CO_2 in annual per cent growth rates 1990 - 2010

	ΔC_{tot}	ΔC_{ffse}	ΔC_{repe}	ΔC_{int}	ΔC_{ypc}	ΔC_{pop}	ΔC_{emc}
1990-1993	0.19	-0.39	0.02	-0.09	0.58	0.18	-0.10
1993-2001	5.14	-0.67	0.00	-2.81	9.56	0.95	0.16
2001-2007	0.92	-0.45	-0.25	-3.01	3.20	2.13	-0.01
2007-2010	-3.85	-0.43	-0.53	0.59	-4.26	1.01	-0.07
1990-2010	1.72	-0.57	-0.14	-1.87	4.69	1.38	0.04

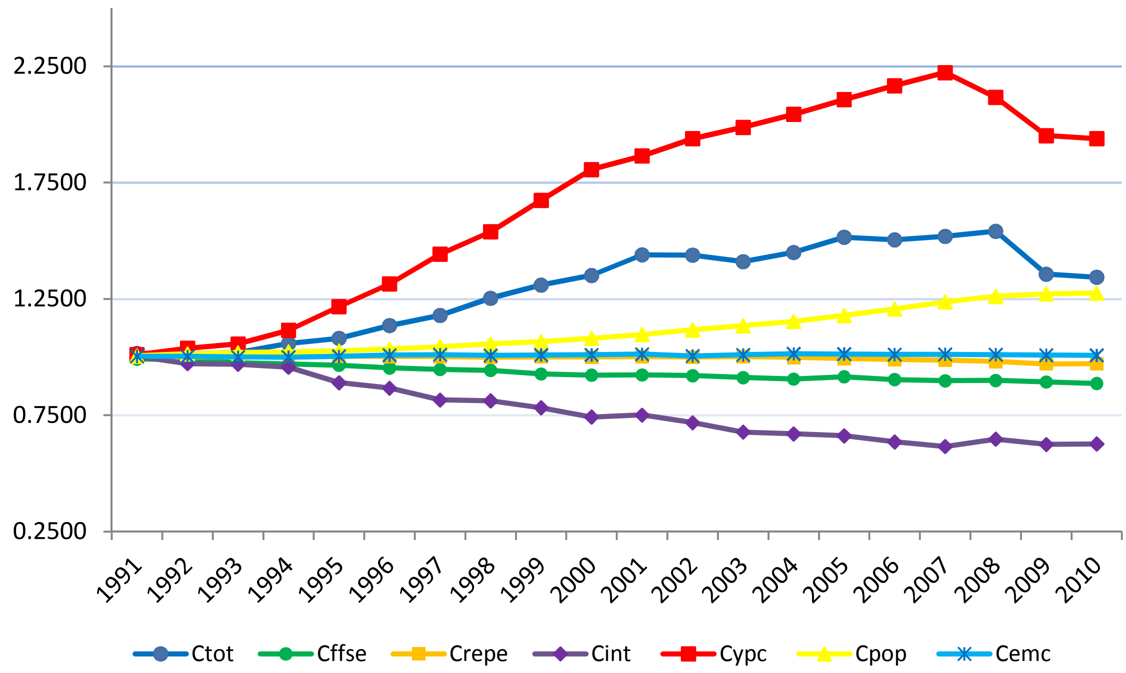

Fig. 3. Accumulated decomposition of Ireland's energy carbon emissions 1990-2010

The impact of the affluence effect (C_{ypc}) can be seen throughout the time series, particularly during the period from 1993-2001. Rapid economic growth acted as a scale effect to increase the energy requirement and carbon emissions. While this was not a linear relationship, the patterns of production and consumption across the economy and society were not sufficiently delinked from energy. Ireland also experienced population growth, but this scale effect (C_{pop}) was not significant when seen in comparison with the (C_{ypc}). Not only was the (C_{pop}) effect less significant but it was linked to economic growth. Increases in population have been attributed to labour migration due to economically defined immigration policy (Zaiceva and Zimmerman, 2008).

The (C_{ffse}) effect primarily measures the substitution of gas and oil for coal and peat in particular, as a graduation occurred to more convenient forms of energy through technological choices. The trend in (C_{ffse}) continued to improve from 1990-2010. Technological change, both on the supply side in electricity generation, and on the demand-side, delivered fuel substitution[5]. The (C_{emc}) effect has registered an increase over the period. This is attributable to change in sub-fuel types such as bituminous coal, anthracite and lignite within aggregated 'coal'. Although increasing in recent years, the (C_{repe}) effect failed to make notable progress in reducing national emissions over the analysis period. In proportion of TPER, it increased penetration through wind energy in electricity generation and biofuels in transport. This slow progress could be attributed to three factors; insufficient policy support including the lack of internalisation of externalities in fossil fuel prices, the cost and fledgling nature of some technologies and physical limitations e.g. to the expansion of hydro in Ireland. While some renewable technologies could have been described as less mature, wind offers significant potential for expansion as a more mature technology.

The energy intensity effect (C_{int}) is frequently recorded as the most significant negative effect in decomposition analysis studies (Schleich *et al*., 2001; Ma and Stern, 2008). In studying China, Ma and Stern (2008) describe energy per GDP, or 'energy intensity' as usually interpreted as a technological effect. It is important to recognise that this macro level indicator based on TPER, as used similarly in this study, encompasses more than technology. Tapio *et al.* (2007) point to a critical distinction in the interpretation of energy intensity results at the macroeconomic scale. It includes not just technical efficiency described as 'dematerialisation,' but also includes the often less tangible but crucially important 'immaterialisation'. Immaterialisation occurs where there is decoupling of material production and consumption from economic production. It is linked to factors such as economic structure and socio-cultural development of

[5]Electricity was included as a fuel type in the demand side decomposition of eleven final consumption sectors from 1990 to 2007 detailed in O´ Mahony *et al*. (2012) and in O´ Mahony (2010). In general, the declining emissions coefficient of electricity was important in limiting emissions on the demand side due to fuel switching, efficiency and renewables in power generation. Its increasing share in final energy acted to reduce emissions in the case of the residential sector, but it acted to increase emissions in industry, commercial services and rail transport due to absolute increases in consumption.

society. Socio-cultural development determines overarching choices such as spatial patterns, transport trends, housing types and lifestyles, in addition to actual behaviour with technology. Studies such as Baksi and Green (2007) attribute changes in energy intensity to economic structure and technical efficiency alone. This appears to reflect an economic focus in the analysis, but a wider focus as a development indicator is necessary as 'energy intensity' encompasses more than 'economic activity.'

In understanding what has occurred in energy intensity, sectoral trends aid interpretation. Energy intensity improvement has been high in Irish industry (Diakoulaki and Mandaraka, 2007; O' Mahony *et al*., 2012), but is largely attributable to structural change (Cahill and Ó Gallachoir, 2009) as a post-industrial development model (Kaivo-oja and Luukkkanen, 2004). However, energy intensity in commercial services, public services and agriculture has either weakly improved or has dis-improved (O' Mahony *et al*., 2012). O' Mahony *et al*. (2012) also showed retrograde developments in Irish transport. Increasing transport activity has co-occurred with shifts to more intense modes and increased intensity within mode[6], and these phenomena emphasise the importance of socio-cultural factors. The significant achievement in overall energy intensity in this study, attributable to high output growth, masks underlying trends away from immaterialisation and dematerialisation. In addition, socio-cultural factors, including lifestyles and preferences have been recognised for a number of years for their crucial importance in determining emissions[7], yet the domination of economic and technical effects in many studies leaves these factors poorly understood or entirely ignored in causation.

[6] While technical efficiency should theoretically improve, actual energy intensity of Irish transport has increased. Energy intensity calculated per p-km and t-km increased in all sectors apart from rail including; road private car, road freight, road public passenger and domestic aviation (O' Mahony *et al*., 2012).

[7] The importance of lifestyle is reflected in the large differences between energy per capita across nations. This can only partly be explained by weather and wealth and is attributed to different lifestyles, traditions and cultures (OECD/ IEA, 1997). Lifestyle, behaviour factors and consumer choice are significant across all sectors including buildings, transport and industry and include management practices (IPCC, 2007).

5. Policy implications

As an Annex I signatory of the Kyoto Protocol, Ireland is subject to emission limitation and reduction targets from 2008 - 2012. In line with deepening mitigation requirements under the EU "Effort Sharing Decision" Decision No 406/2009/EC, it is further obliged to reduce GHG emissions by -20 per cent of 2005 levels by 2020, from sources outside the EU Emissions Trading System (ETS). As a key GHG, the reduction of carbon emissions has consequently become of increased political and strategic significance. Understanding the driving forces of carbon emissions is essential to a robust policy-making process. In decomposition analysis, driving forces are specified as scale, intensity and structural effects providing a useful tool to discuss policy levers to reduce emissions. Nonetheless, cognisance is necessary of the potential limitations of rigid interpretation and attribution of quantitative results. Other dimensions should be considered in keeping with the transdisciplinary approach to the Kaya identity in Nakicenovic *et al*. (2000).

In viewing possible policy levers and options evident from the analysis, it is not usual for limitations on the scale effects of economic growth or indeed population to be acceptable policy prescriptions. Despite the significance of economic growth in increasing emissions, perceived national economic and social objectives take precedence. The national debt repayment requirements under the European Union/ International Monetary Fund (EU/ IMF) intervention programme in Ireland now necessitate acceleration of economic growth, while dealing with increased unemployment and public finance challenges are also accorded the same policy remedy. This creates potential policy conflict with emission reduction objectives. However, in spite of this, it is important to note that economic growth does not have linear relationship with energy demand or carbon emissions. This relationship is dictated by the development path (Sathaye *et al*., 2007) and is imperative to future mitigation strategy. Economic growth could potentially be accommodated with mitigation if its quality or nature is sufficiently directed into energy and emissions extensive forms. Lower intensity development paths are facilitated at source by immaterialisation, where material production and consumption are decoupled from economic growth (Tapio *et al*., 2007). This is achieved through sustainability considerations in wider policy domains such as economic development, spatial development, transport policy and lifestyles but requires mainstreaming across all policies, programmes and individual actions (Sathaye *et al*., 2007). Mitigation is more expensive, targets become more distant and potential policy synergies are lost without fundamental changes in the development path. This realisation was a key finding of the IPCC Third Assessment Report (IPCC, 2001) and involves more than technical energy efficiency alone as is represented by the broad energy intensity indicator in this study.

The importance of improving energy efficiency in achieving mitigation and energy policy objectives is well accepted, particularly in the EU. EU policy has sought to maximise achievement of cost-effective energy efficiency through an evolving range of policy and measures[8]. EU member states are required to submit national energy efficiency action plans (NEAAP) under the Energy End-Use Efficiency and Energy Services Directive (ESD) (2006/32/EC)[9] seeking a non-binding target of a 9 per cent cost effective saving in energy consumption by 2016, or 1 per cent per annum. Ireland's NEEAP (DCENR, 2009) envisages 20 per cent energy efficiency savings by 2020 based

[8] These include efficiency standards for energy using products in the revised Eco-design Directive (2009/125/EC), an enhanced Energy Performance of Buildings Directive (2002/91/EC) and legislation to limit carbon emissions from cars (Regulation (EC) No 443/2009). Industry large emitters are subject to the cap-and-trade European Union Emissions Trading Scheme (EU ETS) since 2005, and including aviation since 2012.
[9] This will be upgraded by the proposed Energy Efficiency Directive (COM/2011/0370 final) with legally binding measures.

on the average of 2001 - 2005. The ninety policies and measures established are predominantly 'technical' although they include some provision for mobility and demand-side management. Progress towards this target is as yet unclear but the dominance of 'technical' measures is a sub-optimal policy response. The technical focus provided for by the ESD and the ODEX method envisaged by the directive is a valuable policy contribution, as represented in the Irish NEEAP. Nevertheless, it should not lead to a reduced focus on decoupling measures to harness non-technical change such as industry structure, higher density spatial planning, shift to active transport and delinking consumption and well-being/ wealth. This approach would be a serious diminution of mitigation plans and prevention first, not technological and end-of-pipe measures, should be prioritised as the path of higher sustainability and lower cost. These approaches should be first order responses in mitigation plans and fully integrated with development, sustainability and energy-efficiency policies. The reductionist approach focussing on techno-economic aspects, as reflected in the Irish NEEAP and its antecedent (OECD/ IEA, 2008), needs to be expanded to encompass issues of development and sustainability for optimal policy outcomes. This is what Sathaye *et al.* (2007) termed; "framing the debate as a sustainable development problem rather than only as climate mitigation". The analytical methods applied, including decomposition analysis, should not lead to a narrow focus on policies and measures to respond. While measuring energy intensity is an aggregation of factors, it does give an idea of overall progress towards decoupling which is not provided by technical efficiency analysis.

Fossil fuel substitution has reduced emissions successfully by transferring energy consumption to forms of lower carbon intensity. Increasing fuel substitution and renewable energy penetration usually also improves energy efficiency but requires investment in technological change. Modernisation has occurred away from coal and peat consumption to gas and electricity as more convenient forms of energy services. The carbon tax implemented in Ireland in 2010 on liquid fuels and natural gas does not apply to the solid fuels coal and peat and providing potentially perverse incentives for use of these more carbon intensive fuels. While fuel substitution can aid a transition path and compliance to 2020, ultimately energy requirements must be found from renewable or carbon-free sources to deliver significant long-term reductions in emissions. Fossil fuel substitution can buy governments time by continuing to reduce emissions in the short-term, but caution must be applied in risking longer-term carbon lock-in (Unruh, 2000) and failing to engender the more fundamental changes required towards sustainability.

Ireland does not have sufficient hydro development potential, nuclear generation is subject to statutory prohibition and the viability of large-scale carbon capture and storage (CCS) is as yet unclear. While renewable energy has led to only a minor reduction in emissions it has significant future economic potential through on-shore wind (OECD/ IEA, 2007). For on-shore wind, Delucchi and Jacobson (2011) found that on private cost, generating electricity often costs less than conventional fossil-fuel generation and significantly less when social costs are included[10]. Ireland was subject to EU directive RES-E (2001/77/EC), with a target of 13.2 per cent of electricity produced from renewables by 2010. A higher national target of 15 per cent led to the actual achievement of 14.8 per cent in 2010 (Howley *et al.*, 2011). This was primarily achieved through on-shore wind for which the new government target is 40 per cent by 2020, with policy support by a feed-in-tariff. Continued policy support will be required for wind to meet this target, and thereby contribute to the separate binding Renewable Directive (2009/28/EC) target for 2020 of 16 per cent renewables in Gross Final

[10] Delucchi and Jacobson (2011) found that the barriers to a 100% conversion to renewables globally are not technological or even economic but primarily social and political.

Consumption. In addition, this new Directive includes a binding target of 10 per cent transport energy from renewables (RES-T).[11] National non-binding targets for heating and cooling from renewables have also been established known as 'RES-H'.[12] Growth has largely occurred through biomass wood waste use in industry, while residential grant support has increased uptake of geothermal.

The monitoring of progress in mitigation Policies and Measures (PAM's) to limit carbon emissions is required to achieve designated targets. Decomposition analysis offers a robust approach to monitor change which must be accompanied by review and corrective action in an effective policy cycle that is intended to deliver on targets rather than rhetoric. This historical analysis may also have important insights into development paths for other nations attempting to attain or currently experiencing rapid economic development, and the issues that can arise for carbon emissions. As a methodological observation, the macro Kaya identity used here yields deeper insights than an Environmental Kuznets Curve (EKC). This highlights not only the limits of EKC but also the emergence of decomposition as a more appropriate method to disentangle the relationship between development and environment (Stern, 2004).

6. Concluding remarks

Ireland has experienced a sharp increase in carbon emissions since 1990, coinciding with a period of rapid economic development. Understanding the driving forces of increasing emissions is important for policy formulation and decomposition analysis is a useful approach to quantify changes in predetermined factors of interest.

[11] Ireland's achievement in RES-T was marginally below the indicative target of 3 per cent in 2010 at 2.4 per cent, pursued through measures including a biofuels obligation on suppliers and tax relief. The target was reduced in 2008 from 5.75 per cent due to concerns in national government about the sustainability of biofuels. The binding RES-T target for 2020 of 10 per cent remains.

[12] This envisages 5.5 per cent renewables by demand for thermal requirements in 2010 against 4.4 per cent achieved and a further target of 12 per cent has been set for 2020.

This study applies the LMDI I technique from 1990 – 2010 using an extended Kaya identity that includes a measure of the effect of renewable energy penetration on carbon emissions. Distinctly different development periods are evident from the analysis. The scale effects of affluence and population growth act to increase emissions and are countered primarily by intensity and fuel substitution. Renewable energy penetration has a minor effect but has been increasing in recent years. While intensity improved significantly, only a relative and not an absolute delinking occurred given the high rate of output growth. Assuming continued economic and population growth, policy must seek to significantly reduce intensity and increase renewables if applicable targets are to be reached, and this will require a comprehensive suite of PAM's. While the analytical methods, including decomposition analysis, frequently guide policy discourse towards technical and economic aspects, this should not exclude 'non-technical' change. While these can be less tangible, they are paramount to mitigation efforts, as the challenge should be viewed as one of sustainable development rather than mitigation or indeed technical energy efficiency alone. While this study adopted the objective of a macro-oriented approach to analysis similar to studies such as Ma and Stern (2008), further quantitative evaluation of sustainability issues such as that represented in Kaivo-oja *et al*. (2001) is desirable to deepen analysis and insight.

References

Ang, B.W. and Liu, F.L., 2001: A new energy decomposition method: perfect in decomposition and consistent in aggregation. Energy 26 (6), 537–548.

Ang, B.W., 2004: Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy 32, 1131–1139.

Ang, B.W., 2005: The LMDI approach to decomposition analysis: a practical guide, Energy Policy **33**, 867–871.

Ang, B.W., Liu, F.L. and Chew, E.P., 2003: Perfect decomposition techniques in energy and environmental analysis, Energy Policy 31, pp. 1561–1566.

Ang, B.W., Zhang, F.Q. and Choi, K.H., 1998: Factorising changes in energy and environmental indicators through decomposition, Energy 23, 489–495.

Baksi, S. and Green, C., 2007: Calculating economy-wide energy intensity decline rate: the role of sectoral output and energy shares. Energy Policy 35, 6457-66.

Cahill, C. and Ó Gallachoir, B. P., 2009: Comparing the use of ODEX indicators with Divisia decomposition analysis to measure true energy efficiency achievements: case study Irish industry. eceee 2009 Summer Study Conference Proceedings. Act! Innovate! Deliver! Reducing energy demand sustainably. 1–6 June 2009 La Colle sur Loup, France, 1147-1154.

Commoner, B., 1972: A Bulletin Dialogue on 'The Closing Circle': Response. Bulletin of the Atomic Scientists 28 (17), 42-56.

CSO, 2011a: Gross Domestic Product National Income and Expenditure Accounts Table 4 from 1990 to 1995 and from 1996 to 2010. Personal Communication, Sibley, C., 10 November, 2011.

CSO, 2011b: PEA01 Population Estimates by Sex, Age Group and Year (1950-2011) - Modified on 15/09/11. <http://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/saveselections.asp> accessed 18 November, 2011.

DCENR, 2009: Maximising Ireland's Energy Efficiency. The National Energy Efficiency Action Plan 2009. Department of Communications, Energy and Natural Resources. – 2020<http://www.dcenr.gov.ie/NR/rdonlyres/FC3D76AF-7FF1-483F-81CD-52DCB0C73097/0/NEEAP_full_launch_report.pdf> accessed 29 May, 2012.

Delucchi, M. A., and Jacobson, M. Z., 2011: Providing all global energy with wind, water and solar power, Part II: Reliability, system and transmission costs, and policies. Energy Policy 39 (3), 1170–1190.

Diakoulaki D. and Mandaraka, M., 2007: D. Decomposition analysis for assessing the progress in decoupling industrial growth from CO_2 emission in the EU manufacturing sector, Energy Economics 29, 636–664

Douthwaite, R., 1992: The Growth Illusion. Green Books, Bideford, UK..

Duffy, P., Hanley, E., Hyde, B., O'Brien, P., Ponzi, J., Cotter, E. and Black, K., 2012: Ireland National Inventory Report 2012. Grennhouse Gas Emissions 1990 – 2012 reported to the United Nations Framework Convention on Climate Change. Environmental Protection Agency. <http://coe.epa.ie/ghg/nirdownloads.jsp> accessed, 29 May, 2012.

EEA, 2006: Urban sprawl in Europe The ignored challenge. EEA Report No 10/2006. European Commission Directorate General, Joint Research Centre and the European Environment Agency. EEA Copenhagen.

Ehrlich, P. R., and Holdren, J.P., 1972: A Bulletin Dialogue on the 'Closing Circle': Critique. One-Dimensional Ecology. Bulletin of the Atomic Scientists 28:16-27.

Halsnæs, K., P. Shukla, D. Ahuja, G. Akumu, R. Beale, J. Edmonds, C. Gollier, A. Grübler, M. Ha Duong, A. Markandya, M. McFarland, E. Nikitina, T. Sugiyama, A. Villavicencio, J. Zou, 2007: Framing issues. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Howley, M., Dennehy, E., Holland, M., Ó Gallachóir, B., 2011: Energy in Ireland 1990 – 2010 2011 Report. Sustainable Energy Authority of Ireland Energy Policy Statistical Support Unit. <http://www.seai.ie/Publications/Statistics_Publications/EPSSU_Publications/Energy%20In%20Ireland%201990%20-2010%20-%202011%20report.PDF> accessed 29 May, 2012.

IPCC, 1997: Revised 1996 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. OECD, Paris.

IPCC, 2001: Climate Change 2001: Mitigation - Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [Metz, B., O. Davidson, R. Swart, and J. Pan (eds.)]. Cambridge University Press, Cambridge, 700 pp.

IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jennings, M., Ó Gallachóir, B.P., Schipper, L., 2013: Irish passenger transport: Data refinements, international comparisons, and decomposition analysis. Energy Policy 56, 151-164.

Kaivo-oja, J. and Luukkanen J., 2004: The European Union balancing between CO_2 reduction commitments and growth policies: decomposition analyses. Energy Policy 32 (13), 1511-1530.

Kaivo-oja, J., Luukkanen, J., and Malaska, P., 2001: Sustainability Evaluation Frameworks and Alternative Analytical Scenarios of National Economies, Population and Environment - A Journal of Interdisciplinary Studies 23(2), 193–215.

Kaya, Y., 1990: Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, (mimeo).

Kuznets, S., 1934: National Income, 1929-1932. 73rd US Congress, 2nd session, Senate document no. 124, page 6-7. <http://library.bea.gov/u?/SOD,888> accessed 26 January 2010.

Lovins, A.B., 1990: The Negawatt Revolution. Across the Board XXVII (9), 21-22.

Ma, C., and Stern, D.I., 2008: Biomass and China's carbon emissions: A missing piece of carbon decomposition. Energy Policy 36 (7), 2517-2526.

Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenham, S. Gaffin, K. Gregory, A. Grübler, T.-Y. Jung, T. Kram, E.L. La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Reohrl, H.H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, and Z. Dadi, 2000: Special report on emissions scenarios. Working Group III, Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge. pp 595.

O' Mahony, T., 2010: Energy Related Carbon Emissions in Ireland: Scenarios to 2020. Doctoral Thesis. Dublin Institute of Technology. Dublin, Ireland.

O' Mahony, T., Zhou, P. and Sweeney, J., 2012. The driving forces of energy-related CO_2 emissions in Ireland：A multi-sectoral decomposition from 1990 to 2007. Energy Policy 44, 256-267.

O'Doherty, J. and Tol, R.S.J., 2007: An Environmental Input-Output Model for Ireland. The Economic and Social Review 38 (2), 157-190.

OECD/ IEA, 1997: The link between energy and human activity. International Energy Agency.

OECD/ IEA, 2007: Energy policies of IEA countries. Ireland 2007 Review. International Energy Agency/ Organisation for Economic Cooperation and Development, Paris.

OECD/ IEA, 2008: Energy Efficiency Policy Recommendations. In support of the G8 Plan of Action. International Energy Agency/ Organisation for Economic Cooperation and Development. <http://www.iea.org/g8/2008/G8_EE_recommendations.pdf> accessed, 30 May 2012.

Sathaye, J., A. Najam, C. Cocklin, T. Heller, F. Lecocq, J. Llanes-Regueiro, J. Pan, G. Petschel-Held , S. Rayner, J. Robinson, R. Schaeffer, Y. Sokona, R. Swart, H. Winkler, 2007: Sustainable Development and Mitigation. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Schleich, J., Eichhammer, W., Boede, U., Gagelmann, F., Jochem, E., Schlomann, B., Ziesing, H.J., 2001: Greenhouse gas reductions in Germany – lucky strike or hard work? Climate Policy 1, 363–380.

SEAI, 2011: Expanded Energy Balance Sheets 1990-2010, frozen 17 October 2011. Sustainable Energy Authority of Ireland Energy Policy Statistical Support Unit. Cork, Ireland. Personal Communication Howley M., 11 November 2011.

Steenhof, P., Woudsma, C. and Sparling, E., 2006: Greenhouse gas emissions and the surface transport of freight in Canada, Transportation Research Part D-Transport and Environment, 11 (5), 369–376.

Stern, D.I., 2004: The rise and fall of the environmental Kuznets curve. World Development 32 (8), 1419–1439.

Tapio, P., Banister, D., Luukkanen, J., Vehmas, J. and Willamo, R. 2007: Energy and transport in comparison: Immaterialisation, dematerialisation and decarbonisation in the EU15 between 1970 and 2000, Energy Policy 35, 433-451.

UNFCCC, 2004: Report on the workshop on the preparation of fourth national communications from Parties included in Annex I to the Convention. Note by the secretariat. United Nations Framework Convention on Climate Change, (FCCC/SBI/2004/INF.14). <http://unfccc.int/resource/docs/2004/sbi/inf14.pdf>, accessed 1 March 2010.

Unruh, G. C., 2000: Understanding carbon lock-in Energy Policy 28 (12), 817-830.

UNSTATS, 2010: Environment Indicators GHG's. United Nations Statistics Division. <http://unstats.un.org/unsd/ENVIRONMENT/qindicators.htm> accessed, 05 June 2012.

Wang, C., Chen, J. and Zou, J., 2005: Decomposition of energy-related CO_2 emission in China: 1957–2000, Energy 30 (1), 73-83.

Zaiceva, A. and Zimmermann, K.F., 2008: Scale, Diversity, and Determinants of Labour Migration in Europe. Discussion paper series IZA DP No. 3595.

Zhang, F.Q. and Ang, B.W., 2001: Methodological issues in cross-country/region decomposition of energy and environment indicators, Energy Economics 23 (2), 179–190.

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Appendix A. Annual time series decomposition results 1990 to 2010

	ΔC_{total}	ΔC_{ffse}	ΔC_{repe}	ΔC_{int}	ΔC_{ypc}	ΔC_{pop}	ΔC_{emc}	ΔC_{rsd}
1991-1992	0.9985	0.9956	1.0006	0.9685	1.0274	1.0082	0.9992	0.0000
1992-1993	1.0058	0.9882	1.0005	0.9974	1.0175	1.0055	0.9970	0.0000
1993-1994	1.0378	0.9938	0.9994	0.9871	1.0554	1.0033	0.9997	0.0000
1994-1995	1.0206	0.9950	1.0022	0.9306	1.0912	1.0043	1.0036	0.0000
1995-1996	1.0511	0.9882	0.9996	0.9734	1.0802	1.0069	1.0051	0.0000
1996-1997	1.0382	0.9928	0.9996	0.9412	1.0976	1.0105	1.0021	0.0000
1997-1998	1.0625	0.9964	0.9970	0.9957	1.0667	1.0106	0.9965	0.0000
1998-1999	1.0452	0.9836	1.0018	0.9632	1.0877	1.0104	1.0020	0.0000
1999-2000	1.0316	0.9942	0.9996	0.9491	1.0791	1.0128	1.0007	0.0000
2000-2001	1.0656	1.0011	1.0011	1.0117	1.0322	1.0152	1.0029	0.0000
2001-2002	0.9991	0.9965	0.9983	0.9560	1.0398	1.0182	0.9922	0.0000
2002-2003	0.9805	0.9912	1.0015	0.9439	1.0252	1.0160	1.0047	0.0000
2003-2004	1.0279	0.9930	0.9970	0.9889	1.0282	1.0164	1.0046	0.0000
2004-2005	1.0454	1.0111	0.9950	0.9875	1.0308	1.0219	0.9989	0.0000
2005-2006	0.9926	0.9867	0.9966	0.9603	1.0284	1.0240	0.9981	0.0000
2006-2007	1.0099	0.9941	0.9966	0.9684	1.0261	1.0251	1.0008	0.0000
2007-2008	1.0144	1.0015	0.9942	1.0516	0.9521	1.0191	0.9984	0.0000
2008-2009	0.8803	0.9931	0.9895	0.9652	0.9223	1.0084	0.9979	0.0000
2009-2010	0.9905	0.9925	1.0003	1.0028	0.9932	1.0026	0.9992	0.0000

1990-2010	1.3435	0.8867	0.9710	0.6265	1.9387	1.2751	1.0075	0.0000