Technical support on developing low carbon sector roadmaps for Ireland

Low Carbon Energy Roadmap for Ireland

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KEY FINDINGS

Significant investment in energy efficiency and renewable energy technologies would be required for Ireland to transition to a low carbon economy by 2050. Investment by 2050 may be 30% higher in a low carbon energy system compared with a business as usual scenario and this is offset by a 33% reduction in fuel costs.

Fossil fuels are incompatible with a low carbon economy and there use could be greatly diminished. Oil consumption could reduce to 1 – 4 million barrels per annum by 2050 compared with 61 million barrels in a business as usual. Natural gas may still be used in 2050 but reduced limited to electricity generation with carbon capture and storage. Coal may be mostly removed from the energy system and peat could be removed entirely.

Energy savings of 30% may be achieved in the low carbon scenarios by 2050 and **bioenergy** (comprising woody biomass, liquid biofuels and biogas) **could become the dominant energy source**. This is in stark contrast to today where bioenergy supplies approximately 2% of final energy consumption and has significant implications for land use and for energy security. All the 6.9 GW of onshore wind energy may be harnessed and as carbon dioxide is further constrained also some offshore wind and solar power.

Significant **changes in infrastructure** may be required. Electrification of heat and transport could increase the electricity share of energy use from 18% to 25 – 40%. Gas networks are anticipated to deliver more biogas than natural gas to final customers, in addition to the natural gas to power plants with carbon capture and storage. Oil distribution could be replaced by liquid biofuel distribution, apart from kerosene use in aviation.

Significant changes may be envisaged for **energy consumers**. Private car transport could be completely electrified in 2050. Residential heating may switch from oil and gas to air source heat pumps and biogas.

INTRODUCTION

The Department of the Environment, Community and Local Government has commissioned the Economic and Social Research Institute (ESRI) and University College Cork (UCC) to provide technical advice and guidance on the development of a low carbon roadmap for Ireland with the aim of achieving transition to a low carbon, climate resilient and environmentally sustainable economy in the period up to and including the year 2050.

The project incorporates three phases:

Phase 1. Develop a methodological approach for the analysis and a description of the anticipated outputs of the analysis.

Phase 2. Build i) a business as usual (BAU) reference scenario to 2050 and ii) a least cost low carbon scenario to achieve near zero emissions by 2050.

Phase 3. Revise the scenarios generated in Phase 2 based on comments from relevant Government Departments

The project focuses on energy supply and energy end-use in Ireland, i.e. Ireland's energy system. Energy use in Ireland currently accounts for approx two-thirds of Ireland's greenhouse gas emissions, with the bulk of the remainder (approximately 30%) accounted for by agriculture.

This report relates to Phase 3 of the project. It presents and discusses a revised Low Carbon Roadmap for Ireland. The focus is on technological changes in the energy system and the associated implications. While this is the final phase of this project, the authors view it as one stage only, in an ongoing process to inform and plan for Ireland's transition a low carbon economy.

As stated in the EU Energy Roadmap 2050[1], *forecasting the long-term future is not possible*. The purpose of this Low Carbon Energy Roadmap for Ireland to 2050 is not to predict the future but to explore possible routes towards decarbonisation of the energy system, with a focus on

[1] European Commission (2011) *Energy Roadmap 2050.* Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2011)885/2

achieving this at least cost to the economy and to society. The roadmap provides insights into when changes in the fuel mix are likely to occur (e.g. transitioning from oil to biogas and biomass), the timing of new technologies (e.g. when and to what extent will electric vehicles penetrate the transport fleet) and the future role of electricity and gas infrastructure. It also emphasizes the scale of the challenge ahead and points to a number of areas of opportunity for Ireland as it transitions for a low carbon future. This roadmap does not stipulate which policies are necessary to achieve the transition; it rather focuses on the implications for the energy system of moving to a low carbon economy. The trajectory and milestones achieved in different periods do point to what the policy focus should be at different stages in the roadmap.

PART I: CONTEXT, METHODOLOGY AND SCENARIOS

1.1 CONTEXT

In line with the NESC Secretariat report (Ireland and the Climate Change Challenge: Connecting 'How Much' with 'How To') the Government has decided realign climate policy moving beyond a sole compliance approach, and re-focussing on a whole-of-government and societal agenda. This is reflected in the *General Scheme of a Climate Action and Low Carbon Development Bill (CA&LCD Bill) 2013.* Key to achieving this reframing will be the development of a national low carbon roadmap informed by sectoral input with the aim of achieving transition to a low carbon, climate resilient and environmentally sustainable economy in the period up to and including the year 2050.

According to Head 4 of the CA&LCD Heads of Bill, *The Government shall arrange for the adoption and implementation of plans, ..., to enable the State to pursue and achieve transition to a low carbon, climate resilient and environmentally sustainable economy in the period up to and including the year 2050.* Article 5 stipulates that a key objective of a National Low Carbon Roadmap is to *articulate a national vision for the transition to a low carbon, climate resilient and environmentally sustainable economy over the period to 2050*.

Government Departments with responsibility for key sectors in the transition to a low carbon economy have already been tasked with the preparation of individual 2050 low-carbon sectoral roadmaps. Departments in the relevant areas are best placed in terms of ownership and understanding of their sectors, to frame the low-carbon vision/objective for their sectors and to manage the evaluation that is necessary to develop a robust and cost-effective policy platform for delivery of that vision in their area. The focus of this national low carbon energy roadmap is based on energy scenario analysis for the economy as a whole, which presents results both economy wide and at the sectoral level.

The European Council reconfirmed in February 2011 the EU objective of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels from developed countries as a group (CEC (2011)). Ireland already faces challenging climate and energy targets for 2020 (Chiodi *et al.,* 2013) and further interim targets to 2050 will be agreed in the future (It is anticipated that targets for 2030 will be agreed over the next year). As we move towards a low carbon economy

there are choices that can reduce the negative socio-economic impacts and also realise potential opportunities that a low carbon economy will provide. In this regard, there are choices surrounding the timing of particular emissions targets, sectoral breakdown of targets, as well as associated policies that will play an important role in terms of minimising the cost even with a fixed endpoint for 2050.

The choice is not whether we move to a low carbon economy but how and when the transition to a low carbon economy should be achieved. The focus here is on achieving the transition at least cost to the economy and to society. The key issue is making well informed policy choices. That will be achieved by developing an understanding of the drivers in the energy system in the period to 2050. Modelling the energy system within the wider economy delivers such insights, providing a consistent framework to analyse policy choices. In the absence of such a modelling framework decisions about policy choices, as well as negotiations in Europe, will be much more challenging.

1.2 METHODOLOGY

The analysis in this report derives from scenario analysis using the Irish TIMES energy systems model (Ó Gallachóir *et al., 2013)*. The Irish TIMES model provides a range of energy system configurations for Ireland that each delivers projected energy service demand requirements optimised to least cost and subject to a range of policy constraints for the period out to 2050. It provides a means of testing energy policy choices and scenarios, and assessing the implications for a) the Irish economy (in certain areas, including energy prices, investments in the energy system, marginal CO_2 abatement costs, etc.), for b) Ireland's energy mix (fuels and technologies) and energy dependence, and for c) the environment (mainly focussing on greenhouse gas emissions). It is used to both examine baseline projections, and to assess the implications of emerging technologies and mobilising alternative policy choices such as meeting renewable energy targets and carbon mitigation strategies.

The Irish TIMES model was developed with TIMES (The Integrated MARKAL EFOM System) energy systems modelling tool. TIMES is a widely applied[2] linear programming tool supported by ETSAP (Energy Technology Systems Analysis Program), an Implementing Agreement of the International Energy Agency (IEA) [3]. TIMES is an economic model generator for local, national or multi-regional energy systems, which provides a technology-rich basis for estimating energy dynamics over a long-term, multi-period time horizon. The objective function to maximize is the total surplus. This is equivalent to minimizing the total discounted energy system cost while respecting environmental and many technical constraints. This cost includes investment costs, operation and maintenance costs, plus the costs of imported fuels, minus the incomes of exported fuels, minus the residual value of technologies at the end of the horizon.

[2] The MARKAL / TIMES family of modelling tools currently being used in 177 institutions across 69 countries

[3] See www.etsap.org for more details

The Irish TIMES model has been developed and calibrated by UCC and is driven by a macroeconomic scenario covering the period to 2050, which is based on the ESRI HERMES macroeconomic model of the economy. HERMES is used for medium-term forecasting and scenario analysis of the Irish economy and most recently the model has been used to generate the scenarios underpinning the 2013 edition of the ESRI's Medium-Term Review (FitzGerald *et al.* (2013).

Irish TIMES Energy Systems Model

The Irish TIMES full energy system model is the only model of its kind in Ireland. The model is unique as it considers all modes of energy use (electricity, heating and transport) across all sectors of the economy in an integrated fashion rather than treating individual modes or sectors in isolation, which can lead to sub optimal solutions. The model is a techno-economic linear optimisation model with the objective of producing a least cost energy system subject to defined constraints. TIMES models are used in over 70 countries worldwide and are being used to inform energy and climate policy in a number of EU Member States.

Fuel prices are based on IEA's current policy scenario in World Energy Outlook 2012 Report. Given the importance of renewable energy for the achievement of mitigation targets, Ireland's energy potentials and costs are based on the most recently available data (see Ó Gallachóir *et al.*, 2013 and Chiodi *et al.*, 2013 for details).

Forecasts vs Scenarios

Results for the Irish TIMES energy system model should not be considered as forecasts for the future. Results provide insights into the impacts of a particular scenario, which considers a discrete set of input assumptions in relation to variables such as macroeconomic drivers, fuel prices, resource availability and technology costs. These assumptions should not be seen as prescriptive, but rather as a snapshot of potential outcomes that may be realized. Comparing different scenario results is where the richness lies. The objective of useful systems modelling is to provide an evidence base to inform policy decision regarding potential future energy system configurations.

In the absence of a modelling framework any analysis of the energy system over the coming decades would revert to educated guesswork, due to the multi-dimensional and intricate nature of energy systems. The modelling perspective taken in this analysis is that of a benevolent central planner: as if there was a single decision-maker taking rational choices surrounding all energy-related issues on technologies and fuels at the lowest cost to the economy and to society. This clearly does not reflect reality, where there are many decision makers and not all decisions are rational, but it does provide very useful guidance into how to achieve CO_2 emissions reductions to 2050 using a least-cost approach. The complex dynamics (incorporating technologies, fuel prices, infrastructure and capacity constraints) of the entire energy system, can be anlaysed through a modelling approach to better inform policy choices.

1.2.1 STRENGTHS OF THIS APPROACH

Something of the usefulness (and strength) of TIMES can be gleaned from its popularity: it is currently in use in over 70 countries. A key characteristic of this modelling tool is that it maintained, improved and updated through a collaborative research initiative co-ordinated by the International Energy Agency Energy Technology Systems Programme (IEA-ETSAP). The main "selling point" of the TIMES modelling framework is that it combines a detailed technology rich database with an economically optimizing solver. It is able to generate robust energy policy scenarios over long time horizons and it is able to offer strategic insight into long-term policy formation. This is especially important for the energy sector, which has such large capital investments with long project lifetimes.

The challenge of de-carbonizing the energy system is an enormous and expensive one and the insights that TIMES provides is both unique and very useful.

It produces energy pathways over multiple time slices for a long-term time horizon and the solutions of the scenario runs is in terms of technology choice; it also provides indicative results for the carbon price required to achieve certain reductions which can in turn be useful to inform policy design.

1.2.2 LIMITATIONS

Like all energy models, Irish TIMES has a number of limitations. In some instances these are simply limitations born of the structure of the model; they are inevitable based on the way the model is built. In other instances, they could be considered weaknesses and in these cases, work is on going to make improvements:

Macro-economic assumptions: This is a key limitation of the model. The results of the scenarios are tied to the assumption and results of the macro-economic model, which by themselves are inherently uncertain. While scenario analysis, by its nature, tries to counteract this uncertainty by producing a range of results, this uncertainty is nevertheless present.

Limited macro-economic feedback: This is a current weakness in the Irish TIMES model: there is currently no feedback between the output of the energy system analysis and the macro-economy. However, UCC and ESRI are engaged in a research project to develop this feedback response.

Time resolution: For the electricity sector, there are 12 time slices (seasonal, day, night and peak); these are inadequate to capture daily supply and demand curves. For the rest of the TIMES system, there are only seasonal time slices. This is a limitation of the model. It would become computationally unwieldy if the model had to make decade long decision as well as hourly decisions. A working solution to this shortcoming is achieved via *soft-linking* the model to more specialized power systems models, which has been pioneered by UCC (Deane *et al.*, 2012).

Behaviour: A further limitation of the Irish TIMES model is the limited capacity to simulate behavioural aspects. This is a limitation of most energy (and indeed macro-economic) models, in that consumer behaviour is generally limited to simple price response and non-price related behaviour in generally very poorly treated.

Specific Infrastructural costs: The Irish TIMES model does not currently have all necessary data to comprehensively consider the extra costs associated with the expansion of the gas network, shipping ports, or electrical transmission costs (other than onshore wind). These costs are considered in a simple manner and work is ongoing to improve the representation of these costs into future versions of the model

1.3 SCENARIOS

According to the Programme for the development of national climate policy and legislation[4], *while near zero carbon dioxide (CO_2) emissions in 2050 should set the context for the energy/built environment and transport sectoral roadmaps, generally reflecting the ambition at EU level, carbon neutrality is the more appropriate approach in the case of the agriculture sector.*

This report focuses on the near zero CO_2 emissions (complementing separate analysis on carbon neutrality in agriculture). The results for three distinct scenarios are presented in this report to explore transitions to a near zero CO_2 future.

- A **business as usual** (*BAU*) scenario does not impose emissions targets and is used as a reference case (counterfactual) against which to compare the two distinct near-zero CO_2 scenarios.
- In the ***CO2-80*** **scenario** CO_2 emissions are constrained across the entire time horizon to be no greater than 80% below 1990 levels in 2050.
- In the ***CO2-95*** **scenario** CO_2 emissions are constrained across the entire time horizon to be no greater than 95% below 1990 levels in 2050.

The CO_2 emissions pathways for the three mitigation policy scenarios are shown in Figure 2.1

The two low carbon scenarios, $C0_2$-80 and CO_2-95, might naturally be seen as incremental to each other but should be considered as mutually exclusive. In the context of 2050 CO_2 emissions, they mean very different outcomes in terms of the fuels and technologies used across the sectors. The chosen technologies, fuels and trajectories in the CO_2-80 scenario cover the full period to 2050 and are not incremental towards achieving a more stringent 95% reduction in emissions in 2050. Achieving a more stringent 95% reduction is modelled in the CO_2-95 scenario,

[4] DECLG 2012 *Programme for the development of national climate policy and legislation. Statement on progress at 28 December 2012.* Available from http://www.environ.ie/en/Environment/Atmosphere/ClimateChange/PublicationsDocuments/FileDownLoad,32079,en.pdf

which implies a different set of choices regarding technologies, fuels and investment profile across the entire time period to 2050.

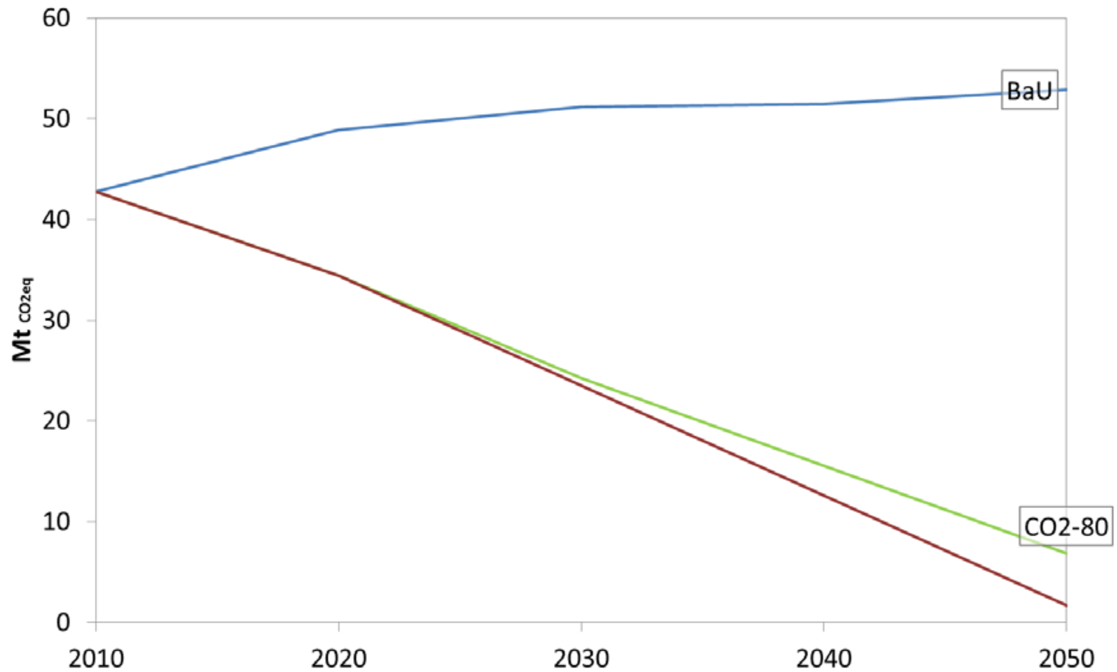

FIGURE 1-1: TRAJECTORY FROM 2010 TO CO_2 EMISSIONS REDUCTON TARGETS IN 2050

1.3.1 INTERIM TARGETS AND THE OPTIMAL PATH TOWARDS THE 2050 GOAL

In theory, interim targets in the context of a single end target are not efficient in economic terms. If the level of emissions in 2050 is the ultimate policy goal, it will generally not be cost optimal to also comply with interim emissions targets (e.g. in 2030 or 2040). For example, it would not be cost efficient to accelerate the depreciation of existing assets (e.g. coal-fired electricity generation plant) to comply with arbitrary interim targets. However, in practice, they make good sense, and will be necessary to achieve the 2050 targets in a smooth and controlled manner without significant distortion to the economy. This is borne out by analysis with the Irish TIMES model. In the absence of interim targets the investment profiles under the two low carbon scenarios would be the same as the BAU profile until the latest extent possible. As low carbon technologies are more expensive, it is likely that investment in such technology would be

delayed until absolutely required. The impact of such an approach is that there is the possibility that a potential Klondike-type investment rush in low-carbon technologies would occur post 2040.

The year 2030 and 2050

This report focuses primarily on the year 2050 and results are presented in that context. It is acknowledged that the year 2030 is important in terms of informing Ireland's engagement with the EU 2030 Energy and Climate White Paper. A more detailed consideration of potential 2030 emissions targets for Ireland and their associated economic impact is outside the scope of this work and would require separate analysis.

The scenario analysis suggests that using interim targets would entail additional energy system costs but that these additional costs would be relatively small. Under the CO_2-80 scenario, the energy system costs are just 2% higher with interim targets versus no interim targets. Even though there are higher system costs with associated with interim targets there are a number of practical risks associated with setting a single terminal policy target for 2050.

The EU's Energy Roadmap suggests that if investment is postponed it will ultimately lead to greater costs and disruption in the longer term. Energy investments take time to produce results. Investment decisions today about replacing existing 30-40 year old infrastructure will affect the cost of achieving the 2050 emissions targets. Acting now with 2050 targets in mind can avoid costly changes in later decades and reduces lock-in effects.

If investment is postponed to the latest possible time there will be a relatively narrow window in which investment must occur both for large scale projects (e.g. power plants) as well as residential level investments. In such circumstances there is a high risk that capacity bottlenecks in the construction and engineering sectors will prevent the investment from occurring. In addition, if investment is deferred for 15-20 years there is a risk that priorities will change in the future and the investment not happen then either.

From a climate emissions perspective there is also a cost if investment is postponed until post 2040, as emissions mitigation in the intervening decades will be higher than otherwise. In the CO_2-80 scenario cumulative emissions in the period to 2050 would be 30% higher if there are no interim targets. Also if action is delayed until post 2040 the implicit cost of carbon necessary to

achieve the 2050 emission targets will be substantially higher; as much as 50% higher in 2050 under the CO_2-80 scenario without interim targets compared to with interim targets.

There are ongoing discussions and analysis at EU-level regarding pathways to and targets for 2030. It is not yet decided whether there will be separate targets for renewable energy or energy efficiency and the pathway analysis here focuses on emissions reduction. It does however consider the implications for energy efficiency and renewable energy associated with achieving emissions reduction milestones at least cost.

1.3.2 IRELAND'S LOW CARBON ROADMAP TO 2050

Table 1 summarises the results of this Low Carbon Energy Roadmap analysis for Ireland. It distinguishes between the *BAU* scenario and the range of results arising from the two low carbon scenarios considered (*CO_2-80* and *CO_2-95*). The results for 2030 are also shown separately. The overall results indicate that under a *BAU* scenario, energy-related CO_2 emissions are anticipated to rise by 50% relative to 1990 levels by 2030 and by 55% relative to 1990 levels by 2050. The Low Carbon Energy Roadmap results point to ~30% emissions reductions by 2030 relative to 1990 levels and 80% - 95% by 2050.

TABLE 1 IRELAND'S LOW CARBON ROADMAP TO 2050

Sector	2030 relative to 1990			2050 relative to 1990	
	BAU	Low Carbon		BAU	Low Carbon
Electricity	**45%**	**-56% to -58%**		**31%**	**-84% to -94%**
Buildings	**-11%**	**-53%**		**-11%**	**-75% to -99%**
Services	**5%**	-33%		-6%	-70% to -99%
Residential	**-16%**	-59%		-13%	-77% to -98%
Transport	**226%**	**104% to 122%**		**285%**	**-72% to -92%**
Total	**50%**	**-29% to -31%**		**55%**	**-80% to -95%**

The results shown in Table 1 also indicate the sectoral emissions reductions that contribute to Ireland's overall Low Carbon Energy Roadmap. Electricity generation achieves CO_2 emissions reduction of 56% - 58% below 1990 levels by 2030 and a reduction of 84% -94% by 2050. This compares with a 31% emissions growth by 2050 in the *BAU* scenario.

CO_2 emissions associated with energy use in buildings reduce in the Low Carbon Energy Roadmap by 53% by 2030 relative to 1990 levels and by 75% - 99% by 2050. This compares with an anticipated reduction of 11% by 2050 in the *BAU* scenario.

The scenario results show CO_2 emissions in transport growing to 104% - 121% above 1990 levels by 2030 in the Low Carbon Energy Roadmap and reducing by 72% - 92% below 1990 levels by 2050. This compares with a nearly threefold increase in emissions by 2050 in the *BAU* scenario above 1990 levels.

PART II: 80% CO_2 EMISSION REDUCTION BY 2050

2 TECHNOLOGY SOLUTIONS

2.1 ENERGY SYSTEM RESULTS

This section firstly presents the CO_2 emissions for the resultant energy systems from the BAU and 80% CO_2 emissions reduction scenarios for the period to 2050. Results are presented on a system wide basis and also for individual sectors. Energy usage in 2050 by sector and fuel are also presented along with the potential energy savings for each of the three scenarios.

2.1.1 CO_2 EMISSIONS

Figure 2-1 shows the energy-related CO_2 emissions results for both the *BAU* and the *CO_2-80* scenarios. In the absence of mitigation policies beyond 2020, the *BAU* scenario results shows CO_2 emissions growing to approximately 51 MT by 2050, an increase of up 21% from 42 MT in 2010 (or 55% growth relative to 1909).

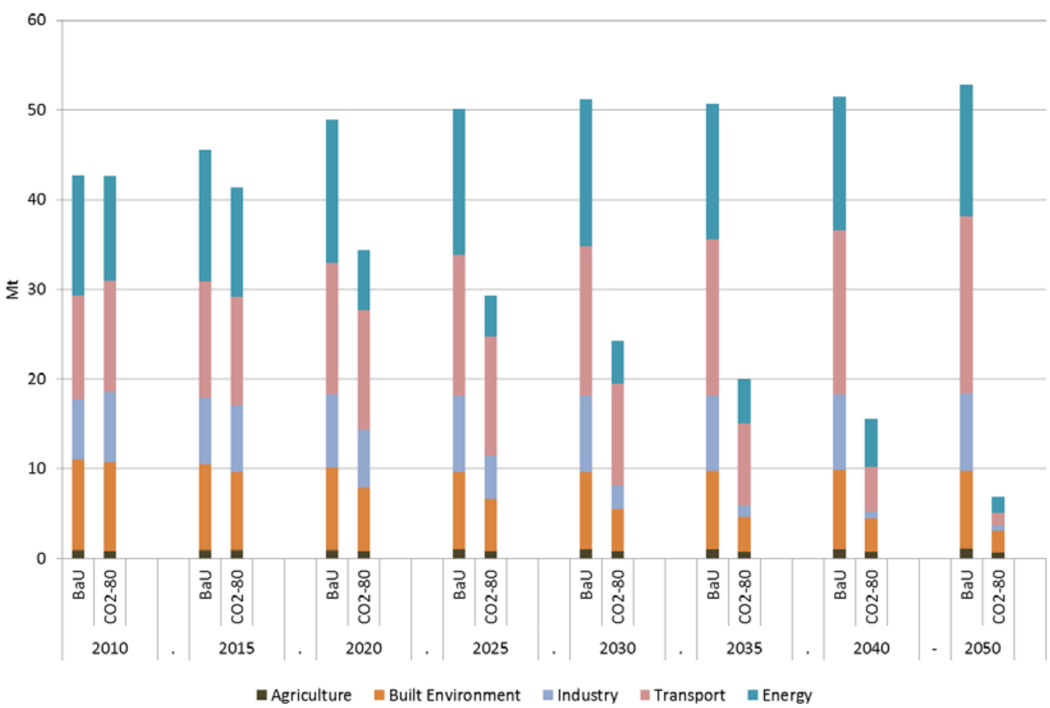

FIGURE 2-1: SECTORAL CO2 EMISSIONS FOR HORIZON TO 2050 FOR BAU AND 80% REDUCTION SCENARIO

By contrast, in the *CO_2-80* scenario the greatest reduction in emissions relative to 2010 is in the transport sector (from 11.6 MT to 1.5 MT CO_2-80%) followed then by electricity generation (from 13.3 MT to 1.3 MT CO_2- 80%). Figure 2-2 compares the *BAU* results with the *CO_2-80* results.

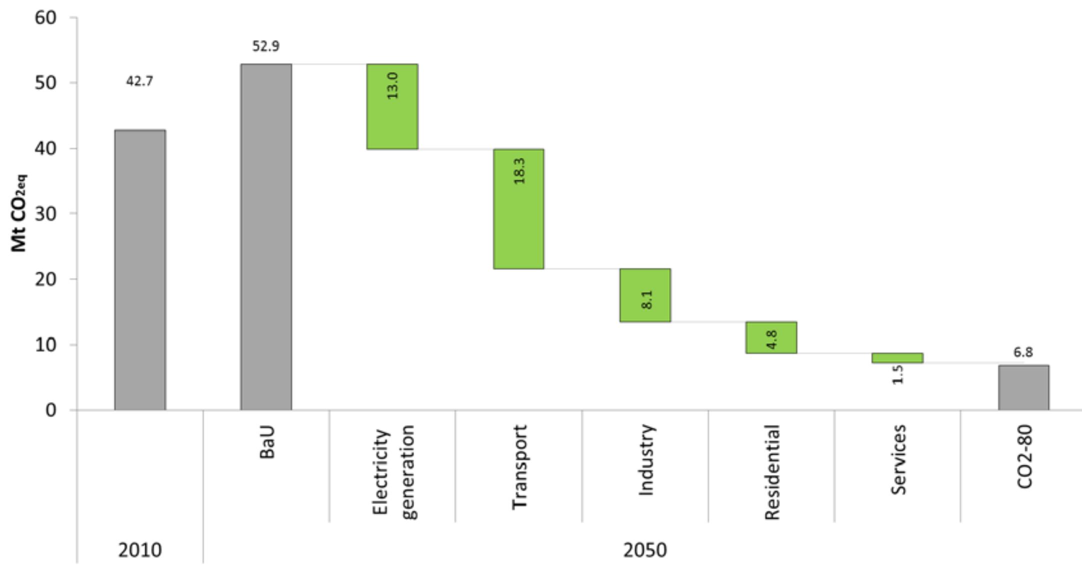

FIGURE 2-2: INCREMENTALCHANGE IN CO2 EMISSION REQUIRED BY EACH SECTOR TO REACH AN 80% REDUCTION IN CO2 EMISSIONS RELATIVE TO BAU SCENARIO AND 2010.

The largest emissions savings (relative to BAU scenario) in the *CO_2-80* scenario are made in the Transport sector (18.3Mt) with significant savings also make also made in electricity generation (13 MT).

Figure **2-3** decomposes the emissions reductions for the *CO_2-80* scenario to summarize the contributions to mitigation arising from three key system wide effects, namely (1) energy efficiency, (2) renewable energy and (3) fuel switching amongst fossil fuels.

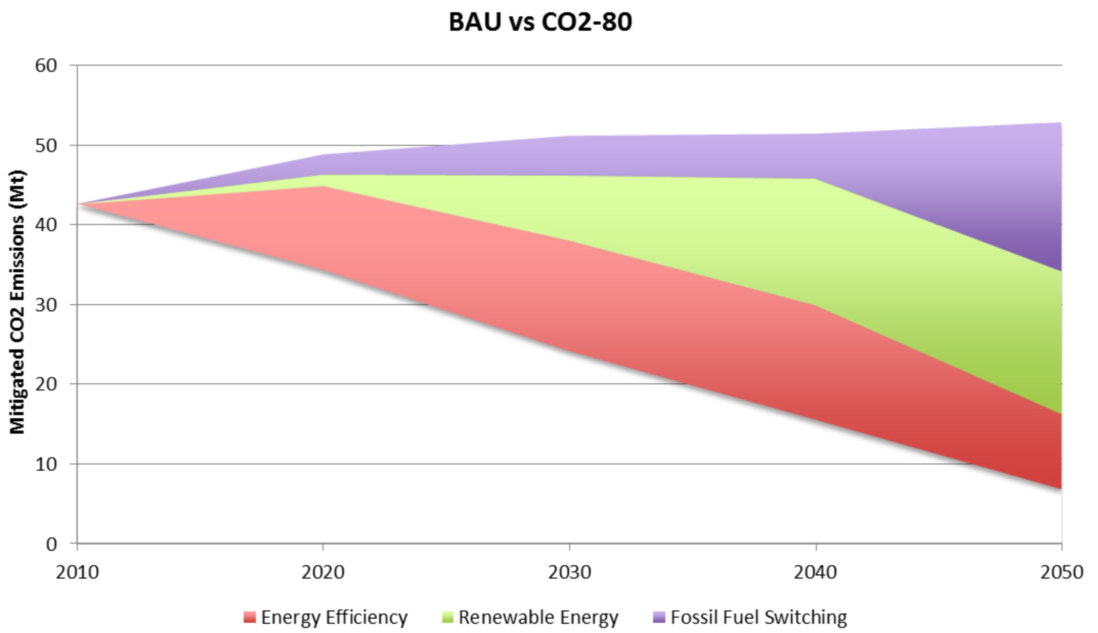

FIGURE 2-3: DECOMPOSITION OF 80% CO2 EMISSIONS REDUCTIONS SCENARIO VS BAU SCENARIO

Energy efficiency is the most cost optimal mitigation strategy and in the early part of the modelling time-horizon energy efficiency is responsible for more than 50% of the total mitigated emissions. This clearly points to an "energy efficiency first" trend. In the *CO_2-80* scenario, energy efficiency is responsible for a majority (39%) of the cumulative mitigated emissions

Energy Efficiency First

Energy efficiency is the most cost optimal mitigation strategy and in the early part of the modelling time-horizon energy efficiency is responsible for more than 50% of the total mitigated emissions.

The *renewable energy* effect combines the emissions mitigation due to wind, bioenergy, solar and geothermal sources; it also includes a very small quantity of imported electricity. [Note that individual sectors and their renewable energy content is presented and discussed later in the report]. In the *CO_2-80* scenario, its share of the overall mitigation effort steadily increases over time and it has a 35% share of the cumulative mitigated emissions.

Fossil *fuel switching* is the third emission reduction strategy. In the early part of the modelling time horizon fossil fuel switching achieves emissions mitigation by switching from coal to oil and

from coal and oil to gas; in the later part of the modelling time horizon, it is overwhelmingly the impact of carbon capture and sequestration (CCS). In the *CO_2-80* scenario fossil fuel switching contributes 26% to the mitigation effort.

2.1.2 Energy System in 2050

Energy usage for different primary fuels and within different sectors of the energy system is presented in the following Sankey Diagrams for the target year of 2050. Note that associated tables of final primary energy requirement and final energy consumption by fuels are shown in the Appendix.

Figure 2-5 shows the BAU scenario energy system for 2050, which is very similar to the current energy system that substantially relies on oil and gas with a small share for renewables. The CO_2-80 scenario is represented in Figure 2-6, which shows a dramatic drop in reliance on oil, whereas bioenergy expands. Liquid biofuels are extensively used in transport, with biomass in industry. There is a significant expansion in wind energy and electricity used both in transport and heating for the residential sector.

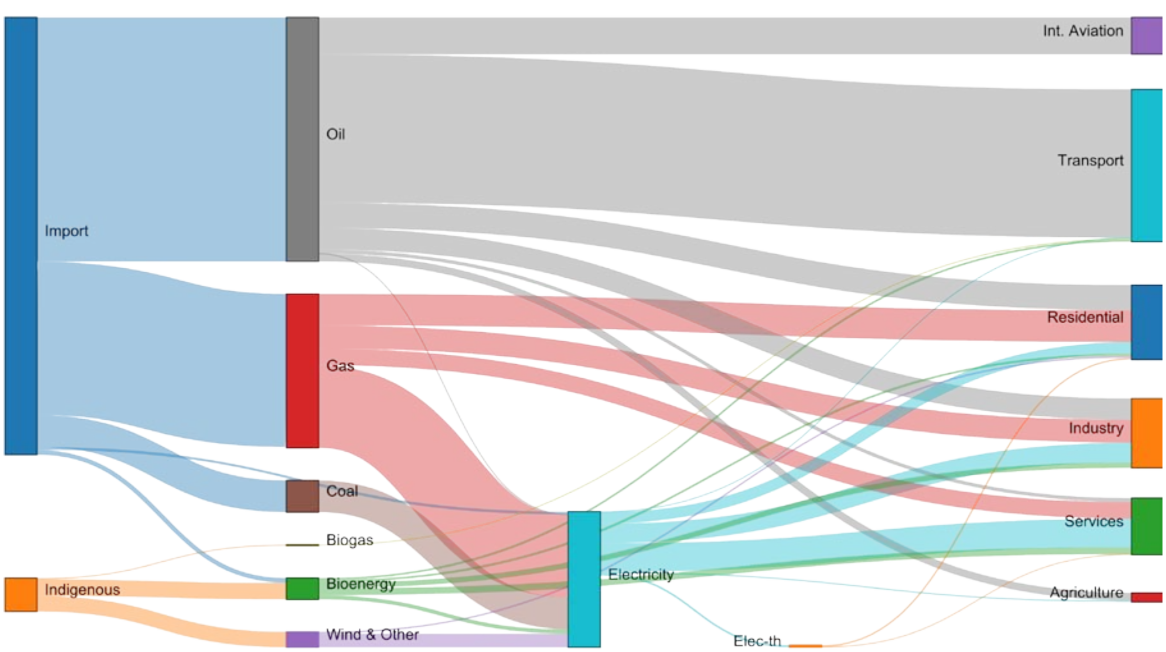

FIGURE 2-4: 2050 SANKEY DIGRAM FOR ENERGY SYSTEM UNDER BUISNESS AS USUAL SCENARIO

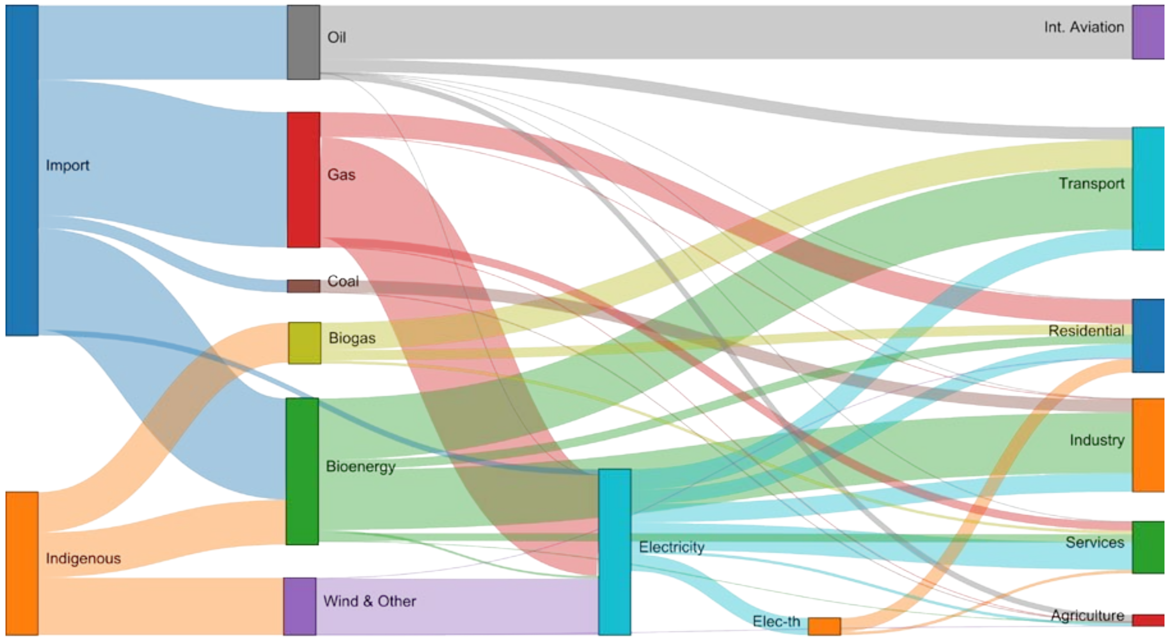

FIGURE 2-5: 2050 SANKEY DIGRAM FOR ENERGY SYSTEM UNDER CO2-80 SCENARIO

2.2 ENERGY EFFICIENCY

Energy savings are quantified in the model as a reduction in final energy consumption as compared to the BAU scenario. The BAU scenario does not assume any technology improvements over the time horizon to 2050 and is therefore a counterfactual against which the other scenarios can be compared. Note that figures quoted for final consumption do not include international aviation unless otherwise stated. International aviation represents approximately 1,590 ktoe)

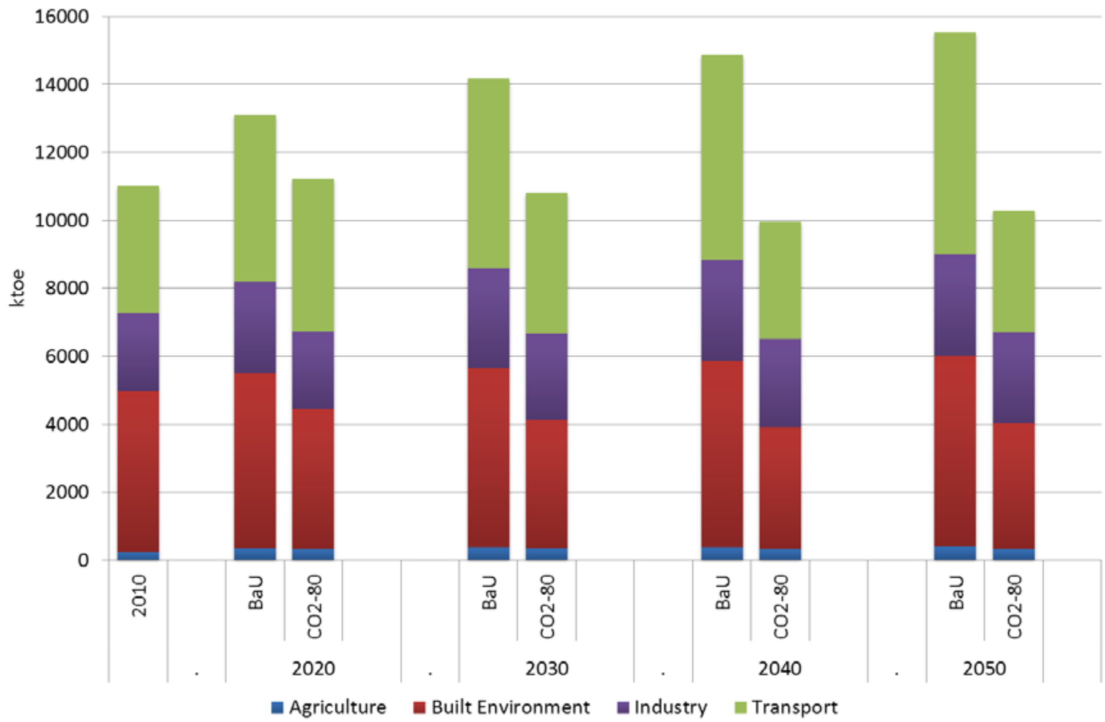

FIGURE 2-6: FINAL ENERGY CONSUMPTION BY SECTOR FOR BAU AND CO2-80 REDUCTION SCENARIO

The *BAU* scenario in 2050 shows that the total final consumption of energy in 2050 is 15,522 ktoe. This is an increase of approximately 30% on 2010 levels. In the *CO_2-80* reduction scenario, total final energy consumption drops to 10,295 ktoe. The sector with the greatest reduction in energy consumption (as compared to the BAU scenario) in absolute terms is the transport sector with a reduction of 2,950 ktoe (or 68%) followed by the Built Environment (residential and services sector) which shows a reduction of 1,039 ktoe in the residential sector and 865 ktoe on the services sector.

2.3 RENEWABLE ENERGY

This section details the modal results for renewable heat, transport and electricity from the energy system cost optimal analysis for the BAU scenario and the two CO_2 reduction scenarios. Note values below are presented in ktoe for the year 2050 unless otherwise specified.

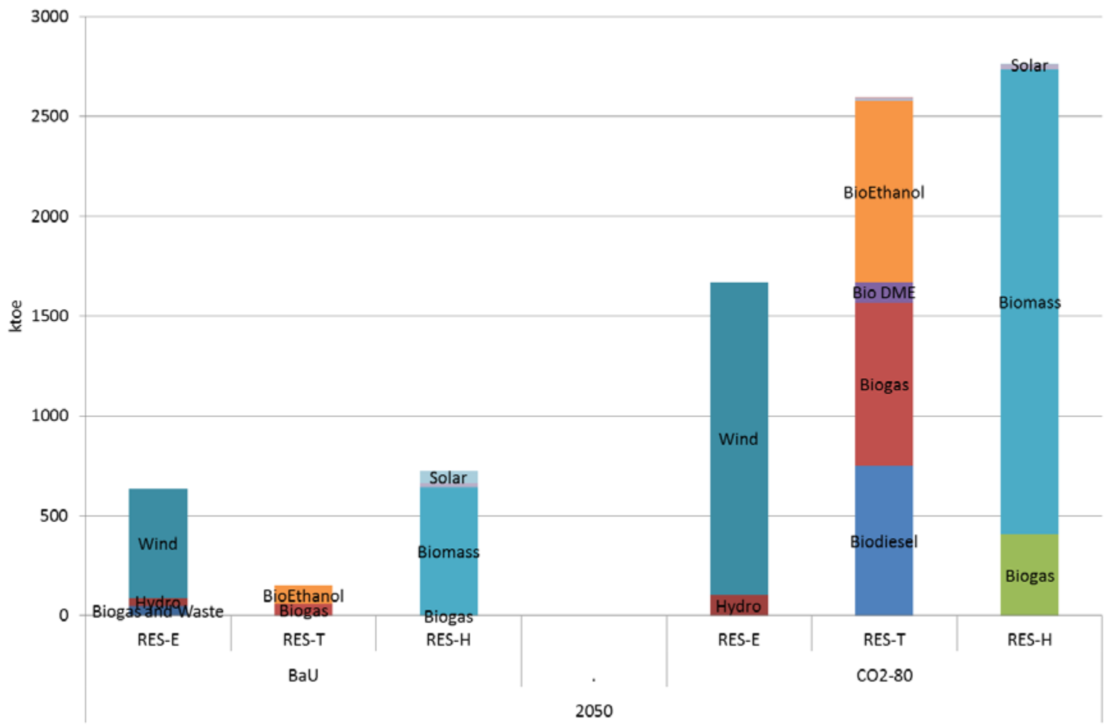

FIGURE 2-7: RENEWABLE ENERGY BY SCENARIO AND MODE OF ENERGY FOR BAU AND CO2-80 SCENARIOS

2.3.1 Renewable Heat-The year 2050

Renewable heat supplied by bioenergy grows to a penetration level of 62% (2,761 ktoe) of total thermal energy use for the *CO2-80* scenario. This compares to 5% (724 ktoe) in the *BAU* scenario. In the *CO2-80* scenario 84% of renewable heat is supplied by solid biomass with 14% coming from biogas. Biomass is used predominantly in industry (1,783 ktoe) for heating and industrial processes with lower amounts of biomass (279 ktoe) used in the residential sector for space and water heating. The services sector also uses 247 ktoe for space and water heating.

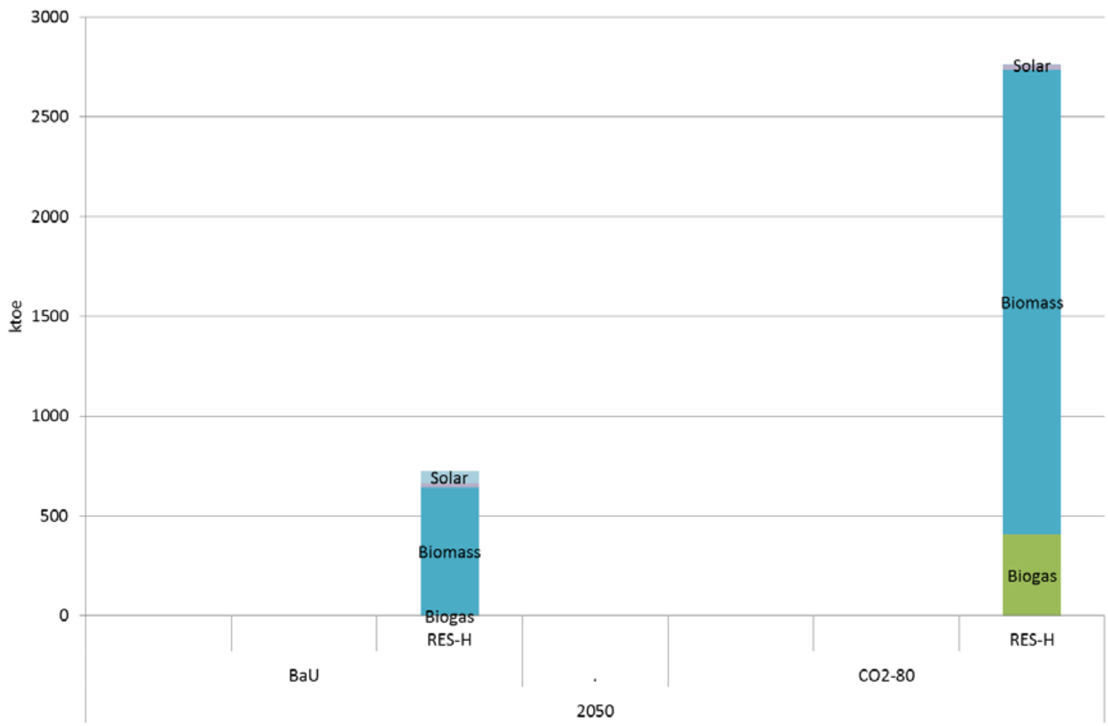

FIGURE 2-8: RENEWABLE HEAT FOR BAU AND CO2-80 SCENARIOS

In the residential sector biomass meets the space and water heating demands of approximately 340,000 average dwellings. Within the residential sector biomass can only be used in rural dwellings as it is assumed that storage issues would not be practical in urban dwellings. Biogas (408 ktoe) is also used in residential sector for space and water heating and also in the service sector (102 ktoe). In the residential sector, biogas supplies 306 ktoe or approximately 373,000 average dwellings. Of the available indigenous resource for woody biomass (1,125 ktoe) approximately 1,006 ktoe is exploited for renewable heat with the remaining requirement (1,417 ktoe) imported from oversees. This is equivalent to between 3-4 MT of imported biomass or approximately 60 shipments per year[5]. This split is driven by cost differentials and a higher cost for imported biomass would see greater exploitation of the domestic resource. Within the model domestic biomass is constrained by land and resource availability and is incorporated into the model as cost curves with increasing costs associated with higher levels of exploitation. Values for Bioenergy resource availability (including wastes) are sourced from published

[5] Assumes NCV of 17GJ/tonne and shipments of 60 kT.

information from SEAI, COFORD and Teagasc (McEniry ey al). Links to these reports are provided in the appendix.

The currently assumed available land resource for woody biomass such as willow and miscanthus is 177,000 hectares (approximately 4% of available agricultural land[6]) with just under 300,000 hectares (approximately 7% of available agricultural land) available for biogas from grass.

Renewable heat is also supplied by electric heat pumps and this is reported separately in TIMES model results. Electric heating supplies 410 ktoe of thermal energy to the residential sector meeting the demand of approximate 725,000 average dwellings. The decarbonisation of the electricity sector and high efficiencies of the technology enable the technology to appear in the cost optimal solution.

The model does not currently consider district heating systems in Ireland but it is planned to incorporate this technology for Ireland in the future.

2.3.2 RENEWABLE TRANSPORT-THE YEAR 2050

In 2050 Renewable Transport in the form of bioenergy and renewable generated electricity grows to a penetration of 92% of transport energy use in the *CO_2-80* scenario. This is in contrast to 3% in the *BAU* scenario. Total final consumption for the sector is approximately 45% lower in 2050 (compared to the BAU scenario) due to technology switching, efficiency improvements and a reduction in demand due to demand response. Bioliquids are used in the freight and public transport while electricity is used in private transport and small amounts in public transport.

[6] The land area of Ireland is 6.9million hectares, of which about 4.2million hectares is used for agriculture or about 64% of total land area and 745,456 hectares for forestry or about 10.8% of total land

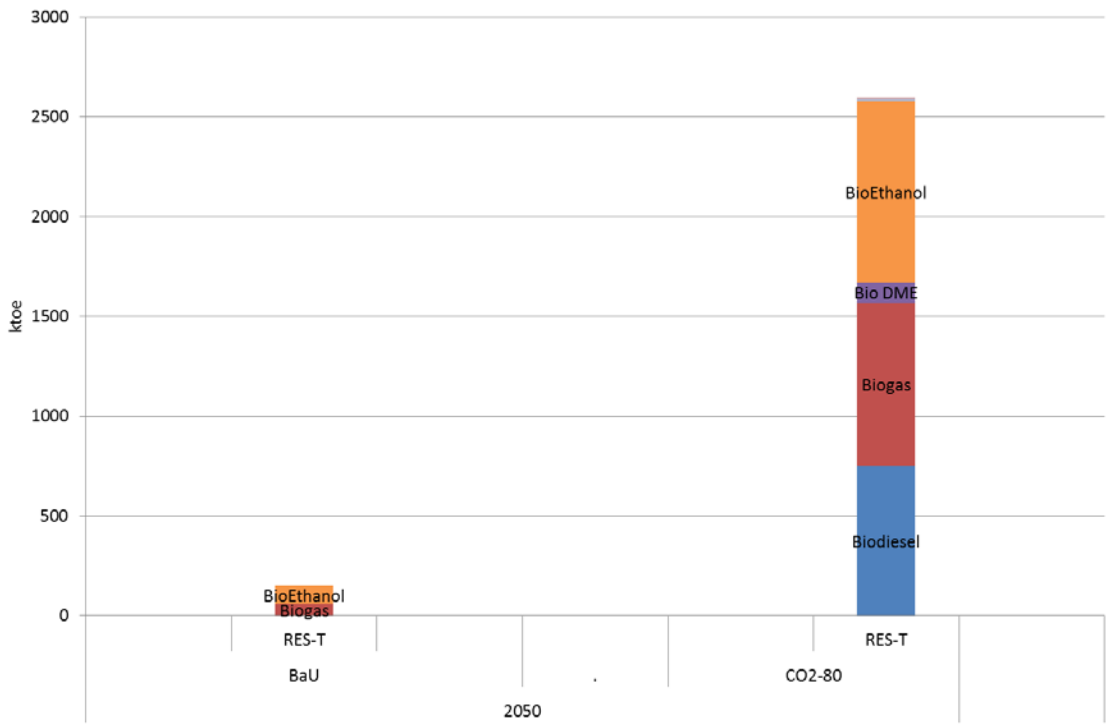

FIGURE 2-9: RENEWABLE TRANSPORT FOR BAU AND CO2-80 SCENARIOS

The private car stock (just fewer than 3 million vehicles) is almost completely electric in 2050 (528 ktoe) with small amounts of gasoline required for hybrid vehicles. The demand for electricity adds an extra load on the power system (6 TWh) and increases the requirement for renewables. Freight has just under three times the energy demand of private transport at 1,875 ktoe and the main renewable contributions are made by ethanol (781 ktoe) and biogas (725 ktoe). The available indigenous resource for biofuels (liquids mainly from rape seed) in the TIMES model is relatively small at 100 ktoe, so the bulk of biofuels are imported.

2.3.3 Renewable Electricity-The year 2050

The demand for electricity in 2050 is higher in the *CO_2-80* scenario compared to the *BAU* scenario. The increase in demand for electricity is driven by growth in autonomous demand, an increased demand for electric heating in the residential and services sector and an increased demand for electricity in private transport.

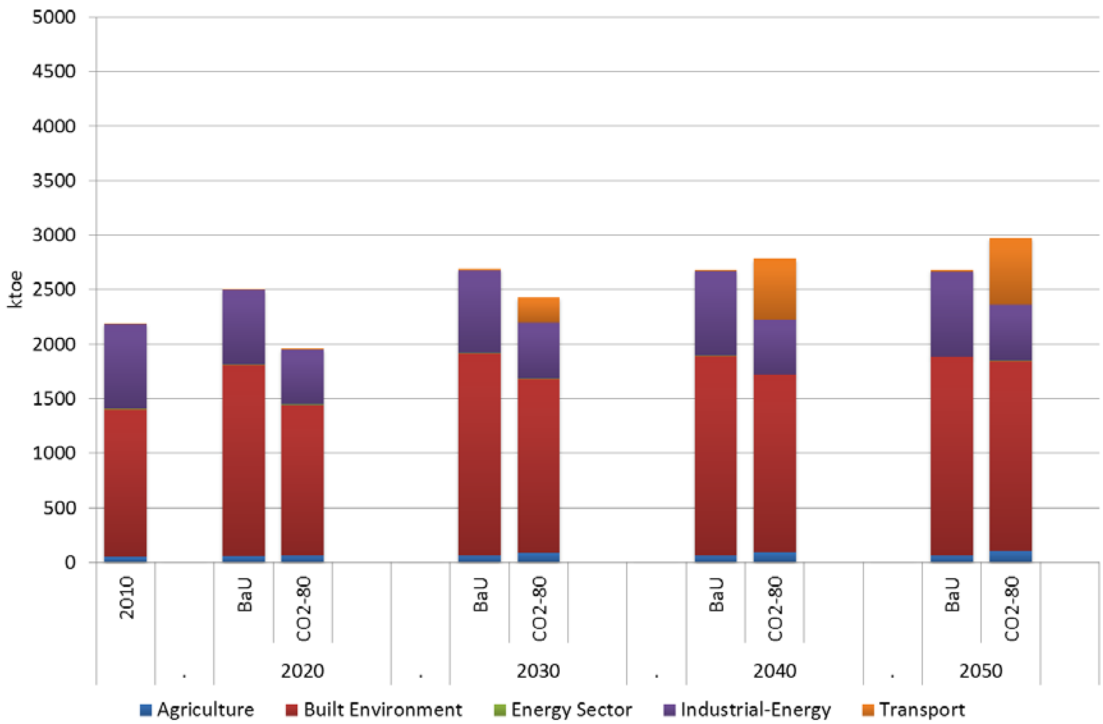

FIGURE 2-10: ELECTRICITY (RENEWABLE AND FOSSIL) CONSUMPTION BY SECTOR FOR BAU AND CO2-80 SCENARIOS

In 2050 the electricity demand is 2,975 ktoe [35 TWh] for the *CO_2-80* scenario. Almost all of the available 6.9 GW onshore wind resource is exploited and the remaining requirement for energy is provided by gas CCS and conventional Gas CCGT's. Within the model structure it is assumed that a carbon storage site is available. However the feasibility of CCS in Ireland may require a more in-depth study in relation to the technical feasibility and potential for the technology. In 2050 the CO_2 intensity of the power system under a *BAU* scenario is 459 gCO2/kWh (compared with 2010 levels at 528 gCO_2\kWh). The carbon intensity of the power system under the *CO_2-80* scenario is 38 gCO_2\kWh.

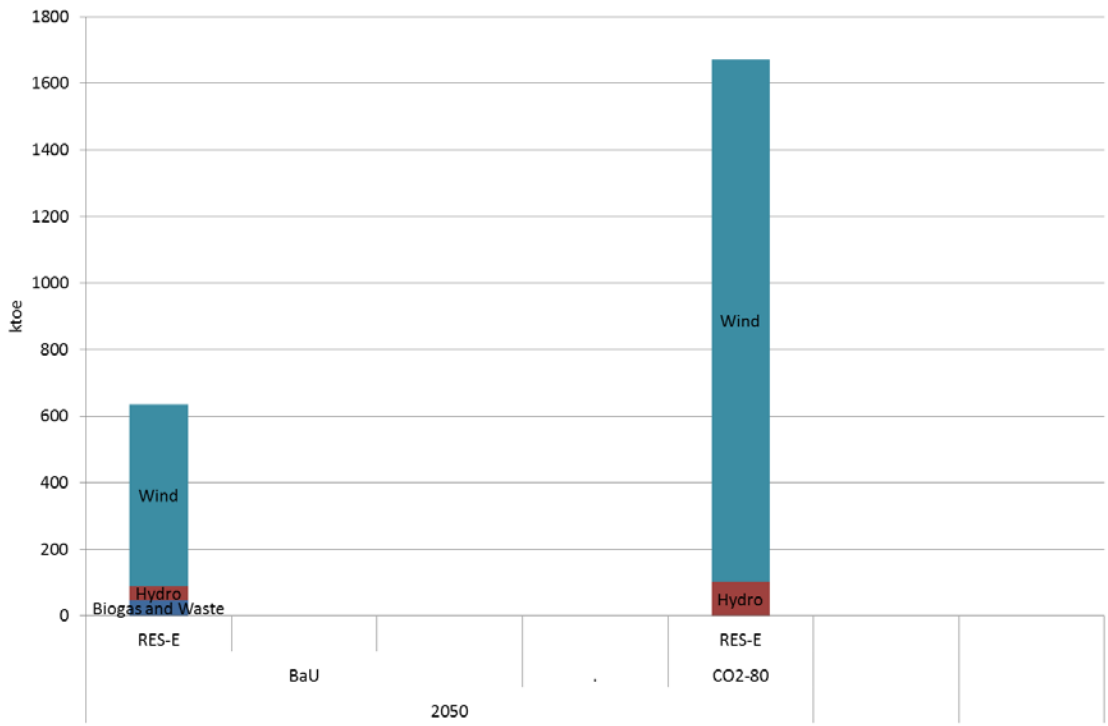

FIGURE 2-11: RENEWABLE ELECTRICITY FOR BAU AND CO2-80 SCENARIOS

In the *CO_2-80%* scenario, no renewable source other than onshore wind energy (except existing hydro) makes a contribution in the cost optimal solution and the penetration of renewables (onshore wind and existing hydro) reaches 51% of electricity generation. Variable renewable electricity (in this case wind energy) in the current Irish TIMES model is constrained to a maximum instantaneous penetration limit of 70% in any timeslice and an overall annual generation limit of 50%. Work is on-going in UCC to verify the technical appropriateness of these and other power system assumptions using soft-linking techniques where a higher resolution dedicated power system model is used to analyse these issues in greater detail.

2.4 GAS, ELECTRICITY, SOLID AND LIQUID FUELS

As CO_2 constraints are applied to the energy system two common pathways to decarbonisation emerge, one of electrification where a greater portion of the energy system switches to electricity as a secondary fuel and another of gasification where the use of gas becomes more

common in different sectors of the energy system. These two themes are presented and discussed below along with a discussion of the impact on solid and liquid fuels.

2.4.1 ELECTRIFICATION

The demand for electricity in 2050 is approximately 40% higher than 2010 levels for the *CO_2-80* scenario.

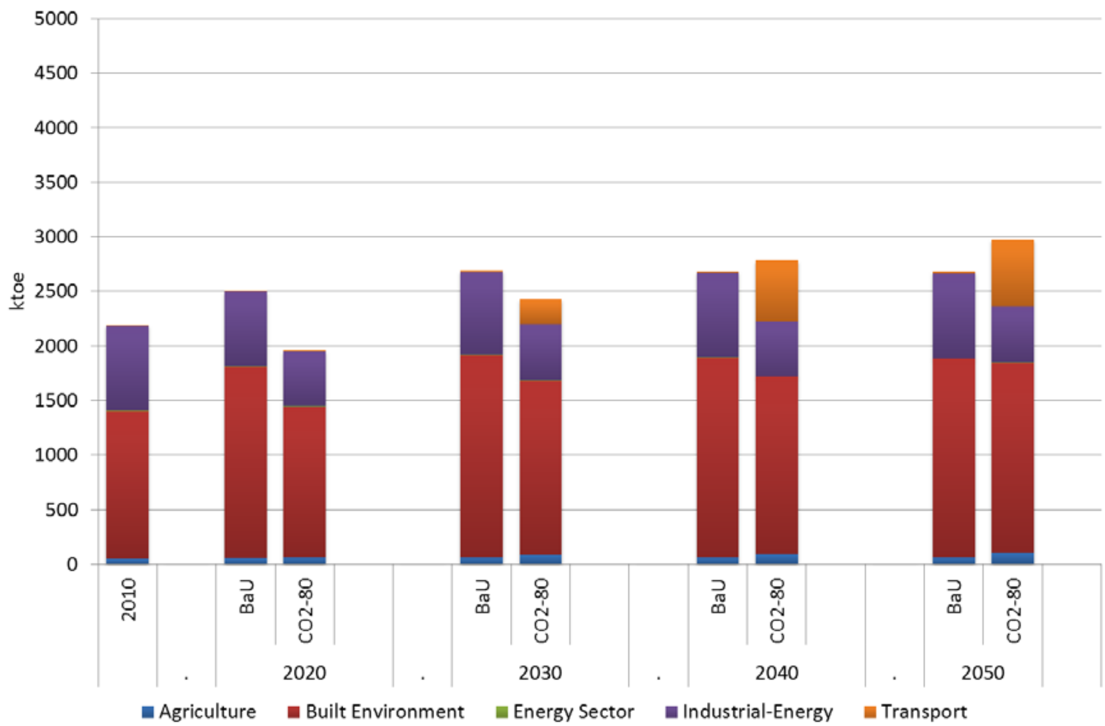

FIGURE 2-12: ELECTRICITY CONSUMPTION BY SECTOR FOR BAU AND 80% REDUCTION SCENARIOS

The growth of electricity within each sector of the energy system is varied. In absolute terms the largest growth is in the private transport sector with an increase in demand for electricity of over 600 ktoe on 2010 levels. Growth in the electrification of heating through heat pumps in the residential sector is also strong but total growth of electricity in the residential sector is softened somewhat by reduced demand for electricity in appliances and in the lower thermal requirement due to improved building regulations and retrofits. The growth in renewables and associated decarbonisation of the electricity sector enable a number of technologies such as electric vehicles and heat pump technology to come through in the cost optimal solution, this has the impact of 'freeing' up other energy resource such as biomass and biogas for use elsewhere in the energy system.

2.4.2 GASIFICATION

As the energy system trends towards lower CO_2 emission, gas (both natural and biogas) play an important role across a number of sectors of the energy system, as shown in Figure 2-13. Gas consumption in 2050 in the *CO_2-80* scenario is lower than the *BAU* scenario but is 19% above 2010 levels. However the usage patterns of gas are quite different to 2010 (with biogas blending, gas use for transport and natural gas electricity generation with CCS). Natural gas for non – electricity generation purposes reduces by approximately 40% from 2010 levels driven by a reduction in demand in the industrial sector where gas is replaced by biomass (1,704 ktoe) and to a lesser extent by coal CCS (in cement production).

The residential sector sees a strong usage of natural gas in the *CO_2-80* scenario (702 ktoe) which is similar on 2010 levels of 710 ktoe. Due to energy efficiency improvements and lower thermal demand per dwelling this level of natural gas use meets the thermal requirement of approximately 850,000 dwellings which is an increase of over 50% in dwellings connected to the gas network from 2011 levels (550,000 dwellings according to CSO 2011).

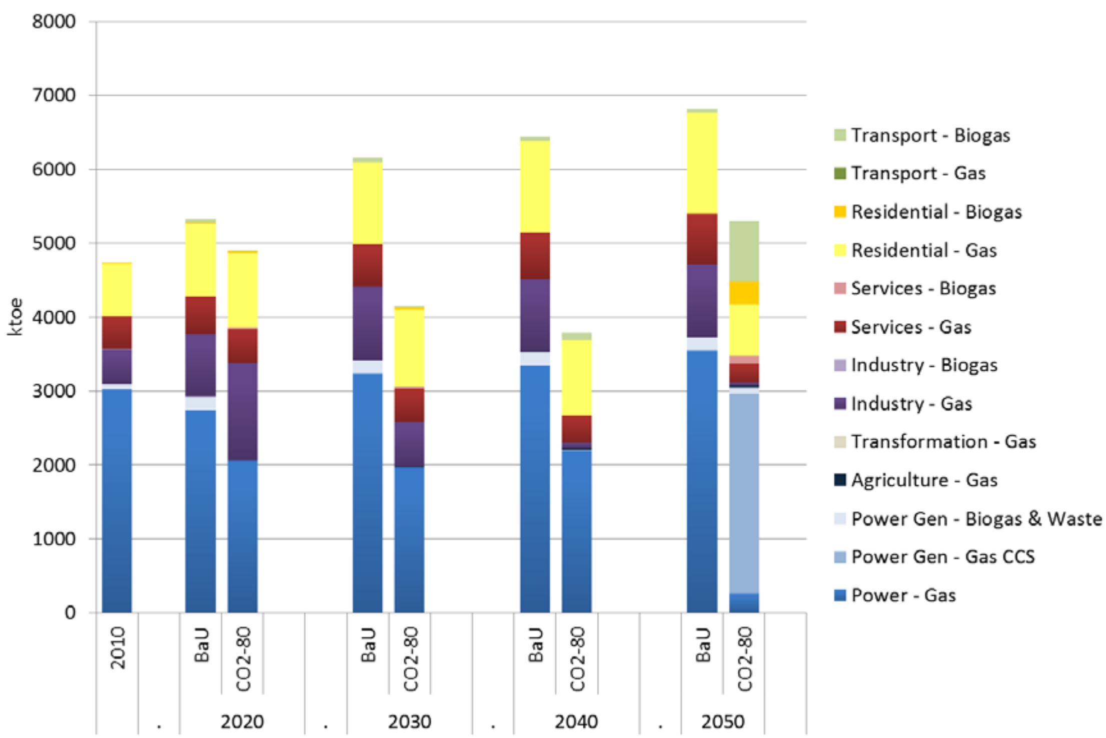

FIGURE 2-13: GAS USAGE BY SECTOR AND TYPE FOR BAU AND CO2-80 SCENARIOS

Biogas features in the cost optimal solution and provides 1,224 ktoe or 12% of total final energy consumption in 2050 meeting the needs of 370,000 average dwellings bringing the total number of average dwellings that use natural and biogas to just over 1.2 million dwellings. This equates to just under 300,000 hectares of land required for indigenous biogas production and is the full resource available to the TIMES model. Of this resource available for biogas, 67% is used in transport (mainly for freight), 25% is used in the residential sector and 8% in the services sector for heat.

Gas consumption for electricity generation is 3,045 ktoe in 2050 in the 80% CO_2 reduction scenario which is similar to 2010 levels. Of this 3,045 ktoe, 2,072 ktoe is used in gas CCS power plants.

2.4.3 Solid Fuels

In the 80% CO2 reduction scenarios, coal and peat are almost completely removed from the energy mix replaced in part by biomass both indigenous and imported.

2.4.4 Liquid Fuels

Oil in 2050, except for use in international aviation (1,539 ktoe), is also almost removed from the energy mix and is replaced by bioliquids such as ethanol and biodiesel. Oil reduces from 58% of final consumption in 2050 in the BAU scenario to 6% in the 80% CO2 reduction scenario. Kerosene and diesel oil which are traditionally used in Ireland for home heating are replaced by electric thermal heating, biomass heating and increased use of gas for home heating. Diesel and petrol see a sharp decline in use from 2030 onwards in the transport sector being replaced by electricity for private transport and bioliquids for freight transport.

2.5 IMPORT DEPENDENCY

Energy dependence, as defined as the ratio of imported energy to primary energy consumption, decreases from approximately 91% in the BAU scenario to 70% in the 80% CO_2 reduction scenario. Comparing the two energy systems (*BAU* and *CO2-80*) shown in Figure 2-4 and Figure 2-5, it is clear that import dependency changes from a reliance on imported oil and gas to a reliance on imported gas, biomass and biofuels. This will results in changes in the nature of future energy security that will require further investigation. brings

2.6 SECTORAL RESULTS

This section presents detailed results for each of the sector of the energy system for the *BAU* and *CO_2-80* scenarios.

2.6.1 RESIDENTIAL SECTOR

The residential sectors see a growth in population and dwellings out to the year 2050, over this period new building regulations and energy efficiency measures will see a reduction in the energy demand per dwelling. A reduction of approximately 30% in final energy demand is seen compared to the *BAU* scenario for the *CO_2-80* scenario. The number of dwellings in 2050 grows to 2.3 million. Energy consumed per average dwelling drops from 20,000 kWh (SEAI 2012) to 10,600 kWh (2050). 40% of consumption in 2050 is for electricity (plug loads and electric heating) with the remainder being non-electrical consumption. This is a change in the traditional usage of electricity in the residential sector which in generally 25% for electricity and 75% for non-electrical consumption. The energy consumption associated with thermal demand for an average dwelling in 2050 is estimated to be 8,600 kWh/yr.

There will see a phasing out of some technologies such as oil fired boiler as the energy demand per dwelling drops and the cost of the technology is high. Only a small amount of oil (28 ktoe) remains in the *CO_2-80* scenario in 2050. A strong use of natural gas is seen in the *CO_2-80* scenario (702 ktoe) which is similar to 2010 levels of 710 ktoe. This level of natural gas use meets the thermal requirement of approximately 850,000 dwellings which is an increase of over 50% in

dwellings connected to the gas network from 2011 levels (550,000 dwelling CSO 2011). Biomass meets the space and water heating demands of approximately 340,000 average dwellings in 2050. Biogas (408 ktoe) is used in residential sector for space and water heating and it supplies 306 ktoe or approximately 370,000 average dwellings in 2050.

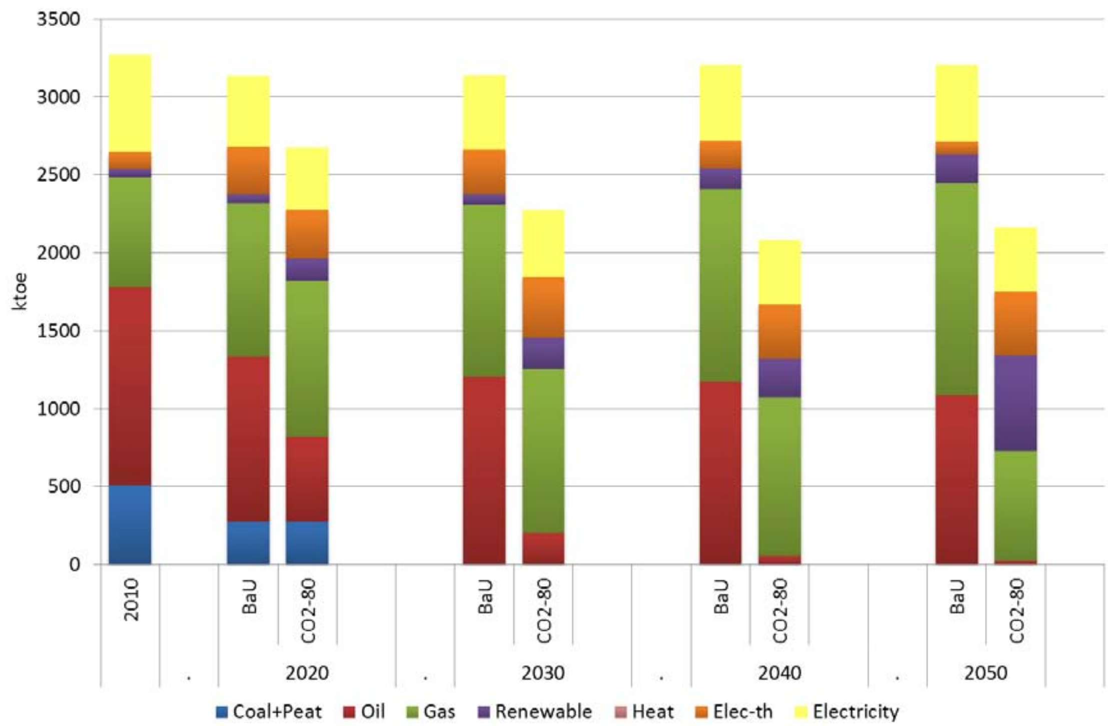

FIGURE 2-14-ENERGY COMSUMPTION IN THE RESIDENTIAL SECTOR FOR BAU AND CO2-80 SCENARIOS BY FUEL TYPE

The trajectory to 2050 shows that use of coal and peat decline and are removed from the residential fuel mix as the CO_2 emissions associated with these fuels are too high. As the percentage of coal and peat drop, renewables such as woody biomass (in rural dwellings) and biogas comes into the mix and start to build from 2020 to 2050. A small amount of geothermal (24 ktoe) comes through in the *CO_2-80* scenario.

2.6.2 Services Sector

Final energy demand in the Services Sector is approximately 36% lower in the CO_2 reduction scenarios compared to the business as usual scenario. Similar to the residential sector, the service sector sees a phasing out of oil use and an increased uptake in renewables such as biomass (246 ktoe) and biogas (102 ktoe) for space and water heating in the *CO_2-80* scenario.

Gas use sees a reduction in demand from 2011 figures of 400 ktoe to 260 ktoe in the 80% CO_2 reduction scenario.

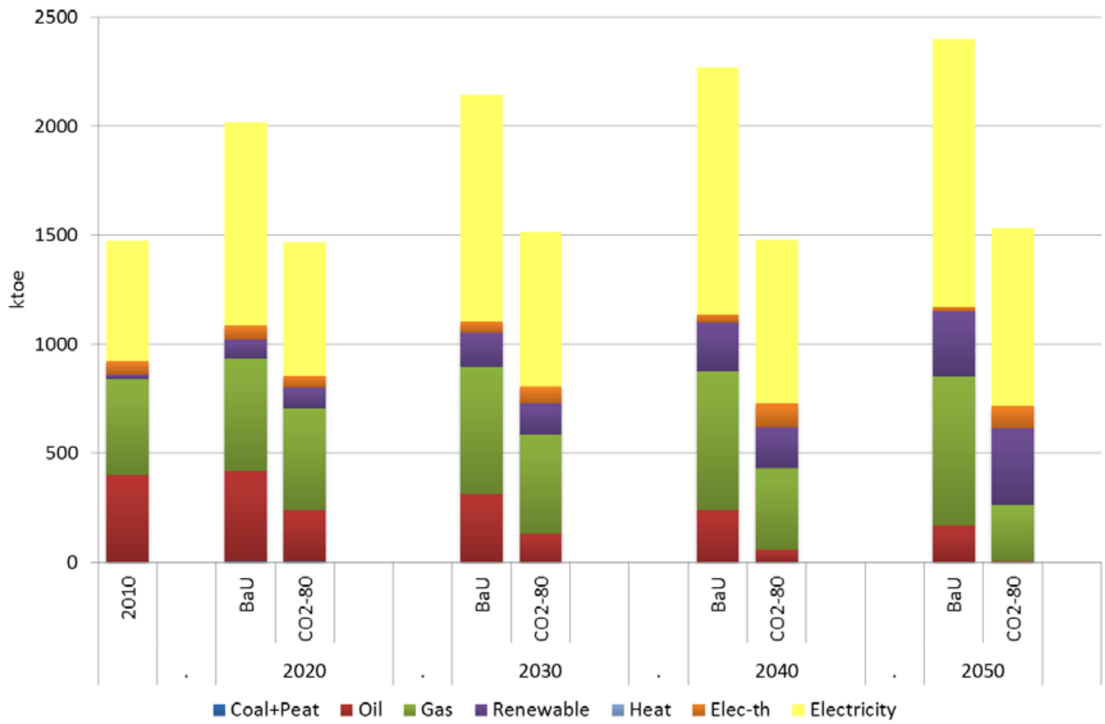

FIGURE 2-15-ENERGY COMSUMPTION IN THE SERVICES SECTOR FOR BAU AND CO2-80 SCENARIOS BY FUEL TYPE

2.6.3 Transport Sector

The transport sector sees a strong reduction (approximately 45%) in energy use in 2050 in the 80% CO_2 reduction scenario compared to the BAU scenario. Diesel is the primary fuel used in transport out to the year 2030, thereafter it is replaced by renewables such as biodiesel and bioethanol.

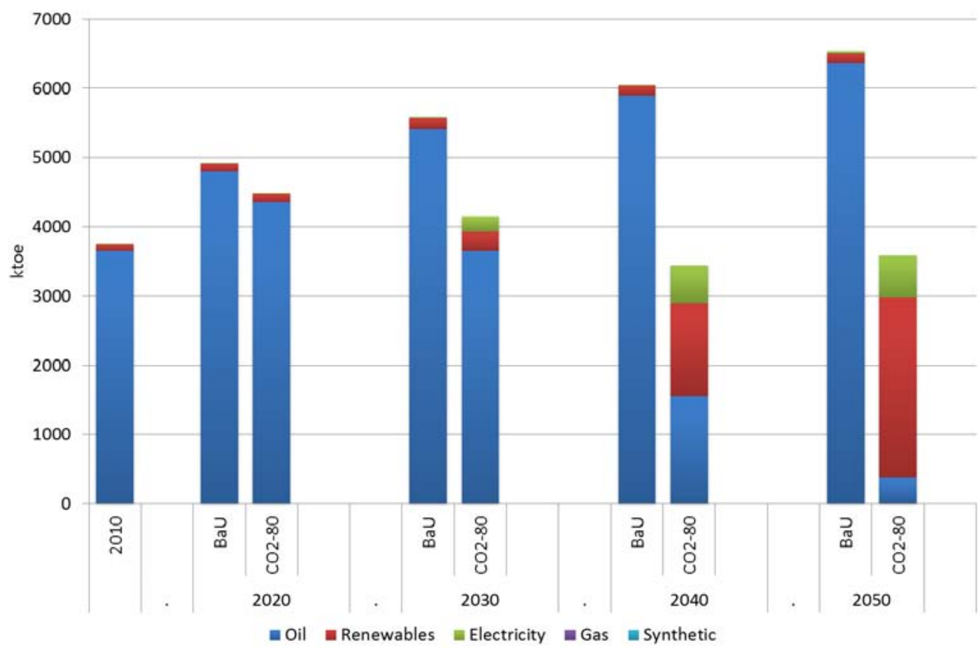

FIGURE 2-16-ENERGY COMSUMPTION BY FUEL TYPE IN TRANSPORT FOR BAU AND CO2-80 SCENARIOS

In the *CO_2-80* scenario electric vehicles appear in the energy mix in 2030 and by 2050 all the private car fleet (approximately 3 million vehicles) are electrified. Freight transport which cannot be electrified is fuelled by biogas (725 ktoe) and the remainder is supplied by ethanol (781 ktoe) and diesel (208 ktoe).

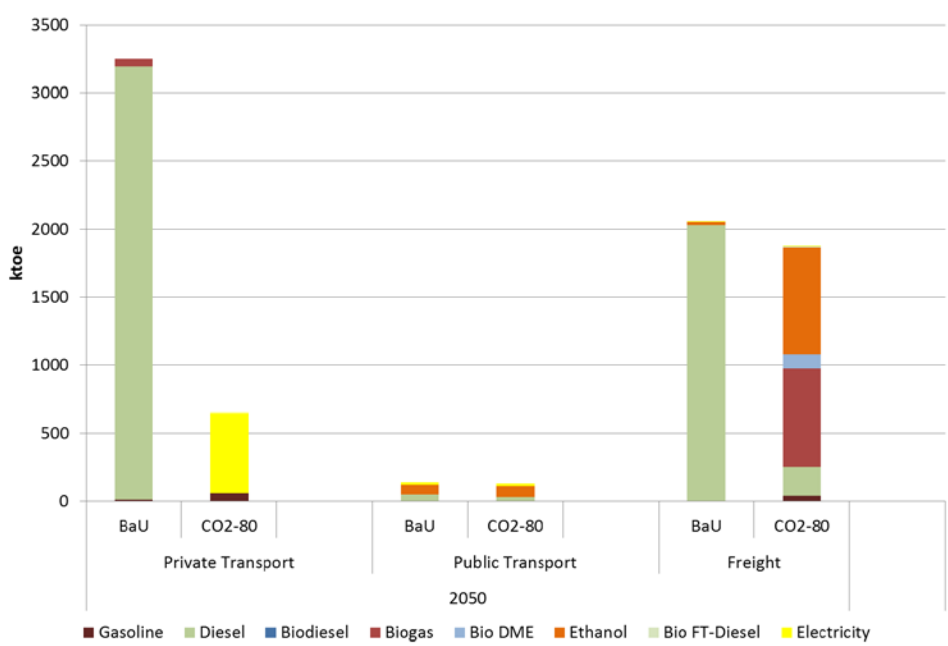

FIGURE 2-17- DETAILED BREAKDOWN OF ENERGY COMSUMPTION IN TRANSPORT FOR BAU AND CO2-80 SCENARIOS

2.6.4 Electricity Generation (Power) Sector

The demand for electricity in 2050 is approximately 40% higher than 2010 levels (SEAI 2010 EB 2080 ktoe) for the scenario. This growth is due to the electrification of heat in the residential and services sector and also the electrification of the private car fleet. The power sector begins a strong decarbonisation trajectory and (similar to other sectors) coal and peat are dropped from the energy mix and the power system is mainly a dual-fuel system (gas and wind) in 2030 for the 80% reduction scenario.

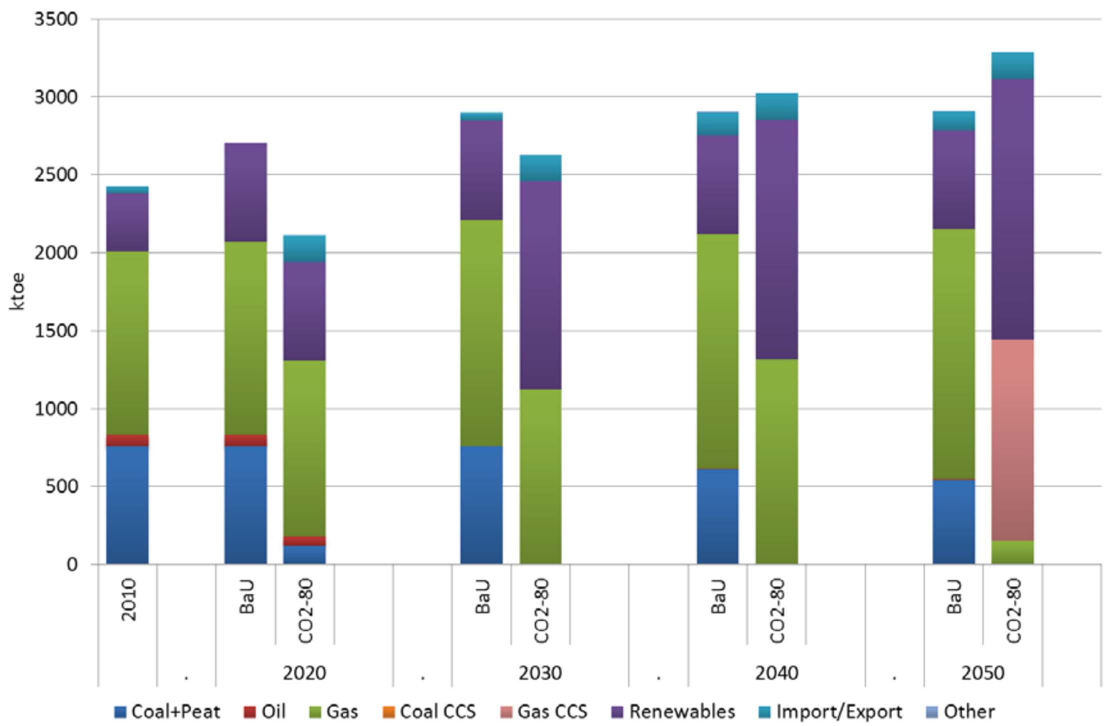

FIGURE 2-18-ENERGY COMSUMPTION IN THE POWER SECTOR FOR BAU AND CO2-80 SCENARIOS BY FUEL TYPE

The power system is constrained to limit wind to 70% instantaneous penetration and 50% annual yield. Gas CCS appears in the energy mix in 2050 for the 80% reduction scenario and produces 1296 ktoe of energy. It is recommended that the results for the power sector be scrutinised more closely. UCC employ a soft-linking technique where the power sector results from Irish TIMES are re-examined at much higher resolution in an operational power system model.

2.6.5 Industry

The industrial sector sees a modest increase in final energy consumption in 2050 in all scenarios compared to 2010 levels of 2,280 ktoe. The *CO_2-80* scenario shows a relative reduction of 10%

against the *BAU* 2050 scenario. Industry has a large thermal requirement which is met predominantly by woody biomass (1,704 ktoe).

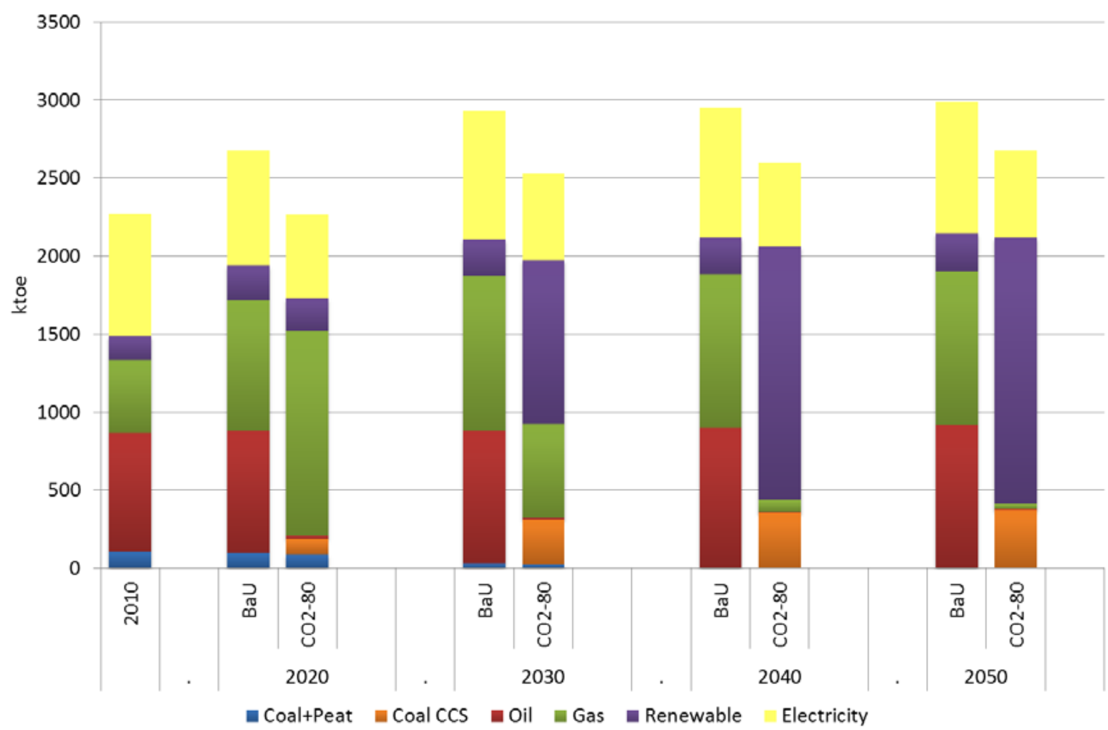

FIGURE 2-19: ENERGY COMSUMPTION IN THE INDUSTRIAL SECTOR FOR BAU AND CO2-80 SCENARIOS BY FUEL TYPE

2.7 ENERGY INFRASTRUCTURE

To achieve emissions reduction of 80%, the analysis suggests that there will be dramatic changes in the quantities of fuels consumed, for instance, the decline of oil and gas in the residential sector and the expansion in biomass fuels, as well as the electrification of energy demand in both the residential and services sectors. Large scale fuel switching is not without potential significant implications for associated infrastructures, both private and publicly owned.

2.7.1 GAS

The *BAU* scenario sees in excess of 70% growth in sector wide (non-electricity generation) natural gas consumption by 2050, with expansion in demand coming from the residential, services and industry sectors. By contrast the CO_2-80 scenario sees a contraction in natural gas

in the residential, services and industrial sectors by almost 40% by 2050. But biogas use increases, displacing natural gas with the net effect being roughly a 25% increase in gas use by 2050 compared to 2010. Gas consumption for electricity generation is 3,045 ktoe in 2050 in the CO_2-80 scenario, which is similar to 2010 levels. Of this 3,045 ktoe, 2,072 ktoe is used in gas CCS power plants.

2.7.2 OIL

Oil is generally used for two purposes: as a transport fuel and for heating. For both uses oil consumption is projected to decline. In transport under the *BAU* there is a projected growth in oil use whereas in excess of a 90% decline is projected (excluding international aviation) under *CO_2-80* scenario (largely due to fuel switching to renewable fuels and electric transport). For heating oils (residential and commercial sectors), there are reductions projected for 2050 in both the BAU and *CO_2-80* scenario. In 2050 under the *CO_2-80* scenario oil use in the services sector is projected at roughly 1% of current levels and at 2% of current levels in the residential sector. Such change in oil consumption will affect the capacity requirements for associated distribution infrastructure.

- In transport mineral oil based fuels will be partly displaced by renewable fuels, which in many instances can avail of the existing distribution network for transport fuels.
- In the case of heating fuels it is envisaged that the capacity of the distribution network will need to shrink dramatically.
- Even with rationalisation in the oil distribution network there is a risk that oil customers will be isolated from suppliers. The *CO_2-80* scenario suggests that residential use of oil will decline to roughly 2% of current levels, equivalent to roughly 33,000 average dwellings. If there is a wide geographical dispersion of oil consumers the size of the market may not be of sufficient size to support a viable business model for the distribution network.

2.7.3 Biomass

The use of biomass fuels is anticipated to grow dramatically in the years to 2050 under the *CO_2-80* scenario. It is envisaged that the majority of biomass fuels will be wood based (e.g. wood chips) and while a growth in indigenous supplies is envisaged, some 60% will need to be imported. The use of indigenous biomass is projected grow rapidly. In 2011 wood fuel production from Irish forestry totalled 0.9 million cubic metres (Kent (2012)[7]). Indigenous supplies could double that by 2030 but under the CO_2-80 scenario could increase to 5-fold current levels by 2050.

- In the decade to 2030 it is projected that imports of biomass will increase substantially, totalling almost 5 million cubic metres (which is more than 4-fold current wood fuel production from Irish forestry) under the low carbon scenarios. Imports are envisaged to grow to almost 8 million cubic metres by 2050 under the CO_2-80 scenario

- This has potential implications for the state's ports, whether they have sufficient capacity, including for bulk storage. By 2030 biomass imports could be equivalent to roughly a 60,000 tonne ship per fortnight rising to a shipment per week in 2050.

- The two primary destinations for biomass are in the residential sector and in power generation. Distribution to the residential sector will occur through normal distribution channels. The location of biomass fuelled power generation plants will significantly affect the number of associated traffic movements. To minimise the impact on the road network it would be preferable if new-build biomass power plants are located proximate to a sea port.
- While air borne particulate matter is not a major concern for air quality at present, the growth in the use of bio-mass fuels, particularly in the residential sector, could be an issue of concern in the future. Any measures to increase the use of biomass fuels will need to be mindful of potential air quality issues.

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[7] Kent, T. 2012. Use of wood for heat in buildings in Ireland, UCD Earth Institute-NESC Workshop, 16 May 2012

2.7.4 Biofuels

The use of biofuels (mostly as transport fuels) is anticipated to increase under both the BAU and 80% CO_2 emissions reduction scenario. Under the BAU scenario the growth is relatively modest whereas the dramatic increase in the implicit price of carbon under the CO_2-80 scenario drives roughly a 20-fold growth in consumption compared to current levels. However, it is envisaged that roughly 50% of consumption levels in 2050 will be from imports.

- The expansion in liquid biofuel imports will offset the decline in imports of conventional mineral oil fuels. Accordingly there should not be any significant impact for the infrastructure and distribution network for transport fuels.

PART IIB: IMPLICATIONS FOR THE ECONOMY

3 MACRO-ECONOMIC IMPLICATIONS OF DECARBONISATION

3.1 COMPETITIVENESS

The movement to a low carbon energy system will impact the economy but it is not possible at this early stage to quantify the nature of such impacts. The current modelling framework does not incorporate a feedback mechanism between the developments in the energy system (i.e. Irish TIMES) and the wider economy (i.e. HERMES macroeconomic model). Developing such a feedback mechanism requires further research but the analysis, as is, demonstrates the potential scale of effects within the energy system of achieving low carbon policy targets by 2050. The feedback impact on the economy is potentially significant but its scale depends on how a low carbon roadmap is implemented in Ireland compared to its trading partners in Europe and around the world. It is also worth noting that all the impacts are not necessarily negative; there are potential opportunities across a range of areas including renewable fuels, technology development or low carbon services.

Based on the modelling in Irish TIMES modelling there is an implicit carbon price associated with achieving various levels of emissions reductions. Under the CO2-80 scenario the marginal abatement cost of carbon (priced in € per tonne of carbon dioxide) would increase to in excess of €335/tonne by 2050, as shown in Table 2. Assuming a similar carbon price in EU member states, for example through a mechanism such as the EU-ETS allowance prices, Irish exports should not lose competitiveness versus producers from other EU member states. Ireland will suffer a loss in competitiveness if carbon is not priced at similar levels elsewhere. As the majority of Irish trade is with EU countries, with 59% of exports to EU member states in 2012 (see Table 2 below), it will be important that the price of carbon within Ireland is similar to carbon prices within Europe. However, where competitors are from outside the EU, the price competitiveness of Irish exports will be eroded both in EU and non-EU markets. This will not be a problem unique to Ireland but will apply across EU member states. If Europe's major trading bloc partners do not follow similar measures to raise the cost of carbon the issue of cost competitiveness will become a pan-European issue to be resolved.

TABLE 2: MARGINAL ABATEMENT COSTS (IMPLICIT CARBON DIOXIDE PRICES), CO2-80 SCENARIO, - 2010 PRICES

	2020	2030	2040	2050
All emissions, €/tonne	74	88	235	336

TABLE 3: MAIN TRADING PARTNERS - 2012 €MILLION

	Exports	%	Imports	%
Great Britain and Northern Ireland	15,171.1	16.5	16,428.6	33
Other EU Countries	38,918.3	42.4	13,740.0	28
USA	18,156.9	19.8	6,441.4	13
Rest of World	19,494.9	21.3	12,541.1	26
Total	91,688.0	100.0	49,151.0	100
Source: CSO				

An increase carbon prices potentially rising to €336/tonne in 2050 under CO_2-80 is severe compared to a current ETS price of less than €10/tonne or a carbon tax of €20/tonne. Compared to a current 'average'[8] carbon price of €10/tonne, this is equivalent to an annual average growth rate of 10% per annum. It is useful to set such a growth in carbon prices in context by illustrating the impact of rising cost of carbon on the price of oil. The CO_2 ultimately emitted from a barrel of oil will vary by type of crude oil and depend on the types of refined products. For these calculations we assume that the combined liquid fuels from an average barrel of crude oil will produce a minimum of 317kg of CO_2 when consumed.[9] Table 4 shows projected real oil price and the associated CO_2 costs implied under the CO_2-80 scenario. In 2013 carbon costs represent approximately 7% of the total price of oil. With rising carbon prices, as implied under scenario CO_2-80, carbon costs would represent a bigger share of total oil costs even with the real price of

[8] While the carbon tax is €20/tonne, ETS allowance prices during 2013 have been as low as €3/tonne.

[9] "Carbon dioxide emissions per barrel of crude", The Quiet Road, Jim Bliss, http://goo.gl/iPuDME

oil increasing. In 2020 and 2030 carbon costs are projected to be almost one quarter of the total cost of oil, rising to in excess of half the cost of oil by 2050. Under scenario CO_2-80 the price of oil, including carbon costs, will be 23% higher in 2020 than today, almost 50% higher in 2030, over double today's price by 2040, and 2.4 times today's price by 2050. It is through higher real oil prices (incl. carbon costs) that the primary impact of low carbon policies will impact economic activity. Over the entire period to 2050 the projected annual average growth in oil prices (incl. carbon) is equivalent to 2.4%. This growth in real oil prices is comparable to the growth in Irish energy prices over the past decade, where gas, electricity and fuel oil prices increased by an average of 3-4% per annum.[10] This is not to say that the potential increases in carbon prices are neither substantial nor additional. They are of sufficient magnitude to dampen economic activity but given the timeframe in question and given potential innovation by businesses and households the scale of change in carbon prices need not be catastrophic for the economy. If energy practices remain 'business-as-usual', without innovation and technological change but carbon prices increase to the levels envisaged under CO_2-80, there will be severe economic and social impacts.

In the context of a global low carbon economy with declining fossil fuel demand it is feasible that the price of oil will decline contrary to the assumptions on oil prices used in the CO_2-80 scenario. But with a rising carbon prices, and with carbon representing a greater share of the total cost of a barrel of oil, fossil fuel prices including carbon costs are still likely to be significantly higher than current prices.

If the carbon tax is levied at rates similar to that implicit in the CO_2-80 scenario the tax, it will generate significant increases in exchequer revenue. But as outlined earlier in the chapter, fossil fuel consumption is anticipated to dramatically decline in response to higher carbon prices so any initial increase in carbon tax revenue will be followed by a dramatic decline in such revenue. In the short term the additional revenue could be used to invest in the transition to renewable energy and provide supports to help households and business adapt to the new energy environment.

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[10] Nominal energy prices have increased by an average of 6-7% per annum.

TABLE 4. IMPACT ON OIL PRICES UNDER CO2-80

		2013	2020	2030	2040	2050
Real Oil Price[1]	€/barrel	79.6	82.0	99.4	99.4	99.4
CO2 price - CO2-80	€/tonne	20.0[2]	74.0	87.5	235.4	335.8
CO2 price	€/barrel	6.3	23.5	27.7	74.6	106.4
Oil price (incl. CO2)	€/barrel	85.9	105.5	127.1	174.0	205.8
Oil Cost Index - CO2-80	2013=100	100.0	122.8	148.0	202.6	239.6
Carbon as a share of oil price (incl. carbon)		7%	22%	22%	43%	52%
Average annual oil price growth rate (incl CO2), 2013-2050		2.4%				

[1] Based on MTR oil price assumptions 2020-30 and assumed real price unchanged to 2050

[2] Current carbon tax rate of €20/tonne

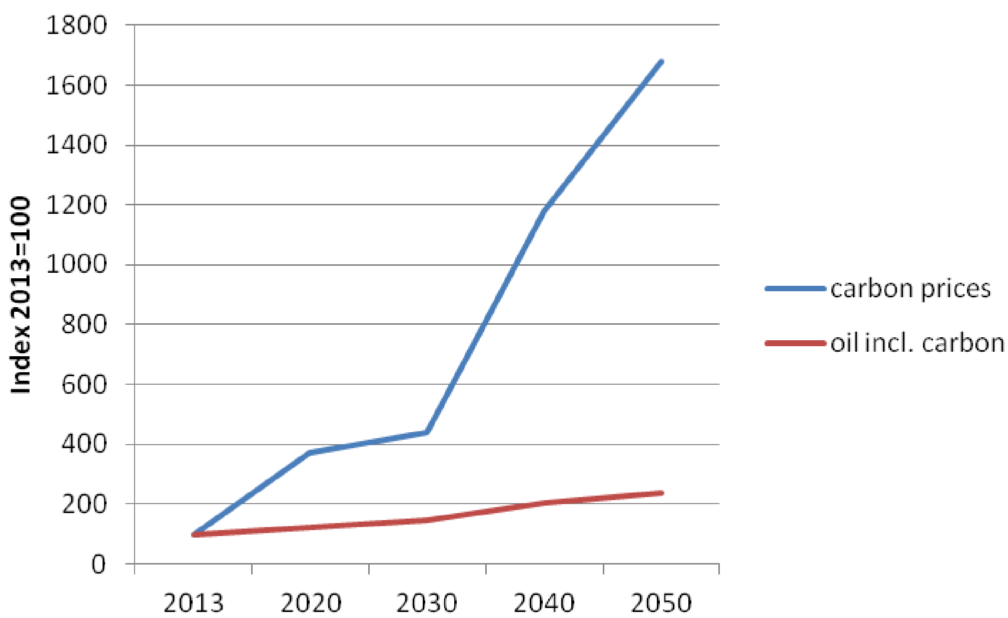

FIGURE 3-1: INDEX OF CARBON AND OIL PRICES, 2013=100

While the rise in the implicit cost of carbon will be a significant issue for cost competitiveness, two related issues are potentially more significant: the pace of increase in carbon prices and the long term expectations for real carbon prices. Dramatic price increases, especially if not anticipated, are more damaging as energy users cannot quickly adapt to minimise costs. Businesses can develop plans to accommodate predictable price increases, whereas volatile price fluctuations introduce additional costs and uncertainty. While climate change is in the

wider public dialogue there is no clear public discussion or reference to the long term cost of carbon. Carbon price expectations form part of the longer term expectation on energy prices, which in turn can influence investment decisions. Without a credible expectation of dramatically increasing carbon prices investment decisions will not be mindful to move towards low carbon alternatives.

The profile of carbon prices from the Irish TIMES modelling is not a uniformly increasing carbon price but one in which the price rapidly grows in the 2030-2050 period, as shown in the Figure 3-2 below. Such a price profile has positive and negative implications for the economy and a low carbon future. For existing sunk investments (whether boilers or power plants) the rising cost of carbon is not projected to be immediately prohibitive, which means that the natural lifecycle of most existing energy using equipment will cease prior to the projected dramatic carbon price increases post 2030.

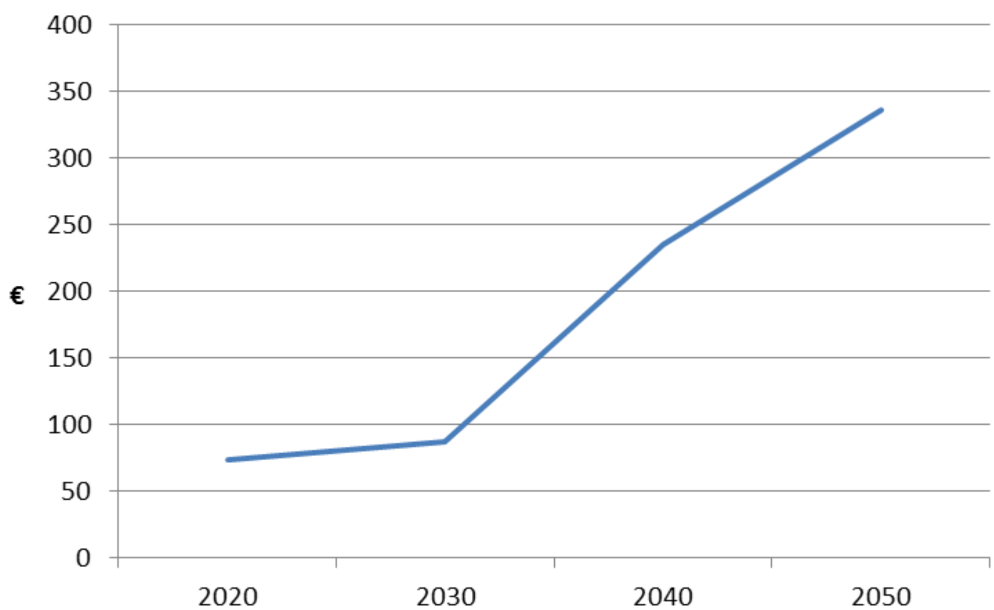

FIGURE 3-2: IMPLICIT CARBON PRICES UNDER SCENARIO CO2-80, €2010/TONNE

The implication is that the low carbon roadmap will not force retire existing fully functioning equipment due to high carbon prices. In such circumstances the move to a low carbon economy does not introduce premature additional costs on businesses or households. When current equipment reaches the end of its useful life there will be an opportunity to invest in carbon efficient alternatives.

A potential negative aspect of the carbon price profile is that there is no mechanism that signals the very high price of carbon (consistent with the carbon roadmap policy ambitions) in the longer term. Even though the implicit price of carbon rises to €98 by 2030 under the CO_2-80 scenario, there is a risk that investments in long life equipment (e.g. 15-20+ years) in 2030 might be based on carbon prices closer to €100/tonne than significantly higher prices post 2040, which are projected to reach €336/tonne by 2050. Into the future if expectations of carbon prices do not resemble the projected scenario price profiles the necessary investments in low carbon technologies will not occur.

3.2 SECTORAL IMPACTS

As there are no modelled feedback mechanisms from the Irish TIMES model to the HERMES macroeconomic model, we use other means to determine the potential sectoral impacts of a low carbon regime. While all sectors of the economy will be affected by rising fuel prices, input-output tables give some insight on the relative impacts across sectors. The most recent input-output tables for Ireland are for 2005 (CSO (2009)) and while the economy has suffered through a recession since then, the broad results from the tables should still be relevant for today's economy. The Leontief inverse of the input-output table can help evaluate to some extent the impact of a shock to energy prices but it should also be noted that input-output analysis assumes that the structure and behaviours in the economy are static over time and do not respond to new price incentives. For this reason, as well as the implied assumption of constant returns to scale, input-output analysis is likely to over estimate the effect of an energy price shock.

The 2005 input-output tables separately identifies the electricity and gas sector (NACE rev1, sector 40), which incorporates the generation, transmission, distribution of electricity and gas. Rising energy costs will affect all sectors that use electricity and gas but the input-output Leontief coefficients show the extent to which the value of output from each sector is dependent on other sectors. A unit change in demand for each sector's products (e.g. agriculture sector output) requires a specific amount of electricity and gas sector output. Table 5 reports the sector outputs that are most reliant, proportionately in value terms, on the output of the electricity and gas sector. For example, for each €1 of final demand of water services output (NACE 41, collection, purification and distribution of water) requires €0.095 of output from the electricity

and gas sector. Figures for the equivalent UK sectors are also included in the Table for comparison. The water services sector has the largest such coefficient across the economy and therefore a rise in energy costs (in electricity and gas) would have the largest proportionate effect on water treatment services. Ireland does not have very energy intensive industry and the impacts of rising energy cost within the sectors are generally equivalent or substantially lower than the UK. In Ireland the sectors where energy costs comprise a higher share of the value of total output include the production of bricks, lime, cement (NACE 26), metals production, mining and quarrying activity, wood products, rubber and plastics manufacture (see Table 5). In each of these sectors, with the exception of water services, energy costs represent a higher share of the value of output in the UK than Ireland. For the majority of the 53 sectors in the Irish input-output tables the value of electricity and gas used as input relative to the value of output in each sector is relatively low.

TABLE 5. LEONTIEF INVERSE COEFFICIENTS FOR THE ELECTRICITY AND GAS SECTOR

Sector	NACE rev1	Leontief multiplier	
		Ireland[1]	UK[2]
Water collection and distribution	41	0.095	0.079
Basic metals	27	0.057	0.105
Other non-metallic mineral products	26	0.057	0.105
Coal, peat, petroleum and metal ore extraction	10-13	0.052	0.066
Other mining and quarrying	14	0.051	0.077
Wood and wood products (excl furniture)	20	0.041	0.041
Rubber and plastics	25	0.035	0.049
Sewage and refuse disposal services	90	0.030	0.025
Hotel and restaurant services	55	0.027	0.022
Education	80	0.025	0.015
Agriculture, forestry and fishing	1-5	0.025	0.051
Retail trade and repair of household goods	52	0.024	0.019
Manufacture of food and beverages	15	0.023	0.047
Research and development services	73	0.022	0.020
Recycling	37	0.021	0.048
Public administration and defence	75	0.021	0.023
Pulp, paper and paper products	21	0.021	0.106
Textiles	17	0.021	0.044
Other services	93	0.021	0.011

[1] CSO (2009), [2] ONS (2011)

The sectors listed in Table 5 are potentially those most vulnerable to high energy costs. While all are important sectors, especially water treatment services, they are not the most significant sectors in the economy in terms of gross value added and employment.

Table 6 reports gross value added and employment by sector for 2012. The manufacturing sector has the highest value added and employs roughly 200,000 people, primarily in food processing, pharmaceuticals, IT/computers, and machine & equipment manufacture.

TABLE 6. GROSS VALUE ADDED AND EMPLOYMENT BY SECTOR, 2012

Sector (NACE rev2)	Description	Gross Value Added[1]	Employment[2]
A	Agriculture, forestry and fishing	2,346	85.8
B	Mining and quarrying	525	234.0
C	Manufacturing	34,423	
D	Electricity, gas, steam and air-conditioning supply	2,942	
E	Water Supply; sewerage, waste management	941	
F	Construction	2,300	101.8
G	Wholesale and retail trade, repair of vehicles	14,382	271.4
H	Transportation and storage	6,348	90.1
I	Accommodation and food services activities	2,904	119.8
J	Information and communication	13,568	80.3
K	Financial and insurance activities	13,940	101.4
L	Real estate activities	9,918	
M	Professional, scientific and technical activities	6,255	100.8
N	Administrative and support service activities	7,274	63.8
O	Public administration and defence	6,036	98.7
P	Education	8,395	144.7
Q	Human health and social work activities	11,884	243.7
R	Arts, entertainment and recreation	2,523	99.3
S	Other service activities	373	
T	Activities of households as employers	165	
U	Activities of extra-territorial organisations and bodies	2	
	Total	148,792	1837.9

1. Source: CSO, Gross Value Added at Current Basic Prices, 2012, €million, National Income and Expenditure 2012.
2. Source: CSO, Person aged 15 years and over in Employment, Thousand, Quarterly National Household Survey

The sector activities that are more exposed to rising energy prices (as identified in Table 5) are mostly sectors with lower gross value added. Both the wood products and rubber & plastics sectors, which have a relatively higher energy requirement, are in the manufacturing sector in Table 6 below.[11] Employment in these sub-sectors is approximately 5% of total employment in the manufacturing sector and on an economy-wide scale these sub-sectors are relatively small.

3.3 INVESTMENT IN ENERGY[12]

Regardless of whether a low carbon or business-as-usual scenario applies significant levels of investment will be required in the coming decades in both energy generation and energy using infrastructure. This includes investment in power generation plants, transport vehicles, heating boilers and equipment. The cost of a low carbon policy is not the absolute investment cost necessary to achieve the policy targets but the additional costs compared to the BAU scenario, which is illustrated in the figure below. The BAU and CO_2-80 scenarios have similar investment profiles; increasing investment on a per annum basis until 2040, with investment levels beginning to plateau by 2050, as shown in Figure 3-3. Beginning in the 2020s additional investment is required in CO_2-80 compared to the BAU if the 2050 emissions ambition is to be achieved at lowest cost. The level of additional investment gradually increases reaching approximately €3 billion per annum in the 2040s and 2050s, with total investment costs under the CO_2-80 scenario reaching €14 billion per annum.

[11] The sector classifications in Table 3-4 and Table 3-5 are not equivalent. Table 3-4 uses NACE revision 1, whereas Table 3-5 uses NACE revision 2. In addition, the CSO does not publish the QNHS employment figures to the same sectoral detail as gross value added.

[12] 'Investment' in the Irish TIMES model includes conventional investment categories, such as power generation plant, but also includes consumption expenditure in energy using equipment such as the household sector's purchase of vehicles or domestic boilers. Investment costs include installation and build costs.

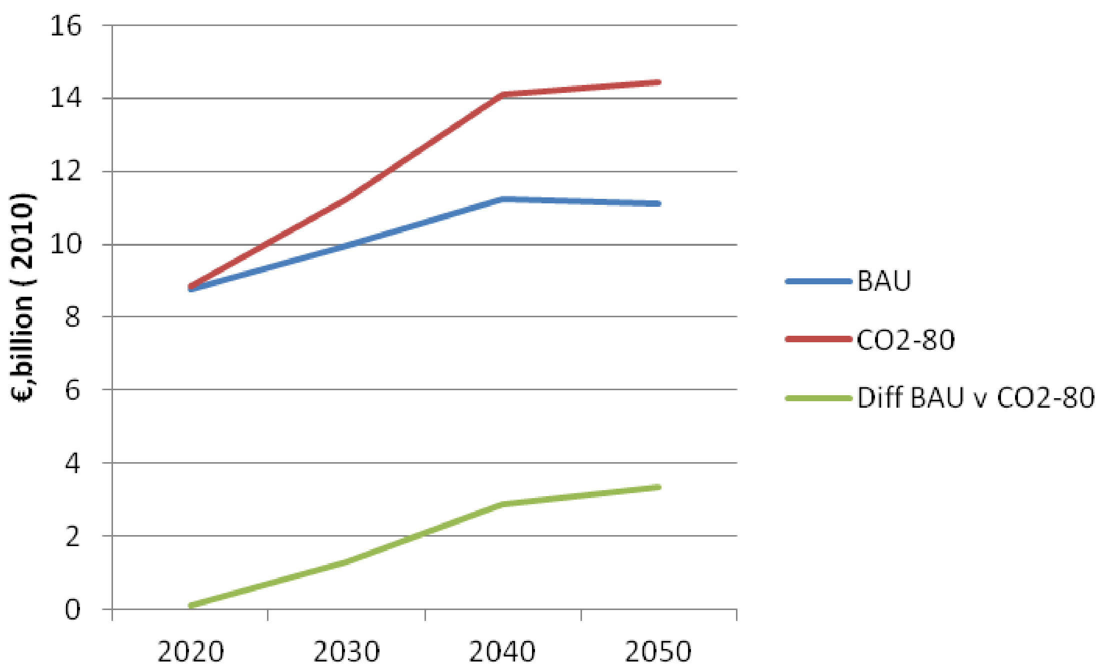

FIGURE 3-3: INVESTMENT UNDER BAU AND CO2-80 SCENARIOS

The Irish TIMES model provides some indication of where the burden of this additional investment will fall across the major sectors of the economy but doesn't distinguish between public and private sector. This breakdown is presented in Figure 3-4 and Table 7. Across the sectors investment costs are higher under the low carbon CO_2-80 scenario but not substantially so with the exception of the transport sector. The additional investment costs in transport reflect, in part, higher vehicle costs for biofuel and electric vehicles compared with conventional fossil fuel vehicles. Under CO_2-80 scenario by 2050 the majority of the transport fleet will use biofuels with much smaller shares using fossil fuels or electric vehicles. Both under the BAU and CO_2-80 scenarios the assumed transport service demand (i.e. passenger or goods kilometres) is projected to increase but the investment cost becomes noticeably higher post 2040 under the CO_2-80 scenario. The scenarios and associated costs are based on best current available information. Over time the relative cost differential between conventional fossil fuel based transport versus low carbon alternatives may narrow more than currently envisaged and the accordingly the additional transport investment costs may be less than projected. In addition, any transport policy interventions that achieve significant increases in public transport in the future (i.e. reduce reliance on private cars) are not assumed in the transport service demand projections. If in the future there is a reduction in the reliance on private cars, in commuting for instance, transport investment requirements would potentially be lower.

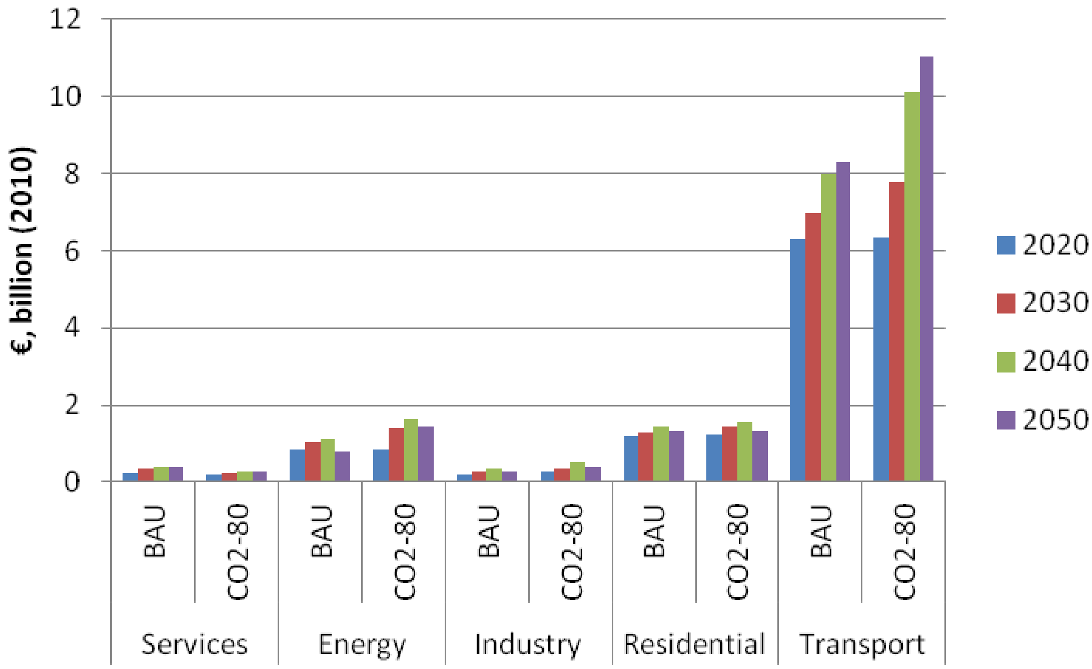

FIGURE 3-4: INVESTMENT BY SECTOR UNDER BAU AND CO2-80 SCENARIOS

TABLE 7. INVESTMENT BY SECTOR UNDER BAU & CO2-80 (BILLION, 2010)

Sector	Scenairo	2020	2030	2040	2050
Services	BAU	0.2	0.3	0.4	0.4
	CO2-80	0.2	0.3	0.3	0.3
Energy	BAU	0.8	1.0	1.1	0.8
	CO2-80	0.8	1.4	1.7	1.4
Industry	BAU	0.2	0.3	0.3	0.3
	CO2-80	0.3	0.4	0.5	0.4
Residential	BAU	1.2	1.3	1.4	1.3
	CO2-80	1.2	1.5	1.6	1.3
Transport	BAU	6.3	7.0	8.0	8.3
	CO2-80	6.3	7.8	10.1	11.0

As noted earlier, the models do not contain a feedback between the energy system and the wider economy. However, given the assumed projected growth rates for the economy, the economy as a whole should be able to bear the cost of this additional investment. The economic projections assume that the economy will grow relatively strong in the latter half of this decade, with more moderate growth in the 2020s, and just above 1% growth in the period to 2050. Over the last twenty years total investment in rich EU economies accounted for around 20 per cent of GDP each year (see Figure 3-5). While investment plummeted in Ireland since the recession,

with a return to growth and the economy expanding as projected total investment by 2050 could roughly quadruple current levels exceeding €67 billion per annum. Assuming historical investment norms the level of investment in 2050 should be roughly equivalent to the investment requirements under the low carbon scenarios.

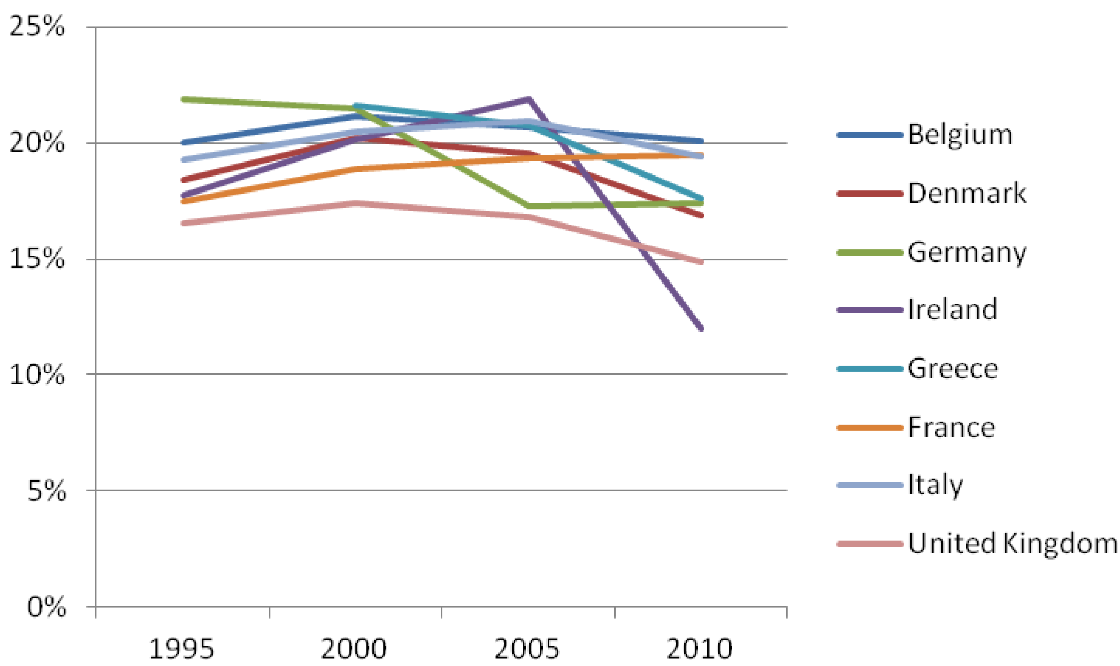

FIGURE 3-5: GROSS FIXED CAPITAL FORMATION AS SHARE OF GDP BY COUNTRY, SOURCE EUROSTAT

In the event of a low carbon objective similar to the CO_2-80 scenario the relative profile of sector level investment will likely change (as shown in Table 7). The two tables below provide historical details of investment in Ireland by activity and sector. Neither of these tables is directly comparable with the investment categories in the Irish TIMES model (reported in Table 7) but they indicate how investment shares have varied historically both across activities and sectors. For instance, investment in transport equipment has varied between 13-20%, and building and construction has varied between 17-23% of total investment over the past twenty years (). Investment shares have also varied substantially in the sectors (e.g. other market services 24-37% - Table 9).

TABLE 8. GROSS DOMESTIC FIXED CAPITAL FORMATION

	1995	2000	2005	2010
Dwellings	36%	34%	39%	25%
Roads	4%	4%	5%	9%
Other building and construction	18%	20%	17%	23%
Costs assoc. with transfer of land & buildings	6%	5%	5%	1%
Transport equipment	14%	13%	14%	20%
Agricultural machinery	2%	1%	1%	1%
Other machinery and equipment	12%	14%	11%	14%
Other	8%	10%	8%	7%
Source: CSO (2013)				

Historically investment has evolved considerably responding to contemporary needs. Generally the scale of sector level investment under CO_2-80 is within the historical ranges and the sectors would appear capable of financing and absorbing such investment.

TABLE 9. GROSS DOMESTIC FIXED CAPITAL FORMATION BY SECTOR OF USE

	1995	2000	2005	2010
Agriculture, forestry and fishing	6%	3%	2%	3%
Fuel and power products	5%	5%	5%	9%
Manufacturing products	12%	11%	9%	9%
Building and construction	2%	2%	2%	0%
Market services	70%	73%	77%	71%
- Dwellings (incl. transfer costs)	40%	36%	42%	26%
- Roads	4%	4%	5%	9%
- Other market services	24%	29%	27%	37%
Non-market services	5%	6%	5%	8%
				Source: CSO (2013)

3.4 ENERGY COSTS

While investment costs increase under the CO_2-80 scenario, fuel costs decline. In essence the investment in low carbon alternatives, in particular wind for electricity generation, means that the cost of energy declines. In practice the lower annual fuel costs offset the increase in investment costs. Figure 3-6 compares fuel and investment costs under the two scenarios for 2050.[13] Total annual investment and fuel cost in 2050 are broadly similar under the BAU and

[13] Aggregate fuel costs here exclude costs associated with fuel transformation and distribution, which are incorporated in the sector fuel costs presented later.

CO_2-80 scenarios (CO_2-80 scenario is slightly lower). The share of fuel costs is just over 50% in the BAU scenario but less than 40% in the CO_2-80 scenario. A significant outcome of the low carbon scenario is the potential for the increase in annual investment in low-carbon technologies to be partially offset by lower fuel bills.

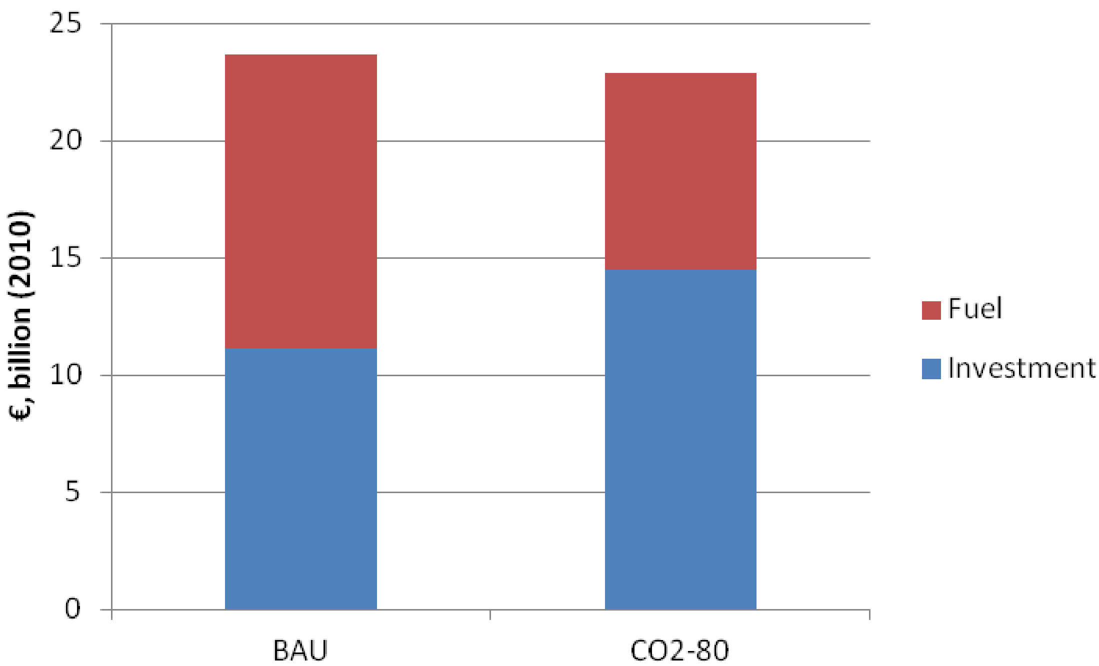

FIGURE 3-6: FUEL AND INVESTMENT COSTS IN 2050 UNDER BAU & CO2-80 SCENARIOS

Sector fuels costs are presented in Figure 3-7 and Table 10 but relate only to the energy component of fuel bills (incl. electricity) and exclude costs such as excise duties, PSO levies, and profit, which are normally incorporated in energy bills faced by households and businesses. Whether in the BAU or CO_2-80 scenarios fuel bills are expected to increase reflecting growth in the economy and the population. Across all the sectors fuel costs are lower under the BAU than the CO_2-80 scenario.

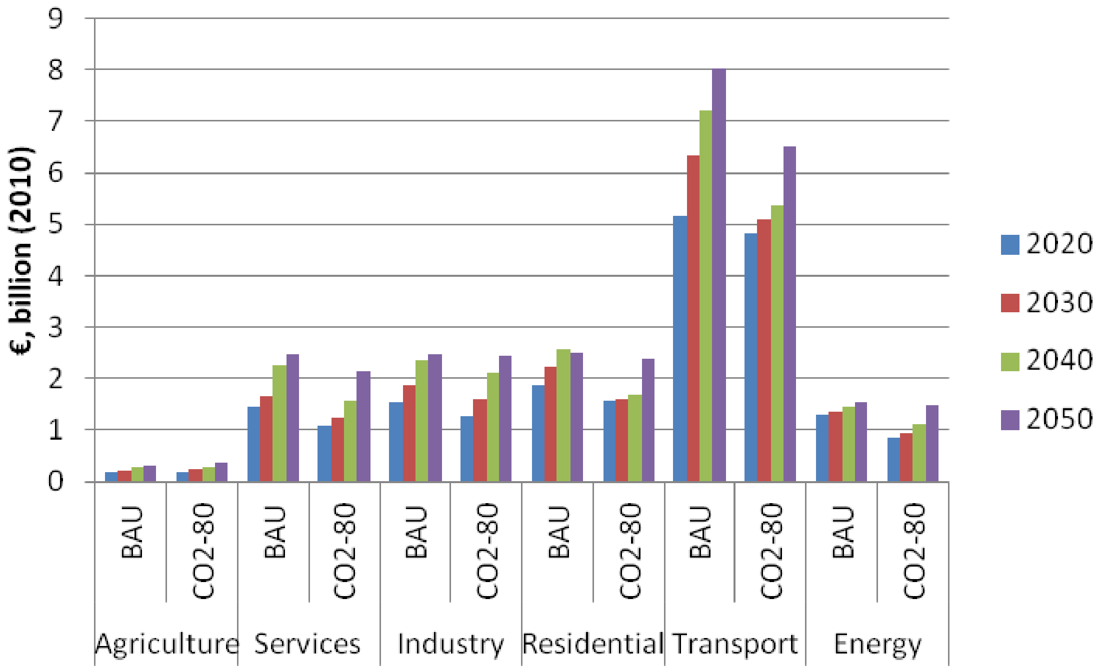

FIGURE 3-7: FUEL COSTS UNDER BAU & CO2-80 BY SECTOR

TABLE 10. FUEL COSTS BY SECTOR, BAU & CO2-80 SCENARIOS, €BILLION (2010)

Sector	Scenario	2020	2030	2040	2050
Agriculture	BAU	0.2	0.2	0.3	0.3
	CO2-80	0.2	0.2	0.3	0.3
Services	BAU	1.4	1.6	2.3	2.5
	CO2-80	1.1	1.2	1.6	2.2
Industry	BAU	1.5	1.9	2.3	2.5
	CO2-80	1.3	1.6	2.1	2.5
Residential	BAU	1.9	2.2	2.6	2.5
	CO2-80	1.6	1.6	1.7	2.4
Transport	BAU	5.2	6.3	7.2	8.0
	CO2-80	4.8	5.1	5.4	6.5
Energy	BAU	1.3	1.4	1.4	1.5
	CO2-80	0.9	0.9	1.1	1.5
Total	BAU	11.5	13.7	16.1	17.3
	CO2-80	9.8	10.7	12.1	15.3

The reduction in fuel costs under the CO_2-80 scenario will lead to an improvement in the balance of trade, given the high import content of fuels. The import cost of fuels is anticipated to

continually increase under the BAU scenario, whereas under the CO_2-80 scenario the import cost of fuels is largely static until after 2040 (see Figure 3-8). A number of factors drive the reduction in fuel import bill compared to the BAU scenario. There is an increase in 'free' renewables, such as wind, that displace fossil fuels; renewables such as biogas will be produced domestically and while more expensive than natural gas are not imported; and technological efficiency improvements also replace some of the fuel requirement under the BAU. Import fuel costs increase post 2040 because domestic supplies of biofuels and biomass need to be supplemented with imports.

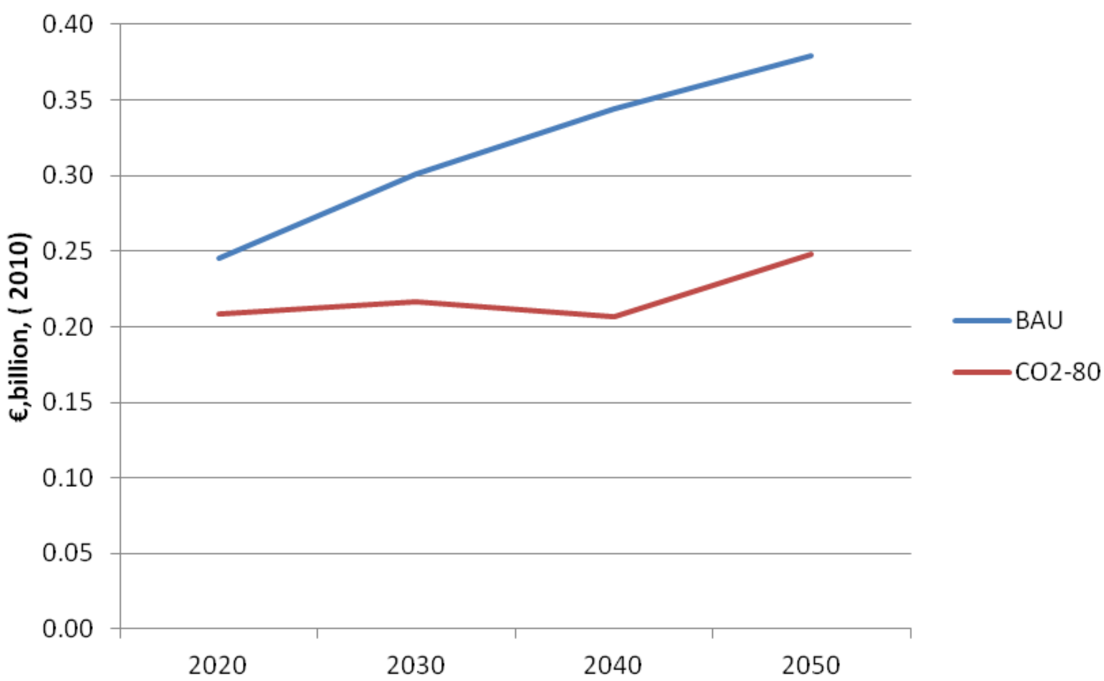

FIGURE 3-8: IMPORT FUEL COSTS UNDER BAU AND CO2-80 SCENARIOS

3.5 SUMMARY

It is not possible to project with certainty what the economic impact of low carbon on the economy will be. The change in the energy system will present both opportunities and challenges and it is impossible at this early stage to decipher how these may materialise. The move to low carbon will require additional investment but fuel bills will also decline, as will reliance on fuel imports. Rising carbon prices will affect economic activity but in the longer term

as fossil fuels represent a declining share of total energy the impact of rising fossil fuel prices on the economy will decline. If the wider global economy adapts a low carbon roadmap, demand for fossil fuels will decline significantly. Fossil fuel prices may decline too but the real price of fossil fuels, including the cost of carbon, should not fall if carbon is priced sufficiently high. An explicit and sufficiently high price for carbon will mean that developments in world fossil energy markets will not impede a low carbon future.

It is also difficult to decipher without further research the potential sector level economic impacts. Compared to other European economies Ireland does not have much energy intensive industry and consequently the impact of rising carbon prices may be more muted than elsewhere. Nonetheless, energy represents a significant cost to business and some sectors are more vulnerable to rising energy prices than others. Sudden dramatic changes will cause economic hardship but in the context of a 2050 target, there are more than three decades in which sectors can plan for and invest in the transition to low carbon.

PART III MOVING TO 95% CO_2 REDUCTION

4 TECHNOLOGY SOLUTIONS

4.1 ENERGY SYSTEM RESULTS

This section presents the resultant energy system CO_2 emissions for the BAU and the 95% CO_2 Emission reduction Scenario out to 2050. Results are presented on a system wide basis and also for individual sectors. Energy usage in 2050 by sector and fuel are also presented along with the potential energy savings for each of the three scenarios.

4.1.1 CO_2 EMISSIONS

In the absence of mitigation, associated CO_2 emissions grow unabated and in year 2050 the BAU scenario shows the energy system emissions at approximately 51 MT up 21% from 42 MT in 2010. In the CO_2 emission reduction scenario the greatest reduction in emissions relative to 2010 is in the transport sector (from 11.6 MT to 0.5 MT CO_2-95%) followed then by electricity generation (from 13.3 MT to 0.6 MT CO_2-95%).

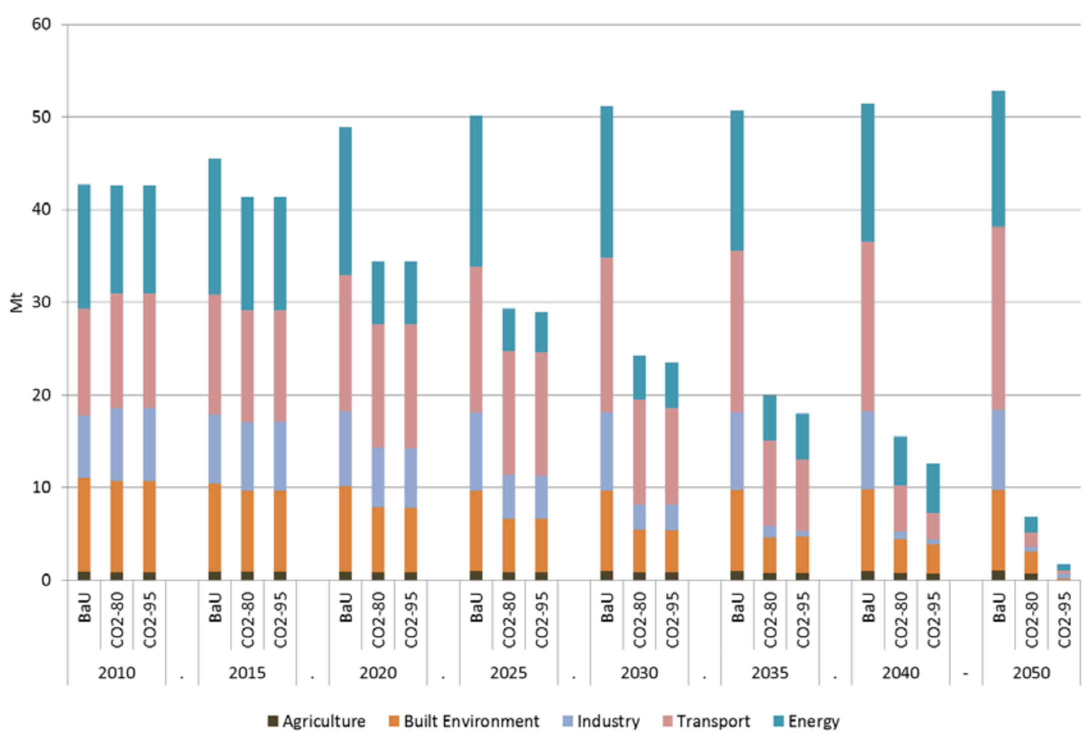

FIGURE 4-1: SECTORAL CO2 EMISSIONS FOR HORIZON TO 2050 FOR BAU AND 95% EMISIONS REDUCTION SCENARIOS

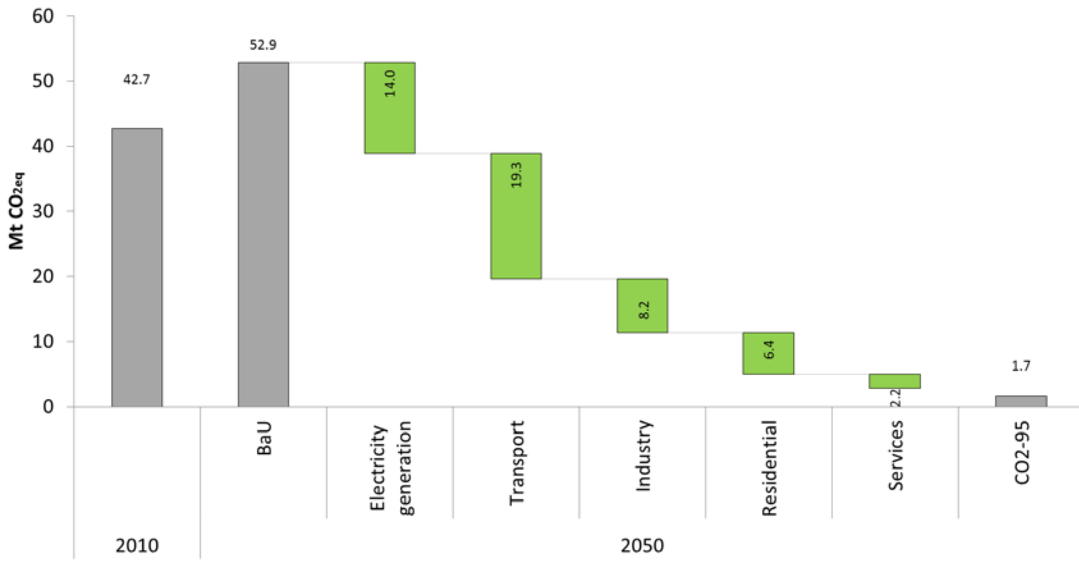

FIGURE 4-2: INCREMENTALCHANGE IN CO2 EMISSION REQUIRED BY EACH SECTOR TO REACH CO2 95% REDUCTION TARGETS RELATIVE TO BAU SCENARIO AND 2010[14].

In the 95% CO_2 reduction scenario the largest emissions savings (relative to BAU scenario) are made in the Transport sector (19.3 MT) with significant savings also make also made in electricity generation (14 MT).

A simple decomposition analysis was used to summarize the mitigation contributions from (1) energy efficiency, (2) renewable energy and (3) fuel switching amongst fossil fuels.

[14] Agricultural reduction of 1MT is not shown in graph.

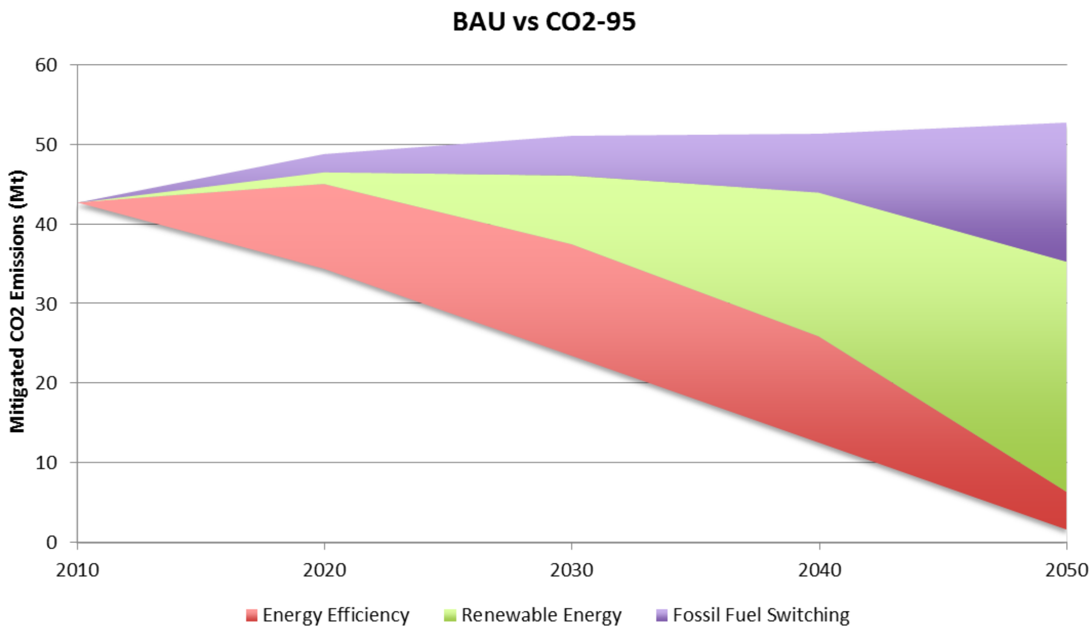

FIGURE 4-3: DECOMPOSITION OF 95% CO2 EMISSIONS REDUCTIONS SCENARIO VS BAU SCENARIO

The *energy efficiency* effect (GDP/total energy) is stripped of any hidden structural effects because for all scenarios (*BAU & CO_2-95*), GDP is the same. Energy efficiency is the most cost optimal mitigation strategy and in the early part of the modelling time-horizon for the *CO_2-95* scenario, energy efficiency is responsible for more than 50% of the total mitigated emissions. This is a clear "energy efficiency first" trend.

The *renewable energy* effect is emissions mitigation from wind, bioenergy, solar and geothermal sources; it also includes a very small quantity of imported electricity. In the *CO_2-95* scenario, renewable energy has a majority share from 2040 and for the period as a whole it makes the largest contribution (43%) to cumulative emissions mitigation.

Fossil *fuel switching* is the third emission reduction strategy. In the early part of the modelling time horizon fossil fuel switching achieves emissions mitigation by switching from coal to oil and from coal and oil to gas. In the *CO_2-95* scenario fuel switching as technical limits are reached, contributes 24% to the cumulative emissions reduction.

4.1.2 ENERGY SYSTEM IN 2050

Energy usage for different primary fuels and within different sectors of the energy system are presented in the following Sankey Diagrams for the target year of 2050. Note that associated tables of final primary energy requirement and final energy consumption by fuels are shown in the Appendix.

Figure 4-4 shows the BAU scenario, which is very similar to the current energy system that substantially relies on oil and gas with a small share for renewables. Under CO_2-95 in Figure 2-7 oil has all but disappeared from the domestic energy system, as has gas except for use in power generation in combination with CCS technology. Bio-energy dominates, with biofuels used in transport, and biomass used for electricity generation. Electricity generation in the energy system expands greatly to service a growing use of electric heating in the residential and services sectors, as well as the domestic private car fleet.

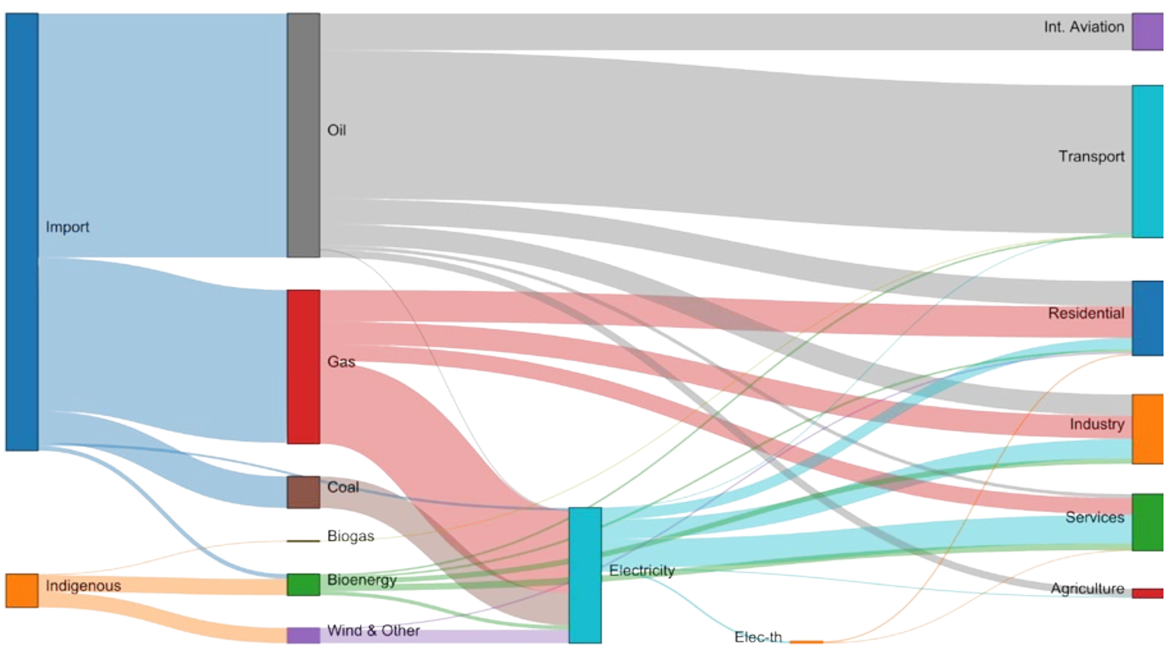

FIGURE 4-4: 2050 SANKEY DIGRAM FOR ENERGY SYSTEM UNDER BUISNESS AS USUAL SCENARIO

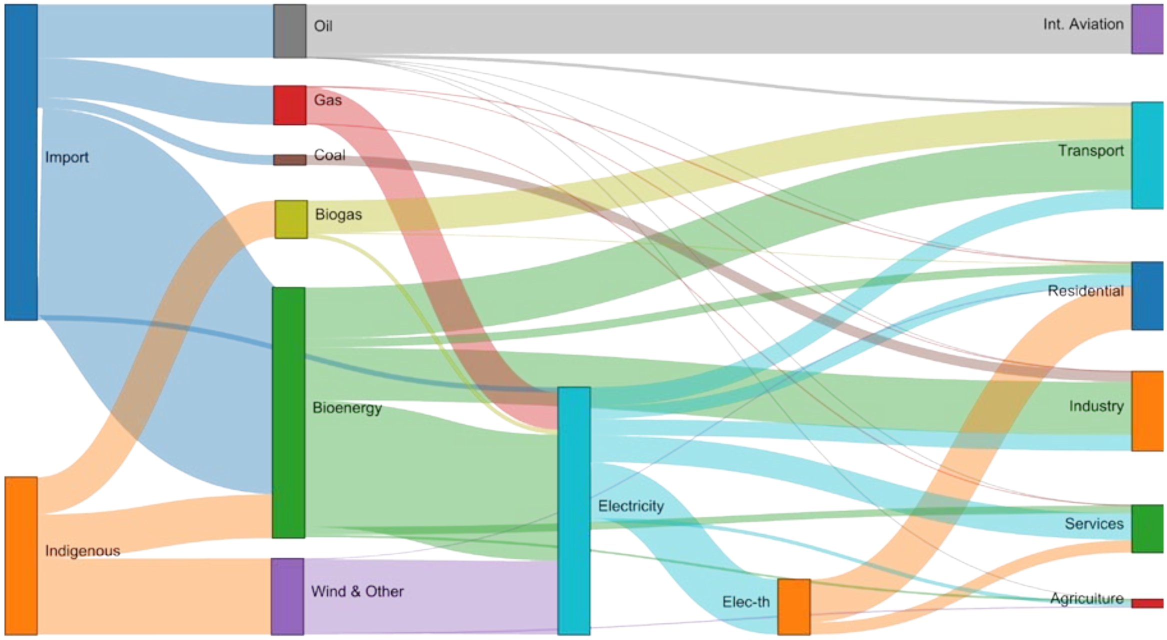

FIGURE 4-5: 2050 SANKEY DIGRAM FOR ENERGY SYSTEM UNDER 95% CO2 REDUCTION SCENARIO

4.2 ENERGY EFFICIENCY

Energy savings are quantified in the model as a reduction in final energy consumption as compared to the BAU scenario. The BAU scenario does not assume any technology improvements over the time horizon to 2050 and is therefore a counterfactual against which the other scenarios can be compared. Note that figures quoted for final consumption do not include international aviation unless otherwise stated. International aviation is approximately 1,590 ktoe)

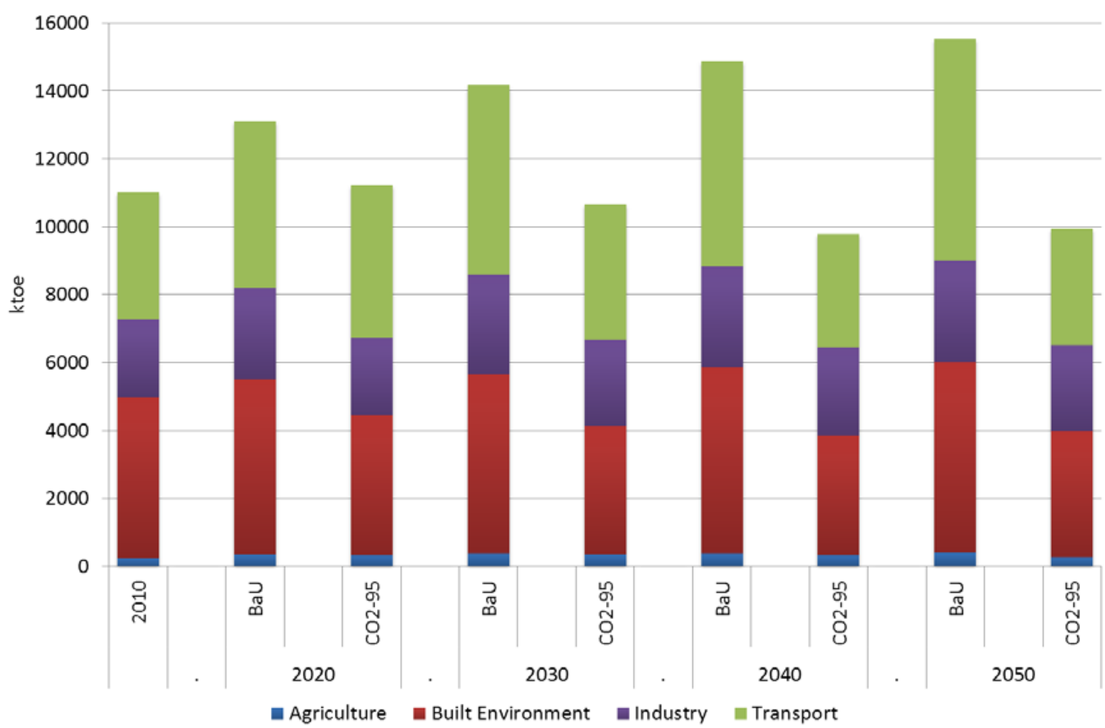

FIGURE 4-6: FINAL ENERGY CONSUMPTION BY SECTOR FOR BAU AND 95% REDUCTION SCENARIO

The BAU scenario in 2050 shows that the total final consumption of energy in 2050 is 15,522 ktoe. This is an increase of approximately 30% on 2010 levels. In the 95% CO_2 reduction scenario total final consumption reduces to 9,928 ktoe with the largest absolute reductions (as compared to BAU 2050 scenario) seen in the built environment (1,892 ktoe) and the transport sector (3,110 ktoe).

4.3 RENEWABLE ENERGY

This section details the modal results for renewable heat, transport and electricity from the energy system cost optimal analysis for the BAU scenario and the 95% CO_2 emissions reduction scenario. Note values below are presented in ktoe for the year 2050 unless otherwise specified.

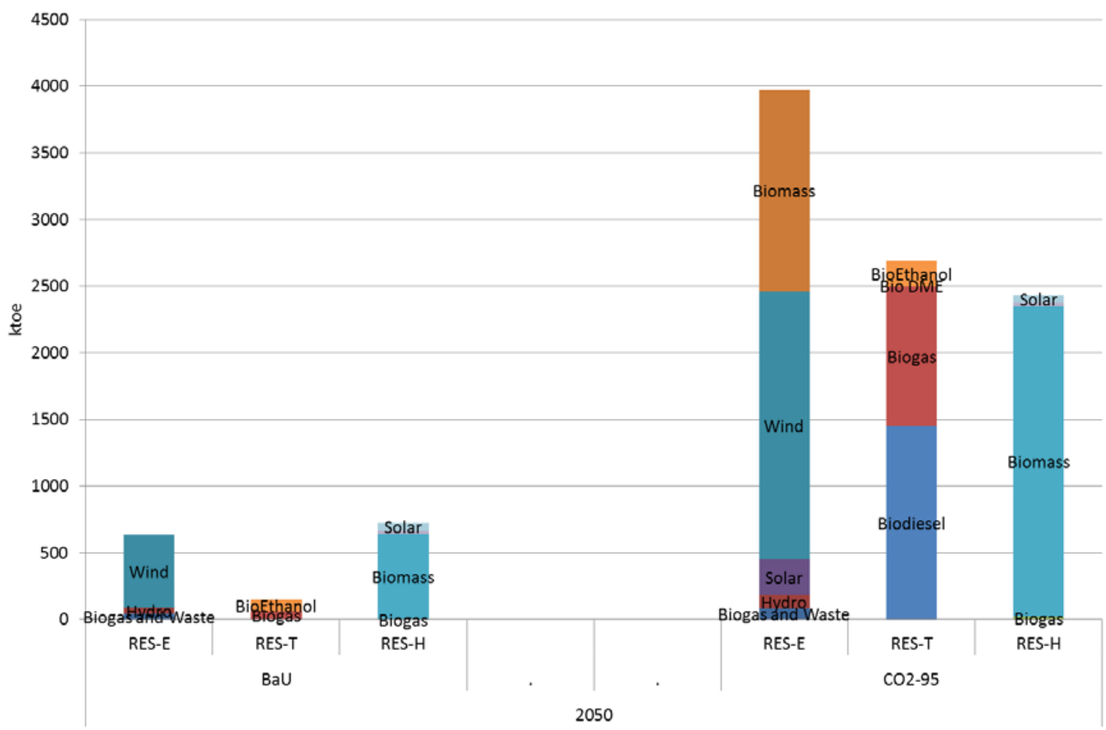

FIGURE 4-7: RENEWABLE ENERGY FOR BAU AND 95% REDUCTION SCENARIO AND BY MODE OF ENERGY

4.3.1 RENEWABLE HEAT-THE YEAR 2050

Renewable heat supplied by bioenergy grows to a penetration level of 24% (2,340 ktoe) of total final consumption for the 95% reduction scenario. This is compared to 5% (724 ktoe) in the business as usual scenario.

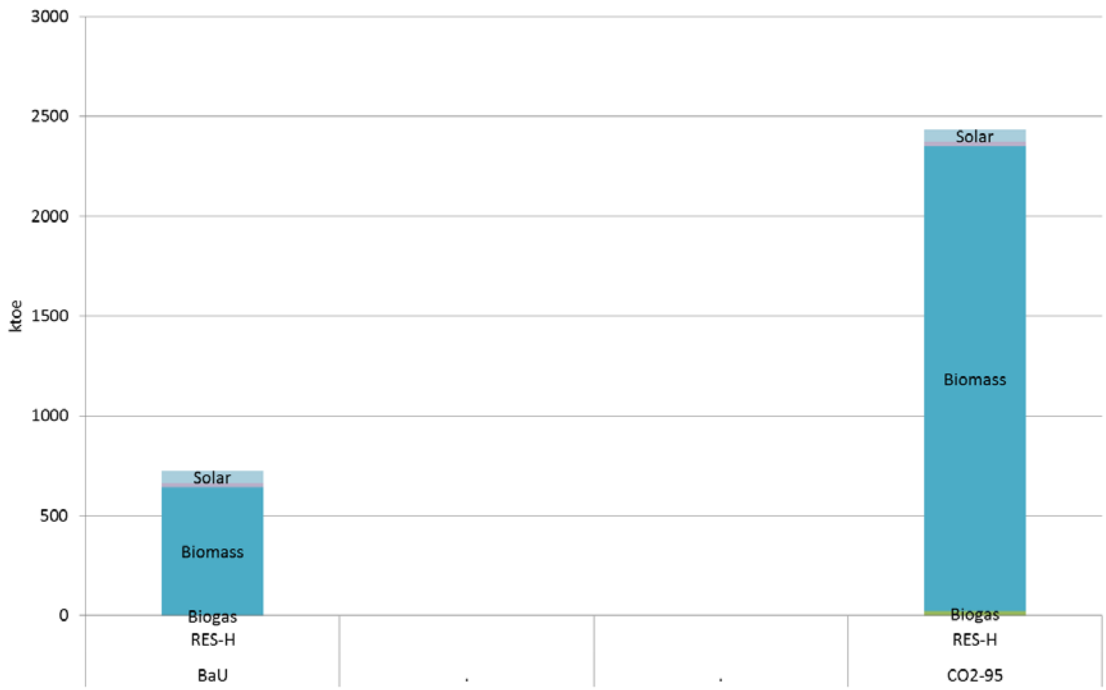

FIGURE 4-8: RENEWABLE HEAT FOR BAU AND 95% EMISSIONS REDUCTION SCENARIOS

The 95% CO_2 reduction scenario sees a much strong demand for renewable heat in relative terms and reaches 85% of total final consumption of heat. Imports of biomass increase by over a factor of three driven primarily by a need to produce low carbon electricity. This scenario sees a much stronger electrification of residential heat with over a 300% increase in supply of heat to the sector compared to the 80% reduction scenario. This has the impact of increased demand for electricity capacity in the power sector and the greater requirement for increased renewable electricity generation.

The model does not currently consider district heating systems

4.3.2 Renewable Transport-The year 2050

In 2050 Renewable Transport in the form of Bioenergy and Electricity grows to a penetration of 94% in the 95 % reduction scenario. This is in contrast to 3% in the BAU scenario. Total final consumption for the sector is approximately 46% lower in the reduction scenarios (compared to the BAU scenario) due to technology switching, efficiency improvements and a reduction in

demand due to demand response. Bioliquids are used in the freight and public transport while electricity is used in private transport and small amounts in public transport.

FIGURE 4-9: RENEWABLE TRANSPORT FOR BAU AND 95% EMISSIONS REDUCTION SCENARIOS

4.3.3 RENEWABLE ELECTRICITY-THE YEAR 2050

The demand for electricity in 2050 is higher in the 95% mitigation scenario compared to the BAU scenario. The increase in demand for electricity is driven by natural growth, a strong increase in demand for electric heating in the residential and services sector and an increased demand for electricity in private transport.

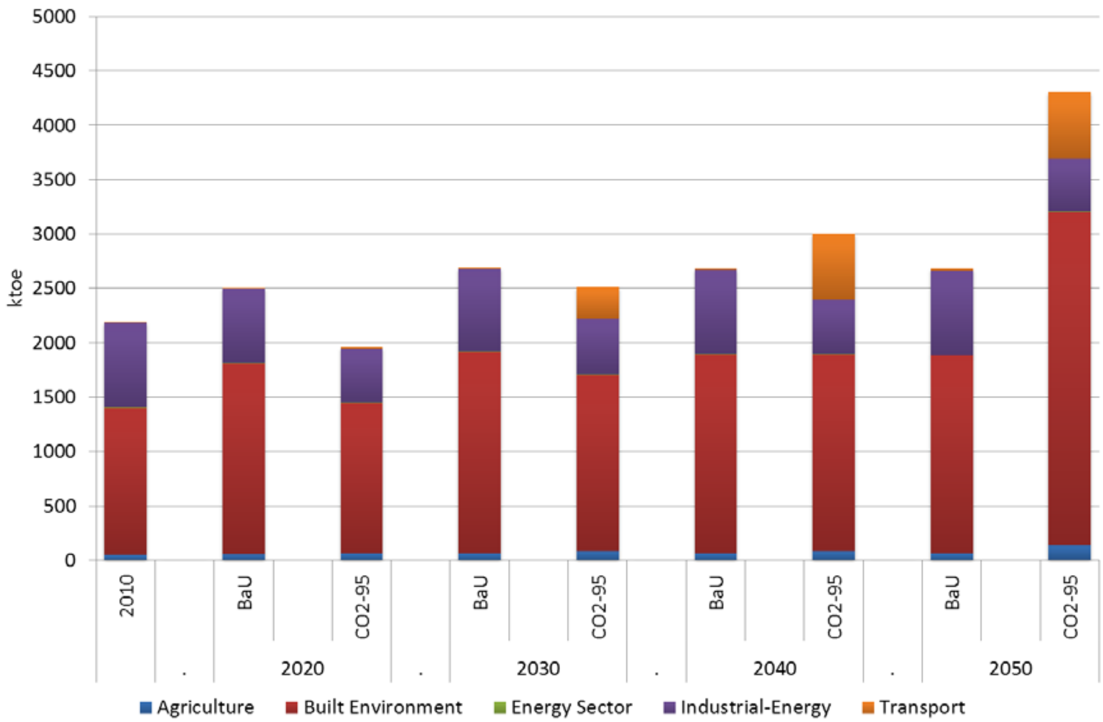

FIGURE 4-10: ELECTRICITY (RENEWABLE AND CONVENTIONAL) CONSUMPTION BY SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIO

In 2050 the electricity demand is 4,308 ktoe [50 TWh] for the 95% CO_2 reduction scenario. In the 95% reduction scenario all of the available 6.9 GW onshore wind resource is exploited and the remaining requirement for energy is provided by offshore wind, biomass fired plant and a contribution from solar. In 2050 the CO_2 intensity of the power system under a BAU scenario is 459 gCO2/kWh which is just over 2010 levels at 528 gCO_2\kWh. The carbon intensity of the power system under this carbon reduction scenario is 7 gCO_2\kWh .

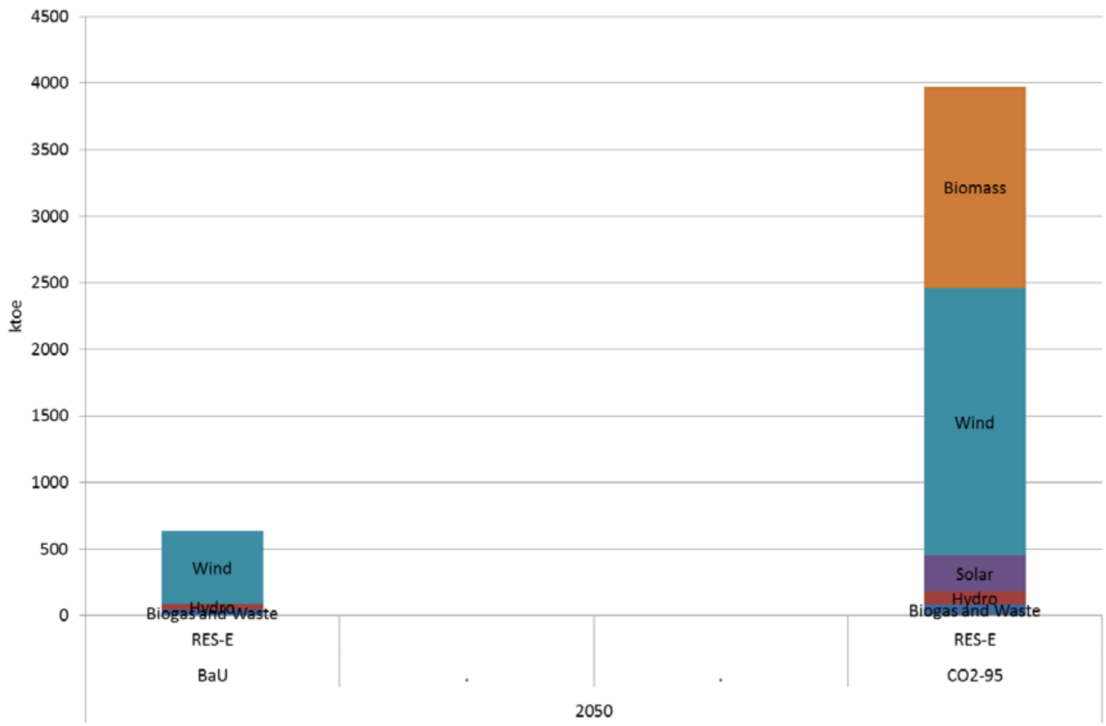

FIGURE 4-11: RENEWABLE ELECTRICITY FOR BAU AND 95% REDUCTION SCENARIO

The 95% CO_2 reduction scenario sees a marked increase in demand for electricity as the more binding CO_2 constraint drives an increase in electric heating. Under this scenario the model exploits 2 GW (440 ktoe) of the offshore wind resource and almost 4 GW (263 ktoe) of solar energy. Also because of the constraints on instantaneous penetration of wind generation and very strong CO_2 reduction targets the model exploits thermal power plant using wood fuel to meet the extra demand in electricity. Gas CCS does not come through in this emission reduction scenario as the residual emissions are too high.

4.4 GAS, ELECTRICITY, SOLID AND LIQUID FUELS

As CO_2 constraints are applied to the energy system two common pathways to decarbonisation emerge, one of electrification where a greater portion of the energy system switches to electricity as a primary fuel and another of gasification where the use of gas becomes more common in different sectors of the energy system. These two themes are presented and discussed below along with a discussion of the impact on solid and liquid fuels.

4.4.1 ELECTRIFICATION

The demand for electricity in 2050 is approximately 100% higher than 2010 levels for the 95% CO_2 reduction scenario.

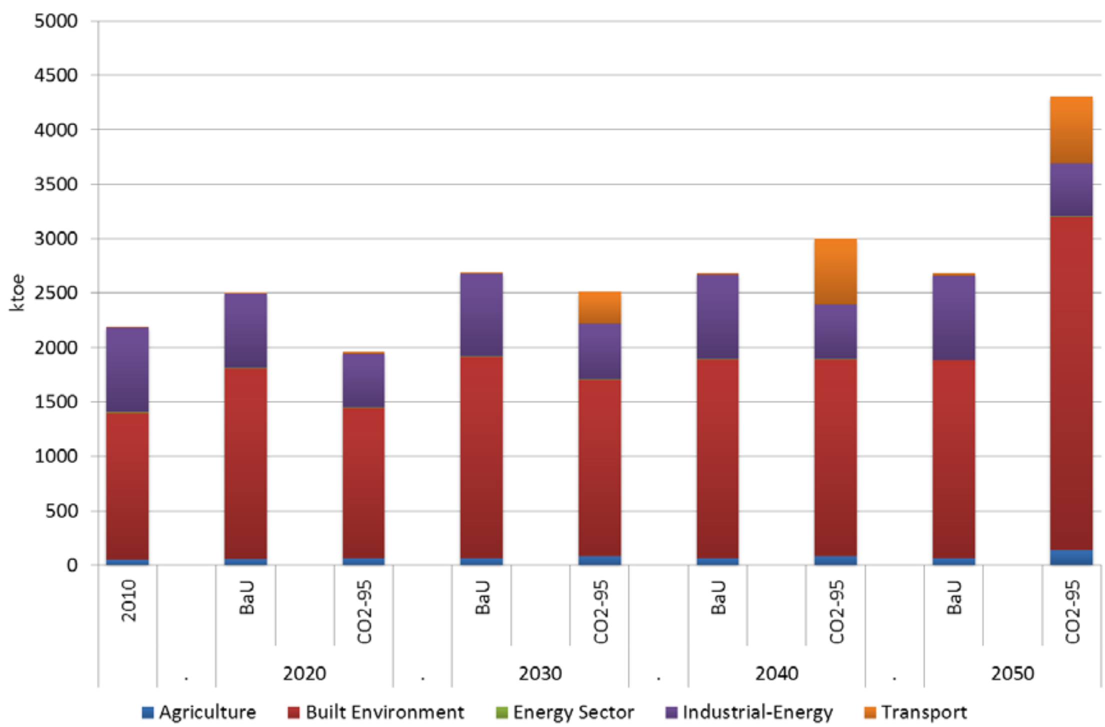

FIGURE 4-12: ELECTRICITY CONSUMPTION BY SECTOR FOR BAU AND 95% REDUCTION SCENARIO

The growth of electricity within each sector of the energy system is varied. In absolute terms the largest growth is in the built environment with almost 1,246 ktoe of extra demand for electricity. This is driven by a very strong demand for electric heating replacing gas fired boilers.

4.4.2 Gasification

As the energy system trends towards a 95% CO_2 emission reduction, natural gas plays a diminishing role in the energy system as its associated emissions are too high.

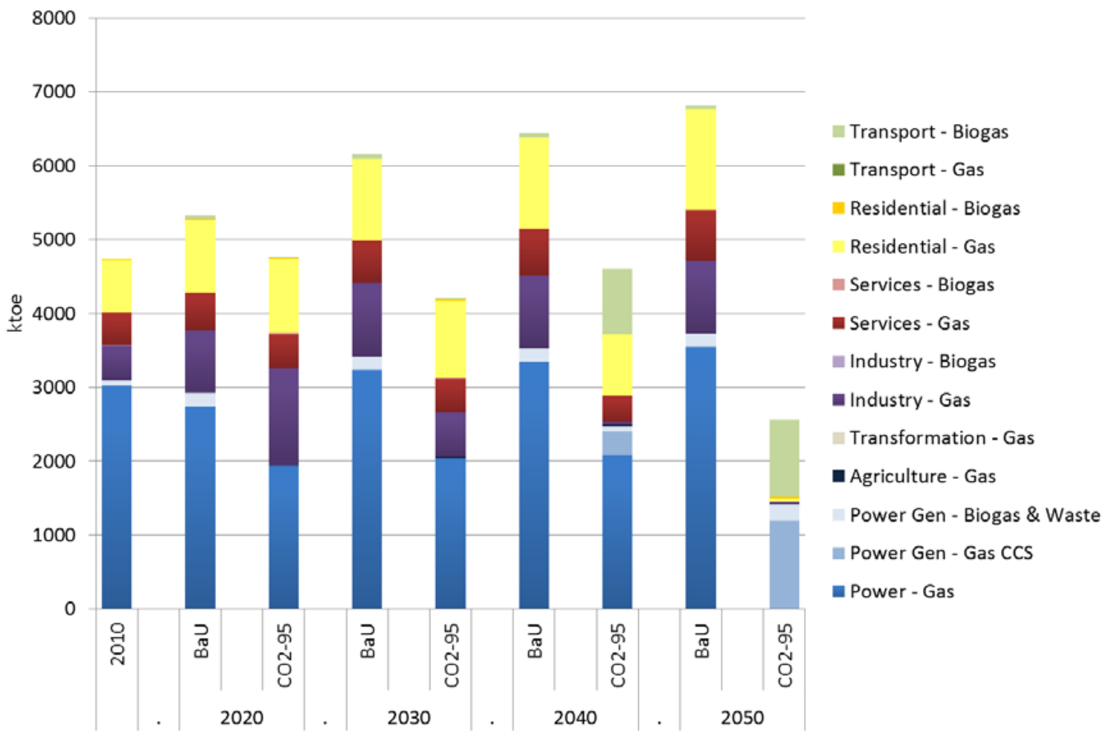

FIGURE 4-13: GAS USAGE BY SECTOR AND TYPE FOR BAU AND 95% REDUCTION SCENARIO

In the 95% CO_2 reduction scenario the residual emissions from gas CCS exclude it from being in the cost optimal energy system solution and gas usage in electricity generation drops to 1,417 ktoe.

4.4.3 Solid Fuels

In the 95% CO_2 mitigation scenario, coal and peat are almost completely removed from the energy mix replaced in part by biomass both indigenous and imported.

4.4.4 Liquid Fuels

Oil in 2050, except for use in international aviation (1,539 ktoe), is also almost removed from the energy mix and is replaced by bioliquids such as ethanol and biodiesel. Oil reduces from 58% of

final consumption in 2050 in the BAU scenario to 2% in the 95% CO_2 reduction scenario. Kerosene and diesel oil which are traditionally used in Ireland for home heating are replaced by electric thermal heating, biomass heating and increased use of gas for home heating. Diesel and petrol see a sharp decline in use from 2030 onwards in the transport sector being replaced by electricity for private transport and bioliquids for freight transport.

4.5 IMPORT DEPENDENCY

Energy dependence, as defined as the ratio of imported energy to primary energy consumption, decreases from approximately 91% in the BAU scenario to 64% in the 95% CO_2 reduction scenario. A strong import dependence on imported bioenergy such as biomass and bioliquids emerges in the 95% CO_2 reduction scenario.

4.6 SECTORAL RESULTS

This section presents detailed results for each of the sector of the energy system for BAU and 95% CO_2 reduction mitigation scenarios.

4.6.1 RESIDENTIAL SECTOR

The residential sector see a growth in population and dwellings out to the year 2050, over this period new building regulations and energy efficiency measures will see a reduction in the energy demand per dwelling. A reduction of approximately 30% in final energy demand is seen compared to the BAU scenario for the 95% CO_2 reduction scenario. The number of dwellings in 2050 grows to 2.3 million. The trajectory to 2050 shows that use of coal and peat decline and are removed from the residential fuel mix as the CO_2 emissions associated with these fuels are too high. As the percentage of coal and peat drop, renewables such as woody biomass (in rural dwellings) and biogas comes into the mix and start to build from 2020 to 2050. Electric heating, primarily in the form of heat pump technologies, develop strongly in the residential sector post 2030.

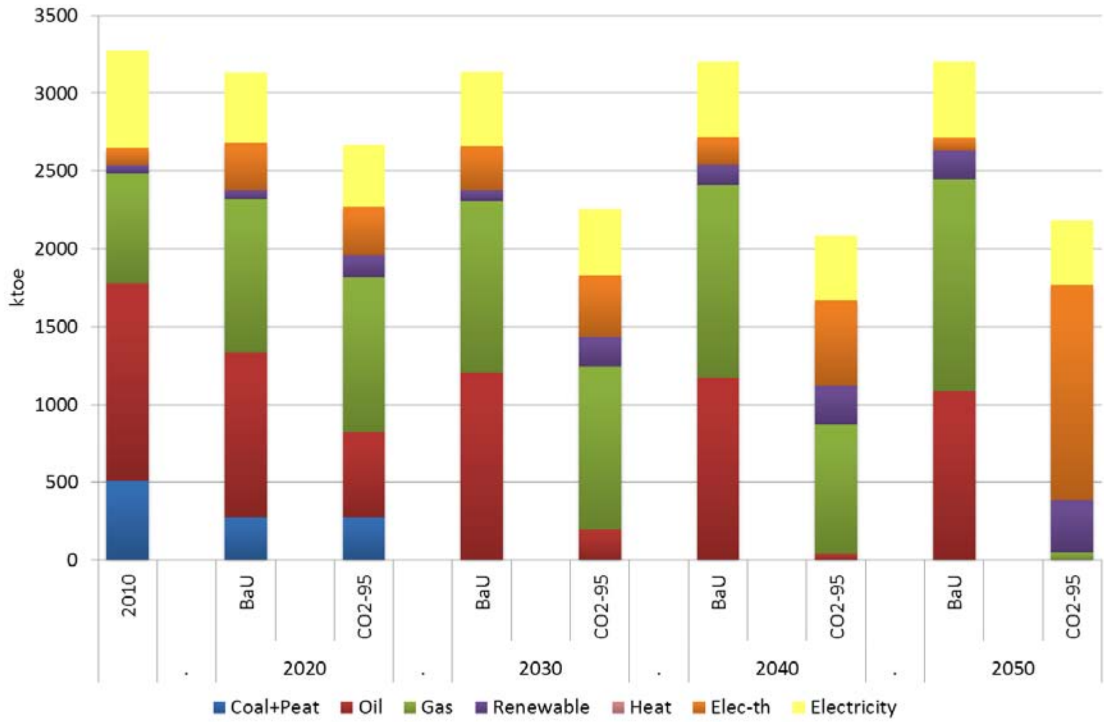

FIGURE 4-14-ENERGY COMSUMPTION IN THE RESIDENTIAL SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIOS BY FUEL TYPE

4.6.2 SERVICES SECTOR

Final energy demand in the Services Sector is approximately 36% lower in the CO_2 reduction scenario compared to the business as usual scenario. Similar to the residential sector, the service sector sees a phasing out of oil use and an increased uptake in renewables such as biomass and biogas. The 95% CO_2 reduction scenario sees gas usage being replaced by a much greater use of electricity and electric heating.

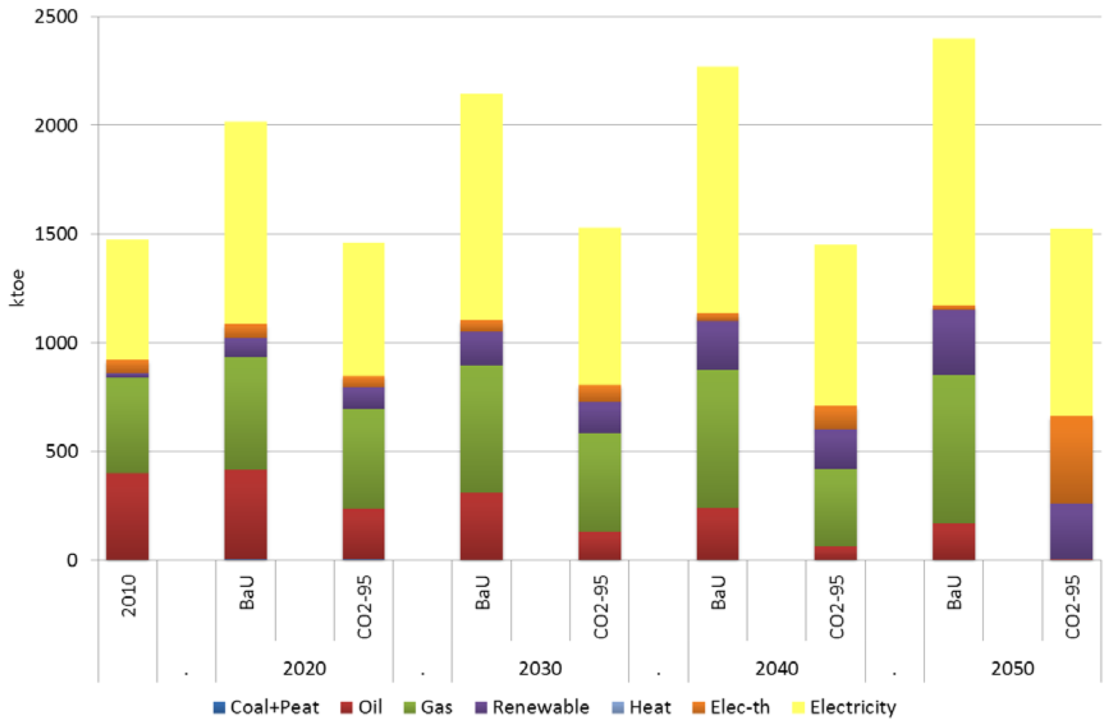

FIGURE 4-15-ENERGY COMSUMPTION IN THE SERVICES SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIOS BY FUEL TYPE

4.6.3 TRANSPORT SECTOR

The transport sector sees a strong reduction (approximately 47%) in energy use in 2050 in the CO_2 reduction scenario compared to the BAU scenario. Diesel is the primary fuel used in transport out to the year 2030, thereafter it is replaced by renewables such as biodiesel and bioethanol.

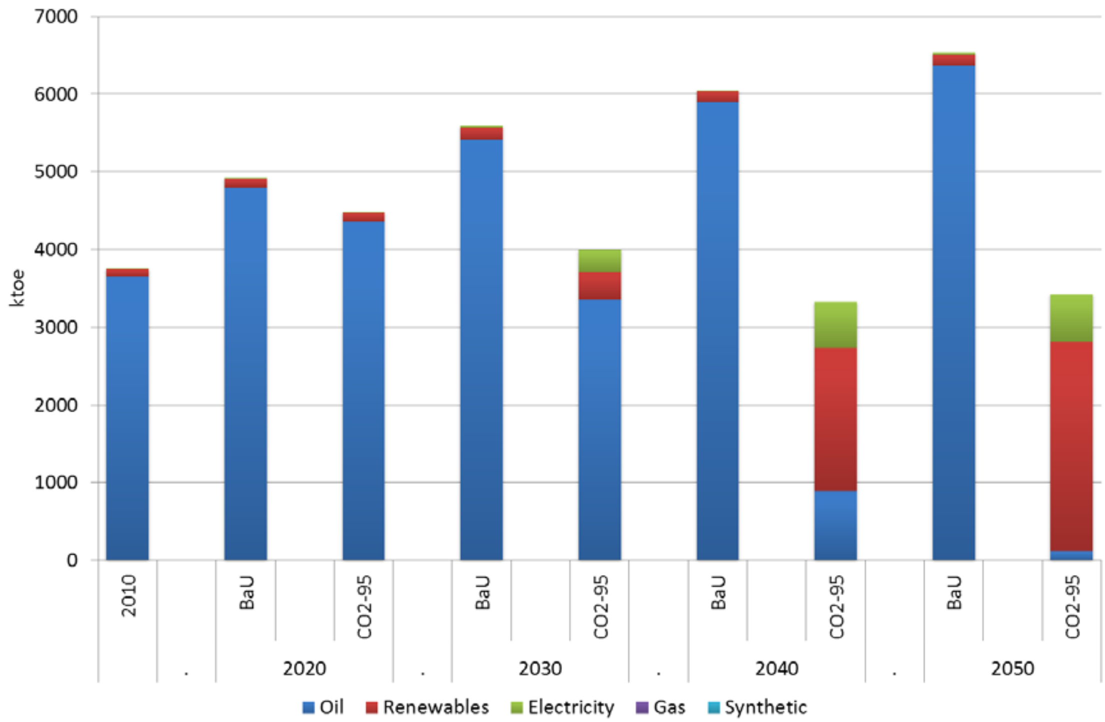

FIGURE 4-16-ENERGY COMSUMPTION IN THE TRANSPORT SECTOR FOR 2 SCENARIOS BY FUEL TYPE

In the 95% reduction scenario electric vehicles appear in the energy mix in 2030 and by 2050 all the private car fleet (approximately 3 million vehicles) is electrified in both scenarios. Freight transport which cannot be electrified is fuelled by biogas (725 ktoe) and the remainder is supplied by ethanol (781 ktoe) and diesel (208 ktoe).

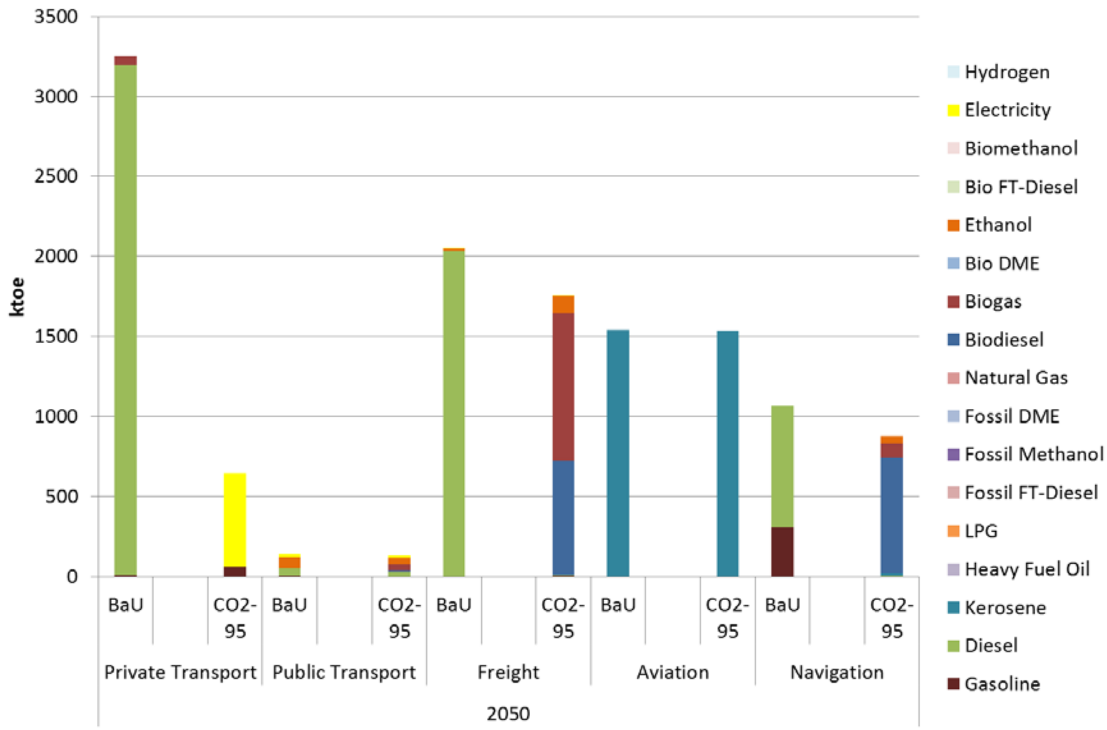

FIGURE 4-17- DETAILED BREAKDOWN OF ENERGY COMSUMPTION IN THE TRANSPORT SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIO

4.6.4 Power Sector

The demand for electricity in 2050 is approximately 100% higher than 2010 levels (SEAI 2010 EB 2080 ktoe) for the 95% CO_2 reduction scenario. This growth is due to the electrification of heat in the residential and services sector and also the electrification of the private car fleet. The power sector begins a strong decarbonisation trajectory and (similar to other sectors) coal and peat are dropped from the energy mix and the power system is mainly a dual-fuel system (gas and wind) in 2030.

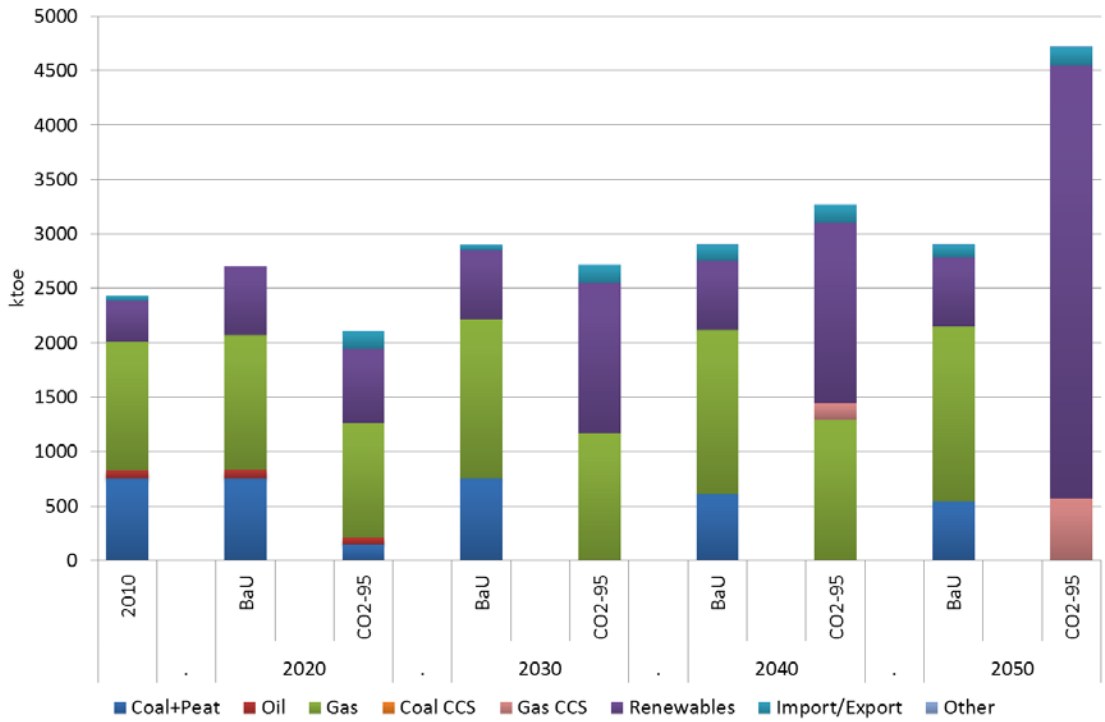

FIGURE 4-18-ENERGY COMSUMPTION IN THE POWER SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIO BY FUEL TYPE

The power system is constrained to limit wind to 70% instantaneous penetration and 50% annual yield. In the 95% CO_2 reduction scenario a small amount of gas CCS can be accommodated as the residual CO_2 emissions make it incompatible with a low carbon solution. In this scenario biomass fired thermal generation is required producing 1,513 ktoe of electricity. In 2050 the available onshore wind resource (6.9 GW) is exploited and in the 95% reduction scenario other renewables such as offshore wind and solar appears in the generation mix.

4.6.5 INDUSTRY

The industrial sector sees a modest increase in final energy consumption in 2050 in all scenarios compared to 2010 levels of 2,280 ktoe. The 95% CO_2 reduction scenario shows a relative reduction of 16% against the BAU 2050 scenario. Industry has a large thermal requirement which is met predominantly by woody biomass.

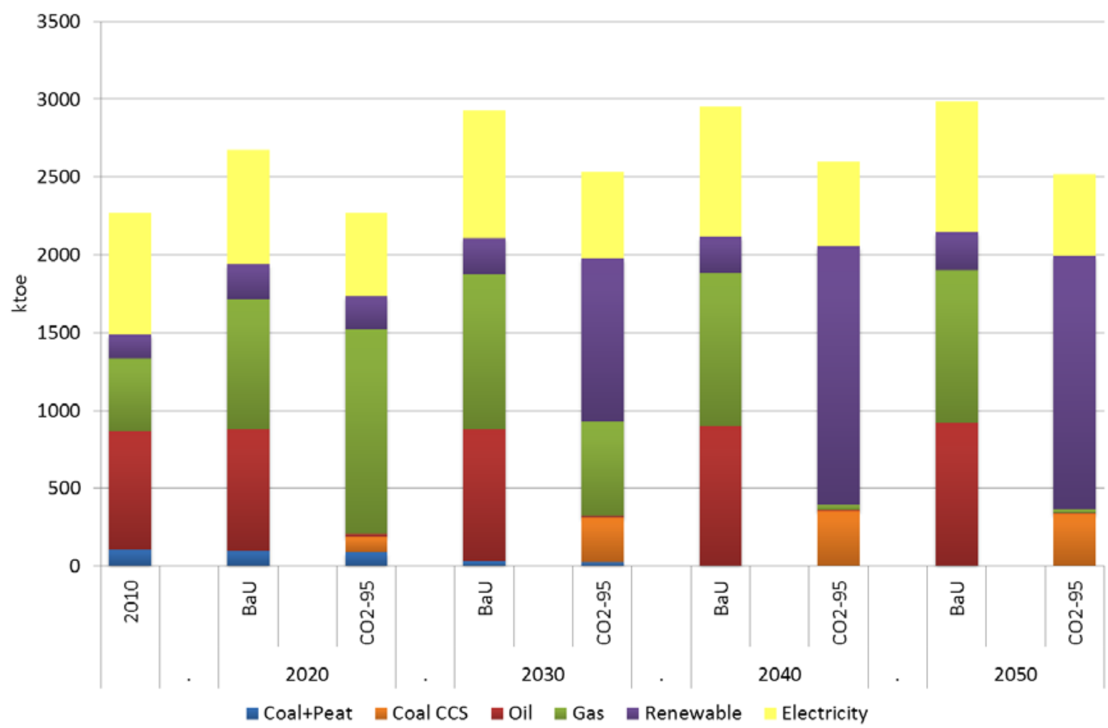

FIGURE 4-19: ENERGY COMSUMPTION IN THE INDUSTRIAL SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIO BY FUEL TYPE

4.7 ENERGY INFRASTRUCTURE

To achieve the 2050 targets the analysis suggests that there will be dramatic changes in the quantities of fuels consumed, for instance, the decline of oil and gas in the residential sector and the expansion in biomass fuels, as well as the electrification of energy demand in both the residential and services sectors. Large scale fuel switching is not without potential significant implications for associated infrastructures, both private and publicly owned.

4.7.1 GAS

The BAU scenario sees in excess of 70% growth in sector wide (non-electricity generation) natural gas consumption by 2050, with expansion in demand coming from the residential, services and industry sectors. In the 95% CO_2 reduction scenario the residual emissions from gas CCS exclude it from being in the cost optimal energy system solution and gas usage in electricity generation drops to 1,417 ktoe.

4.7.2 Biomass

The use of biomass fuels is anticipated to grow dramatically in the years to 2050. It is envisaged that the majority of biomass fuels will be wood based (e.g. wood chips) and while a growth in indigenous supplies is envisaged, some 60% will need to be imported. The use of indigenous biomass is projected grow rapidly. In 2011 wood fuel production from Irish forestry totalled 0.9 million cubic metres (Kent (2012)[15]).

- In the decade to 2030 it is projected that imports of biomass will increase substantially, totalling almost 5 million cubic metres (which is more than 4-fold current wood fuel production from Irish forestry) under the low carbon scenarios.

- This has potential implications for the state's ports, whether they have sufficient capacity, including for bulk storage. By 2030 biomass imports could be equivalent to roughly a 60,000 tonne ship per fortnight rising to a shipment per week in 2050. Under the CO2-95 scenario biomass imports of 3-4 60,000 tonne shipments per week are projected by 2050.

- The two primary destinations for biomass are in the residential sector and in power generation. Distribution to the residential sector will occur through normal distribution channels. The location of biomass fuelled power generation plants will significantly affect the number of associated traffic movements. To minimise the impact on the road network it would be preferable if new-build biomass power plants are located proximate to a sea port.
- While air borne particulate matter is not a major concern for air quality at present, the growth in the use of bio-mass fuels, particularly in the residential sector, could be an issue of concern in the future. Any measures to increase the use of biomass fuels will need to be mindful of potential air quality issues.

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[15] Kent, T. 2012. Use of wood for heat in buildings in Ireland, UCD Earth Institute-NESC Workshop, 16 May 2012

4.7.3 BIOFUELS

The use of biofuels (mostly as transport fuels) is anticipated to increase under both the BAU and low carbon scenarios. Under the BAU scenario the growth is relatively modest whereas the dramatic increase in the implicit price of carbon under the CO_2-95% scenario drives very strong levels of bioenergy use. However, it is envisaged that roughly 50% of consumption levels in 2050 will be from imports.

- The expansion in liquid biofuel imports will offset the decline in imports of conventional mineral oil fuels. Accordingly there should not be any significant impact for the infrastructure and distribution network for transport fuels.

PART IIIB: IMPLICATIONS FOR THE ECONOMY: 95% CO2 EMISSIONS REDUCTION SCENARIO

5 MACRO-ECONOMIC IMPLICATIONS OF DECARBONISATION

5.1 COMPETITIVENESS

As mentioned previously, the current modelling framework does not incorporate a feedback mechanism between the developments in the energy system (i.e. Irish TIMES) and the wider economy (i.e. HERMES macroeconomic model). It is therefore only possible to discuss competitiveness issues in a general context, as was the case in the discussion of the CO_2-80 scenario earlier. That earlier discussion is also relevant under the CO_2-95 scenario but is not repeated here.

The implicit carbon price associated with the CO_2-95 scenario is shown in Table 11 and envisages the cost of carbon (priced in € per tonne of carbon dioxide) rising to almost €1800/tonne by 2050.

TABLE 11: IMPLICIT CARBON DIOXIDE PRICES, CO2-95 SCENARIO, - 2010 PRICES

	2020	2030	2040	2050
All emissions, €/tonne	74	90	318	1799

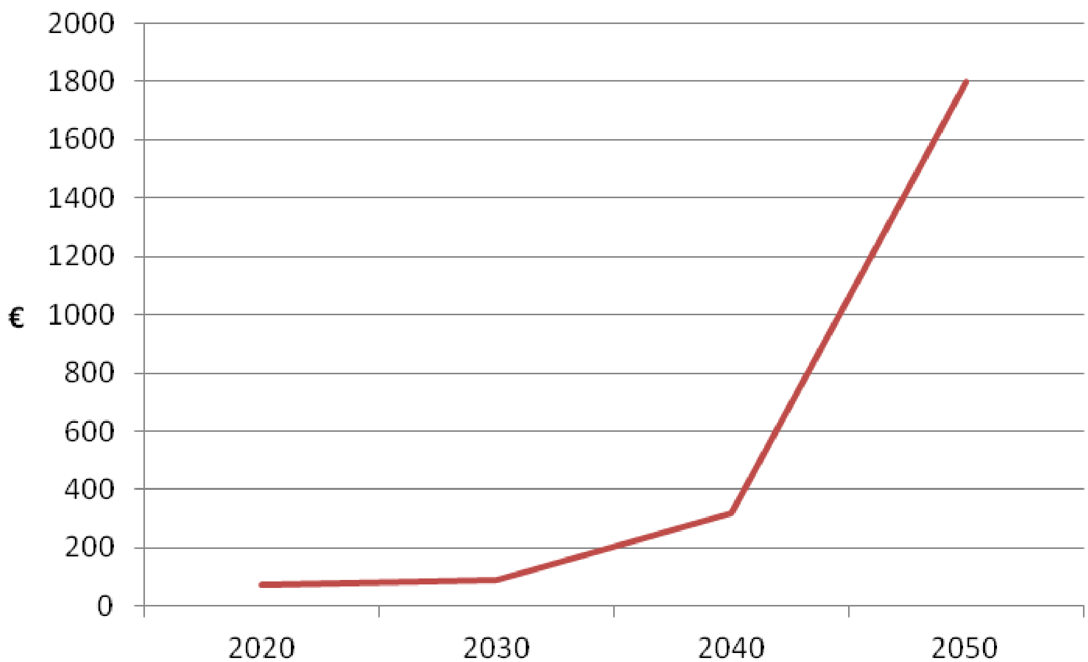

FIGURE 5-1: IMPLICIT CARON PRICES UNDER SCENARIO CO2-95, €2010/TONNE

For illustrative purposes it is useful to see what this profile of carbon prices will mean for oil prices. The CO_2 ultimately emitted from a barrel of oil will vary by type of crude oil and depend on the types of refined products. For these calculations we assume that the combined liquid fuels from an average barrel of crude oil will produce a minimum of 317kg of CO_2 when consumed.[16] In 2013 carbon costs represent approximately 7% of the total price of oil (see Table 12). In 2050 under scenario CO_2-95, carbon costs would represent 85% of the total share oil costs. Figure 5-2 shows that the increase in the price of oil will be significant under the CO_2-95 but relatively muted compared to the increase in the cost of carbon (almost 90-fold increase in price compared to today). Oil prices in 2050, including carbon costs, will be almost 8 times today's price.

[16] "Carbon dioxide emissions per barrel of crude", The Quiet Road, Jim Bliss, http://goo.gl/iPuDME

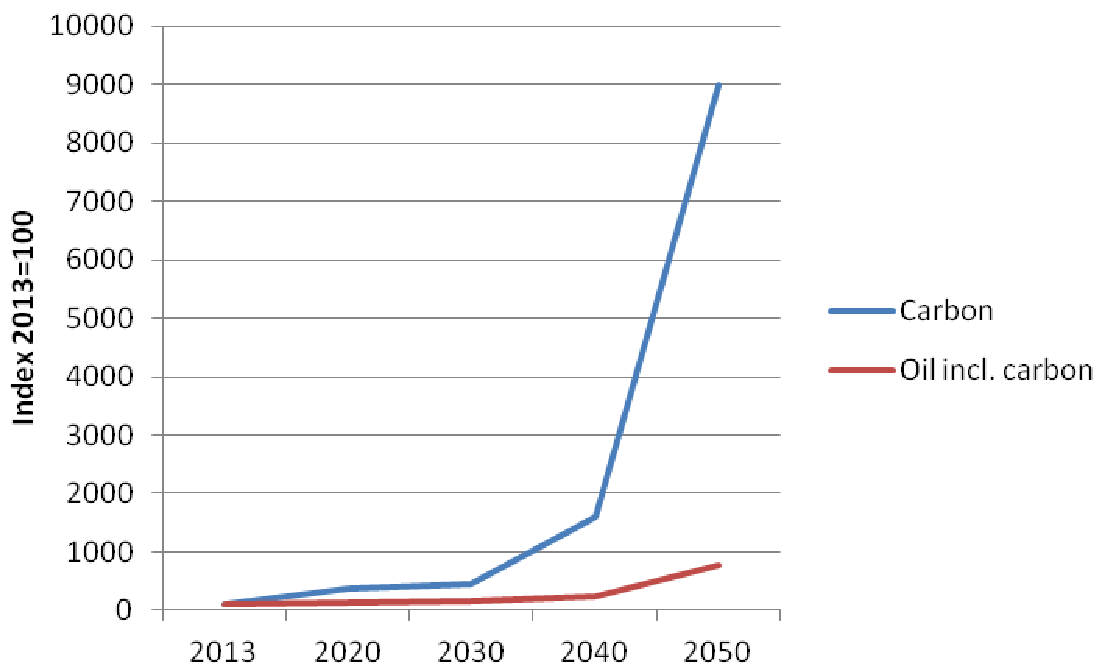

FIGURE 5-2: INDEX OF CARBON AND OIL PRICES, 2013=100

It is through higher real oil prices (incl. carbon costs) that the primary impact of low carbon policies will impact economic activity. In the period to up to 2040 the analysis suggests that oil prices would increase by roughly between 2-4.5% on annum. On an annual basis this would be a substantial increase in costs. In the past decade real prices for gas, electricity and fuel oil prices in Ireland have increased by comparable amounts, an average of 3-4% per annum.[17] The carbon reduction ambitions under the CO_2-95 scenario are much more onerous (compared to CO_2-80) and the costs of reducing carbon from the economy escalate. By 2040 in scenario CO_2-95 all the 'easy' opportunities to remove carbon will have been exploited and the more expensive technologies and processes will be necessary to achieve the emissions reductions ambitions. The cost of carbon by 2050 is projected to reach almost €1800/tonne, with the knock-on effect on oil prices being roughly 13% annual growth post 2040. Price increases of this order in such a short period of time would have a detrimental impact on the economy, invariably causing substantial restructuring and associated effects.

[17] Nominal energy prices have increased by an average of 6-7% per annum.

TABLE 12. IMPACT ON OIL PRICES UNDER CO2-95

		2013	2020	2030	2040	2050
Real Oil Price[1]	€/barrel	80	82	99	99	99
CO2 price - CO2-95	€/tonne	20[2]	74	90	318	1799
CO2 price	€/barrel	6	23	28	101	570
Oil price (incl CO2)	€/barrel	86	105	128	200	670
Oil Cost Index - CO2-95	2013=100	100	123	149	233	780
Carbon as a share of oil price (incl. carbon)		7%	22%	22%	50%	85%
Annual average growth rate in oil price (incl CO2)			3%	2%	5%	13%
Average annual oil price growth rate (incl CO2), 2013-2050		5.7%				

[1] Based on MTR oil price assumptions 2020-30 and assumed real price unchanged to 2050

[2] Current carbon tax rate of €20/tonne

5.2 INVESTMENT IN ENERGY

Compared to the CO_2-80 scenario the level of investment required under the CO_2-95 scenario is substantially higher. Substantially more carbon must be eliminated requiring more abatement and utilising more expensive technology. But regardless of carbon targets significant levels of investment will be required in the coming decades in both energy generation and energy using infrastructure. Power generation plants, transport vehicles, heating boilers etc., with be upgraded or replaced. Depending on the carbon ambition and the cost of carbon which technologies is cost effective will vary. Both under the BAU and CO_2-95 scenarios energy system investment will increase on a per annum basis. Under the BAU investment levels begin to plateau beyond 2040 but continue to grow under CO_2-95, as shown in Figure 5-3. The level of additional investment gradually increases reaching approximately €5 billion per annum by 2050, with total investment costs under the CO_2-95 scenario reaching €16 billion per annum.

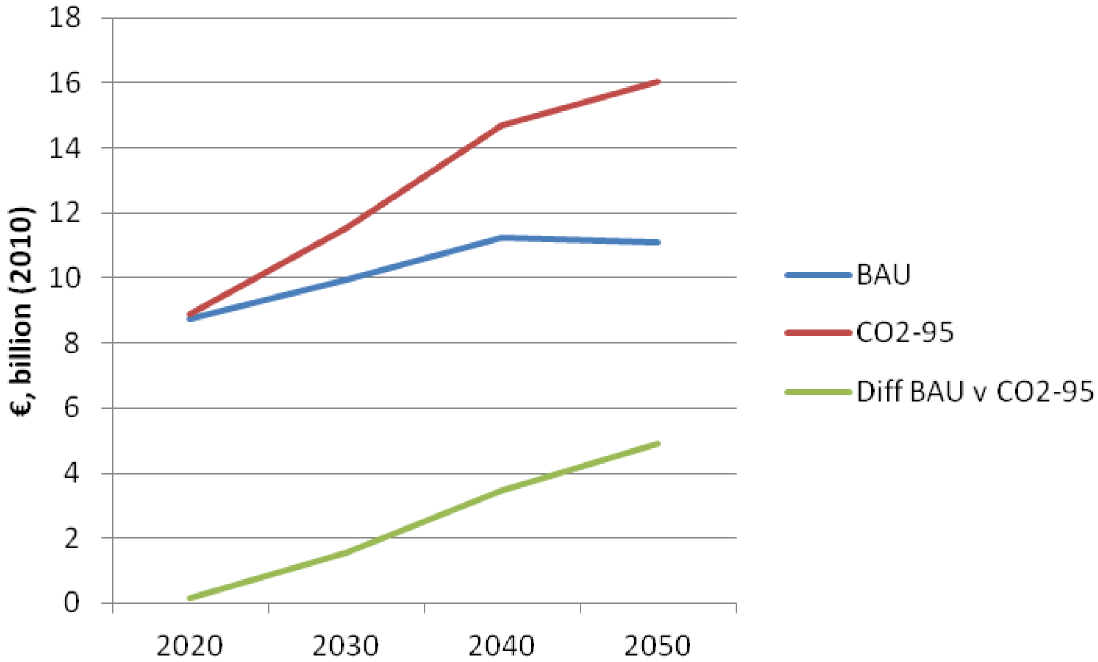

FIGURE 5-3: INVESTMENT UNDER BAU AND CO2-95 SCENARIOS

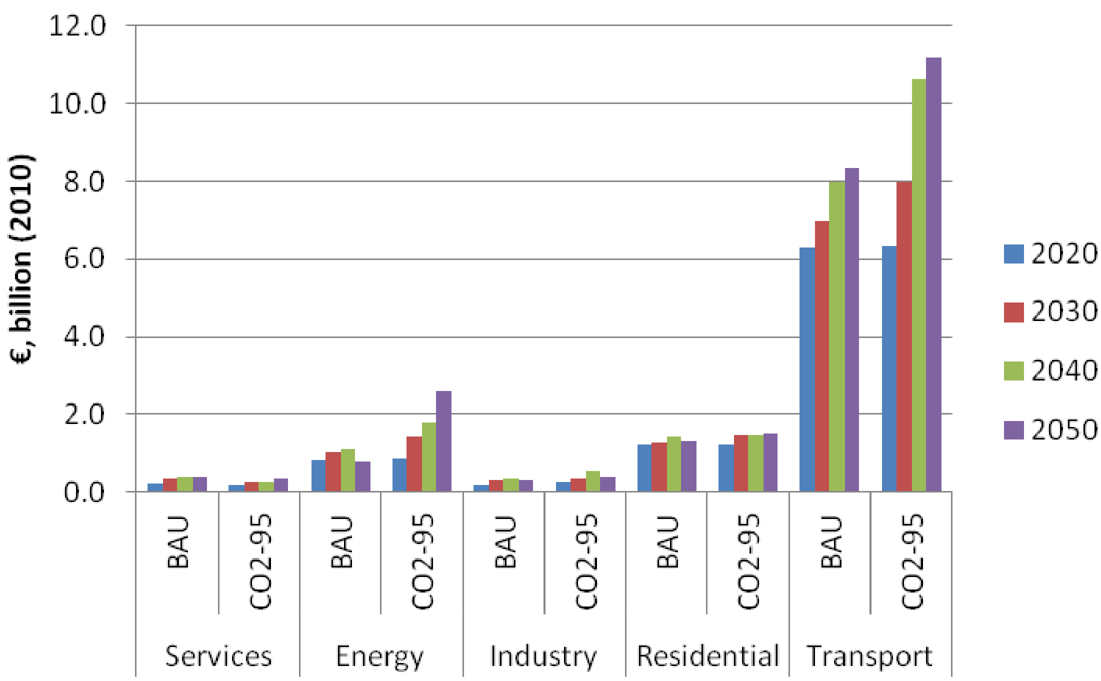

FIGURE 5-4: INVESTMENT BY SECTOR UNDER BAU AND CO2-95 SCENARIOS

At sector level, with the exception of the energy and transport sectors, annual investment under the BAU and CO_2-95 scenarios are broadly similar, thought generally higher under CO_2-95 scenario (see Figure 5-4). In both the energy and transport sectors investment under the CO_2-95 scenario is substantially higher than under BAU. Renewable transport in the form of biofuels and electricity grows to a penetration of 94% by 2050 requiring a significant investment in new equipment and infrastructure[18]. Most of the timing of the additional transport investment under the CO_2-95 scenario is delayed until 2040 and later. Though the scale of investment in the energy sector is significantly less on an annual basis than transport (e.g. roughly €6-8 billion less, see Table 13), the level of additional energy investment under the CO_2-95 scenario compared to the BAU is proportionately much greater. In the transport sector the additional investment under CO_2-95 scenario is at most one-third greater than the BAU level. In the energy sector in 2050 investment under the CO_2-95 scenario is over 3 fold the level under BAU.

TABLE 13. INVESTMENT BY SECTOR UNDER BAU & CO2-95 (BILLION, 2010)

Sector	Scenario	2020	2030	2040	2050
Services	BAU	0.2	0.3	0.4	0.4
	CO2-95	0.2	0.3	0.3	0.4
Energy	BAU	0.8	1.0	1.1	0.8
	CO2-95	0.9	1.4	1.8	2.6
Industry	BAU	0.2	0.3	0.3	0.3
	CO2-95	0.3	0.4	0.5	0.4
Residential	BAU	1.2	1.3	1.4	1.3
	CO2-95	1.2	1.5	1.5	1.5
Transport	BAU	6.3	7.0	8.0	8.3
	CO2-95	6.3	8.0	10.6	11.2

[18] Investment in the transport sector includes purchases of new bio-energy and electricity vehicles both for commercial and private use.

In many instances we associate low carbon or renewable energy fuel systems with a higher investment cost followed by lower fuels costs. For example, in solar and wind energy the fuels are free. At an aggregate level that becomes less so under the CO_2-95 scenario. As illustrated in Figure 5-5 fuel costs under the BAU and CO_2-95 scenarios are broadly similar in 2050, whereas investment costs are substantially higher in CO_2-95 versus BAU.[19] In 2050 aggregate investment and fuel costs are 20% higher under the CO_2-95 than BAU scenario.

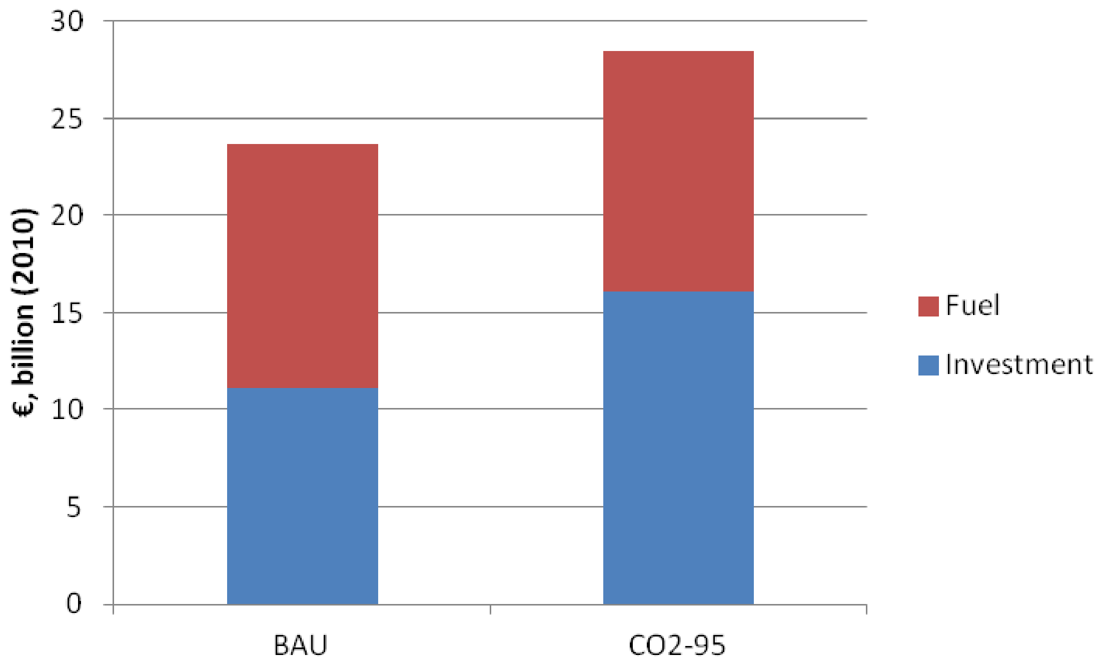

FIGURE 5-5: FUEL AND INVESTMENT COSTS IN 2050 UNDER BAU & CO2-95 SCENARIOS

5.3 ENERGY COSTS

Sector fuels costs are presented in Figure 5-6 and Table 14 but relate only to the energy component of fuel bills (incl. electricity) and exclude costs excise duties, PSO levies, and profit, which are normally incorporated in energy bills faced by households and businesses. In general across the sectors and under both scenarios, fuels costs are projected to increase. This reflects the underlying assumption of increases in service demand for heat, transport and electricity

[19] Aggregate fuel costs here exclude costs associated with fuel transformation and distribution, which are incorporated in the sector fuel costs presented later.

associated with a growing population and economy in the period to 2050. Figure 5-6 also illustrates two significant issues associated with the CO2-95 scenario. The first is the dramatic increase in fuels costs between 2040 and 2050, especially in the services, residential, transport and energy sectors. Energy costs in the services and residential sectors are projected to more than double between 2040 and 2050, whereas in the industry and transport sectors the increase is of the order of one-third. Such dramatic increases in fuel costs will negatively affect economic activity and competitiveness, as well as have significant welfare implications in the residential sector.

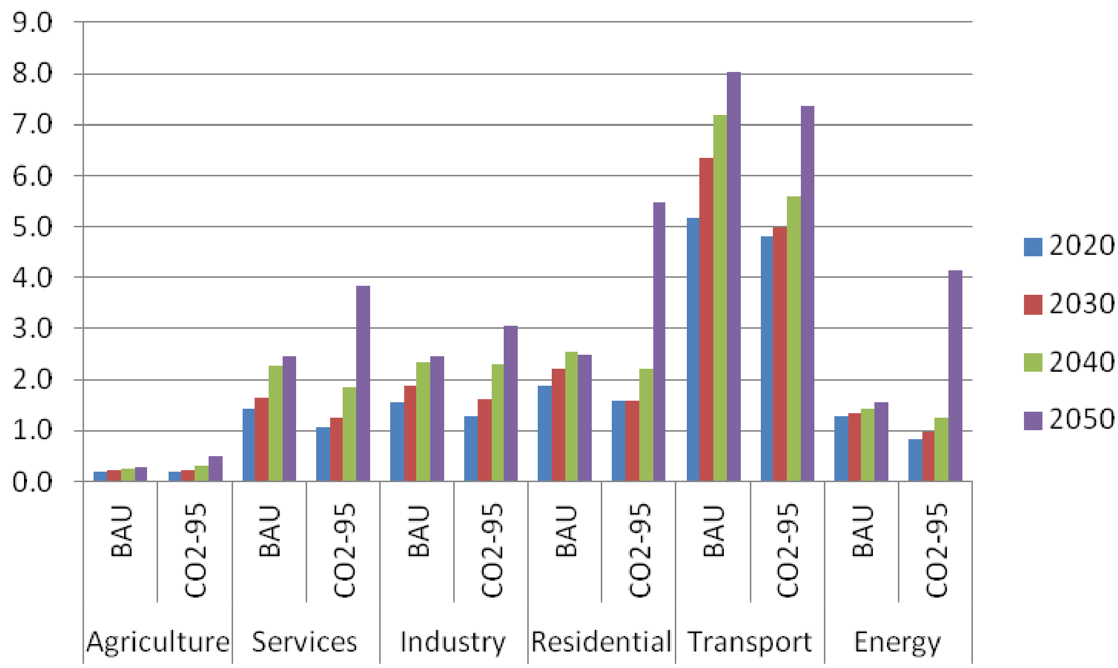

FIGURE 5-6: FUEL COSTS UNDER BAU & CO2-95 BY SECTOR

TABLE 14. FUEL COSTS BY SECTOR, BAU & CO2-95 SCENARIOS, €BILLION (2010)

Sector	Scenario	2020	2030	2040	2050
Agriculture	BAU	0.2	0.2	0.3	0.3
	CO2-95	0.2	0.2	0.3	0.5
Services	BAU	1.4	1.6	2.3	2.5
	CO2-95	1.1	1.2	1.9	3.8
Industry	BAU	1.5	1.9	2.3	2.5
	CO2-95	1.3	1.6	2.3	3.0
Residential	BAU	1.9	2.2	2.6	2.5
	CO2-95	1.6	1.6	2.2	5.5
Transport	BAU	5.2	6.3	7.2	8.0
	CO2-95	4.8	5.0	5.6	7.4
Energy	BAU	1.3	1.4	1.4	1.5
	CO2-95	0.8	1.0	1.2	4.1
Total	BAU	11.5	13.7	16.1	17.3
	CO2-95	9.8	10.6	13.5	24.4

One of the benefits of a switch to renewable fuels is the potential to reduce the country's dependence on imported fuels. Figure 5-7 clearly shows that under the CO_2-95 scenario fuel import costs will be substantially less than under BAU. The reduction in import fuel costs under CO_2-95 is due to an increase in domestic renewables such as wind and biomass that displace imported fossil fuels, as well as technological efficiency improvements that reduce the fuel requirement. However, import fuel costs increase post 2040 because domestic supplies of biofuels and biomass are exhausted (based on underlying assumptions on the resource) and need to be supplemented with imports, as shown in Figure 5-7. The modelling analysis assumes that there will not be a global shortage of biomass and biofuel resources.

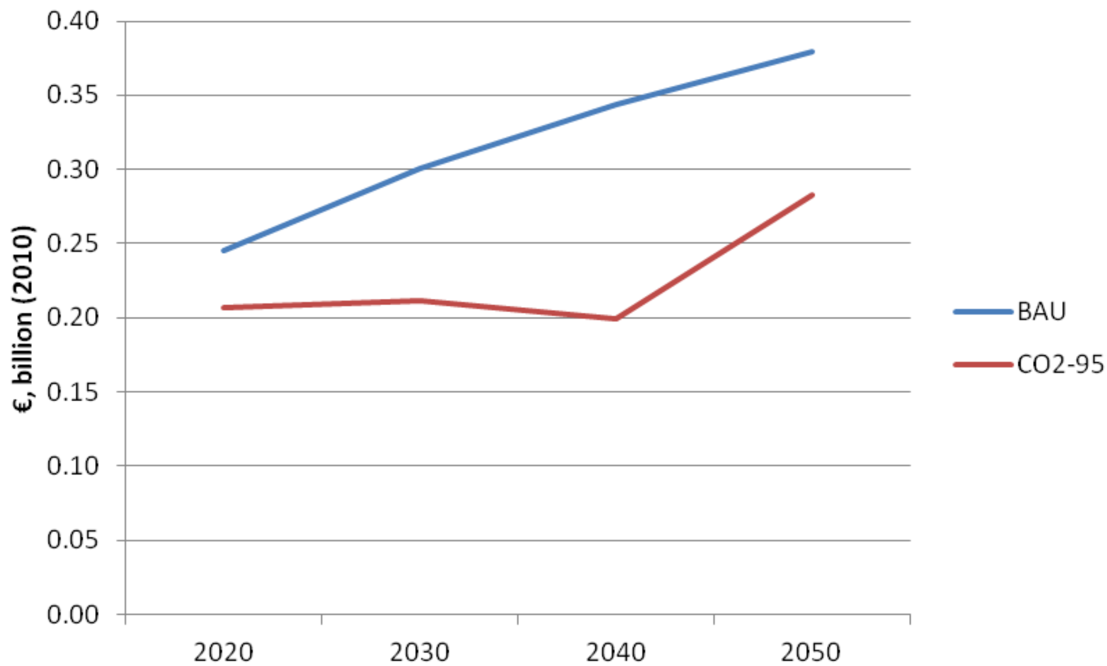

FIGURE 5-7: IMPORT FUEL COSTS UNDER BAU AND CO2-80 SCENARIOS

5.4 SUMMARY

It is not possible to project with certainty what the economic impact of low carbon on the economy will be. Nonetheless there are clear indicators that the economic impact under a carbon scenario similar to CO_2-95 have the potential to be quite severe. While the CO_2-95 scenario would present opportunities, given that much of the additional costs associated with such a low carbon scenario are both very large and concentrated in the period after 2040 the economic and social impacts would be significant and especially so without much time for businesses and households to adjust.

Under the CO_2-95 scenario the cost of carbon is projected to reach almost €1800/tonne by 2050, with the knock-on effect on oil prices being equivalent to roughly 13% annual growth post 2040. In 2050 combined investment and fuel costs are 20% higher under the CO_2-95 than BAU scenario. Cost increases of this order in such a short period of time would have a detrimental impact, invariably causing substantial restructuring and associated effects. Energy costs in the services and residential sectors are projected to more than double between 2040 and 2050.

Such dramatic increases in fuel costs will negatively affect economic activity and competitiveness, as well as have significant welfare implications in the residential sector.

The CO_2-95 scenario also assumes significant levels of additional investment to meet the carbon reductions ambitions, particularly so the in the transport and energy sectors. Investment in the energy sector in 2050 is over 3 times the level under the BAU scenario. The feedback from the rising carbon costs on the economy was not modelled but it is likely that economic growth would be impacted and the appetite for expanded levels of investment potentially undermined.

All scenario analysis is subject to uncertainty. The level of uncertainty inherent in the CO_2-95 scenario is substantially higher than under the two alternative scenarios examined. The large increase in carbon costs in the CO_2-95 scenario, with associated knock-on effects through the economy, would precipitate structural change in the economy. It is extremely difficult to envisage what that would mean for growth, incomes and employment. There are clear indicators that a strategy similar to the CO_2-95 scenario could have significant negative impacts but change also brings new opportunity. At this early stage is it impossible to determine likely outcomes. However, under such a scenario it is clear that early action, especially signalling long term carbon prices, is necessary to incentivise behavioural change and minimise the likelihood of more disastrous outcomes.

6 RECOMMENDATIONS FOR FUTURE WORK

The work presented in this report provides some very useful insights into the technology changes, challenges and issues associated with Ireland transitioning to a Low Carbon Energy Economy by 2050. It has the potential for future enhancements to improve and further inform the transition to a low carbon future.

This analysis is merely a first step however that was carried out to a tight timeframe. Additional analysis can provide new insights (for example in relation to the roadmap to 2030) and address some of the limitations associated with the current work that were highlighted in Section 1.2.2 (for example higher resolution modelling of the results for electricity generation).

In addition, a transition to a low carbon economy is a societal challenge that requires careful consideration of technology, cost and policy options and their alternatives. The journey is not static and should develop and evolve over time as new information is realized and model improvements incorporated.

The authors recommend the following topics for consideration of follow up analysis :

- **Focus on 2030 –** in light of the EU 2030 White Paper on energy and climate change, additional analysis focusing explicitly on a roadmap for 2030 will assist Ireland in developing a strengthened negotiating position with respect to Member State burden sharing agreements.
- **Sensitivity analysis on key resource and technologies** – given the significant role of bioenergy in Ireland's Low Carbon Energy Roadmap, and the uncertainties relating to availability of imports, costs, sustainability issues, it would be very useful to carry out sensitivity analysis on key parameters such as costs and resource constraints (for example biofuel import constraints, land use availability). Sensitivity analysis would also be useful to gain insights into the implications of technology risk, for example natural gas CCS power plants and availability of EVs.
- **Increased insights into power sector results –**Soft-linking power system results to an integrated gas and electricity model is recommended to better determine the impacts of variable electricity generation on power system operation

- **Focus on energy policy priorities** – this analysis focuses on the contribution of the energy system to emissions reduction – additional analysis is recommended focusing on the implications for energy security, on the implications of the resulting increased energy prices, on the policies required to achieve the levels of energy efficiency and renewable energy associated with a low carbon economy.
- **The role of infrastructure –** the modeling currently incorporates infrastructure costs in a simple way. Further insights can be gained by a more detailed assessment of the implications for the gas and electrical networks in particular but also for EV charging and biogas dispensing.
- **Feedback to the economy –** This analysis assesses a number of the implications for the economy associated with reducing CO_2 emissions. However, additional analysis would be beneficial incorporating a feedback mechanism between the energy system and the economy to analyse the structural changes to the economy associated with the transition to a low carbon economy.

The above elements comprise an important but not fully comprehensive list of additional analysis that can provide further insights into Ireland's transition to a low carbon future.

APPENDIX A: MACRO-ECONOMIC SCENARIO

A.1 THE ECONOMY TO 2050

The development of a carbon emissions roadmap for the economy to 2050 requires making assumptions about the nature of economic activity in the economy. During the period to 2050 the composition and size of the population will change, consumption patterns will evolve, and the nature of activity within the productive sectors will progress. Each of these factors will affect the nature of energy use and accordingly carbon emissions. Therefore, before contemplating how carbon policies might be best adjusted in the future we need to establish how existing policy mechanisms and technologies will evolve to enable an assessment of what is the gap to target in terms of 2050 carbon goals.

Modelling what will happen to the Irish economy over the next 40 years involves huge uncertainty. Invariably economic projections will be wrong, not least because they are intended to inform and change policy. But developing economic projections based on reasonable scenarios can illustrate a potential growth path for the economy, which in turn can be used to learn how energy demand might develop over the longer term.

The analysis here is based on the macroeconomic projections in the *Medium-Term Review: 2013-20* (MTR) that was recently published by the ESRI (FitzGerald *et al.* (2013)). We use the MTR's 'Recovery Scenario', which provides scenarios for the economy out to 2030 in some detail. The Recovery Scenario is the scenario within the MTR that projects the strongest economic growth path for the economy. In this context the scenario represents the strongest energy demand projection for the medium term. Underlying the Recovery Scenario is an assumption of return to growth in the EU economy and that the problems in the Irish financial sector are resolved. In such circumstances, the export sector of the economy is expected to grow, leading to increases in output and employment. The Recovery Scenario is discussed in detail in the MTR report.

Developing economic projections for the medium term to 2020 is difficult but there is considerably more uncertainty developing economic projections several decades into the future. Our approach for the period from 2030 to 2060 is very simple. The same models as used in the

MTR 2013-2020 are used to provide projections to 2030. For the period 2030-2050 we make extensive use of the ESRI's Demographic Model to take account of the dynamics of the population inherent in the current population structure. This model forecasts the population in the following year as being equal to the population in the base year, subject to births, deaths, and migration in the intervening period. The model accounts for the fact that the population is not distributed evenly by age group or by educational attainment, both of which affects the dynamics of the population. For example, births next year depend on the number of women in the relevant age groups and the assumptions about age-specific fertility. On the economy our approach has been to use a simplifying assumption that GDP will grow at a constant rate over the 2030-2050 period within the current structure of the economy. This assumption and its implications are discussed further below but it enables us to determine a reasonable scenario projection of likely energy demand during the period.

A.2. DEMOGRAPHIC ASSUMPTIONS

A.2.1. FERTILITY

While it is known that the educational attainment of women affects completed fertility and the timing of births (Fahey and Lunn, 2011) there is not, as yet, adequate evidence to allow the calibration of fertility to educational attainment in the Demographic Model. We impose an assumption about the Total Fertility Rate.[20] The current Total Fertility Rate (TFR) is around 2.05 – which would see the population just about replace itself in the long run. This is exceptionally high by European standards. Hence we assume an upper bound TFR of 2.0 – slightly below the level observed today (Table 1). This is assumed to hold out to 2060. The CSO in their population projections assume a 'High' TFR of 2.1 (CSO, 2013).

A.2.2. LIFE EXPECTANCY

We assume that life expectancy rises broadly in line with the pattern assumed by the CSO in their population projections. Here we assume that male life expectancy at birth rises to 89.5 by 2061 whereas female life expectancy rises to 91.1 in 2061. The increase to 2041 is substantially

[20] This is an artificial measure of the number of children that a woman would have over her lifetime if she experienced the age specific fertility rates observed for a particular year.

driven by the assumption that life expectancy in Ireland, which is currently well below the best in the EU, will improve to narrow some of the gap with the best performing countries. With life expectancy still rising in countries such as France, this is the basis for the CSO's 2041 figure.

A.2.3. Participation Rates

In the Demographic Model the rate of labour force participation is differentiated by gender, age and educational attainment. The model assumes that the proportion of the population completing third level education remains broadly unchanged in the future at the current historically high level. However, because the final educational attainment of the current cohort of the population in their late twenties is much higher than for older cohorts, there will be a continuing increase in the average educational attainment of the total population of working age over the period to 2030.

The recent crisis has seen a fall in age and education specific labour force participation rates compared to the previous peak. For the future we make the rather conservative assumption that participation rates by gender, age and educational attainment will return to their previous peak by 2020. From 2020 onwards they are held unchanged. We also allow for some increase in the participation rate of the over 65s, reflecting the gradual increase in the retirement age.

Primarily because of rising educational attainment the age specific participation rates are expected to rise over time. The rise in rates would be particularly marked for women as there is a much bigger difference in their education specific participation rates than is the case for men.

Table 1: Demographic Assumptions

Assumptions		Annual Average		
		2013-20	2020-30	2030-50
Emigration		Number		
	Recovery Scenario	8750	-5000	-5000
Total fertility Rate		Number of children		
	Recovery Scenario	2.0	2.0	2.0
Headship rates				
	Recovery Scenario	Unchanged headship 2011		

A.2.4 MIGRATION

The single most uncertain variable in forecasting population in the medium term is the likely trajectory for migration. The past in Ireland has seen periods of exceptionally high emigration and exceptionally high immigration. Migration is very much driven by economic factors. We assume annual net immigration of 5,000 a year between 2020 and 2060

A.2.5. EDUCATION

We assume that the current share of each year cohort of young people completing the leaving cert and completing third level education remains unchanged in the future. However, because the educational attainment of previous cohorts was much lower than that for the cohort currently completing its education, there is a continuing impact on the population for some time to come. Because those with a good education earn substantially more than those with a limited education, reflecting higher productivity, rising average educational attainment in the population contributes to higher productivity. This productivity effect is estimated by the demographic model and it has its biggest impact over the next ten or fifteen years.

A.2.6 HEADSHIP RATES

An important factor in driving energy demand is the number of households. This is, in turn, driven by the size of the adult population and the extent to which they congregate in separate households. Compared to the rest of the EU 15, people in Ireland tend to establish an independent household at a much later age (Conefrey and FitzGerald, 2010). They tend to remain at home with family or share accommodation with a group of friends to a greater extent than is normal elsewhere for people in their twenties or early 30s. This may partly reflect the high cost of accommodation in Ireland over the last fifteen years as well as possibly differences in culture. We assume that headship rates remain as they are today.

A.3. ECONOMIC ASSUMPTIONS

A.3.1. PRODUCTIVITY & LABOUR FORCE

We define productivity as output per person employed. For the period to 2030 the assumptions on productivity are taken from the recent MTR. For the period 2030-2060 the assumption on productivity is consistent with recent EU experience. We assume productivity growth (the growth in output per head) from 2030-60 of 1% a year. This would be similar to the rate seen in countries such as Belgium, France, Spain and the Netherlands over the last twenty years. Also, because of measurement difficulties, economies that are relying more on services growth may see slower growth in measured productivity. Thus we feel that when considering economic growth over a fifty year period an assumption of an upper bound for productivity growth of one per cent a year is realistic. The demographic assumptions set out above were applied to the Demographic Model. The resulting growth in the labour force is shown above in Table 2.

Table 2: High Level Economic Assumptions

		Annual Average %		
		2013-20	2020-30	2030-60
	Productivity	1.8	1.2	1.00
	Labour Force	0.6	0.7	0.2

A.3.2. CAPITAL

An alternative approach to modelling GDP growth would be to use a simple production function and make assumptions concerning the growth in the labour and capital input over the relevant period. However, for simplicity we have assumed that the capital stock adjusts so as to facilitate the growth rate determined as set out below. Experience with other EU rich countries over the last twenty years would suggest that this would involve investment equal to around 20 per cent of GDP each year[21]. Within this total for investment, investment in dwellings would be between 4 per cent and 5 per cent of GDP (Conefrey and FitzGerald, 2010) with public infrastructural investment being around 2 per cent of GDP each year.

A.3.3. GDP GROWTH

We estimate the average growth in GDP over the fifty year period using the following formula.

$$\Delta \log(Y) = \Delta \log(F) + \Delta \log(P)$$

Where:

Y	=	GDP
F	=	Labour Force
P	=	Labour Productivity

The labour market is assumed to adjust so that by 2030 the economy is close to full employment. Thus the growth in employment for the period 2030-60 should be similar to the growth in the labour force.

A.4. MACRO-ECONOMIC RESULTS

As a result of the assumptions made above, we present a scenario for the growth in GDP over the period 2013-60. The detailed results for the period 2013-30 are taken from the MTR. The results for the full period to 2060 are summarised in Table 3.

[21] In the Irish case a more appropriate denominator would be GNP.

Table 3: Annual Average Growth of GDP 2011-2050

Average annual growth %		
2013-20	2020-30	2030-50
3.8	2.1	1.2

While Table 3 shows the average growth rates over a very long period of almost half a century, the pattern of growth within that period is affected by the demographic trends. This means that, on the assumptions made, there would be significant variation over time in the growth rate due to differences in the growth rate of the labour force.

Table 4: Number of Households

	2013-20	2020-30	2030-50
Average annual growth %	1.0	1.1	0.6
Number of households, million	1.73	1.90	2.21

Table 4 shows the results for the number of households, which involves a substantial increase in the number of households over the period, reaching almost 2.4 million households by 2050.

A.5. ECONOMIC STRUCTURE

In forecasting energy demand it is not enough to have scenarios about the growth in GDP, the population and the number of households. It is also necessary to make some assumptions about the structure of output in the economy. This poses major difficulties as, in principle, it requires a fully worked out model of the economy to produce such data. While detailed results for MTR Recovery Scenario are available out to 2030 using the HERMES model, there are no good grounds for forecasting the change in structure after that date. As a result we use the composition of output from that HERMES simulation out to 2030 and assume that the economic structure does not change in terms of output shares after that date.

A.6. ECONOMIC UNCERTAINTY

The economic figures used in this analysis are not intended to be forecasts of future economic outturns. Instead they represent a scenario of one possible outcome for the economy through the period to 2050. What is certain is that the scenario will be wrong, as detailed forecasts of the economy in the long term are subject to huge margins of error. Any other scenario will be subject to the same issues. We use a single rather than multiple scenarios because the purpose of the economic scenario to 2050 is to develop a likely energy demand profile from the economy. A single economic scenario is sufficient for that purpose. The output from the ESRI demographic model in terms of population and household formation will be largely unchanged under alternative scenarios. The key demographic issue is migration, which we cannot realistically model in the long term. Also, as mentioned earlier there are no good grounds for forecasting the change in the structure of the economy beyond 2030 - we have assumed it constant. The substance of the conclusions based on multiple economic scenarios would not be substantially different than what is presented here.

APPENDIX B ENERGY SYSTEMS SCENARIO RESULTS 2010 - 2050

B.1. PRIMARY ENERGY SUPPLY 2010 - 2050

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Fossil Fuels (Total)	34.4%	1.8%	0.7%	0.2%	0.3%	14,436	19,408	95.3%	91.6%
Coal and Peat	-29.3%	1.4%	-1.5%	-2.2%	-1.1%	2,031	1,436	13.4%	6.8%
Oil (incl. Int Aviation)	47.8%	2.4%	0.7%	0.5%	0.4%	7,713	11,397	50.9%	53.8%
Oil (excl. Int Aviation)	*42.3%*	*2.0%*	*0.6%*	*0.5%*	*0.4%*	*6,939*	*9,872*	*45.8%*	*46.6%*
Natural Gas	40.1%	0.8%	1.5%	0.5%	0.6%	4,692	6,575	31.0%	31.0%
Renewables (Total)	143.1%	6.5%	1.1%	0.7%	0.8%	679	1,651	4.5%	7.8%
Hydro	-15.7%	-1.3%	0.0%	0.0%	-0.4%	52	43	0.3%	0.2%
Wind	125.2%	8.5%	0.0%	0.0%	0.0%	242	545	1.6%	2.6%
Biomass	294.2%	10.1%	2.1%	0.8%	1.2%	211	830	1.4%	3.9%
Bioliquids	-0.1%	-2.6%	1.4%	0.2%	1.0%	93	93	0.6%	0.4%
Biogas	-2.0%	-0.2%	0.0%	0.0%	0.0%	58	57	0.4%	0.3%
Other Renewables	243.8%	-37.3%	39.5%	22.6%	5.5%	24	82	0.2%	0.4%
Electricity Imports	195.0%	-100.0%	-	10.2%	-1.9%	40	119	0.3%	0.6%
Total	39.7%	2.0%	0.7%	0.3%	0.4%	15,156	21,178		

FIGURE B-1 *BAU* SCENARIO PRIMARY ENERGY SUPPLY 2010 - 2050

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Fossil Fuels (Total)	-47.6%	-0.7%	-1.9%	-2.7%	-1.1%	14,436	7,561	95.3%	50.6%
Coal and Peat	-78.4%	-8.8%	-6.7%	0.7%	0.2%	2,031	439	13.4%	2.9%
Oil (incl. Int Aviation)	-59.5%	0.1%	-1.6%	-4.1%	-3.2%	7,713	3,127	50.9%	20.9%
Oil (excl. Int Aviation)	*-76.9%*	*-0.7%*	*-2.2%*	*-5.8%*	*-5.6%*	*6,939*	*1,602*	*45.8%*	*10.7%*
Natural Gas	-14.8%	0.3%	-1.7%	-1.0%	0.8%	4,692	3,995	31.0%	26.7%
Renewables (Total)	962.6%	6.0%	9.5%	5.2%	3.7%	679	7,216	4.5%	48.3%
Hydro	100.9%	5.5%	0.6%	0.5%	0.5%	52	104	0.3%	0.7%
Wind	547.6%	8.5%	8.5%	1.5%	0.9%	242	1,568	1.6%	10.5%
Biomass	1205.2%	7.6%	12.4%	4.7%	2.2%	211	2,749	1.4%	18.4%
Bioliquids	1600.8%	-0.3%	10.1%	17.6%	2.8%	93	1,575	0.6%	10.5%
Biogas	1943.7%	-0.2%	0.0%	0.0%	35.5%	58	1,193	0.4%	8.0%
Other Renewables	14.3%	-37.3%	17.9%	34.8%	1.6%	24	27	0.2%	0.2%
Electricity Imports	320.3%	15.4%	0.0%	0.0%	0.0%	40	170	0.3%	1.1%
Total	-1.4%	-0.2%	-0.4%	-0.5%	0.9%	15,156	14,947		

FIGURE B-2 *CO2-80* SCENARIO PRIMARY ENERGY SUPPLY 2010 – 2050

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Fossil Fuels (Total)	-70.9%	-0.8%	-2.1%	-3.4%	-5.9%	14,436	4,197	95.3%	26.1%
Coal and Peat	-80.4%	-8.1%	-7.5%	0.7%	-0.8%	2,031	399	13.4%	2.5%
Oil (incl. Int Aviation)	-67.2%	0.1%	-2.1%	-5.3%	-3.6%	7,713	2,529	50.9%	15.7%
Oil (excl. Int Aviation)	*-85.5%*	*-0.7%*	*-2.8%*	*-7.8%*	*-7.5%*	*6,939*	*1,004*	*45.8%*	*6.2%*
Natural Gas	-73.0%	0.0%	-1.2%	-1.3%	-10.0%	4,692	1,269	31.0%	7.9%
Renewables (Total)	1623.5%	6.4%	9.6%	6.2%	7.4%	679	11,704	4.5%	72.8%
Hydro	100.9%	5.5%	0.6%	0.5%	0.5%	52	104	0.3%	0.6%
Wind	729.9%	9.4%	8.1%	1.8%	2.8%	242	2,009	1.6%	12.5%
Biomass	2985.7%	7.6%	12.4%	5.1%	10.9%	211	6,499	1.4%	40.4%
Bioliquids	1580.1%	-0.7%	13.6%	11.2%	5.7%	93	1,556	0.6%	9.7%
Biogas	1943.7%	-0.2%	0.0%	31.0%	3.4%	58	1,193	0.4%	7.4%
Other Renewables	1338.7%	-37.3%	17.9%	46.1%	20.7%	24	344	0.2%	2.1%
Electricity Imports	320.3%	15.4%	0.0%	0.0%	0.0%	40	170	0.3%	1.1%
Total	6.0%	-0.2%	-0.4%	-0.4%	1.6%	15,156	16,071		

FIGURE B-3 *CO2-95* SCENARIO PRIMARY ENERGY SUPPLY 2010 – 2050

B.2. TOTAL FINAL ENERGY USE BY FUEL 2010 - 2050

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Fossil Fuels (Total)	42.9%	1.9%	0.7%	0.5%	0.4%	9,441	13,492	79.1%	78.8%
Coal and Peat	-100.0%	-4.9%	-22.0%	-100.0%	-	619	0	5.2%	0.0%
Oil (incl. Int Aviation)	45.2%	1.9%	0.9%	0.5%	0.4%	7,206	10,463	60.4%	61.1%
Oil (excl. Int Aviation)	*37.9%*	*1.3%*	*1.0%*	*0.5%*	*0.4%*	*6,431*	*8,871*	*53.9%*	*51.8%*
Natural Gas	87.4%	3.8%	1.4%	0.7%	0.6%	1,616	3,029	13.5%	17.7%
Renewables (Total)	181.0%	4.7%	2.4%	1.7%	1.7%	312	876	2.6%	5.1%
Biomass	244.0%	6.8%	2.4%	1.9%	1.6%	187	642	1.6%	3.8%
Bioliquids	1.4%	-2.1%	3.7%	-2.3%	1.0%	93	94	0.8%	0.5%
Biogas	583.5%	21.2%	0.0%	0.0%	0.0%	8	57	0.1%	0.3%
Other Renewables	243.8%	-37.3%	39.5%	22.6%	5.5%	24	82	0.2%	0.5%
Electricity	25.6%	1.6%	0.7%	0.0%	0.0%	2,186	2,747	18.3%	16.0%
Total	43.4%	2.0%	0.8%	0.5%	0.4%	11,939	17,114		

FIGURE B-4 *BAU* SCENARIO FINAL ENERGY DEMAND 2010 - 2050

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Fossil Fuels (Total)	-61.9%	0.6%	-2.1%	-4.3%	-3.7%	9,441	3,598	79.1%	30.3%
Coal and Peat	-39.1%	-2.8%	-3.9%	1.3%	0.6%	619	377	5.2%	3.2%
Oil (incl. Int Aviation)	-69.6%	-0.6%	-1.7%	-5.0%	-4.4%	7,206	2,191	60.4%	18.4%
Oil (excl. Int Aviation)	*-90.7%*	*-1.7%*	*-2.4%*	*-7.8%*	*-10.8%*	*6,431*	*599*	*53.9%*	*5.0%*
Natural Gas	-36.3%	5.6%	-2.7%	-3.5%	-3.6%	1,616	1,029	13.5%	8.7%
Renewables (Total)	1594.2%	6.2%	11.4%	7.4%	4.5%	312	5,279	2.6%	44.4%
Biomass	1103.6%	8.0%	12.9%	4.2%	1.0%	187	2,247	1.6%	18.9%
Bioliquids	1822.0%	1.6%	9.2%	17.0%	3.6%	93	1,780	0.8%	15.0%
Biogas	14522.1%	21.2%	0.0%	4.8%	29.6%	8	1,225	0.1%	10.3%
Other Renewables	14.3%	-37.3%	17.9%	34.8%	1.6%	24	27	0.2%	0.2%
Electricity	37.7%	-0.9%	2.1%	1.3%	0.7%	2,186	3,011	18.3%	25.3%
Total	-0.4%	0.6%	-0.3%	-0.7%	0.3%	11,939	11,888		

Figure B-5 *CO2-80* Scenario Final Energy Demand 2010 – 2050

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Fossil Fuels (Total)	-77.3%	0.6%	-2.4%	-5.8%	-6.8%	9,441	2,140	79.1%	18.6%
Coal and Peat	-45.5%	-2.8%	-3.9%	1.3%	-0.5%	619	337	5.2%	2.9%
Oil (incl. Int Aviation)	-76.0%	-0.6%	-2.2%	-6.6%	-4.5%	7,206	1,726	60.4%	15.0%
Oil (excl. Int Aviation)	*-97.9%*	*-1.7%*	*-3.1%*	*-11.2%*	*-19.7%*	*6,431*	*134*	*53.9%*	*1.2%*
Natural Gas	-95.3%	5.5%	-2.7%	-5.2%	-24.3%	1,616	76	13.5%	0.7%
Renewables (Total)	1519.2%	6.2%	12.0%	8.5%	2.5%	312	5,045	2.6%	43.8%
Biomass	1107.3%	8.0%	12.9%	4.4%	0.8%	187	2,254	1.6%	19.6%
Bioliquids	1667.6%	1.2%	12.3%	11.0%	5.5%	93	1,637	0.8%	14.2%
Biogas	12722.1%	21.2%	0.0%	31.5%	1.9%	8	1,074	0.1%	9.3%
Other Renewables	236.5%	-37.3%	17.9%	34.7%	13.3%	24	80	0.2%	0.7%
Electricity	98.3%	-0.9%	2.5%	1.8%	3.6%	2,186	4,336	18.3%	37.6%
Total	-3.5%	0.5%	-0.4%	-0.7%	0.2%	11,939	11,521		

Figure B-6 CO2-95 Scenario Final Energy Demand 2010 - 2050

B.2. FINAL ENERGY USE BY SECTOR

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Industry	29.6%	0.8%	0.8%	0.9%	0.1%	2,280	2,955	19.1%	18.0%
Transport (Incl. Int. Aviation)	64.1%	1.1%	2.0%	1.1%	0.7%	4,624	7,590	38.7%	46.3%
Transport (Excl. Int. Aviation)	*57.2%*	*1.1%*	*1.4%*	*1.3%*	*0.8%*	*3,850*	*6,052*	*32.2%*	*36.9%*
Residential	-2.0%	-0.4%	0.0%	0.0%	0.2%	3,270	3,205	27.4%	19.5%
Commercial / Public	53.7%	2.1%	1.1%	0.6%	0.6%	1,476	2,269	12.4%	13.8%
Agriculture / Fisheries	30.8%	1.1%	0.7%	0.5%	0.4%	298	390	2.5%	2.4%
Total	37.3%	0.8%	1.2%	0.8%	0.5%	11,947	16,408		

FIGURE B-7 *BAU* SCENARIO FINAL ENERGY DEMAND 2010 - 2050

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Industry	14.1%	-0.2%	0.1%	1.1%	0.3%	2,280	2,600	19.1%	22.6%
Transport (Incl. Int. Aviation)	7.8%	0.9%	1.5%	-0.4%	-1.2%	4,624	4,984	38.7%	43.4%
Transport (Excl. Int. Aviation)	*-10.5%*	*0.9%*	*0.7%*	*-0.8%*	*-1.8%*	*3,850*	*3,445*	*32.2%*	*30.0%*
Residential	-36.3%	-0.5%	-1.5%	-1.6%	-0.9%	3,270	2,084	27.4%	18.1%
Commercial / Public	0.2%	1.0%	-1.0%	0.3%	-0.2%	1,476	1,478	12.4%	12.9%
Agriculture / Fisheries	16.1%	1.1%	0.0%	0.6%	-0.2%	298	346	2.5%	3.0%
Total	-3.8%	0.3%	0.2%	-0.3%	-0.7%	11,947	11,492		

FIGURE B-8 *CO2-80* SCENARIO FINAL ENERGY DEMAND 2010 - 2050

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	2010-2050	2010-2020	2020-2030	2030-2040	2040-2050	2010	2050	2010	2050
Industry	14.0%	-0.2%	0.2%	1.1%	0.3%	2,280	2,598	19.1%	22.9%
Transport (Incl. Int. Aviation)	5.3%	0.9%	1.5%	-0.7%	-1.2%	4,624	4,867	38.7%	43.0%
Transport (Excl. Int. Aviation)	*-13.5%*	*0.9%*	*0.7%*	*-1.1%*	*-1.8%*	*3,850*	*3,329*	*32.2%*	*29.4%*
Residential	-36.3%	-0.5%	-1.5%	-1.7%	-0.8%	3,270	2,082	27.4%	18.4%
Commercial / Public	-1.8%	1.0%	-1.1%	0.4%	-0.5%	1,476	1,449	12.4%	12.8%
Agriculture / Fisheries	10.2%	1.1%	0.0%	0.6%	-0.7%	298	328	2.5%	2.9%
Total	-5.2%	0.3%	0.2%	-0.4%	-0.7%	11,947	11,325		

FIGURE B-9 *CO2-95* SCENARIO FINAL ENERGY DEMAND 2010 - 2050

APPENDIX C: DATA FOR GRAPHS

Total CO2 Emissions (MT)					
Scenario	**2010**	**2020**	**2030**	**2040**	**2050**
BaU	*42.73*	*48.89*	*51.13*	*51.50*	*52.86*
CO2-80	*42.73*	*34.40*	*24.25*	*15.54*	*6.83*
CO2-95	*42.73*	*34.40*	*23.49*	*12.58*	*1.67*

TABLE FOR DATA FROM FIGURE 1-1: TRAJECTORY FROM 2010 TO CO2 EMISSIONS REDUCTON TARGETS IN 2050

Period	2010	2020	2020	2030	2030	2040	2040	2050	2050
Scenario	**BaU**	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**
Agriculture	0.9	0.9	0.8	1.0	0.8	1.0	0.7	1.0	0.7
Transport	**11.6**	14.7	13.4	16.7	11.3	18.3	5.0	19.7	1.4
Built Environment	**10.2**	9.2	7.0	8.7	4.6	8.8	3.7	8.7	2.4
Energy	13.4	15.9	6.7	16.3	4.8	15.0	5.3	14.7	1.7
Industry	6.7	8.1	6.4	8.5	2.7	8.5	0.8	8.7	0.6

TABLE FOR FIGURE 2-1: SECTORAL CO2 EMISSIONS FOR HORIZON TO 2050 FOR BAU AND 80% REDUCTION SCENARIO

Period	2010	2020	2030	2040	2050
Energy Efficiency	-	73%	51%	40%	21%
Renewable Energy	-	10%	30%	44%	39%
Fossil Fuel Switching	-	17%	18%	16%	40%

TABLE FOR FIGURE 2-3**: DECOMPOSITION OF 80% CO2 EMISSIONS REDUCTIONS SCENARIO VS BAU SCENARIO**

Units	(ktoe)	2020	2020	2030	2030	2040	2040	2050	2050
Sector		**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**
Agri	Biomass	0	0	0	6	0	12	0	17
	Coal	0	0	0	0	0	0	0	0
	Electricity	59	67	62	83	64	92	67	103
	Gas	0	0	0	12	0	23	0	34
	Geo	0	0	0	0	0	0	0	0
	Heat	0	0	0	0	0	0	0	0
	Oil	299	264	314	252	326	217	338	185
	Solar	0	0	0	1	0	2	0	3
	Total	**358**	**331**	**376**	**353**	**390**	**346**	**404**	**344**
Indus	Renewables	224	212	234	1,050	238	1,621	240	1,705
	Coal	98	88	31	28	0	0	0	0
	Coal CCS	0	100	0	285	0	356	0	377
	Electricity	735	535	820	554	836	543	842	555
	Gas	837	1,312	990	603	984	76	986	33
	Oil	782	20	851	7	898	4	918	4
	Total	**2,675**	**2,267**	**2,926**	**2,527**	**2,955**	**2,600**	**2,986**	**2,674**
Trans	Renewables	121	118	165	277	142	1,347	151	2,596
	Electricity	6	14	13	225	15	549	21	609
	Gas	0	0	0	0	0	0	0	0
	Oil	6,184	5,745	6,894	5,134	7,433	3,087	7,951	1,968
	Synthetic	0	0	0	0	0	0	0	0
	Total	**4,920**	**4,486**	**5,587**	**4,151**	**6,052**	**3,445**	**6,530**	**3,580**
	Oil excl int av	4,793	4,354	5,409	3,649	5,895	1,549	6,358	375
Built Env	Renewables	148	240	227	345	360	433	484	958
	Coal	279	279	0	0	0	0	0	0
	Electricity	1,385	1,011	1,517	1,133	1,615	1,166	1,717	1,228
	Elec-th	369	364	337	468	216	460	100	516
	Gas	1,499	1,467	1,683	1,503	1,869	1,390	2,043	962
	Heat	0	0	0	0	0	0	0	0
	Oil	1,472	780	1,519	336	1,413	113	1,257	34
	Total	**5,151**	**4,141**	**5,282**	**3,786**	**5,474**	**3,562**	**5,601**	**3,697**

TABLE FOR FIGURE 2-6: FINAL ENERGY CONSUMPTION BY SECTOR FOR BAU AND CO2-80 REDUCTION SCENARIO

Units (ktoe)	BaU	BaU	BaU	CO2-80	CO2-80	CO2-80
	RES-E	RES-T	RES-H	RES-E	RES-T	RES-H
Biogas and Waste	46.4	-	-	0.0	-	-
Hydro	43.4	-	-	103.5	-	-
Ocean	0.0	-	-	0.0	-	-
Solar	0.0	-	-	0.0	-	-
Wind	545.2	-	-	1567.7	-	-
Biomass	0.0	-	-	0.0	-	-
Biodiesel	-	1.4	-	-	750.0	-
Biogas	-	57.2	-	-	816.1	-
Bio DME	-	0.0	-	-	105.3	-
BioEthanol	-	92.5	-	-	906.0	-
Bio-FT Diesel	-	0.0		-	10.6	-
Bio Methanol	-	0.0		-	7.8	-
Biodiesel	-	-	0.0	-	-	0.0
Biogas	-	-	0.0	-	-	408.5
Biomass	-	-	642.2	-	-	2326.1
Geothermal		-	23.9	-	-	23.9
Solar	-	-	58.3	-	-	3.4

TABLE FOR FIGURE 2-7: RENEWABLE ENERGY BY SCENARIO AND MODE OF ENERGY FOR BAU AND CO2-80

Units (ktoe)	2020	2020	2030	2030	2040	2040	2050	2050
	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80
Agriculture	59	67	62	83	64	92	67	103
Energy Sector	5	5	5	5	4	4	3	3
Industrial-Energy	680	497	757	514	772	503	778	515
Transport	6	14	13	228	15	557	21	610
Built Environment	1,755	1,375	1,853	1,601	1,831	1,627	1,817	1,744

TABLE FOR FIGURE 2-10: ELECTRICITY (RENEWABLE AND FOSSIL) CONSUMPTION BY SECTOR FOR BAU AND CO2-80 SCENARIOS

Units (ktoe)	2020	2020	2030	2030	2040	2040	2050	2050
	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80
Agriculture - Gas	0	0	0	12	0	23	0	34
Services - Gas	514	463	581	452	632	372	681	260
Services - Biogas	0	21	0	13	0	0	0	102
Power - Gas	2,742	2,063	3,233	1,972	3,343	2,193	3,546	264
Power Gen - Gas CCS	0	0	0	0	0	0	0	2,702
Power Gen - Biogas & Waste	187	1	186	0	186	10	186	79
Transformation - Gas	0	0	0	0	0	0	0	0
Industry - Gas	837	1,312	990	603	984	76	986	33
Industry - Biogas	0	0	0	0	0	0	0	0
Residential - Gas	985	1,003	1,102	1,051	1,237	1,018	1,362	702
Residential - Biogas	11	26	0	29	0	0	0	307
Transport - Gas	0	0	0	0	0	0	0	0
Transport - Biogas	46	9	57	16	57	92	57	816
Total	5,323	4,900	6,149	4,147	6,439	3,785	6,818	5,299

TABLE FOR FIGURE 2-13: GAS USAGE BY SECTOR AND TYPE FOR BAU AND CO2-80 SCENARIOS.

	2020	2020	2030	2030	2040	2040	2050	2050
Units (ktoe)	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80
Kerosene	1,334	1,335	1,430	1,430	1,484	1,496	1,539	1,544
Gasoline	802	711	462	259	294	291	320	105
Diesel	3,979	3,630	4,931	3,377	5,587	1,232	6,024	250
LPG	1	1	3	0	0	0	0	0
Heavy Oil	0	0	0	0	0	0	0	0
Renewables	121	118	165	277	142	1,347	151	2,596
Electricity	6	14	13	225	15	549	21	609
Gas	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0	0	0
Kerosene (no INT AVIATION)	11	11	13	13	13	25	15	19
Total with Aviation	6,243	5,809	7,004	5,568	7,522	4,916	8,055	5,105
Total no Aviation	4,920	4,486	5,587	4,151	6,052	3,445	6,530	3,580

TABLE FOR FIGURE 2-17- DETAILED BREAKDOWN OF ENERGY COMSUMPTION IN TRANSPORT FOR BAU AND CO2-80 SCENARIOS

Units (ktoe)	2020	2020	2030	2030	2040	2040	2050	2050
	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80
Biogas and Waste	46	0	46	0	46	0	46	0
Coal	756	117	756	0	609	0	543	0
Coal CCS	0	0	0	0	0	0	0	0
Gas	1232	1128	1454	1122	1506	1313	1605	146
Gas CCS	0	0	0	0	0	0	0	1297
Hydro	45	88	45	93	45	98	43	104
Nuclear	0	0	0	0	0	0	0	0
Ocean	0	0	0	0	0	0	0	0
Oil	79	62	0	0	2	2	1	2
Other	0	0	0	0	1	0	1	0
Solar	0	0	0	0	0	0	0	0
TradeEn ELC	0	170	55	170	145	170	119	170
Wind	545	547	545	1243	545	1439	545	1568
Wood	0	0	0	0	0	0	0	0

TABLE FOR FIGURE 2-18-ENERGY COMSUMPTION IN THE POWER SECTOR FOR BAU AND CO2-80 SCENARIOS BY FUEL TYPE

Period	2010	2020	2020	2030	2030	2040	2040	2050	2050
Commodity\Scenario	BaU	BaU	CO2-95	BaU	CO2-95	BaU	CO2-95	BaU	CO2-95
Agriculture	0.86	0.93	0.82	0.97	0.81	1.01	0.69	1.05	0.00
Transport	11.60	14.72	13.39	16.71	10.44	18.25	2.83	19.69	0.41
Built Environment	10.16	9.24	7.03	8.68	4.60	8.78	3.17	8.69	0.14
Energy	13.36	15.93	6.75	16.31	4.93	14.98	5.35	14.74	0.62
Industry	6.74	8.07	6.41	8.47	2.71	8.48	0.55	8.70	0.49

TABLE FOR FIGURE 4-1: SECTORAL CO2 EMISSIONS FOR HORIZON TO 2050 FOR BAU AND 95% EMISIONS REDUCTION SCENARIOS

	2010	2020	2030	2040	2050
Energy Efficiency	-	73%	51%	34%	9%
Renewable Energy	-	11%	31%	47%	56%
Fossil Fuel Switching	-	16%	18%	19%	34%

TABLE FOR FIGURE 4-3: DECOMPOSITION OF 95% CO2 EMISSIONS REDUCTIONS SCENARIO VS BAU SCENARIO

		2020 BaU	2020 CO2-95	2030 BaU	2030 CO2-95	2040 BaU	2040 CO2-95	2050 BaU	2050 CO2-95
Agri	Biomass	0	0	0	6	0	11	0	85
	Coal	0	0	0	0	0	0	0	0
	Electricity	59	67	62	83	64	88	67	140
	Gas	0	0	0	12	0	22	0	0
	Geo	0	0	0	0	0	0	0	1
	Heat	0	0	0	0	0	0	0	0
	Oil	299	264	314	252	326	206	338	1
	Solar	0	0	0	1	0	2	0	57
	Total	**358**	**331**	**376**	**353**	**390**	**328**	**404**	**283**
Inds	Renewables	224	213	234	1,050	238	1,662	240	1,624
	Coal	98	87	31	28	0	0	0	0
	Coal CCS	0	100	0	285	0	356	0	337
	Electricity	735	535	820	553	836	542	842	526
	Gas	837	1,316	990	605	984	34	986	26
	Oil	782	20	851	9	898	4	918	3
	Total	**2,675**	**2,270**	**2,926**	**2,530**	**2,955**	**2,598**	**2,986**	**2,517**
Trans	Renewables	121	116	165	359	142	1,842	151	2,689
	Electricity	6	14	13	285	15	596	21	607
	Gas	0	0	0	0	0	0	0	0
	Oil	6,184	5,748	6,894	4,839	7,433	2,429	7,951	1,716
	Synthetic	0	0	0	0	0	0	0	0
	Total	**4,920**	**4,487**	**5,587**	**3,998**	**6,052**	**3,329**	**6,530**	**3,420**
	Oil excl int av	4,793	4,357	5,409	3,354	5,895	891	6,358	123
Built Env	Renewables	148	238	227	337	360	437	484	589
	Coal	279	279	0	0	0	0	0	0
	Electricity	1,385	1,011	1,517	1,149	1,615	1,153	1,717	1,275
	Elec-th	369	365	337	472	216	651	100	1,789
	Gas	1,499	1,456	1,683	1,497	1,869	1,187	2,043	50
	Heat	0	0	0	0	0	0	0	0
	Oil	1,472	782	1,519	331	1,413	103	1,257	6
	Total	**5,151**	**4,131**	**5,282**	**3,785**	**5,474**	**3,531**	**5,601**	**3,709**

TABLE FOR FIGURE 4-6: FINAL ENERGY CONSUMPTION BY SECTOR FOR BAU AND 95% REDUCTION SCENARIO

	BaU	BaU	BaU	CO2-95	CO2-95	CO2-95
Units (ktoe)	**RES-E**	**RES-T**	**RES-H**	**RES-E**	**RES-T**	**RES-H**
Biogas and Waste	46			83	-	-
Hydro	43	-	-	104	-	-
Ocean	0	-	-	0	-	-
Solar	0	-	-	264	-	-
Wind	545	-	-	2,009	-	-
Biomass	0	-	-	1,513	-	-
Biodiesel	-	1	-	-	1,448	-
Biogas	-	57	-	-	1,053	-
Bio DME	-	0	-	-	0	-
BioEthanol	-	93	-	-	189	-
Bio-FT Diesel	-	0	-	-	0	-
Bio Methanol	-	0	-	-	0	-
Biodiesel	-	-	0	-	-	0
Biogas	-	-	0	-	-	21
Biomass	-	-	642	-	-	2,328
Geothermal	-	-	24	-	-	24
Solar	-	-	58	-	-	57

TABLE FOR FIGURE 4-7: RENEWABLE ENERGY FOR BAU AND 95% REDUCTION SCENARIO AND BY MODE OF ENERGY

	2020	2020	2030	2030	2040	2040	2050	2050
(ktoe)	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**
Agriculture	59	67	62	83	64	88	67	140
Energy Sector	5	5	5	5	4	4	3	3
Industrial-Energy	680	497	757	513	772	503	778	486
Transport	6	14	13	289	15	601	21	617
Built Environment	1,755	1,376	1,853	1,620	1,831	1,804	1,817	3,063

TABLE FOR FIGURE 4-10: ELECTRICITY (RENEWABLE AND CONVENTIONAL) CONSUMPTION BY SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIO

	2020	2020	2030	2030	2040	2040	2050	2050
Units (ktoe)	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**
Agriculture - Gas	0	0	0	12	0	22	0	0
Services - Gas	514	461	581	452	632	356	681	0
Services - Biogas	0	20	0	13	0	0	0	0
Power - Gas	2,742	1,938	3,233	2,043	3,343	2,085	3,546	4
Power Gen - Gas CCS	0	0	0	0	0	314	0	1,188
Power Gen - Biogas & Waste	187	1	186	0	186	74	186	225
Transformation - Gas	0	0	0	0	0	0	0	0
Industry - Gas	837	1,316	990	605	984	34	986	26
Industry - Biogas	0	0	0	0	0	0	0	0
Residential - Gas	985	994	1,102	1,044	1,237	832	1,362	50
Residential - Biogas	11	26	0	20	0	0	0	21
Transport - Gas	0	0	0	0	0	0	0	0
Transport - Biogas	46	11	57	25	57	888	57	1,053
Total	5,323	4,767	6,149	4,214	6,439	4,604	6,818	2,567

TABLE FOR FIGURE 4-13: GAS USAGE BY SECTOR AND TYPE FOR BAU AND 95% REDUCTION SCENARIO

	2020	2020	2030	2030	2040	2040	2050	2050
Units (ktoe)	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**
Kerosene	1,334	1,334	1,430	1,431	1,484	1,495	1,539	1,548
Gasoline	802	713	462	258	294	274	320	68
Diesel	3,979	3,631	4,931	3,082	5,587	592	6,024	32
LPG	1	1	3	0	0	0	0	0
Heavy Oil	0	0	0	0	0	0	0	0
Renewables	121	116	165	359	142	1,842	151	2,689
Electricity	6	14	13	285	15	596	21	607
Gas	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0	0	0
Kerosene (no INT AVIATION)	11	11	13	14	13	25	15	24
Total with Aviation	6,243	5,810	7,004	5,415	7,522	4,799	8,055	4,945
Total no Aviation	4,920	4,487	5,587	3,998	6,052	3,329	6,530	3,420

TABLE FOR FIGURE 4-17- DETAILED BREAKDOWN OF ENERGY COMSUMPTION IN THE TRANSPORT SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIO

	2020	2020	2030	2030	2040	2040	2050	2050
Units (ktoe)	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**
Biogas and Waste	46	0	46	0	46	0	46	83
Coal	756	145	756	0	609	0	543	0
Coal CCS	0	0	0	0	0	0	0	0
Gas	1,232	1,057	1,454	1,167	1,506	1,290	1,605	2
Gas CCS	0	0	0	0	0	150	0	570
Hydro	45	88	45	93	45	98	43	104
Nuclear	0	0	0	0	0	0	0	0
Ocean	0	0	0	0	0	0	0	0
Oil	79	62	0	0	2	2	1	0
Other	0	0	0	0	1	0	1	3
Solar	0	0	0	0	0	29	0	264
TradeEn ELC	0	170	55	170	145	170	119	170
Wind	545	592	545	1,287	545	1,531	545	2,009
Wood	0	0	0	0	0	0	0	1,513

TABLE FOR FIGURE 4-18-ENERGY COMSUMPTION IN THE POWER SECTOR FOR BAU AND 95% EMISSIONS REDUCTION SCENARIO BY FUEL TYPE

APPENDIC D: SECTORAL DEMAND DATA

AGRICULTURE DEMAND:

80% Scenario	2020	2020	2030	2030	2040	2040	2050	2050
Units (ktoe)	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**
AGR	358	342	376	359	390	355	404	356

95% Scenario	2020	2020	2030	2030	2040	2040	2050	2050
Units (ktoe)	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**
AGR	358	342	376	359	390	346	404	319

SERVICES DEMAND:

80% Scenario	Units (ktoe)	2020	2020	2030	2030	2040	2040	2050	2050
TIMES Code	**Description**	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**
CCLE	**Space Cool.Large.**	88	88	92	92	95	95	97	97
CCOK	**Cooking.**	103	101	108	106	111	109	115	111
CCSE	**Space Cool.Small.**	38	38	39	39	41	41	42	42
CHLE	**Space Heat.Large.**	447	434	464	443	475	443	487	443
CHSE	**Space Heat.Small.**	187	181	194	185	199	190	204	185
CLIG	**Lighting.**	325	320	372	372	408	408	447	447
COEL	**Other Electric.**	374	368	431	431	477	477	525	525
CPLI	**Public Lighting.**	82	80	88	86	92	90	97	97
CREF	**Refrigeration.**	45	45	49	49	51	51	54	54
CWLE	**Water Heat.Large.**	124	115	129	127	132	129	135	135
CWSE	**Water Heat.Small.**	53	50	55	54	57	55	58	58

95% Scenario	Units (ktoe)	2020	2020	2030	2030	2040	2040	2050	2050
TIMES Code	**Description**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**
CCLE	**Space Cool.Large.**	88	88	92	92	95	95	97	97
CCOK	**Cooking.**	103	101	108	106	111	109	115	111
CCSE	**Space Cool.Small.**	38	38	39	39	41	41	42	42
CHLE	**Space Heat.Large.**	447	427	464	443	475	433	487	399
CHSE	**Space Heat.Small.**	187	181	194	185	199	181	204	173
CLIG	**Lighting.**	325	320	372	372	408	399	447	433
COEL	**Other Electric.**	374	368	431	431	477	467	525	510
CPLI	**Public Lighting.**	82	80	88	86	92	90	97	94
CREF	**Refrigeration.**	45	45	49	49	51	51	54	52
CWLE	**Water Heat.Large.**	124	115	129	127	132	129	135	131
CWSE	**Water Heat.Small.**	53	49	55	54	57	55	58	56

RESIDENTIAL SECTOR DEMAND:

80% Scenario		2020	2020	2030	2030	2040	2040	2050	2050
TIMES Code	Description	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80
RCDR	Clothes Drying.	28	28	29	29	30	30	30	30
RCOK	Cooking	79	79	81	81	82	82	83	83
RCWA	Clothes Washing	31	31	32	32	32	32	32	32
RDWA	Dish Washing	29	29	30	30	30	30	31	31
RHME	Space Heat.Multi.All.Existing.	54	53	50	45	39	34	35	29
RHMN	Space Heat.Multi.All.New	41	41	59	52	76	65	89	73
RHRE	Space Heat.Single.Rural.Ex	480	473	411	398	358	342	289	271
RHRN	Space Heat.Single.Rural.New	85	84	120	117	155	148	182	171
RHUE	Space Heat.Single.Urban.Ex	728	717	696	633	664	589	632	537
RHUN	Space Heat.Single.Urban.New	79	78	111	101	143	127	168	143
RLIG	Lighting	131	129	138	138	143	143	147	147
ROEL	Other Electric	148	146	162	160	168	164	173	168
ROEN	Other Energy	0	0	0	0	0	0	0	0
RREF	Refrigeration	70	70	72	72	73	73	74	74
RWME	Water Heat.Multi.All.Existing.	17	15	15	14	12	10	11	10
RWMN	Water Heat.Multi.All.New	28	25	43	39	59	50	72	69
RWRE	Water Heat.Single.Rural.Ex	147	127	125	118	109	97	88	85
RWRN	Water Heat.Single.Rural.New	56	48	88	82	120	107	145	140
RWUE	Water Heat.Single.Urban.Ex	227	207	217	191	207	165	197	191
RWUN	Water.Heat.Single Urban New	52	48	83	73	113	92	137	132

95% Scenario		2020	2020	2030	2030	2040	2040	2050	2050
TIMES Code	**Description**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**	**BaU**	**CO2-95**
RCDR	**Clothes Drying.**	28	28	29	29	30	30	30	30
RCOK	**Cooking**	79	79	81	81	82	82	83	81
RCWA	**Clothes Washing**	31	31	32	32	32	32	32	32
RDWA	**Dish Washing**	29	29	30	30	30	30	31	31
RHME	**Space Heat.Multi.All.Existing.**	54	53	50	45	39	32	35	24
RHMN	**Space Heat.Multi.All.New**	41	41	59	53	76	62	89	62
RHRE	**Space Heat.Single.Rural.Ex**	480	473	411	398	358	334	289	254
RHRN	**Space Heat.Single.Rural.New**	85	84	120	116	155	145	182	160
RHUE	**Space Heat.Single.Urban.Ex**	728	717	696	633	664	559	632	442
RHUN	**Space Heat.Single.Urban.New**	79	78	111	101	143	121	168	118
RLIG	**Lighting**	131	129	138	138	143	140	147	143
ROEL	**Other Electric**	148	146	162	160	168	164	173	168
ROEN	**Other Energy**	0	0	0	0	0	0	0	0
RREF	**Refrigeration**	70	70	72	72	73	73	74	74
RWME	**Water Heat.Multi.All.Existing.**	17	15	15	14	12	10	11	10
RWMN	**Water Heat.Multi.All.New**	28	25	43	40	59	49	72	69
RWRE	**Water Heat.Single.Rural.Ex**	147	129	125	116	109	95	88	85
RWRN	**Water Heat.Single.Rural.New**	56	49	88	81	120	104	145	140
RWUE	**Water Heat.Single.Urban.Ex**	227	203	217	191	207	160	197	185
RWUN	**Water Heat.Single.Urban.New**	52	47	83	73	113	88	137	128

INDUSTRIAL SECTOR DEMAND:

80% Scenario			2020	2020	2030	2030	2040	2040	2050	2050
	Unit	Description	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80	BaU	CO2-80
ICH	PJ	Other Chemicals	287	283	318	294	326	326	333	303
INF	PJ	Other Non Ferrous Metals	379	374	420	388	430	430	440	400
INM	PJ	Other Non Metallic Minerals	94	93	103	97	103	103	103	91
IOI	PJ	Other Non energy intensive	711	700	764	707	764	764	762	694
ICM	Mt	Cement	5	5	5	5	6	5	6	5
ILM	Mt	Lime	0	0	0	0	0	0	0	0

95% Scenario			2020	2020	2030	2030	2040	2040	2050	2050
	Unit	Description	BaU	CO2-95	BaU	CO2-95	BaU	CO2-95	BaU	CO2-95
ICH	PJ	Other Chemicals	287	283	318	294	326	326	333	283
INF	PJ	Other Non Ferrous Metals	379	374	420	388	430	430	440	374
INM	PJ	Other Non Metallic Minerals	94	93	103	95	103	103	103	80
IOI	PJ	Other Non energy intensive	711	700	764	707	764	764	762	648
ICM	Mt	Cement	5	5	5	5	6	5	6	5
ILM	Mt	Lime	0	0	0	0	0	0	0	0

TRANSPORT SECTOR DEMAND:

80% Scenario			2020	2020	2030	2030	2040	2040	2050	2050
TIMES Code	**Units**	**Description**	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**	**BaU**	**CO2-80**
TAI	**PJ**	**Aviation International**	55	55	59	59	62	62	64	64
TAV	**PJ**	**Aviation Generic**	0	0	1	1	1	1	1	1
TNA	**PJ**	**Navigation**	34	32	38	35	41	36	45	37
TNB	**PJ**	**Navigation Bunker**	3	3	3	3	3	3	3	3
TBI	**MPkm**	**Road Bus Intercity**	5,690	5,604	6,026	5,936	6,272	6,131	6,523	6,328
TBU	**MPkm**	**Road Bus Urban**	1,422	1,422	1,507	1,484	1,568	1,568	1,631	1,582
TCL	**MPkm**	**Road Car Long Dist**	44,693	44,023	51,708	50,933	55,784	54,529	59,856	58,061
TCS	**MPkm**	**Road Car.Short Dist**	11,206	11,038	12,965	12,770	13,986	13,986	15,007	15,007
TMO	**MPkm**	**Road Moto**	522	506	571	562	600	587	630	611
TTL	**MPkm**	**Rail Pass. Light**	128	128	136	136	141	141	147	147
TTP	**MPkm**	**Rail Pass. Heavy**	1,944	1,915	2,059	2,028	2,143	2,095	2,229	2,162
TFR	**MTkm**	**Road Freight**	22,258	21,924	24,984	24,609	27,239	26,014	29,631	27,853
TTF	**MTkm**	**Rail Freight**	369	364	415	408	452	442	492	477

95% Scenario			2020	2020	2030	2030	2040	2040	2050	2050
TIMES Code	Units	Description	BaU	CO2-95	BaU	CO2-95	BaU	CO2-95	BaU	CO2-95
TAI	PJ	Aviation International	55	55	59	59	62	62	64	64
TAV	PJ	Aviation Generic	0	0	1	1	1	0	1	0
TNA	PJ	Navigation	34	32	38	35	41	36	45	37
TNB	PJ	Navigation Bunker	3	3	3	3	3	3	3	3
TBI	MPkm	Road Bus Intercity	5,690	5,604	6,026	6,026	6,272	6,131	6,523	6,328
TBU	MPkm	Road Bus Urban	1,422	1,401	1,507	1,507	1,568	1,533	1,631	1,582
TCL	MPkm	Road Car Long Dist	44,693	44,023	51,708	50,933	55,784	54,529	59,856	58,061
TCS	MPkm	Road Car.Short Dist	11,206	11,038	12,965	12,770	13,986	13,986	15,007	15,007
TMO	MPkm	Road Moto	522	514	571	562	600	587	630	592
TTL	MPkm	Rail Pass. Light	128	128	136	136	141	141	147	142
TTP	MPkm	Rail Pass. Heavy	1,944	1,915	2,059	2,028	2,143	2,095	2,229	2,028
TFR	MTkm	Road Freight	22,258	21,924	24,984	24,609	27,239	25,401	29,631	27,853
TTF	MTkm	Rail Freight	369	364	415	408	452	442	492	448

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