

The Irish Energy Tetralemma

A Framework for Fuel
Choices in Ireland

August 2010

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This report is presented in two parts:

- Part 1 presents the Energy Tetralemma and the policy options for long-term energy in Ireland from a competitiveness and enterprise perspective and proposes a number of overarching policy options for long-term energy policy in Ireland.
- Part 2 presents the analysis of the Energy Tetralemma in more detail and discusses a number of trade-off positions for each fuel type.

This report should be read in conjunction with the 11 fuel specific reports and the report outlining the enterprise opportunities associated with a particular fuel, produced under the framework of the Energy Tetralemma Index for Ireland.

The 11 fuel reports comprise: Coal, Petroleum, Natural Gas, Peat, Biomass, Wind, Solar, Marine, Geothermal, Hydro and Nuclear.

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Part 1

The Energy Tetralemma Overview and Policy Implications

Executive Summary

Introduction

Infrastructure policy and in particular energy policy needs a longer-term framework for development primarily because of the long lead-in times in implementing policy decisions. It is not unusual to look at energy policy within a 30-40 year time horizon.

A competitive, secure, sustainable energy supply is vital for the competitiveness of Irish business into the future both in terms of the requirements of existing firms but also the type of energy requirement for emerging sectors in the future.

The enterprise implications of energy choices are also very significant. The energy choices made may create new businesses and determine the technological development that is undertaken in Ireland, the skills and expertise acquired and the machinery and equipment, the processes and the services that Irish businesses will be able to market abroad.

Recently the concept of fossil fuel depletion has become an area of increasing concern among energy policy makers, particularly the debate around the peaking of oil. This is of critical importance to Ireland as one of the most fossil fuel dependent economies with over 92 per cent import dependence for our primary energy requirements.

The debate around climate change is also shifting in terms of looking not just at the reduction of CO₂ emissions in combating climate change but also looking at adaptation measures in addressing the impact of climate change on energy policy.

Energy policy has entered a new era, with more aggressive policies aimed at mitigating and adapting to climate change with energy policy in the EU and to date in Ireland following a three pillar approach of:

- Competitiveness
- Security of Supply
- Environment (Climate Change)

It is accepted, in developing energy policy, that many trade-offs exists among the pillars.

From a competitiveness perspective, particularly in the longer-term, the energy choices made today will influence the products, processes and services that Irish businesses sell into international markets and the R&D that will be undertaken in Ireland and the investments to be made in skills and infrastructure development. Competitiveness should be viewed within a broader context not only in terms of cost competitiveness but also to include the enterprise opportunities associated with a particular fuel choice. The regulatory environment is also an important determinant of competitiveness, and regulation, combined with market conditions, has an important effect on the costs of particular fuel choices. This is particularly because environmental and climate change considerations are increasingly affecting the final price paid by the user.

The environment pillar has a dominant focus on climate change, primarily consisting of reducing green house gas emissions (GHG). Recently the concept of fossil fuel depletion has become an area of increasing concern among energy policy makers. A new outlook on the long-term availability of supplies of primary fuels has entered the policy debate. Future availability of primary energy fuels is an important consideration for long-term energy policy formulation because of considerable trade-offs with the other goals of current European

policy pillars of climate change, security of supply, and competitiveness. With global primary energy demand projected to increase by 53 per cent to 2030, upward pressures on primary fuel sources will be experienced on a worldwide basis. The concept of sustainability also takes into account non GHG impacts, such as other pollutants, and ecological and social impacts.

Additionally, when taking a long-term perspective on energy policy, the impact of climate change in terms of changing weather patterns and other effects needs to be taken into account in assessing appropriate fuel choices.

The distinction between sustainability and climate change is important because the two objectives can create conflicts. A decision based on short-term risks and goals for climate change could contravene efforts to make energy policy sufficiently sustainable for the long-term. For example, a high percentage of natural gas in the fuel mix might be the preferred option to reduce Ireland's carbon emissions; however because of the inherent sustainability issues with natural gas as a fossil fuel, the degree of long-term environmental sustainability in Irish energy policy could suffer as a result.

Irish energy policy needs to be cognisant of pan-European goals, while also taking into account Ireland's unique challenges:

- Ireland has no significant indigenous fossil fuel reserves and as a result has to import over 92 per cent of its primary energy requirement, making it highly exposed to the state of global fuel reserves and prices set in international commodity markets. Also, Ireland is one of the most oil-dependent countries in the world.
- Ireland's relatively small economy and domestic market impact on the country's ability to secure cheaper fuels and attract inward investment in energy systems, as well as on its ability to achieve the required scale for deploying a significant range of energy technologies.
- Ireland is a small market at the edge of Europe - as an island we are further constrained in our diversity and security of supply options, e.g. pipeline gas and electricity.

Energy policy needs to recognise the key challenges outlined above and to address them by minimising their negative impact and turning them as far as possible into advantages or stimuli for development.

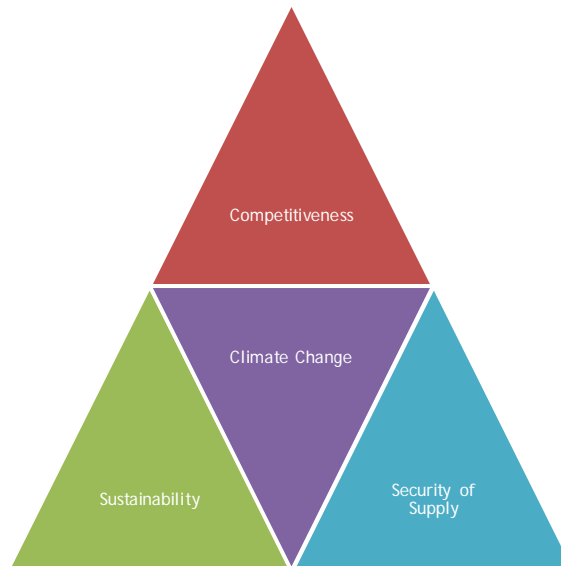
In order to plan adequately for the realities that will accompany fossil fuel depletion, sustainability is best viewed as a stand-alone objective. Therefore, ideally long-term energy planning in Ireland will need to take account of four, rather than three objectives: competitiveness, security of supply, climate change, and sustainability. When combined, these four pillars create the Energy Tetralemma which can be used as a comprehensive framework for the formation of long-term energy policy in Ireland in order to:

- explicitly examine the sustainability issue (in terms of fuel longevity but also in terms of other environmental impacts); and
- look at energy policy in the longer-term to address the question of the impact of energy policy on climate change and the converse impact of climate change on energy policy.

The Tetralemma Index is an integrated approach to measuring the trade-offs between the four policy objectives. It provides a comprehensive review of all relevant fuel types for

Ireland and a quantified and flexible index for the key fuels within separable components under the specific headings of competitiveness, security of supply, sustainability and climate change.

The Energy Tetralemma Framework - concept and scope



The Energy Tetralemma Index categorises twenty fuel categories across fossil, renewable and other fuels against the four pillars, each pillar being made up of a set of indicators - a total of sixteen indicators across the four pillars- over three time frames (2010, 2020, 2030) and across three scenarios. A full list of fuel categories is presented in the follow up table. Enterprise opportunities relating to a particular fuel choice are considered as part of the competitiveness pillar and appropriate indicators are included. A full list of the indicators is discussed in section 2 of the report.

The results from the index can be used in determining the attractiveness of each fuel type in meeting the competing policy objectives. All fuel types were reviewed - currently nuclear energy in Ireland is prohibited by statute, brown coal is not part of the energy system and peat will be phased out by 2020 due to EU directives.

Each fuel has been assessed in terms of its primary energy use, be it in electricity generation, transport or heat. It is clear that a mixture of fuels will be required out to 2030 to satisfy energy demand. While the contribution of renewables will increase, fossil fuels will still play a strong role in the future in Ireland.

Fuels, Categories and Main Applications in the Tetralemma Index

Fuel Type		Main Application	Fuel Type		Main Application
Main Category	Sub-Category		Main Category	Sub-Category	
Fossils			Renewables		
Coal	Brown Coal	Electricity	Biomass	Woody Biomass	Electricity
	Black coal	Electricity		Non-woody Biomass	Transport
Oil	Conventional Oil	Transport		Bio-residues	Electricity
	Unconventional Oil	Transport		Bio-gas	Electricity
Gas	Natural gas	Electricity	Wind	Onshore wind	Electricity
	LNG-Liquefied Natural Gas	Electricity		Offshore wind	Electricity
Peat	Peat	Electricity	Solar	Solar Thermal	Heat
				Solar Photovoltaics (PV)	Electricity
Nuclear			Marine	Wave	Electricity
Nuclear	Nuclear fission	Electricity		Tidal	Electricity
			Geothermal	Geothermal	Heat
			Hydro	Hydro	Electricity

The Energy Tetralemma Index does not of itself provide a portfolio analysis of the whole energy system, although it could be used as part of such an exercise. What it does is provide a summary of the relative attractiveness or appropriateness of different fuels, depending on the policy priorities adopted and the assumptions about wider market-related changes worldwide.

In this work Forfás was assisted by a steering group of energy experts comprising representatives from the Department of Communications, Marine and Natural Resources (DCENR), the Sustainable Energy Authority of Ireland (SEAI), Discover Science and Engineering (DSE) and Forfás. Forfás commissioned an international energy consultancy firm, SQW Energy to assist in the development of the Energy Tetralemma Framework and carry out the detailed

data and information assembly required. It also engaged a panel of international energy experts to peer review the Index - Professor Frank Incropera, Aerospace & Mechanical Engineering, University of Notre Dame, United States, Professor Michelle Michot Foss, Chief Energy Economist, University of Texas at Austin, United States and Professor Pantelis Capros, Head of Energy Economics and Operations Research, National Technical University of Athens, Greece. Wider consultation also took place at national and international levels.

Key Findings

- A complex picture emerges from bringing together the range of dimensions explored by the study. There is recognition that fossil fuels will continue to play a part in Ireland's future fuel mix, particularly as back-up generation will be required for a heavy penetration of renewables (specifically wind);
- Overall the relative ranking of fuels was most influenced by three factors - the national policy and regulatory framework, commodity and technology prices, and the stage of technological development;
- The prospect of renewable energy becoming fully competitive in terms of delivered energy costs as technology matures is significantly influenced by policy and regulatory support;
- Fossil fuels continue to outperform renewables and nuclear energy under the competitiveness pillar out to 2030 in terms of their attractiveness in meeting cost competitiveness objectives. However, fossil fuels are not as attractive in terms of security of supply, sustainability and climate change over that period;
- Black coal and in some instances LNG (Liquefied Natural Gas) are the exceptions to the relative unattractiveness of fossil fuels and perform well under security of supply and climate change pillars, although this is on the assumption that clean coal and other technologies will develop commercially to 2030;
- The extent to which policy is supportive plays a major role in the development of offshore wind and marine energy;
- Solar thermal and geothermal are consistently high scorers for heat applications for Ireland;
- Despite nuclear having competitive delivered energy costs overall, its competitiveness on the whole is relatively low, primarily because of the absence of a supportive policy and regulatory context in Ireland; and
- Enterprise opportunities are particularly favourable for black coal, LNG, wind, with long-term potential for offshore wind, assuming a favourable policy context.

Pillar Specific Objectives

As a first step each pillar within the Energy Tetralemma was examined in isolation under three different scenarios, thereby focussing on one set of policy objectives alone and identifying the best performing fuels to meet the particular policy requirements. The scenarios were developed separately, to provide background for the analysis. They are based

on different assumptions about what might happen especially at a global level in terms of resource availability, price evolution, technological development and regulatory change.

The scenarios considered are as follows:

High Scenario	Cheap, clean, secure and advanced energy system with low commodity prices, carbon capture and storage (CCS) deployment developed and a high carbon price.
Medium Scenario	Fossil fuel dominance in a moderately inexpensive, relatively clean, reasonably secure and conservatively advanced energy system with medium range commodity prices, CCS deployment underway and a medium carbon price.
Low Scenario	Expensive, dirty, insecure and less-advanced energy system with high commodity prices, no CCS deployment and a low carbon price.

A number of different trade-off positions were explored in this project varying from equal weighting positions for all the policy objectives to a greater degree of focus on competitiveness issues.

Competitiveness

Competitiveness shows a mixed picture where fossil fuels as a group are nominally more competitive than renewables across all scenarios, particularly in the short-term, but fuels such as solar thermal and biogas become very attractive in several scenarios and time periods for heat applications.

Of the fossil fuels, natural gas tends to achieve the higher scores on competitiveness with a slight decline in terms of attractiveness over time and is only outperformed by black coal in the medium scenario. Clean coal is a choice that, much like renewables, requires policy support and investment in advanced technology. Oil tends to be in the middle of the league table in all scenarios, but in reality it remains the only viable option for transport, in the short-term.

In all three scenarios, renewables improve their competitiveness by 2030 and in some instances outperform some of the fossil fuels. Onshore and offshore wind occupies a middle band, increasing over time. Wave and tidal also increases their attractiveness over time in the high scenario based on the assumption of a high carbon price and the full implementation of the Energy White paper.

Nuclear consistently shows low index of attractiveness scores due a lack of policy support and complex regulatory regimes, despite its low delivered cost which in fact is comparable to that of coal and is cheaper than gas on international markets.

Security of Supply

Security of supply is dominated by renewables, which are indigenous to Ireland (no import dependence) but form a relatively small proportion of the total primary energy supply (TPES).

While renewables are relatively secure, their low capacity factor (due to intermittency of resource) and the short-term supply chain bottlenecks act to offset their attractiveness. Geothermal energy is consistently a favoured option for heat applications. Wave and tidal energy are the lowest scoring among the renewables but still rank above most of the fossil fuels with the exception of black coal.

Nuclear energy emerges as one of the most secure options, often outperforming many renewable sources and much more attractive than fossil fuel alternatives for electricity generation.

The main fossil fuels, black coal, oil and gas, have much lower security than renewables and their positions, except that of black coal, deteriorate over time in all three scenarios. Black coal shows a significant improvement relative to the other fossil fuels, explained by its almost ubiquitous availability globally. Peat is an indigenous fuel and thus secure, but it cannot play a long-term role in Ireland's energy mix due to various European nature conservation regulations and policies, which restrict its use. Natural gas and oil are the lowest scoring of the fossil fuels across all scenarios and all timeframes, primarily because of Ireland's import dependence and the fact that in the longer-term these fuel supplies will be sourced from riskier countries.

Sustainability

As the indicators under the sustainability pillar (i.e. fuel longevity and environmental impact) will not be influenced by any of the conditions within the scenarios, the resulting values under this pillar for each fuel, across all scenarios are similar. There is again a clear, explicit divide between the high-scoring renewable options and low-scoring fossil fuels and sustainability displays the widest spread of scores. This is due to renewables' very nature of being both replenishable (infinite availability) and having a low environmental impact. Biogas is the one exception due to diminishing reserves as a result of stringent waste policy and regulation.

Most fossil fuels maintain their scores and positions between 2010 and 2030. Coal and unconventional oil start out with relatively higher reserves, but by 2030 these reserves rapidly diminish resulting in a low index score. Conventional oil is the least sustainable fuel altogether and natural gas (both varieties) have the highest positions from among the fossil fuels. Longevity of selected fuels in 2030 is as follows: gas - 21 years; coal - 87 years; oil - 16 years and unconventional oil - 208 years.

Climate Change

Climate change sees some of the widest ranges of scores and some of the most dynamic evolution over time to 2030. Renewables firmly occupy the upper end of the score spectrum but there is clear stratification, with solar and geothermal being at the top, followed by biomass and marine. Hydro is the least viable renewable option in terms of climate change. Wind and offshore wind in particular, is the only renewable energy that sees a decline in scores as climate change conditions continue to become more extreme. These results begin to answer the question of what is the impact of climate change on energy policy.

Fossil fuels fluctuate considerably with black coal being the most sensitive fuel. Its performance depends heavily on whether CCS technology is commercialised. CCS deployment results in black coal becoming the most climate friendly fossil fuel by 2030 and in the absence

of CCS it is one of the least viable fuels. Natural gas is by its nature one of the lowest-carbon fossil fuels and in most scenarios and timescales it achieves the highest scores in the group. Oil and peat consistently remain the least climate-friendly option overall.

Trade-Off Positions

Having examined each of the pillars in isolation, a number of differing trade-off positions were analysed by applying a particular combination of weightings across the four pillars. The three different approaches analysed are as follows:

- Equal weightings where a value of 25 per cent was assigned to each pillar -with each policy objective having a similar importance;
- By mirroring the traditional three pillar approach with competitiveness and security of supply being assigned a weighting of 33.3 per cent respectively with 16.65 per cent assigned to sustainability and climate change; and
- Competitiveness issues, particularly from an enterprise perspective are most important: in this particular example a weighting of 70 per cent was assigned to competitiveness with a weighting of 10 per cent to each of the other three pillars.

Results from the three differing weighted positions are presented below.

Equal weightings - 25 per cent Competitiveness / 25 per cent Security of Supply / 25 per cent Sustainability / 25 per cent Climate Change

In terms of equal weightings for the four competing objectives across all scenarios, fossil fuels occupy the lower band of scores with renewables achieving the higher scorings. The main reason behind this is that fossil fuels do not score well on carbon emissions reductions and sustainability issues, combined with dependency on imported fuels. Conventional oil is the lowest scoring fuel in terms of meeting the four equally weighted competing objectives. In terms of renewables, solar thermal and geothermal score are most attractive for heat applications with solar PV and onshore wind most attractive for electricity generation. Nuclear energy is ranked in the middle between renewables and fossil fuels. Over the time period out to 2030 the attractiveness of the varying fuel types does not converge.

Traditional “Three Pillar” Approach - 33.3 per cent Competitiveness / 33.3 per cent Security of Supply / 16.65 per cent Sustainability / 16.65 per cent Climate Change

This particular weighting arrangement mirrors the traditional three pillar approach. Increasing the weight given to competitiveness and security of supply is not sufficient to create a radical break for the results obtained when all pillars were assigned equal weightings, but a slight convergence is noted. Renewables still outperform fossil fuels with an increasing gap over time for all scenarios. Nuclear still remains in a middle band between renewables and fossil fuels but in terms of attractiveness is closer to renewables. Conventional oil is the least attractive for all fuels studied with the performance of coal again very much dependent on the scenario and the state of deployment of CCS.

A Strong Focus on Competitiveness - 70 per cent Competitiveness / 10 per cent Security of Supply / 10 per cent Sustainability / 10 per cent Climate Change

With the severity of the current economic downturn and the high price of electricity in Ireland, competitiveness issues, particularly from an enterprise perspective are most important. In this particular example competitiveness is weighted much more strongly than the other pillars. Initially the index is quite mixed with no clear distinction between renewables, nuclear and fossil fuels. However, over time out to 2030 a separation becomes apparent with renewables scoring higher than fossil fuel alternatives. Peat and nuclear are among the lowest scoring fuels across all scenarios and all timeframes, with solar thermal and biogas amongst the most attractive. This is based on the assumption that increasing the penetration of renewable energy fuel supplies within the Irish portfolio leads to a reduction in the marginal cost of delivered energy. The price of carbon in the longer term will also influence the final delivered energy cost.

Policy Implications

The analysis of the Energy Tetralemma shows the complex environment that energy policy needs to take into account and the competing objectives to which it needs to respond. A number of policy responses are necessary to ensure a competitive, secure and sustainable energy system that also addresses the challenges of climate change. Each pillar within the Energy Tetralemma was examined in isolation, (in other words, assigning 100 per cent weighting to one pillar), thereby focusing on one set of policy objectives alone and identifying pillar specific policy directions as set out below.

Pillar Specific Policy Directions

If Competitiveness alone is the key objective:

- Change the policy and regulatory environment for black coal and incentivise the adoption of new conversion technologies and carbon capture and storage, allowing for realisation of coals existing advantages in fuel and delivered energy costs.
- A technical and economic feasibility study of the possible use of nuclear energy should be undertaken and incorporated into the policy debate.
- Only by funding research into the deployment of renewable energy alternatives, particularly offshore wind and marine technology, will they become competitive as economies of scale lead to a reduction in delivered energy costs.
- Available resources of biogas and bio-residues should be promoted and more effectively utilised as these are competitive under most scenarios.
- Solar thermal is very competitive as a heat application and needs increased policy support.

If Security of Supply alone is the key objective:

- Shift from imported fossil fuels to domestically available renewable alternatives where practical, allowing for intermittency difficulties.
- Following a technical and economic feasibility study, consider nuclear as an alternative to fossil fuel for base load back up generation for high levels of renewables on the system.
- Keep coal as part of the generating mix on account of its larger reserves from more stable regions.
- Oil use should be avoided where possible.

If Sustainability alone is the key objective:

- Rapidly shift from fossil fuels to renewables where possible based on their superior environmental performance and infinite supply.
- Avoid all fossil fuels due to extremely limited global reserves to production ratios.
- In a choice between fossil fuels and nuclear for sustainable electricity generation, go

with the latter, subject to a technical and economic feasibility study.

- If continuing to use fossil fuels, LNG should be prioritised over coal and natural gas.
- Closely monitor the sustainability of biomass production to ensure its long term availability and minimal environmental impact.

If Climate Change alone is the key objective:

- Shift from fossil fuel electricity generation to greater use of renewables.
- Choose nuclear over fossil fuels subject to a technical and economic feasibility study.
- Pursue Carbon Capture and Storage (CCS) which substantially benefits black coal and, to a lesser extent, gas.
- Fund research into how offshore wind and marine can protect against climate change induced infrastructure vulnerability.
- Ensure that current biomass will be available under altered climatic conditions.

Whether one analyses each pillar on an individual basis or assesses the trade-off positions there are a number of overarching policy directions that are necessary as follows:

Overarching Policy Directions

- The long-term energy fuel mix for Ireland should be diverse and flexible and not as reliant on fossil fuels as it is today.
- Significant expansion/reinforcement/renewal of the transmission grid will be required over the next decade to support the renewables targets and demand growth. Progression towards a smart energy grid should be a top priority for infrastructure spending.
- Enhanced electricity interconnection between Ireland and the UK is necessary to improve security of supply; additionally, a connection between Ireland and mainland Europe should be assessed.
- Identify and implement regulatory, legislative and planning process changes for competitive, long-term energy development. Develop a new, integrated planning regime for energy projects.
- Ensure that energy-related research funding is focused on demonstration and commercialisation.
- Consider the introduction of a nuclear regulatory regime in Ireland that would allow Ireland to benefit from nuclear's good sustainability and climate change characteristics and comparatively low delivered energy cost. This would be subject to a technical and economic feasibility study.
- Carbon Capture and Storage (CCS) plans should be extended to all types of fuel generation plants in Ireland by 2020, and all plants should be CCS ready by 2030.
- Review the adequacy of Ireland's current strategic storage requirements and consider increasing oil reserves at gas-fired generation plants as an alternative to increasing gas

storage.

- The Sustainable Travel and Transport Plan published by the Department of Transport should become a priority for cross-departmental implementation.
- Increase the uptake of solar thermal and geothermal for heating purposes by enhancing planning regulations or developing market incentives for heat supplies.

1. Introduction & Background

Energy is essential in almost every aspect of life and its importance for economic growth cannot be overstated. Energy policy plays a strategic role in the development of Ireland's economic future and underpins Ireland's competitiveness as a nation. A long-term policy perspective is vital in the creation of Irish energy policy because of the far-reaching implications of today's decisions on tomorrow's reality. Energy policy has entered a new era, with more aggressive policies aimed at mitigating and adapting to climate change. Future environmental and economic impacts will be directly related to Ireland's current energy policies.

Perhaps more so than any other policy area, energy has the ability to dramatically contribute to a successful Irish economy. With global primary energy demand projected to increase by 53 per cent to 2030, upward pressures on primary fuel sources will be experienced on a worldwide basis. Ireland's geographic location, the small size of its internal market and its current heavy reliance on imported fossil fuels (Ireland is over 92 per cent import dependent for its energy needs) means that it is vulnerable to physical disruptions in fuel supplies as well as to increasing prices on world markets. A successful future business environment must include the availability of secure, reliable, sustainable energy sources that are offered at comparably competitive rates.

The enterprise implications of energy choices are also very significant. The choices made will affect the technological development that is undertaken in Ireland, the skills and expertise acquired, and the machinery and equipment, the processes and the services that Irish businesses will be able to market abroad. Other countries are recognising the importance of energy-related and environment-related goods and services as opportunities for the future, and it is important to consider in Ireland's case not only the immediate issues of energy policy for their effects on existing enterprises but also the growth path for the future that new energy sources can provide. The report of the High Level Group on Green Enterprise Opportunities highlights that the effective use of our natural resources in terms of wind and wave for energy production can drive exports and job creation for the Irish economy.

1.1 Energy Policy in Ireland

Energy policy in Ireland is based on the Government's White Paper on Energy, published by the Department of Communications, Energy and Natural Resources, which sets out an energy framework from 2007-2020 to deliver a sustainable energy future for Ireland. It is centred on ensuring security of supply, promoting the sustainability of energy supply and enhancing the competitiveness of energy supply through an integrated approach for delivery. The White Paper follows the three pillar approach to energy policy as used by the European Commission i.e.:

- Competitiveness
- Security of Supply
- Environment (Climate Change)

Under the European model, the environment pillar has a dominant focus on climate change, with the emphasis on reducing greenhouse gas emissions.

Recently the concept of fossil fuel depletion has become an area of increasing concern among energy policy makers. A new outlook on the long-term availability of supplies of primary fuels has entered the policy debate. Future availability of primary energy fuels is an important consideration for long-term energy policy formulation because of considerable trade-offs with the other goals of current European policy pillars of climate change, security of supply, and competitiveness. Additionally, when taking a long-term perspective on energy policy, the impact of climate change in terms of changing weather patterns and other effects need to be taken into account in deciding appropriate fuel portfolios.

The distinction between sustainability and climate change is important because the two objectives can create conflicts. A decision based on short-term risks and goals for climate change could counter efforts to make energy policy sufficiently sustainable for the long-term.

Long-term energy planning raises questions on trade-offs in selecting energy policies for Ireland, such as:

- What impact does a short-term focus on competitiveness have on long-term availability of a fuel resource?
- Is there a way to promote sustainable energy production while reducing costs and carbon emissions?
- How will long-term climate changes affect prices?

Irish energy policy must complement pan-European goals, while also taking into account Ireland's unique challenges. Ireland faces similar energy challenges to those confronted worldwide but Ireland's situation is more acute due to the small size of the internal energy market, Ireland's peripheral geographic location, and its limited indigenous fuel supplies. A new framework with which to weigh the trade-offs of long-term implications on energy policy is needed for Ireland.

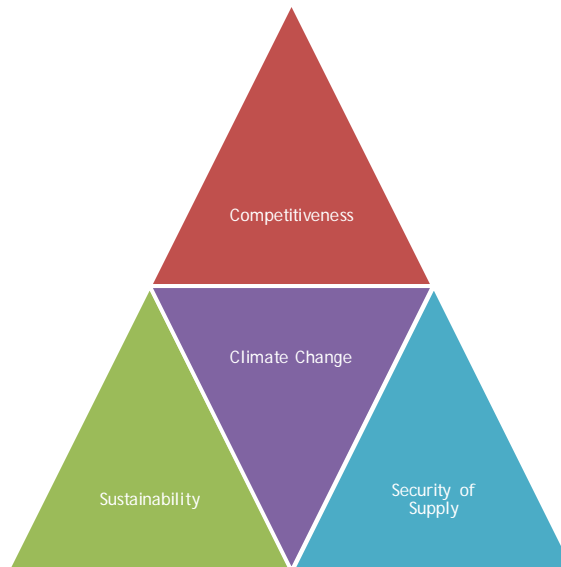
From a competitiveness perspective, particularly in the longer-term, the energy choices made today will influence the products, processes and services that Irish businesses sell into international markets and the R&D that will be undertaken in Ireland and the investments to be made in skills and infrastructure development. Competitiveness should be viewed within a broader context not only in terms of cost competitiveness but also to include the enterprise opportunities associated with a particular fuel choice. The regulatory environment is also an important determinant of competitiveness, and regulation, combined with market conditions, has an important effect on the costs of particular fuel choices. This is particularly because environmental and climate change considerations are increasingly affecting the final price paid by the user.

In order to plan adequately for the realities that will accompany fossil fuel depletion, sustainability is best viewed as a stand-alone objective. Sustainability refers to energy resources and their continued availability to Ireland. Limited non-renewable resources, such as oil, are considered unsustainable energy sources. Sustainability is a function of the use of renewable energy resources, such as wind, hydro, and solar. This separation also allows for the more explicit long-term examination of climate change in terms of mitigation but also in terms of adaptation, in other words assessing the impact of energy policy on climate change but also the impact of climate change on energy policy.

Therefore, long-term energy planning in Ireland can usefully be examined in relation to four objectives rather than three: competitiveness, security of supply, climate change, and environmental sustainability. When combined, the four objectives/pillars form the base of

the Energy 'Tetralemma' which can be used as a comprehensive framework for the formation of long-term energy policy in Ireland, (see Figure 1 below). Forfás has developed an integrated approach to measuring the trade-offs between the four policy objectives, by examining the role of different fuel types through quantitative indices under the specific pillars.

Figure 1: The Energy Tetralemma Framework - concept and scope



In this work Forfás was assisted by a steering group of energy experts comprising representatives from the Department of Communications, Marine and Natural Resources (DCENR), the Sustainable Energy Authority of Ireland (SEAI), Discover Science and Engineering (DSE) and Forfás. Forfás commissioned an international energy consultancy firm, SQW Energy¹ to assist in the development of the Energy Tetralemma Framework and carry out the detailed data and information assembly required. It also engaged a panel of international energy experts to peer review the Index - Professor Frank Incropera, Aerospace & Mechanical Engineering, University of Notre Dame, United States, Professor Michelle Michot Foss, Chief Energy Economist, University of Texas at Austin, United States and Professor Pantelis Capros, Head of Energy Economics and Operations Research, National Technical University of Athens, Greece. Wider consultation also took place at national and international levels.

2. Objectives & Methodology

2.1 Objectives

The focus of this particular piece of work is on the assessment of fuel choices for enterprises into the future, both in terms of an input into energy policy but also in realising the enterprise opportunities that may arise.

The outputs for this study are twofold:

- A comprehensive review of all relevant fuel types for Ireland, taking into account the trade-offs associated with the four pillars of the Energy Tetralemma resulting in 11 fuel reports, and;
- A fully quantified and flexible Tetralemma index for the key fuels with separable components under the specific headings of competitiveness, security of supply, environmental sustainability and climate change across three timeframes of 2010, 2020 and 2030, and three scenarios.

This paper provides an enterprise perspective and builds on the commissioned research by SQW Energy on long-term energy policy in Ireland and the enterprise opportunities that may arise. It presents the results using the quantitative Tetralemma index and prescribes policy options for long-term energy choices for Ireland.

2.2 Methodology

The Energy Tetralemma Index categorises twenty fuel types across fossil, renewable and other fuels (or energy sources) against fifteen indicators under the four dimensions ('pillars') - competitiveness, security of supply, sustainability and climate change. The study looked at three broad future scenarios (high, medium and low) over three timescales (2010, 2020 and 2030) on the key dimensions of commodity and carbon prices, technological development, the policy and regulatory environment and international markets. To provide an evolving view of outputs across the four pillars, the Index employs a systems analysis technique by using distinct scenarios to represent possible future factors which would affect the outcome of the scores for each fuel.

The main assumptions for the development of each of the time frames were:

- Markets evolution;
- Technology development and deployment; and
- Policy formulation, implementation and regulation.

Assumptions were first formulated for the 2030 timeframe, as a 'final' outcome, and then traced back to 2010 in a broadly gradual trend.

In addition to the Index itself, 11 comprehensive fuel reports which covered detailed analysis of each fuel type and its application in Ireland, and a separate report on the enterprise opportunities associated with a particular fuel choice, along the four pillar framework, have been produced.

The Index is best considered in conjunction with the 11 fuel reports. By viewing both the Index and the fuel reports together, a more complete picture of each fuel's advantages and disadvantages across three timeframe, three scenarios, and four policy pillars emerges.

High scenario ('optimistic')

This scenario assumes the most favourable conditions in 2030 across all four pillars of the Tetralemma Index - 'cheap, clean, secure and advanced energy system'.

- Low commodity prices;
- Uptake of advanced fossil-fuel conversion technologies;
- Carbon capture and storage deployment;
- Renewables technologies are fully developed and deployed (e.g. marine, solar, geothermal) and achieve economies of scale;
- 'Environment-friendly' Irish and international policy framework - sustainability and climate change remain top priorities;
- High carbon price;
- The Irish Energy White Paper is fully implemented; and
- Relatively stable/predictable/open international markets (certainty).

Low scenario ('pessimistic')

This scenario assumes the least favourable conditions in 2030 across all four pillars of the Tetralemma Index - 'expensive, dirty, insecure and less-advanced energy system'.

- High commodity prices;
- Low/no uptake of advanced fossil-fuel conversion technologies;
- No Carbon capture and storage deployment;
- Renewables technologies are slow to develop and deploy (e.g. marine, solar, geothermal) and do not achieve economies of scale;
- 'Competitiveness-friendly' Irish and international policy framework - cheapest options supported;
- Low carbon price;
- The Irish Energy White Paper only partly implemented; and
- Unstable/volatile/politically-driven international markets (uncertainty).

Medium scenario ('neutral')

This scenario uses a mixture of assumptions from the high and low scenarios in terms of 'extreme values'; for some parameters it also takes the 'central forecasts' (as opposed to the extreme values). The scenario can be described as 'fossil fuel dominance in a moderately inexpensive, relatively clean, reasonably secure and conservatively advanced energy system'.

- Medium-range commodity prices;
- High uptake of advanced fossil-fuel conversion technologies on the basis of prudent investment and future-proofing;

- Carbon capture and storage deployment;
- Renewables technologies are deployed but only those that are already commercially viable (wind, solar); they achieve economies of scale and lower capital costs. Other renewables are not fully developed and deployed commercially (marine, geothermal);
- ‘Security-friendly’ Irish and international policy framework - most accessible and reliable supplies supported;
- Medium carbon price;
- The Irish Energy White Paper only selectively implemented; and
- Moderate level of certainty across international markets.

Energy efficiency is a critically important factor in the national energy system of Ireland, as in any other country. It should also be a key element of a national energy strategy. Energy efficiency was not considered in the Index as a fuel as such - it displaces fuel demand by reducing the energy service demand, be it electricity, heat or transportation. Moreover, energy efficiency comprises a very large and diverse range of measures, solutions and interventions. Nevertheless, energy efficiency as a concept and on the basis of its well established benefits, presents an ideal combination of cost-competitiveness, high security of supply, excellent sustainability performance and a sound measure to contribute to both climate change adaptation and mitigation. Therefore, from a policy perspective, energy efficiency should be considered first when assessing the options for improving Ireland’s performance and resilience against the four pillars subject to this study.

Although the Tetralemma Index does not explicitly examine energy efficiency as an energy source, other reports do examine this issue in greater detail. The 2009 Forfás ‘Opportunities in Energy Related Goods and Services’ paper highlights many areas in which Ireland could progress energy efficiency measures.

More detailed descriptions of the methodologies used and the results and analysis can be found in Part 2 of this report.

2.3 Definition of the Pillars in the Energy Tetralemma

Each pillar under the Energy Tetralemma is composed of a set of indicators with associated weightings. Both quantitative and qualitative indicators were used and the number within each pillar varies. Index scores are relative and absolute. This means that the Index is capable of ranking fuels in order, but the differences in the absolute scores would not necessarily correspond with the user’s perception of the policy gap.

Competitiveness

For the competitiveness pillar, five indicators were used as follows:

- Fuel Cost (5 per cent) - This is the commodity price of the fuel in different markets;
- Delivered Energy Cost (25 per cent) - This is the levelised cost excluding taxes and duties;
- Policy & Regulatory Framework (30 per cent) - Policy and regulatory barriers and incentives and includes the cost of carbon;

- Market Context (20 per cent) - Market conditions in Ireland that can affect the competitiveness of a fuel, for example access to the grid or final energy price; and
- Enterprise Opportunities (20 per cent) - Contribution to the national economy in terms of domestic market and export opportunities and employment benefit associated with a particular fuel choice.

Security of Supply

For the security of supply pillar five indicators were used as follows:

- Weighted Import Dependence (30 per cent) - Exposure of Ireland in terms of the imports and the percentage share in the total primary energy requirement;
- Fuel Place of Origin (20 per cent) - This indicator measures the level of access to the fuel;
- Supply and Infrastructure Resilience (20 per cent) - How complex and robust is the infrastructure associated with the fuel;
- Market Volatility (15 per cent) - Market supply-demand balance in terms of fuel commodity and the supply chain for conversion technologies; and
- Energy Availability/intermittency (15 per cent) - Measurement of the capacity factor of each fuel.

Sustainability

For the sustainability pillar, two indicators were used as follows:

- Fuel Longevity (55 per cent) - this measures the reserves-to-production ratio; and
- Environmental Impacts (45 per cent) - this indicator captures the externality cost incurred using the fuel.

Climate Change

For the climate change pillar four indicators were used as follows:

- Carbon Content of fuel (10 per cent) - This measures the carbon content of the fuel and does not take into account conversion efficiency;
- Lifecycle Carbon Footprint (55 per cent) - this is the carbon emissions produced per unit of delivered energy;
- Supply and Infrastructure (30 per cent) - this measures the risk of damage to and /or failure of the supply and infrastructure associated with the fuel as a result of climate change; and
- Availability Change (5 per cent) - this aims to qualify the extent to which fuel resources may be affected by climate change.

3. Analysis of Fuel Types

While many fuels supply energy in multiple ways (electricity, transport, or heat) the primary usage of each fuel was analysed for the purposes of this study. In total 11 fuel categories and 20 fuel types were analysed and are listed in Table 1 as follows.

Table 1: Fuels, Categories, and Main Applications in the Tetralemma Index

Fuel Type		Main Application
Main Category	Sub-Category	
Fossils		
Coal	Brown Coal	Electricity
	Black coal	Electricity
Oil	Conventional Oil	Transport
	Unconventional Oil	Transport
Gas	Natural gas	Electricity
	LNG-Liquefied Natural Gas	Electricity
Peat	Peat	Electricity
Renewables		
Biomass	Woody Biomass	Electricity
	Non-woody Biomass	Transport
	Bio-residues	Electricity
	Bio-gas	Electricity
Wind	Onshore wind	Electricity
	Offshore wind	Electricity
Solar	Solar thermal	Heat
	Solar Photovoltaic (PV)	Electricity
Marine	Wave	Electricity
	Tidal	Electricity
Geothermal	Geothermal	Heat
Hydro	Hydro	Electricity
Nuclear		
Nuclear	Nuclear fission	Electricity

A summary of the analysis of each fuel type under the four pillars is presented below. For more detailed analysis of each fuel, the fuel reports should be consulted. It should be noted, that while peat and brown coal will not feature in the energy mix out to 2030, for completeness both fuel types are considered in all the following discussions. Harvesting of peat in Ireland will be completely phased out within the next ten years, primarily due to EU directives. Brown coal, because it is only economic when the fuel can be extracted near the power plant, will not be used for electricity generation in an Irish context.

3.1 Coal

Black Coal

Coal offers a range of trade-offs and there is a clear distinction between black and brown coal. Black coal's main 'strength' is its competitiveness - it is a relatively cheap fuel as a commodity and delivered energy costs are also very low. This is driven by a high abundance of coal world-wide and diversity of supply options (competition) which maintain a low market price. Over time and through the different scenarios, competitiveness remains the main feature of black coal as commodity markets continue to be stable and conversion technology continues to improve (incrementally or more markedly (depending on the scenario)).

Overall security of supply of black coal scores in the mid range (at ca. 53 per cent in 2030) in the Index results and with the exception of peat scores the highest of the fossil fuels. This mid range result is compromised by the high exposure of Ireland to coal, as part of its energy mix, coupled with the fact that all of it is imported, notwithstanding the fact that coal is easily stock piled. Over time, security of supply of black coal improves slightly in all three scenarios.

Sustainability of black coal is relatively low compared to the other fuel types. On the one hand, this due to the fact the coal is a finite fuel which despite large global reserves will fall below the 100-year reserves-to-production ratio by 2030. On the other hand, coal has a very high negative environmental impact (at present) along its entire value chain, which is likely to remain a key issue in the future. As a result of these two trends, black coal's sustainability deteriorates over time in all three scenarios and is one of the lowest scoring fossil fuels.

In terms of climate change, black coal currently has a very negative profile as stack emissions are high. There are two main possible future paths in this respects related to the carbon capture and storage (CCS) technology. If CCS is deployed on a commercial scale in Ireland, this could transform coal's climate change profile dramatically - under the high and medium scenarios, climate change scores as highly as security of supply and is slightly below competitiveness. Without CCS, the climate change pillar will remain the weakest of the four pillars for coal.

In 2010, black coal provides domestic market value and employment due to the coal-fired power station at Moneypoint. From 2020 onwards, the potential for enterprise development for coal is high assuming the advent of carbon capture and storage. Ireland potentially has the opportunity both to build cleaner coal-fired power plants with CCS in Ireland, from which indigenous firms can benefit, and through demonstration, Irish firms could also gain expertise and develop technology which could then be exported. In terms of employment, global estimates suggest 0.1 person years per MW for operation and maintenance of coal-fired power plants.

Brown Coal

Brown coal's leading 'strength' is security of supply. It is abundant in many countries across the globe and is easily accessible. Because Ireland does not have any indigenous reserves, brown coal has a negligible share of the national energy mix and overall exposure and import dependence are low. The limited volumes of imports come from low risk countries in Europe and this will remain the case (primarily due to cost issues). Similarly, the supply chain and conversion technologies involved are relatively simple and resilient. Security will remain high over time and in all three scenarios.

The competitiveness of brown coal is low. This is particularly the case in Ireland which has no domestic reserves. Brown coal is economic where the fuel is close to the generation plant. Furthermore, due to its high sulphur and other chemicals content, ever more stringent policy and regulation will undermine its competitiveness.

As with black coal, both sustainability and climate change are fairly low. Sustainability is somewhat impacted by gradually diminishing global research (particularly in comparison with most renewables), but importantly it is the negative environmental impacts that really make brown coal unattractive as an option. Regarding climate change, brown coal is associated with very high carbon emissions, which will remain the case as CCS may not be a viable solution due to its very high cost, which will be unviable for brown coal (unlike for black coal). This situation is fairly constant over time and in the three scenarios explored.

Brown coal is highly unattractive in terms of enterprise opportunities in Ireland under all scenarios to 2030. This is due to the fact that Ireland has no brown coal reserves of its own and that for use in the power sector, black coal is preferable to brown coal in terms of cost and environmental considerations.

Summary Position for Coal

- Coal's main strength is its competitiveness in terms of its fuel costs and delivered energy costs. Assuming CCS deployment, the potential enterprise value for coal is high in the long-term.
- Notwithstanding the ease of stockpiling coal, being sourced from a number of low-risk countries, security of supply is mainly compromised by Ireland's import dependence.
- Sustainability of coal is relatively low compared to other fuels because of its environmental impacts rather than its relatively lengthy fuel longevity compared with other fossil fuels.
- Coal is one of the fuels with the highest carbon content and without CCS technology coal has one of the largest carbon footprints.

3.2 Petroleum

The two categories of oil show certain similarities, but also have a range of differences.

Conventional Oil

Conventional oil (as a transport fuel) is competitive (scoring between 64 per cent - 73 per cent depending on which scenario) both currently and in the future but its scoring is somewhat comprised by the limited associated enterprise opportunities. The commodity price is very high; however it offers a very low delivered energy price (due to the limited conversion loss before reaching the fuel tank). Currently oil-derived transport fuels do not have a viable alternative in Ireland - neither in cost, nor in volume. As a result of its ubiquitous nature in the transport sector, there is a very well developed, flexible and resilient infrastructure associated with oil in Ireland. The regulatory regimes are overall supportive and the market is mature. This is expected to remain the case in the foreseeable future, even though the development of an infrastructure for electric cars is now under way.

Security of supply and climate change shows a similar moderate level of attractiveness. Security on the one hand is low and becoming lower in the future due to the high import dependence of Ireland coupled with limited options for supply, mainly from higher risk regions. Markets are highly volatile and the supply chain is subject to sometimes severe disruptions. In the short term, oil will continue to be supplied from the UK which lowers the risk; however this changes abruptly in the medium to long term. On the other hand, oil can be stored and its availability is high which helps to offset some of the low scores under security.

Sustainability is the main weakness of conventional oil. This is due to rapidly diminishing global reserves, which by 2030 may have fallen to less than 20 years. Its environmental impacts are also rather negative along the entire value chain. The trend to 2030 is for sustainability of conventional oil to deteriorate.

Ireland will experience minimal enterprise value in the upstream supply chain due to the lack of indigenous production of conventional oil. However, some enterprise opportunities will continue through transportation and refining of oil, based on the assumption that the transport sector will not have fully decarbonised by 2020 but may be reduced moderately due to the peaking of conventional oil production and the use of alternative transport fuels by 2020 and 2030. In a low carbon price scenario, there will be little alternatives to oil for transport and as a result could generate greater emphasis value than most other fuels. There are very limited export opportunities for Ireland in terms of conventional oil due to lack of indigenous supplies.

Unconventional Oil

Unconventional oil is less competitive (56 per cent - 63 per cent in 2030) when compared to conventional oil. It is traded and used in exactly the same way as conventional but enterprise opportunities are further limited and hence the reduction in the scoring.

A considerable advantage of unconventional oil is its markedly higher security of supply for Ireland. This is due to two factors. Firstly, Ireland uses very little unconventional oil as such and thus exposure and import dependence are low - this may increase in the future, though. Secondly, one of the major global suppliers of unconventional oil (having large reserves) is Canada, which is seen as a low-risk place of origin. All the other advantages attributable to conventional oil - infrastructure resilience and availability - also apply to unconventional oil.

Unconventional oil however has a much worse climate change profile which is due to the highly energy and carbon intensive way of extracting it - from tar sands, oil shale and by deep drilling.

Sustainability is moderate to low. On the one hand unconventional oil's longevity is much longer as its reserves will last well into the future, whilst production rates will only gradually increase (due to the associated technical difficulties). On the other hand, it has a far worse environmental impact than conventional oil. Thus the two indicators of sustainability offset each other.

As with conventional oil, limited enterprise opportunities exist as Ireland does not have the necessary resources nor the expertise compared to other countries in order to compete. Some refining and transportation opportunities may exist as conventional oil becomes prohibitively expensive for some uses due to oil peaking.

It should be noted that with respect to both conventional and unconventional oil supplies, the transportation sector in Ireland will be fully exposed to competitiveness and security issues. As reported in the Sustainable Energy Ireland publication Energy in Ireland 1990-2007 this sector is currently Ireland's largest consumer of fossil fuels¹.

Summary Position for Petroleum

- While the fuel costs for petroleum are high, its delivered energy costs are competitive, particularly for use in the transport sector but from an overall competitiveness perspective it is somewhat limited by enterprise opportunities, hence the medium range scoring.
- In terms of security of supply, Ireland is highly import-dependent on oil. While current sources of oil are from low risk countries, in the longer-term term it is expected that Ireland may have to rely on riskier countries for sources of supply. Unconventional oil scores higher in terms of security of supply.
- Conventional oil is among the fuels with the shortest longevity - oil peaking - and hence sustainability is the weakness pillar for oil.
- Oil as a transport fuel has the lowest lifecycle carbon footprint among the fossil fuels with conventional oil having a better climate change profile compare to unconventional oil.

3.3 Natural Gas

The two categories of natural gas show certain similarities, but also have distinct differences.

Natural Gas

Pipeline natural gas is fairly 'strong' in terms of competitiveness and climate change and scores poorly in terms of security of supply. Competitiveness is the best characteristic of the fuel - this is mainly due to the lower cost and higher efficiency in generating power and a fairly supportive policy framework in Ireland, complemented by an established domestic market. Gas has been the recent fuel of choice when adding new generation capacity in

¹ http://www.sei.ie/Publications/Statistics_Publications/Energy_in_Ireland/Energy_in_Ireland_1990-2007.pdf

Ireland as it offers a good combination of lower investment costs and competitive prices. This is likely to remain the case in future, with competitiveness being the key attraction of gas.

Gas also scores well on climate change - pipeline gas is the cleanest of all fossil fuels and may significantly benefit from carbon capture and storage technologies as they develop (CCS), further reducing its emissions. CCS is a key differentiator in the future, but in either case (with or without CCS) gas loses some of its climate change benefits in terms of the lifecycle carbon footprint especially upstream emissions.

Sustainability is moderate to low, which is a reflection of diminishing global reserves. This is coupled with some negative environmental impacts upstream (e.g. exploration and pipelines).

Security of supply is the clear weakness for pipeline gas. Ireland has a relatively high exposure to this fuel and whilst it currently comes via the UK (low risk), in the future, imports will have to come from other sources (mainly Norway, but possibly Russia and some central Asian countries). International markets are highly volatile (i.e. surges in demand and supply deficits) and Ireland is particularly exposed to that as it is at the end of the pipeline. Moreover, pipeline gas is by its very nature vulnerable to interruptions along the supply chain (pipelines). Despite high levels of planned availability, natural gas is difficult to store and in any case storage is practicable to cover a short period of disruption only.

In terms of economic value to the economy, even with an increase in imports gas will generate limited value to Ireland. The development of the Corrib gas field could temporarily halt this trend in the short term and is estimated to contribute €3 billion to Irish GDP over its lifecycle of 15-20 years. Globally it is estimated that the gas sector provides 16 persons years of employment per MW for construction, installation and manufacture; for operation and maintenance, the figure is 0.05 person years per MW. In terms of enterprise opportunities for Ireland, gas CCS is limited and compared to coal CCS, the potential is very limited in the long-term.

Liquefied Natural Gas (LNG)

LNG is less competitive than pipeline gas in 2010 but surpasses natural gas by 2030 because of slightly lower commodity prices coupled with potential enterprise opportunities. Otherwise it shares the same characteristics in terms of competitiveness. LNG also demonstrates similar balance regarding sustainability (moderate-to-low) and climate change (relatively high) as it is essentially the same fuel as pipeline gas.

The main difference, and advantage, of LNG is in its higher level of security of supply. This is due to the more diverse options of supply - LNG can be imported from virtually anywhere in the world. This reduces both the place of origin risks, and the market volatility risk. In the future, however, with global reserves diminishing, LNG's security will also subside due to more volatile markets.

Overall, LNG has a more balanced Tetralemma profile with all four pillars, but offers higher security in the short term. Over time the security gap between the two closes. LNG has a good overall balance of competitiveness and sustainability. It is worse off than pipeline gas on climate change. These positions are fairly consistent across the timescales and scenarios.

Development of LNG infrastructure has the potential to make a contribution to the Irish economy over the medium to longer timeframe, particularly in the domestic market.

According to an assessment of the economic impact of the proposed LNG terminal at Shannon, it is estimated that the construction phase will contribute €129 million per annum to the Irish economy. The assumed lifespan of the LNG terminal is 30 years or longer with €30 million per

annum operation costs and an estimated yearly contribution to GDP including indirect effects of €33 million.

Summary Position for Gas

- Competitiveness is the strongest pillar for both natural gas and LNG and is a relatively cheap source of energy. Only coal and nuclear offer cheaper alternatives. LNG surpasses natural gas in the long-term, primarily due to the associated potential enterprise opportunities.
- Ireland is highly import dependent on natural gas and is positioned at the end of a very long pipeline which puts at risk its security of supply because of the high risk of supply disruptions. LNG in the longer-term will provide a more secure source of energy because of more diverse supply options and the potential for storage.
- Sustainability is moderate to low, which is a reflection of diminishing global reserves. This is coupled with some negative environmental impacts upstream.
- Pipeline gas is the cleanest of all fossil fuels and may significantly benefit from carbon capture and storage (CCS), further reducing its emissions and hence scores high under the climate change pillar.

3.4 Peat

Peat's primary 'strength' is in security of supply. It is an indigenous fuel and therefore highly reliable. It is also an established fuel with a mature and resilient supply chain, stable domestic market and relatively simple conversion technology. Within the policy context, a revision of the EC Directive on Soils² will prevent the use of peat as a fuel source in the future.

Competitiveness is currently also strength for peat, due to the relatively low costs of both the resource and delivered energy. The regulatory framework and market both currently value the comparative benefits of peat the Irish energy mix. As the fuel becomes scarcer in the future, competitiveness will subside considerably by 2030.

The sustainability of peat is fairly low as indigenous reserves are expected to disappear entirely by 2030 and there is limited scope for imports. Ireland is likely to have to close its peat plants over the next decade to comply with EU directives.

The climate change profile of peat is also very poor. It has one of the higher carbon intensities of all fuels researched and is also perceived to be vulnerable to changes in the climate (e.g. higher rainfall and humidity). Peat's performance against this pillar worsens significantly over time.

While the Irish peat extraction and processing industry currently provides economic value to the Irish economy, estimated to be worth €153 million in sales in 2005, this value is set to decline dramatically by 2020 and by 2030 peat resources in Ireland will have been depleted to such an extent that its enterprise value will be minimal under all scenarios. This is

² For the original directive see:

<http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32004L0035:EN:HTML> and for the revision: http://ec.europa.eu/environment/soil/pdf/com_2006_0232_en.pdf

notwithstanding the fact that the harvesting of peat could be completely halted within the next 10 years in any case.

Summary Position for Peat

- Peat is a relatively cheap fossil fuel for Ireland but in terms of delivered energy costs is among the highest of the fossil fuels.
- Peat's primary strength is security of supply but this could be compromised by EU legalisation regarding the harvesting of peat.
- Sustainability of peat is low with reserves estimated for another 10-15 years and to comply with EU directives Ireland will have to cease peat fired electricity generation over the next decade.
- Peat has one of the highest carbon contents and highest carbon footprints - peat bogs are a huge store for carbon dioxide - and hence performs poorly under the climate change pillar.

3.5 Biomass

There are some common patterns but also clear differences between the biomass fuels in terms of trade-offs.

Woody Biomass

Woody biomass is particularly strong under the climate change pillar and almost as strong in sustainability - both are scored at close to 100 per cent. In terms of climate change, this is due to the fact that it is considered a carbon-neutral fuel and its growing cycle is likely to benefit (marginally) from warmer climates. Sustainability is high mainly as it is a renewable resource with virtually infinite longevity, but it does not achieve the highest score because of perceived impacts on the environment. Over time, these positions are fairly constant. However, under climate change woody biomass tends to lose some of its edge by 2030 due to possible vulnerability of supply and impacts on infrastructure and supply chain.

The security of supply of woody biomass is also rather high (but not as much as climate change and sustainability) mainly as a reflection of the indigenous nature of the fuel and its low share in the energy mix. Security of supply shows as a constant over time in the different scenarios.

The weakest pillar for woody biomass is competitiveness (although it is not disproportionately lower than the other three pillars, (e.g. it scores between 55 per cent - 66 per cent in 2030 depending on the scenario). The position marginally improves or worsens over time, depending on the scenario; however woody biomass remains relatively expensive and subject to a less developed and cautious domestic market.

The woody biomass market will be a key part of the greater bioenergy market in the future as it is not only a renewable fuel but also has the additional advantage of bolstering rural communities, providing additional income to forest landowners and diversifying local economies. At a global rate of US \$4/GJ, the value of the Irish market could potential reach US \$393 million in 2030. Employment is forecast to increase in 2020 and 2030 as supply chain issues surrounding the provision of wood for energy are resolved and a greater level of certainty can be attributed to its supply.

Non-woody Biomass

Non-woody biomass which includes bioethanol, bio-oil and biodiesel, is similarly well placed in terms of climate change and sustainability, but sustainability dominates (for the same reasons as woody biomass - being a renewable, low-impact fuel). Climate change is slightly less prominent due to a perceived higher potential impact on the supply and infrastructure - this position marginally deteriorates by 2030.

Security of supply is relatively high as well, again due to the indigenous nature of the fuel and its small contribution to the energy mix. Non-woody biomass however is more viable to import (than woody biomass) and over time security declines slightly as a reflection of the variety of low and high risk places of origin.

Competitiveness is again the weakest pillar, but the gap (especially with security of supply) is relatively small and closes over time as non-woody biomass become more competitive - due to larger volumes of production, mature markets and a supportive regulatory framework.

Non-woody biomass is fairly balanced across the four pillars and there is limited scope for specific trade-offs.

Biofuels (primarily made up of bioethanol and biodiesel) is a fast growing industry worldwide. The biofuel market within the EU is relatively well developed, spurred on by national government adoption of EU directives. In scenarios where renewables are supported and there is a high carbon price, it can be expected that biofuel uptake will increase both domestically and in the international market, thereby contributing to the national economy.

Bio-residues

Bio-residues have an almost identical profile to non-woody biomass. It has a balanced position against all four pillars, with a marginal lead on sustainability followed by climate change. Competitiveness is the weakest pillar and slightly behind security of supply, but in all three scenarios there is a discernible improvement over time (competitiveness closes the gap with security by 2030) mainly as a result of stringent policy objectives which are then taken up by the market.

Bio-residues are used to a large extent already in Ireland and internationally. It is a technically mature technology and is considered independent of commodity prices and a carbon price and as a result its contribution to the national economy is not expected to increase over the time period between 2010 and 2030.

Biogas

Biogas is the main exception within the group of biomass fuels. It is highly competitive, both currently and in the future, due to an established market driven by a firm regulatory regime. This is coupled with a virtually free resource and an efficient conversion technology. Biogas also achieves high scores on climate change and security of supply, together with competitiveness this forms a triangle of strengths. Climate change and security are strong largely for the same reasons as all other biomass fuels - low-carbon impact and a domestic supply.

Sustainability is the weak element for biogas. Whilst it is a renewable fuel, it is produced from landfill waste and sludge, whose availability is rapidly declining due to tightening waste regulations. Thus, biogas will have a very short longevity in the medium term.

Biogas as a source of fuel is not expected to grow or diminish substantially out to 2030 despite the possible decrease in landfill gas as the size of landfills decrease under new

regulations. Sewage gas will continue to grow as a market and will counter any decrease in availability in landfill gas.

Summary Position for Biomass

- Biomass is one of the few renewable fuel sources with a fuel cost, which cost varies significantly depending on the source of the fuel, the conversion technology and the location. Enterprise opportunities remain constant out to 2030 with the exception of non-woody biomass where Ireland has potential to capture some of the opportunities both in the domestic market and for exports.
- Most biomass is sourced locally and is therefore relatively secure compared to other fuel types - the exception being non-woody biomass of which some is imported.
- Sustainability is generally high as most sources are renewable (with the exception of bio-gas) but is undermined by the environmental impacts.
- Biomass has a low carbon impact and use of biomass in electricity generation is defined as 'carbon-neutral'. Scoring for biomass under the climate change pillar is also high.

3.6 Wind

Onshore and offshore winds have very similar Tetralemma profiles. The only difference is in their levels of competitiveness - over time and across the three scenarios.

Onshore Wind

Onshore wind is particularly strong in climate change and sustainability where it achieves maximum scores. In terms of climate change, this is due to its carbon-free nature and potential increase in overall availability (resource). In the medium to long term, however, the climate change pillar loses some of its prominence as the infrastructure may become increasingly vulnerable to stress and disruptions. Sustainability on the other hand is constantly high as the wind resource is infinite and environmental impacts are low.

The security of supply and competitiveness of onshore wind are positioned broadly at the same level: medium-high. Security achieves good scores as the energy resource is indigenous, but less than the maximum as wind is fairly intermittent and the supply chains (internationally) of equipment are known to experience bottlenecks. Competitiveness is reasonably high and increases over the longer term, as onshore wind is an established technology itself and the resource are free. There is also a good market environment in Ireland, coupled with a favourable (though not in all scenarios) regulatory framework. Whilst security remains constant over time, the competitiveness of onshore wind tends to improve slightly overtime.

Wind is possibly the most lucrative renewable market for Ireland. Ireland is well positioned to capitalise on wind energy as it has some of the best wind resources in the world and has an existing expertise base in operating wind farms. Whilst not having the industry base present to manufacture wind turbines in Ireland, the real value added to the economy will come from operations and maintenance, which accounts for approximately 25 per cent of lifetime costs and from planning, development, financing and management. The onshore wind market in Ireland is performing well at present and is a high value source of energy with an installed

capacity of 1,457 MW generated from 119 wind farms in 22 counties. Assuming that the high scenario plays out where the Energy White Paper is fully implemented, a potential 6,000 MW of wind energy could be deployed by 2030 with export potential. Statistics show that 15.1 jobs are created in the EU for every MW installed and 0.4 jobs are created per MW of cumulative capacity in operation and maintenance and other activities.

Offshore Wind

Offshore wind shows very similar characteristics to onshore wind against three of the pillars: sustainability, climate change and security of supply. Whilst sustainability is permanently at the highest level, climate change tends to deteriorate significantly (and more so than onshore wind) due to the greater exposure of offshore facilities to extreme weather conditions. There may also be changes in the wind patterns that further affect performance against this pillar. Security of supply is relatively high as the resource is domestic; offshore wind has a higher energy availability than onshore wind, but this is offset by greater volatility in the wind supply markets and thus the results are similar for both categories.

Competitiveness of offshore wind is the weakest pillar in the Tetralemma, but it fluctuates considerably over time and depending on the scenario. In the high scenario, by 2030 competitiveness of offshore wind improves its position by about 50 per cent and overtakes both security of supply and climate change (the latter has deteriorated by 2030). This reflects a high penetration of offshore wind which drives costs down due to economies of scale and a very supportive policy and regulatory framework in Ireland, which also gives confidence to the domestic market.

Compared to onshore wind energy, the offshore sector is still in its infancy. Current policy focus is on the development of onshore wind generation as it currently provides a lower cost solution than offshore wind development. However, in a high scenario where there is a lot of support for renewables it is assumed that the rate of acceleration of the technology increases and as a result deployment of offshore wind could contribute to employment in Ireland.

Whilst the exploitation of wind as a fuel source can bring significant benefit to Ireland across all of the pillars of the Tetralemma, its uptake is dependent upon policy factors that do not relate to its resource base. Onshore wind is already well developed in Ireland but full exploitation of the resource requires strengthening of the onshore grid and/or the introduction of storage technologies to reduce network stability problems that can arise from variable generation. Both onshore and offshore wind would make a greater contribution to the diversity of energy supplies in Ireland if there was a strong degree of interconnection to the UK and mainland Europe.

Summary Position for Wind

- The competitiveness of onshore wind is positioned in the mid-range, more expensive than fossil fuels, but cheaper than some other renewables, but increases over time as the technology is relatively mature, the resource is free with a favourable policy and market context. Offshore wind, in the short-term, is less competitive but assuming technology advances similar to onshore wind it increases its attractiveness over the longer-term as the technology matures and the enterprise potential is realised. Wind is possibly the most lucrative renewable market for Ireland.
- Security of supply is strong both for onshore and offshore wind, as the resources are indigenous but the inherent intermittency associated with wind serves to diminish its overall score.
- The sustainability of both onshore and offshore wind scores very highly as the resource is available indefinitely and the externality costs are minimal.
- Onshore wind achieves the highest score for its climate change benefits but climate change benefits on offshore wind may diminish in the longer-term, primarily due to supply and infrastructure vulnerability.

3.7 Solar

Solar thermal and solar photovoltaics (PV) have very similar Tetralemma profiles against three of the four pillars, but show significant differences on competitiveness.

Solar Thermal

Solar thermal has strong and balanced profile in all pillars of the Tetralemma. Climate change and sustainability achieve the maximum scores on climate change as it is a carbon-free technology with a potentially increasing resource; and on sustainability as it will be available indefinitely into the future.

Competitiveness is also very high and only slightly below the maximum score. This reflects the high cost-effectiveness of the technology, market confidence in it and a broadly supportive public sector in Ireland. Competitiveness remains high in all timescales and scenarios.

Security of supply is only marginally below competitiveness. Solar energy is a domestic resource with no fuel imports. However it is inherently intermittent and thus reduces the overall availability of the delivered energy.

The use of solar energy for space/water heating receives the highest overall score within the Tetralemma across all time periods as it is both cost competitive (at current market prices) and has a net benefit in carbon terms through displacing up to 60 per cent of the fossil fuel costs. Combined with energy efficiency measures, solar thermal can make a significant contribution to energy use in Ireland's built environment and should be considered as a key, low cost component of demand reduction.

Solar thermal does not show any large variations over time or in the different scenarios.

Solar PV

Solar photovoltaics (PV) is also very strong in terms of climate change and sustainability metrics much for the same reasons as solar thermal. Security of supply is also high, due to the indigenous nature of solar energy, but solar PV is subject to high intermittency (low availability) as well as more volatile supply chains where demand may exceed supply (as silicon has many other competing applications).

The competitiveness of solar PV is the weakest area of its profile. The technology is relatively very expensive which results in high delivered energy costs (despite the fact the solar energy is free in the first place). The market in Ireland is still in its infancy and policy support is only moderate. Its competitiveness scores improve marginally when PV does not achieve economies of scale and its competitiveness improved only as a result of technological advancements. Significant gains in competitiveness are observed when policy is 'pro-climate' and stimulates demand. In any case, competitiveness remains the weakest element for solar PV in all scenarios.

Much of the employment creation is at the point of installation, giving a boost to local economies, particularly for solar thermal. According to Solar V, 10 jobs are created per MW during production and about 33 jobs per MW during the process of installation. Wholesaling of the systems and indirect supply each create 3-4 jobs per MW with research adding another 1-2 jobs per MW. The solar energy market is at a very early stage of development and accounts for less than 0.01 per cent of total final energy demand. However potential does exist in technology development of PV and thin film technologies as Ireland has some of the leading semiconductor and electronics companies, well established in Ireland, as well as highly qualified surface chemists and engineers. Solar power has an estimated global market of €10 billion per annum growing at a rate of 25 per cent per annum. In 2007, the solar sub-sector was second only behind wind for total investment and attracted the largest share of private equity/venture capital funding.

Summary Position for Solar

- Competitiveness scores differ greatly between solar thermal and solar PV. For solar thermal, competitiveness receives a high score as the technology is well developed and proven in terms of an energy source for heating. For solar PV, the technology is very expensive with high delivered energy costs.
- Security of supply for both solar thermal and solar PV is high, primarily due to its indigenous nature but again is compromised by its inherent intermittent nature.
- Solar thermal and solar PV score maximum scores in terms of sustainability due to the fact that solar energy is an infinite resource and a very low environmental impact.
- Climate change impacts of solar energy are minimal and it achieves the highest score against this indicator for all fuel types particularly in the longer-term.

3.8 Marine

The two categories of marine energy share very similar Tetralemma profiles in all timescales and scenarios.

Wave Energy

Wave energy's main 'strength' is in sustainability. It is a renewable resource with very little environmental impact - it achieves the maximum scores consistently in all timescales and scenarios. This is followed by climate change, where also very high scores are achieved. However the reason for less than maximum scores is potential climate impacts on both the resource and infrastructure.

Security of supply is moderate as the resource and technology are both subject to certain risks: while the resource is indigenous, it is also rather intermittent; the technology is in the early stages of commercialisation and there are tangible concerns regarding both supply chain capacity to meet demand and infrastructure resilience as it operates in a highly hostile environment. Security of supply remains at this level in all timescales and scenarios.

Competitiveness of wave energy is fairly low as the technology moves through different stages of commercialisation. Over time, wave energy improves its competitiveness, but the rate of change depends heavily on the scenario. Where the markets and policy framework are not fully susceptible and supportive, only marginal progress is achieved and competitiveness remains the weakest pillar. In the high scenario, however, where renewables in general receive regulatory and financial support, the technology matures more quickly and achieves economies of scale - its competitiveness improves dramatically to 2030.

Tidal Energy

Tidal energy is a 'sister' technology to wave energy and the two develop somewhat in tandem. This is expected to continue in the future and as such their Tetralemma profiles are very similar. The main differences between the two are that tidal energy is driven by the gravitational field of the moon and is therefore independent of the earth's climate; and the degree of stress borne by tidal devices is within a tighter range than wave energy device, tidal energy shows slightly better scores under climate change. Also, tidal energy is far more predictable and therefore reliable, it has a marginally better standing in security of supply due to resource availability.

Competitiveness is, similarly, fairly low but improves over time, again assuming technology advances in tidal energy. It can reach a very strong position if the right mixture of policy and market stimuli is in place over the longer-term.

Ireland's wave and tidal energy resource has significant potential to contribute to indigenous energy supply but the technology sector is currently at an emergent stage with few conversion technologies that can be deployed on a 'commercial' basis. Tidal energy improves its score over the period to 2030, partly due to a more competitive starting position than wave energy technology and due to less resource vulnerability issues in comparison to wave.

While the scale of the ocean energy resource is substantial, there are no commercially viable ocean energy systems available at present and the market for this technology at the development stage. Assuming that the development of wave / tidal energy follows a similar path to wind energy, a developed ocean energy market could accommodate a number of ocean energy devices manufacturing companies. As the world market has yet to form there are minimal barriers to entry which Ireland could exploit. The opportunity exists to develop technical solutions that will allow the economic exploitation of the technologies and it is

estimated to be worth €176 million in 2020 creating 313 jobs in the research, manufacturing, installation and maintenance sectors³. Following a period of sustained growth the industry could reach a cumulative value of €784 million by 2025 supplying 911 jobs to the Irish economy. In addition export sales could add a value of €360 million and an additional 574 jobs to the Irish economy in 2020 and by 2025 these figures could rise to €1,587 million and 1,329 jobs respectively.

Summary Position for Marine

- The competitiveness of marine based energy sources in the short-term is unattractive compared with other fuel sources but improves over time as the technology moves nearer to full deployment, at the same time technology advances are very dependent on the policy regime in place. As the market for marine energy has yet to be established globally, barriers to entry are low and there is potential for enterprise opportunities in Ireland in this area.
- Security of supply is moderate as the resource and technology are both subject to certain risks since the market is not yet fully established and the energy source is intermittent.
- For both wave and tidal energy, sustainability is their strength; they are renewable resources with very little environmental impact.
- Again both wave and tidal score highly under the climate change pillar but this is undermined somewhat by the impact of climate change on the availability of the resource and the vulnerability of the grid infrastructure.

3.9 Geothermal

Geothermal energy is rather 'strong' against three of the Tetralemma pillars - it offers very high security of supply and sustainability and is climate-proof (both mitigation and adaptation). Its main weakness is a relatively low competitiveness.

Climate change and sustainability are the top-scoring pillars. Geothermal energy is carbon-free and as it originates deep below the surface, it is independent of the climate. It is also a renewable resource with fairly low environmental impacts. (However, there have been cases where it is suspected of increasing the risk of earthquakes).

Security of supply is also high as the resource is indigenous and not subject to import. The technology is tried and tested and is one of the very few non-intermittent renewables (with a high availability coefficient). Security does not achieve the highest score because the technology is not widespread and there are potential bottlenecks with the supply chain. Its infrastructure involves heat pipelines and other conversion points which may be subject to disruptions.

Competitiveness is the main weakness of geothermal energy. Whilst the resource is free and conversion is relatively cost effective, there are certain deficiencies regarding market confidence and development in Ireland, and a policy framework which does not prioritise geothermal energy. This position evolves in a positive direction over time and

³ SEI, 2005

competitiveness improves its position by 2030. The rate of change depends on the scenario – it is rather low in the low and medium scenarios but quite significant in the high scenario.

Geothermal power tends to keep economic benefits local as construction and then subsequent costs tend to be incurred locally. There is some scope for geothermal energy in Ireland but this is unlikely to come online in 2010. With increasing support for geothermal and a potentially significant growth in the US market there will be room for Irish expansion into this market both domestically and internationally by 2020 and 2030.

Summary Position for Geothermal

- Geothermal energy is among the more cost-competitive renewable technologies but its competitiveness is comprised by market development in Ireland.
- Security of supply for geothermal is high as it is an indigenous resource, is non-intermittent and these patterns are seen across all time frames and all scenarios.
- Geothermal scores the maximum value under sustainability as it is an infinite resource with apparently negligible environmental impacts.
- As geothermal is a carbon-free resource, has a very low lifecycle carbon footprint with a very limited perceived impact on geothermal infrastructure due to climate change, it receives a very high score under the climate change pillar.

3.10 Hydro

Hydropower offers scope for clear trade-offs within the Tetralemma pillars. Its leading pillar is sustainability where it achieves the maximum score in all timescales and against all scenarios. Hydro is a renewable resource, and the environmental impacts (of future schemes, which will only be smaller-scale) are minimal.

Against this, competitiveness is the weakest pillar. This is due to a range of factors, but mainly because any new schemes in Ireland would tend to be smaller scale and thus not necessarily very cost-effective (despite the free energy source itself). The real setbacks however are the policy framework, where any further capture of hydro resource is not seen as a priority area (due to limited practical scope for exploitation) and the market is not particularly geared up to develop further schemes (other energy options are seen as more attractive). This position is fairly static over time and across the three scenarios.

Security of supply and climate change both achieve medium-to-high score. Hydro offers a good degree of security from the point of view of it being an indigenous resource, which can also in many cases be stored and thus made more available. The latter advantage however cannot be fully utilised for future hydro capacity additions, which would be smaller-scale and thus less suitable for storage. This is the main reason for its lower score. Climate change, in turn, is a relatively strong pillar because hydro is a carbon-free fuel. Also, the resource may see an aggregate increase due to higher precipitation in the future. The factor that lowers the score is the perceived risk of disruption to hydro infrastructure as a result of climate change (namely extreme weather events, as well as distorted rainfall patterns with periods of overflow or drought).

The large hydro potential in Ireland has mostly been exhausted. There is little potential for further development because of lack of suitable sites. This market domestically and

internationally is negligible for Ireland now and into the future. However, availability is managed and increased by way of reservoirs and pumped storage schemes⁴.

Summary Position for Hydro

- Competitiveness is the weakest pillar for hydro energy mainly due to the fact that any new schemes being introduced into Ireland would be of a small scale and not as cost effective as the existing schemes.
- Hydro offers a good degree of security from the point of view of it being an indigenous resource, which can also in many cases be stored and thus made more available.
- Sustainability is the key strength of hydro as it is a renewable resource and has one of the lowest costs for environmental externalities.
- Hydro scores extremely high under the climate change pillar but does not achieve maximum scores because of the increased vulnerability of supply and infrastructure as a result of climate change.

3.11 Nuclear

Uranium's use in nuclear generation could provide significant energy supplies to Ireland, either directly through development of indigenous nuclear generating capacity (which would require a statutory change to its prohibition) or through indirect supply of nuclear generated electricity via an interconnector.

The Tetralemma profile for nuclear power shows an axis of strengths between security of supply and climate change and an axis of weakness between competitiveness and sustainability. This is consistent in all timescales and scenarios.

Climate change is the only pillar where a nearly maximum score is achieved (but only the short term). Nuclear is a carbon-free fuel and its lifecycle carbon footprint is very low as well. Some potential risks are perceived from extreme climate events in the future, in the form of flooding and sea level rise.

Security of supply achieves good scores as the nuclear sector globally is heavily regulated and as a result is highly reliable. The fuel is available principally from lower risk countries and markets have historically been very stable (even in periods when other markets have been highly volatile).

Competitiveness achieves lower scores mainly due to an essentially prohibitive policy and regulatory regime in Ireland. This is coupled with a lack of a market for nuclear altogether. The factor that helps to push this pillar up is the cost of delivered energy which is rather low.

Sustainability is also a low-performing pillar. Nuclear fuel is a finite resource and despite the relatively abundant reserves (high production-to-consumption ratio) it cannot be regarded as a sustainable option.

If nuclear is deployed in Ireland, there is likely to be a significant minimum level of employment necessary up to and beyond 2030 to meet the construction, operational, regulatory, decommissioning and supply chain requirements for a nuclear unit compared with

⁴ See www.spiritofireland.org

other forms of energy. Given the very scale of nuclear power that could be deployed in Ireland, it is unlikely that significant local nuclear supply chain infrastructure such as uranium enrichment and reprocessing facilities would be feasible. Fuel element manufacture and assembly may be possible and desirable and although export potential is likely to be limited, local employment prospects would be strong.

Summary Position for Nuclear

- Despite nuclear having a relatively competitive delivered energy cost it scores poorly under the competitiveness pillar because of the lack of regulatory systems and market development in Ireland at present. Nuclear energy in Ireland is currently prohibited by statute.
- Security of supply is a high scoring pillar as the global market is heavily regulated and as a result is highly reliable.
- Sustainability of nuclear energy is relatively low compared to other fuels principally because nuclear is a finite resource.
- Climate change is the only pillar where a nearly maximum score is achieved (but only the short term). Nuclear is a carbon-free fuel and its lifecycle carbon footprint is very low as well.

The fuels described above all display certain trade-offs that are of interest from a policy perspective. Further exploration of these trade-offs is provided below.

4. Policy Implications for Long-term Energy

As stated previously, energy is essential in almost every aspect of life and its importance for economic growth cannot be overstated. Energy policy plays a strategic role in the development of Ireland's economic future and underpins Ireland's competitiveness as a nation.

The analysis of the Energy Tetralemma shows the complex environment that energy policy needs to take into account and the competing objectives that it needs to respond to. A number of policy responses are necessary to ensure a competitive, secure and sustainable energy system that also addresses the challenges of climate change.

4.1 Pillar Specific Policy Directions

Competitiveness

If competitiveness is the only policy objective then the following actions should be considered:

- Change the policy and regulatory environment for black coal and incentivise the adoption of new conversion technologies and carbon capture and storage, allowing for realisation of coals existing advantages in fuel and delivered energy costs.
- A technical and economic feasibility study of the possible use of nuclear energy should be undertaken and incorporated into the policy debate.
- Only by funding research into the deployment of renewable energy alternatives, particularly offshore wind and marine technology, will they become competitive as economies of scale lead to a reduction in delivered energy costs.
- Available resources of biogas and bio-residues should be promoted and more effectively utilised as these are competitive under most scenarios.
- Solar thermal is very competitive as a heat application and needs increased policy support.

Security of Supply

If security of supply is the only policy objective then the following actions should be considered:

- Shift from imported fossil fuels to domestically available renewable alternatives where practical, allowing for intermittency difficulties.
- Following a technical and economic feasibility study consider nuclear as an alternative to fossil fuels for base load back-up generation to high levels of renewable on the system.
- Keep coal as part of the generating mix on account of its larger reserves from more stable regions.
- Oil use should be avoided where possible.

Sustainability

If Sustainability is the only policy objective then the following actions should be considered:

- Rapidly shift from fossil fuels to renewables where possible based on their superior environmental performance and infinite supply.
- Avoid all fossil fuels due to extremely limited global reserves to production ratios.
- In a choice between fossil fuels and nuclear for sustainable electricity generation, go with the latter, subject to a technical and economic feasibility study.
- If continuing to use fossil fuels, LNG should be prioritised over coal and natural gas.
- Closely monitor the sustainability of biomass production to ensure its long term availability and minimal environmental impact.

Climate Change

If Climate Change is the only policy objective then the following actions should be considered:

- Shift from fossil fuel electricity generation to a greater use of renewables.
- Choose nuclear over fossil fuels, subject to a technical and economic feasibility study.
- Pursue Carbon Capture and Storage (CCS) which substantially benefits black coal and, to a lesser extent, gas.
- Fund research into how offshore wind and marine can protect against climate change induced infrastructure vulnerability.
- Ensure that current biomass will be available under altered climatic conditions.

4.2 Overarching Policy Directions for Long-Term Energy

Whether one analyses each pillar on an individual basis or assesses the trade-off positions there are a number of overarching policy directions that are necessary. These are as follows.

The long-term energy fuel mix for Ireland should be diverse and flexible and not as reliant on fossil fuels as it is today.

The correct energy mix for Ireland will, ideally, include a mix of many different types of fuels with reduced reliance on fossil fuels. Optimally, the fuel mix should reflect a long term strategy that ensures all four Tetralemma policy goals are met. A balanced energy portfolio of energy supplies will ideally maximize Ireland's ability to meet its international climate change policy obligations, while fostering a competitive enterprise environment and ensuring a safe, sustainable supply. Such an approach should concentrate not on choosing the correct fuel, but on choosing a basket of fuels that will be an optimal energy mix for Ireland in the long-term⁵. The use of oil should be eliminated in the electricity sector and alternative

⁵ Awerbuch, Shimon and Martin Berger, 2003, *Applying Portfolio Theory to EU Electricity Planning and Policy-Making*, IEA/EET Working Paper Series

energy sources need to be explored to meet the energy requirements in the transport and heating sectors.

Significant expansion of the transmission grid will be required over the next decade to support the renewables targets and demand growth. Progression towards a smart energy grid should be a top priority for infrastructure spending.

Reducing long-term dependence upon fossil fuels and diversifying supply are complex goals that will require long-term solutions. Strategies put in place today may only begin to reap benefits years from now. Over the long term, the Index reveals that renewables become the most attractive option because they offer the best performance across the range of the Tetralemma - assuming the further development of renewable technologies. Fossil fuels remain the lowest performing fuel option.

Enhanced electricity interconnection between Ireland and the UK is necessary to improve security of supply; additionally, a connection between Ireland and mainland Europe should be assessed.

Interconnection could enable the expansion of indigenous renewable fuel supplies as a result of system support benefits and security of connection to a larger system, a goal which the Department of Communications, Energy, and Natural Resources is currently progressing.

Identify and implement regulatory, legislative and planning process changes for competitive, long-term energy development. Develop a new, integrated planning regime for energy projects.

The current planning regime and other regulatory and legislative requirements are possible bottlenecks for new renewable infrastructure projects. There is a need to identify and implement regulatory and legislative changes for long-term energy planning such as the regulations around connection to the grid (e.g. gate 3, fixed wire issues). There is also a need to develop a new integrated planning regime for energy projects to incorporate the streamlining of appeals. A new impact assessment methodology is required to reflect the interconnectedness between different policy issues (costs, technical, environmental).

Governance should be expanded to encompass an integrated approach among local authorities and national government departments to ensure that progress is made on renewable energy, the transport sector, and other areas of energy policy.

Ensure that energy related research funding is focused on demonstration and commercialisation.

Marine energy is among the very top performers on the Index overall and is gaining a strong degree of interest across Europe and the world. Ireland is ideally placed to be at the forefront of the application of marine technology and market development given our natural resource and R&D base. A strategic implementation plan is needed in order to prove the route to market for this sector; this should include a strategic review of the resource and licensing processes, realistic infrastructure requirements to support early commercial scale projects

and investment in R&D. Only by funding and deploying renewable energy alternatives, particularly offshore wind and marine technology, will they become competitive as economies of scale lead to a reduction in delivered energy costs. This is a lesson from the high scenario where full policy support, and a high carbon price, renders marine and offshore wind competitive by 2030. Research funding should include how offshore wind and marine can protect against climate-change-induced infrastructure vulnerability.

Consider the introduction of a nuclear regulatory regime in Ireland that would allow Ireland to benefit from nuclear's good sustainability and climate change characteristics and comparatively low delivered energy cost. This would be subject to a technical and economic feasibility study.

Nuclear energy outperforms all fossil fuels by 2030 in the Index and in terms of overall performance under competitiveness, security of supply, sustainability and climate change is closer to the renewables group of fuels than fossil fuels. Any dialogue on fuel options for Ireland should include the possible use of nuclear energy in the future. The recent recommendation of the National Competitiveness Council (NCC) for a technical and economic feasibility study on nuclear energy should be part of a long-term strategy to progress dialogue on nuclear as an option for Ireland.

Carbon Capture and Storage (CCS) plans should be extended to all types of fuel generation plants in Ireland by 2020, and all plants should be CCS ready by 2030.

In order to achieve the high scenario in the Tetralemma Index by 2030, availing of advances in technology is key. Development must be followed by widespread utilisation; therefore CCS should factor strongly in all new plant and plant retrofitting projects. The ESB is already planning CCS for its coal burning plant, Moneypoint, by 2025. In terms of energy supply from both a cost competitiveness and security of supply perspective coal should be part of the fuel mix, assuming advances in CCS. To support this policy objective there is a need to change the policy and regulatory environment for coal to support the adoption of new conversion technologies and carbon capture and storage. The competitiveness of coal is undercut by an unfavourable policy and regulatory regime. If this can be solved then coal will become more attractive based on existing advantages in fuel and delivered energy costs.

Review the adequacy of Ireland's current strategic storage requirements and consider increasing oil reserves at gas fired generation plants as an alternative to increasing gas storage.

Natural gas performs poorly on the Index mostly due to security of supply concerns relating to its compromised supply lines and the risk of disruption given the geographical location of natural gas reserves from which Ireland imports its supply over the period to 2030. Continued dependence on natural gas leaves Ireland highly vulnerable to supply shocks in the future. Strategic fuel storage in Ireland should be expanded to increase security of supply by using oil as a backup for natural gas and coal shortages, at least in the short-term.

The Sustainable Travel and Transport Plan published by the Department of Transport should become a priority for cross-departmental implementation.

Electricity production is but one sector of energy consumption in Ireland. The Tetralemma highlights the fact that only limited gains can be made by fuel switching in the electricity sector. Until the primary fuel import dependency on oil in the transport sector is addressed, gains along any of the pillars will be limited and will likely be wiped out by further growth of oil usage for transport. The Sustainable Travel and Transport Plan published by the Department of Transport should become a priority for cross-government implementation. At a minimum, Government should look at retrofitting mass transit for electrified or non-petroleum based fuel options.

Increase the uptake of solar thermal and geothermal for heating purposes by enhancing planning regulations or developing market incentives for heat supplies.

Home heating is an area that remains relatively underdeveloped in terms of adoption of alternatives to fossil fuels. While the two best-performing fuels in the index, geothermal and solar thermal are readily available, their adoption remains low. Combined with energy efficiency measures, solar thermal and geothermal can make a significant contribution to energy use in Ireland's built environment and should be considered as a key, low cost component of demand reduction and an alternative to fossil fuels in domestic and space/water heating sectors in Ireland. These sources should be optimised on the Island; therefore, regulations should be put in place to integrate planning and development of sites suitable for geothermal and solar thermal energy use.

5. Conclusions

A complex picture emerges from bringing together the range of dimensions explored by the study. There is recognition that fossil fuels will continue to play a part in Ireland's future fuel mix particularly as back-up generation will be required for a heavy penetration of renewables (specifically wind):

- Overall the relative ranking of fuels was most influenced by three factors - the national policy and regulatory framework, commodity and technology prices, and the stage of technological development.
- The prospect of renewable energy becoming fully competitive in terms of delivered energy costs as technology matures is significantly influenced by the degree to which Ireland develops a supportive policy and regulatory environment.
- Fossil fuels continue to outperform renewables and nuclear energy under the competitiveness pillar out to 2030 in terms of their attractiveness in meeting cost competitiveness objectives. However, fossil fuels are not as attractive in terms of security of supply, sustainability and climate change over that period.
- Black Coal and in some instances LNG are the exceptions to the relative unattractiveness of fossil fuels and perform well under security of supply and climate change pillars, on the assumption that clean coal and other CCS technologies will develop commercially to 2030.
- The extent to which regulatory and R&D policy is supportive plays a major role in the development of offshore wind and marine energy.
- Solar thermal and geothermal are consistently high scorers for heat applications for Ireland.
- Despite nuclear having competitive delivered energy costs overall, it currently suffers from the absence of a supportive and regulatory context and the economic and technical merits of the technology for Ireland need to be further explored.
- Enterprise opportunities are particularly strong in relation to marine, black coal, LNG, wind, with long-term potential for offshore wind, assuming a favourable policy context.

The Irish Energy Tetralemma

A Framework for Fuel Choices for Ireland

Part 2

Detailed Analysis

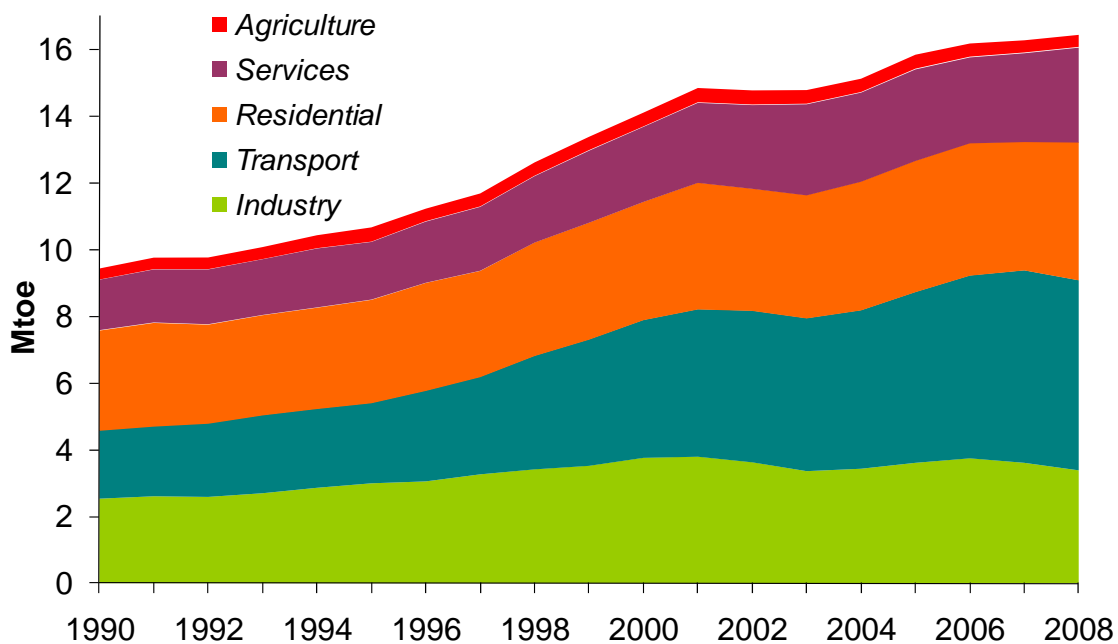
6. Energy in Ireland

The four pillars of the Tetralemma and the fuels they represent sit within the broader environment of the Irish economy and society. The relationship between the fuels and the Irish environment creates the context in which policy decisions are made.

This environment is a complex product of history, the current physical energy infrastructure, market regulation, geography, climate, urbanisation, industry sectors, culture and many other factors including the direction in which Ireland wishes to develop in the future and the potential of its own natural resources.

The demand for energy in Ireland had grown along with significant and until very recently, virtually uninterrupted economic growth over the previous quarter of a century. Figure 2 illustrates the impact of growth on the consumption of energy in key sectors of the economy. Transport is the main area of energy growth.

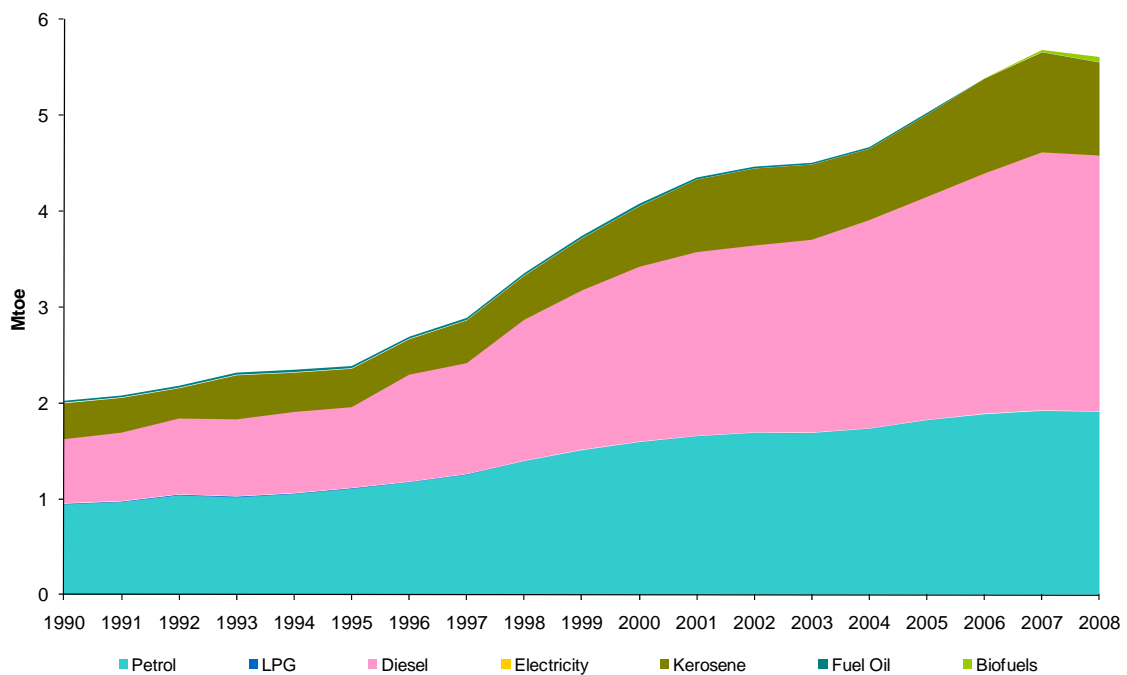
Figure 2: Total Primary Energy Requirement by Sector



Source: Sustainable Energy Ireland, Energy in Ireland 1990-2008, 2009

Within the transport sector, the main fuels for which demand has grown are petrol and diesel as can be seen in Figure 3 below. This growth has been driven primarily by growth in freight and tourism.

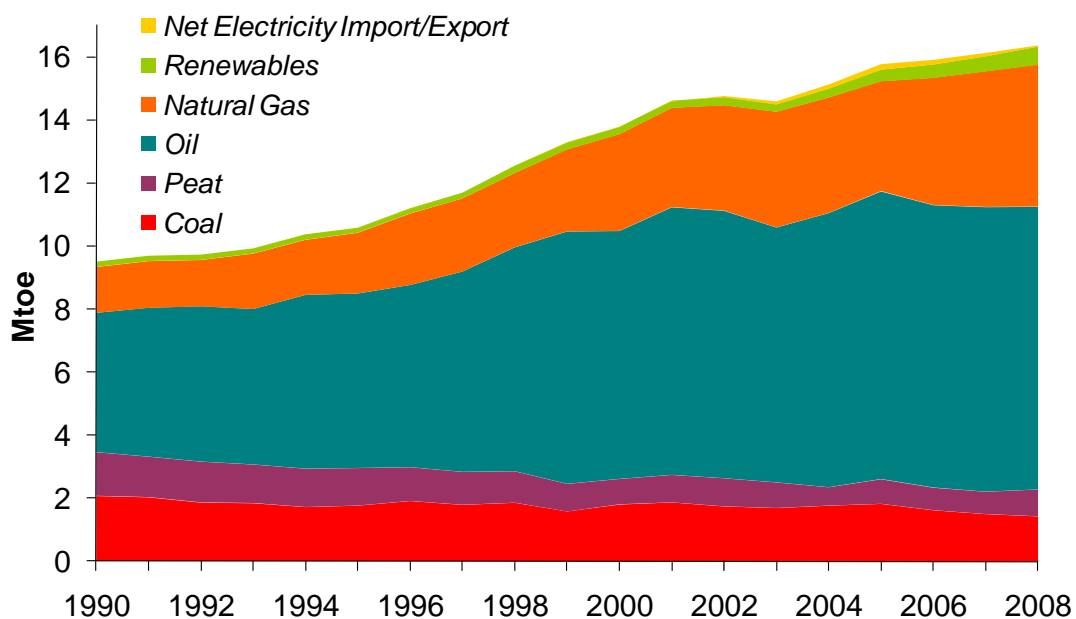
Figure 3: Transport Final Energy Mix by Fuel



Source: Sustainable Energy Ireland, Energy in Ireland, 1990-2008, 2009

Figure 4 below shows the broader picture of energy sources by fuel type and illustrates the increasing dependence on oil and gas as the fuels for economic growth. Renewables have made no significant penetration, notwithstanding Ireland’s considerable wind and marine resource potential.

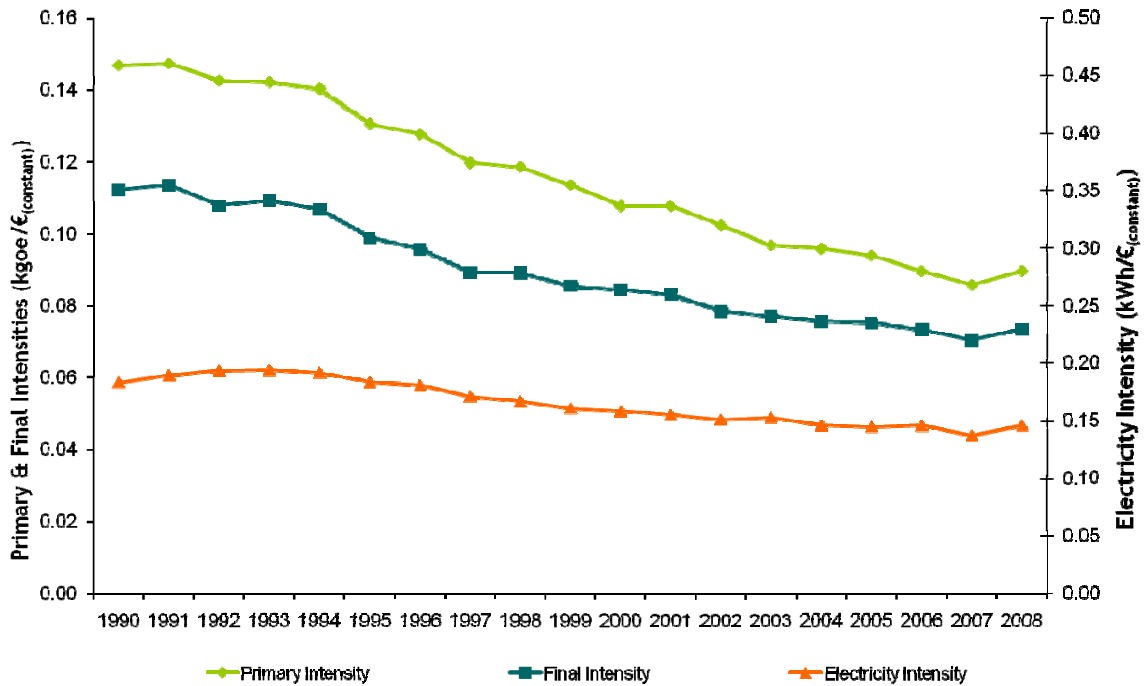
Figure 4: Total Primary Energy Requirement by Fuel Type



Source: Sustainable Energy Ireland, Energy in Ireland, 1990-2008, 2009

Partially offsetting the demand for energy has been a continuous decline in the energy intensity across the demand for primary energy, final consumption and electricity in particular as illustrated in Figure 5.

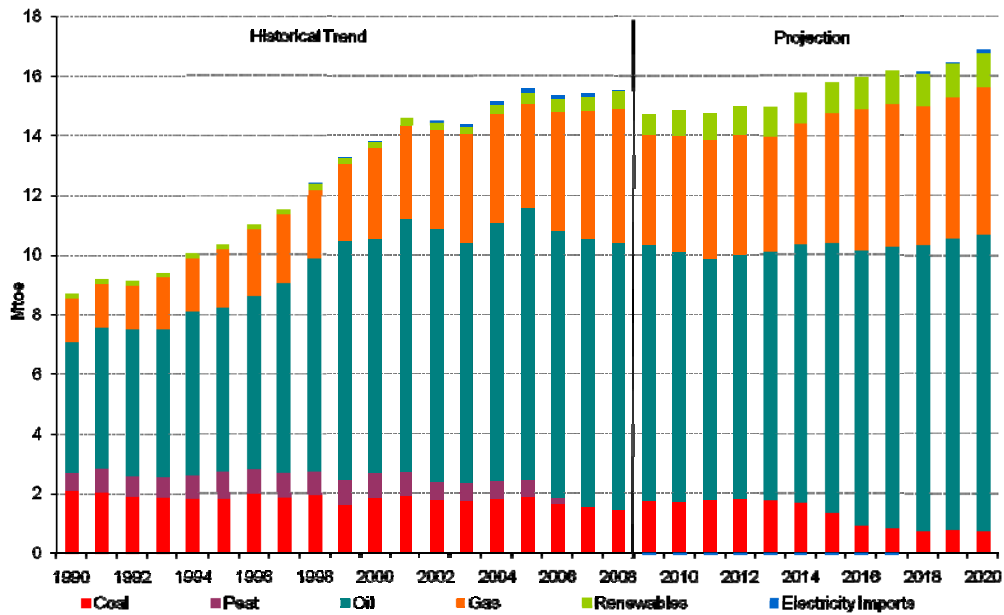
Figure 5: Primary, Final and Electricity Intensity



Source: Sustainable Energy Ireland, Energy in Ireland, 2008

In terms of future energy demand, Figure 6 illustrates the forecasted energy demand out to 2020 (perhaps to some degree displaced by the recent financial crisis which was unforeseen at the time of the analysis). Moreover, there is a high expectation of continuing or increasing demand for fossil fuels, particularly gas and oil.

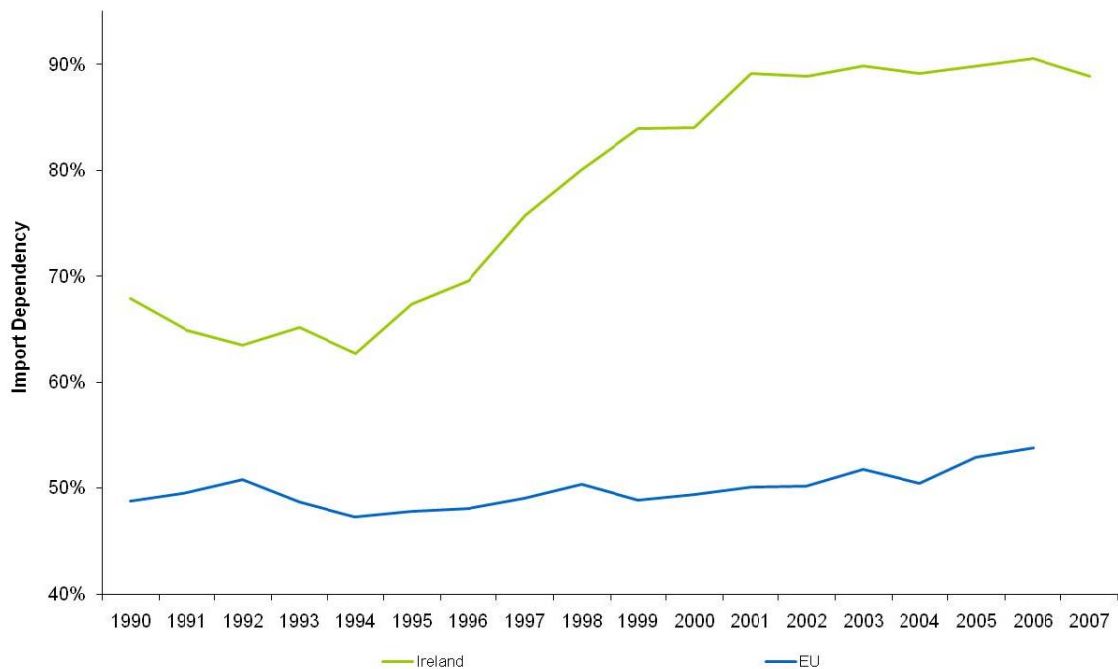
Figure 6: Total Primary Energy Requirement 1990 to 2020



Source: Sustainable Energy Ireland, Energy Forecasts for Ireland to 2020, 2009

Ireland is geographically at the furthest, westerly fringe of Europe with no significant fossil fuel resources other than peat. During Ireland’s economic growth period, the increase in demand for energy and the use of fossil fuels to satisfy that demand has necessarily resulted in an increase in Ireland’s dependency on imports as illustrated in Figure 7 below.

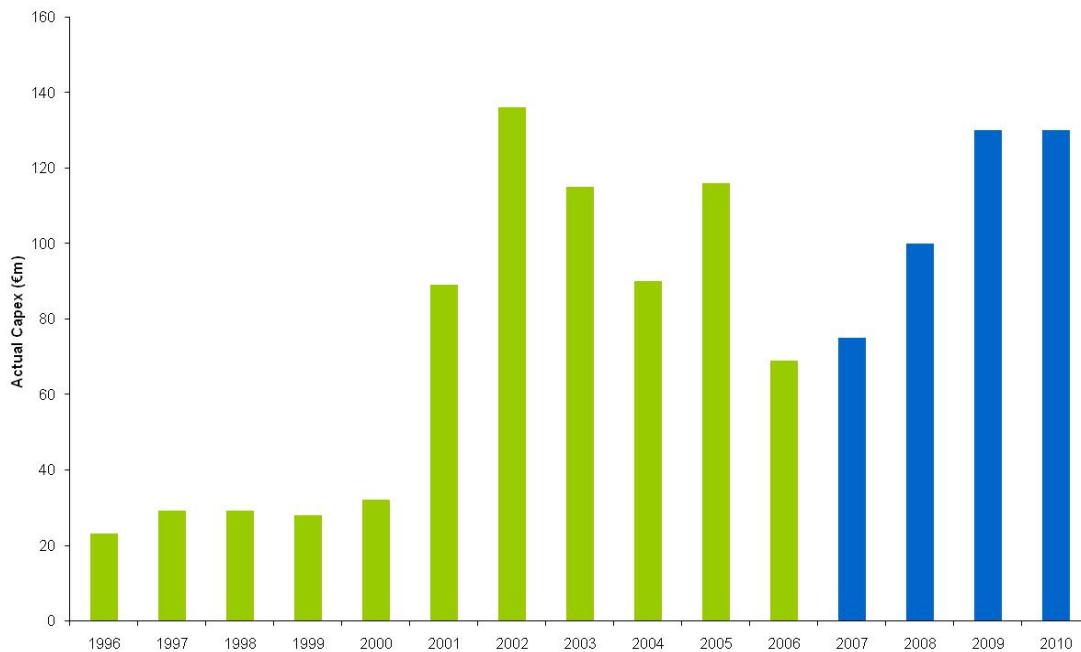
Figure 7: Energy Import Dependency of Ireland and the EU



Source: Sustainable Energy Ireland, Energy in Ireland, 2008

For much of the early part of Ireland's economic growth period, investment in the transmission system for carrying electricity has been relatively low as shown in Figure 8 below.

Figure 8: Electricity Transmission Investment 1996 to 2010

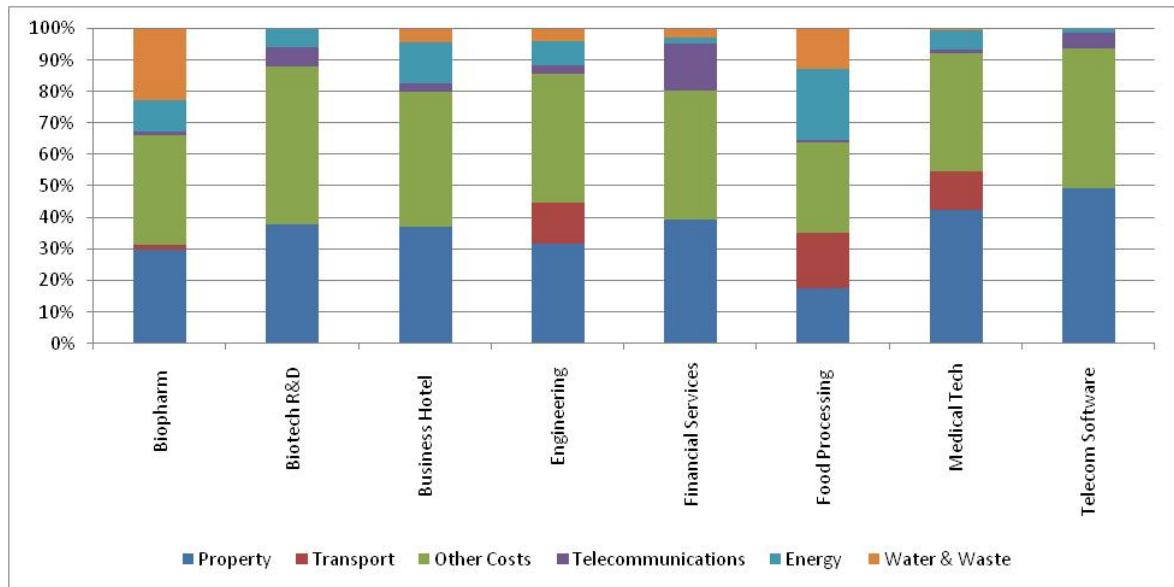


Source: Security of Supply in Ireland, 2007 / ESB Networks

Investment is now increasing of necessity. As well as strengthening the interconnections within the island of Ireland, the Government is supportive of the progressive development of a regional electricity market with UK and North West Europe over the next five years, underpinned by new interconnection. Such interconnection potentially increases the value of variable and intermittent sources of indigenous energy such as wind and marine. Most recently, An Bord Pleanála has granted EirGrid permission to build a €600m electricity Interconnector between Ireland and Wales.

Aside from the physical aspects of security, Ireland and the products and services it produces and exports must remain competitive. Figure 9 illustrates the role played by energy in securing competitiveness by sector, with food processing firms having the highest energy input at around 20 per cent and software firms having the lowest.

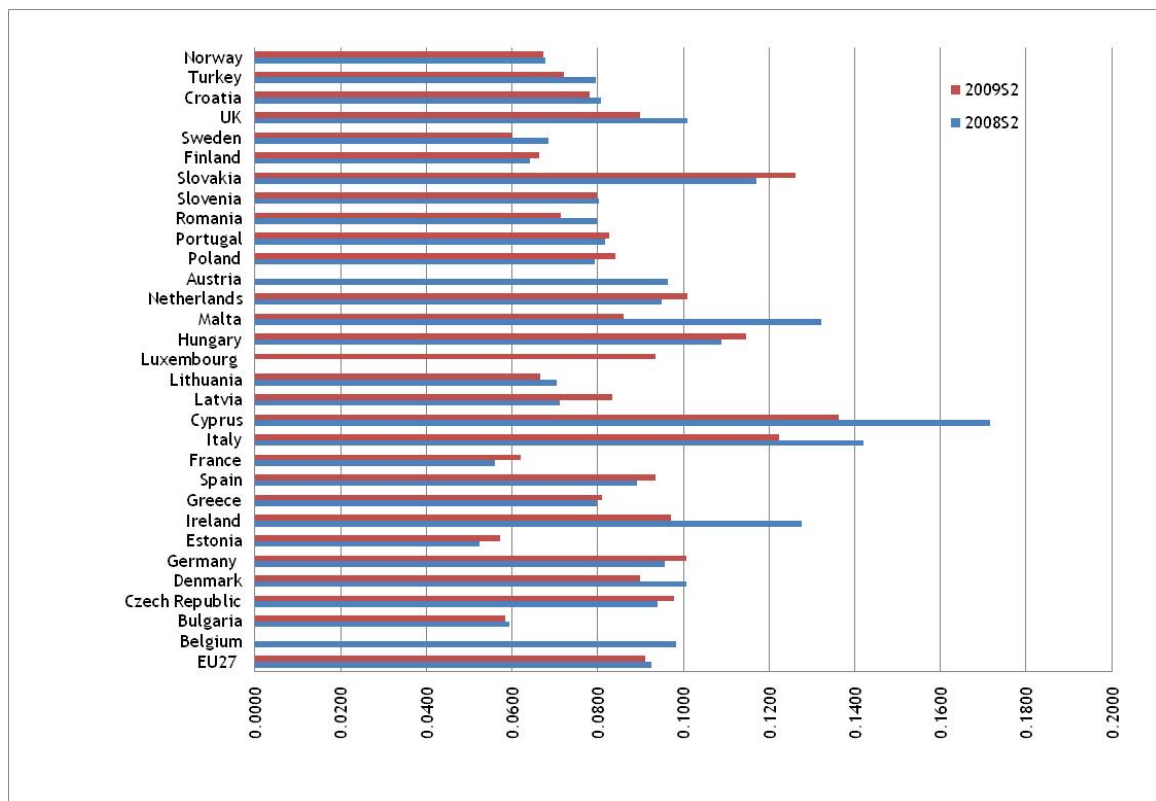
Figure 9: Cost Profile (excluding labour costs) of a “Typical” Firm by Sector, 2009



Source: NCC, Cost of Doing Business, 2009

The costs of electricity to industry have been amongst the least favourable in the whole of the European Union as shown in Figure 10 below.

Figure 10: Industrial Electricity Prices (excl. VAT but incl. other taxes) 1 Jan. 2008 vs. 1 Jan 2009



Source: NCC Energy Statement, 2009

The future of energy in Ireland is to a high degree constrained by regulations which set renewable, carbon and environmental goals and targets. In addition to the obligations under the proposed Renewable Energy Directive, the Energy White Paper also specified targets for renewable energy, which have since been modified further as follows as shown in Table 2.

Table 2: Irish renewables targets in the Energy White Paper

Sector	Existing Contribution	Interim Target	2020 Target
Electricity	14.4 per cent of gross electricity consumption	15 per cent of gross electricity consumption by 2010	40 per cent of gross electricity consumption. (Originally 33 per cent in the White Paper)
Heat	3.9 per cent of thermal energy	5 per cent of thermal energy by 2010	12 per cent of thermal energy
Transport	1.5 per cent energy from petrol and diesel (excluded kerosene)	2 per cent energy from petrol and diesel (excluded kerosene) by 2008 3 per cent by 2010 (originally 5.75 per cent in the White Paper)	10 per cent energy from petrol and diesel (excluded kerosene)
Total	4.7 per cent of Total Final Consumption		16 per cent of Total Final Consumption

Source: DCENR 2007/ SEAI 2010⁶

Whilst the policy and technology drivers in Ireland are ostensibly the same as across the EU (if not the world), the context of its current position with respect to fuel supplies and future risk exposure mean that energy supply will be one of the strongest determinants of Ireland's economic growth, and also the means by which it can meet environmental targets.

A further major consideration is the environmental effect of choices of energy supply. Unless commercial scale carbon capture and storage or similar technologies come forward, dependence on fossil fuels could make compliance with carbon and other environmental commitments at national and EU level all but impossible.

To meet the energy challenge, Ireland will need to make some very difficult and urgent policy choices and trade-offs in all policy areas of transport, electricity and heat. The Energy Tetralemma Index and the associated fuel reports help to analyse some of the major policy decisions facing Ireland into the future and help to understand the trade-off positions of the various fuels in determining how best to:

⁶ SEAI, 2010, Renewable Energy in Ireland, 2010 Update

- Secure significant, indigenous sources of energy;
- Provide low marginal cost energy to underpin competitive economic growth;
- Decarbonise significantly the Irish energy sectors;
- Export low carbon low margin cost energy through interconnection;
- Develop export potential of wave and marine technical expertise and related products and services; and
- Align, integrate and optimise policy between all three energy consumption sectors.

7. The Tetralemma Index

Energy systems can appear to be bewilderingly complex. When analysing the development of an entire energy system within a country over a long period of time, there are far too many issues to consider simultaneously, either to be able to come to a comprehensively reasoned conclusion or to communicate complex issues in a simple manner. The Tetralemma Index aims to simplify the process of policy development whilst not compromising consideration of the vast array of dimensionally differing factors that bind energy into a single concept. The index seeks to simplify the choices by providing a framework of policy-relevant fact and analysis that is separate from the policy objective. Once the factual evidence base is established, attention can shift to a smaller set of assumptions that affect outcomes. This enables policy development, by making explicit points of commonality and disagreement, without the need to revisit excessive and often obscure detail. Crucially the index is not a static tool. Being fully transparent and flexible allows for changing issues and new data sources to be easily included.

7.1 Benefits of using the Energy Tetralemma Index

There are a number of benefits of using the Energy Tetralemma for long-term energy policy development and these are outlined as follows:

Completeness

- The pillars of the Energy Tetralemma Index are reduced to their key indicators and each indicator is scored using referenced sources. (The weighting of each indicator and pillar remains a policy decision).

Consistency

- When fuel types are compared using the Index, known parameters are adjusted using the same set of underlying data thereby ensuring consistency.

Policy intent

- The variables that determine policy are limited in number and their weightings are explicit.

Policy assumption

- The fixed referenced assumptions that underpin policy are explicit and can be reviewed and challenged as necessary.

Communication

- The clarity with which assumptions and policy choices can be identified allows communication to become clear and focussed with the added benefit of more meaningful stakeholder engagement.

Separation of fact and analysis from policy decisions

- Confusion and distraction can be avoided by separating consideration of fact and analysis from policy selection.

Helps to isolate the real reasons why people may disagree on energy policy

- Where disagreement arises regarding different policy options, the reasons for this can more easily be traced to a root cause than would be the case without an Energy Tetralemma framework.

Holistic or partial applicability

- By setting certain parameters to zero, subsets of the whole can be evaluated in isolation. If the Tetralemma Index approach were extended to evaluate the whole energy system, it could be used, for example, to identify areas where a wider benefit in a system (e.g. the whole energy system) can be obtained even though this may incur a disbenefit in a smaller subsystem (e.g. the electricity sector).

7.2 Limitation of the Energy Tetralemma Index

However, there are also a number of limitations in using the Energy Tetralemma that need to be considered and understood and these are outlined as follows:

Does not assess the full practicality of implementing any particular fuel type

- Although many aspects of feasibility are considered in scoring the indicators for each fuel type in a local context, a number of important constraints are not considered, such as the particular configuration and time evolution of the energy distribution system.

Does not assess the portfolio effect of the whole energy system

- The Energy Tetralemma Index will deliver a list of fuel types ranked in order of highest Index score. This should not be taken to mean that creating an energy mix across the whole energy system by maximising the use of available fuels in the order in which they appear in the list, until energy demand is satisfied, will automatically maximise a similar Tetralemma Index representing the whole portfolio. This is because the portfolio of fuels will have emergent policy-related characteristics that differ from the sum of the characteristics of the fuels used.

For example, let us suppose that wind individually achieves the highest Index score. It may be that a very high penetration of wind in the electricity sector would lead to the practical need for a significant capacity of highly carbon-intensive peaking plant for system balancing purposes. This in turn may lead to a situation where the system delivers higher carbon intensity than would be the case if there were a lower penetration of wind.

8. Methodology

The Energy Tetralemma Index comprises an extensive research-based data set that assesses individual fuels against indicators that fall within four main pillars of long-term energy policy as discussed earlier - competitiveness; security of supply; sustainability; and climate change. Each policy pillar is made up of a set of indicators. Each of the fuels is then given a score between 1 and 10 for each indicator. A higher score indicates a better performance of the fuel in relation to that indicator. Then each indicator is given a weighting to reflect the relative policy importance of each indicator within a pillar. The process is repeated for each pillar. Depending on the policy objective, each pillar is assigned a weighting and when the scores for all the pillars are summed together, the result is the overall Energy Tetralemma Index for the fuel under consideration.

Index scores are relative and not absolute. This means that the Index is capable of ranking fuels in order, but the differences between Index scores would not necessarily correspond with a user's perception of the policy gap. This is very similar to the representation of position and distance on a public transport schematic (e.g. a metro map) as compared to the real position.

In applying the Energy Tetralemma the policy maker must decide the relative importance (percentage weighting) of each indicator within each pillar, and the relative importance of the pillars themselves. In effect by having the ability to change the assigned weightings the Index allows the policy maker to focus clearly on the key policy issues.

8.1 Indicators

A large number of indicators were defined and applied to the fuel categories across the four pillars of the Tetralemma Index. Both quantitative and qualitative indicators were used and the number within each pillar varies.

The methodology used recognises that individual indicators have a different importance and impact on the overall position of the fuels, particularly from a policy perspective. Therefore, they were assigned weightings, represented as percentage. Weightings are relative to the indicators within an individual pillar only and within that pillar they add up to 100 per cent. The indicators used under each pillar and the assigned weightings are presented in Table 3 below.

Table 3: Energy Tetralemma Indicators and Assigned Weightings

Competitiveness

Fuel Cost

Key question	What is the (international) market price of the fuel (as a commodity)?
Definition and rationale	This is the commodity price of the fuel as traded in different markets, before it is converted into energy.
Metric(s)	Euros per gigajoule (€/GJ). In practice, fuel prices are reported in a wide variety of metrics, depending on the specific form and quantity of the fuels, as well as the dominant currencies (e.g. US\$). In order to achieve consistency across these different metrics, the methodology adopts joules (J) as the standard international (SI) unit for energy/energy content. Also given the Irish context, other currencies are converted into Euros (€).
Weighting	5 per cent - whilst an important indicator, the fuel cost is also captured in the delivered cost indicator and thus the reduced weighting addresses the issue of representing this indicator twice (i.e. double counting).

Delivered Energy Cost

Key question	What is the levelised cost of energy from the fuel (before delivered to the market and excluding taxes and duties)?
Definition and rationale	This is the price of a unit of delivered energy after the full conversion of the fuel at the stage of wholesale to businesses users. It is commonly referred to as the 'levelised' cost and as such comparisons across countries and markets are possible.
Metric(s):	Euros per gigajoule (€/GJ). In practice, fuel prices are reported in a wide variety of metrics, depending on the specific form of energy they provide (kWh, litres), as well as the currency used by the particular source. In order to achieve consistency across these different metrics, the methodology adopts joules (J) as the standard international (SI) unit for energy/energy content. Also given the Irish context, other currencies are converted into Euros (€).
Weighting:	25 per cent - this is a primary indicator for competitiveness.

Policy and Regulation Framework

Key question	What policy and regulatory barriers and incentives are associated with the fuel and how are they affecting cost competitiveness?
Definition and rationale	This is the current and likely future policy/regulatory framework affecting the fuel in terms of specific standards, requirements, targets and incentives at various geographical levels (Ireland, EU, international). This indicator explores the ease of using the fuel and deploying/operating the required infrastructure. It is qualified by way of two criteria - 'barriers' and 'incentives', each of which is scored on a 1-5 scale to give a combined score range of 1 to 10, (NB: combined score of 1 is attributed 'manually' to the worst performing fuel of the set).

Metric(s):	Coefficient (1 to 10) - this is a qualitative indicator, where the score is given on a relative basis comparing all the different fuels on the basis of stringency of the regulatory framework, as well as the enabling role of policy.
Weighting:	30 per cent - the policy and regulatory framework is very important for a fuel's competitiveness, but due to the relative subjectivity of scoring this indicator, its weighting has been reduced in order not to skew the competitiveness pillar.

Market Context (Ireland)

Key question	What are the specific market conditions in Ireland that can affect the competitiveness of the fuel?
Definition and rationale	This assesses the current and likely future market barriers and advantages of the fuel specific to Ireland in terms of for example access to grid and market, final (end user) energy price and uptake of the conversion technology. Its purpose and rationale are to fully contextualise the competitiveness of the fuel to Ireland.
Metric(s):	Coefficient (1 to 10) - this is a qualitative indicator, where the score is given on a relative basis comparing all the different fuels on the basis of overall market ease (barriers or lack thereof).
Weighting:	20 per cent - the market context in Ireland is relatively important as an adjustment for a fuel's actual competitiveness, but as it is subjectively scored, its weighting has been reduced in order not to skew the competitiveness pillar.

Enterprise Opportunities

Key question	What is the enterprise value of the fuel with regard to Ireland's economy?
Definition and rationale	This explores the additional benefit of locking into the fuel as part of the national energy mix through contributing to the overall competitiveness of the national economy. Enterprise value is qualified by way of three criteria: (1) domestic market associated with the fuel and its value in terms of contribution to GDP; (2) export opportunities associated with the fuel and their value in terms of contribution to GDP; and (3) employment creation potential of the fuel in terms of number of jobs across the entire supply chain. The scope of enterprise covers the entire supply chain that is specific to the fuel, i.e. extraction, processing and transport of the fuel, as well as conversion technology, manufacturing, deployment and all associated ancillary services.
Metric(s):	Each of the three criteria are scored on a high(green), medium(amber) and low(red) scale to give a combined score of high, medium and low. All scores are aligned with the rest of the Tetralemma index by converting them into a scale of 1-10. Coefficient (1-10) - this indicator combines quantitative and qualitative aspects and therefore is expressed as a coefficient. The total score is given on a relative basis comparing all the different fuels on the basis of their overall enterprise value to the national economy.
Weighting:	20 per cent - the enterprise value is considered as important as some of the other indicators under the competitiveness pillar.

Security of supply

Weighted Import Dependence

Key question	How much of the fuel is imported and the share of the Irish fuel mix that it represents?
Definition and rationale	This is the combined exposure of Ireland to the fuel measured as the percentage of imports multiplied by the percentage share of the total primary energy requirement (TPER). Dependence is higher (and security lower) where the fuel has a larger share of TPER and is mostly imported.
Metric(s):	Percentage of imports in the national fuel mix.
Weighting:	30 per cent - this is a key indicator, especially given Ireland's limited indigenous fossil fuel reserves.

Fuel Place of Origin

Key question	Where does the fuel come from?
Definition and rationale	This indicator measures the level of access to the fuel on the basis of where the resources/reserves are located. The indicator is complex in that it takes into account factors such as political stability, government effectiveness, regulatory quality, rule of law and control of corruption. It is calculated as the average value of the above factors as reported by sources such as the World Bank.
Metric(s):	Coefficient (1-10) on the basis of averaging World Bank (political stability) and OECD (country risk) indicators. This indicator can be simplified or further elaborated if similar type country indicators are included in the calculation.
Weighting:	20 per cent

Supply and Infrastructure Resilience

Key question	How complex and robust is the infrastructure associated with the fuel?
Definition and rationale	This is a composite indicator comprising two criteria: 1) the complexity of the delivery infrastructure in terms of the number of 'segments' along the supply chain (i.e. how many points of potential fault/damage exist) and 2) the fragility (or robustness) of the infrastructure, in terms of how easy and likely it is for it to be damaged/interrupted. Both criteria are qualified separately as 'low' (1), 'medium' (3) and 'high' (5) impact, thus giving a combined score range of 1 to 10, (NB: combined score of 1 is attributed 'manually' on the basis of the worst performing fuel in the set).
Metric(s):	Coefficient (1 to 10). Higher scores denote higher security.
Weighting:	20 per cent

Market Volatility

Key question	What is the capacity and volatility of markets for the fuel and relevant conversion technologies?
Definition and rationale	This is the market supply-demand balance (e.g. how frequent and severe are periods of shortage or surplus, especially in terms of large market players, including entire countries) in terms of both the fuel commodity and the supply chain for conversion technologies. The indicator mainly measures the risk associated with supply bottlenecks and as such is qualitative in nature, based on qualified reports by different sources.
Metric(s):	Coefficient (1 to 10) - this is a qualitative indicator, where the score is given on a relative basis comparing all the different fuels and their supply chains on the basis of observed and forecast fluctuations in the different markets. Higher scores denote higher security.
Weighting:	15 per cent - whilst this is recognised as an important indicator, market security is given a lower weighting as its impact is already implicitly captured in other indicators, such as fuel place of origin and fuel cost.

Energy availability/intermittency (of supply)

Key question	How much of the time can energy be supplied using the fuel?
Definition and rationale	This indicator is the equivalent of the so-called 'capacity factor' for energy plant, typically defined as the ratio between a plant's rated capacity (or maximum capacity) to its average production. It captures two factors - 1) the availability (or capacity factor) of the fuel itself over a period of time to be converted into energy and 2) the frequency and length of plant downtime (when it is not generating due to maintenance of faults).
Metric(s):	Percentage of the time over 1 year equivalent to generating power at the plant's full capacity.
Weighting:	15 per cent - this indicator is given a lower weighting because fuel and plant availability are relatively predictable and can be managed by e.g. diversification, substitution and demand management.

Sustainability

Fuel longevity (reserves-to-production ratio)

Key question	How long will the fuel last given rates of annual consumption?
Definition and rationale	This is a composite indicator calculated as the total proven reserves of the fuel in a particular year divided by the total consumption of the fuel in that year.
Metric(s):	Number of years (#).
Weighting:	55 per cent - this is the main indicator for sustainability.

Environmental impacts

Key question	What are the range, scale and cost of the broader environmental impacts from using the fuel? (i.e. environmental pollution, waste generation and disposal, social impacts (e.g. health problems)).
Definition and rationale	This indicator captures the externality cost incurred by using the fuel and its associated infrastructure.
Metric(s):	Euros per mega-watt hour (€/MWh).
Weighting:	45 per cent

Climate Change

Carbon content of fuel

Key question	What are the fuel's nominal carbon emissions (as raw, natural material)?
Definition and rationale	This is the carbon content of the fuel itself, not taking into account conversion efficiency.
Metric(s):	Grams of carbon dioxide equivalent per gigajoule (gCO ₂ e/GJ).
Weighting:	10 per cent - whilst this is a key indicator, it is not given the full weighting as it is captured in the total carbon indicator and thus the aim is to avoid double-counting.

Lifecycle carbon footprint

Key question	What is the total/lifecycle global warming potential ("carbon footprint") of the fuel?
Definition and rationale	This is the carbon emissions produced per unit of delivered energy. This indicator takes into account the various transactions and conversions related to the fuel, including its transportation, the carbon embodied in building the plant, the plant's conversion efficiency and finally the plant's decommissioning.
Metric(s):	Grams of carbon dioxide per gigajoule (gCO ₂ /GJ), (NB: in the case of comparing fuels on the basis of electricity generation, the metric used is gCO ₂ e/kWh).
Weighting:	55 per cent - this is the main indicator for climate change.

Supply and infrastructure vulnerability

Key question	What is the risk of damage to and/or failure of the supply and infrastructure associated with the fuel as a result of climate change?
Definition and rationale	This is a qualitative indicator that explores the various impacts of climate change and how these can affect individual fuels-related supply and infrastructure.
Metric(s):	Coefficient (1 to 10) - based on the observed and forecast frequency and severity of damage to energy infrastructure.
Weighting:	30 per cent - this indicator is given a lower weighting because the climate is not expected to change dramatically over the period to 2030 and its impact on fuel

and energy infrastructure are less tangible to stratify for the three time horizons.

Availability change (of the fuel resource)

Key question	What will be the effect of climate change on the availability of the fuel?
Definition and rationale	This is a qualitative indicator that explores the future resources/reserves of each fuel specifically in the context of climate change. The indicator aims to qualify the extent to which fuel resources may be affected.
Metric(s):	Coefficient (1 to 10) on the basis of the level of change (high, medium, low) where higher scores show a potential resource increase and lower scores represent a potential expected resource decrease.
Weighting:	5 per cent - this indicator is only nominally factored in on the basis that limited evidence has been identified that provides distinctive and definitive directions of fuel availability change due to the changing climate. Whilst some renewables will most likely become more abundant (e.g. biomass and hydro), these changes are rather minor and difficult to objectively capture and compare in an index.

8.2 Index Calculation Methodology

A multi-step approach was designed and applied where each step adds a degree of detail and refinement. The Tetralemma Index looks at the future characteristics of the selected fuels. Numerous future outcomes are possible, but in order to enable the fuel indexation three scenarios detailed in Chapter 9 below were used to run the model. The scope of the study included three time horizons for fuel indexation - 2010, 2020 and 2030. Thus each indicator was assessed against the three time horizons. A detailed description of the index calculation methodology is presented below.

Below, each step of the calculation methodology is explained and an illustrative example is provided.

Step 1: Indicator quantification and qualification

A matrix was produced cross-referencing all fuels and indicators. Each matrix cell (value of indicator for each fuel) was populated with the real value of the indicator for that particular fuel (i.e. using different metrics such as €/MWh and gCO₂/GJ). All values were based on evidence acquired from reputable sources and referenced accordingly, including the assumptions made by the sources. Qualitative indicators were scored by way of a coefficient on a scale of 1 (worst) to 10 (best).

Step 2: Indicator value normalization and primary scoring (1-10)

Taking the minimum and maximum real value for each indicator, its total range was established. The adopted normalised score scale was 1 to 10 and each real value was given a normalised score (1-10). This was done by manually comparing real values, and not mathematically by deciles. The reason for this approach is that the real fuel values are not subject to a normal distribution (i.e. where within a large sample group the full value/score range is covered, with a peak around the middle value/score). Applying normal distribution,

given that the group of fuels featured many extreme real values, would conceal the differentiation between fuels.

Each indicator for each fuel was given its primary score on the basis of the normalised real values.

Step 3: Indicator weighting and scoring

Each indicator was given a weighting as a percentage (1 per cent-100 per cent), relative to the indicators within the same theme (pillar) only. Weightings within a theme sum up to 100 per cent. Weightings show the relative importance of each indicator for the final index scores. (NB: in order to fully exclude an indicator (i.e. 'switch it off') it should be give a weighting of 0 per cent).

Applying the weightings, each indicator received its weighted score.

Step 4: Total score for each pillar

All individual indicator weighted scores for each of the four pillars were added up to show the total score for that pillar.

Step 5: Final scoring (as percentage)

The total score for each pillar from Step 4 was then set against the theoretical maximum score for the pillar, expressed as a percentage of the maximum.

Step 6: Total fuel score for league table (as percentage)

A grand total score combining all four pillars was calculated as the average percentage across the four pillars, i.e. adding up the final scores from Step 6 (as per cent) and dividing the sum by 4 (the number of pillars).

9. Scenario Development

This section presents the range of scenarios and their definitions used to calculate the Energy Tetralemma Index. Three scenarios were defined as outlined below. The main assumptions applied were based on markets evolution, technology development and deployment, and policy formulation and implementation. Assumptions were mainly made for 2030, as a 'final' outcome and traced back to 2010 in a broadly gradual trend.

9.1 High scenario ('optimistic')

This scenario assumes the most favourable conditions in 2030 across all four pillars of the Tetralemma Index - 'cheap, clean, secure and advanced energy system'.

- Low commodity prices;
- Uptake of advanced fossil-fuel conversion technologies;
- CCS deployment;
- Renewables technologies are fully developed and deployed (e.g. marine, solar, geothermal) and achieve economies of scale;
- 'Environment-friendly' Irish and international policy framework - sustainability and climate change remain top priorities;
- High carbon price;
- The Irish Energy White Paper is fully implemented; and
- Relatively stable/predictable/open international markets (certainty).

9.2 Low scenario ('pessimistic')

This scenario assumes the least favourable conditions in 2030 across all four pillars of the Tetralemma Index - 'expensive, dirty, insecure and less-advanced energy system'.

- High commodity prices;
- Low/no uptake of advanced fossil-fuel conversion technologies;
- No CCS deployment;
- Renewables technologies are slow to develop and deploy (e.g. marine, solar, geothermal) and do not achieve economies of scale;
- 'Competitiveness-friendly' Irish and international policy framework - cheapest options supported;
- Low carbon price;
- The Irish Energy White Paper only partly implemented; and
- Unstable/volatile/politically-driven international markets (uncertainty).

9.3 Medium scenario ('neutral')

This scenario uses a mixture of assumptions from the high and low scenarios in terms of 'extreme values'; for some parameters it also takes the 'central forecasts' (as opposed to the extreme values). The scenario can be described as 'fossil fuel dominance in a moderately inexpensive, relatively clean, reasonably secure and conservatively advanced energy system'.

- Medium-range commodity prices;
- High uptake of advanced fossil-fuel conversion technologies on the basis of prudent investment and future-proofing;
- CCS deployment;
- Renewables technologies are deployed but only those that are already commercially viable (wind, solar); they achieve economies of scale and lower capital costs. Other renewables are not fully developed and deployed commercially (marine, geothermal);
- 'Security-friendly' Irish and international policy framework - most accessible and reliable supplies supported;
- Medium carbon price;
- The Irish Energy White Paper only selectively implemented; and
- Moderate level of certainty across international markets.

10. Detailed Results and Analysis

As a first step each pillar within the Energy Tetralemma was examined in isolation under the three different scenarios and weighted at 100 per cent. By so doing archetype results were obtained for each policy objective, identifying the best performing fuels for the fulfilment of individual policy objectives. For example, if competitiveness is the sole concern, what are the most attractive fuels? If on the other hand, the policy objective is absolute security of supply, which fuels score best? It must be remembered that when comparing fuels, one is assessing the relative scorings to each other and are not absolute. The difference in index values between fuels does not necessarily represent a similar policy gap when comparing fuels. Once the base position for each pillar has been set, we can begin to see the structure of potential trade-offs between competing objectives. Detailed below is the analysis of each pillar in its own right, which discusses the index scores in terms of each fuel meeting specific policy objectives.

10.1 Competitiveness Pillar

If the competitiveness pillar is isolated and weighted at a 100 per cent, with no marks given to security of supply, sustainability or climate change the following results are observed:

High Scenario

Cheap, clean, secure and advanced energy system

- Under these assumptions the index spans a wide range of values, with a high degree of change over time. In the short-term (2010) fossil fuels occupy the top end of the index. Over the period to 2030, most renewables markedly improve their position in absolute and relative terms. This is driven by the assumption of sustained policy support leading to higher market penetration and lower capital costs.
- Biogas and solar thermal occupy some of the highest positions (75 per cent and 77 per cent) for heat applications - this is due to a combination of the free resource coupled with established infrastructure, markets and supply chains (for biogas) and policy support (for solar thermal) as well as a high carbon pricing structure.
- Natural gas in 2010 is the most competitive fuel for electricity generation scoring an initial 88 per cent. The attractiveness of natural gas declines over the time frame to 71 per cent due to an anticipated increase in fuel cost, tightening of the policy and regulatory environment and more limited enterprise opportunities. Nevertheless its delivered energy cost, based on already available natural gas combined cycle (NGCC) technology should make it amongst the cheapest fuels, in terms of levelised costs of generation by 2030.
- Liquefied Natural Gas (LNG) improves over time to become the most competitive fuel for electricity generation by 2030 with a score of 82 per cent. This shift is predicated on a more supportive market context and greatly enhanced enterprise opportunities.
- The attractiveness of offshore wind increases dramatically out to 2030 (by nearly 100 per cent) as the technology matures under a supportive policy and regulatory framework. This reflects a high penetration of offshore wind which drives costs down, and a very supportive policy and regulatory framework in Ireland, which also gives

confidence to the domestic market. This is in contrast with onshore wind where difficulties in gaining planning consent and grid connection continue to undermine its competitive position. This scenario anticipates that these barriers will remain and may increase for onshore wind as deployment increases and available grid capacity fills up. However, it is expected that these barriers will fall between 2010 and 2030 for offshore wind as the permitting, licensing and planning consent regime matures for that sector. Both show significant enterprise opportunities relative to other fuels.

- Wave and tidal also register strong increases to 2030 (from 38 per cent to 74 per cent) on the back of a supportive policy and market context leading to excellent enterprise opportunities. Regulatory barriers and difficulties accessing the grid are assumed to be overcome.
- Oil moves down the index as policy and regulation becomes less favourable and enterprise opportunities from conventional oil decrease. Fuel costs remain expensive relative to alternatives although delivered energy costs are competitive.
- Black coal also improves its score from 67.5 per cent to 71 per cent, although still placing behind both forms of ocean and wind energy. This is due mainly to an unfavourable policy and regulatory framework and market context for coal. Both its fuel and delivered energy costs are competitive while enterprise opportunities remain good over the time frame.
- Peat declines sharply over time as the market context and enterprise opportunities collapse.
- Nuclear is uncompetitive on account of the non existence of the requisite regulatory environment or market context in Ireland. This is despite low fuel and delivered energy costs. Enterprise opportunities are assumed to be more limited than best performers based on the necessity to import necessary skills and expertise.

Medium Scenario

Fossil fuel dominance in a moderately inexpensive, relatively clean, reasonably secure and conservatively advanced energy system

- The index displays a wide band of values with no real convergence over time.
- Fossil fuels start off, and remain, relatively more competitive than renewables. Black coal is the most attractive fuel, by some margin. Under this scenario the policy and regulatory framework remains very supportive of black coal due to its relative inexpensiveness, price stability and international availability. As a result CCS is deployed, as are advanced conversion technologies that re-enforces a positive market context and contribute to a maintained excellence in delivered energy costs. New coal generation plants and the deployment of CCS also translates into significant enterprise opportunities across the time frame.
- LNG improves its position considerably to be the 2nd most attractive fuel in 2030 as the market context develops, the policy and regulation matures and new enterprise opportunities associated with storage are realised.
- Natural gas dips somewhat to 2020 before recovering to finish the 3rd most attractive fuel in 2030. This is largely driven by excellent delivered energy costs, full policy and regulatory support (in a scenario where fossil fuels are prized) and an established domestic market.

- Fossil fuels are far more attractive for electricity generation than most renewable alternatives except for peat where tightening regulation and declining market context lead to a collapse in the competitive position.
- Bio-residues and bio-gas become competitive by 2030 due to favourable policy regulation while bio-residues also benefit from a more established market context.
- Onshore and offshore wind register improvements to 70 per cent and 50 per cent as delivered energy costs begin to fall and enterprise opportunities, particularly for onshore wind are realised. Ultimately offshore wind remains uncompetitive at 2030 and while onshore closes the gap with the main fossil fuels it still places behind black coal (97 per cent), LNG (89 per cent) and natural gas (77 per cent).
- Wave and tidal are the least competitive due to high delivered energy costs and an unsupportive market context or regulatory framework. Limited improvements in enterprise opportunities are not sufficient to offset poor results on these three indicators.
- Nuclear also scores low, but does improve slightly in line with lower delivered energy costs and some enterprise opportunities. Again the non-existent regulatory regime and undeveloped market context are preventing nuclear from achieving a higher index score.

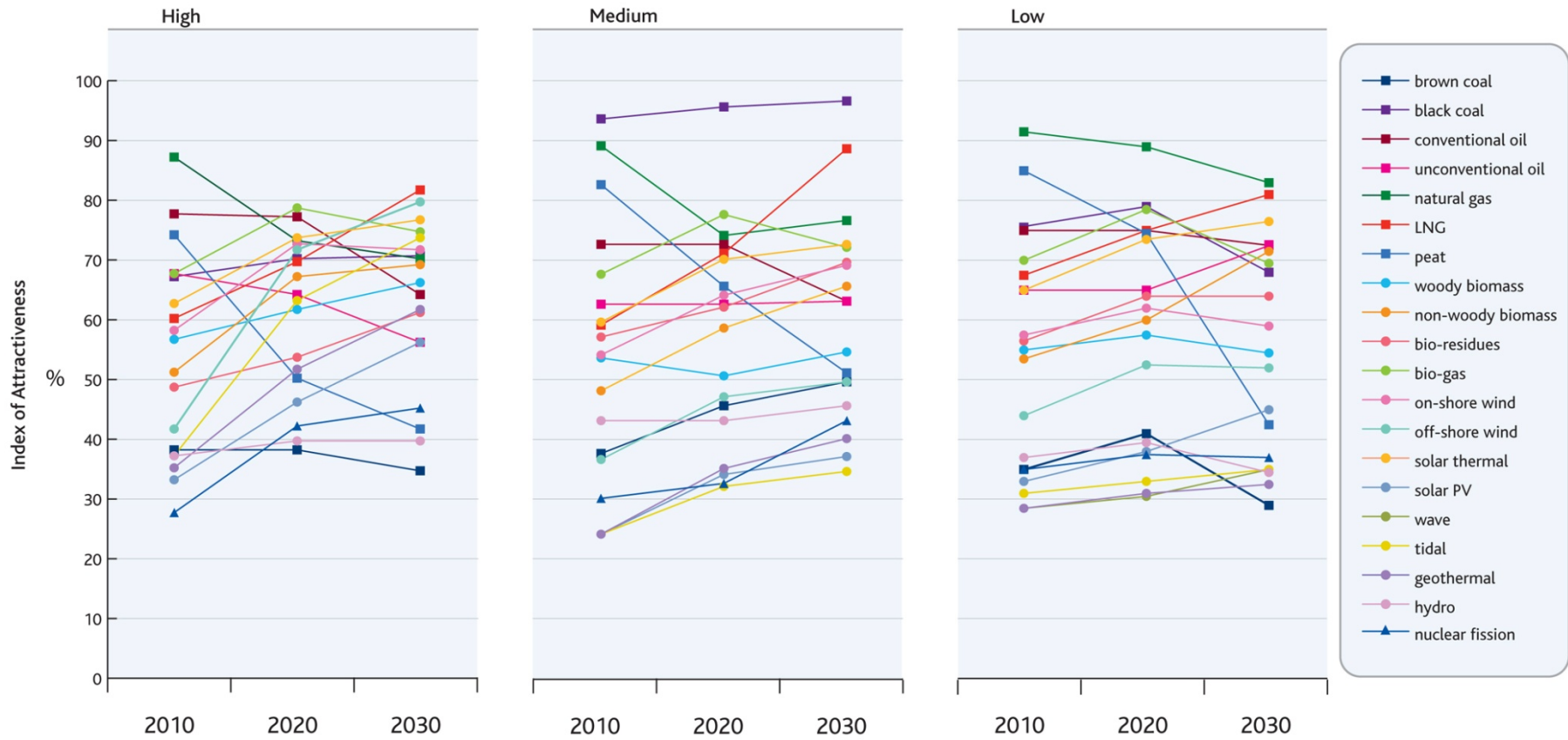
Low Scenario

Expensive, dirty, insecure and less-advanced energy system

- Overall fossil fuels are declining in attractiveness (apart from LNG and unconventional oil) but a gap persists between an upper band of fossil fuels and a middle, to lower, band of renewables. The decline in the absolute scores of fossil fuels is due to high commodity prices and uncertain markets.
- Natural gas and LNG occupy the top two spots on the index with scores of 83.5 per cent and 81.5 per cent respectively in 2030. Slight declines in delivered energy costs are offset by maintained or improved competitiveness across the other sub indicators.
- Black coal initially does well, becoming more attractive to 2020 before declining sharply to below the 2010 level thereafter. Higher fuel and delivered energy costs account for the fall although the full effects are cushioned somewhat by greater enterprise opportunities.
- Biogas also does well to 2020 before declining, due to a more unfavourable market context, to finish just above black coal but below non-woody biomass which improves across all of the sub indicators.
- Based on inexpensive delivered energy costs, strong enterprise opportunities and a favourable market context, conventional and unconventional oil are competitively placed near the top of the index.
- Wave and tidal are uncompetitive due to high delivered energy costs and an unsupportive policy and regulation environment, which act as a drag on improvements in the market context. No enterprise opportunities are realised over the time frame.
- Wind occupies a middle band registering only a slight increase in attractiveness over time due to improvements in market context for offshore and enterprise opportunities for onshore.

- Solar thermal becomes competitive as a heat application by 2030 with better delivered energy costs, supportive policy and more enterprise opportunities.
- Nuclear remains uncompetitive for the same reasons outlined above.

Figure 11: Competitiveness Index Scores in 2010, 2020 and 2030 across the three scenarios (high, medium and low)



Competitiveness Pillar Summary

- Natural gas and LNG score well across all three scenarios, with LNG always having some of the highest scores and natural gas only declining relatively in the high scenario where renewables are favoured. Fuel costs do increase towards 2030 but higher efficiencies prevent this from having an adverse impact on delivered energy costs in all except the low scenario where advanced technology is not deployed. Enterprise opportunities score well and both benefit from gas being the established mainstay of the current Irish electricity system with a correspondingly favourable policy and regulatory regime (due to their status as a clean fossil fuel).
- Coal is most attractive in the medium scenario where policy and regulation are most disposed towards fossil fuel generation but also scores reasonably well in the low and high scenarios. Coal is a choice that, much like renewables, requires policy support and investment in advanced technology. The future competitiveness of coal largely depends on the development and deployment of advanced conversion technologies. An 'optimistic' scenario where technologies such as supercritical, ultra-supercritical and IGCC plants become widely used still shows the real delivered cost almost doubling by 2030 (due to their high capital cost). By that time, coal will lose its relative competitiveness to natural gas and renewables such as hydro and bio-gas, but will still be cheaper than mainstream renewables, e.g. wind and woody biomass. CCS technology will also need to be deployed for coal to maintain its competitive position. High commodity prices (in the low scenario) also undermine the traditional advantages of coal, namely low fuel and delivered energy costs. Enterprise opportunities in coal are assumed to be good across all scenarios.
- In a choice between gas and coal for base load generation coal is cheaper with lower delivered energy costs while the competitiveness of gas (natural and LNG) is bolstered by a favourable market context and supportive policy and regulation (in the high and low scenarios). Both have similarly sized enterprise opportunities, although black coal and LNG score higher than natural gas in this regard. This suggests that if the policy and regulatory framework can be improved for coal then it would be a more attractive option than gas for electricity generation, assuming competitiveness was the only policy objective.
- Wind occupies a middle band in the low and medium scenario, increasing over time, but scoring better in the high scenario. Onshore wind is more attractive than offshore in both the low and medium scenarios with positions only reversed in the high scenario where both do well. Partly this is because enterprise opportunities are assessed to be greater for onshore wind in the low and medium scenario and equal in the high scenario. Currently, the levelised cost of wind energy is relatively high and much less competitive than that from fossil fuels. Offshore wind has a markedly higher capital cost component. Bottlenecks in the manufacture and supply of wind turbines have prevented significant capital cost reductions from being realised to date. Cost reductions are expected in the delivery of onshore and offshore wind over the period 2010 to 2030 as a result of technological and grid infrastructure improvements and a more widespread reliable manufacturing base (high scenario).
- Marine energy is very uncompetitive in the low and medium scenario but becomes very competitive in the high scenario with a high carbon price and full implementation of the Energy White Paper.

- Across all scenarios nuclear scores lowest because no regulatory regime exists in Ireland and there is no market context. Internationally, however, the fuel and delivered energy costs for nuclear are very competitive, and in fact compares with coal and is cheaper than gas.

10.2 Security of Supply Pillar

When security of supply is the only policy objective renewable energy sources dominate all three scenarios, scoring highly, primarily as a result of their indigenous nature to Ireland. The differentiation between most renewables is rather marginal. Many renewables, however, are intermittent and energy availability is rather low. This is particularly the case for wind, solar, and marine but has had a minor impact on their overall score as the availability indicator is assigned a weighting of 15 per cent.

High & Medium Scenario

- Renewables are the highest ranking fuels in terms of attractiveness in meeting security of supply objectives as domestically available resources, renewables are inherently more secure. Renewables outperform fossil fuels with the exception of brown coal because of Ireland's low import dependence and peat because of our indigenous supplies. Vulnerability of the infrastructure and the intermittency of energy generation are the issues of concern for renewables. Wind turbines for example only have an average capacity factor⁷ of approximately 27 per cent for onshore and 30 per cent for offshore wind.
- There are no major improvements forecast in the energy availability (capacity factor) of the main renewable options (marine, wind or solar) implying a continued need for back-up generation or interconnection.
- Biomass renewable fuels overcome the intermittency inherent in mainstream renewables although all except bio-gas are susceptible to a certain level of market volatility. This is because biomass has a finite supply potential as an economically viable resource. Irish indigenous supply is limited and importing biomass has a transport cost. Moreover agricultural land has a range of uses, mainly food production, which will continue to compete with biomass for energy use. Therefore, the market is inherently volatile.
- Nuclear is very attractive, scoring well on all indicators (an average of 75 per cent). This is because despite its complex supply chain and infrastructure, the technology involved is considered highly reliable and there is a rigorous procedure for assigning responsibility. Nuclear's whole supply chain is highly regulated, including the various markets and thus uncertainty is very low. Nuclear outperforms wind (67-69 per cent) or marine power (63 per cent), both of which are only intermittently available.
- Fossil fuels are the inverse of renewables, only scoring well on energy availability. Natural gas, LNG and conventional oil are the least secure fuels in the index. Both start from a position of high import dependence with a supply chain that is subject to

⁷ the ratio of actual output over a period of time and its installed maximum output

sometimes severe disruption. Over the timeframe supplies are anticipated to come from more risky countries with international markets becoming increasingly volatile.

- Initially LNG is more attractive than natural gas due to more diverse options of supply, reducing both the place of origin risks and the market volatility risk. This advantage is expected to erode over time as global gas reserves diminish.
- Peat, as an indigenous fossil fuel, scores highly (75 per cent) and is highly secure across all indicators out to 2030. But as noted in Part 1 of this report, it is forecasted that peat will not be part of the energy supply mix in Ireland passed 2019 due to EU directives.
- Solar PV (71 per cent) slightly outperforms both types of wind primarily due to a more resilient supply infrastructure.
- Black coal is on a strong upward trend (scoring 39 per cent in 2010 and 53.5 per cent in 2030 in the high scenario) and far more attractive than LNG and natural gas by 2030 at 36 per cent and 33 per cent respectively. This is because in the future natural gas and LNG will be sourced from riskier countries of origin while coal is sourced from a large number of exporting countries which are a mixture of low and high-risk. Black coal also has a more robust supply infrastructure and is easy to stockpile but coal will maintain its relative weighted import dependence position in the future, despite a slight decline of its role in TPER.

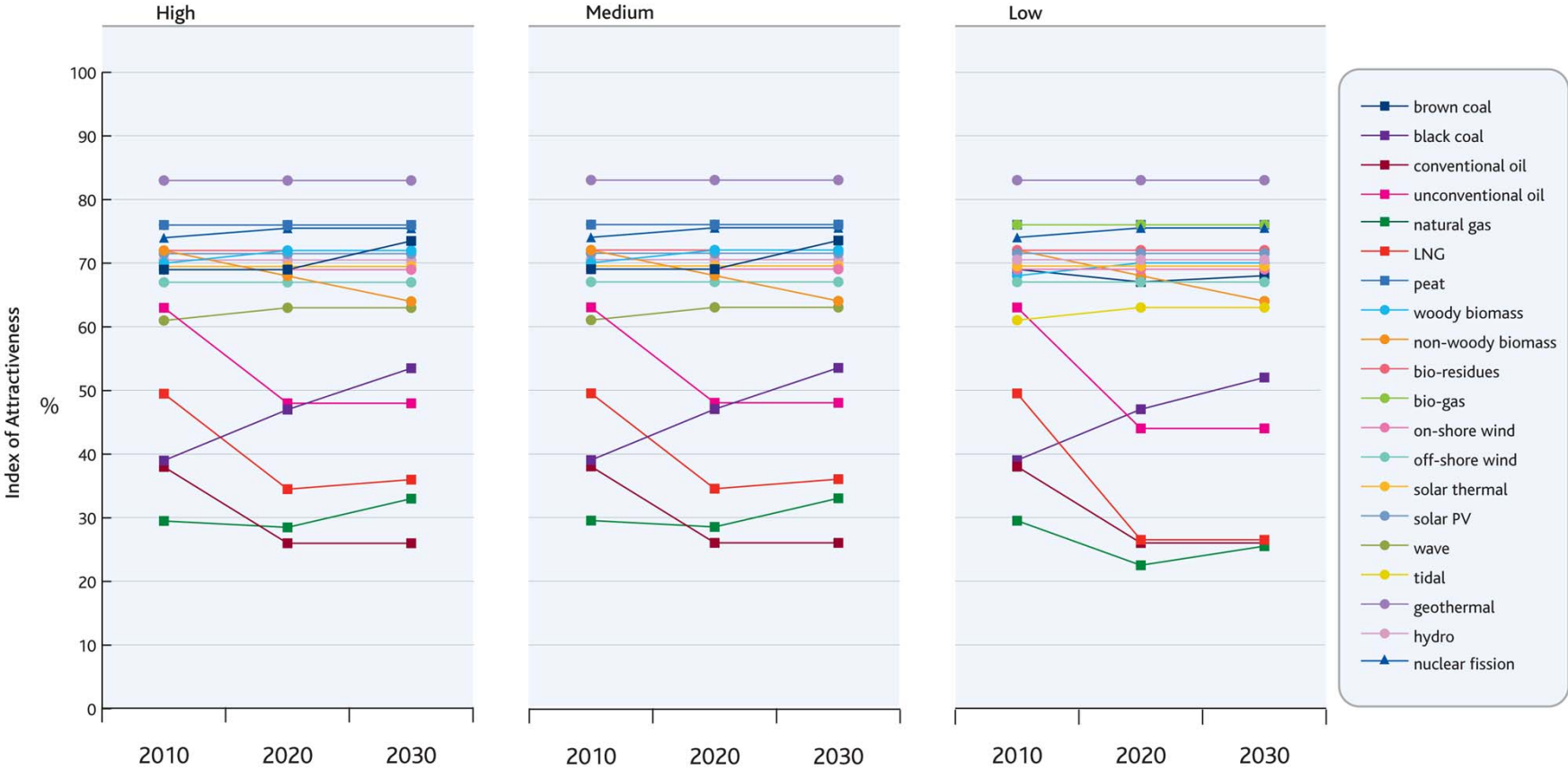
Low Scenario

- Overall trends are similar for each fuel type as in the high and medium scenarios, despite the underlying assumptions for security of supply (mainly in relation to fuel place of origin and market volatility). The downward trend in fossil fuels is somewhat more pronounced than in the high or medium scenarios. This is due to a more rapid exhaustion of supplies from politically stable sources in the case of brown coal, unconventional oil and LNG. Compounding this is a sharp fall in the energy availability indicator as plants will be forced to cease generation more frequently for maintenance.
- The main characteristic of this pillar under all scenarios is the relatively wide spread of scores (20 per cent to over 80 per cent) and the significant dynamics among the fossil fuels.

Security of Supply Summary

- As renewables are produced domestically they are inherently more secure than fuels sourced from other, more unstable countries. This confers significant advantage in terms of weighted import dependence and fuel place of origin.
- The energy availability/intermittency indicator provides information on the capacity factor for energy plants. For electricity purposes fossil fuels, nuclear and biomass applications provide near constant generation capacity. Renewables such as wind, marine and solar have significantly less availability, between 25 per cent and 35 per cent.
- While renewables initially suffer due to market volatility around the supply of necessary components, by 2030 more mature markets are expected to provide a steady stream of necessary inputs. Conversely, fossil fuels start well but their market volatility increases quickly, related more to the availability of the fuel rather than the requisite technology.
- The strength of nuclear as a more secure alternative to fossil fuel base load generation is revealed. It combines many of the strengths of fossil fuels with those of renewables, namely near constant generation but with longer fuel availability, less market volatility and lower levels of risk attached to the sources of supply.

Figure 12: Security of Supply Index Scores in 2010, 2020 and 2030 across the three scenarios (high, medium and low)



10.3 Sustainability Pillar

Sustainability scores appear very similar under the three scenarios. On the one hand this is due to the fact that domestic and global reserves of different fuels and their rate of exploitation are broadly the same regardless of the technology, policy and market conditions. On the other hand, the environmental impacts of fuels are also taken as constant (in all scenarios and all timeframes).

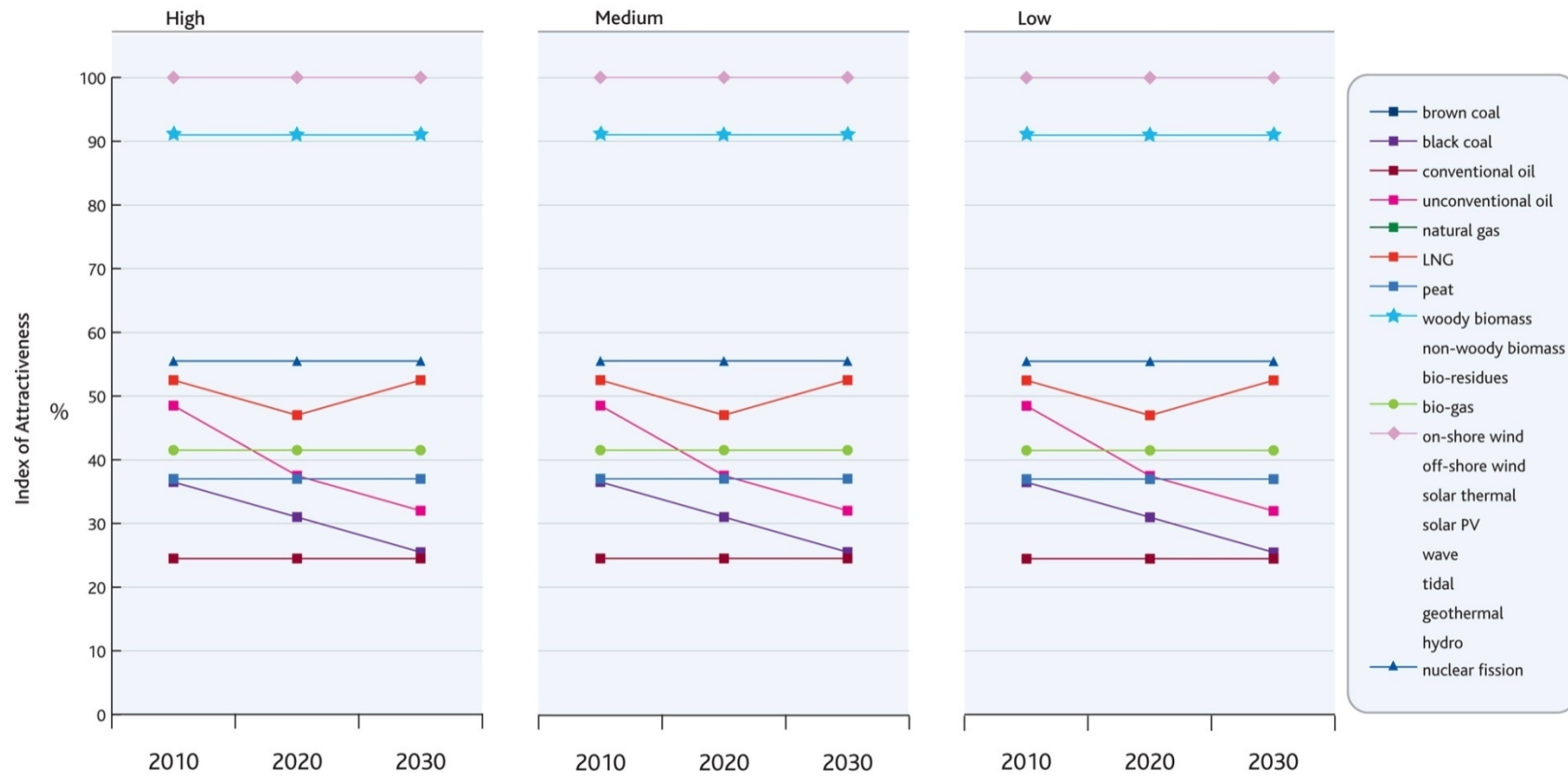
All Scenarios

- Renewable energy sources dominate this pillar as many of the fuels achieve the top score of 100 per cent (hence they overlap in Figure 13). Renewables are by definition infinite in their availability and longevity, with very limited effects on the environment.
- Within renewables, biomass applications are slightly less sustainable than other renewable sources. Biomass fuels have a slightly higher cost of environmental externalities compared to other renewables as they are associated with long and complex supply chains and often require considerable amount of natural resources, such as land, chemicals, feedstock, etc. Biogas in particular is only projected to last a further 10 years due to changes in the regulation surrounding landfill.
- The vulnerability of fossil fuels is made explicit under the fuel longevity indicator. At current reserves to production rates conventional oil is projected to last 40 years while natural gas and LNG are only slightly more abundant with 51 years left. Black coal has the largest reserves of the mainstream fossil fuels, with best current reserves to production ratio estimated between 131-150 years. Peat has the worst longevity with estimates in the range of 10 to 40 years remaining.
- Among fossil fuels, sustainability is somewhat complex. The fuels with the longest reserves (unconventional oil, brown and black coal) have more environmental impacts than natural gas and LNG, which have fewer reserves but also less environmental impacts. This is a true example of the use of the Energy Tetralemma Index in making trade-off positions explicit, even within a pillar.
- Conventional oil has neither longevity nor limited environmental impacts in its favour.
- As a result of declining reserves and high and constant environmental impacts the sustainability of coal is set to decline over the timeframe finishing at the bottom of the index just above conventional oil.
- Nuclear is reported to have a relatively low environmental cost per unit of energy output, which coupled with long fuel availability places it, above all fossil fuels.

Sustainability Summary

- Sustainability scores appear very similar under the three scenarios – high, low and medium. On the one hand this is due to the fact that domestic and global reserves of different fuels and their rate of exploitation are broadly the same regardless of the technology, policy and market conditions. On the other hand, the environmental impacts of fuels are also taken as constant (in both scenarios and in all years) – this reflects the relative severity of impacts within the set of selected fuels.
- The sustainability pillar features the widest spread of scores – 25 per cent to 100 per cent with a clear separation between renewable and fossil fuels.

Figure 13: Sustainability Index Scores in 2010, 2020 and 2030 across the three scenarios (high, medium and low)



10.4 Climate Change

The impacts of climate change on each fuel type is analysed with respect to the carbon content of the fuel and the corresponding total carbon footprint but also in terms of the impact of climate change on each fuel type for energy production.

High and Medium Scenarios

- Renewables outperform fossil fuels due largely to their excellent carbon content and lifecycle carbon footprint scores.
- Nuclear declines from 1st place in 2010 (97.5 per cent) but remains attractive for electricity generation out to 2030 (82.5 per cent). This is due to firstly, the anticipated gains in overall resource availability for renewables as a result of climate change and secondly, the vulnerability of any future nuclear power station to rising sea levels (given a probable location for such a facility on the coast).
- Wave and tidal are also vulnerable to supply and infrastructure disruption, as are on- and offshore wind after 2020. By 2030 offshore wind decreases its score under this indicator (from 97.5 per cent in 2010 to 72 per cent in 2030) reflecting the view that the marine environment will become more difficult for engineering projects over the time period due to the impacts of climate change.
- Overall, wave and tidal improve marginally over the time frame with the former placing just above onshore wind by 2030.
- Woody and non-woody biomasses move down the index in 2030 due to greater exposure to supply and infrastructure disruption, such as crop failure and logistical bottlenecks.
- Within fossil fuels, LNG and conventional oil are particularly vulnerable from a supply and infrastructure perspective. This occurs between 2020 and 2030.
- Black coal climbs consistently as CCS technology is commercialised (boosting the lifecycle carbon footprint indicator) finishing above natural gas by 2030.
- Natural gas and LNG also benefit from CCS improvements to their carbon footprint.

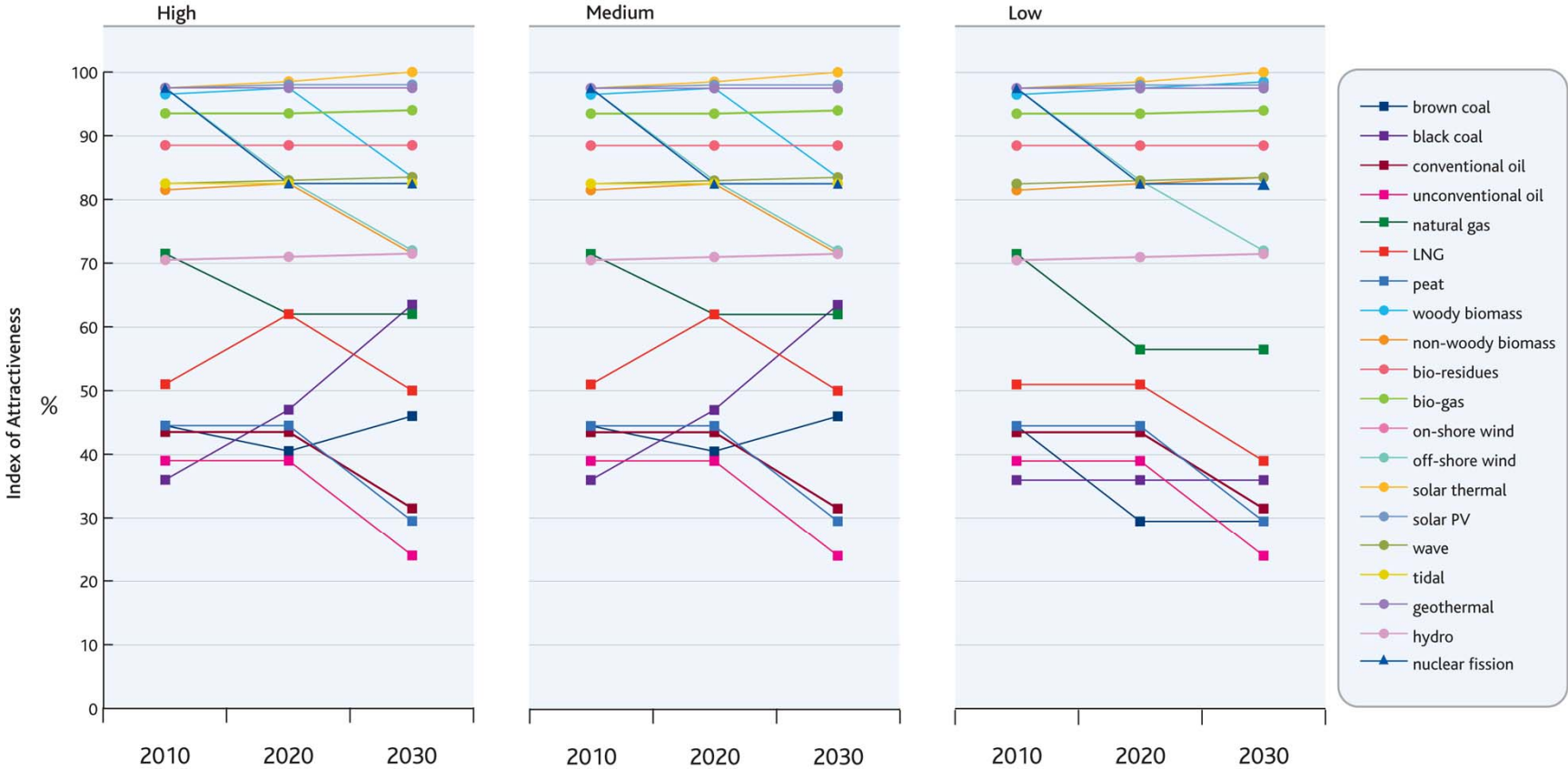
Low Scenario

- Results obtained in the low scenario are similar to those in the high/medium scenarios.
- The main difference is that under the low scenario Carbon Capture and Storage (CCS) is not commercialised. As a result black coal does not improve its lifecycle carbon footprint indicator and is left static near the bottom of the index (at 36 per cent in 2030).
- The absence of CCS commercialisation also has an impact on gas. LNG decreases its score (from 51 per cent in 2010 to 39 per cent in 2030) and natural gas (from 72 per cent to 57 per cent) due to higher emissions but maintains its relative position.

Climate Change Summary

- The climate change pillar is one of the most varied in scores across the three timescales and in the three scenarios. This is mainly driven by the assumptions applied for technology development and deployment and the role of carbon as a traded commodity.
- Renewables achieve the highest score as their carbon emissions are rather low and are generally resilient to climate change.
- Most of the renewable energy sources are perceived to gain in overall resource availability as a result of climate change. This is the reason for nuclear to drop in the relative ranking in relation to renewables.

Figure 14: Climate Change Index Scores in 2010, 2020 and 2030 across the three scenarios (high, medium and low)



11. Trade-Off Positions

11.1 Introduction

In this section we build on the results of the previous analysis where each pillar was examined individually. Most of the focus of this section is on each pillar having an equal weighting on the assumption that each of the four policy objectives are equally important. Then to demonstrate the power of the index as an analytical tool we present various different weightings which prioritise one or more of the policy objectives above the others. While increasing the weight for any one pillar will move the results closer to the archetype positions detailed in the previous section, it is instructive to note how even small counter weightings for the other pillars can change the overall results.

As the Tetralemma provides a means to explore different policy options and opportunities it enables the explicit examination of potential trade-offs that could not otherwise be explored due to their sensitivity. The systemic change that is required in the future (depending on the key policy priorities that are highlighted) is of such a scale that all plausible options for the system should be considered; some may be ruled out on the basis of constraints analysis, regulation or political and social acceptability (including cost). However, the value of the Tetralemma is to initiate debate about long-term energy policy and the fuel choices that should be made and explore those options that are deemed the optimal solutions. Illustrative examples of policy options that could be explored have been expanded upon and are discussed below.

As referred to earlier in this report the Tetralemma Index is not intended to generate a fuel portfolio-mix for Ireland but does allow analysis of different fuel mixes. Creating a suggested energy mix across the whole energy system cannot be achieved simply by maximising the use of available fuels in the order in which they appear in the Index. In fact, a few of the highly ranked fuels cannot satisfy demand in Ireland due to future availability of the fuels and sufficiency issues.

11.2 Trade-off Position - Equal Weighting of Each Pillar

**25 per cent Competitiveness /25 per cent Security of Supply/25 per cent Sustainability/
25 per cent Climate Change**

With regard to total scores, the three scenarios - high, low and medium - show a rather similar picture overall. This is due to the complex and composite nature of the Energy Tetralemma Index where higher scores under certain indicators are offset by lower scores under other indicators. Overall, fossil fuels occupy the lower band of the scores between 35 per cent and 60 per cent, while renewables achieve the higher end of scores between 70 per cent and 90 per cent. Nuclear is in the middle at about 65 per cent. A summary of the fuel profile within each scenario across the three timeframes is presented below. The profile of each scenario has already been presented in Chapter 9 above.

High Scenario

- Starting from 2010 renewables outperform nuclear and fossil fuels. The gap between renewables and fossil fuels is growing over time.
- Solar thermal and geothermal score very well for heat applications.

- Solar PV, onshore wind, wave, tidal and offshore wind are all very attractive for electricity generation.
- Wave and tidal are on an upward trend becoming more attractive over the time frame.
- Nuclear places in a middle tier, some distance below renewables and above fossil fuels.
- Of the fossil fuels natural gas, LNG and black coal register similar scores by 2030 although natural gas is becoming less attractive while LNG and to a greater extent black coal are on upward trajectories.
- The attractiveness of peat, conventional oil and unconventional oil declines over time.

Medium Scenario

- Renewables outperform nuclear and fossil fuels.
- Solar thermal scores very high as a heat application.
- Geothermal also places near the top of the index, if a little behind solar thermal.
- Onshore wind is attractive at each of the three points in time.
- The attractiveness of offshore wind declines somewhat but is placed above wave and tidal and well above nuclear and fossil fuels.
- Wave and tidal improve but remain at the bottom of the band of renewables, some distance ahead of both nuclear and fossil fuels.
- Of the fossil fuels, black coal improves considerably, outstripping natural gas and LNG by 2030 although still finishing behind nuclear.

Low Scenario

- A clear and expanding gap separates renewables at the top from nuclear in the middle and fossil fuels at the bottom of the index.
- Renewables form a tight upper band with little separating individual fuel types but solar PV and onshore wind score as the most attractive for electricity generation.
- Solar thermal is the best fuel for heat but geothermal also fares well.
- Wave and tidal enter the top 10 with the latter outperforming offshore wind, bio-gas and hydro.
- Bio residues and woody biomass score well.
- Natural gas is the pick of the fossil fuels, followed by LNG and peat/black coal at intervals.

As stated previously, in general renewable fuels score and rank above all fossil fuels across all time periods and scenarios - the reason behind this is that logically not only do they score well on carbon emissions reductions and sustainability issues; their increasing contribution to energy supplies also reduces dependencies on fossil fuel imports. Increasing the penetration of renewable energy fuel supplies within the Irish portfolio will also lead to a reduction in the marginal cost of delivered energy. However, the degree to which they contribute to a long term sustainable energy landscape in Ireland is wholly determined by policy influence.

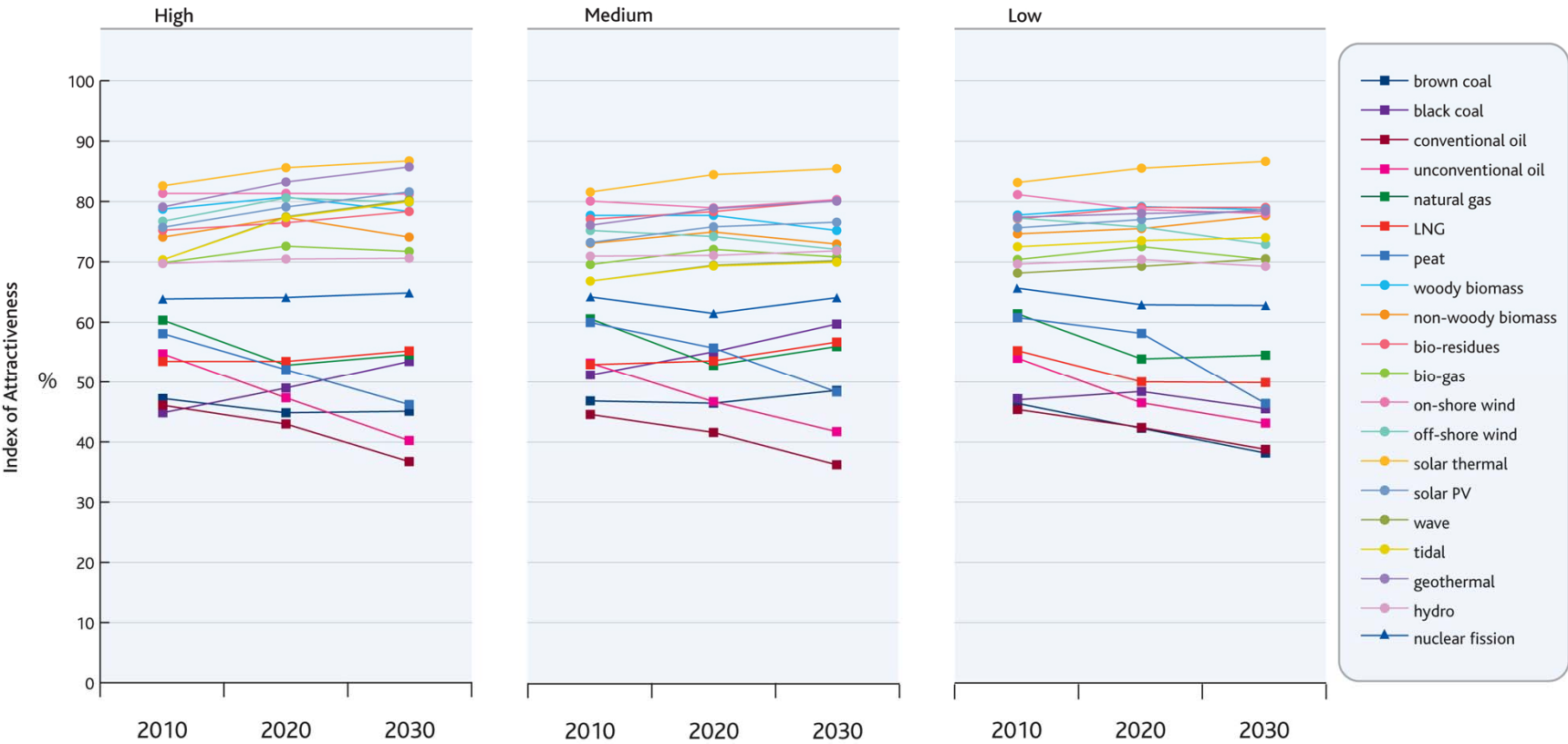
There is an explicit trade-off between the scenarios that have been run - the low scenario is founded on a near-term cost competitiveness position which from a policy perspective does

not bring forward either advanced fuel technologies, or see the introduction of Carbon Capture and Storage (CCS) in Ireland. With high commodity prices for imported fuels and a low national and international carbon price, Ireland continues to remain exposed to significant levels of price/volume risk from volatile energy markets and becomes 'locked-in' to fossil fuel technologies due to continuing investments in infrastructure and storage that are made on the basis of security of supply and market hedging.

The high scenario is more strongly driven by meeting, and even exceeding, the ambitions of the Energy White Paper. Acceptance of systemic change to the energy system, that will deliver a lower carbon future for Ireland, sees the full implementation of the proposals in the Energy White Paper; advanced fuel technologies enter the market; CCS is deployed and operational and renewable energy sources are fully exploited. This scenario assumes that commodity prices will be low with a high carbon price which incentivises fuel switching and carbon abatement strategies. The overall result of this scenario is that Ireland diversifies its fuel supply base, is less exposed to international market risks (for price and security) and gains significant benefits with respect to climate change and sustainability impacts.

Figure 15: Equal Weighting Index Scores in 2010, 2020 and 2030 across the three scenarios (high, medium and low)

25 per cent Competitiveness / 25 per cent Security of Supply/ 25 per cent Sustainability / 25 per cent Climate Change



11.3. Trade-off Position - "Traditional" Three Pillar Approach

33.3 per cent Competitiveness / 33.3 per cent Security of Supply/ 16.65 per cent Sustainability / 16.65 per cent Climate Change

This particular weighting arrangement mirrors the traditional three pillar approach for energy policy. The two target pillars are given a weighting of 33.3 per cent, climate change and sustainability are weighted at 16.65 per cent each, effectively combining the two environmental pillars into one.

High Scenario

- Increasing the weight given to competitiveness and security of supply is not sufficient to create a radical break from the results of the equal weighting test.
- Renewables still outperform nuclear and fossil fuels. The gap between renewables and fossil fuels is growing over time.
- Solar thermal and geothermal score very well for heat applications.
- By 2030 renewables for electricity generation form a tight band between 72 and 78 per cent. All are attractive with hydro obtaining a slightly lower value but still ahead of nuclear and a clear distance above fossil fuels.
- Wave and tidal are on a strong upward trend, climbing from 63 per cent to 76 per cent, becoming very attractive for electricity generation.
- Nuclear places in a middle tier, a clear distance below renewables and a similar distance above fossil fuels.
- LNG and black coal are the most attractive fossil fuels. Both become more attractive over time.
- Natural gas finishes just below LNG and black coal but is declining over the time frame.
- The attractiveness of peat, conventional and unconventional oil declines consistently.

Medium Scenario

- Results are similar to the equal weighting test - the main difference is the relative performance of wave, tidal, nuclear and black coal.
- With more relaxed environmental criteria the performance of black coal, already on an upward trajectory under the equal weighting scenarios, improves considerably.
- Wave and tidal start from a lower base and remain flat. As a result both are less attractive than black coal by 2030.
- Black coal also outperforms nuclear in this test although nuclear does remain considerably more attractive than the next best performing fossil fuels, LNG and natural gas.
- Wave and tidal are only slightly more attractive than nuclear.
- Other renewable fuels comfortably place above nuclear and fossil fuels.
- Solar thermal scores very high as a heat application.
- Geothermal places near the top of the index but does not perform as well as under equal weighting position.

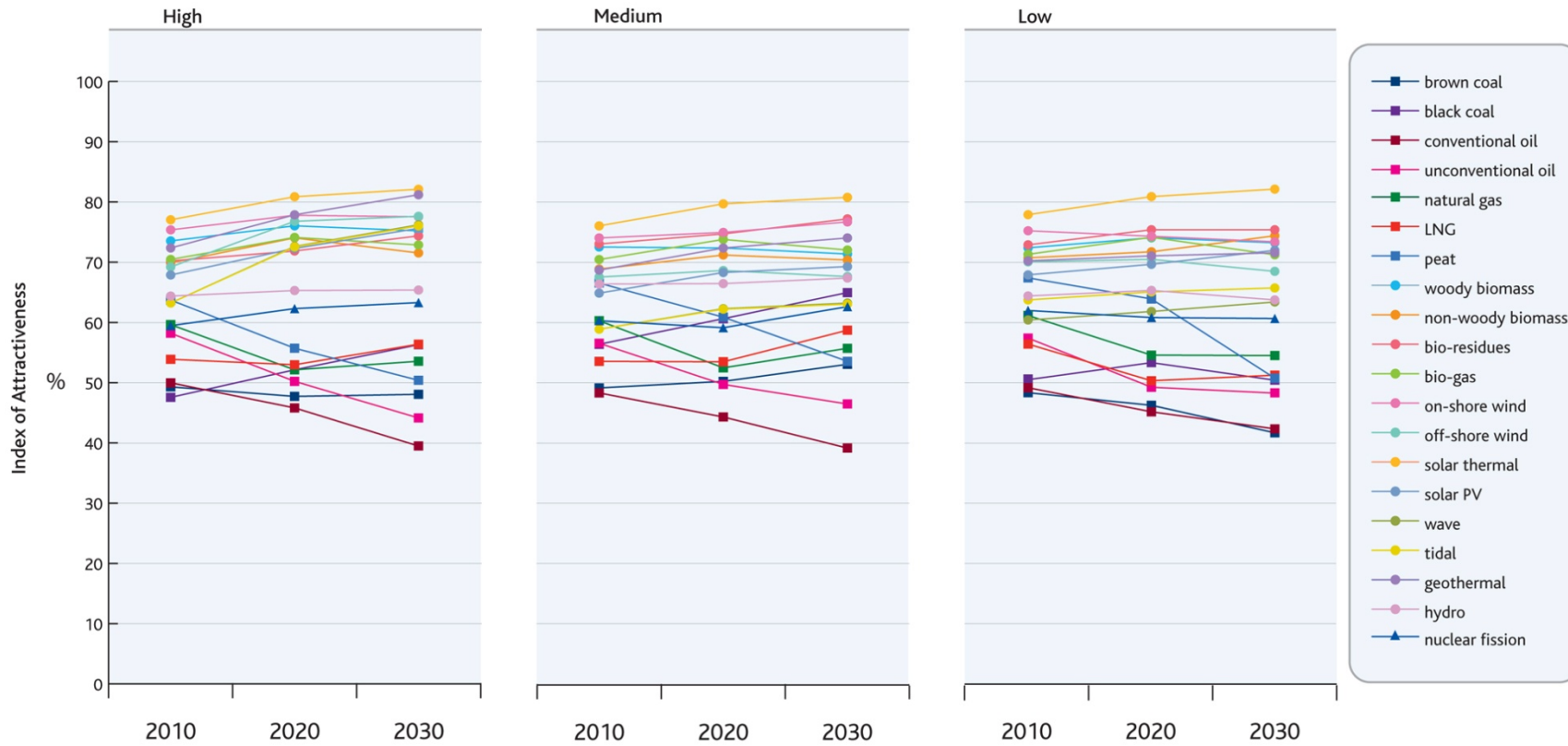
- Bio residues improve strongly to become the most attractive fuel for electricity generation by 2030. Bio-gas declines post-2020 but still remains an attractive option.
- Onshore wind scores near the top of the index at each of the three points in time. The attractiveness of offshore wind remains flat placing at the bottom of the band of renewables just above hydro.

Low Scenario

- Results are very similar to the equal weighting test.
- A clear and expanding gap separates renewables at the top from nuclear in the middle and fossil fuels at the bottom of the index.
- Solar thermal is the best fuel for heat but geothermal also fares well.
- Bio residues, non woody biomass and onshore wind are very attractive for electricity generation. Bio-gas also gets a strong boost from a more competitiveness focus.
- Wave and tidal are not as attractive when the environmental criteria are relaxed and competitiveness concerns increased although they do score better than fossil fuels.
- Natural gas is the best performer of the main fossil fuels, followed by LNG and black coal at intervals.
- In this scenario the performance of black coal is restricted by the non-commercialisation of CCS and advanced combustion technologies.
- Peat declines precipitously from 67 per cent to 51 per cent.

Figure 16: “Traditional” Three Pillar Index Scores in 2010, 2020 and 2030 across the three scenarios (high, medium and low)

33.3 per cent Competitiveness / 33.3 per cent Security of Supply/ 16.65 per cent Sustainability / 16.65 per cent Climate Change



11.4 Trade-off Position with a focus on Competitiveness

70 per cent Competitiveness / 10 per cent Security of Supply/ 10 per cent Sustainability/
10 per cent Climate Change

With the severity of the current downturn and the high price of electricity in Ireland competitiveness could be prioritised as the most important policy objective. Various tests have been run with different weightings for the competitiveness pillar. This example is included as it is a good indication of the results that are achieved when competitiveness is weighted strongly but with some balance given to the other three pillars. What is noteworthy is the reasonably strong showing of renewables, even in less favourable low and medium scenarios.

High Scenario

- Initially the index is quite mixed between renewable and fossil fuels but by 2030 a clear separation has occurred with renewable mostly occupying the upper band and fossil fuels the lower.
- Two exceptions exist. LNG improves strongly over the time frame to finish just above woody biomass, bio residues, solar PV and some distance above hydro. Hydro fares particularly poorly scoring below natural gas, black coal and nuclear.
- Solar thermal again occupies the top position and geothermal rises sharply to become very attractive by 2030.
- Offshore wind and onshore wind both register strong improvements to become very attractive for electricity generation in 2030 with offshore wind doing a little better.
- Wave and tidal also improve considerably over the period from 51 per cent to 77 per cent to place near the top of the index.
- Bio-gas, non woody biomass, woody biomass and bio residues form a distinct band at the bottom of the renewable group, some way ahead of most fossil fuels and nuclear.
- Natural gas declines from the most attractive fuel in the index in 2010 to finish behind most renewable in 2030. Peat and conventional oil also decline sharply.
- Black coal improves steadily but still places behind most renewable alternatives.
- Nuclear is very uncompetitive under these assumptions.

Medium Scenario

- Black coal is very attractive across all three time points, for electricity generation.
- LNG is on a pronounced upward trajectory improving from 57 per cent to 76 per cent to become the second most attractive fuel for electricity purposes.
- Natural gas declines from 1st place on the index in 2010 to 8th in 2030 behind onshore wind and most biomass applications.
- The biomass fuels and onshore wind are the highest scoring renewables and are all attractive for electricity generation in 2030.
- Solar thermal is again very attractive for heat but geothermal although improving does not score highly.
- Peat, conventional and unconventional oil all register declines over the time frame.

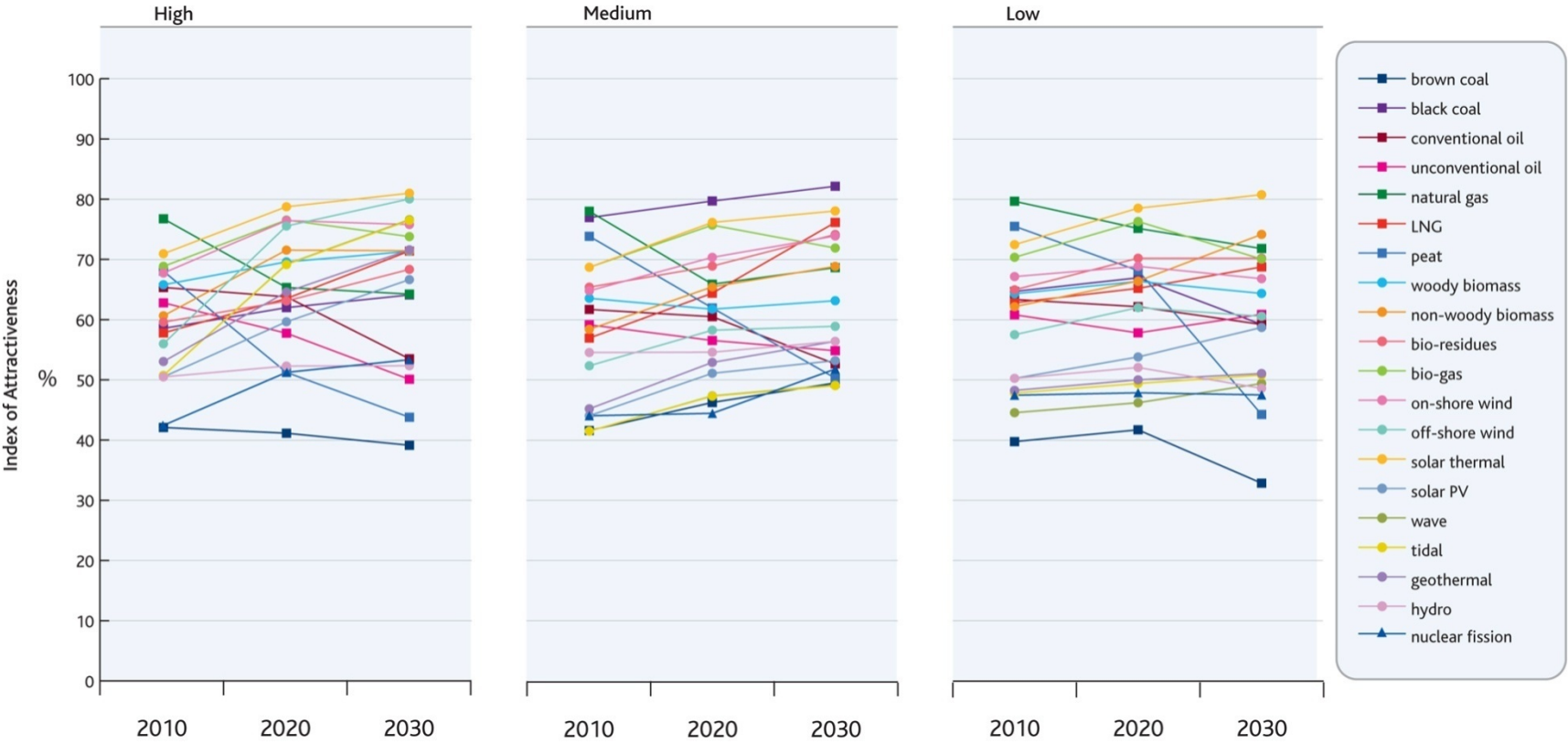
- Offshore wind, solar PV and hydro place mid index and are relatively unattractive for electricity generation.
- Wave and tidal remain rooted to the bottom of the index with nuclear.

Low Scenario

- The initial index for 2010 is quite mixed but by 2030 a separation is occurring with the top largely populated by renewables and the bottom with fossil fuels.
- Solar thermal is the most attractive fuel by 2020 and remains so. Geothermal is unattractive as a fuel for heat.
- Natural gas declines in attractiveness from 80 per cent to 72 per cent while LNG improves over the same timeframe from 63 per cent to 69 per cent, both remain attractive for electricity generation in 2030.
- Non woody biomass, biogas and bio residues are the highest scoring renewables and are very attractive.
- Onshore wind scores remains constant over the timeframe, scoring above black coal and only a little behind LNG.
- Woody biomass, offshore wind, black coal, unconventional oil, conventional oil and solar PV form a middle band by 2030.
- Peat declines sharply from a very attractive position in 2010 to a very unattractive position in 2030.
- Wave and tidal, hydro and nuclear form a lower band of unattractive fuels at the bottom of the index.

Figure 17: Competitiveness at 70 per cent Index Scores in 2010, 2020 and 2030 across the three scenarios (high, medium and low)

70 per cent Competitiveness / 10 per cent Security of Supply/ 10 per cent Sustainability / 10 per cent Climate Change



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