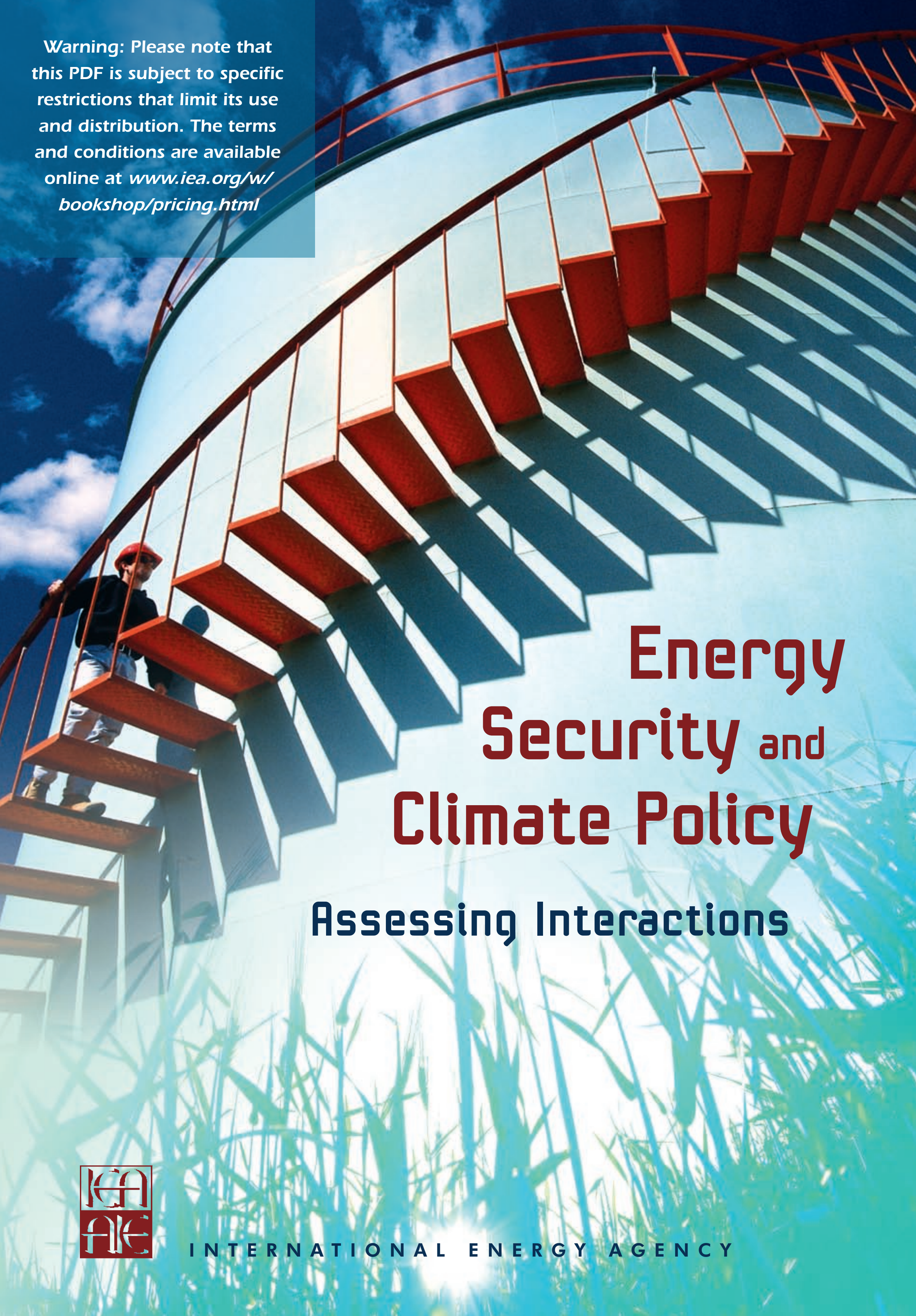

Energy Security and Climate Policy

Assessing Interactions

INTERNATIONAL ENERGY AGENCY

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-six of the OECD thirty member countries. The basic aims of the IEA are:

- To maintain and improve systems for coping with oil supply disruptions.
- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations.
- To operate a permanent information system on the international oil market.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
- To assist in the integration of environmental and energy policies.

The IEA member countries are: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the IEA.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of thirty democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

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Foreword

Climate change and energy security are key drivers for future energy policy. While energy security has been a pillar of energy policy for about a century, concern about climate change is more recent and is bound to radically change the landscape of energy policy. Policy makers are now under increasing pressure to address these twin challenges: to develop cost-effective policies that will both ensure the security of our energy system and reduce greenhouse gas emissions. Therefore, we need new tools to assess objectively the interactions between the implementation of these multiple policies and to maximise their impact across these two important goals.

This report puts forth such tools. It adopts a pragmatic approach towards energy security and identifies areas of overlap between greenhouse gas reduction and security policy goals. It defines new approaches to quantify how the causes of energy insecurity and climate change evolve and how policies to address these concerns may interact. The analysis presented here is by no means a definitive answer, but rather an effort by the IEA to bring two vital policy concerns under the same analytical lens.

This book is part of the IEA work in support of the G8 Gleneagles Plan of Action that mandated the Agency in 2005 to chart the path to a "clean, clever and competitive energy future". It is my hope that this study will provide another step toward the realisation of a sustainable energy future.

Claude Mandil
Executive Director

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Executive Summary

Energy security and climate change mitigation are two key objectives of governments. Which policies can achieve and maximise the realisation of both of these goals? This report offers an analytical approach to quantify which measures are effective under varying conditions.

The study reviews interactions between energy security and climate change mitigation policies. It does not determine whether the extent or the type of government action towards either climate change or energy security is justified or not. Rather, the study focuses on interactions given stated policy objectives and foreseen policy choices. It proposes, to the extent possible, the use of quantitative tools to assess the effects of government intervention in a context of multiple energy policy objectives. It ultimately intends to help guide policy-making towards policies that achieve both energy security and climate change mitigation objectives as efficiently as possible.

Results from the country case studies reflect a generally worsening trend in terms of CO_2 emissions and energy security and highlight the linkages between these energy policy concerns. The various policy cases investigated underline that policies deemed acceptable either to reduce CO_2 emissions or to improve energy security may no longer hold when considered through the prism of an integrated climate-security energy policy. It is the IEA's hope that countries will start undertaking a systematic review of the energy security implications of their climate policy initiatives and vice versa. The tools elaborated in this report should shed interesting, objective light on challenges and opportunities that lay ahead for countries seeking to develop sustainable energy policies.

The various aspects of energy security policy

Carbon dioxide emission trends are commonly used as a tool to assess efforts to mitigate climate change, yet there is no similar approach for energy security. Historically, the assessment of energy security has been almost exclusively based on expert judgment, making unwieldy any systematic appraisal of policy interactions under various scenarios. This report proposes a pragmatic approach to assess energy security policies.

Energy insecurity stems from the welfare impact of either the physical unavailability of energy, or prices that are not competitive or overly volatile. In practice, however, such impacts are difficult to gauge and, therefore, so is the magnitude of an appropriate policy response.

There are several kinds of government actions addressing energy security. First, a distinction can be made between government actions to mitigate the short-term risks of physical unavailability in case of a supply disruption and efforts to improve energy security in the long-term.

In the first case, actions include establishing strategic reserves. For oil, the International Energy Agency co-ordinates the use of member countries' emergency oil stocks. Governments may also seek to establish contingency plans to curtail consumption in order to mitigate the magnitude of physical unavailability.

In the second case, policies tend to focus on tackling the root causes of energy insecurity, which can be separated into four broad types:

- **Energy system disruptions linked to extreme weather conditions or accidents:** Government policies are generally precautionary in nature. Governments notably have an important role in preparing contingency arrangements for the management of, and recovery from, such incidents after they happen.

- **Short-term balancing of demand and supply in electricity markets:** To ensure the security of electricity systems, governments establish independent transmission system operators (TSO) responsible for the short-term balancing of demand and supply.
- **Regulatory failures:** Government action aims to monitor the effectiveness of regulations and to adjust regulatory structures when inefficiencies are detected.
- **Concentration of fossil fuel resources:** Government action aims to minimise the exposure to resource concentration risks in fossil fuel markets and includes moving away from fossil fuels, or diversifying supply routes and means.

This typology of energy security policy helps identify areas of potential overlap with policies and measures to reduce energy-related greenhouse gas emissions. Policies addressing concerns linked to resource concentration may have the most significant implications for climate change mitigation and vice versa: both policies are likely to affect fuel and associated technological choices. In contrast, interactions with policies correcting for regulatory failures may have only secondary effects on greenhouse gas mitigation policies in the energy sector. Finally, energy security measures responding to the risks of short-term physical disruptions and the balancing of electricity grids have very limited interactions with climate mitigation efforts. This work therefore focuses on resources concentration as a driver of longer-term energy security.

Measuring resource concentration as a driver of energy security

Instead of trying to determine in quantitative terms the welfare losses resulting from resource concentration, we define indicators that focus on measuring the cause of energy insecurity. These indicators address the two components of energy security independently: the price and the physical availability of energy.

A measure of the price component of energy security is useful in markets where prices are allowed to adjust in response to changes in demand and supply. In such cases the risk of physical unavailability is reduced to extreme events. The prevailing energy security concern is related to prices not set competitively or that are overly volatile. The international oil and coal markets can be included in this category.

The energy security indicator for this price component (ESI_{price}) is based on a measure of market concentration (ESMC) in each international fossil fuel market. For a given country, ESI_{price} weighs the relative importance of each ESMC value based on the exposure of the country to each fuel. The more a country is exposed to high concentration markets, the lower is its energy security.

A measure of the physical unavailability component of energy security is useful in markets where prices are regulated or pegged on other commodities. In such cases the price cannot contribute to balance supply and demand – an excess demand for gas, when such gas is indexed on oil prices, will not result in a price adjustment, and therefore not trigger the appropriate supply response. The principal concern, in such cases, is that of physical unavailability as markets then lack a crucial adjustment mechanism. The gas markets in most European countries and in several Asian countries where gas is indexed to oil fall in this category.

We find that the energy security indicator focusing on physical unavailability (called ESI_{volume}) is mostly useful for gas trade transiting through pipelines. ESI_{volume} measures a country's share of total energy demand met by oil-indexed, pipe-based gas imports. The higher this share, the less secure the country's gas supply.

When gas is indexed to oil, in addition to a risk of physical unavailability occurring, gas consumption is also exposed to the price risk of the oil market. Gas therefore links the price and physical availability components of energy security.

Case studies

Five IEA countries have volunteered to participate as case studies in this analysis of energy security and climate change policy interactions: the Czech Republic, France, Italy, the Netherlands, and the United Kingdom. The quantitative assessment was undertaken following a "reference" energy projection. It provides insights on how energy-related CO_2 emissions, ESI_{price} and ESI_{volume} evolve between now and 2030, without significant efforts to abate CO_2 emissions.

In a second step, a number of discrete policy measures that reduce CO_2 emissions are applied to these energy projections. These policy cases change the trend of energy security indicators and allow gauging the interaction between specific CO_2 reduction measures and energy security goals.

While the analysis undertaken was based on five OECD European countries, the framework defined may be applied to any country, including non-OECD countries. It does require, however, a projection of fossil fuel supply, broken down by key regions or countries.

Results from the reference scenario

For our five case studies, reference scenarios generally show a worsening trend in CO_2 emissions, ESI_{price} and ESI_{volume}. However, differences in fuel mixes and the organisation of the gas sector lead to significant variations in the five countries.

Compared to 2004, CO_2 emissions are projected to decrease by 27% in 2030 in the Czech Republic, by 3% in 2020 in the UK, while they increase by up to 38% in France. ESI_{price} increases by 6% by 2030 in the Czech Republic, 15% by 2020 in the UK and up to 42% in France. ESI_{volume} grows by 12% in 2030 in the Czech Republic and 31% in France, while it emerges as a new concern in the UK starting between 2004 and 2010 and in the Netherlands between 2020 and 2030.

The price indicator defined here (ESI_{price}), though it is difficult to appreciate in absolute terms, allows gauging trends and undertaking cross-cutting comparisons. This is particularly useful in assessing market concentration. For example, when OPEC countries are considered as a single participant in the market, the oil market is twice as concentrated as the coal market throughout the 2004-2030 period. When OPEC countries are considered as individual participants, however, the oil market is in fact characterised by less than half the level of concentration of the coal market.

If OPEC countries are considered as a single participant in the international oil market, the measure of market concentration (ESMC) is projected to increase by approximately 30% between 2004 and 2030. Over the same period, concentration in the coal market grows by some 22%, remaining much lower than that of oil.

Market concentration in the gas market only captures volumes traded on gas-based terms (e.g. Henry Hub and National Balancing Point contracts). Nevertheless, comparing concentration levels in the gas market to those in the oil or coal market also provides some useful insights. In 2004, when the gas market is geographically restricted, it is 18% more concentrated than the coal market. By 2030, when the gas market is assumed to be global thanks to the growth in LNG trade, the market concentration in gas is 60% lower than that of coal.

The gas sector is unique in this assessment as it links the price and the physical availability components of energy security. By considering both a case of unchanged price structures in Europe, where oil-indexation of gas continues to be the norm (case 1), and a case of a gradual switch from oil-indexed contracts to gas-based pricing (case 2), we quantify the impact of changing gas price structures in the European context on security concerns. Gas market concentration remains roughly unaffected by considering either case 1 or case 2. Importantly, however, gas market concentration is significantly lower than that of the oil market. Oil-indexed gas pricing, therefore, exposes gas importers to a market characterised by higher concentration than if gas were purchased on gas-indexed terms. In addition, oil-indexed pricing creates important physical availability concerns, as reflected in the evolution of the ESI_{volume} indicator described above.

Countries concerned about the political stability of exporting countries may wish to factor such considerations in their energy security analysis. This assessment includes an attempt to do so, through a combination of the measure of energy market concentration and a political stability rating applied to countries that supply the international fossil fuel markets. This new factor has a varying influence on the energy security rating of each fossil fuel market. The effect of factoring political risk in 2004 was nearly twice as large in the oil market when OPEC countries were considered as a single participant than in the coal market. In the case of oil, factoring political stability has a growing effect over 2004-2030 whether OPEC countries are considered a single market player or not. In comparison, gas and coal markets would record favourable evolutions.

Results from the policy cases

The adoption of a quantitative framework to assess policy impacts in terms of CO_2, ESI_{price} and ESI_{volume} allows identifying and gauging possible policy synergies and conflicts. This study illustrates how specific climate policy mitigation measures in the electricity and transport sectors could affect the energy security outlook of various countries. For the sake of simplicity, all policy measures considered are compared against an identical 5% reduction in countries' emissions from baseline by 2030. While measures are assessed individually, the framework could also be used to evaluate a mix of policy tools. Some interactions between various policies may emerge that are not reflected in these illustrations.

End-use efficiency improvements and an enhanced reliance on non-fossil fuel technologies (renewables or nuclear) in the electricity sector have positive impacts of similar magnitude on energy security. This reflects the similarity of the changes in fuel mix required to reduce emissions by 5%, essentially a reduction in coal- and gas-based electricity generation. Country specificities, however, imply different effects. For our assumed 5% reduction in CO_2 emissions, ESI_{price} in 2030 decreases by 2.5% to 4.3% from the baseline, while that of ESI_{volume} ranges from 2.3% to 38.1%. These results indicate an overall improvement in energy security indicators, when energy efficiency and non-fossil fuel generation are enhanced to reduce emissions from the power sector.

Achieving a 5% reduction in emissions through a switch from coal to gas, on the other hand, has a negative impact on both security indicators. The increase in ESI_{price} in 2030 ranges from 0.1% to 4.1%. This may seem a relatively small increase, but the resulting changes in traded energy also influence countries' exposure to the different market concentration levels. Indeed, the greater the difference between the efficiency of the new gas plant and that of the coal plant it is replacing, the smaller – on an energy basis – are the volumes of gas required compared to the volumes of coal displaced. In other words, there are conflicting effects. On the one hand, due to lower concentration levels in the coal market compared to that of the oil market[1] a switch from coal to gas induces a negative effect on ESI_{price}. On the other, it reduces energy volumes required which lowers the overall exposure to concentration risks and therefore induces a positive effect on ESI_{price}. In contrast, the impact on ESI_{volume} (the exposure to pipe-based, oil-indexed gas imports) is much more predictable: a switch from coal to gas leads to an increase in ESI_{volume} ranging from 4.4% to 87.1%.

Fuel efficiency improvements in transport lead to important benefits in ESI_{price}, ranging from a reduction of 4.6% to one of 8.2%. Again, differences depend on the respective role of oil in each country case study, with a greater benefit for countries where oil represents a greater share of total consumption. These benefits are more significant in all countries than those obtained through efficiency improvements in electricity end-uses, due to the importance of oil in driving ESI_{price} trends.

1. Remember that through oil-indexation gas is effectively exposed to the price risk of the oil market.

Switching from oil to biofuels in transport has complex implications for energy security, as one needs to account for the energy used in biofuel production. In this case, a switch from oil to biofuels lowers the ESI_{price} indicator in 2030 from between 3.5% to 6.4%. The underlying contributions to ESI_{price} are, however, conflicting. On the one hand, the drop in oil and coal consumption lowers the exposure to oil and coal market risks which contributes to lower ESI_{price}. On the other, the enhanced consumption of – oil-indexed – gas increases the exposure to oil risks, reflected in a higher ESI_{price}. At the same time, due to enhanced gas requirements, ESI_{volume} increases in 2030 by 3.5% to 44.9%, compared to baseline.

Conclusion

Any analysis based on the use of indicators rests necessarily on a number of simplifications. The energy security indicators developed here nevertheless provide a framework allowing a systematic, quantitative evaluation of energy security and climate change mitigation. The quantitative framework defined enables us to determine with precision how each indicator changes and why. Changes in indicator levels can entail conflicting effects which could not be identified without the tools defined in this report. As such, they can complement expert judgments on a matter where the complexity of policy interactions and their effects, inside and outside country borders, can rapidly blur the policy picture. The energy security indicators developed by the IEA should be viewed as a stepping stone for future elaboration and improvement.

PREMISE FOR AN INTEGRATED ENERGY POLICY

The role of government in liberalised energy markets

Since the late 1970s, most OECD countries have taken steps to liberalise their energy markets offering a greater role to market forces in the allocation of resources. Although this has been carried out differently depending on the country and the sector concerned, the political and economic rationale for liberalisation has been the same: to increase economic efficiency through the introduction of greater competition.

The process of market liberalisation requires governments to clearly separate previously vertically integrated activities and decide which segments should be open to competition and which – if any – should remain monopolistic. Governments must then establish market rules to create a level playing field in those segments open to competition and to ensure that monopolies are operated and regulated transparently and efficiently.

While the basic principles governing liberalised market structures are relatively straightforward, each market has unique characteristics and regulations need to be tailored accordingly. The process is of significant political importance due to the nature of energy as a commodity: energy markets are among the most capital intensive, lead times for planning and construction are long, while energy itself is the primary feedstock of many productive activities. Regulatory misjudgements can therefore have economic consequences of great magnitude.

Yet aside from providing the regulatory foundation of energy markets, governments have another important task: accounting for market failures.[2] Indeed market forces alone sometimes fail to achieve an efficient allocation of resources. Such sub-optimal outcomes can stem from a variety of circumstances including imperfect competition or the incomplete reflection of certain costs and

2. We adopt here an economic definition of the term *market failure*. It covers all the circumstances in which equilibrium in free unregulated markets (*i.e.* not subject to quantity or price regulation by the government) will fail to achieve an efficient allocation of resources (Begg *et al.*, 1984).

benefits in prices due to public good considerations or externalities. It is the role of government to identify market failures and, to the extent that the benefits exceed the costs, implement measures to correct them.

In theory, the fact that governments must tackle more than one market failure should not have any specific impact on the policy-making process. The different failures should be evaluated individually and policy responses designed correspondingly. If the market failures and the policy responses are gauged and defined with precision there should be no cross-cutting policy inefficiencies.

Yet in most cases, identifying market failures, assessing their magnitude and designing adequate policies is not a straightforward task. In the case of externalities, for example, appropriately gauging the magnitude of policy response implies giving the externality an economic value, which involves identifying the nature of the external impacts, identifying the parties affected, and estimating implied costs. This can be particularly difficult for a number of reasons. First, impacts can be widely diffused and exhaustively identifying all parties affected may be impossible. Second, estimating costs requires distinguishing the externality from other market imperfections which can also be difficult. Third, external impacts can involve considerations related to health, the environment or equity, which can be difficult to evaluate in monetary terms.

The choice of policy instrument can also be problematic. Instruments which economists may consider as most effective, such as a tax, can be politically unpopular. This has notably led governments to adopt other, and often more hands-on types of measures to address market failures, such as direct financial or regulatory support to specific technological or fuel alternatives. The downside is that these may be more expensive to implement and have unforeseen repercussions on other aspects of the economy.

Inevitably therefore, accounting for market failures involves a certain degree of political subjectivity. Governments have to determine energy policy objectives based on best available information and implement measures deemed most suited to achieve them given existing political and economic constraints. In this context, interactions between different policy objectives may be significant and should be assessed carefully.

Historic energy policy drivers

Aside from the shift to liberalised market structures, two topics have driven OECD energy policy: air pollution and energy security.[3] The first stems from pollutants produced during the combustion of fossil fuels which when emitted in the air can have important environmental and health impacts. The second refers to the economic and social impacts of high or volatile energy prices and of energy supply interruptions. As discussed in the next section, potential causes of energy insecurity are diverse. They include the abuse of a dominant position in international fossil fuel markets as well as failures in the regulatory system underpinning energy markets.

While important policy efforts and public funds have been mobilised on both fronts, air pollution and energy security have generally been considered independently of one another. Probably the most important reason for this is linked to the difference in the type of response measures adopted to respectively tackle each. On the one hand, energy security measures have generally attempted to influence fuel mix composition, supply routes, or the regulatory structures underpinning energy and adjacent markets. On the other, air pollution policies have tended to lead to the adoption of fuel treatment (such as low lead and sulphur fuel or coal washing) or end-of-pipe technologies (such as the installation of smokestack scrubbers in power plants or exhaust controls on automobiles). Such applications have no, or only limited, impact on more up-stream measures and, due to their inherent flexibility to adapt to various fuel configurations, can relatively easily cope with up-stream adjustments. Policy interactions may therefore have been deemed minimal.

There may also be an institutional justification for the limited attention attributed to potential interactions between air pollution and energy security. The evolution of our common understanding on both issues has been progressive and this has naturally transpired in the policy-making process. Air pollution regulations were first introduced during the 19th century while energy security became a political concern somewhat later, in the early years of the 20th century. Both issues have evolved as markets, fuel use, and technologies changed over time and policies and measures were progressively tightened and expanded. On either topic, due to the slow and incremental nature of the policy process there was no clear incentive

3. Arguably, equity issues linked to access to energy constitute another, separate, OECD energy policy driver. These are however considered here within the process of market liberalisation.

to assess potential impacts on the other. In addition, due to the very different nature of energy security and air pollution they have most often fallen under the responsibility of different government branches – usually the industry or economy ministry on the one hand and the environment and health on the other. Given the weak historical integration of energy policy concerns a joint assessment was unlikely.

Climate change and energy security interactions

The emergence of anthropogenic climate change as a new and important energy policy concern requires that greater attention be given to interactions between different policy efforts in the future.

To mitigate climate change, energy-related emissions of greenhouse gases, which – much like air pollutants – are emitted as by-products in the combustion of fossil fuels, will ultimately have to be reduced to a fraction of current levels. Whether through the adoption of economic instruments – such as carbon taxes or emissions trading schemes – or more hands-on measures, emissions reductions can be achieved in a number ways, including end-of-pipe approaches such as improved end-use efficiency and, in the future, the capture and storage of carbon dioxide prior- or post-combustion, or more up-stream measures such as switching to non-fossil fuels or to less greenhouse gas intensive fossil fuels. Government actions are therefore likely to overlap with those targeting air pollution and energy security.

The need to address energy policy objectives simultaneously is increasingly recognised by policy-makers. It is notably reflected in the International Energy Agency's (IEA) Shared Goals[4] and recognition of the need to maintain a balance between the '3 Es', namely energy security, economic efficiency, and environmental protection. But due to the potential macro-economic implications of up-stream actions, interactions between climate change mitigation and energy security policies have, in particular, been the object of growing attention. Energy security and climate change linkages are underscored in recent national energy policy plans, such as the white papers on energy policy in Australia (Department of Prime Minister and Cabinet, 2004), the UK (DTI, 2003) and France (MINEFI, 2003). At

4. The "Shared Goals" were adopted by IEA member country ministers at their 4 June 1993 meeting in Paris.

EU level they are referred to extensively in the European Commission green papers on energy security (EC, 2000) and in the strategy for sustainable, competitive, and secure energy (EC, 2006).

Yet there have been, so far, few in-depth analyses of energy security and climate change policy interactions. When put in perspective with long-term goals, we can argue that we are only at the beginning of the climate change mitigation process: interactions are still limited and a specific assessment would have been premature. Yet over time, efforts to reduce emissions are likely to have more profound impacts on the energy system, and interactions with energy security objectives may intensify. A sound understanding of these interactions is necessary to ensure the efficiency of government action.

Scope and outline

This study aims to review interactions between energy security and climate change mitigation policies. It does not intend to determine whether the extent or the type of government action towards either climate change or energy security is justified or not. Rather, the study focuses on interactions given stated policy objectives and foreseen policy choices. It proposes, to the extent possible, the use of quantitative tools to assess the effects of government intervention in a context of multiple energy policy objectives. The study ultimately intends to help guide policy-making towards policies that achieve both energy security and climate change mitigation policy objectives as efficiently as possible.

Section two describes both energy security and climate change mitigation as energy policy drivers. It identifies areas of policy overlap and outlines the approach adopted to assess interactions. Section three proposes a new set of indicators to quantify energy security. These are then applied in section four to assess the evolution of energy security and climate change mitigation concerns in five case study countries following a reference scenario. The nature and extent of possible policy interactions are assessed in section five where a number of policy outcomes are considered. Finally, section six offers a discussion of the results obtained and of policy implications.

THE NATURE OF CLIMATE CHANGE AND ENERGY SECURITY POLICY INTERACTIONS

In order to assess policy interactions, a clear understanding of both climate change and energy security as energy policy drivers is necessary. This section will address each in turn, before identifying areas of potential policy overlap and ways in which interactions can be assessed.

Climate change and its mitigation

From science to policy

Due to human activities, concentrations of greenhouse gases in the atmosphere are progressively rising. Measurements of atmospheric concentrations of carbon dioxide (CO_2), the most important long-lived greenhouse gas, show that concentrations were stable at roughly 280 parts per million (ppm) over most of the last 1 000 years and started increasing from the mid 19th century to reach approximately 378 ppm in 2004 (IPCC, 2001a; Keeling *et al.*, 2005). The consequence is that the greenhouse effect, which has maintained an average temperature on the earth's surface at about 15°C, is intensifying, further warming the earth and changing the climate system. While this may entail both beneficial and adverse effects on the environment and socio-economic systems, the larger the changes and the rate of change in climate, the more the adverse effects are likely to predominate (IPCC, 2001b).

Scientific evidence pointing towards anthropogenic climate change only started accumulating over the course of the 1970s and 1980s leading to the first international policy response in 1992, with the adoption of the United Nations Framework Convention on Climate Change (UNFCCC). The Convention's ultimate objective is to stabilise "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, article 2). Over a decade since its adoption the Convention is now approaching global membership.[5] However, there is still much scientific

5. For more details: http://unfccc.int.

uncertainty around what the appropriate level of greenhouse gas concentration in the atmosphere should ultimately be.

What we do know, however, is that to stop the rise in atmospheric greenhouse gas concentration at any level, emissions will ultimately have to be reduced to the level of uptake of greenhouse gases by natural sinks (IPCC, 2001a), such as land, oceans and forests, which is a fraction of current emissions levels. The timeframe in which this is done will effectively determine the level at which concentrations in the atmosphere are stabilised.

This relationship between atmospheric concentration and the timing of emissions reductions is reflected in Figure 1, which shows the result of modelling exercises assessing emissions profiles to stabilise atmospheric CO_2 concentrations at various levels (IPCC, 2001a). Stabilisation at 450, 650, or 1 000 ppm would require global anthropogenic CO_2 emissions to drop below 1990 levels within a few decades, about a century, or about two centuries respectively and continue to decrease thereafter.

Different emission pathways, however, could lead to the same ultimate atmospheric concentration. Indeed, early emissions reductions followed by progressive, low-level emissions could have the same result in terms of concentration as limited reductions in the near-term followed by more aggressive reductions in the future.

The energy sector at the heart of the problem

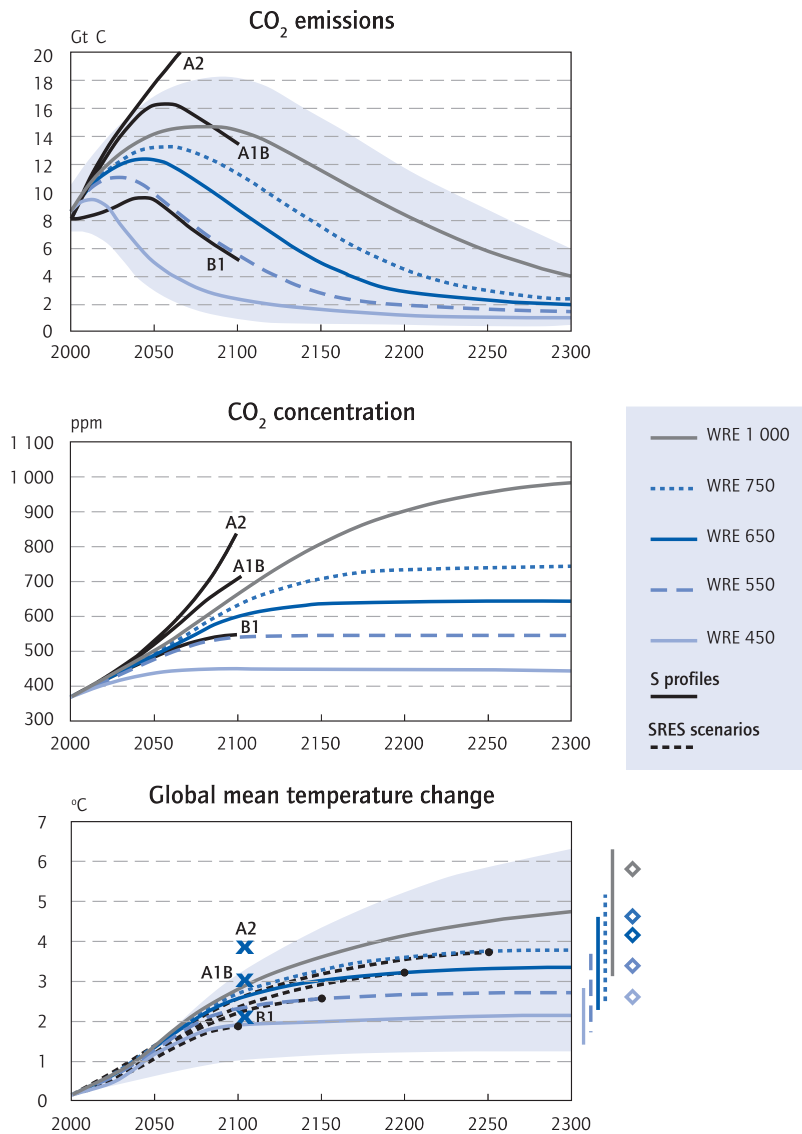
The burning of fossil fuels – coal, gas and oil – to produce energy is by far the main source of anthropogenic greenhouse gas emissions. At the global level, it is responsible for over 60% of total emissions (WRI, 2005), and when only considering OECD countries and countries with economies in transition, this value rises to 80% (IEA, 2005a).[6] Mitigating climate change cannot, therefore, be successful without a radical change in the way we produce, transform and use energy.

Energy-related greenhouse gas emissions, which are predominantly in the form of CO_2, can ultimately be reduced through one, or a combination, of the following approaches:

6. Different greenhouse gases have different global warming potentials. In order to calculate total greenhouse gas emissions, non-CO_2 emissions are converted to CO_2 equivalents by using 100-year global warming potentials.

FIGURE 1

Emissions, concentration and temperature changes corresponding to different stabilisation levels for CO_2 concentrations



Source: IPCC (2001b).
Note: the shaded area illustrates the range of uncertainty; WRE, S and SRES are various CO_2 stabilisation profiles/scenarios found in the literature.

- **Improving energy efficiency:** Technological improvements can increase the efficiency of power plants, energy-using equipment such as appliances[7], cars, lighting equipment[8], as well as buildings. In addition, behavioural change towards more economical utilisation can also contribute in reducing overall energy use. The more carbon intensive the input fuel of the targeted activity or process, the more emissions will be reduced.
- **Switching to less carbon-intensive fossil fuels:** The type of fossil fuel used defines the resulting level of emissions. Coal is the most carbon-intensive fuel with a carbon emission factor of about 26 tC/TJ, while crude oil has a carbon emission factor of about 20 tC/TJ, and natural gas 15 tC/TJ (IPCC, 1997). Switching to less carbon intensive fuels therefore reduces the level of emission per unit of energy generated.
- **Switching to emission-free energy sources:** Greenhouse gas emissions related to nuclear and renewable energy sources, such as wind and solar power, are negligible[9]. Switching from fossil-based fuels to emission-free energy sources therefore leads to a reduction in greenhouse gas emissions.
- **Capturing and storing CO_2 emissions:** Carbon can be captured prior- or post-fossil fuel combustion. Through this approach, the energy production process is not directly affected as an add-on component is installed instead. The carbon can then be stored in geological formations such as oil and gas fields, unminable coal beds or deep saline formations, in oceans, or through industrial fixation of CO_2 into inorganic carbonates (IPCC, 2005). This results in the removal of emissions which would have otherwise been emitted into the atmosphere.

The stringency and timing of implementation of policies and measures to spur the adoption of such approaches depends on the ultimate climatic goal to be reached and on the costs of action. Both of these are uncertain and likely to change over time rendering the policy-making process all the more complex.

On the one hand, the climatic objective may change in response to new scientific findings. This uncertainty may notably justify more stringent early action to keep the option open of stabilising atmospheric concentrations at lower levels if

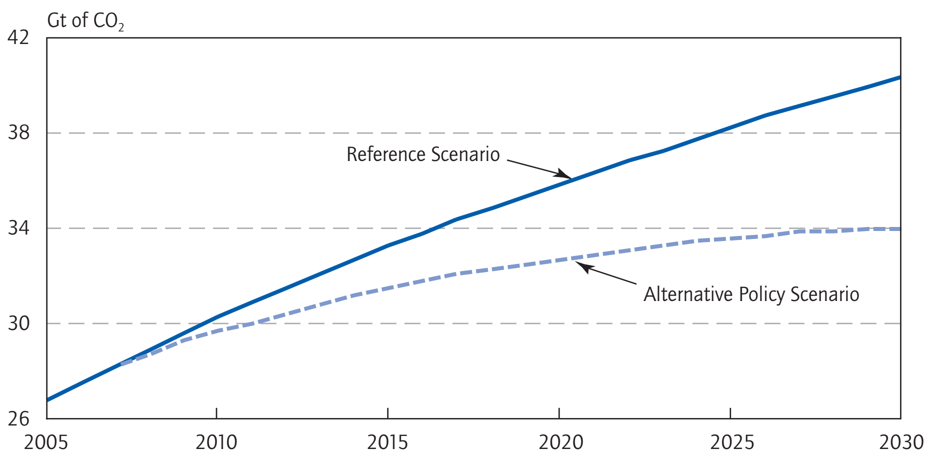
7. See IEA (2003) for an extensive discussion of policy options to stimulate energy efficiency improvements in home appliances.
8. See IEA (2006b) for an extensive discussion of policy options to stimulate energy efficiency improvements in lighting equipment.
9. Electricity generation in nuclear plants is an emissions free process yet on a life cycle basis, including plant construction and nuclear fuel reprocessing, nuclear power, albeit on a limited scale, can be a source of emissions.

necessary. On the other, energy-related capital stock is typically long lived[10] and premature retirement is expensive. Also, low-cost mitigation technologies may become available in the future, justifying a more delayed action.

Looking at medium-term projections of energy-related emissions provides some indication of the timeframe in which emissions could be reduced. Figure 2 shows

Figure 2

Projection of world energy-related CO_2 emissions in the IEA World Energy Outlook reference and alternative policy scenario



Source: IEA (2006c).

projections of energy-related emissions to 2030 following a reference scenario as well as an alternative scenario in which policies currently on the drawing board are assumed to be implemented (IEA, 2006c). If no new measures are taken to reduce emissions (reference scenario), global energy-related emissions will continue to rise, growing by approximately 50% between 2005 and 2030 in parallel to fossil fuel consumption. If policies currently planned or likely to be implemented are included (alternative scenario), emissions are projected to grow by 27% between 2005 and 2030. Importantly, however, the emission profile of this alternative case shows that the rate of growth of emissions reduces significantly and indicates that emissions peak shortly after 2030.

10. Capital stock lifetime ranges from a few years for end-use equipment, to 50 years for infrastructures, buildings, and production processes, and over 100 years for urban land use.

Untangling energy security

What is energy security?

Energy insecurity can be defined as the loss of welfare that may occur as a result of a change in the price or availability of energy (Bohi and Toman, 1996). Whether energy insecurity stems from price or physical availability concerns, however, depends on the nature and effectiveness of price-volume linkages in the market.

In regulated energy markets, prices are fixed or pegged to other energy commodities. This is notably the case of natural gas prices which in many regions of the world are indexed to oil prices. Such arrangements may bring greater price security, yet the lack of price-volume linkages raises important physical availability concerns. In the case of a supply shortfall, for example, prices are unable to adjust, leading to excessive demand compared to available volumes, which raises the risk of physical unavailability.

In markets where prices do reflect market fundamentals, a shortfall in supply leads to a number of responses to re-establish market equilibrium. These generally include more expensive suppliers entering the market as well as consumers unwilling to pay the higher price reducing their consumption or switching to alternative fuels. The price mechanism therefore lowers risks of physical unavailability. In the end, the main energy security concern is one of price being set at uncompetitive levels.

So while energy security always consists of both a physical unavailability component and a price component, the relative importance of these depends on the market structure, and in particular the extent to which prices are set competitively or not.

Addressing energy insecurity

The welfare losses referred to in the above definition of energy security, whether due to prices set at uncompetitive levels or physical unavailability are in fact the external costs of energy insecurity. Due to the ubiquity of commercial energy use, however, determining these external costs in practice is difficult. This is particularly true in the case of energy sources traded on international markets as impacts are all the more diffused. Appropriately gauging the magnitude of the problem and an adequate policy response is therefore a difficult task.

Nevertheless, governments have defined a variety of tools to mitigate the risk of physical unavailability occurring in extreme events. These include, when economically viable, establishing strategic reserves. Among major energy consuming countries, for example, the risk of physical unavailability led to establishing co-ordinated emergency oil stocks.[11] Governments may also seek to establish contingency plans to curtail consumption in times of major supply disruptions.[12]

In the longer term, governments have tended to focus policy efforts on tackling the root causes of energy insecurity. These can be broken down into four broad categories:

- **Energy system disruptions linked to extreme weather conditions or accidents:** A recent example from this category is the impact on the energy system of Hurricane Katrina which hit the Gulf of Mexico in 2005. Several refineries and other energy infrastructures were affected and had to be completely or partially shutdown for repairs that took several weeks or months. The impacts were so severe that the physical shortage of oil became a serious threat, leading the IEA to release oil stocks for the first time since 1991. However, while such incidents may be potentially disastrous and have far reaching economic implications, government action to address such potential causes of energy insecurity is not necessarily mandated. In many cases, for example, industry itself establishes standards of construction, provides spare capacity or diversifies sources and supply routes to ensure a given level of resilience of the system and avoid costly disruption. In any case, the scope of action is precautionary in nature. It should be noted, however, that governments have a clear role in preparing contingency arrangements for the management of and recovery from such incidents after they happen.
- **Short-term balancing of demand and supply in electricity markets:** As electricity is a non-storable commodity, it is both technically and economically impossible to deliver electricity of varying quality as a function of consumers' willingness to pay: brown outs or black outs affect everyone. Thus, quality is a characteristic of electricity that everybody can benefit from without reducing the benefit for others – one of the defining characteristics of a public good. Without intervention from governments, markets alone are unlikely to manage the short-term operational phase of balancing demand and supply in order to provide an acceptable level of quality and ensure system security (IEA, 2005b). The policy response to this is in

11. The rules governing the management and use of the co-ordinated emergency oil stocks are defined in the 1974 International Energy Programme (available on the International Energy Agency website: www.iea.org).
12. IEA (2005g) and IEA (2005h) present a review of measures which could substantially reduce oil and electricity demand respectively in times of emergency.

fact relatively straight forward. Governments have established independent Transmission System Operators (TSOs) responsible for the short-term balancing of demand and supply to ensure a given standard of quality.

- **Regulatory failures:** Governments play an essential role in ensuring market rules are clearly defined to create effective marketplaces. In addition, electricity and gas networks tend to be considered as natural monopolies and are therefore under considerable regulatory supervision. Regulatory failures that have energy security implications may therefore occur. The policy response to such regulatory failures is by definition complex as in most cases the failure is not known until a problem occurs. It consists principally of monitoring and adjusting regulatory frameworks when a failure is identified.
- **Concentration of fossil fuel resources:** This is the most long-lasting cause of energy insecurity. Due to the concentration of resources in certain regions of the world, exploration and production as well as the transport of fuels to the market are also characterised by a certain degree of concentration. In addition, in many cases, fossil fuel resources are concentrated in politically sensitive regions. In the case of the transport of fuels to market, this is often exacerbated by local geographic constraints. These include for example choke points along oil trade routes, such as the Strait of Hormuz or the Suez Canal. Resource concentration can affect almost the entire energy system as fossil fuels play a prevailing role in most energy applications. The policy response to this cause of energy insecurity aims to reduce the exposure of a country to the resource concentration risks.

Out of these four categories policy implications are most significant in the case of regulatory failures and resource concentration. These are presented in more detail below.

Regulatory failures as a source of energy insecurity

Over recent years, the energy security implications of regulatory failures have attracted significant attention due in large part to renewed efforts to liberalise energy markets in many OECD countries. Among the latest of these efforts, are the European Community Electricity and Gas Directives adopted in 2003[13], which officially launched the process of market liberalisation in European gas and electricity sectors.

13. Electricity Directive 2003/54/EC, Gas Directive 2003/55/EC.

The institutional shift involved in the transition to liberalised markets is complex and takes place over many years. While the basic regulatory foundation may be established over a relatively short period of time, the learning process for regulators, firms, and end-users is linked to long-lived capital investment cycles. The establishment of a sound regulatory structure in support of energy markets can therefore be a long process spanning over many years, if not decades. Throughout this process, governments must monitor the evolution of markets and adjust market rules accordingly. Many electricity market structures, for example, underwent significant changes as they found themselves facing new challenges. In England and Wales the entire market structure was fundamentally changed in 2001, eleven years after its initial launch. Similarly, following an extensive market review in 2002, significant modifications were made to the electricity market structure in Australia (IEA, 2005b).

Regulatory failures can take a variety of forms depending on the specificities of markets. Nevertheless, based on experience accumulated to date, certain types of regulatory failures common to most market structures can be identified as potential sources of energy insecurity. One, for example, is the limited consumer response to price variations. In an efficient market, the price is formed through the interaction of supply and demand. If buyers do not participate actively in this price-setting process, prices cannot play their balancing role. Instability may result such as excessive price volatility. In most cases, the limited demand response is a legacy of old vertically integrated energy systems, where the focus was largely set on the supply side and energy prices were uniformly set. By enhancing demand participation, governments can improve the efficiency of markets and enhance energy security. Demand response (even when only by a few large consumers) can notably dampen price peaks, reducing costs and risks to all market participants.

Another example of a market failure with potentially important energy security implications is the inability of markets to spur investments when those are necessary. As it is only through actual investments in new capacity that one can gauge the efficacy of the regulatory structure to spur new investments, it is difficult to assess whether there is in fact a regulatory failure before a complete investment cycle takes place. In the oil products markets, for example, fears of underinvestment in refining capacity in OECD countries are growing and policy-makers are actively considering how to adjust regulations in order to spur new investments. Over the past decade, demand for motor gasoline in the US has grown 2.4 times faster than the rate of refinery production capacity and there have been no new refineries built since 1976.[14] In response, the US government is actively trying to spur new investments in refineries notably by simplifying environmental regulations.[15]

The policy response consists of monitoring the effectiveness of market rules and adjusting regulations when a regulatory failure is detected. It is a learning-by-doing process. In principle, therefore, such concerns should fade as experience accumulates and regulatory structures are fine tuned. In practice, however, this is complicated by the inherent difficulty of distinguishing energy security concerns linked to regulatory imperfections from the normal functioning of energy markets.

Fossil fuel resource concentration as a source of energy insecurity

The uneven distribution of fossil fuel resources around the world is the most long-lasting cause of energy insecurity. 62% of global proved[16] oil reserves are found in the Middle East. Taken together, members of the Organization for the Petroleum Exporting Countries (OPEC) countries account for 75% of global reserves while OECD countries only account for 7% and consume close to 60% of world total. Similarly, over half of global proved gas reserves are found in three countries: the Russian Federation (27%), Iran (15%), and Qatar (14%) while the OECD accounts for only 8% of the total and consumes over 50% of world total (BP, 2005).

As illustrated in Figure 3 in the case of oil, resources in the Middle East and North African countries are more easily and economically accessible than those found in the OECD. Many OECD countries have, therefore, relied significantly on imports from these regions. In 2004, OECD countries imported 59% of their oil consumption while in the case of gas, OECD Europe and OECD Pacific imported respectively 40% and 69% of their total consumption.

The limited number of import sources and the sensitive political climate in many exporting countries has fuelled much political concern in OECD countries. As illustrated in Figure 4, most significant world oil supply shortfalls were politically charged. While historically there have never been equivalent supply shortfalls in

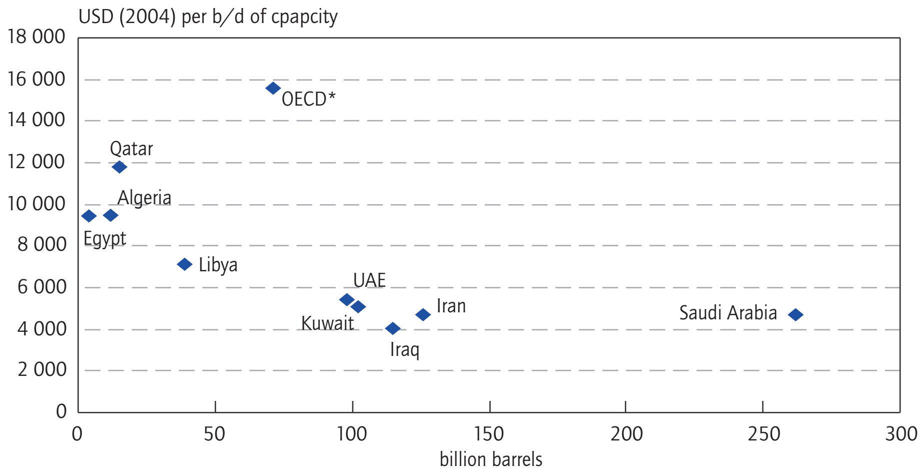
14. Source: IEA data.

15. See for example the Energy Policy Act of 2005, Title III, Subtitle H: "Refinery Revitalization".

16. "Proved reserves" refers to fossil fuels that have been discovered and for which there is reasonable certainty that they can be extracted profitably (mainly on the basis of assumptions about cost, marketability and future prices).

Figure 3

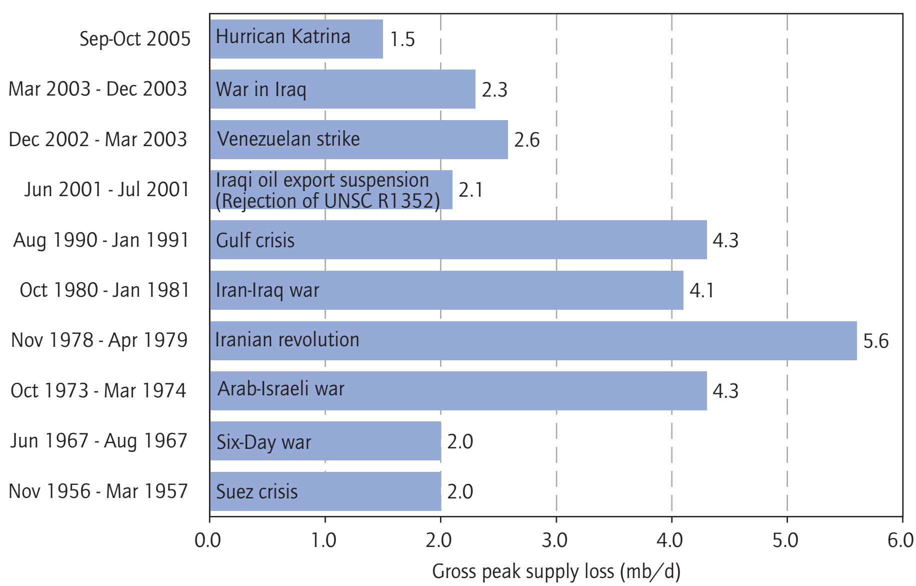
Average exploration and development costs versus proven oil reserves in Middle East and North Africa countries*



Source: IEA (2005e).
* OECD value added for reference. It excludes Canadian non conventional oil reserves.

Figure 4

World oil supply disruptions



Source: US Department of Energy and the IEA Secretariat.
Note: Initial production loss only.

the gas sector (since gas has tended to be mostly locally produced and used), the growing importance of long distance gas imports in OECD gas supplies is of increasing concern to policy makers. The Russia-Ukraine dispute and the echo it had across Europe in January 2006 is an indication of the sensitivity of the gas sector to potential supply disruptions.

Looking at reserve-to-production (R/P) ratios[17] provides some insights on future trends. For oil, 2005 estimates show an R/P of approximately 81 years for the Middle East and 11 years for the OECD, indicating a likely increasing reliance on imports from the Middle East in the future. Gas R/P estimates are also much higher in the main resource rich countries than for the OECD – 81 years for the Russian Federation, over 100 years for both Iran and Qatar and only 14 years for the OECD – also indicating a trend towards rising imports by the OECD (BP, 2005). This is confirmed by recent IEA projections which also indicate a progressive concentration of import sources (IEA, 2006c).

Policy response to the energy security implication of resource concentration aims to minimise the exposure to concentration risks. This has taken a variety of forms ranging from energy efficiency measures to the promotion of less sensitive fuel sources. For example, though probably due as much to cost considerations as to energy security measures, the share of oil in electricity generation notably fell at the OECD level from 24% in 1974 to 5% in 2004, while the share of nuclear power rose from 5% to 23% (IEA, 2005d). Governments have also endeavoured to diversify the mix of supplier countries, trade means and routes.

Assessing climate change and energy security policy interactions

Areas of potential policy overlap

From this brief overview, policies designed to address energy security concerns linked to resource concentration are likely to have the most significant implications for climate change mitigation, and visa versa, as in both cases policies are most likely to directly affect fuel choices. In the first case the goal is

17. R/P is calculated by dividing remaining reserves at the end of a year by the production in that year. It is expressed in years and represents the length of time that those remaining reserves would last if production were to continue at that level. Of course, reserves are a dynamic quantity, changing over time with prices, technology, and demand.

to move away from risk-prone fuels; while in the second, it is to reduce the carbon intensity of the fuel mix. The policy overlap may therefore be significant.

In contrast, interactions between regulatory adjustments to address regulatory failures and climate change mitigation efforts are likely to be of secondary importance. In a first instance, policies designed to address regulatory failures have little direct impact on fuel or technological choices and therefore interactions with climate policy are likely to be limited. Measures designed to address the problem of demand response mentioned above, for example, may have some implications on greenhouse gas emissions to the extent that they may reduce overall energy consumption; yet, this is highly uncertain and unlikely to be of significant importance.[18] Similarly, regulatory adjustments to ensure sound and timely investments are unlikely to have specific implications for climate friendly technologies.

Nevertheless, one consequence of regulatory failures or of regulatory uncertainty in a given fuel market can be that consumers choose to move away from the fuel in question to an alternative. In a second instance, therefore, to the extent that government intervention affects such consumer response, it also affects the fuel and technological mix and therefore may have implications in terms of climate change mitigation objectives.

Interactions between measures which address the other two causes of energy insecurity mentioned above – extreme weather events/accidents and electricity system security – and those designed to mitigate climate change are likely to be minimal. The level of resilience of the energy system has no clear link to climate change mitigation efforts and visa versa. Similarly, climate change mitigation efforts are unlikely to directly affect the ability of system operators to balance supply and demand on the market. Some have argued that climate change mitigation may lead to an increase in the role of intermittent renewable sources of electricity, such as wind, and that that may render the system less secure. However, if system operators have the means necessary, and in particular the ability to charge for the additional back-up capacity needs, then system security should be unaffected. If they don't, then the problem is of a regulatory nature rather than of electricity system security per-se.

It is also important to note that interactions between policy efforts that specifically aim to mitigate physical unavailability risks in times of emergency, and those to

18. The primary effect demand response measures is likely to be a displacement of demand that would normally take place during peak hours to times when prices are lower. This however, does not necessarily imply an overall reduction in demand.

reduce greenhouse emissions, are also likely to be minimal. Emergency response measures, such as holding stocks in the case of oil, or defining contingency plans to curtail the consumption of a fuel in case of a major supply disruption are short-term in scope and are unlikely to have major impacts on overall fuel consumption and therefore on emissions. In contrast, climate related policies aim to influence long-term trends in fuel choices and technological choices.

Assessment method

The assessment of energy security and climate change mitigation policy interactions proposed here will therefore focus on the energy security implications of fossil fuel resource concentration (Box 1). Other areas of potential policy overlap, and in particular with respect to regulatory adjustments in the scope of regulatory failures, are not directly addressed.

Box 1

Resource concentration: only a concern for fossil fuels?

Resource concentration materialises as a cause of energy insecurity through the physical development of the market. In the case of oil, for example, the uneven distribution of resources only became a political concern with the development of a global energy market and trade. We are therefore interested in energy sources which are not only characterised by unevenly distributed resources but which are also exploited through international market structures. While the three fossil fuels – oil, but also coal and gas – evidently meet these criteria and will be considered in this assessment, it is important to ask whether any other energy source should also be considered.

All renewable energy resources are also unevenly distributed. Solar insolation, for example, is much higher in certain regions of the world than in others. Similarly, wind or geothermal resources vary from country to country and within countries from region to region. Yet to date, these resources have principally been developed through national market structures and have therefore not been the object of energy security concerns related to the uneven distribution of resources. They are effectively considered as domestic resources exploited within domestic boundaries and will be considered as such in this analysis. However, in the longer term one cannot exclude that such sources of *energy become the object of security concerns. For example, in a scenario of long-term sustained high oil prices, OECD countries may increasingly turn to biofuels as a substitute for transportation purposes. Many developing countries may exploit this opportunity to become important suppliers to OECD markets. Depending on how the market develops this may cause new energy security concerns linked to resource concentration.*

Uranium, the fuel used in nuclear power plants, is also unevenly distributed and, like fossil fuels, is exploited within an international market structure. However, uranium is unlike fossil fuel markets on many accounts including two which are particularly pertinent to the energy security concerns of interest here. First, uranium has a higher energy density than fossil fuels. This means that uranium can more easily be stored and is less dependent on international trade and market infrastructures than fossil fuels. Storage of one year's worth of nuclear fuel is both economically and physically feasible. Second, fuel costs represent only approximately 10-15% of electricity generation costs from nuclear plants compared to much higher levels in the case of fossil fuel-based plants (approximately 30-40% for coal and 60-85% for gas). Nuclear generation is therefore much less affected by fuel price fluctuations than fossil fuel-based generation (IEA, 2001b). For these reasons, nuclear power can be considered to be significantly less prone to energy security risks related to resource concentration than fossil fuels.*

* Data of projected electricity generation costs calculated at 10% discount rate.
Source: IEA (2005c).

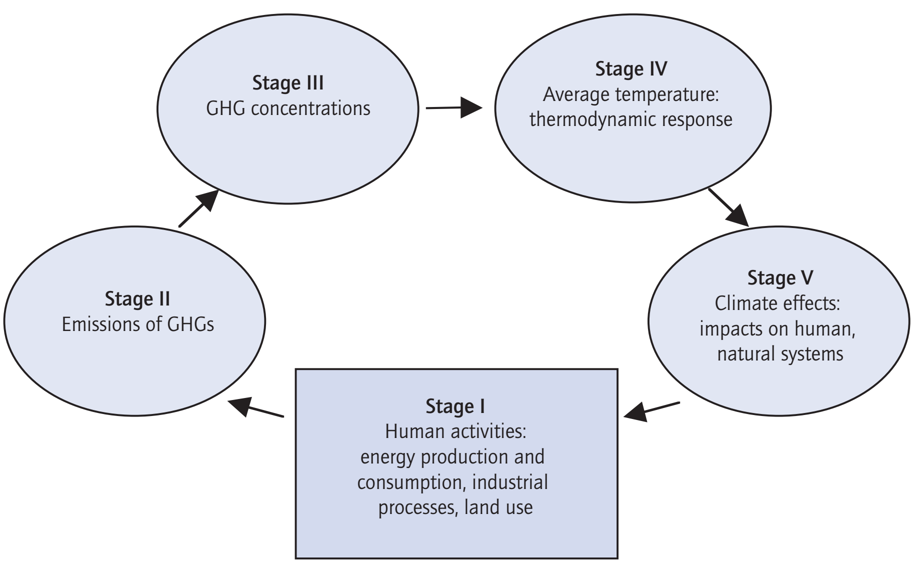
The assessment is based on the combination of qualitative and quantitative analysis. The methodology for the quantitative analysis rests on the use of indicators to track the impacts of changes in the energy system – whether due to normal market dynamics or policy induced – and systematically evaluate cross cutting policy interactions.

For such a quantitative analysis to be a valuable complement to a qualitative analysis, however, the indicators should be simple and comprehensive. Indicators should notably focus on characterising the root causes of both climate change and energy insecurity in order to avoid having to directly assess impacts.

The benefits of this are evident when considering the case of climate change, for which the use of such a quantitative approach is already common practice. Figure 5 schematises the causal links of anthropogenic climate change. Human activity (stage I) produces greenhouse gases (stage II), which lead to a rise in atmospheric concentrations (stage III). This enhances the natural greenhouse effect leading to rising average temperatures (stage IV) which impacts human and natural systems (stage V). Each of these stages presents new uncertainties. For example, while emissions of greenhouse gases (stage II) from human activity can be measured with relative certainty based on energy consumption data and carbon emission factors, measuring the impact on atmospheric concentrations (stage III) requires understanding and gauging carbon exchanges between land, oceans and the atmosphere as well as the evolution of greenhouse gases in the atmosphere (including gas life-times and subsequent reactions with other gases). Measuring resulting temperature increases (stage IV) is characterised by further uncertainty. This is notably reflected in the IPCC's Third Assessment Report: "the uncertainty about climate sensitivity yields a wide range of estimates of temperature change that would result from emissions corresponding to a select concentration level." (IPCC, 2001b, p. 98). Ultimately, measuring precise climate effects (stage V) is a daunting task.

Figure 5

Causal links in the climate change cycle



Source: adapted from Pershing and Tudela (2003).

So while defining a measure based on "effects" (stage V) might be a more accurate reflection of actual climate change mitigation, due to the accumulated uncertainty it would be difficult to link with any accuracy to "human activity" (stage I), and therefore loses policy relevance. For this reason policy makers have adopted a policy assessment approach which emphasises the need for certainty: climate change mitigation policies are, simply, assessed based on their impacts on greenhouse gas emissions (stage II) and in particular CO_2. We adopt the same approach in this study and use CO_2 as our indicator for climate change mitigation.

Similarly in the case of energy security, defining a measure based on "effects" – the welfare losses referred to in Section 2 – might be a more accurate guide to energy security. However, due to a high level of uncertainty in determining these losses, it is best to focus the design of an indicator on the cause of interest: fossil fuel resource concentration, as far as interactions with climate change policy is concerned. Defining such an indicator – or set of indicators – is, however, less simple than in the case of climate change mitigation. Much has been said and written about this cause of energy insecurity yet few efforts have attempted to quantify it. One difficulty, notably, rests in the dual nature of energy insecurity, characterised by both price and physical availability components.

The following section will therefore focus on the difficult task of quantifying how fossil fuel resource concentration affects energy security. It proposes a new set of indicators to be used in the analysis while a review of existing quantitative efforts can be found in Annex I.

Summary

Climate change stems from anthropogenic greenhouse gas emissions. The energy sector is by far the main source of such emissions worldwide. Policy options to reduce energy-related emissions consist of improving energy efficiency, switching to less carbon intensive fossil fuels or to emissions-free energy sources, and capturing and storing CO_2.

With regard to energy security policy, a distinction can be made between government actions to mitigate the short-term risks of physical unavailability occurring in case of a supply disruption and efforts to improve energy security in the long-term.

In the first case, actions include establishing strategic reserves, dialogue with producers, and determining contingency plans to curtail consumption in times of

important supply disruptions. In the second case, policies tend to focus on tackling the root causes of energy insecurity. These can be broken down into four broad categories:

- Energy system disruptions linked to extreme weather conditions or accidents.
- Short-term balancing of demand and supply in the electricity market.
- Regulatory failures.
- Concentration of fossil fuel resources.

Through this typology of energy security policy it is possible to clearly identify areas that overlap with climate change mitigation actions. Policies designed to address energy security concerns linked to resource concentration have potentially the most significant implications for climate change mitigation, and visa versa, as in both cases policies are likely to affect fuel and associated technological choices. This report therefore focuses on resources concentration as a driver of longer-term energy security.

NEW TOOLS TO MEASURE THE ENERGY SECURITY IMPLICATIONS OF RESOURCE CONCENTRATION

We propose two new indicators to illustrate the energy security implications of resource concentration. In doing so, we make a distinction between the price and physical availability components of energy security: the first focuses on characterising the price component while the second focuses on the physical availability component.

Measuring the price component of energy security

Concern over prices being set at uncompetitive levels is important in liberalised market settings, such as in the international oil and coal markets. With respect to gas, much depends on the region of interest. The North American gas market is a liberalised market in which prices are set competitively. Similarly, spot-based gas trading exists in the UK, which has at its heart the National Balancing Point (NBP). More recently, similar markets – though on a much smaller scale – have developed in Belgium and the Netherlands.

In most OECD Europe countries and in OECD Asia countries, however, gas contracts are negotiated bilaterally, and in the vast majority of cases are linked to crude or oil product prices. Such contracts only take into account the prevailing economics of gas demand and supply during contract negotiation and are immune to gas market price risks thereafter. As discussed below, by indexing the gas price to oil, gas traded within such contract terms is effectively exposed to the price risks of the oil market while retaining separate physical availability risks.

Drawing from competition law

The energy security competition law analogy

In a perfectly competitive market model, numerous suppliers compete. The price of their output is set either at marginal cost or, in the case of high fixed costs, at a price somewhat above marginal costs. Each firm is too small to affect the market price by itself. If a firm attempts to increase prices above the competitive level, it will lose its customers. Similarly, if a firm reduces output, it will not affect the market price because its output is too small to significantly reduce the market output.

In reality, however, some firms have stronger market positions than others and may have the ability to harm competition. Competition law therefore seeks to promote economic competition by prohibiting anticompetitive behaviour and unfair business practices by such firms. To do so, the notion of market power is used extensively in competition regulation. In basic economic terms market power is defined as the ability of a firm, or group of firms, to set prices above competitive levels and for this to be profitable.[19] In practice, this definition can be expanded to include other ways to harm competition, such as restricting output or quality below competitive levels, raising entry barriers, or slowing innovation (McFalls, 1997; OFT, 2004a). Competition law aims to prohibit the abuse of market power. In the case of European countries, for example, this objective is included in Article 82 of the Treaty establishing the European Community, which states that "any abuse by one or more undertakings of a dominant position within the common market or in a substantial part of it shall be prohibited as incompatible with the common market insofar as it may affect trade between Member states". In Australia, for example, it is included in Section 46 of the 1974 Trade Practices Act, which sets the regulatory framework with regard to the "Misuse of Market Power".

A parallel can be made between government concerns related to the abuse of market power and those related to the energy security implications of fossil fuel resource concentration in liberalised markets. Indeed, due to the concentration of fossil resources, large producing countries hold a form of "market power" in international energy markets, which gives them the ability to harm competition in its broadest sense.

A measure of "market power" therefore seems to constitute a solid foundation for an indicator of the price component of energy security. In this section we first review the process of measuring market power in the scope of competition law before describing how we define an analogous approach to assess energy security.

19. Source: European Commission Competition Directorate General glossary.

Measuring market power

The assessment of market power in competition law is not straightforward. Market power is highly dependent on the circumstances of each case. In addition, it is, to a large extent, at the discretion of the competition authorities to decide whether there is a case of market power in a given market (OFT, 1999).

Nevertheless, proxies have been developed to assist policy makers in measuring market power. Three stand out in the literature (McFalls, 1997):

- **The Lerner Index:** A firm's ability to set price above cost increases with market power. The Lerner Index therefore aims to measure market power directly by subtracting cost from price, and then dividing the result by the price. The Lerner ratio ranges from 0 to 1 with increasing market power.
- **Market Share:** Market power is unlikely without concentration in the market (FTC, 1992; OFT, 2004a). A measure of market concentration therefore provides a proxy of market power. Market share is probably the simplest measure of market concentration. It has attracted significant policy attention, particularly in Europe where, while no specific market share threshold has been established, it is used extensively in support of the law.
- **Herfindhal-Hirschman Index (HHI):** HHI is calculated by summing the squares of the individual market shares of all the participants. It is a more elaborate measure of market concentration as it takes into account both the number of firms in the market and their respective market shares. HHI is notably used to assist the US Federal Trade Commission in the assessment of horizontal mergers (FTC, 1992).[20]

As highlighted by McFalls (1997), while the Lerner Index seems theoretically very close to the definition of market power, there are in fact a number of difficulties with its practical use. In particular, it provides no benchmark apart from the case of perfectly competitive markets. In addition, producing reliable estimates of costs is difficult. Finally, due to its reliance on price, the Lerner Index seems particularly inappropriate to assess likely future market power as this would require price projections independent of costs.

An approach based on the measure of market concentration is attractive for its simplicity. It is already widely used by governments and will form the basis of our analysis.

20. HHI, also known as the Simpson diversity index in ecology, is one of the dual-property measures identified by Sterling (1998) in his work on diversity.

Defining the relevant market

While simple, a measure of market concentration is highly dependent on the definition of the relevant market. In competition law, this process comes down to determining the closest substitutes to the product under investigation as these constitute the most immediate competitive constraint. The *Hypothetical Monopolist Test*[21] (HMT) is widely used by competition authorities as a conceptual framework to determine the products which should be considered as part of the relevant market and its geographic boundaries (OFT, 2004b).

HMT asks whether customers of a given product would switch to readily available substitutes or to suppliers located elsewhere in response to a hypothetical permanent price increase of a "small but significant amount" (usually 5-10%). If such substitutions would be enough to make the price increase unprofitable, the substitutes and areas identified should be considered as part of the relevant market and included in a new iteration of the analysis. This should be repeated until the set of products and geographic areas is such that a small and permanent increase in the products price would be profitable. The ultimate product group and geographic area identified then constitute the relevant market (EC, 1997; OFT, 2004b; OFT, 1992).

While applying HMT seems straightforward, much depends on the context of the investigation, and in particular whether the competition law authorities are investigating a merger or a case of existing dominance in the market. This is of particular relevance as the assessment of the energy security implications of uneven energy resource distribution is closest to a dominance investigation.

In the case of a merger, the analysis aims to assess whether the merger would reduce the competitive constraints on the pricing behaviour of the merging parties. The benchmark price on which the test is based is the prevailing price, which can be assumed to be set at the competitive level. The approach is forward looking and the test provides a suitable analytical framework to define market boundaries in a systematic manner.

When investigating cases of existing dominance, however, determining market boundaries is more complex. In such cases one is interested in assessing whether the firm already has market power. Or, in other words, whether the prevailing price

21. This test is also known as the "SSNIP" test following the wording used in the US horizontal mergers guidelines (FTC, 1992): Small but Significant Non-transitory Increase in Price.

is above what would be the competitive level. Applying HMT as described above would therefore imply using a price above the competitive level as the benchmark and risk identifying a broader market than is actually the case.

In a study commissioned for the UK Office of Fair Trading, NERA[22] (2001) analyses the problems involved in defining market boundaries in dominance inquiries. It concludes that there is no sensible alternative methodology to HMT and that it remains a useful framework for market analysis. NERA stresses, however, that in the case of dominance investigation the proper definition of market boundaries depends extensively on the expert judgment of competition authorities.

Defining fossil fuel market boundaries in the scope of energy security analysis

Assessing fossil fuel markets concentration is closest to a dominance enquiry in competition law and, as such, identifying market boundaries is a particularly difficult task. Nevertheless the notion of substitution at the heart of HMT should still be used to define market boundaries. We focus here on short- to mid-term substitution as this seems most relevant to energy security analysis.

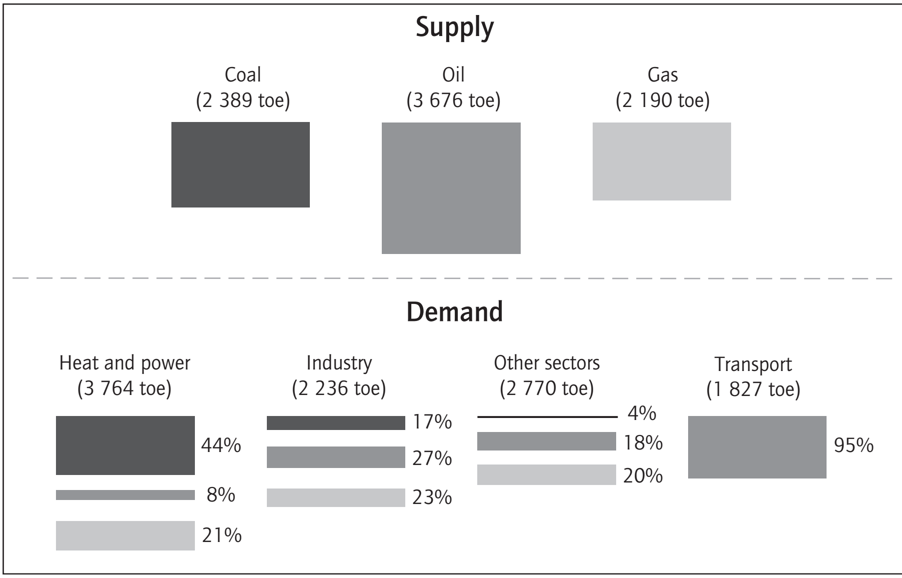
Identifying potential substitutes for fossil fuels is a unique exercise. Fossil fuels are unlike any other products. They are the primary feedstock to the essential processes underpinning economic activity: electricity and heat generation, industrial processes, and transportation, among others (Figure 6). These processes are complex, capital intensive technological systems developed over several decades. In order to assess fuel substitutability therefore requires assessing the technological flexibility to switch fuels in each of these processes and end-uses.

Observing how markets have responded to price movements over the recent past is instructive in assessing this substitutability. Figure 7 shows the evolution of fossil fuel prices between January 2000 and January 2006. During this period, average monthly benchmark crude oil prices more than tripled in four years to over USD60/bbl. When looking at gas, hub prices in the UK (National Balancing Point) and in the US (Henry Hub) show a rising trend over the six-year period, being frequently above oil prices on an energy basis. Monthly average NBP prices were at close to USD18/MMBtu in November 2005. In contrast, oil-indexed border

22. National Economic Research Associates.

Figure 6

Fossil fuels' share of world TPES and final consumption by sector, 2002



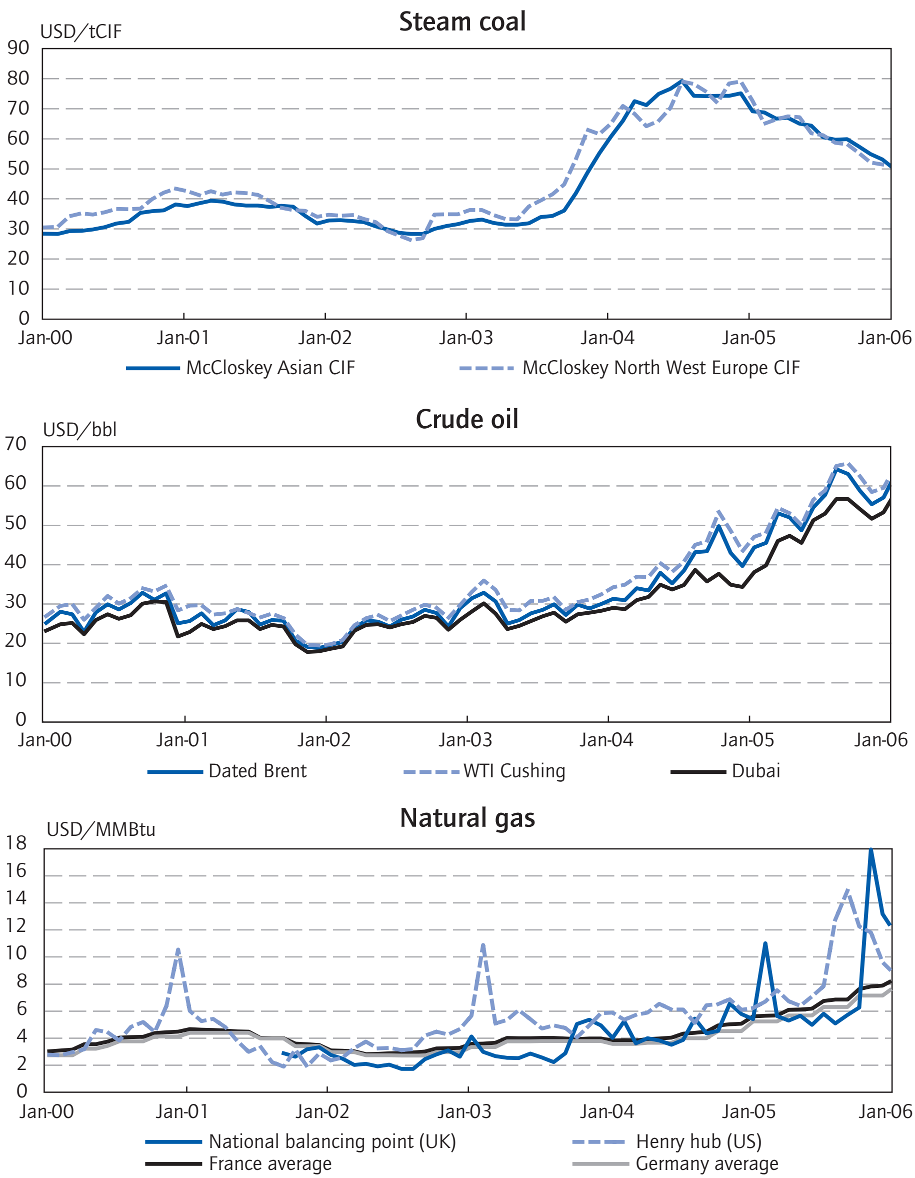
* Residential, commercial, public services and agricultural sectors.
Source: IEA Statistics.

prices also shown in Figure 7 fluctuated between USD3 and USD8/MMBtu over 2000-2006. McCloskey Steam coal index prices for Europe and Asia also reflect significant movements. Prices more than doubled in five years from approximately USD30/tCIF in 2000 to USD60/tCIF in 2006, with peaks close to USD80/tCIF during the second half of 2005.

In the case of transportation, 95% of global transport demand is met by oil to power vehicles for road transportation purposes. The crude oil price increase led to an important rise in motor fuel prices across the OECD. This triggered a reduction in demand but did not lead to any significant fuel switching. Indeed, other modes of transport exist, such as rail and waterways, yet none provide the flexibility offered by road transportation for which extensive and far reaching road and refuelling networks have been developed. Other fuels, to the extent that they are used by other modes of transport, cannot be considered as potential substitutes as they do not provide the same level of service as oil does through road transportation. The only potential substitute to oil in the short-term is

Figure 7

Average monthly fossil fuel prices, 2000-2006



(1) Crude oil prices – *Source*: Platt's. *Note*: Benchmark crude oil spot prices.
(2) Gas – *Source*: Platt's; Energy Intelligence Group. *Note*: Average prices for France and Germany are border price estimates.
(3) Steam coal – *Source*: McCloskey. *Note:* CIF prices include insurance and transport.

biofuels. Ethanol can be blended with gasoline in modern conventional vehicles without any modification to engines, for up to 10% of the fuel input. Similarly biodiesel can be blended with, or totally substituted for diesel in conventional diesel engines (IEA, 2004b). Globally, however, existing production capacity is limited and infrastructures to bring biofuels to the market on any large scale are not in place. In the short- to medium-term therefore, biofuels cannot be considered as a significant substitute for oil.

With regard to electricity and heat generation, neither can be cost-effectively stored in any meaningful volume. Different plant types therefore have very different purposes. Oil-fired plants, for example, are predominantly used as peaking plants – *i.e.* over a short period of time to serve peak demand – and have a different purpose than say coal plants which are predominately used as base load generators. Peak and base load generation may be considered to constitute different markets and one may argue that within these specific uses fuel substitutability exists. For example, coal and gas can be considered to serve similar purposes and are therefore potential substitutes. Yet, in the short- to medium-term, the potential for substitutability depends on the availability of spare capacity and on multi-fuel generation capacity. Depending on the time of year, there may be some spare capacity in the market, but this is not necessarily the case. When markets are tight, substitutability opportunities are limited as plants operate close to full capacity to serve demand.

Similarly, while multi-fuel generation capacity can be significant in OECD countries, fuel switching costs are important and it is only with a large fuel price differential that this can be considered a viable option. This occurred during the second half of 2005 in the US when, following hurricane damage on natural gas and oil installations in the Gulf of Mexico, gas prices soared, leading to significant switching from gas to fuel oil by utilities and industries with dual-fuel capacity. However, these were exceptional circumstances. Substitutability in multi-fuel generation plants should not be assumed to be of significant importance if HMT is considered under less extreme circumstances. The same is also true for most industrial processes. Alternatives which rely on different input fuels exist in many industrial processes. Yet the flexibility to switch is bound to important price differentials over significant timeframes.

Based on this assessment it seems that while fuel substitutability is possible in some sectors, due to technological and infrastructural constraints this remains limited in the short- to medium-term, particularly in times of high demand and limited spare capacity. The three fossil fuels will therefore be considered as the sole “products” in separate markets.

With regard to the geographic boundaries of these markets, much depends on existing infrastructures and trade. In the case of oil, physical infrastructures are well developed and freight costs are sufficiently low to allow global trade. This is reflected in price movements (Figure 7) which show a high degree of correlation between benchmark crude oils from the Gulf of Mexico (WTI Cushing), North Sea (Dated Brent), and Middle East (Dubai). A global oil market can therefore be assumed in the analysis.

Physical infrastructures are also in place to allow global coal trade. Due to the importance of freight costs, however, physical trade takes place predominantly in two separate spheres: an Atlantic sphere, including Europe, Mediterranean countries, and North, Central and South America, and a Pacific sphere which mainly serves Asian countries. [23] In the case of steam coal, the volume of trade between these two geographic areas in 2004 is estimated at just under 7% of total maritime trade[24] (RWE, 2005) yet due to the role of South Africa, which supplies mainly the Atlantic market but can also supply the Pacific market, prices on both markets are largely synchronous. This is reflected in price indices for North West Europe and East Asia (Figure 7). For this reason our analysis considers the coal market to be global.

For gas, infrastructural limitations are much more significant. Gas trade is predominantly pipe-based and therefore regional in scope. Major demand regions correspond to the OECD regions: North America, Europe, and Asia Pacific. Nevertheless, the emergence of Liquefied Natural Gas (LNG) as a new and increasingly important means of gas transport is progressively changing the geographic boundaries of gas markets. In the past, high LNG production and transport costs limited the scope of interregional trade. However, costs have reduced substantially in recent years and LNG is starting to emerge as a link between the various regional markets. A few liquefaction plants built recently are notably supplying all three markets described above. As highlighted in the IEA Natural Gas Market Review 2006 “Competition for the few uncontracted ships (spot cargoes) is on a global scale. Since LNG is the marginal supplier in some markets, it means that the three previously separated markets are beginning to

23. This distinction in physical trade exists mostly in the case of steam coal. In contrast, coking coal is traded globally.

24. Maritime trade accounts for 90% of total global hard coal trade (RWE, 2005).

be exposed to each other." (IEA, 2006a, p.21). In the case of gas, therefore, the market boundaries considered in this analysis will evolve as LNG infrastructures develop. Details of gas market boundaries are discussed in more depth in the case studies presented in Section 4.

Measuring market power in the scope of energy security analysis

A measure of market concentration in each fossil fuel market is at the heart of the proposed approach to quantify the price component of energy security. However, a number of modifications need to be made to reflect the specific nature of energy security concerns. We distinguish two elements in the analysis:

- The characterisation of energy security risks through a modified measure of market concentration, referred to here as Energy Security Market Concentration (ESMC).
- The exposure of a given country to such energy security risks. This element is considered through the definition of an Energy Security Index (ESI).

Energy Security Market Concentration (ESMC)

The basis of the Energy Security Market Concentration measure is the Herfindhal-Hirschman Index (HHI), equal to the sum of the square of the individual market shares of all the participants. As discussed previously, HHI is a well established measure of market concentration commonly used by governments as a tool to assist them in determining market power.

In the context of this analysis, the market participants are considered to be countries. Arguably, private companies, which play an essential role in fossil fuel markets, could be considered as the market participants. However, governments ultimately have control over the level of exploitation of their natural resources.[25] From a security perspective, therefore, a country level approach seems best suited.[26]

The question now is to define on what basis the market shares of each country should be measured. As mentioned, while the uneven distribution of energy resources is the cause of the energy security concern we are interested in, it is only

25. In fact, in the case of oil and gas, approximately 80% of reserves are operated by state-owned companies.

26. Due to the unique level of integration of Canada and the US in the field of Energy through the North American Free Trade Agreement (Chapter 6) these countries are considered jointly in this analysis.

through the physical development of the market that this concern materialises. Basing the measure of market shares on resources is therefore inappropriate.

With regard to using production or exports, much depends on how each is priced and on physical export capacity. Assuming the hypothetical case of unlimited trade capacity, if no price distinction is made between energy for domestic consumption and exports, then one should measure market shares based on total production. If, on the contrary, a distinction is made when pricing energy for domestic use and for exports[27], then this effectively means that not all domestic production is made available on the international market, and therefore exports should be used to measure international market shares.

However, in reality trade capacity is limited by infrastructures and, in the case of gas, contractual arrangements. Therefore the measure of market shares should reflect each country's real export potential. Using a measure of net export potential as the basis for the definition of market shares reflects both physical and contractual limitations and the available quantity on international markets, whether countries price domestic consumption differently from exports or not. Market shares should therefore be based on *net export capacity*. In other words, the total level of exports a country can physically put on the market.

For each fossil fuel *f*, therefore, the Energy Security Market Concentration measure (ESMC) in the market is defined by (1):

$$ESMC = \sum_i S_{if}{}^2$$

Where S_{if} is the share of each supplier *i* in the market of fuel *f* defined by its net export potential (S_{if} varies from 0 to 100 percent). Values of ESMC as defined in equation (1) vary between zero, which signifies a perfectly competitive market, and 10 000 for a pure monopoly. A higher ESMC value, therefore, implies less energy security.

Additional modifications may also be considered. Yet while these can contribute to better account for the specificities of energy security concerns, the downside is that one loses in transparency, simplicity and balance. Integrating such ad-hoc

27. While the liberalisation of fossil fuel markets in OECD countries has led to the alignment of pricing policies in OECD countries, this is not necessarily the case in other countries. In fact most resource rich countries have different pricing policies for domestic use and exports. Russia, for example, which holds the largest natural gas resources in the world, has historically maintained a very significant price differential between gas used for domestic consumption and for exports. Similarly, according to the World Bank, Iran, which holds the third largest proven oil reserves, and the second largest natural gas reserves, maintains the highest energy subsidies in the world (World Bank, 2003).

factors inevitably raises questions as to the relative importance given to each. We therefore focus on a core measure of market concentration as outlined above.

However, in a second instance we consider the inclusion of one additional factor which seems of particular importance: political stability. Indeed, in addition to being geographically concentrated, energy resources are also often located in politically sensitive areas of the world. This fact plays an important role when measuring the energy security implications of resource concentration as it affects the reliability of countries as trade partners. Energy sector operations may notably be affected by civil unrest. Over the past few years, for example, strikes have affected output in a number of oil producing countries, including most prominently Nigeria and Venezuela, with sometimes significant adverse effects on oil prices. The political stability of a country may also reflect the likelihood that its government abuses the country's position in the market (large share of the market in ESMC).

In order to account for political stability when measuring the energy security implications of resource concentration in a given fossil fuel market, the measure of ESMC as defined in equation 1 can be modified in the following way (2):

$$ESMC_{pol} = \sum_i (r_i * S_{if}^2)$$

Where r_i is the political risk rating of country *i*. The inclusion of this parameter should scale up market concentration risks when market participants are considered politically unstable. The extent of the scale-up then reflects the importance given to political stability when considering concerns linked to resource concentration. We consider a case here were *r* ranges from 1 to 3. In other words that the worst possible level of political stability leads to a tripling of the country's contribution to ESMC and the best does not affect the country's contribution. $ESMC_{pol}$ therefore ranges from 0 for perfect competition amongst countries with the best level of political stability to 30 000 for a pure monopoly of a country with the worse level of political stability. Any range of *r* could be selected depending on the importance given to political stability in measuring $ESMC_{pol}$. The main objective here, however, is simply to compare ESMC and $ESMC_{pol}$ in the three fossil fuel markets. An illustrative case such as the one chosen is therefore appropriate.

A number of potential political stability ratings can be used. In the scope of this study we chose to base our analysis on the World Bank's Worldwide Governance Indicators. These use a transparent methodology first developed in the late 1990s and which has continually been revised and improved. It is based on a statistical aggregation of a large number of survey responses on the quality of governance in OECD and developing countries compiled by survey institutes, think tanks, non-governmental organisations and international organisations (World Bank, 2006). Also, indicators are devised for over 200 countries which suits the broad country-level analysis proposed here.

The Governance Indicators assess six dimensions of governance through six separate indicators. Two of these are of particular interest from an energy security perspective:[28]

- "Political Stability and Absence of Violence" measures perceptions of the likelihood that the government in power will be destabilised or overthrown by possibly unconstitutional and/or violent means, including domestic violence and terrorism.
- "Regulatory Quality" measures the incidence of market-unfriendly policies such as price controls or inadequate bank supervision, as well as perceptions of the burdens imposed by excessive regulation in areas such as foreign trade and business development.

These indicators are defined on an annual basis and range from about –2.5 and +2.5 with high values indicating better governance performance. A percentile ranking is also available. In order to consider both dimensions of interest we use a composite governance indicator based on the average of the two[29] which we then scale to our chosen range for r (1 to 3). With this approach, our composite governance indicator ranges from 2.99 in the case of Somalia to 1.02 in the case of Finland and Luxembourg. The OECD average is 1.38 while OPEC countries average 2.31.

Importantly, in the case studies presented in the next section we assume that composite governance indicator remains constant over the 2004-2030 timeframe. Although this is obviously inaccurate it is difficult if not impossible to predict how governance will change in the future. The methodology, however, allows one to run different scenarios and see quantitatively how $ESMC_{pol}$ would be affected by given changes in the different components of the index used.

28. Source: Kaufmann *et al.* (2006). More information on the World Bank Governance Indicators at: www.govindicators.org.
29. To avoid giving too much importance to events in a specific year we consider the average of the 2002 to 2005 yearly values.

Energy Security Index $_{price}$ (ESI_{price})

The measures of ESMC or $ESMC_{pol}$ characterise the price component of energy security in fossil fuel markets due to resource concentration. A country's exposure to these resource concentration risks, however, depends on the role of that fossil fuel in the country's economy. While a detailed assessment would require a sectoral appreciation of the role of each fuel, we can simply account for this by multiplying $ESMC_{pol}$ with the fuel's share of the country's mix. In other words we multiply the country's dependence on a given fuel by our characterisation of the resource concentration risk.

An Energy Security $Index_{price}$ (ESI_{price}), which sums the products of $ESMC_{pol}$ for each fuel times the share of the fuel mix exposed, can be compiled as follows (3):

$$ESI_{price} = \sum_{f} \left[ESMC_{pol\text{-}f} * C_f / TPES \right]$$

Where $C_f / TPES$ is the share of the fuel mix and $ESMC_{pol\text{-}f}$ is the Energy Security Market Concentration of the international market for fuel *f*.

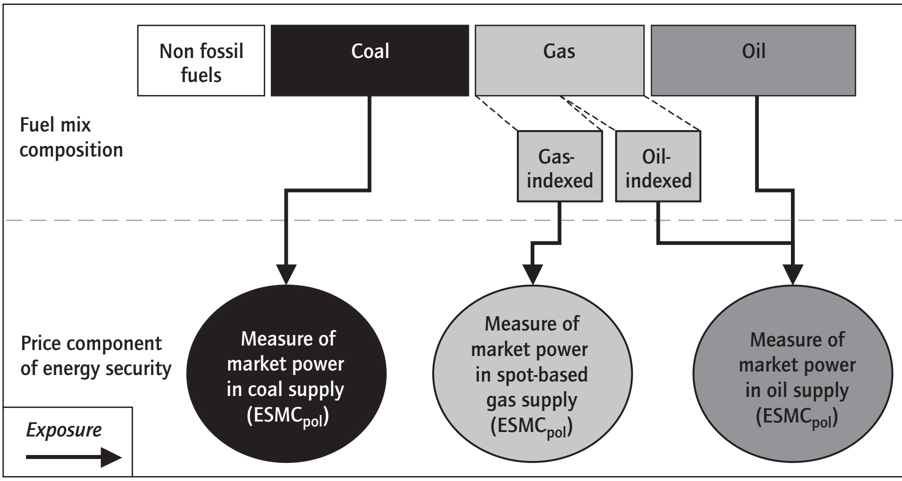
In the case of gas, however, the situation is a little more complicated as much depends on whether gas prices are set competitively or indexed to oil. When natural gas prices are set competitively, this is straightforward as in the case of oil and coal. In the case where gas is indexed to oil, however, it is effectively susceptible to the energy security price risk in the oil market. In this case therefore, the gas share of the fuel mix should also be exposed to the oil market price risk. It should be noted that in some cases in Europe, the gas market is partly based on oil-indexed contracts and partly spot-based. In such cases the share that is spot-based is exposed to gas market $ESMC_{pol}$ while the share that is oil-indexed is exposed to oil market $ESMC_{pol}$. This process is schematised in Figure 8 below. In equation 3 above, therefore, for coal, $C_f / TPES$ is simply the share of coal in the mix. In the case of oil and gas, much depends on how the gas market is structured.

When considering a country's exposure to market risks, another important aspect needs to be addressed: how to consider a country's own share of the market in measuring ESMC and $ESMC_{pol}$. Indeed, if a country is a net exporter and has an important share of the market it may be in a position to influence the market price. As a result, is it exposed to a different market risk than, say, a country with no export potential and a zero share of the market?

The answer to this question is in fact quite complex. If a country is a large net exporter then prices set above the competitive level would lead to an enhanced revenue stream. From a consumer welfare perspective, however, much depends on

FIGURE 8

Measuring the price component of energy security



the magnitude of this revenue stream and on wealth redistribution policies. In a case where there are no wealth redistribution policies, a price increase would not benefit consumers and therefore the market risk should be considered the same as a country with no share of the market. If, on the contrary, a country has an effective wealth redistribution policy then the risk on the market should be considered less than a country with no share of the market. For simplicity however, and as a precautionary stance, we assume here a single market risk, irrespective of a country's own position on the market.

Measuring the physical availability component of energy security

The risks of physical unavailability are of greatest concern where prices do not reflect market fundamentals, as in such cases the price effect is unable to contribute to balance demand and supply in response to a supply shortfall.

In most OECD Europe countries, the vast majority of demand is met by long-term import contracts indexed on crude or oil-products. This is also the case in Japan and Korea, though the linear relationship is broken by a floor and ceiling arrangement often referred to as an "S-curve" (IEA, 2006a). In these cases, therefore, gas price movements do not reflect gas market supply and demand on the market.

Imports to European countries are predominantly, and in many cases entirely, pipe-based due to the proximity of large resources within a short distance (Figure 9). In contrast, due to geological and geographical constraints, the gas industry in Japan and Korea has developed entirely based on LNG import infrastructures.[30] Due to the differing inherent flexibility of LNG- and pipe-based trade, a distinction should be made between these modes of transport when assessing the physical unavailability component of energy security.

- **Pipe-only based trade:** In the case of pipe-based oil indexed contract between two countries a supply shortfall cannot be easily compensated for by other supplies. Generally, the importing country cannot use the same infrastructure to import from other sources, as a pipeline tends to tie a customer to a given supplier. If the country has access to other import pipes then it may be able to compensate for some of the lost supply though this is highly uncertain. Spare capacity availability generally depends on the time of year with no or very limited spare capacity during periods of strong demand (*e.g.* winter peak). Also, supplier countries may not be able to increase production to compensate for a supply shortfall in recipient countries as their export infrastructure may also be operating at maximum capacity. Finally, much depends on infrastructures and available capacity to transport the gas from one import pipe network to another.
- **Pipe- and LNG-based trade:** If the importing country also has access to spot cargoes thanks to LNG infrastructures, much depends again on physical availability constraints. It will only be able to increase LNG imports to compensate for a supply shortfall from pipe-based imports if there is available capacity at the regasification terminals and throughout the gas network linking the LNG terminal and the import pipe.
- **LNG-only based trade:** In the event of a supply shortfall, the country to which the LNG cargo was destined has the opportunity to use the freed liquefaction capacity to import LNG from elsewhere. The country would most likely look at LNG spot cargoes to replace lost volumes. Unlike the case of pipe-based oil indexed contracts, there is, in theory, no capacity constraint and physical unavailability risks are limited. In reality tanker availability may be an issue, yet as LNG trade volumes increase this should become less and less of a problem.

30. A number of pipelines are currently planned or under construction to import Russian gas to both Japan and Korea.

FIGURE 9

Gas infrastructure in Europe

The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the IEA.

Due to the relative inflexibility of pipelines, therefore, physical unavailability concerns in gas are predominantly linked to pipe-based imports. We therefore propose to consider the share of a country's total energy demand met by pipe-based gas imports purchased through oil-indexed contracts as the measure of the physical availability component of energy security. An Energy Security Index$_{volume}$ (ESI_{volume}), expressed in percentage, can therefore be defined as (4):

$$ESI_{volume} = Pipe\ Imp\ (gas)_{oil\text{-}indexed} / TPES$$

Where $Pipe\ Imp\ (gas)_{oil\text{-}indexed}$ is the net imports of gas via pipeline purchased through oil-indexed contracts.

ESI_{volume} therefore ranges from 0 in the case of either a fully liberalised gas sector (*i.e.* 100% gas-based pricing), no pipe-based imports (*i.e.* 100% LNG), or 100% self sufficiency in gas (*i.e.* no imports), to 100 in the hypothetical case of 100% oil-indexation gas consumption, 100% pipe-based import dependence and a fuel mix 100% based on gas.

With the inclusion of this measure of the physical availability component of energy security, our overall approach to quantitatively assess the energy security implications of resource concentration can be summarised as shown in Figure 10.

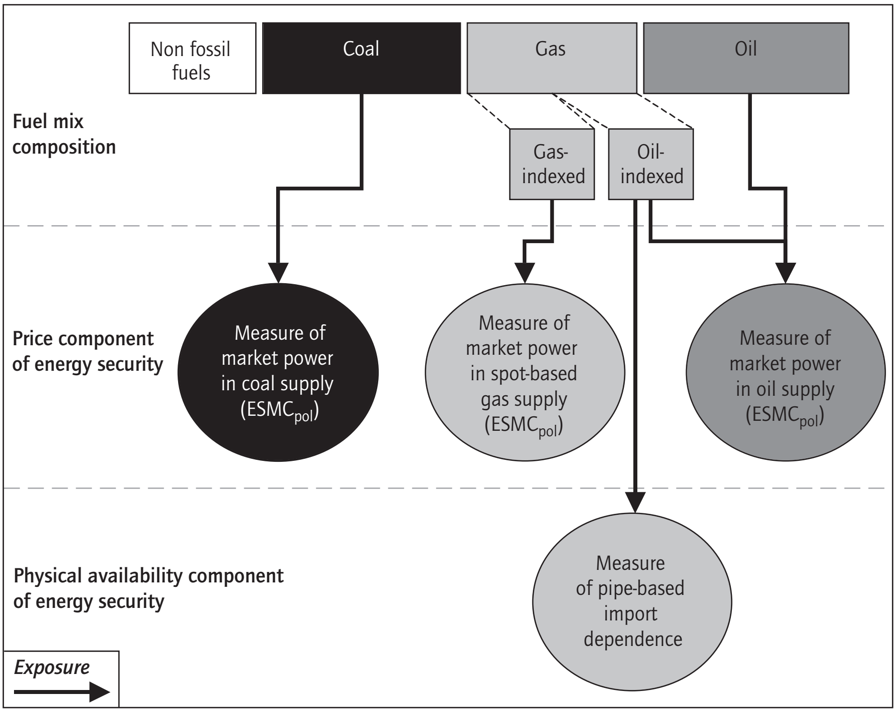
Summary

We propose two new indicators which specifically focus on measuring the evolution of resource concentration as an energy security concern. These indicators follow the distinction made between the price and the physical availability components of energy security.

A measure of the price component of energy security is useful in markets where prices are allowed to adjust in response to changes in demand and supply. In such cases the risk of physical unavailability occurring are reduced to extreme events and the price component is the prevailing energy security concern. The international oil and coal markets can be included in this category. The indicator – ESI_{price} – is based on a measure of market concentration – $ESMC_{pol}$ – in each fossil fuel market. It factors the exposure of a given country to each of the market concentration levels. The more a country is exposed to high concentration markets the less it is secure.

Figure 10

Quantifying the energy security implications of resource concentration



A measure of the physical unavailability component of energy security is useful in markets where prices are regulated or pegged to other commodities. In such cases the price effect cannot contribute to balance demand and supply. Physical unavailability is therefore the principal concern. The gas markets in most European countries and in several Asian countries fall into this category. This indicator – ESI_{volume} – focuses on pipe-based gas trade. For a given country it is a measure of the share of total energy demand met by oil-indexed pipe-based gas imports. The higher this share, the less the country is secure.

As gas is often indexed to oil, in addition to a risk of physical unavailability occurring, gas consumption is also exposed to the price risk of the oil market. Gas therefore links the price and physical availability components of energy security.

ENERGY SECURITY AND CLIMATE CHANGE POLICY DRIVERS: A REFERENCE SCENARIO

The previous sections describe the approach based on indicators defined to jointly assess energy security and climate change mitigation policies. Table 1 summarises

Table 1

Climate change mitigation and energy security indicators: summary

Policy driver	Climate change mitigation	Energy security implications of resource concentration	
		Price component	Physical availability component
Indicator name	Energy related emissions	Energy Security Index $_{price}$ (ESI_{price})	Energy Security $Index_{volume}$ (ESI_{volume})
Description	CO_2 emissions from the production, transformation and use of energy	ESI_{price} is a composite measure of the Energy Security Market Concentration (ESMC) in each fuel market. A modification can be made to account for the political stability of exporting countries. ESMC is based on a measure of market concentration of suppliers based on their net exports to the international market.	ESI_{volume} is a measure of the level of pipe-based import dependence in oil-indexed contracts.
Inputs	Primary energy consumption of fossil fuel Emission factor of each fossil fuel	Share of each fuel in the total primary energy supply of the country for which the analysis is being carried out. In the case of gas the share of gas demand met by oil-indexed contracts is also necessary. Net export potential of all suppliers in each fossil fuel market. In the case of gas this should only include exports available on the spot-based market.	Share of gas demand met by oil-indexed contracts Share of imports from pipeline.

the three measures adopted. In this section we apply the approach to five countries which have volunteered to participate in this analysis as case studies of energy security and climate change policy interactions: the Czech Republic, France, Italy, the Netherlands, and the United Kingdom. The first step is to assess how the indicators evolve following a reference scenario to 2030. The second step, presented in the next section, will be to consider a number of policy cases to assess the level of interactions between climate change and energy security.

This section starts by looking at the fuel mix composition of each case study country in 2004, the base year of our analysis, before observing reference case projections to 2030. The evolution of energy-related emissions will then be assessed as well as ESMC in the coal, oil, and gas markets and finally ESI_{price} and ESI_{volume} will be calculated for each case. This will allow a joint assessment of energy security and climate change mitigation policy trends which will form the basis of the policy assessment presented in Section 5.

As detailed in Box 2, the data used in this reference scenario analysis is a compilation of data provided by case study countries and of data extrapolated from regional projections from the *IEA World Energy Outlook 2006* reference scenario (IEA, 2006c).

Fuel mix

The projected trends in the evolution of the fuel mix in the five case study countries considered are shown in Figure 11. In 2004, France has the largest Total Primary Energy Supply (TPES) of the five case study countries (281 Mtoe) followed by the UK (233 Mtoe), Italy (181 Mtoe), the Netherlands (81 Mtoe) and the Czech Republic (47 Mtoe). In the case of Italy, France, the Netherlands and the UK, TPES grows progressively in the coming decades following a reference scenario. Italy is the country with the largest projected TPES growth with an increase of 37% by 2030. Projections for the Netherlands show an increase of 31% by 2030 while France's TPES is projected to grow by 21% by 2030. The UK, which only projects energy trends to 2020, foresees a growth in TPES of 13% in this timeframe. In the Czech Republic, TPES is expected to remain stable to 2010 before reducing slightly and stabilising.

The composition of the fuel mix varies significantly in the five case study countries. In 2004, the share of oil ranged from a minimum of 21% in the case of the Czech Republic to 46% TPES in the case of Italy. The share of gas ranged

Box 2
Data compilation for reference case analysis to 2030

The measure of $ESMC_{price}$ in each fossil fuel market is based on a measure of the net export potential of countries and therefore requires information on total available export capacity. Due to the difficulty of projecting such data we assume that the export potential of a country is equal to its net exports as defined by:
Net Exports = Total Production – Total Consumption.

For the case study countries, government projections for production and consumption following a reference scenario are used. For all other countries, 2004 statistics collected by the IEA are used as the starting point. Regional trends from the IEA World Energy Outlook *(WEO) reference scenario projections (IEA, 2006c) were then applied to the 2004 data in order to define data for 2010, 2020 and 2030. When available, country level data from the WEO was used. In the case of gas, a more refined approach was used to define country level trends based on observations of remaining reserves. Whenever possible, country level projections were fine tuned by export review. Apart from data used for the five case study countries, the data used in this study are not based on a rigorous modelling exercise nor do they necessarily represent the official view of the IEA or of the countries concerned. These case studies should be considered as illustrative for the analysis presented in this report.*

Data on the evolution of the rest of the fuel mix over the 2004-2030 period for the case study countries is also based on government projections.

Other, more specific assumptions used in this section are referred to in the text.

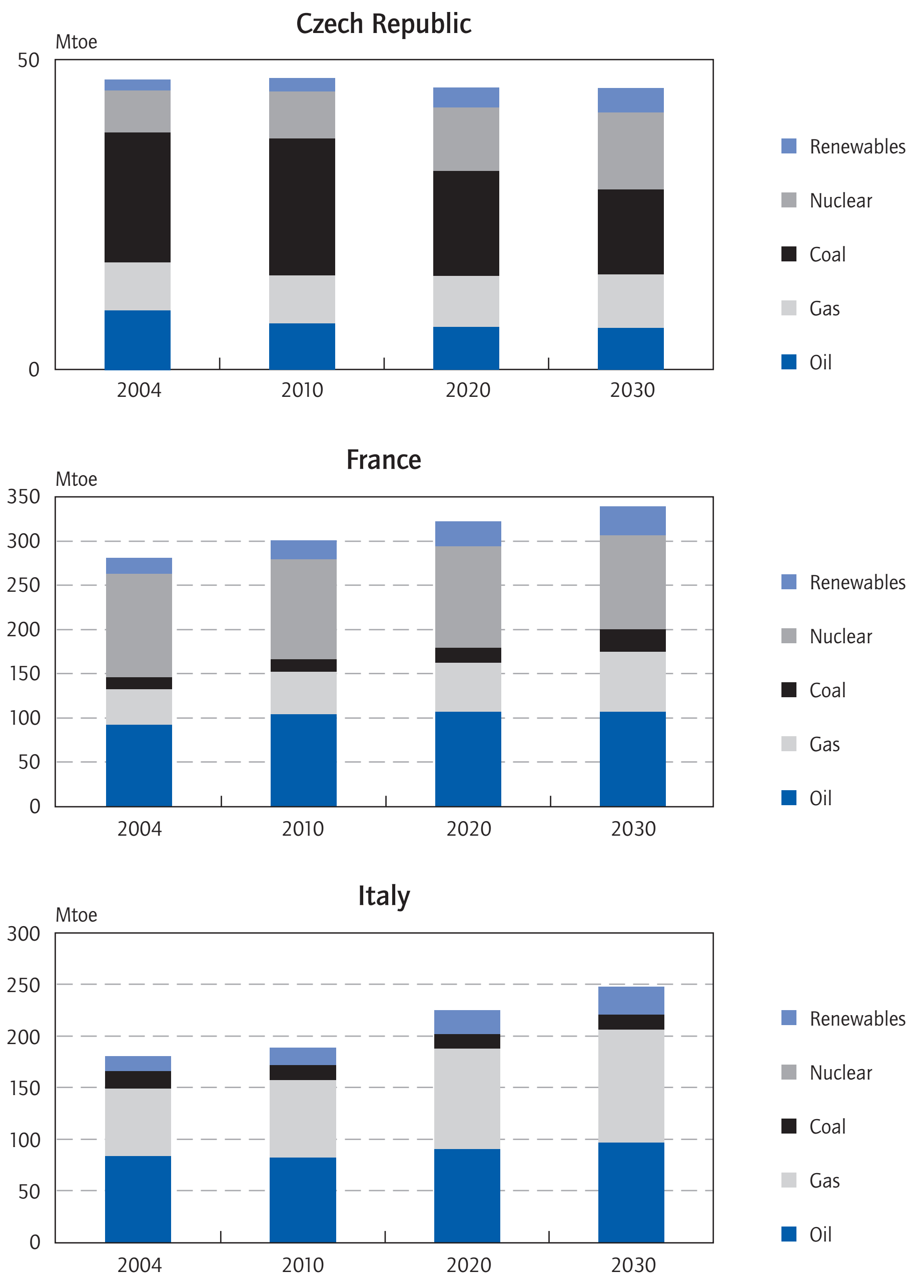
from a minimum of 14% for France to a maximum of 45% for the Netherlands. The share of coal ranged from a minimum 5% in France to nearly 45% in the Czech Republic. Nuclear ranged from zero in Italy to 42% in France. Finally, renewables accounted for between 2% of TPES in the UK to 8% in Italy.

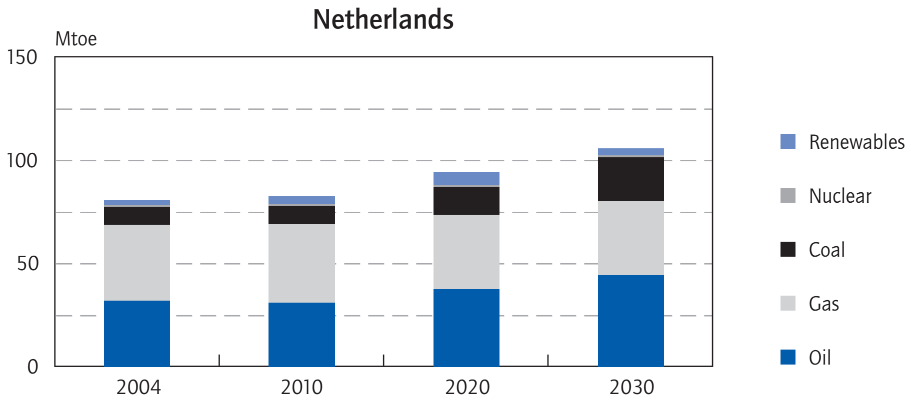
Oil consumption is expected to grow in absolute terms in all countries, except the Czech Republic (29% drop). Its share of the fuel mix, however, falls between 2004 and 2030 in Italy (by 7%), the Czech Republic (by 6%) and France (by 1%), while it grows in the UK (4% by 2020) and the Netherlands (3%).

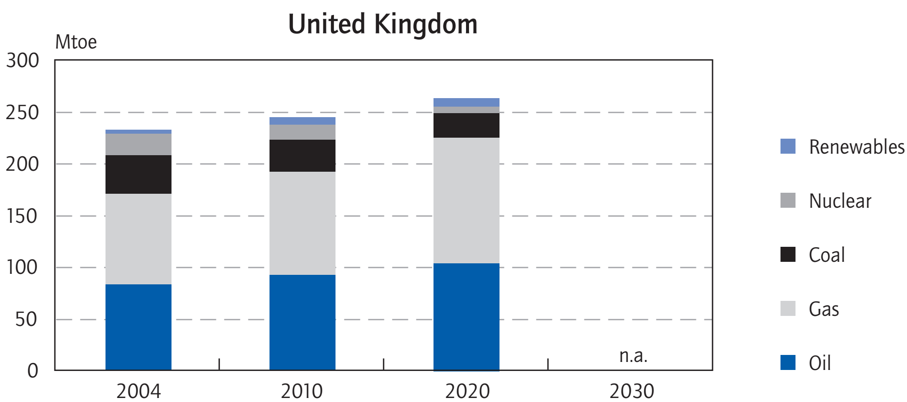
Gas consumption is also expected to grow in all cases except the Netherlands (3% reduction). The largest growth takes place in France (68% increase) and Italy (76%

Figure 11

TPES and fuel mix composition, 2004-2030







increase). This is reflected in the gas share of TPES which also grows significantly reaching 20% and 44% of total by 2030 in France and Italy respectively. The Netherlands is the only country where the gas share of TPES drops.

The largest projected rise in coal consumption occurs in the Netherlands (145% increase) and France (79% increase). Even though coal consumption is expected to drop by 35% in the Czech Republic, it remains the country where coal represents the largest share of TPES (30% in 2030). The share of coal drops in the UK and Italy to 9% of TPES by 2020 and 6% of TPES by 2030 respectively.

In France, by far the largest producer of nuclear energy out of the five countries considered, energy consumption from nuclear drops by 9% between 2004 and 2030. Nuclear, however, still accounts for 31% of the fuel mix in 2030. In the UK, nuclear power is expected to drop by 70% between 2004 and 2020, representing just 2% of the mix from 9% in 2004. In contrast, the Czech Republic will see a large growth in nuclear energy between 2004 and 2030 which is expected to account for 28% of the mix in 2030.

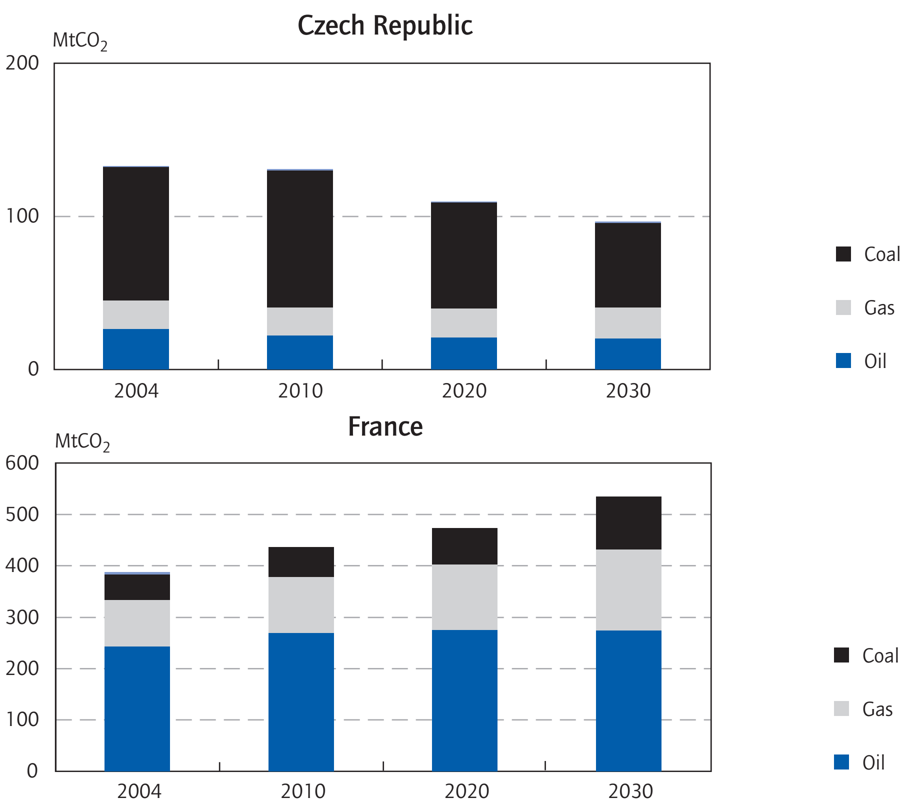
Although consumption of renewables is expected to grow significantly in all countries, France and Italy are the countries where renewable energy plays the most important role throughout the 2004-2030 timeframe. By 2030, renewables are expected to represent respectively 10% and 11% of the total in these countries.

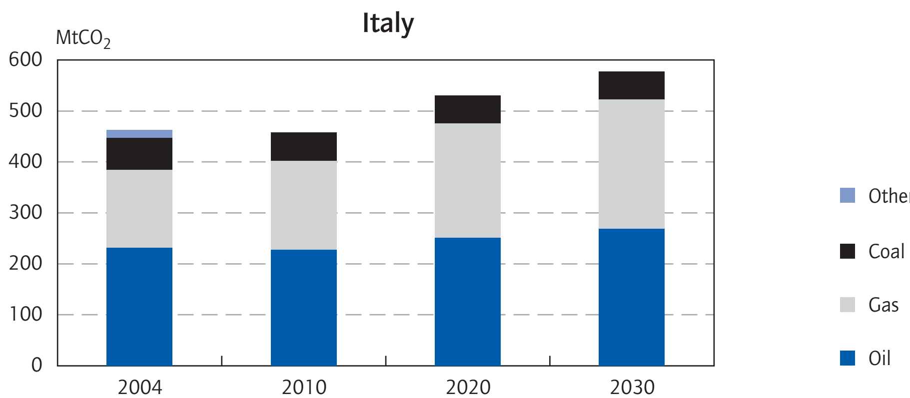
Carbon dioxide emissions

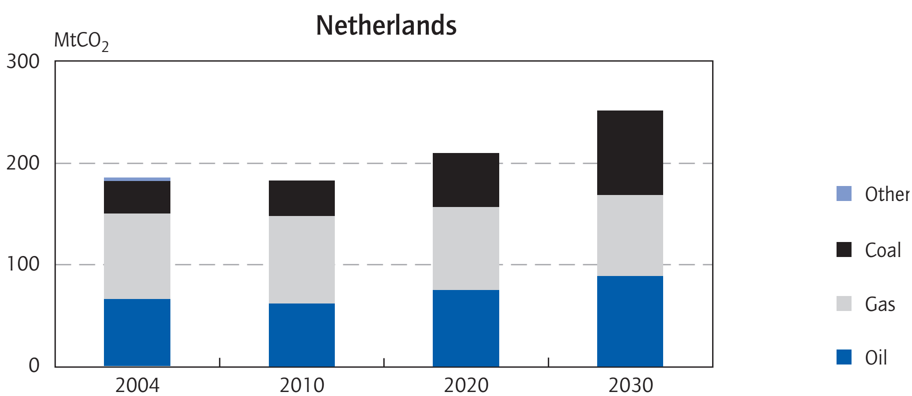
Figure 12 shows the evolution of total energy-related CO_2 emissions as well as the contribution of each fossil fuel for the five case study countries. In 2004, the largest emitter out of the five case study countries is the UK (537 $MtCO_2$) while the smallest is the Czech Republic (133 $MtCO_2$).

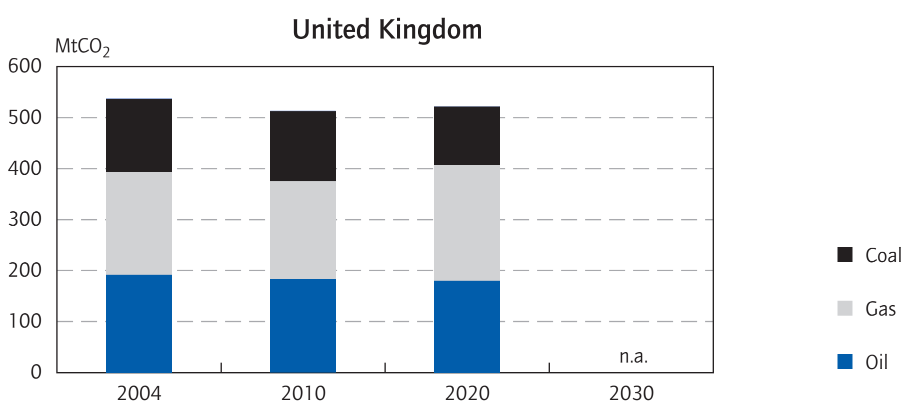
FIGURE 12

Energy-related CO_2 emissions, 2004-2030









Following the projected fuel mix developments discussed above, energy-related emissions should grow between 2004 and 2030 by 38% in France, 36% in the Netherlands and 25% in Italy. Emissions in the UK are projected to drop by 3% between 2004 and 2020, while emissions in the Czech Republic are projected to drop by 27% by 2030.

In France, the rise in both coal and gas consumption drives the rise in emissions while in the Netherlands the growth in coal consumption is the main factor affecting future emissions. In Italy, emissions are driven by the projected increase in gas consumption. In the UK, the projected rise in emissions from growing oil and gas consumption is balanced by the reduction in coal demand leading to an overall reduction in emissions by 2020. In contrast, the important reduction in emissions in the Czech Republic is due to the significant projected reduction in coal consumption.

Price component of energy security

Energy security market concentration in the international oil market

One of the main issues when measuring market power in the international oil market is the treatment of OPEC countries. On the one hand, production quotas for each member country have been set since the early 1960s in a co-ordinated manner via OPEC. On the other, the effectiveness of this process is uncertain: defining and enforcing production quotas in a centrally co-ordinated manner is difficult, especially when oil revenues represent an important part of the economy. Quotas have not always been respected, especially in times of low world oil prices.

We therefore consider two alternative cases. The first considers OPEC as a single supplier to the international oil market while the second considers OPEC member countries as individual suppliers.

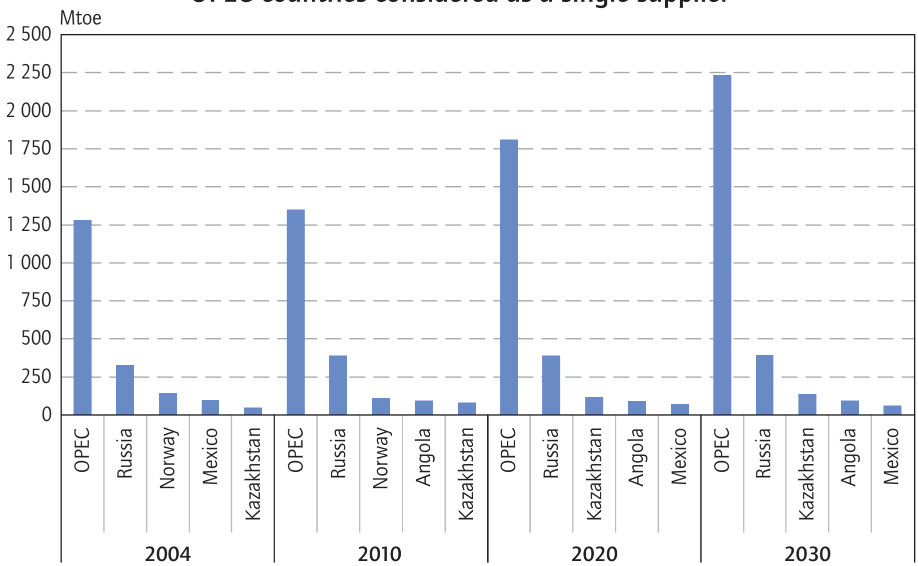
Figure 13 shows the five most important participants in the oil market in terms of their net export potential[31] in 2004, 2010, 2020 and 2030 in both the OPEC and non-OPEC case. Where OPEC is considered as a single participant in the market, its net export potential is by far the most important, representing in 2004 close to four times the level of Russia, the second largest participant. Over the 2004-2030 period the net export potential of OPEC is also projected to grow at a faster pace than most other market participants. It notably grows by close to 74% between 2004 and 2030 while in Russia the growth is only 20%. The combined export potential of the five most important participants in the market in 2004 represents 86% of the total with OPEC alone accounting for 56%. By 2030, this share increases to 88% of which 67% is accounted for by OPEC.

31. As detailed in Box 2, we assume export potentials are equal to net exports.

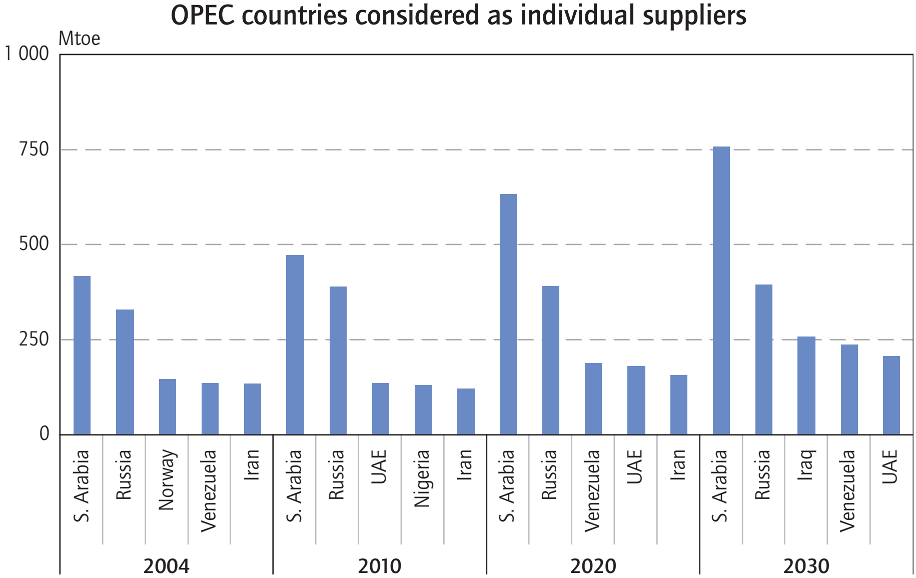
Figure 13

Export potential of the five largest participants in the oil market, 2002-2030

OPEC countries considered as a single supplier



OPEC countries considered as individual suppliers

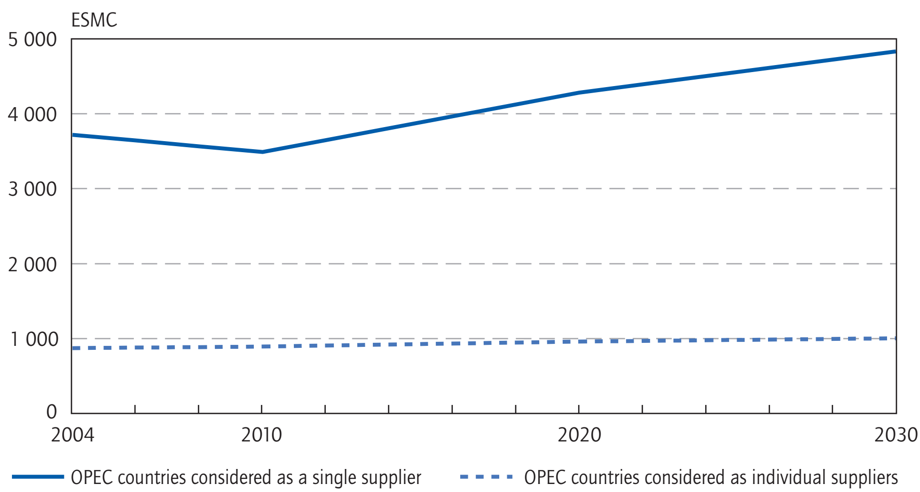


When OPEC countries are considered as individual suppliers to the market, Saudi Arabia has the largest export potential throughout the 2004-2030 timeframe. The gap with Russia, the second largest participant, is of course much smaller in this case though it grows at a faster rate than when OPEC is considered as a single participant. The five largest participants in this case represent approximately 52% of the total in 2004 and this share increases only slightly to 53% by 2030. Saudi Arabia's share grows from 19% in 2004 to 23% in 2030.

Figure 14 shows the evolution of ESMC in the international oil market in both the OPEC and the non-OPEC case. In 2004, when OPEC is considered as a single participant, ESMC is about 3700 while it is only 850 when OPEC countries are considered individually. In other words, the market concentration is over 4 times higher when OPEC countries are considered jointly than when they are not.

FIGURE 14

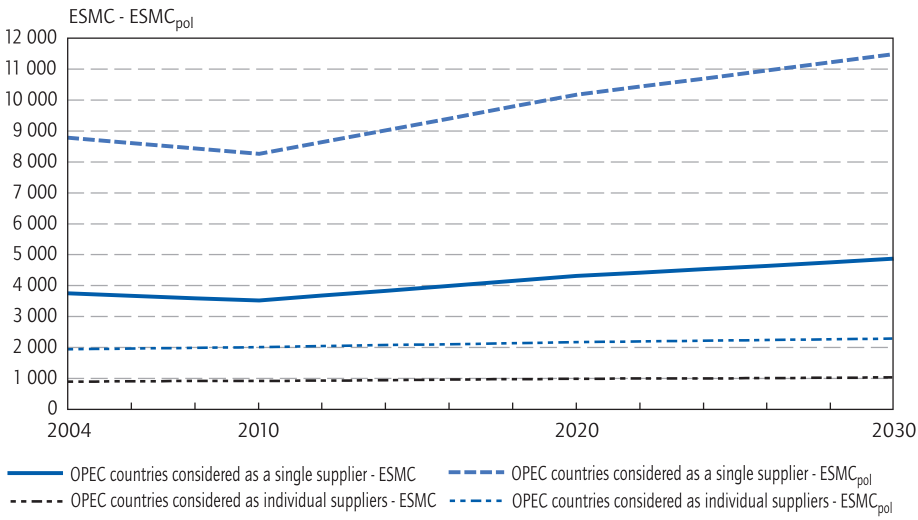
Oil market ESMC, 2004-2030



When looking at the 2004-2030 period, in both cases ESMC first drops between 2004 and 2010 before a significant and sustained rise, reaching approximately 4 810 by 2030 in the case where OPEC is considered as one, and close to 990 when OPEC countries are considered separately. This represents an increase in ESMC of 30% between 2004 and 2030 in the first case while only 15% in the second.

Figure 15

Oil market ESMC and $ESMC_{pol}$, 2004-2030



Finally, Figure 15 shows the impact of including the political risk rating *r* in the measure of ESMC. When OPEC countries are considered jointly, $ESMC_{pol}$ is at about 8 730 in 2004, which represents an increase of 136% compared to the case when political risk is not included. $ESMC_{pol}$ then increases to about 11 440 by 2030, 138% higher than ESMC.

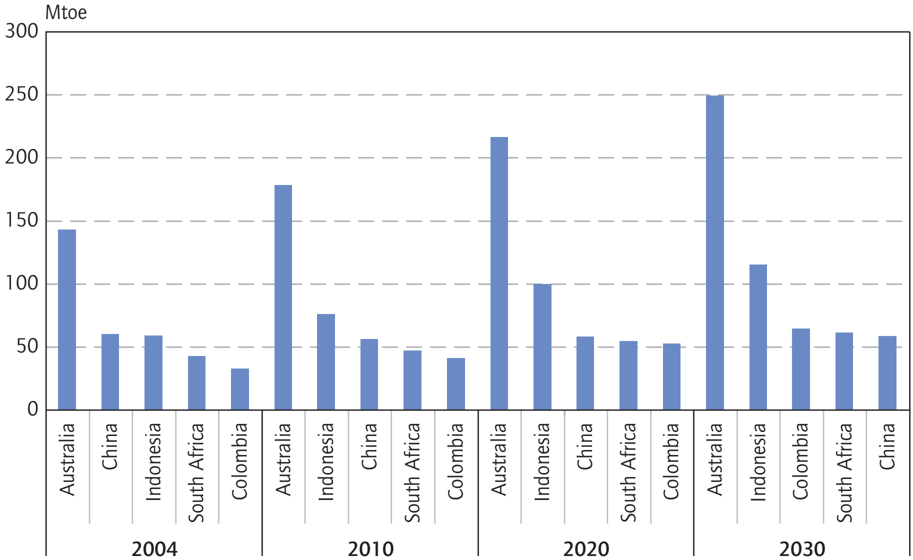
When OPEC countries are considered as individual participants in the market, $ESMC_{pol}$ is close to 1 780 in 2004, a value 122% higher than when political risk is not included in measuring ESMC. $ESMC_{pol}$ then grows to a value slightly over 2 000 in 2030, 125% higher than when *r* is not included. The slightly faster rise in $ESMC_{pol}$ compared to ESMC reflects the fact that the market concentration will shift slightly to less politically stable countries.

Energy security market concentration in the coal market

As in the case of oil, the coal market is considered to be global. Figure 16 shows the evolution between 2004 and 2030 of the five most important participants in the global market in terms of net export potential. The same five countries remain the largest participants in the market throughout the 2004-2030 timeframe, namely Australia, China, Colombia, Indonesia, and South Africa.

FIGURE 16

Export potential of the five largest participants in the coal market, 2004-2030



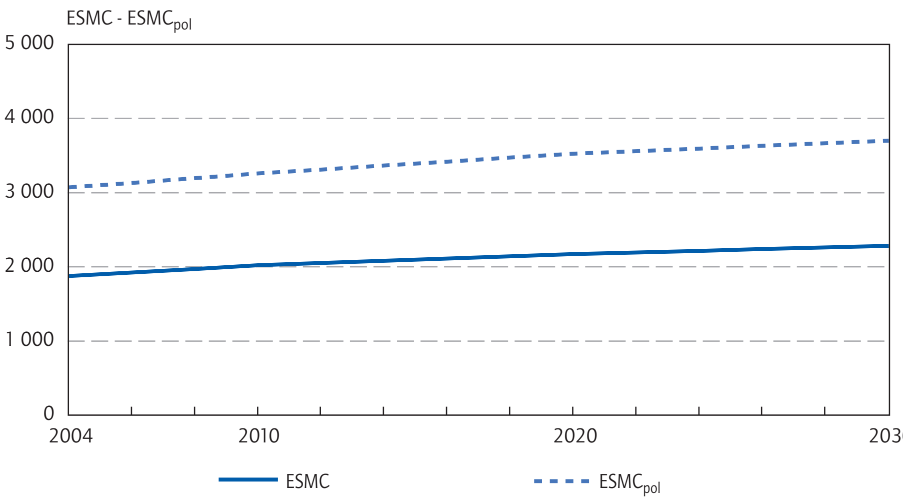
Australia is the largest net exporter in the market throughout the 2004-2030 timeframe. Its net export potential grows by 74% between 2004 and 2030. Indonesia and Colombia see their export potential almost double in the same time, while South Africa's grows by some 44% and China's drops slightly. The gap between the first and second position in the market grows slightly. Taken together, these five countries represent 83% of the global market in 2004 and this share increases to 88% in 2030.

Figure 17 shows the resulting evolution of ESMC and $ESMC_{pol}$ in the world coal market between 2004 and 2030. In 2004, ESMC is about 1 860 and reaches 2 270 by 2030, a 22% increase.

When the political risk rating *r* is included, $ESMC_{pol}$ is at approximately 3 050 in 2004, some 64% greater than ESMC. $ESMC_{pol}$ then grows to reach 3 680 in 2030, a value 62% higher than ESMC.

Figure 17

Coal market ESMC and ESMC$_{pol}$, 2004-2030



Energy security market concentration in the natural gas market

In North America, Australia and New Zealand, and to a large extent the UK, natural gas prices reflect the economics of gas supply and demand. In the case of the UK, it is estimated that approximately half of total gas demand is purchased on the market while the remaining half is based on long-term predominantly oil-indexed contracts.

Gas prices in these markets have tended to respond to regional if not domestic market dynamics. Nevertheless, LNG is now increasingly being used to transport gas over long distances and regional markets are starting to interact. This trend is likely to intensify and regional markets are likely to continue to be exposed to one another and ultimately constitute a single world gas market. While it is difficult to determine the pace at which this is likely to occur, we assume in this analysis that by 2010, price levels in different regions are reflected in the spot LNG price. In contrast, for 2004, we consider such price interactions to be limited to, on the one hand, Europe, Africa, the Middle East and Asia and on the other North, Central and South America. While African suppliers may not physically export to Asia, the Middle East exports to both Europe and Asia creating price linkages between these different regions.

The size of the market, however, depends to a large extent on what happens in Europe. While the European gas sector is for the most part regulated, the European Union has engaged in a process of gas market liberalisation. This may result in a progressive shift away from long-term oil-indexed contracts to transactions based on gas supply and demand, as has happened in North-America and the UK. However, due to the complexity of this and the importance of existing long-term oil-indexed contracts, this transition is uncertain and at best likely to be slow.[32]

To reflect this we consider two separate cases in our assessment of energy security. The first case considers that existing contractual arrangements based on oil-indexed prices remain the norm throughout the 2004-2030 timeframe. For simplicity we assume that these account for 100% of gas demand except in the case of the UK.[33] In the second case we assume that a growing share of demand in Europe will be met by volumes contracted on the market. We assume here a 1% annual increase in the share of demand met by gas-based transactions. Assuming that 100% of gas demand was met by long-term oil-indexed contracts in 2004, the share of demand purchased on gas-based terms in 2030 will be 26% for all European countries except the UK where the share of demand met by gas-based transactions rises to 76% (Table 2).

Table 2

Share of gas demand met by gas-based transactions

		2004	2010	2020	2030
United Kingdom	Case 1: no change in gas price structure	50%	50%	50%	50%
	Case 2: enhanced gas-based pricing	50%	56%	66%	76%
Other European countries	Case 1: no change in gas price structure	0%	0%	0%	0%
	Case 2: enhanced gas-based pricing	0%	6%	16%	26%

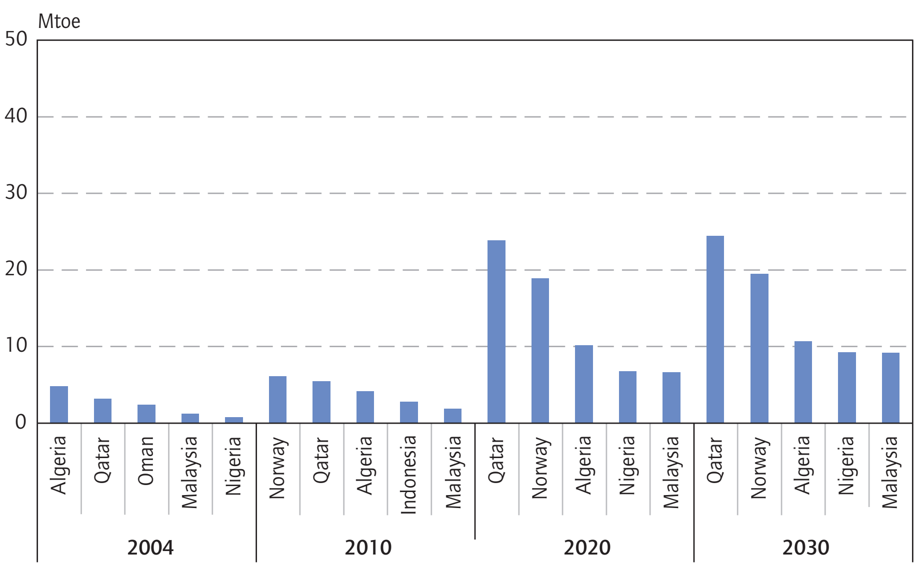
32. This process, which began 20 years ago in the UK, has resulted in approximately 50% market share today.
33. While some spot-based trades are already taking place in several countries aside from the UK, these represent a fraction of total contracted volumes and therefore this seems to be a workable assumption.

Case 1: No change in gas price structure in Europe

Figure 18 shows the five largest participants in terms of their net export potential in case 1. In 2004, the market is dominated by LNG exporters. Algeria is the largest participant representing 35% of the total. It is followed by Qatar and Oman who represent 23% and 17% respectively of the market. In 2010, Norway, the only pipe-based exporter among the top five in the market, is the most important participant. Norway then moves to second position from 2020 following Qatar.[34] In 2004, the five largest participants represent 90% of the total market. This value drops to 60% in 2010 as the market is diluted based on the assumed shift to a more global market structure. By 2030, the five largest market participants account for 54% of the total.

FIGURE 18

Export potential of the five largest participants in the gas market, 2004-2030
Case 1: No change in price structure in Europe

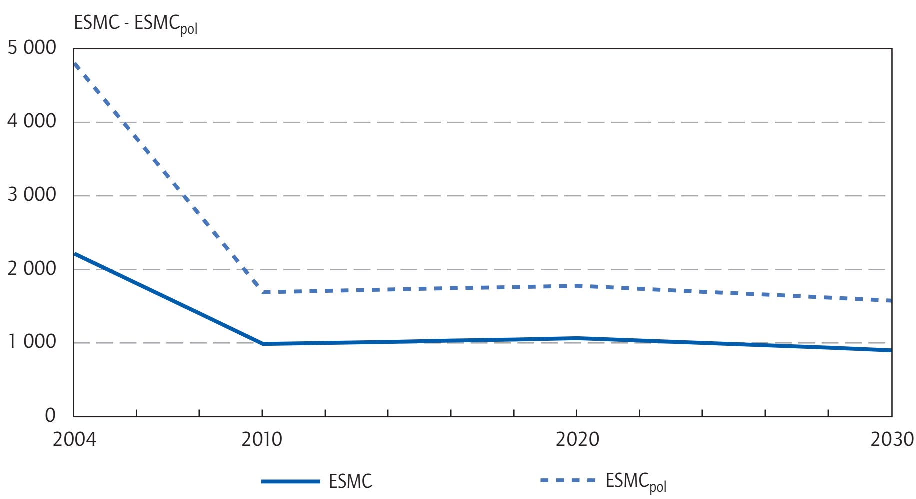


34. While somewhat counter-intuitive as based on the simplified assumptions adopted, Norway only exports from 2010 on gas-based terms to the UK, prices are ultimately linked through inter-regional LNG trade.

Figure 19 shows the resulting trends in ESMC and $ESMC_{pol}$. In the more regionally constrained market in 2004, ESMC is of 2 200. The assumed shift to a more global market structure between 2004 and 2010 leads to a significant reduction. By 2010, ESMC drops to 970, representing a reduction of 56% compared to the 2004 value. ESMC subsequently increases to 1 050 in 2020 before reducing again to 890 in 2030.

FIGURE 19

Gas market ESMC, 2004-2030
Case 1: No change in price structure in Europe



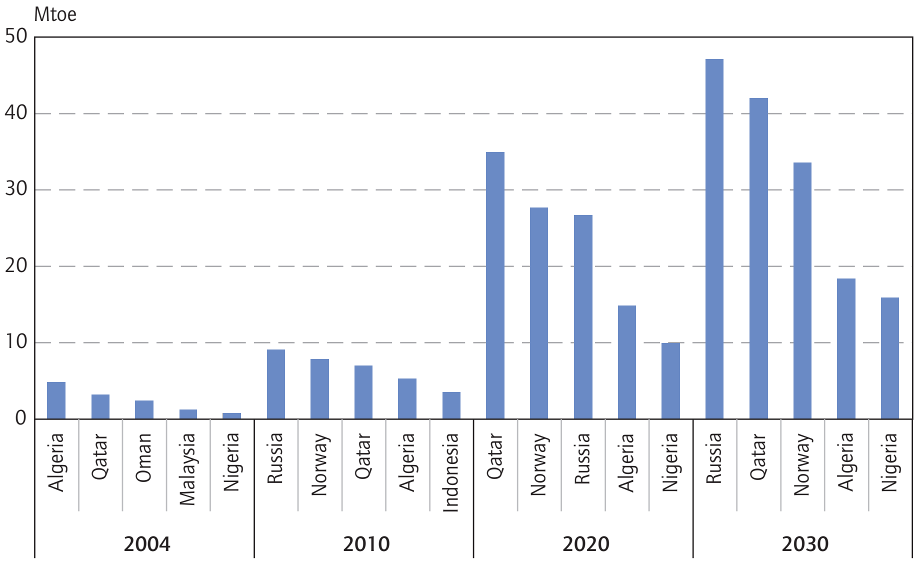
When the political risk rating *r* is included, $ESMC_{pol}$ is of 4 790 in 2004, 118% higher than the ESMC value. Between 2004 and 2010, $ESMC_{pol}$ also drops significantly to 1 690, some 73% higher than ESMC. This represents a much lower increase that in 2004, as countries with better political stability ratings now play a more important role. Between 2010 and 2030, $ESMC_{pol}$ follows the same trend as ESMC, reaching 1 560 by 2030.

Case 2: Enhanced gas-based pricing in Europe

Turning to the case of enhanced gas-based pricing in Europe (case 2), Figure 20 shows the five largest participants in terms of their net export potential. In this case, the growing demand for gas-based volumes in Europe is paralleled by an increase in the trade on gas-based terms from pipe-based suppliers in so-called

FIGURE 20

Export potential of the five largest participants in the gas market, 2004-2030 Case 2: Enhanced gas-based pricing in Europe



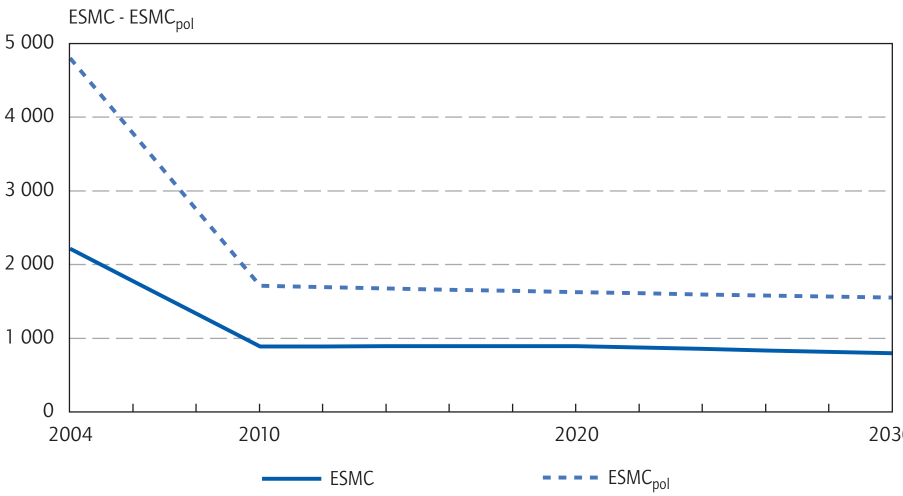
economies in transition countries. This notably explains the important role of Russia from 2010 onwards. The three largest participants in the market from 2010 onwards are Russia, Norway and Qatar.

The five largest participants have higher export potentials in this case reflecting the enhanced demand for gas sold on gas-based terms compared to the case where no change in gas pricing in Europe is assumed (case 1 discussed above). Together, the five largest market participants account for 90% of the market in 2004 and this share drops to 51% in 2030. This is an even bigger drop than in case 1 reflecting greater balance in the market.

Figure 21 shows the resulting trends in ESMC and $ESMC_{pol}$. The assumed shift to a more global market structure between 2004 and 2010 leads to an even greater reduction in ESMC than in case 1. In 2010, ESMC drops from 2 200 to 870, a 60% drop compared to 56% in case 1. ESMC then increases slightly to 2 020 before reducing again, reaching 780 by 2030.

Figure 21

Gas market ESMC, 2004-2030
Case 2: Enhanced gas-based pricing in Europe



In contrast, the drop in $ESMC_{pol}$ between 2004 and 2010 is no different to case 1. The benefits in terms of greater diversity among participants observed in case 2 is balanced by the negative impact of a market comprising of more countries with worse political stability ratings than in case 1. $ESMC_{pol}$ then continues to reduce progressively, reaching 1 530 by 2030.

Energy Security Index $_{price}$

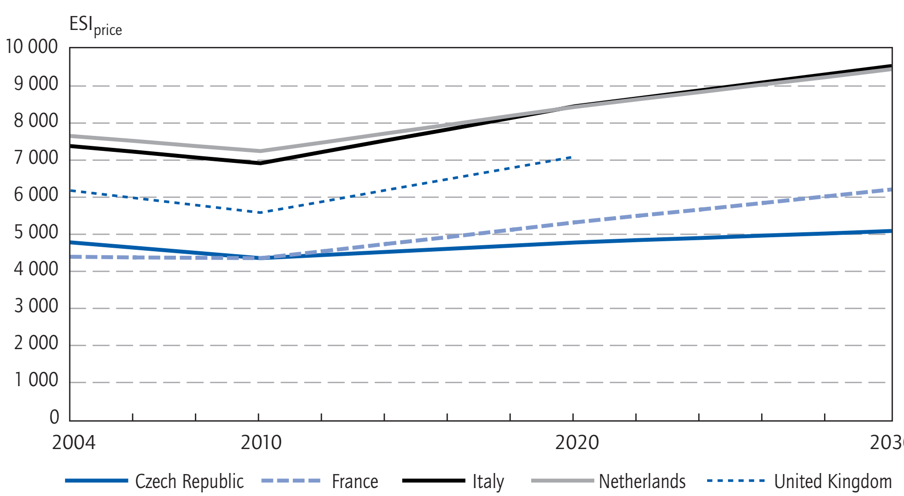
The Energy Security Index$_{price}$ (ESI_{price}) aims to reflect the exposure of a country to the price risk due to resource concentration in the various international markets. It is determined by summing the products of $ESMC_{pol}$ and the share of TPES exposed to the concentration risk in question.

In the discussion above, we considered two separate cases when measuring ESMC and $ESMC_{pol}$ in the oil market, and again when measuring ESMC and $ESMC_{pol}$ in the gas market. For oil, the aim was to assess the impact of considering OPEC producers as a single participant on the market or as individual participants. For gas, the aim was to assess the impact of enhanced gas-indexed pricing in Europe. When compiling ESI_{price} we focus on worst case scenarios. This leads us to adopt the case of OPEC as a single supplier in the oil market and the case of no change in gas pricing in Europe in the gas market, as this effectively means that the share of gas in the fuel mix exposed to resource concentration risk of the oil market is the highest.

Figure 22 shows the evolution of ESI_{price} for the five case study countries. Annex I shows in tabulated form input data used. In 2004, the Netherlands and Italy have the highest ESI_{price} value at respectively 7 620 and 7 350. The UK has an ESI_{price} of approximately 6 140, while the Czech Republic and France have ESI_{price} values of 4 740 and 4 350 respectively. The comparatively high values of the Netherlands and Italy are principally due to the high share of gas in these countries as this enhances the share of TPES exposed to oil market risk ($ESMC_{pol}$).

Figure 22

Evolution of Energy Security Index $_{price}$, 2004-2030



Note: UK projections only go to 2020.

In all five case study countries, ESI_{price} first drops between 2004 and 2010, though to varying degrees, before increasing to 2030. This, to some extent, reflects the importance of oil market risk as $ESMC_{pol}$ in the oil market has a similar profile. In the case of the Netherlands and Italy, ESI_{price} reaches 9 510 and 9 420 respectively by 2030 while in the case of France, ESI_{price} is of 6 170 and in the Czech Republic, ESI_{price} is of 5 050. As half of the UK's gas demand is met by gas purchased on gas-based terms it is the only one of the five case studies to be exposed to gas market concentration risks, which is, overall, significantly lower than that of oil. After falling to 2010, ESI_{price} in the UK grows to 7 070 by 2020.

Physical availability component of energy security

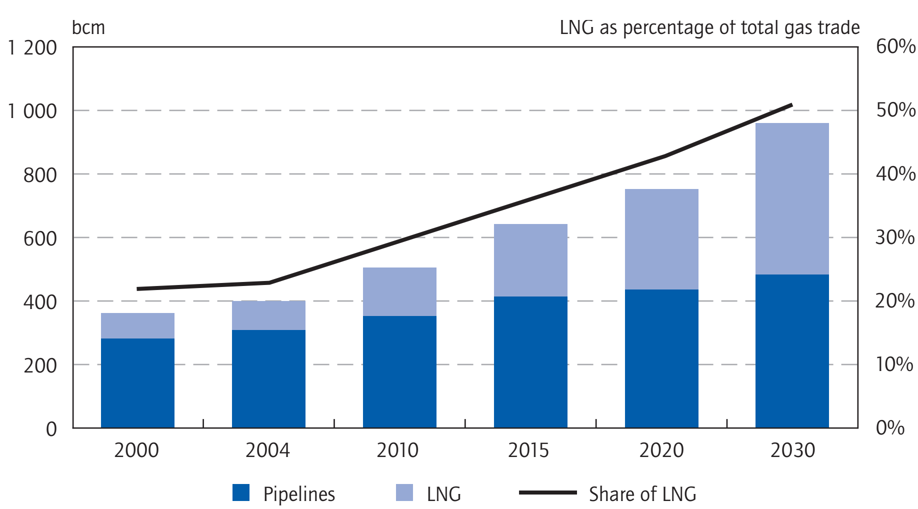
Out of the five case study countries, the Czech Republic is the only land-locked country and does not have the possibility to import gas in the form of LNG. All other case study countries have sea access and are able to turn to LNG as a transport means to import gas.

While the existing reliance on both LNG and pipe-based trade is known in each of these case study countries, defining future prospects over the 2004-2030 period is difficult as it depends on a number of uncertain parameters, including the evolution of gas prices and infrastructure costs, in particular of LNG regasification technologies. For simplicity, we assume that the same growth in LNG penetration in inter-regional trade projected to take place at the global level over the 2004-2030 timeframe in the *WEO 2006* takes place at the country level (Figure 23).

Table 3 shows the evolution of projected net gas imports dependence over the 2004-2030 timeframe, as well as the resulting breakdown between pipe-based and LNG in the five case study countries. The Czech Republic and France have very limited domestic production throughout the 2004-2030 timeframe and are

FIGURE 23

World inter-regional natural gas trade by type in the reference scenario



Source: IEA (2006c).

Table 3

Projected pipe-based import dependence

	2004			2010			2020			2030		
	Import dependence (%)			Import dependence (%)			Import dependence (%)			Import dependence (%)		
	Total	Pipe-based	LNG-based	Total	Pipe-based	LNG-based	Total	Pipe-based	LNG-based	Total	Pipe-based	LNG-based
Czech Republic	98	98	0	97	97	0	97	97	0	97	97	0
France	97	77	20	100	78	22	100	77	23	100	75	25
Italy	84	81	3	89	85	4	93	85	8	94	84	10
Netherlands	0	0	0	0	0	0	0	0	0	11	11	0
United Kingdom	1	1	0	35	32	3	88	71	17	n.a.	n.a.	n.a.

Note: UK projections only go to 2020.

therefore both close to 100% import dependent. As seen above, in the case of the Czech Republic all imports are pipe-based. France, on the other hand, has the highest share of LNG penetration, accounting for 20% of total consumption in 2004 growing to 25% in 2030.

Italy is approximately 84% import dependent in 2004 and this share is projected to increase to 94% by 2030. In 2004, 81% of domestic consumption was met by pipe-based imports and this share increases to 84% by 2030.

The UK and the Netherlands are important producers of gas. In 2004 the UK became a net importer, importing approximately 1% of total consumption – all of which was via pipelines. As production is projected to decline, import dependence rises reaching 88% of total consumption by 2020, of which 71% is expected to come by pipe and 17% by LNG. The Netherlands, on the other hand, remains a net exporter beyond 2020. However, by 2030 it is expected to import up to 11% of total consumption, all of which is assumed to be pipe-based.

The evolution of the Energy Security Index $_{volume}$ (ESI_{volume}) however, depends on how markets evolve in Europe and on the extent to which gas-based pricing develops. We adopt here the same two cases considered in the scope of ESI_{price} analysis (see Table 2).

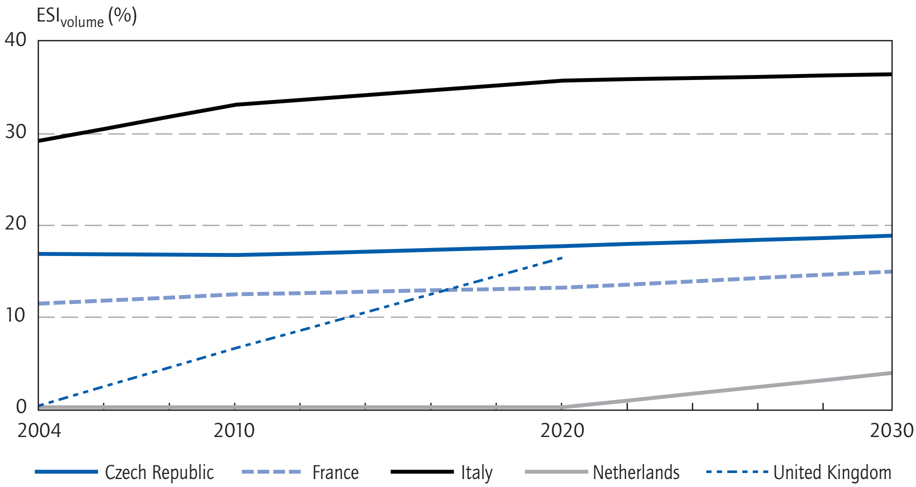
- Case 1: no change in existing contractual arrangements (100% oil-indexation in all case study countries throughout the 2004-2030 timeframe except the UK where the share is of 50%).
- Case 2: Share of consumption met on gas-based terms increases by 1% a year to 2030.

Figure 24 shows the evolution of ESI_{volume} in the five case study countries in case 1. Italy has the highest share of total energy consumption met by pipe-based oil-indexed gas imports in 2004 throughout the 2004-2030 timeframe, growing from 29% in 2004 to 36% in 2030. ESI_{volume} in the Czech Republic grows roughly linearly from 17% to 19% while ESI_{volume} in France follows a similar trend growing from 11% to 15%. In these three cases, the trends observed reflect the projected evolution of the role of gas in the fuel mix. In the case of the UK, ESI_{volume} grows from zero in 2004 to 16% by 2020 while ESI_{volume} for the Netherlands grows from zero to 4 between 2020 and 2030.

Figure 25 shows the evolution of ESI_{volume} in the five case study countries in case 2. When compared to case 1, ESI_{volume} drop by 1% annually in the case of the Czech Republic, France and Italy, the same rate at which gas-based purchases are

FIGURE 24

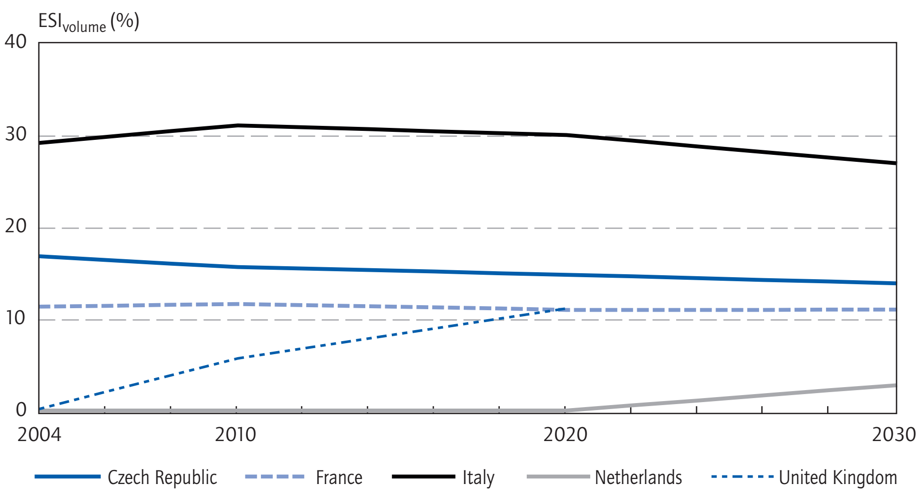
ESI$_{volume}$, 2004-2030
Case 1: No change in price structure in Europe



Note: UK projections only go to 2020.

FIGURE 25

ESI$_{volume}$, 2004-2030
Case 2: Enhanced gas-based pricing in Europe



Note: UK projections only go to 2020.

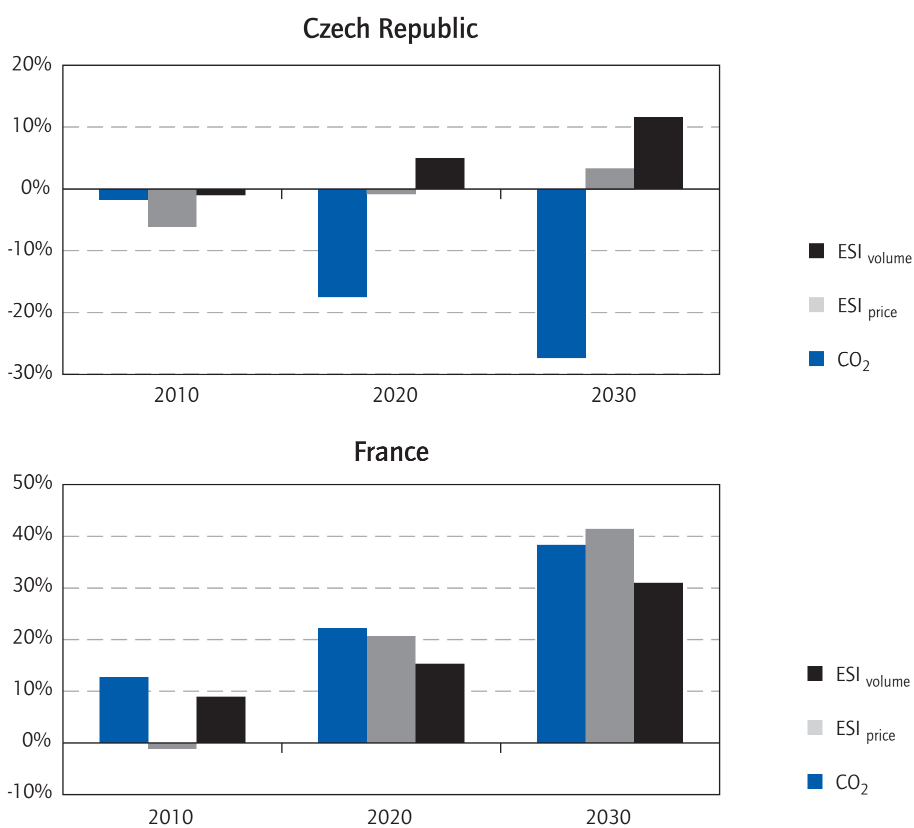
assumed to penetrate the market. In Italy ESI$_{volume}$ only grows marginally between 2004 and 2010 before reducing and reaching 27% in 2030. In the case of the Czech Republic ESI$_{volume}$ drops progressively, reaching 14% in 2030, while in the case of France ESI_{volume} remains roughly stable at 11%. ESI_{volume} in the UK grows to 11% by 2030 while in the Netherlands ESI_{volume} grows to 3% between 2020 and 2030.

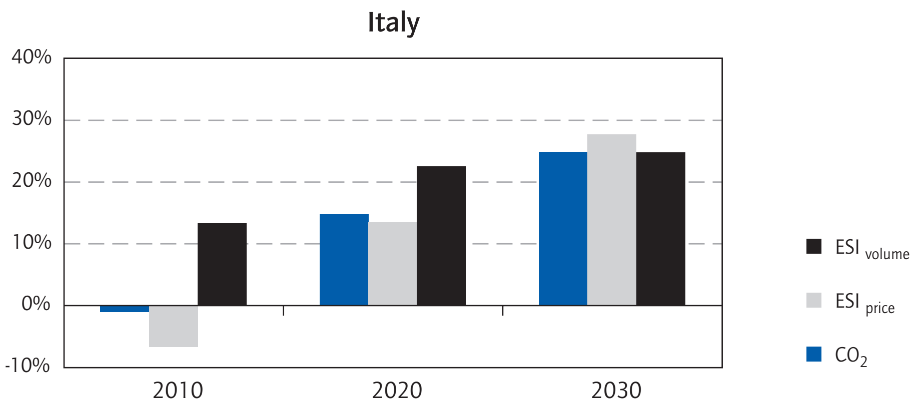
Summary

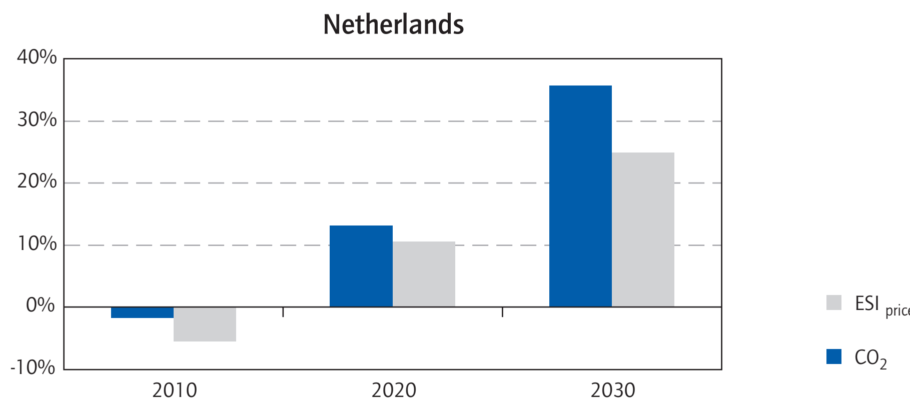
The energy security indicators defined allow a joint quantitative evaluation of energy security and climate change mitigation developments. This section assessed how each indicator evolves in five case study countries following a reference scenario to 2030. Figure 26 compiles results obtained for each country.

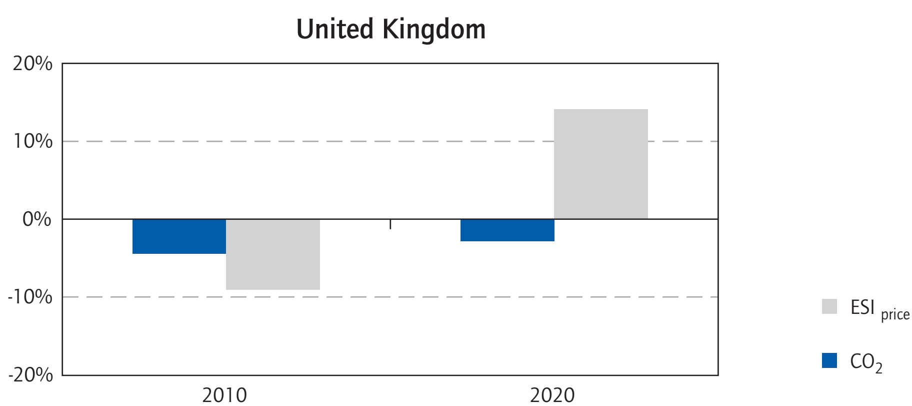
FIGURE 26

Percentage change in CO_2 emissions, ESI_{price} and ESI_{volume} relative to 2004 following a reference scenario









Though the Czech Republic is the only country with a projected sustained and significant drop in CO_2 emissions to 2030, at the same time both energy security indicators are expected to increase, even if only to a limited degree compared to other case study countries. In the case of France, by 2030 energy security indicators and CO_2 emissions are over 30% higher than in 2004, with ESI_{price} over 40% higher than its 2004 value. In the case of Italy, all three indicators also increase significantly, reaching levels between 20% and 30% greater than 2004. In the Netherlands also, both climate and security indicators rise. CO_2 emissions reaches levels 35% greater than in 2004, ESI_{price} grows by some 24% and ESI_{volume} emerges as a new security concern starting from 2020. Finally, while emissions continue to progressively drop in the UK, ESI_{price} increases by some 15% by 2020 and ESI_{volume} emerges as a new policy concern starting from 2004.[35] In sum, while to varying degrees, if no new policies and measures are implemented, the climate and security factors are likely to worsen in all five case study countries and in some instances, quite significantly.

35. ESI_{volume} is not shown in Figure 26 in the case of the Netherlands and the UK as values were of zero in 2004 a measure of percentage change relative to 2004 values has no meaning in this case.

ENERGY SECURITY AND CLIMATE CHANGE POLICY INTERACTIONS: EXPLORATORY POLICY CASES

Governments have a variety of tools to address the rising trends in CO_2 emissions, ESI_{price} and ESI_{volume}. As seen at the beginning of this report, these can take a number of forms, ranging from the definition of taxes to a more hands on approach such as mandatory technological standards.

In the case of climate change mitigation, energy-related CO_2 emissions can be brought down by consuming fewer fossil fuels, switching to less carbon intensive fossil fuels or non fossil alternatives, or in the future, capturing and storing carbon before it is emitted.

In the case of energy security, ESI_{price} can be lowered by reducing exposure to high $ESMC_{pol}$ fossil fuel markets, and in particular that of the international oil market which has by far the highest value throughout the 2004-2030 period. This can be achieved by reducing dependence on oil through energy efficiency improvements or switching to alternatives, as well as by relying less on oil-indexed contracts in the gas sector. Cooperation with exporting countries to improve their reliability as trade partners (effectively lowering *r* in $ESMC_{pol}$) can also contribute to lower ESI_{price}.

With regard to ESI_{volume}, levels can also be reduced by moving away from oil-indexed contracts to prices which reflect gas supply and demand on the market, as well as by enhancing domestic gas production or turning to LNG.

As discussed in Section 2, policies which are likely to result in the highest level of interaction between climate change mitigation and energy security are those which ultimately affect the composition of the fuel mix. We therefore propose to focus on these in this section. Others measures with less direct impacts will be addressed in the following section.

To assess and compare the level of synergy or conflict between both policy drivers, we consider the impact of achieving a specific indicator target through a single policy approach on the other two indicators. In all that follows, we assume that each measure is to achieve a 5% reduction in CO_2 emissions in 2030 and study the impacts on ESI_{price} and ESI_{volume}.

While any type of action can be envisioned, we focus this assessment on potential government actions in two sectors: electricity and transport. In the first case we consider three policy approaches:

- Enhanced energy efficiency,
- Increased use of non fossil fuels (renewables or nuclear power), and
- Fuel switching from coal to gas.

In the case of transport, we consider two separate policy approaches:

- Enhanced fuel efficiency, and
- Increased use of biofuels.

Policy-induced changes in the electricity sector

Much as the fuel mix at the country level, the power generation mix varies significantly from country to country. Figure 27 shows the projected evolution of the mix in each country following reference scenario projections.

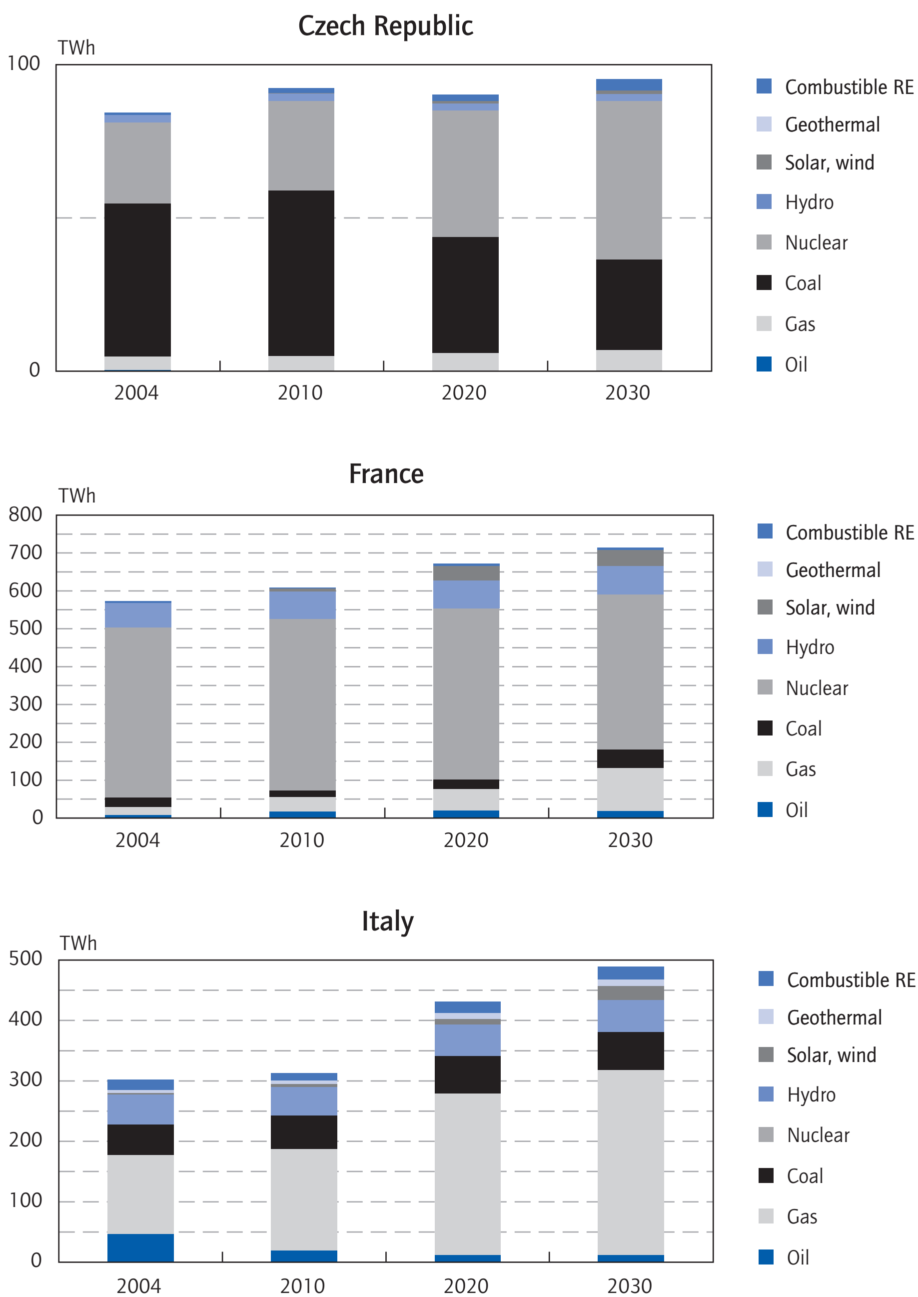
The Czech Republic projects total power generation to remain relatively stable with a switch occurring from a mix principally based on coal (59% of total) to one principally based on nuclear (54% of total). Italy projects a rapid increase in total electricity generation (62% between 2004 and 2030) and an enhanced reliance on gas (from 43% of generation mix in 2004 to 63% in 2030). Power generation in France is expected to continue to rely heavily on nuclear power though to a more limited degree (from 78% in 2004 to 57% in 2030). In the Netherlands, power generation is expected to rise significantly (by some 50% between 2010 and 2030) with coal emerging as the principal power generation source (rising from 21% in 2010 to 50% in 2030) by the end of the timeframe considered.[36] Finally, the evolution of the UK generation mix is characterised by a strong growth in gas-based generation (from 40% of the generation mix in 2004 to 58% in 2030).

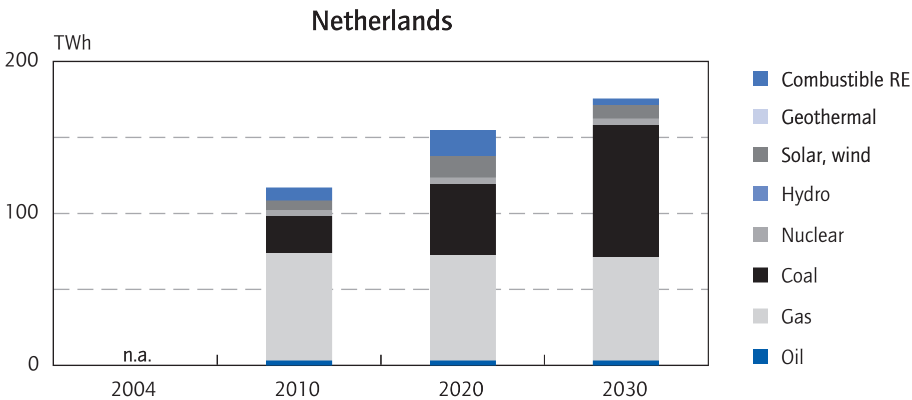
Due to these differences, the policy implications to achieve a 5% CO_2 emissions reduction by 2030 through a given measure in the electricity sector will vary significantly from country to country. Independent of the approach considered,

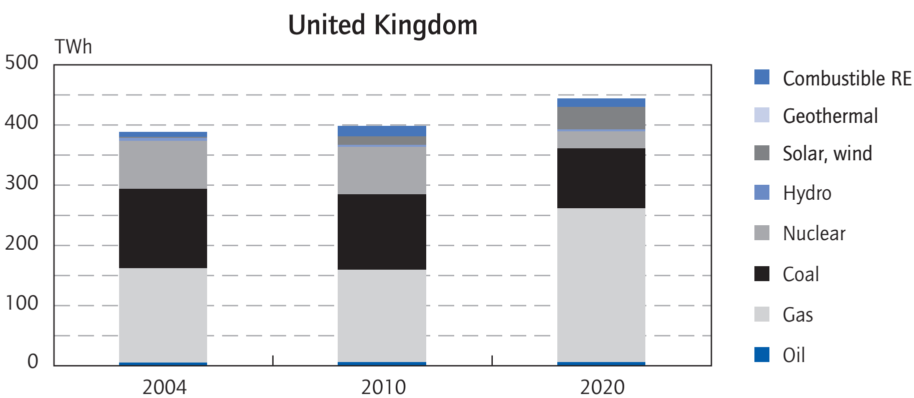
36. Power generation data was not available for the Netherlands in 2004.

Figure 27

Power generation mix, 2004-2030







achieving the target is likely to require less efforts in countries such as the UK or the Netherlands than in a country such as France, with its more limited reliance on fossil fuels. Nevertheless, the exercise allows for a systematic evaluation of cross-cutting policy impacts.

Enhanced energy efficiency

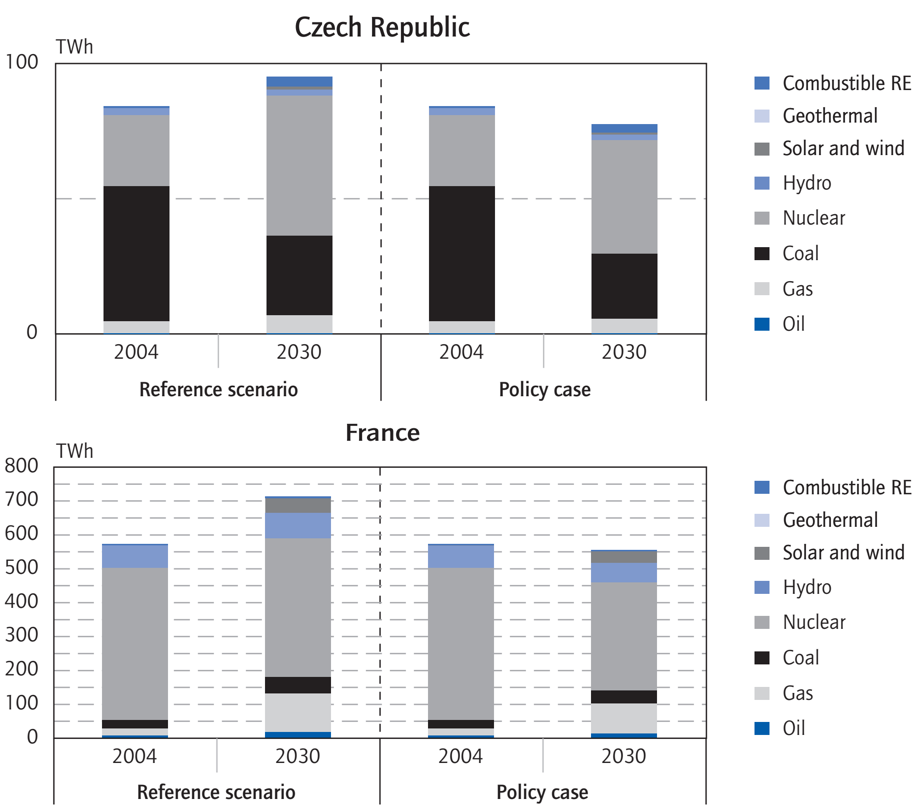
Policies to promote enhanced energy efficiency can be designed to target virtually all aspects of the energy system. In the electricity sector, such measures range from actions which improve the fuel efficiency of power plants to those which promote end-use efficiency (*e.g.*, the deployment of more energy efficient appliances). Implications for CO_2 emissions but also for ESI_{price} and ESI_{volume} will vary depending on the targeted activity.

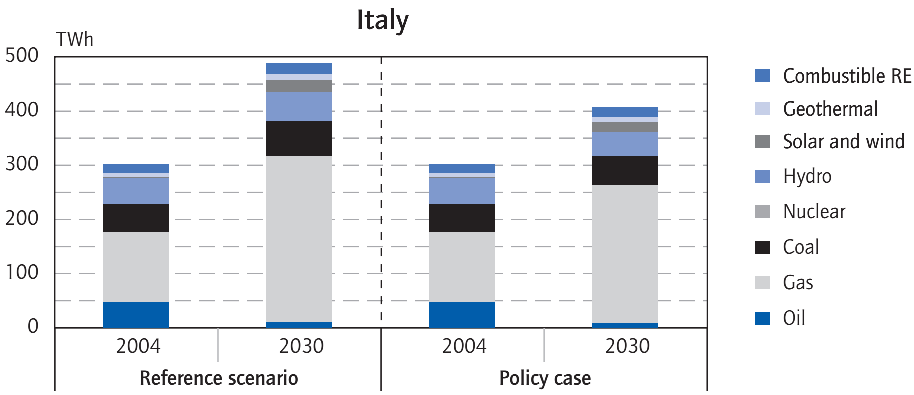
We consider here the impact of measures which promote energy efficiency in electricity uses. The assumption is that these measures do not have a specific effect on the power generation fuel mix. In other words, we assume that the shape of the load curve and the distribution among the various types of generation plants are unaffected. Hence, peak load management measures could lead to different outcomes from those described below.

Figure 28 shows the impact on the generation fuel mix of achieving a 5% reduction in CO_2 emissions by 2030. Due to the importance of nuclear power, the country which requires the most significant reduction in power generation is France, for which total generation needs to drop by 22% in 2030 compared to the reference case. In contrast, the Netherlands only needs to reduce total generation by 12% to achieve the same emissions reduction target.

Figure 28

Change in electricity generation mix: 5% emissions reduction target reached through improved end-use efficiency




Italy
TWh
500
400
300
200
100
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2004
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2004
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Reference scenario
Policy case
Combustible RE
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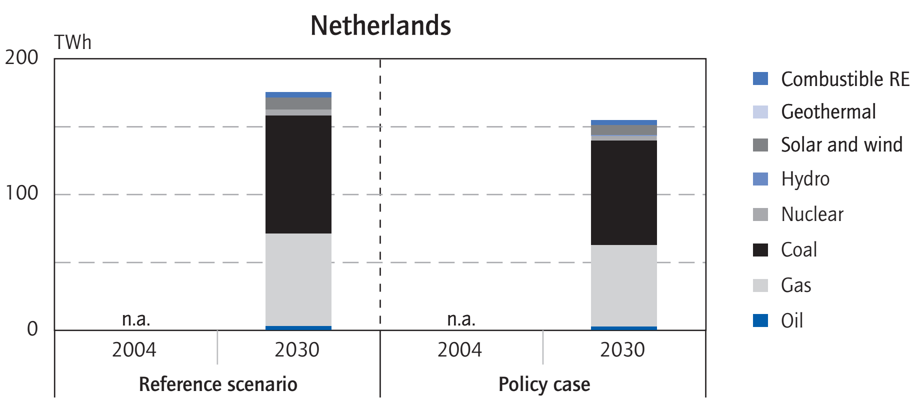
Nuclear
Coal
Gas
Oil


Netherlands
TWh
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Reference scenario
Policy case
Combustible RE
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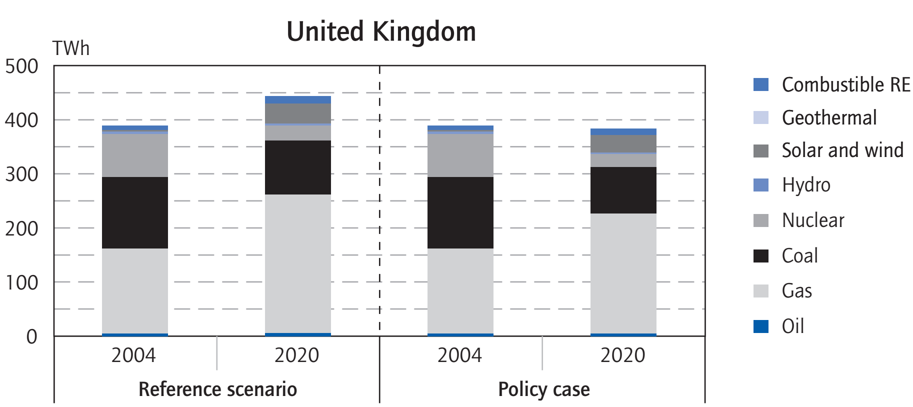
Coal
Gas
Oil


United Kingdom
TWh
500
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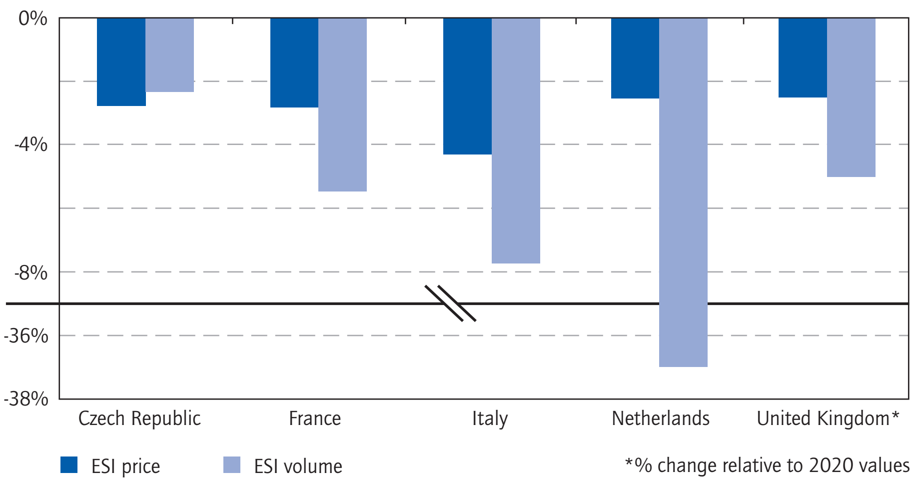
2004
2020
2004
2020
Reference scenario
Policy case
Combustible RE
Geothermal
Solar and wind
Hydro
Nuclear
Coal
Gas
Oil

Figure 29 shows the resulting impact on ESI_{price} and ESI_{volume}.[37] In all case study countries both ESI_{price} and ESI_{volume} drop as a consequence of efforts to improve end-use efficiency. In the case of $ESI_{price,}$ a reduction in electricity demand reduces demand for fossil fuels which lowers the exposure of the country to concentration risks in international fossil fuel markets. Reductions in ESI_{price} are 4.3% compared to the reference scenario value in Italy, 2.8% in the Czech Republic and France, and to 2.5% in the UK and the Netherlands. In the case of ESI_{volume}, values drop depending on the importance of gas in the country's fuel mix.[38] ESI_{volume} drops by 2.3% in the Czech Republic and up to 7.8% in Italy. The Netherlands sees a drop of 37% due to the comparatively low ESI_{volume} in 2030.

FIGURE 29

Change in 2030 ESI_{price} and ESI_{volume} compared to reference scenario values: 5% emissions reduction target reached through end-use efficiency in the electricity sector



37. In the case of the UK, as government projections do not go beyond 2020, we assess the impact of achieving a 5% reduction in CO_2 emissions by 2020.
38. The share of pipe-based imports is assumed to remain unchanged.

Increasing the penetration of non-fossil fuels in electricity

Both a renewable energy policy and a nuclear energy programme are likely to have similar impacts on ESI_{price} and ESI_{volume}. In the case of renewables, the fuel displaced as a result of a renewable energy policy depends on a variety of uncertain parameters including the type of renewable technologies supported and the fossil fuel prices. Yet many renewable energy technologies such as wind and solar power are intermittent and as such cannot be relied upon to serve peak demand. A policy induced increase in renewables is therefore most likely to displace fuels that are typically used in base load generation plants: coal, nuclear power and in some instances gas.

Similarly, nuclear power itself is used as base load generation. A hypothetical increase in the role of nuclear power would therefore also displace fuels typically used in base load power generation plants: coal, but also gas.

Therefore, the simplest assumption that can be adopted in both cases is that coal, gas, and – in the case of a renewable energy policy, nuclear – are displaced proportionally to their role in the fuel mix in the reference case. Based on this assumption, achieving a 5% emissions reduction in either case leads to the same values of gas and coal displaced, and hence similar effects on our energy security indicators.

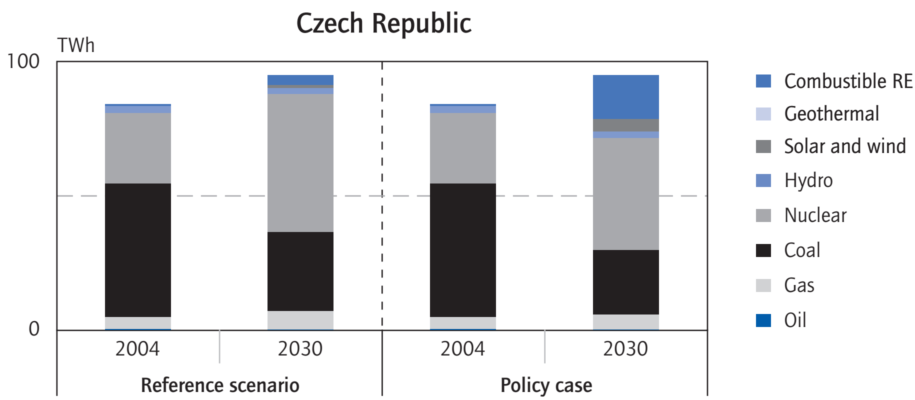
With regard to renewables, while a variety of possibilities exist, we assume that the resulting mix of renewable energy technologies in 2030 following an enhanced penetration case is the same as that in the reference case. The only exception to this is hydro-power, as in many circumstances its remaining potential is limited.

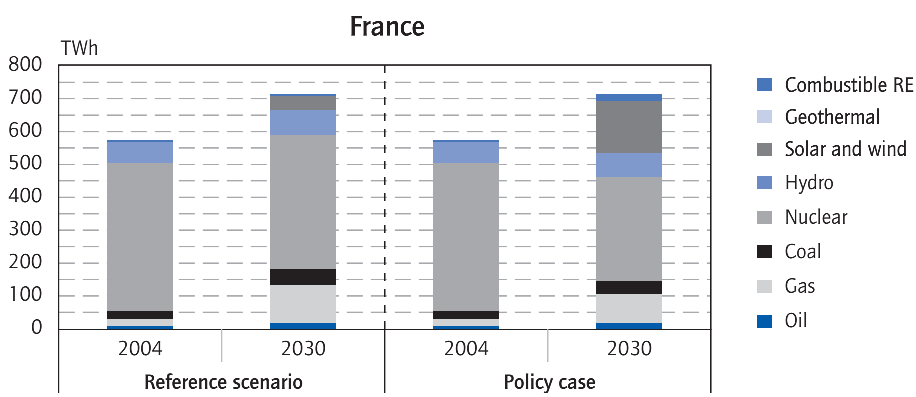
Based on these assumptions, Figure 30 shows the impact on the generation fuel mix of achieving a 5% reduction in CO_2 emissions in 2030 through an increase in renewable energy. Renewables-based electricity generation needs to be multiplied by up to 4.5 times reference scenario levels in the case of the Czech Republic to achieve the 5% target. In the case of the UK electricity generated form renewable sources need to be multiplied by a little under 2.1 times reference scenario levels.

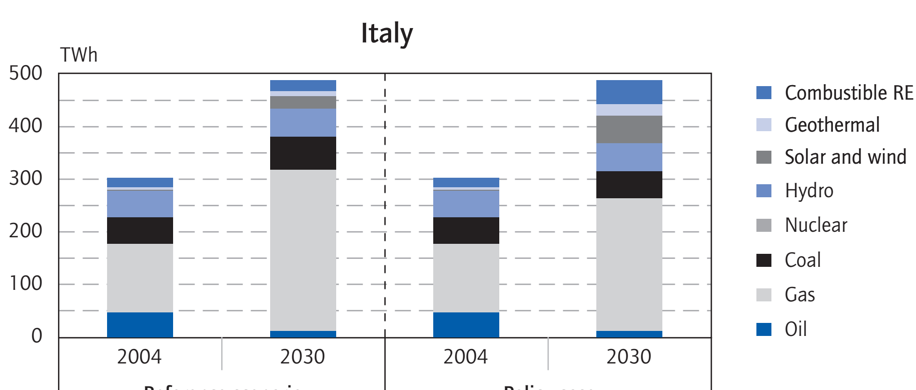
Out of the five countries studied here, nuclear power plays by far the most important role in the power generation mix of France. The importance of nuclear in the Czech Republic is also expected to rise significantly over the 2004-2030

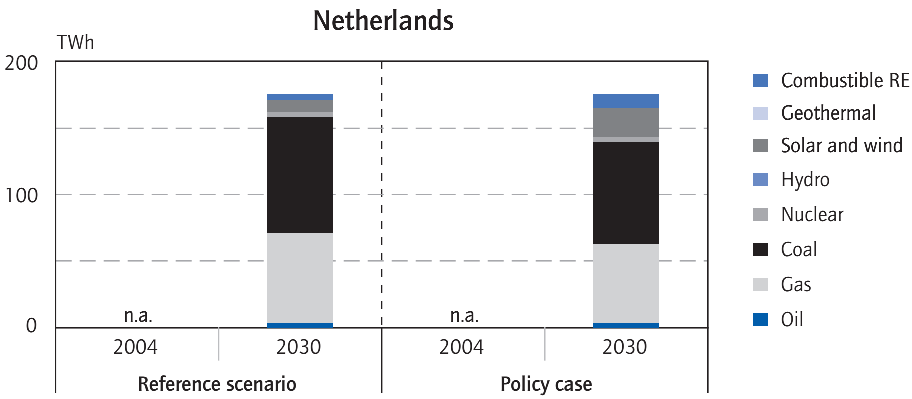
Figure 30

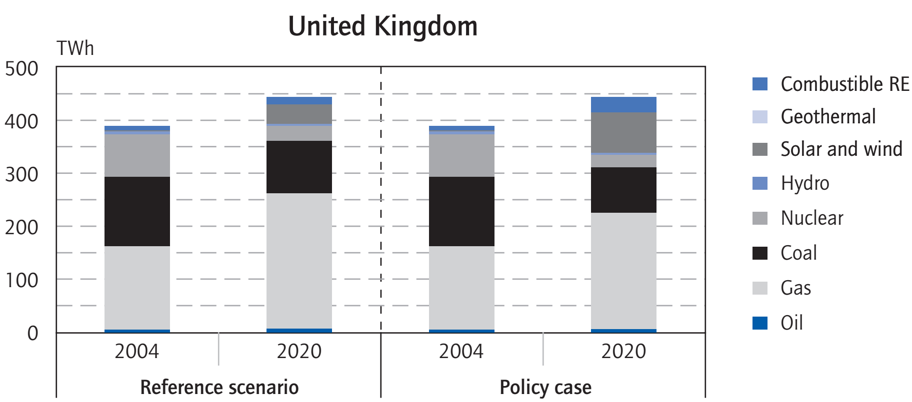
Change in electricity generation mix: 5% emissions reduction target reached through increased penetration of renewable energy sources











period, while it is expected to diminish in the UK. Italy does not produce electricity from nuclear and the Netherlands does not expect to rely significantly on nuclear power throughout the 2004-2030 timeframe. We therefore focus our assessment on the first three countries.

Figure 31 shows the change in 2030 power generation mix required to achieve the 5% emissions reduction target by increasing nuclear power generation. France and the Czech Republic require a 9% and 13% increase respectively in nuclear power generation compared to 2030 reference case levels. Due to the limited projected importance of nuclear power in 2030, the UK requires a comparatively much greater increase – 181% compared to 2030 reference case levels.

The resulting impact on ESI_{price} and ESI_{volume} is shown in Figure 32. Based on the assumptions adopted here, achieving a 5% reduction in emissions by increasing

Figure 31

Change in electricity generation mix: 5% emissions reduction target reached through increased penetration of nuclear power

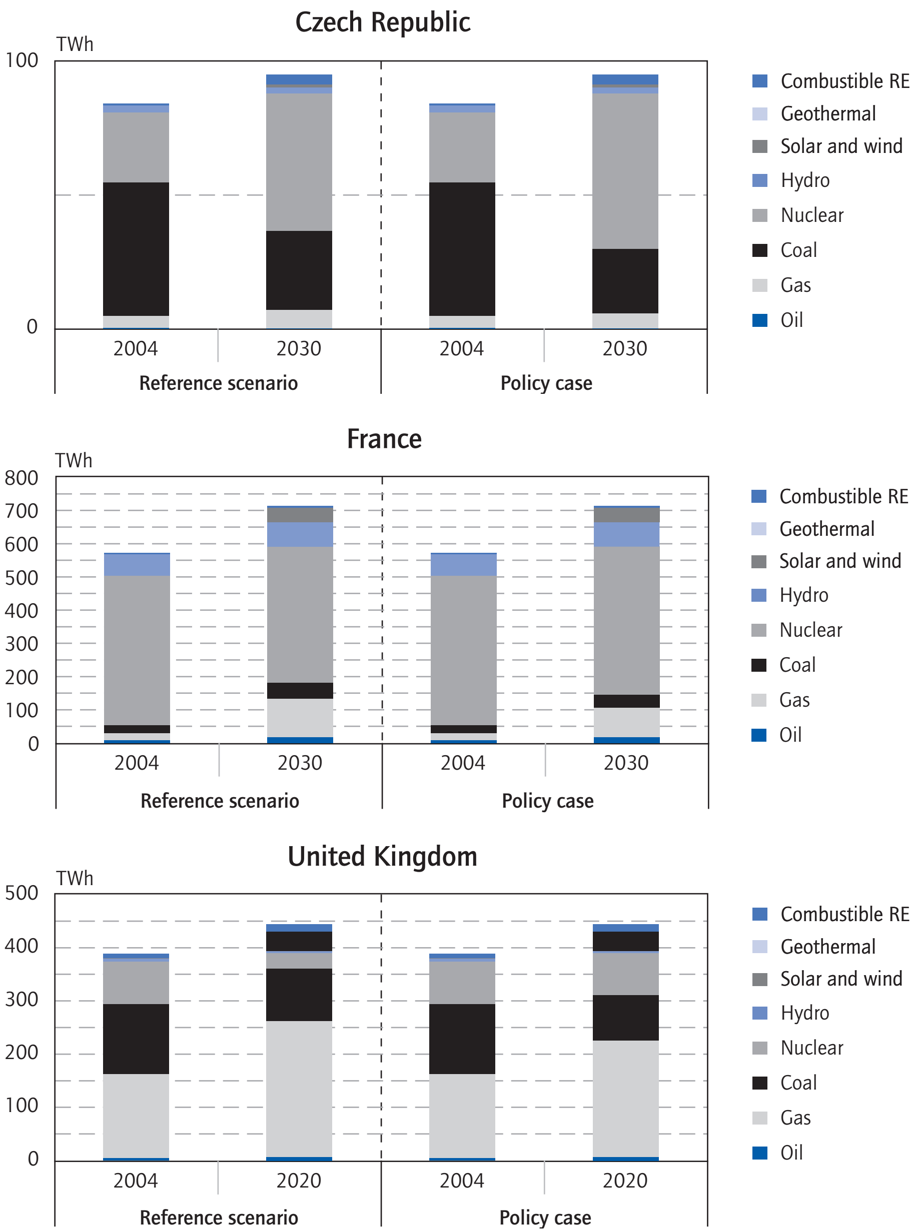
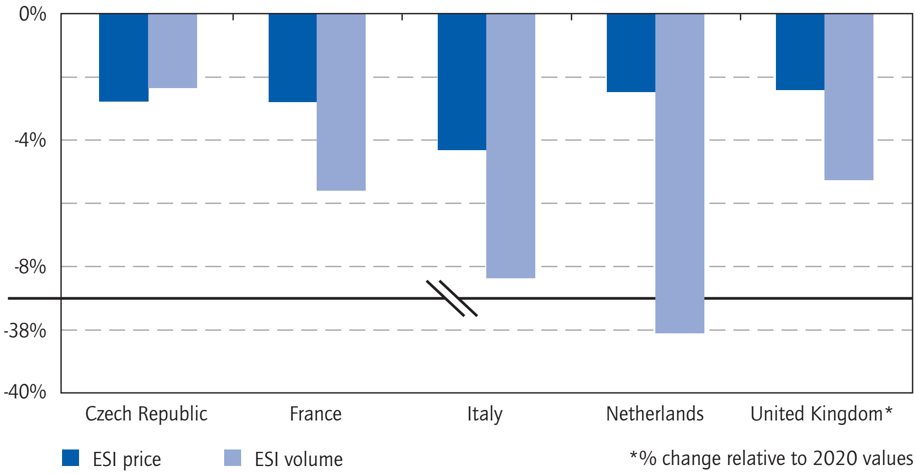


FIGURE 32

Change in 2030 ESI_{price} and ESI_{volume} compared to reference scenario values: 5% emissions reduction target reached through increased penetration of non-fossil fuels in the electricity sector



the role of non-fossil fuels in power generation leads to comparable reductions in both energy security indicators to the case of increased energy efficiency. ESI_{price} drops by 4.3% in Italy, 2.8% in the Czech Republic and France, 2.5% in the Netherlands and 2.4% in the UK. ESI_{volume} drops by 2.3% in the Czech Republic, 82% in Italy, and up to 38.1% in the Netherlands.

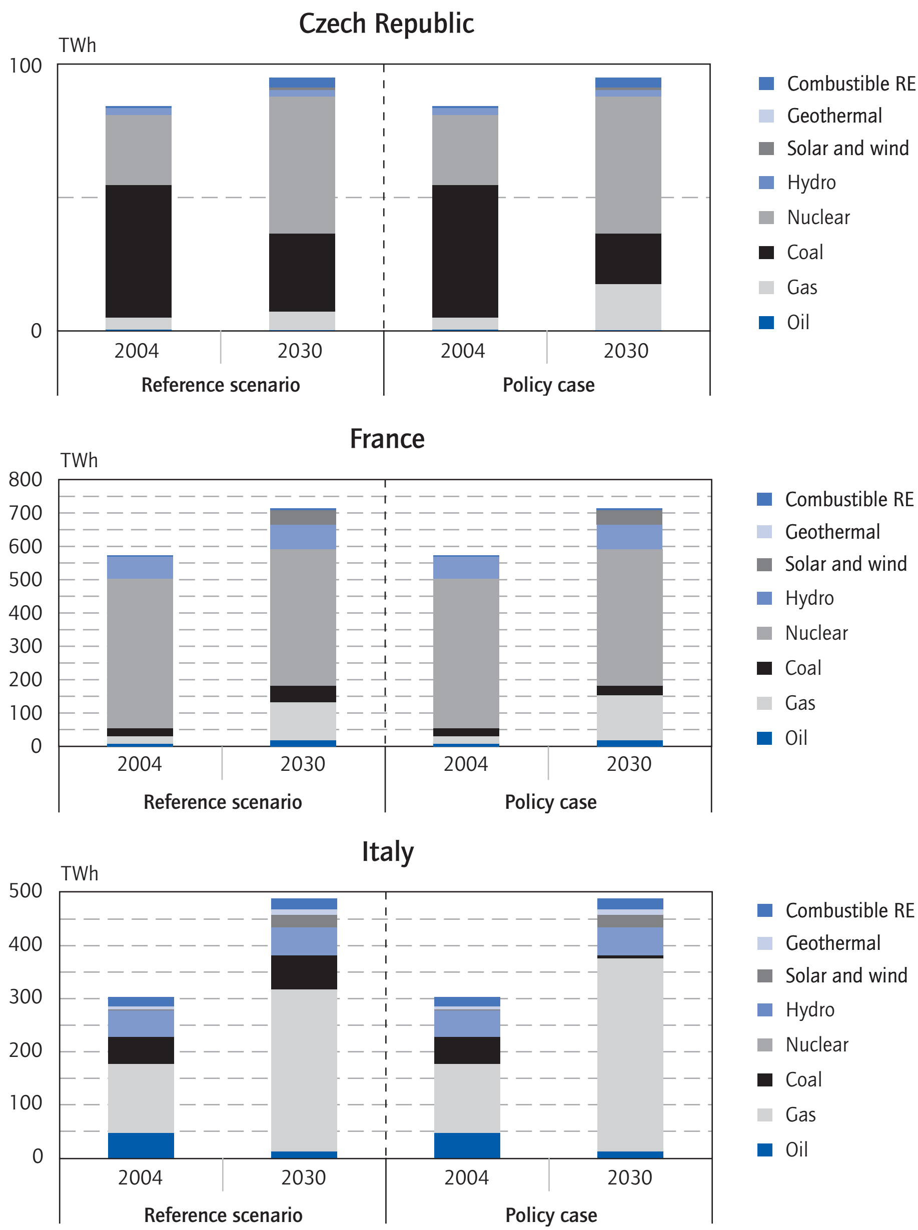
Switching from coal to gas

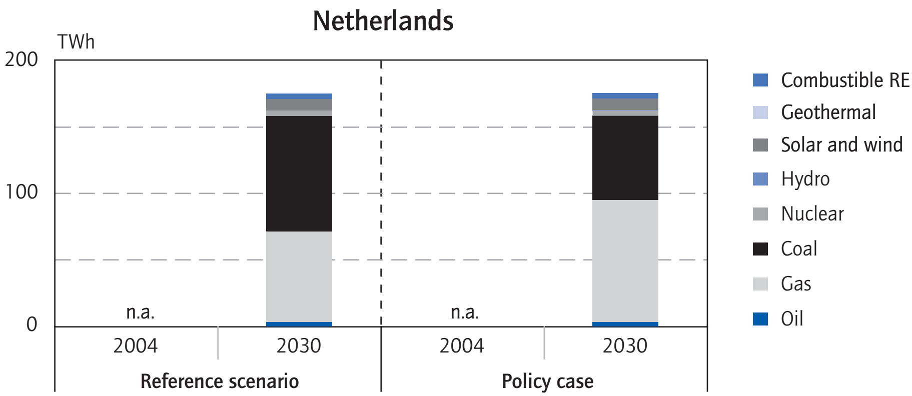
In the case of a switch from coal to gas, we assume that the increase in gas power generation will come from Combined Cycled Gas Turbines with an efficiency of 60%.

Figure 33 shows the impact on the generation mix of achieving the 5% emissions reduction target in 2030 through switching from coal- to gas-based generation. The most significant switch from coal to gas needed to achieve the 5% target is in Italy, where 93% of coal generation in the reference case needs to be switched to gas. The smallest is 27% in the Netherlands.

Figure 33

Change in electricity generation mix: 5% emissions reduction target reached through a switch from coal to gas





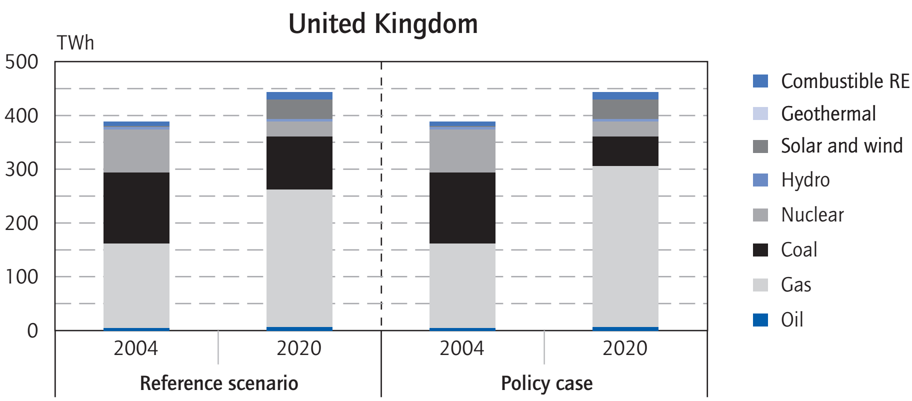


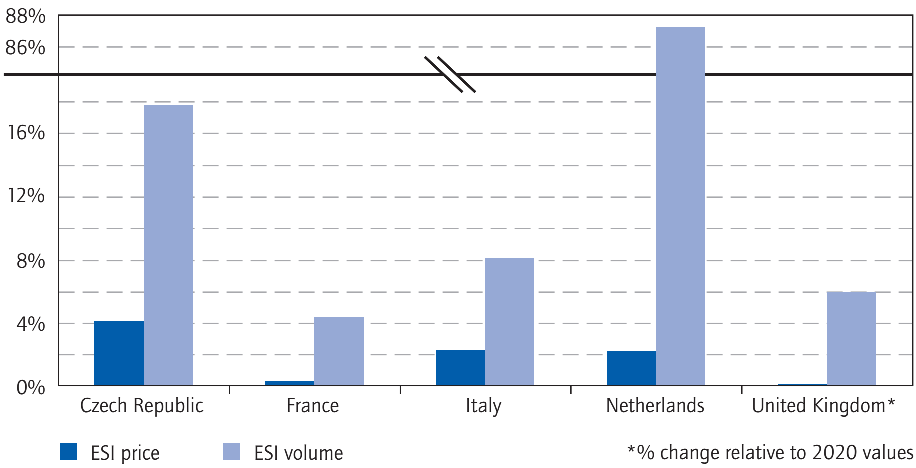
Figure 34 shows the impact in terms of ESI_{price} and ESI_{volume}. Contrary to the previous policy cases, a policy triggering a coal-to-gas switch to reduce CO_2 emissions would lead to a deterioration of countries' energy security objectives. ESI_{price} increases as a result of a coal to gas switch as in all cases the share of the fuel mix exposed to oil market concentration risks increases. The rise varies depending on the volumes affected, from a very small increase of 0.1% in the UK to a rise of 4.1% in the Czech Republic. ESI_{volume} also increases as a result of a switch from coal to gas, from 4.4% in Italy to 17.8% in the Czech Republic and 87.1% in the Netherlands, though this high value is due to the very low ESI_{volume} levels of 2030.

Policy-induced changes in road transport

Road transport accounts for a dominant share of total oil consumption in all case study countries. In the case of France and Italy it represents 47% of total oil

FIGURE 34

Change in 2030 ESI_{price} and ESI_{volume} compared to reference scenario values: 5% emissions reduction target reached through a switch from coal to gas in the electricity sector



consumption in 2004 and will increase up to 66% and 68% respectively by 2030. In the case of the Czech Republic levels are even higher, rising from 59% in 2004 to 88% in 2030.

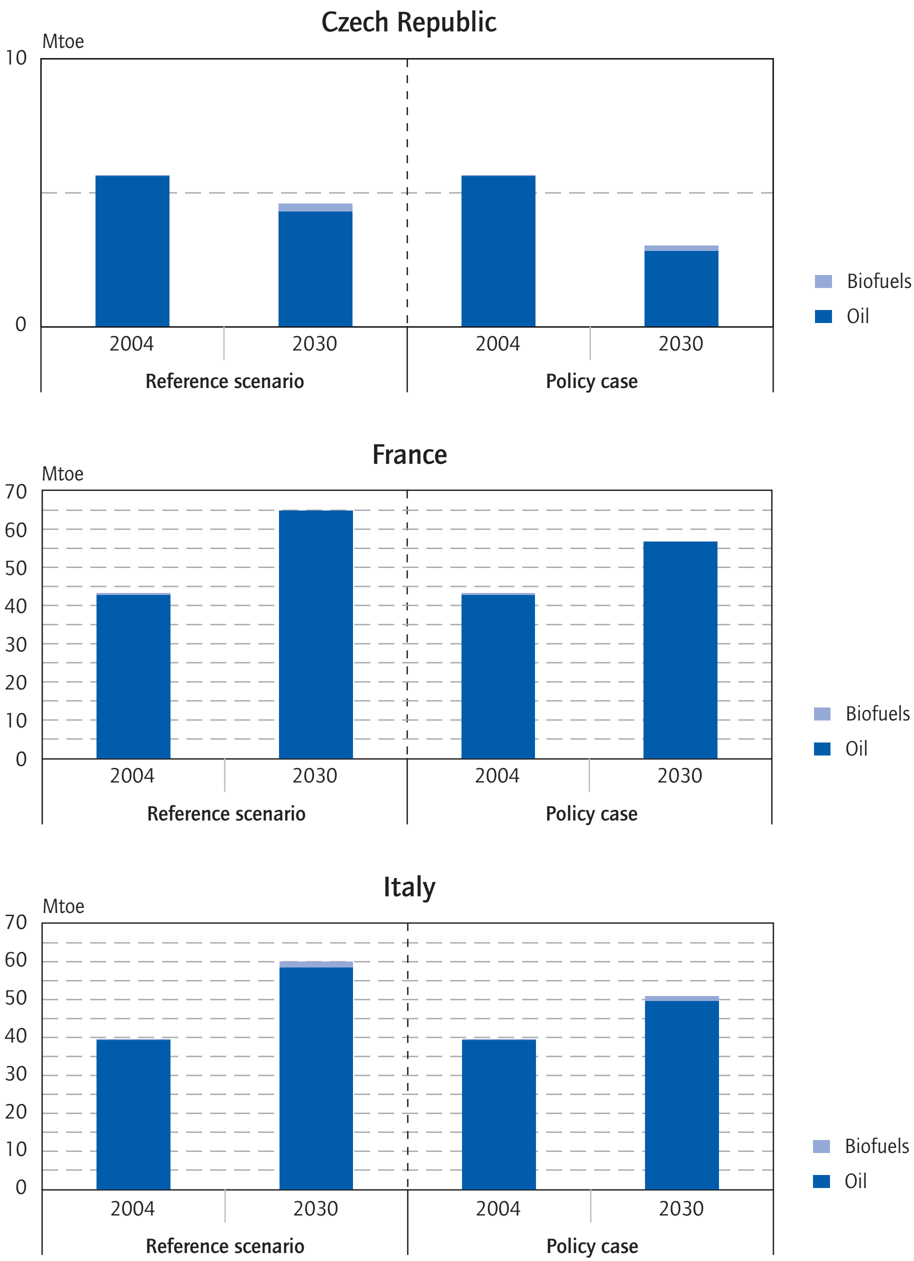
In the five countries, as in the rest of the world, road transport is almost entirely based on oil. The Czech Republic and the UK project the most significant penetration of biofuels in transport between 2004 and 2030. In the first case, the share of biofuels in the road transport mix is expected to increase from approximately 1% of the market in 2004 to 6% in 2030, while in the second this share is expected to rise from 0 in 2004 to 5% in 2020.

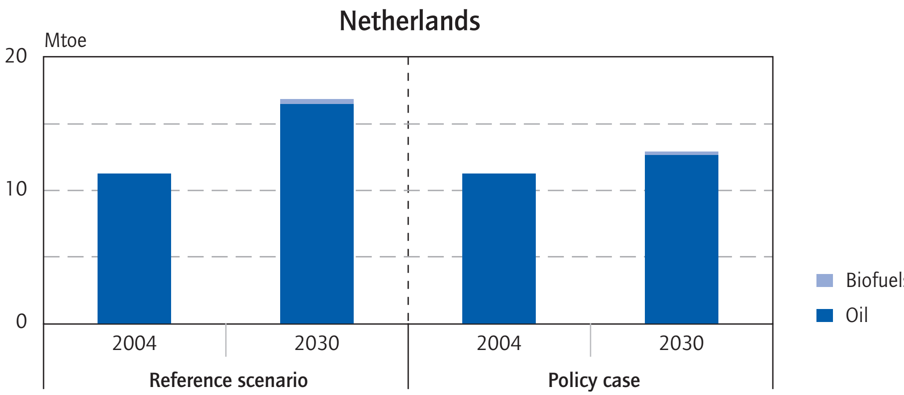
Improving fuel efficiency

Improving the fuel efficiency of vehicles can be an effective way of reducing oil use in transport. Figure 35 shows the required reduction in road-based oil consumption in 2030 to achieve the 5% reduction in total CO_2 emissions in each of the five case study countries. In percentage terms, the magnitude of the effort is greatest in the Czech Republic, where 2030 road based oil demand must be lowered by some 34%, and smallest in France where it must be reduced by 12%.

FIGURE 35

Change in road-based transport fuel mix: 5% emissions reduction target reached through improved fuel efficiency





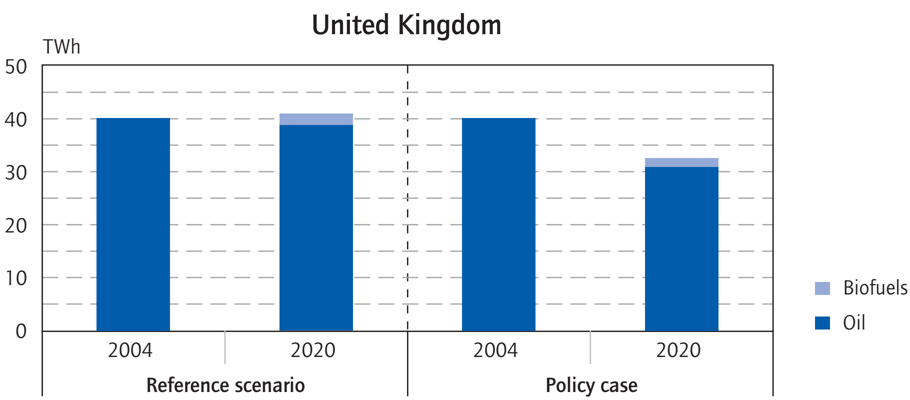


Figure 36 shows the resulting impact on ESI_{price} and ESI_{volume}. A reduction in road-based oil consumption has no impact on gas consumption and therefore ESI_{volume} is unaffected. The impact on ESI_{price} is the largest in the Czech Republic, where ESI_{price} drops by 8.2% compared to 2030 values. This is due to the comparatively lesser importance of oil in the country's fuel mix. All other case study countries see a resulting drop in ESI_{price}, between 4.6% and 4.9% in 2030.

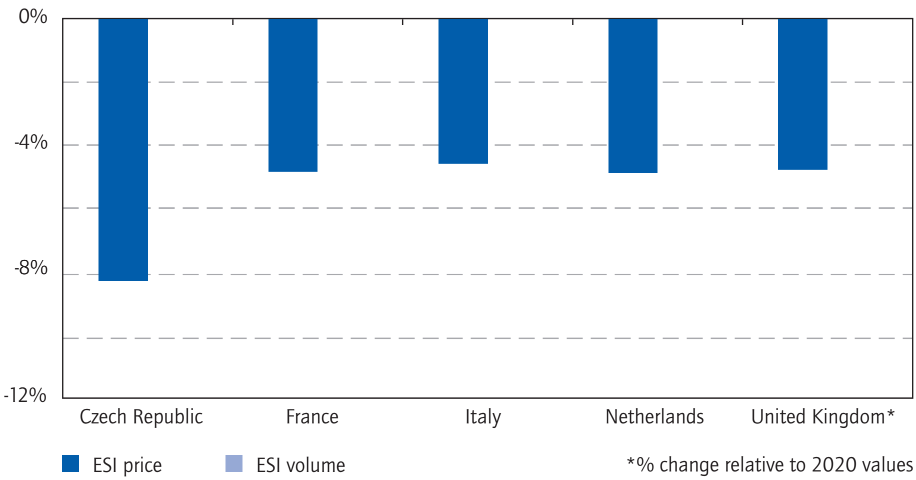
Increasing the use of biofuels

Biofuels can be used instead of oil in conventional vehicles. Ethanol can be used to displace gasoline up to 10% of fuel intake, while biodiesel can be used to entirely substitute conventional diesel with no modifications to engines.

While the biofuel itself is a renewable energy source which on a life-cycle basis does not generate any emissions when burnt, the transformation of biomass into

FIGURE 36

Change in 2030 ESI_{price} and ESI_{volume} compared to reference scenario values: 5% emissions reduction target reached through improved fuel efficiency in road transport



biofuels is generally energy-intensive, often requiring fossil fuel inputs. Therefore, a case which considers enhanced biofuel use should reflect the impact of displaced oil consumption as well as the consumption of other fuels in this transformation process.

A variety of possible pathways exist to produce biofuels with very different implications in terms of energy needs. It is difficult to define which approaches are likely to dominate in the five case study countries in 2030, as much depends on the evolution of technologies as well as developments in oil and process-by-product markets. We assume here that the most established approaches in 2004 are pursued to enhance the production of biofuels to 2030. The details of the underlying assumptions adopted in this simple exercise are listed in Box 3. Table 4 shows the impact on primary fossil fuel consumption of a 1Mtoe switch from oil to biofuels based on these assumptions.

Figure 37 shows the impact on final consumption in road-based transport of achieving the 5% CO_2 emissions reduction target in 2030 through a switch from oil to biofuels. The magnitude of the switch needed depends on the contribution of road-based transport in total emissions and ranges from 15% of consumption in 2030 in France to 42% in the Czech Republic.

Box 3

Assumptions adopted in the case of enhanced biofuel use in transport

Processing biomass into biofuels is assumed to take place domestically. Half of the biofuels used are in the form of ethanol, while the other half is biodiesel.

*The ethanol is assumed to be produced from wheat using a conventional natural gas boiler. Half of the by-product DDGS (Distiller's Dried Grain with Solubles) is used as animal feed while the other half is used as co-firing fuel in coal power stations. 0.75MJ of natural gas is needed in the ethanol plant to produce 1MJ of ethanol. 0.45MJ of coal is assumed to be displaced by DDGS for every 1MJ of ethanol produced.**

*Biodiesel is assumed to come from rapeseed. The by-product glycerine is used as a chemical. 0.12MJ of oil is needed at the processing stage to produce 1MJ of biodiesel.**

*Energy input requirements at other stages of the biofuel process (*e.g. *cultivation and transport to market) are not considered here.*

* The energy input data used is based on CONCAWE *et al.* (2006a; 2006b). See pathways *WTET1a* and *WTET1b* in the case of ethanol production and *ROFA1* in the case of biodiesel. Only fuel requirements at the processing stage are considered in this analysis.

Table 4

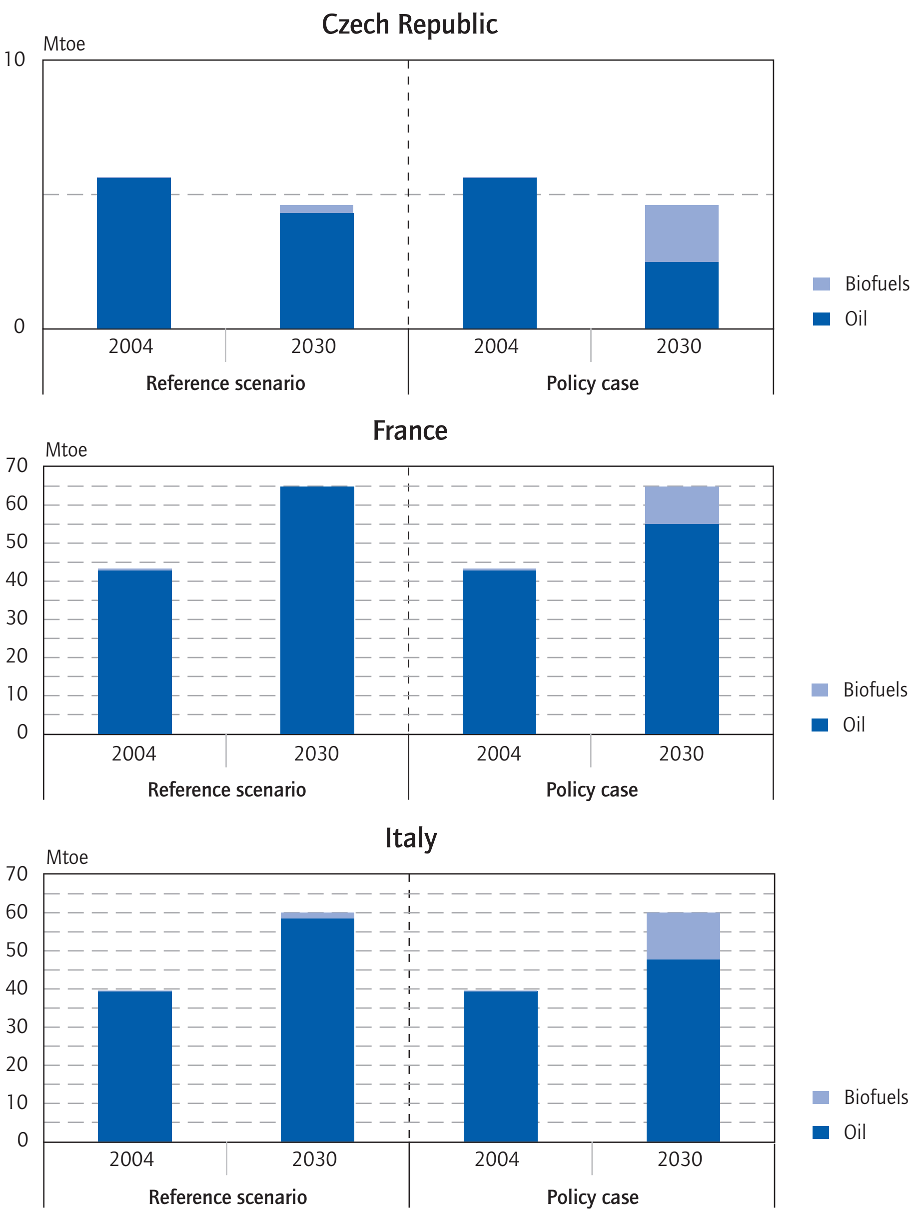
Impact on primary fossil energy consumption of switching 1 Mtoe of oil consumed in road transport to biofuels (Mtoe)

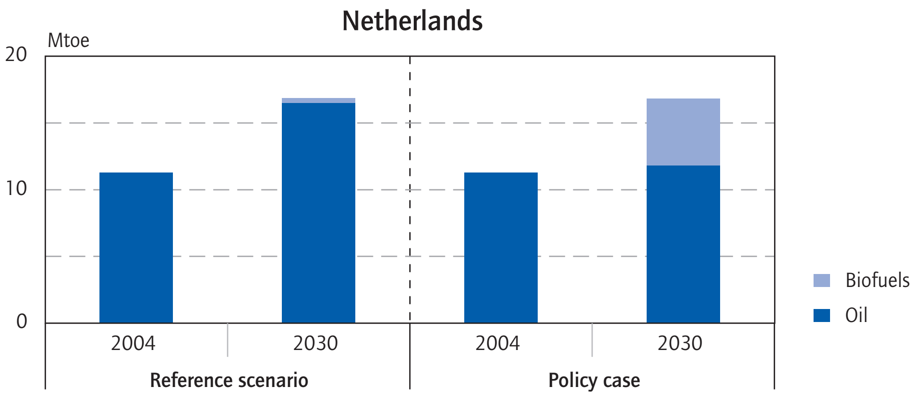
Oil[39]	– 1.03
Gas	0.38
Coal	– 0.11

39. Primary oil displaced.

Figure 37

Change in road-based transport fuel mix: 5% emissions reduction target reached through increased penetration of biofuels





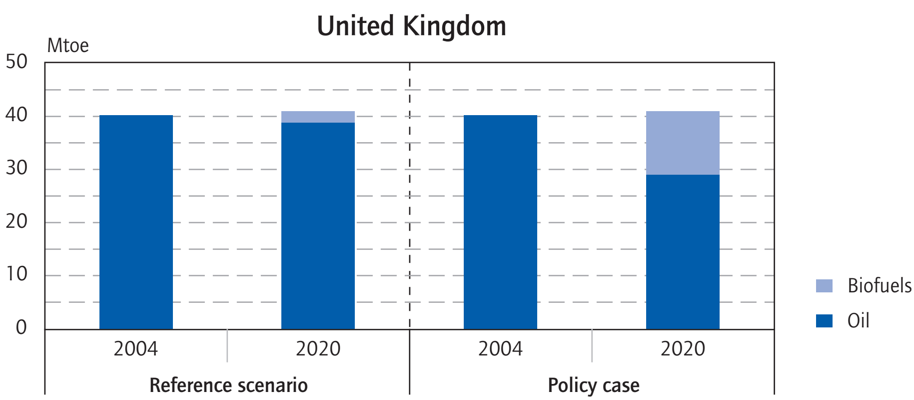
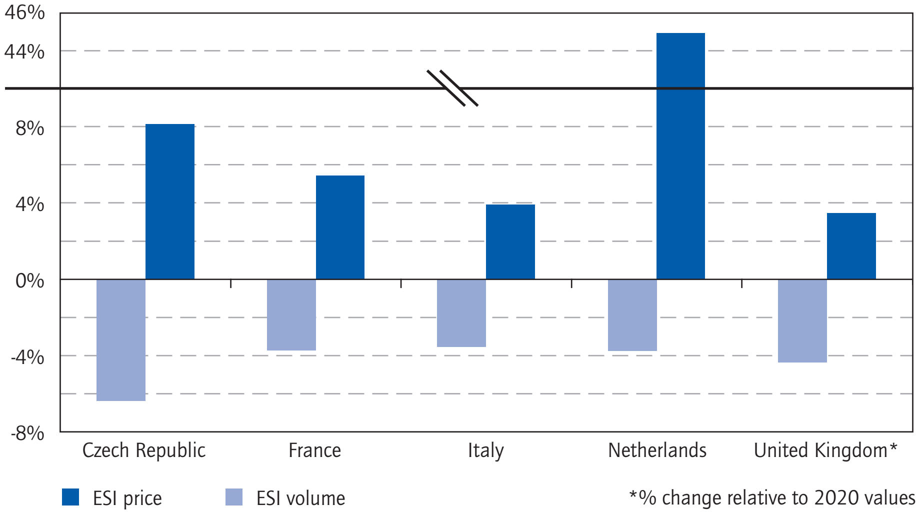


Figure 38 shows the resulting impact on ESI_{price} and ESI_{volume}. A switch from oil to biofuels has a positive effect on ESI_{price}, ranging from a reduction of 6.4% compared to the reference value in the Czech Republic, 4.4% in the UK and 3.5% in Italy. With regard to ESI_{volume}, due to the assumed use of gas in the transformation of ethanol, ESI volume increases to 8.1% in the Czech Republic, 5.4% in France, 3.9% in Italy and 3.5% in the UK. Due to the comparatively low ESI_{volume} value in 2030 in the reference case, the impact on ESI_{volume} in the Netherlands is comparatively much greater, increasing by approximately 45%.

Figure 38

Change in 2030 ESI_{price} and ESI_{volume} compared to reference scenario values: 5% emissions reduction target reached through a switch to biofuels in road transport



Summary

The adoption of a quantitative framework to assess policy impacts in terms of CO_2, ESI_{price} and ESI_{volume} allows identifying and gauging possible policy synergies and conflicts. This section provides an illustration of how specific climate policy mitigation measures in the electricity and transport sectors could affect the energy security outlook of various countries. For the sake of simplicity, all policy measures considered are compared against an identical 5% reduction in countries' emissions from baseline by 2030.

End-use efficiency improvements and an enhanced reliance on non-fossil fuel technologies (renewables or nuclear) in the electricity sector have positive impacts of similar magnitude on energy security. This can be explained by the similarity of the resulting underlying changes in fuel mix required to achieve a 5% reduction in emissions: a move away from coal and gas in power generation. Country specificities, however, imply different effects.

Achieving a 5% reduction in emissions through a switch from coal to gas, has a negative impact on both security indicators. Conflicting effects determine the change in ESI_{price}. On the one hand, due to lower concentration levels in the coal market compared to that of the oil market[40] a switch from coal to gas induces a negative effect on ESI_{price}. On the other, it reduces energy volumes required which lowers the exposure to concentration risks and therefore induces a positive effect on ESI_{price}. In contrast, the impact on ESI_{volume} is much more predictable.

Fuel efficiency improvements in transport lead to important benefits in ESI_{price}. Again, differences depend on the respective role of oil in each country case study, with a greater benefit for countries where oil represents a greater share of total consumption. These benefits are comparatively more significant in all countries than those obtained through energy efficiency improvements in electricity end-use efficiency due to the importance of oil in driving ESI_{price} trends.

Switching from oil to biofuels in transport has complex implications for energy security due to the energy needs of the transformation process involved. Based on assumptions adopted, the impact of a switch from oil to biofuels is a drop in ESI_{price} in 2030. The underlying contributions to ESI_{price} are, however, conflicting. On the one hand, the drop in oil and coal consumption lowers the exposure to oil and coal market risks which contributes to lower ESI_{price}. Yet, on the other, the enhanced consumption of gas leads to a greater share of consumption exposed to oil risks, which contributes to increase ESI_{price}. At the same time, due to enhanced gas requirements, ESI_{volume} increases in 2030 compared to baseline.

40. Remember that through oil-indexation gas is effectively exposed to the price risk of the oil market.

DISCUSSION

Methodology

Assessing energy security in terms of the potential welfare losses resulting from a change in the price or availability of energy is a daunting task. This alone may explain why references to energy security are so often loosely made and, on closer inspection, not robust. Consequently, providing an appropriate response to maintain or improve a country's energy security will always be challenging for governments. It is useful, as a first step, to draw a clear typology of energy security issues. In particular, this has allowed us to identify areas of potential policy overlap with climate mitigation efforts – the focus of this work.

Any analysis based on the use of indicators – here the evaluation of market concentration trends as a driver of energy security – rests necessarily on a number of simplifications. The approach itself, which distinguishes between the price and physical availability components of energy security and applies one or the other to the different international fossil fuel markets, is an important simplification. In reality, all markets are characterised in varying degrees by both components of energy security.

This is also true when looking at the energy security indicators. The measurement of the price component of energy security, for example, considers countries – not companies – as market participants. This may underestimate the role of the private sector in energy security concerns linked to resource concentration. Our indicator does not take this into account. The measure of the physical availability component of energy security, which we use for natural gas only, is based on pipe-based import dependence. This may be overly restrictive, as it does not account for the security benefits of importing gas from several pipelines rather than just one.

Nevertheless, these tools achieve the objective set at the onset of this study: to define a framework to undertake a systematic, quantitative evaluation of energy security and climate change mitigation. As with any similar approach, indicators are only a complement to expert judgment. In addition, we have endeavoured to explain systematically and transparently the assumptions made and how the indicators were defined, but these can be improved and completed in the future. This work is a stepping stone for future work on assessing energy security.

Case study results

The results of the case studies highlight how differences in fuel mix composition and gas sector organisation affect energy security and climate change profiles. In the reference projections for the five case study countries, the change in CO_2 emissions in 2030 compared to 2004 ranges from a drop of 27% to a rise of 38%. The change in ESI_{price} ranges from a rise of between 6% and 42%. Finally, the change in ESI_{volume} ranges from a rise of between 12% and 31% and ESI_{volume} emerges as a new concern in the UK and the Netherlands.

These results reflect a generally worsening trend in CO_2 emissions, ESI_{price} and ESI_{volume} in the five case studies and highlight the linkages between energy security and climate change mitigation. In particular, policies which were deemed acceptable either to reduce CO_2 emissions or to improve energy security may no longer hold when considered through the prism of an integrated climate-security energy policy. This is reflected in the various policy cases investigated. While energy efficiency in both the transport and electricity sectors and an enhanced penetration of non-fossil fuels in power generation lead to clear synergies between climate and security objectives, this is not necessarily the case of a switch from coal to gas or of an enhanced penetration of biofuels in the transport sector.

The quantitative framework defined determines precisely how each indicator changes and why. As seen in the latter two policy cases, changes in indicator levels can entail conflicting effects which could not be identified without the tools defined.

The policy analysis exercise presented in this report considered various individual policy actions, yet this framework could also be used to assess a mix of policy tools. Some interaction between various policies may emerge that are not reflected in the case studies illustrated.

Missing pieces

This analysis focuses on policies and measures that have direct impacts on both energy security and climate change indicators. However, many policy choices which do not directly affect the fuel mix may have important indirect effects. Policies which aim to enhance gas-based pricing to lower the physical availability component of energy security (ESI_{volume}, *i.e.*, the indicator linked to the oil-indexed delivery of gas), for example, are likely to lead to greater reliance on gas in the future. This, in turn, could have positive indirect repercussions on climate policy objectives if gas were substituted for more CO_2-intensive energy sources.

The same may be true for policies and measures that address other energy security policy drivers, in particular, regulatory failures. This may lead to a progressive shift in energy consumption patterns that could affect both the energy security and climate mitigation indicators considered here.

Policy costs are not taken into account in this assessment. To do so would entail indicators being applied to projections from a full macro-economic model. Such models are commonly used to assess the costs of climate change mitigation and may be used in the future to assess costs of achieving improvements in ESI_{price} or ESI_{volume}.

Nevertheless a number of preliminary lessons can be drawn based on results obtained. With regard to the electricity sector analysis, the similarity of effects obtained from enhanced end-use efficiency and from an increased use of non-fossil fuel technologies is all the more significant when considering implied costs of both approaches. Energy efficiency gains can often be achieved at no or only limited net costs while renewable energy policies, such as feed-in tariffs or portfolio standards, are often expensive on a per tonne of CO_2 avoided basis.

It should be stressed, however, that other aspects of energy policy are not directly considered. In particular, a strong rationale for promoting the diffusion of renewables is that costs are likely to decline due to learning effects and economies of scale – possibly down to a point where they become competitive. A longer-term assessment of costs may therefore lead to different implications. With regard to nuclear, cost implications hinge on the electricity market conditions and regulatory measures surrounding this activity (see IEA, 2006c).

The European focus of the study is also instructive regarding the EU Emissions Trading Scheme (ETS) in place since 2005. While the EU ETS could eventually drive important energy efficiency gains, including through rising electricity prices, analysts have long focused on its effects on fuel choice in power generation. This is essentially a switch from coal to gas, which as seen in this report, is not, under current gas market conditions, conducive to an overall improvement of countries' energy security. This study stressed the importance of complementing such measures with others that seek to promote energy efficiency – and to analyse the energy security implications of broad climate policy strategies, in order to take full account of possible policy interactions and compensating effects between policies.

ANNEX I: A REVIEW OF EXISTING QUANTITATIVE APPROACHES

The energy security implications of resource concentration have been a driver of energy policy in OECD countries for over a century[41] yet no standard approach has emerged on how to measure its evolution. The appreciation of the level of energy security at any given point in time has principally been a matter of expert judgment.

Nevertheless, two types of quantitative approaches have been used extensively by policy-makers and scholars. The first focuses on the notion of *diversity* while the second is based on a direct measure of *import dependence*. These, as well as hybrid approaches, are discussed below.

Measuring diversity

Diversity is broadly thought of as a hedge against uncertainty and has attracted much policy attention in the context of energy security. Yet while it seems relatively self-explanatory that the more diversified an energy system is, the less it is likely to be vulnerable to the disruption of one of its elements, on closer inspection a number of issues make the concept of diversity difficult to apply for energy security analysis. First, it is unclear what aspect of the energy system should be diversified and to what extent. Should the fuel mix of the country or that of a given sector, such as electricity generation or transport, be diversified? Should it be the mix of supplier countries for a given fuel or the types of technologies adopted for a given application? Second, while the concept of diversity is familiar to most, it is difficult to grasp in a formalised manner. Should diversity be defined by the number of options considered, their relative importance, their relationship to one another or a combination of these parameters (Stirling, 1993, 1998)?

For these reasons, the vast majority of references to diversity in relation to energy security have remained qualitative. Nevertheless, two quantitative approaches

41. The decision to switch from locally produced coal to imported oil to power vessels at the beginning of the 20th century in Europe and the US can be considered as the decision that for the first time brought energy security to the forefront of the global political agenda.

have been the object of substantial analysis and are potentially of significant policy relevance. They differ in the way they treat experience. The first considers that our experience and knowledge, with respect to most parts of the energy system, are limited and that *uncertainty*, *ambiguity* and ultimately *ignorance* prevail. The second considers that past events are a sufficiently robust guide to understanding future *risks* and that an approach based on probability theory can therefore be applied (Awerbuch *et al.*, 2004). Stirling (in Awerbuch *et al.*, 2004) provides a useful visual organisation of the relationship between *risk*, *uncertainty*, *ambiguity* and *ignorance*, reproduced in Table 5.

TABLE 5

Knowledge about likelihoods and outcomes and the resulting type and degree of uncertainty

		Knowledge about outcomes	
		Well-defined outcomes	**Poorly defined outcomes**
		Degree/type of uncertainty	
Knowledge about likelihoods	**Some basis for probabilities**	Risk	Ambiguity
	No basis for probabilities	Uncertainty	Ignorance

Source: Awerbuch *et al.* (2004).

Measuring diversity in a context of ignorance

The first approach considers that in fields such as industrial strategy, policy analysis or technology assessment, decisions are often large in scale, unique, take place in a complex and rapidly changing environment, or involve irreversible impacts, and that therefore decisions cannot be based on the attribution of specific probabilities. As a result, it assumes that ignorance prevails and that an approach based on the notion of diversity in its purest sense should be applied (Stirling, 1994, 1998).

The basic premise is that diversity provides greater strength to manage unforeseen events. When applied to energy policy, in the case of an unforeseen technical failure, for example, diversity minimises impacts and may even mean that an alternative technical solution is readily available. In theory, much of the energy system can be characterised by ignorance and diversity may therefore be sought at all levels. In reality, of course, one has to balance the benefits of diversity with other performance criteria.

Importantly, there is a fundamental difference between the notion of diversity and any other property of a portfolio of options. Environmental, financial and energy security considerations, for example, are all properties of both the portfolio and the individual options. Diversity in contrast, is a property of the energy system as a whole (Stirling, 1994).

In an extensive cross-disciplinary review of the literature on measures of diversity, Stirling (1998) identifies three basic properties of diversity:

- Variety*:* number of categories into which the quantity in question can be partitioned.
- Balance*:* pattern in the apportionment of that quantity across relevant categories.
- Disparity*:* nature and degree to which the categories differ from each other.

Stirling identifies a number of effective dual-property measures combining *variety* and *balance*, yet finds no metric in the literature that also captures *disparity.* He concludes that the characterisation of *disparity* is inevitably subjective and ultimately depends on the choice of particular performance criteria. Stirling (1998) devises his own Integrated Multi-criteria Diversity Index based on the characterisation of "disparity-space" following a given set of criteria which allows for the accounting of disparity.

A probabilistic approach

Most efforts which follow the second approach are based on Mean-Variance Portfolio theory, originally conceived by Markowitz (1952) as a way to manage risk and maximise performance of financial portfolios. The basic idea of Mean-Variance Portfolio theory is that while return on investments will always be uncertain, overall portfolio risks can be minimised by the combination of assets which have historically covariant returns.

The same logic is applied in the case of real energy assets: assets should not be considered in terms of their individual costs but in terms of portfolio cost. The rational is that in the same way as in financial portfolios, the combination of alternatives can minimise overall portfolio costs relative to risks (Awerbuch, 2000).[42]

Most efforts have focuses on fuel mix diversity in the electricity sector (Awerbuch and Berger, 2003; Awerbuch, 2005; Bar-Lev and Katz, 1976). Diversity of the fuel mix at the country level has only seldom been considered (*e.g.* Humphreys *et al.* (1998) in the case of the US).

In the studies of fuel mix diversity in the electricity sector, historical covariance of returns for different generating technologies is used as the basis for the analysis. This approach uses the information captured in the fluctuations of each technology return stream in the portfolio, whether due to technical failures, management errors, or a period of high fuel prices. While all cost components are considered in the analysis, fossil fuel prices are the defining element as historical price variability indicates the highest level of correlation. In the study of fuel mix diversity at the country level, Humphreys *et al.* (1998) notably only consider fuel prices in their portfolio analysis.

In sum, a probabilistic approach considers that while historic events may not be repeated, the type of events will recur and that this is a sufficient guide to the future.

Critique

The two approaches described above address the notion of diversity in opposite ways. A measure based on the idea that diversity, among other benefits, provides a hedge against ignorance is evidently appealing for its precautionary nature and has already attracted much policy attention. Yet in most cases, considering a state of ignorance seems overly restrictive particularly when factoring the implied costs of diversification. This then raises the question of what source of information should be used to decide upon a certain mix of options.

A probabilistic approach based on historic return covariance seems, however, inappropriate from an energy security policy perspective. Even when prices are set

42. There are however some theoretical limitations to the adoption of portfolio theory in the case of real assets. These stem mainly from the fact that portfolio theory assumes perfect market conditions. While such conditions don't exist in capital markets, it is even less the case in energy and associated energy technology markets (*e.g.* generating equipments) that are often long lived and comparatively inflexible. In addition, compared to financial securities, energy technologies are not indefinitely divisible so there are limits to the level of diversity within the portfolio (Awerbuch and Berger, 2003).

competitively, energy security concerns are, by definition, not appropriately reflected. Using past price correlation to inform fuel mix composition for energy security policy-making would therefore only capture an incomplete view of the problem. This is all the more true when prices are regulated as is the case in many regions of the world. In addition, the prospect of an unprecedented event with potentially irreversible implications calls for a more precautionary approach than one solely based on past price correlations.

So while an approach solely based on the inherent properties of diversity is overly restrictive, an alternative based on historic fuel price correlation is inappropriate. Stirling and Awerbuch, the main proponents of each of the approaches, have proposed combining the measures in a "full spectrum" analysis (Awerbuch *et al.*, 2004). While instructive, the analysis provides no guidance to policy-makers as to what should be the respective contribution of each approach in this combined measure. To some extent, this reflects the dilemma faced when quantifying diversity: there seems to be no workable compromise between an approach based on *risk* and one based on *ignorance*.

Import dependence[43]

To understand how *import dependence* emerged as a widely used measure when discussing the energy security implications of resource concentration, but also why it no longer appropriately captures all aspects of energy security, one must look at the evolving role of government in energy matters and in particular in the oil sector.

It is useful to distinguish three broad phases in oil history. The first phase, between the First World War and the 1950s, is characterised by significant oil discoveries around the world and the emergence of the Middle East as a particularly oil-rich region. European countries and the US secured access to these resources through a system of concessions and ensured industrial control of the upstream sector through either government stakes in oil companies – as in the case of the UK and France – or through close industry-government collaboration – the case of the US. This organisation effectively ensured security of supply to major demand centres around the world. Host governments of the Middle East had little power over the energy system. While they had the power to interrupt

43. Measured as the ratio of imported energy over total energy consumption.

supplies, this could easily be made up from other sources. In addition they ultimately depended on foreign oil companies to market their oil. By the early 1950s, the biggest concern in the oil sector was ultimately one of cartel-like behaviour by the seven largest private oil companies who had gained access to Middle Eastern resources (FTC, 1952).

The second phase takes place over the course of the 1960s and 70s when governments of oil-exporting countries progressively took control of the oil market from large private oil companies (Bohi D.R., M. Russel, 1978). This is epitomised by the creation of the Organisation of Petroleum Exporting Countries (OPEC) in September 1960. The aim of the organisation was to secure a greater share of oil revenues and to gain greater control of oil output levels. OPEC achieved its goal and gained control of both production levels and the determination of prices. By the 1970s the oil market had become a matter of state control, exemplified by the 1973 embargo on shipments of crude oil to the west, and in particular the USA and the Netherlands.

The third phase, which started in the early 1980s and continues today, is that of liberalised oil markets. This transition was spearheaded by a radical policy shift in the US towards the end of the 1970s (Noel P., 1999a). In a short time period the US government removed oil price regulations and allowed domestic crude oil prices to be aligned with the international oil market. This was followed by the progressive liberalisation of oil industries in Europe. As a result of this market organisation shift, in 1987 OPEC officially abandoned its price setting ambitions (Noel P., 1999b) confirming the creation of a truly international oil market.

Over these three phases the nature of energy security concerns linked to resource concentration radically changed. In particular, during the second phase depicted above, the oil sector in OECD countries was under strong regulatory control. Energy security concerns during this phase were predominantly about ensuring physical availability to meet growing domestic demand. To the extent that domestic resources (whether produced domestically or brought into the country by national entities and from secured sources) could be more safely relied upon than imports, a measure of import dependence constituted a good indicator of the risk of physical unavailability.

Through the removal of price regulation during the third phrase, however, domestic and international markets were effectively merged. As highlighted by Lichtblau (1994), there is “a single world export market with a single oil export price (after allowing for quality and freight differentials). Any disruption anywhere in this market large enough to affect world supplies causes the oil price to rise globally, including domestic crude oil prices". Any oil shortage within the global market is likely to affect all oil imports, and indeed all oil producers. Competitive pricing has minimised physical unavailability risks and energy security concerns have become dominated by concerns over cost-reflective pricing in the international oil market. The notion of import dependence has therefore become somewhat less relevant.

In sum, a measure of import dependence may be considered as an indicator of the energy security implications of resource concentration when a distinction can be made between domestic and foreign resources. This is the case in regulated market environments where physical unavailability risks prevail but not in liberalised market environments. In addition to the case of oil discussed above, coal is also traded internationally in a liberalised market environment. The price risk therefore also dominates energy security concerns, and the notion of import dependence is of limited use. In the case of gas, however, many regions of the world still have regulated natural gas prices or, as in the case of most OECD countries, prices indexed on oil. In this case, physical unavailability is a major concern and the notion of import dependence can be a useful measure of energy security.

Hybrid approaches

A number of studies have attempted to assess the energy security implications of resource concentration in fossil fuel markets in a quantitative manner by combining notions of diversity and import dependence. While these will suffer from the shortcomings of each approach, it is instructive to examine some of these efforts. Two are discussed below.

The first is a study commissioned by the Pacific Asia Regional Energy Security (PARES) project (Neff, 1997) which discusses the use of a selection of metrics to help gauge energy security in Pacific region countries. The first of these is a dual-property (variety-balance) diversity metric which Neff first applies to compare the diversity of the fuel mix of Pacific region countries to the mean global value. He considers five energy sources in his categorisation of fuel mix – coal, oil, gas, nuclear and hydro. Neff subsequently applies the same diversity metric to assess diversity of oil and uranium supply sources. In each case, he compares the maximum theoretical diversity of supply sources based on total global exports to the countries' diversity of supply based on actual imports.

In order to account for *risk,* Neff also proposes an innovative application of portfolio theory. In contrast to the more conventional applications in the energy field discussed above, Neff does not examine fuel mix portfolios based on historic price correlations but rather focuses on supplier portfolios for a given fuel based on historic production trends. He illustrates this approach by assessing the correlation of oil production data between individual OPEC countries during the 1990-1991 Gulf War.

Neff also considers systematic market risk (risks which affect the entire market) following a probabilistic approach. Here he proposes to correlate total market variances with that of supplies from individual countries.

This study offers two interesting variations to the diversity quantification approaches described previously. First, Neff considers both total fuel mix diversity and import source diversity. Second, he adopts probability theory to supplier portfolios based on production data. Arguably, however, this suffers from the same limitations as portfolio theory based on fuel prices: history may not repeat itself and past production covariance may not appropriately reflect producer interactions in the future.

In the second study (Jansen *et al.*, 2004)[44], the Energy Research Centre of the Netherlands (ECN) defines a macro indicator for long-run energy security. The analysis rests extensively on the work of Stirling (1998) discussed above. As in the work of Neff, the starting point of the analysis is a measure of fuel mix diversity at the country level based on a dual-property index. In this case however, eight fuel sources are considered: coal, oil, gas, nuclear, hydro, modern biofuels, traditional biofuels, and other renewables.

Jansen *et al.* propose to refine this basic fuel mix diversity measure by integrating a correction factor. The first adjustment is made to incorporate a measure of import dependence and import source diversity. There are therefore two ways of minimising the effect of this import factor: lowering import dependence or changing the country's import mix of fuel towards the most diverse possible mix.

44. The study was commissioned by the Dutch Environmental Assessment Agency in collaboration with the Bureau for Economic Policy Analysis in the scope of a long-term energy scenario study.

Jansen *et al.* propose two additional refinements to the basic fuel mix diversity metric. The first aims to account for the socio-political stability of exporting regions. This is done quite simply, by including a socio-political stability factor[45] in the measurements of import source diversity. The second aims to account for the role of resource depletion in the measure of energy security. The assumption here is that the market will respond to information on the evolution of proven reserves and primarily when the reserve to production ratio reaches a value below 50 years.

While the approach proposed by Jansen *et al.* is instructive for its attempt to combine various energy security concerns into a single indicator: fuel mix diversity, import dependence, political stability of trade partners, and resource depletion, it inevitably raises the question of balance between the different parameters considered (*e.g.* should resource depletion be given greater importance than diversity?). Arguably, this depends on the country's circumstances and should be fine-tuned on a case-by-case basis by experts yet inevitably the approach may be seen as overly complex. The approach also suffers from adopting questionable assumptions such as the 50-year threshold for the reserve to production ratio.

Summary

Historically, the assessment of energy security has been almost exclusively based on expert judgment. Two quantitative approaches are, however, commonly used by policy-makers and scholars to assess the energy security implications of resource concentration. The first focuses on the notion of diversity while the second focuses on measuring import dependence.

The notion of diversity is appealing in the context of energy security yet its practical quantitative application remains problematic. A precautionary approach to measuring diversity seems overly restrictive, yet a probabilistic approach based on observed price correlations is inappropriate for energy security policy analysis.

Focusing more specifically on the root causes of energy insecurity, however, provides an alternative on which to base a rigorous assessment of the energy security implications of various options. This is, to some extent, reflected in the

45. Jansen *et al.* propose to use the UNDP Human Development Indicator.

use of import dependence as a criterion to assess the energy security implications of resource concentration. However, the growing role of market forces in energy markets has meant that the notion of import dependence is now inappropriate in many cases.

Hybrid approaches, combining the notions of diversity and import dependence, inevitably suffer from these limitations. In addition, combining a number of different factors may be seen as complex, highlighting the need for simplicity and transparency when defining new indicators of energy security.

ANNEX II: ESI_{PRICE} CALCULATION INPUT DATA - REFERENCE SCENARIO ANALYSIS, 2004, 2030

Czech Republic, 2004

Total Primary Energy Supply (TPES) Total '000 toe	By fuel Type	By fuel '000 toe	Price structure Oil-indexed / gas-indexed	Exposure '000 toe	Source	Market share '000 toe	Market share %	ESMC
45,527	Oil	9,617		17402	OPEC	1,281,241	58	8,079
					Russia	327,645	15	522
					Norway	145,002	7	50
					Mexico	98,899	5	39
					Kazakhstan	47,942	2	11
		% of TPES		% of TPES	*All others*	*296,978*	*14*	*30*
		21%		**38%**	**TOTAL**	**2,197,708**	**100**	**8,731**
	Gas	7,786	100% / 0%	0	Algeria	4,802	35	3,157
					Qatar	3,185	23	864
					Oman	2,385	17	458
					Malaysia	1,232	9	139
					Nigeria	792	6	92
		% of TPES		% of TPES	*All others*	*1,447*	*10*	*74*
		17%		**0%**	**TOTAL**	**13,843**	**100**	**4,785**
	Coal	20,956		20,956	Australia	143,144	35	1,537
					China	60,301	15	469
					Indonesia	59,135	14	539
					South Africa	42,677	10	209
					Colombia	32,981	8	156
		% of TPES		% of TPES	*All others*	*74,265*	*18*	*143*
		46%		**46%**	**TOTAL**	**412,503**	**100**	**3,054**
	Nuclear and renewables	8,524		8,524				
		% of TPES 19%		% of TPES **19%**				
							ESI: 4,743	

Czech Republic, 2030

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
44,984	Oil	6,783		15453	OPEC	2,231,805	68	11,012
					Russia	393,946	12	339
					Kazakhstan	136,528	4	39
					Angola	93,531	3	22
					Mexico	59,279	2	6
		% of TPES		% of TPES	*All others*	*363,919*	*11*	*20*
		15%		**34%**	**TOTAL**	**3,279,009**	**100**	**11,439**
	Gas	8,670	100% / 0%	0	Qatar	24,425	19	561
					Norway	19,513	15	253
					Algeria	10,675	8	172
					Nigeria	9,232	7	139
					Malaysia	9,182	7	85
		% of TPES		% of TPES	*All others*	*58,639*	*45*	*346*
		19%		**0%**	**TOTAL**	**131,666**	**100**	**1,557**
	Coal	13,662		13,662	Australia	249,443	40	2,020
					Indonesia	115,410	18	889
					Colombia	64,639	10	259
					South Africa	61,457	10	188
					China	58,602	9	192
		% of TPES		% of TPES	*All others*	*77,630*	*12*	*137*
		30%		**30%**	**TOTAL**	**627,182**	**100**	**3,684**
	Nuclear and renewables	16,480		16,480				
		% of TPES 37%		% of TPES **37%**				
							ESI: 5,048	

France, 2004

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
275,169	Oil	92,133		132,301	OPEC	1,281,241	58	8,079
					Russia	327,645	15	522
					Norway	145,002	7	50
					Mexico	98,899	5	39
					Kazakhstan	47,942	2	11
		% of TPES 33%		% of TPES **48%**	*All others*	*296,978*	*14*	*30*
					TOTAL	**2,197,708**	**100**	**8,731**
	Gas	40,168	100%	0	Algeria	4,802	35	3,157
					Qatar	3,185	23	864
					Oman	2,385	17	458
			0%		Malaysia	1,232	9	139
					Nigeria	792	6	92
		% of TPES 15%		% of TPES **0%**	*All others*	*1,447*	*10*	*74*
					TOTAL	**13,843**	**100**	**4,785**
	Coal	14,052		14,052	Australia	143,144	35	1,537
					China	60,301	15	469
					Indonesia	59,135	14	539
					South Africa	42,677	10	209
					Colombia	32,981	8	156
		% of TPES 5%		% of TPES **5%**	*All others*	*74,265*	*18*	*143*
					TOTAL	**412,503**	**100**	**3,054**
	Nuclear and renewables	134,151		134,151				
		% of TPES 49%		% of TPES **49%**				
							ESI: 4,354	

France, 2030

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
339,400	Oil	107,600		175,000	OPEC	2,231,805	68	11,012
					Russia	393,946	12	339
					Kazakhstan	136,528	4	39
					Angola	93,531	3	22
					Mexico	59,279	2	6
		% of TPES 32%		% of TPES **52%**	*All others*	*363,919*	*11*	*20*
					TOTAL	**3,279,009**	**100**	**11,439**
	Gas	67,400	100% / 0%	0	Qatar	24,425	19	561
					Norway	19,513	15	253
					Algeria	10,675	8	172
					Nigeria	9,232	7	139
					Malaysia	9,182	7	85
		% of TPES 20%		% of TPES **0%**	*All others*	*58,639*	*45*	*346*
					TOTAL	**131,666**	**100**	**1,557**
	Coal	25,200		25,200	Australia	249,443	40	2,020
					Indonesia	115,410	18	889
					Colombia	64,639	10	259
					South Africa	61,457	10	188
					China	58,602	9	192
		% of TPES 7%		% of TPES **7%**	*All others*	*77,630*	*12*	*137*
					TOTAL	**627,182**	**100**	**3,684**
	Nuclear and renewables	139,200		139,200				
		% of TPES 41%		% of TPES **41%**				
							ESI: 6,171	

Italy, 2004

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
184,460	Oil	83,471		149,471	OPEC	1,281,241	58	8,079
					Russia	327,645	15	522
					Norway	145,002	7	50
					Mexico	98,899	5	39
					Kazakhstan	47,942	2	11
		% of TPES		% of TPES	*All others*	*296,978*	*14*	*30*
		45%		**81%**	**TOTAL**	**2,197,708**	**100**	**8,731**
	Gas	66,000	100%	0	Algeria	4,802	35	3,157
					Qatar	3,185	23	864
					Oman	2,385	17	458
			0%		Malaysia	1,232	9	139
					Nigeria	792	6	92
		% of TPES		% of TPES	*All others*	*1,447*	*10*	*74*
		36%		**0%**	**TOTAL**	**13,843**	**100**	**4,785**
	Coal	16,595		16,595	Australia	143,144	35	1,537
					China	60,301	15	469
					Indonesia	59,135	14	539
					South Africa	42,677	10	209
					Colombia	32,981	8	156
		% of TPES		% of TPES	*All others*	*74,265*	*18*	*143*
		9%		**9%**	**TOTAL**	**412,503**	**100**	**3,054**
	Nuclear and renewables	14,469		14,469				
		% of TPES		% of TPES				
		8%		**8%**				
							ESI: 7,349	

Italy, 2030

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
254,300	Oil	96,800		206,800	OPEC	2,231,805	68	11,012
					Russia	393,946	12	339
					Kazakhstan	136,528	4	39
					Angola	93,531	3	22
					Mexico	59,279	2	6
		% of TPES 38%		% of TPES **81%**	*All others*	*363,919*	*11*	*20*
					TOTAL	**3,279,009**	**100**	**11,439**
	Gas	110,000	100% / 0%	0	Qatar	24,425	19	561
					Norway	19,513	15	253
					Algeria	10,675	8	172
					Nigeria	9,232	7	139
					Malaysia	9,182	7	85
		% of TPES 43%		% of TPES **0%**	*All others*	*58,639*	*45*	*346*
					TOTAL	**131,666**	**100**	**1,557**
	Coal	14,300		14,300	Australia	249,443	40	2,020
					Indonesia	115,410	18	889
					Colombia	64,639	10	259
					South Africa	61,457	10	188
					China	58,602	9	192
		% of TPES 6%		% of TPES **6%**	*All others*	*77,630*	*12*	*137*
					TOTAL	**627,182**	**100**	**3,684**
	Nuclear and renewables	26,800		26,800				
		% of TPES 11%		% of TPES **11%**				
							ESI: 9,509	

Netherlands, 2004

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
82,147	Oil	31,955		68,690	OPEC	1,281,241	58	8,079
					Russia	327,645	15	522
					Norway	145,002	7	50
					Mexico	98,899	5	39
					Kazakhstan	47,942	2	11
		% of TPES		% of TPES	*All others*	*296,978*	*14*	*30*
		39%		**84%**	**TOTAL**	**2,197,708**	**100**	**8,731**
	Gas	36,734	100%	0	Algeria	4,802	35	3,157
					Qatar	3,185	23	864
					Oman	2,385	17	458
			0%		Malaysia	1,232	9	139
					Nigeria	792	6	92
		% of TPES		% of TPES	*All others*	*1,447*	*10*	*74*
		45%		**0%**	**TOTAL**	**13,843**	**100**	**4,785**
	Coal	8,703		8,703	Australia	143,144	35	1,537
					China	60,301	15	469
					Indonesia	59,135	14	539
					South Africa	42,677	10	209
					Colombia	32,981	8	156
		% of TPES		% of TPES	*All others*	*74,265*	*18*	*143*
		11%		**11%**	**TOTAL**	**412,503**	**100**	**3,054**
	Nuclear and renewables	3,360		3,360				
		% of TPES		% of TPES				
		4%		**4%**				
							ESI: 7,624	

Netherlands, 2030

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
105,480	Oil	44,380		80,030	OPEC	2,231,805	68	11,012
					Russia	393,946	12	339
					Kazakhstan	136,528	4	39
					Angola	93,531	3	22
					Mexico	59,279	2	6
		% of TPES 42%		% of TPES **76%**	*All others*	*363,919*	*11*	*20*
					TOTAL	**3,279,009**	**100**	**11,439**
	Gas	35,650	100%	0	Qatar	24,425	19	561
					Norway	19,513	15	253
					Algeria	10,675	8	172
			0%		Nigeria	9,232	7	139
					Malaysia	9,182	7	85
		% of TPES 34%		% of TPES **0%**	*All others*	*58,639*	*45*	*346*
					TOTAL	**131,666**	**100**	**1,557**
	Coal	21,300		21,300	Australia	249,443	40	2,020
					Indonesia	115,410	18	889
					Colombia	64,639	10	259
					South Africa	61,457	10	188
					China	58,602	9	192
		% of TPES 20%		% of TPES **20%**	*All others*	*77,630*	*12*	*137*
					TOTAL	**627,182**	**100**	**3,684**
	Nuclear and renewables	4,150		4,150				
		% of TPES 4%		% of TPES **4%**				
							ESI: 9,423	

United Kingdom, 2004

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
233,689	Oil	83,663		127,345	OPEC	1,281,241	58	8,079
					Russia	327,645	15	522
					Norway	145,002	7	50
					Mexico	98,899	5	39
					Kazakhstan	47,942	2	11
		% of TPES		% of TPES	*All others*	*296,978*	*14*	*30*
		36%		**54%**	**TOTAL**	**2,197,708**	**100**	**8,731**
	Gas	87,363	50%	43,681	Algeria	4,802	35	3,157
					Qatar	3,185	23	864
					Oman	2,385	17	458
			50%		Malaysia	1,232	9	139
					Nigeria	792	6	92
		% of TPES		% of TPES	*All others*	*1,447*	*10*	*74*
		37%		**19%**	**TOTAL**	**13,843**	**100**	**4,785**
	Coal	37,483		37,483	Australia	143,144	35	1,537
					China	60,301	15	469
					Indonesia	59,135	14	539
					South Africa	42,677	10	209
					Colombia	32,981	8	156
		% of TPES		% of TPES	*All others*	*74,265*	*18*	*143*
		16%		**16%**	**TOTAL**	**412,503**	**100**	**3,054**
	Nuclear and renewables	24,535		24,535				
		% of TPES		% of TPES				
		10%		**10%**				
							ESI: 6,142	

United Kingdom, 2030

Total Primary Energy Supply (TPES)			Price structure	Exposure	Source	Market share		ESMC
Total	By fuel		Oil-indexed / gas-indexed	'000 toe		*'000 toe*	*%*	
'000 toe	*Type*	*'000 toe*						
262,758	Oil	104,049		164,685	OPEC	1,810,146	63	9,577
					Russia	389,846	14	439
					Kazakhstan	115,571	4	37
					Angola	92,430	3	29
					Mexico	70,379	2	12
		% of TPES		% of TPES	*All others*	*373,386*	*13*	*26*
		40%		**63%**	**TOTAL**	**2,851,758**	**100**	**10,120**
	Gas	121,273	50%	60,637	Qatar	23,862	22	766
					Norway	18,897	17	339
					Algeria	10,146	9	223
			50%		Nigeria	6,782	6	107
					Malaysia	6,657	6	64
		% of TPES		% of TPES	*All others*	*43,766*	*40*	*262*
		46%		**23%**	**TOTAL**	**110,109**	**100**	**1,761**
	Coal	23,899		23,899	Australia	216,377	39	1,894
					Indonesia	100,031	18	832
					Colombia	58,269	10	236
					South Africa	54,510	10	184
					China	52,770	9	215
		% of TPES		% of TPES	*All others*	*79,845*	*14*	*149*
		9%		**9%**	**TOTAL**	**561,803**	**100**	**3,510**
	Nuclear and renewables	14,417		14,417				
		% of TPES 5%		% of TPES **5%**				
							ESI: 7,069	

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