CLIMATE CHANGE

Scientific Assessment and Policy Analysis

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Climate, energy security and innovation

An assessment of EU energy policy objectives

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An assessment of EU energy policy objectives

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Wetenschappelijke Assessment en Beleidsanalyse (WAB) Klimaatverandering

Het programma Wetenschappelijke Assessment en Beleidsanalyse Klimaatverandering in opdracht van het ministerie van VROM heeft tot doel:

- Het bijeenbrengen en evalueren van relevante wetenschappelijke informatie ten behoeve van beleidsontwikkeling en besluitvorming op het terrein van klimaatverandering;
- Het analyseren van voornemens en besluiten in het kader van de internationale klimaatonderhandelingen op hun consequenties.

De analyses en assessments beogen een gebalanceerde beoordeling te geven van de stand van de kennis ten behoeve van de onderbouwing van beleidsmatige keuzes. De activiteiten hebben een looptijd van enkele maanden tot maximaal ca. een jaar, afhankelijk van de complexiteit en de urgentie van de beleidsvraag. Per onderwerp wordt een assessment team samengesteld bestaande uit de beste Nederlandse en zonodig buitenlandse experts. Het gaat om incidenteel en additioneel gefinancierde werkzaamheden, te onderscheiden van de reguliere, structureel gefinancierde activiteiten van de deelnemers van het consortium op het gebied van klimaatonderzoek. Er dient steeds te worden uitgegaan van de actuele stand der wetenschap. Doelgroepen zijn de NMP-departementen, met VROM in een coördinerende rol, maar tevens maatschappelijke groeperingen die een belangrijke rol spelen bij de besluitvorming over en uitvoering van het klimaatbeleid. De verantwoordelijkheid voor de uitvoering berust bij een consortium bestaande uit PBL, KNMI, CCB Wageningen-UR, ECN, Vrije Universiteit/CCVUA, UM/ICIS en UU/Copernicus Instituut. Het PBL is hoofdaannemer en fungeert als voorzitter van de Stuurgroep.

Scientific Assessment and Policy Analysis (WAB) Climate Change

The Netherlands Programme on Scientific Assessment and Policy Analysis Climate Change (WAB) has the following objectives:

- Collection and evaluation of relevant scientific information for policy development and decision–making in the field of climate change;
- Analysis of resolutions and decisions in the framework of international climate negotiations and their implications.

WAB conducts analyses and assessments intended for a balanced evaluation of the state-of-the-art for underpinning policy choices. These analyses and assessment activities are carried out in periods of several months to a maximum of one year, depending on the complexity and the urgency of the policy issue. Assessment teams organised to handle the various topics consist of the best Dutch experts in their fields. Teams work on incidental and additionally financed activities, as opposed to the regular, structurally financed activities of the climate research consortium. The work should reflect the current state of science on the relevant topic.

The main commissioning bodies are the National Environmental Policy Plan departments, with the Ministry of Housing, Spatial Planning and the Environment assuming a coordinating role. Work is also commissioned by organisations in society playing an important role in the decision-making process concerned with and the implementation of the climate policy. A consortium consisting of the Netherlands Environmental Assessment Agency (PBL), the Royal Dutch Meteorological Institute, the Climate Change and Biosphere Research Centre (CCB) of Wageningen University and Research Centre (WUR), the Energy research Centre of the Netherlands (ECN), the Netherlands Research Programme on Climate Change Centre at the VU University of Amsterdam (CCVUA), the International Centre for Integrative Studies of the University of Maastricht (UM/ICIS) and the Copernicus Institute at Utrecht University (UU) is responsible for the implementation. The Netherlands Environmental Assessment Agency (PBL), as the main contracting body, is chairing the Steering Committee.

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Preface

This report holds the findings of the project ‘Climate, energy security and innovation’. The project was carried out between 1 January 2007 and 31 March 2008 by the Energy research Centre of the Netherlands (ECN), the Netherlands Environment Assessment Agency (PBL), and the Clingendael International Energy Programme (CIEP). It was commissioned by the Scientific Assessment and Policy Analysis programme for climate change (WAB).

The project was supervised by a Steering Committee including Merrilee Bonney, Frans Duijnhouwer and Caroline Keulemans, representing the Ministry of Public Housing, Spatial Planning and the Environment (VROM), Ronald Schillemans (Ministry of Economic Affairs (EZ), and Cees van Beers (Faculty Technology, Policy and Management, Delft Technical University), who the authors thank in particular for their worthwhile assistance.

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Abstract

The threefold objective for EU energy policies is the mitigation of climate change, the security of energy supply, and the promotion of the competitiveness of the EU economy. Possible synergies and trade-offs between the three related policy goals are discussed in this study by evaluating existing mitigation scenarios, insights from the innovation literature, insights into the potentials of and market barriers to innovative low carbon energy technologies, information on EU policies and measures to date, as well as EU external relations in the energy field. It is concluded firstly that the synergy between climate change mitigation, energy security and competitiveness suggested by the three-fold objective of EU energy policies is not straightforward. Secondly, current EU energy policies to stimulate (nearly) commercial and immature technologies are most likely insufficient to mitigate climate change and secure energy supply up to and beyond 2050.

Executive Summary

Objectives of EU energy policies are threefold: they need to contribute to a mitigation of climate change, a secure energy supply and to the competitiveness of the EU economy. There are reasons to believe that technological innovation will be key to the EU's competitive position. The objectives for energy policy were laid down in the Energy Policy Package proposed by the European Commission in January 2007 and endorsed by the European Council in the Conclusions to the Spring Council a few months later. This report unravels the synergies and trade-offs between climate change, energy security and technological innovation.

The rationale for joint policies for climate change mitigation, supply security and technological innovation

Greenhouse gas abatement policies are driven by the need to avoid the negative global impacts of climate change. A vast body of literature exists on these impacts, but estimations of climate change impacts and their economic value often do not grasp the full implications of extreme weather and possible regional collapses. Nevertheless, the financial implications of climate change impacts are presumed to exceed the costs of mitigating climate change, which by 2100 are on the order of several percents of global GDP per year. Therefore, mitigation costs could be used as a lower bound for the damage cost of climate change. The costs of past oil supply disruptions have been on the order of tenths of percents of GDP per year. That is, much lower than the expect damages caused by climate change.

Energy security has several dimensions. Short term disruption can be caused by events as technological failures, extreme weather or terrorism. Long term supply security regards the structure of an energy system, and may be affected by political instability, resource availability and geo-political relations. The availability of oil and gas at a reasonable and stable price is considered an important aspect of long term supply security for the effect it has on world economy. It has been estimated that world economy would have grown only tenths of percents per year more rapidly had oil and other energy prices not increased since 2002. Therefore, global economic impacts from climate change in the long term probably greatly exceed the regional economic implications of oil and gas supply disruptions in the short and medium term.

Many synergies exist between policies for climate change mitigation and energy security, materializing foremost in the potential contribution to both from a range of innovative energy technologies. Various reasons exist to believe that technological innovation will not only be beneficial to these two fields, but that it may also add to the competitiveness of countries and industries. These include a possible cost reduction, the exploitation of a competitive advantage, improved performance of traditional technologies, re-investment of saved costs, and an improved overall economic efficiency. Many consider it likely that further technological innovation will increase overall EU productivity. While this is a plausible scenario, empirical findings to date seem to provide little support for the claim that innovation of the energy system will actually improve competitiveness.

Nevertheless, there is no doubt that innovative energy technologies are fundamental to a transition to a low carbon economy. A wide range of technologies may be used that are in different stages on their way to market maturity: technologies in the R&D, demonstration, or upscaling stage as well as commercial technologies. Promising (nearly) commercial options include nuclear energy, bioenergy and wind. Furthermore, end use efficiency in buildings and appliances and in industry is an important option, as are second generation biofuels.

Finally, ethanol flex-fuel vehicles could be stimulated more, considering the maturity of the technology. In order to reduce emissions and secure energy supply for the medium and longer term various technologies for CO_2 capture and storage need to be stimulated. These are mostly in the demonstration phase.

An outlook on climate change policies, energy security and technological innovation

In order to provide a combined outlook for climate change mitigation, energy security and technological innovation two climate mitigation scenarios from the WETO-H2 study were analyzed: a reference and a carbon constraint scenario. These scenarios were selected because they were recent, consistent with the EU targets, sufficiently detailed and at the same time including global developments. The carbon constraint scenario reflects a global emissions trading regime. It foresees a share of 12% renewable energy by 2020, and includes the EU's objective to reduce CO_2 by 20% by then. In both scenarios the price of crude oil is assumed to remain close to 40 US$05 per barrel up to 2010 and increase thereafter to reach 60 US$05/b around 2025. Global CO_2 emissions in the reference and carbon constraint scenarios rise with respectively 70% and 48% by 2050 over 1990 levels. These emission levels were compared to other scenarios in the IPCC's Fourth Assessment Report. Scenarios that show a CO_2 emissions increase of 10 to 60% halfway this century over emissions in the year 2000 may lead to atmospheric CO_2 levels ranging from 485-570 ppm. The CO_2 emission increases in the WETO-H2 scenarios are on the same order and may result in atmospheric concentrations in that range.

For both scenarios energy security was assessed by quantifying the so-called Supply/Demand Index as well as oil and gas intensities of the economy and import dependencies. Both the demand and the supply side of energy security would benefit from a global regime. Nevertheless, a cost effective package of options to curb CO_2 emissions by 2050 to relatively low levels (around 50% of 1990 emissions) has only a modest impact on energy security. Primary energy supply would be more secure under such a regime due to a greater reliance on nuclear and renewable energy sources by 2050. Under global emissions trading oil and coal intensities of the EU economy in the long term are likely to decrease, as well as coal imports. Gas intensity how-ever would increase slightly compared to baseline developments. Care should be taken that an emissions trading regime will not result in too large a switch to natural gas technologies. Furthermore, the larger contribution of intermittent renewable energy to electricity production implies a larger risk of short term disruptions in a scenario with a more stringent global emissions regime climate.

The scenario analysis suggested that on the short to medium term (i.e., up to 2020) no technological breakthroughs are necessary in order to curb down emissions to a level sufficiently low to stabilize atmospheric CO_2 under 570 ppm. The IPCC found in its Fourth Assessment Report that this claim holds for lower atmospheric stabilization levels as well. However, effective policies to bring nearly commercial technologies to the market are fundamental, and on the long term (that is, up to 2050) ongoing technological innovation is essential to a transition to a low energy system.

EU energy policies and international cooperation for climate change mitigation and security of supply

In general, a number of ingredients are key to effective policies for a long term transition to a low carbon and energy secure economy. These include firstly a long term horizon to provide companies and consumers with confidence that investments in climate friendly technologies that also secure supply of energy eventually will be paid back. Secondly, a diverse portfolio of innovative and promising technologies should be encouraged to avoid excluding potentially successful technologies. Thirdly, path dependence should be considered. This may be complicated when for instance a standardisation of processes, long life-times of technologies or high investment costs trigger a lock-in to sub-optimal technologies. Fourthly, short term efficiencies gains in the present energy system must be maximised, including in particular a host of energy efficiency measures in all economic sectors. Finally, governments need to facilitate the development of promising technologies by providing financial support, creating niches for promising technologies, stimulating demand by standard setting or by providing economic incentives, and by promoting the exchange and diffusion of knowledge among stakeholders.

While the innovation literature tends to emphasize the above, economists consider flexible and market-based instruments essential for curbing greenhouse gas emissions. The EU Emission Trading System is therefore cornerstone of EU climate policies. In January 2008 the European Commission proposed a number of important modifications to the Emissions Trading Directive, which should lead to a strengthening and expansion of the scheme, including a single EU wide cap up to and beyond 2020, and extension of the scheme to new industries and gases. To what extent these measures will help in setting a sufficiently high and predictable price level will need to be evaluated in due time. Extension of the scheme to a global emissions trading regime, comprising all major emitting countries would enhance both its effectiveness and its cost-efficiency. Obviously, a limitation of the scheme is that it excludes sectors in which major CO_2 emission reductions are conceivable on respectively the short to medium and long term, including the residential and commercial sectors, as well as the transportation sector. Therefore, complementary policy instruments for stimulating specific technologies are necessary.

Although EU regulations other than the EU ETS cover a host of technologies, a number of gaps were identified in the existing policy mix. Firstly, no EU policies exist to assist in overcoming the high upfront costs that may be associated with realising large scale demonstrations of non-commercial technologies, notably CO_2 capture and storage. Secondly, at the EU-level no genuine cost incentives exist to promote technologies in non-ETS sectors, notably transportation. Thirdly, for many abatement technologies in the upscaling and commercialisation phase non-financial barriers need to be overcome. Barriers such as a lack of awareness or expertise among consumers could be overcome by measures such as standard setting and labelling in transport. Such measures could help to steer consumer behaviour during the purchase of cars. In brief, more emissions could be reduced in the short term if EU policies would be better tailored to address the barriers low carbon energy technologies face on their way to commercialisation, particularly in non-ETS sectors.

The EU in its external relations sends out an ambiguous message to fossil fuel exporting countries. On the one hand the EU seeks to assure gas and oil imports from producing countries on the short and medium term (i.e. up to 2030), and good relations with these countries are important to secure fossil supply from these countries. On the other hand, the EU tries to diversify its fossil imports away from these countries - also motivated by security of supply considerations. On the longer term the EU even wants to significantly reduce imports from these countries by pushing for a low-carbon economy. Neither investment in much needed new oil and gas technology in producing countries at this moment, nor their cooperation in a low-carbon energy transition on the longer term are efficiently stimulated in this way.

Samenvatting

Het energiebeleid in de Europese Unie beoogt drie doelstellingen te realiseren. Het dient bij te dragen aan een vermindering van klimaatverandering, aan een gewaarborgde energievoorziening en aan de concurrentiepositie van de Europese economie. Er zijn redenen om aan te nemen dat technologische innovatie van doorslaggevend belang zal zijn voor het concurrerend vermogen van de EU. De doelstellingen voor het energiebeleid staan omschreven in het Energiebeleidspakket dat in januari 2007 is gepresenteerd door de Europese Commissie en bekrachtigd door de Europese Raad in diens conclusies in het voorjaarsberaad een aantal maanden later. Dit rapport ontrafelt de synergieën en afwegingen tussen klimaatverandering, energiezekerheid en technologische innovatie.

De basis voor gemeenschappelijk beleid voor vermindering van klimaatverandering, voorzieningszekerheid en technologische innovatie

Broeikasgasreductiebeleid komt voort uit de noodzaak om de negatieve mondiale gevolgen van klimaatverandering te vermijden. Er bestaat voldoende literatuur over deze invloeden, maar inschattingen van de gevolgen van klimaatverandering en de bijbehorende economische waarde omvatten zelden de implicaties van extreme weers- en mogelijke regionale rampen. Er wordt echter verwacht dat de financiële gevolgen van klimaatverandering de kosten van vermindering van klimaatverandering zullen overstijgen. Deze zullen tegen 2100 in de orde liggen van verschillende procentpunten van het mondiale BBP per jaar. Daarom kunnen reductiekosten gebruikt worden als een ondergrens voor de kosten van de gevolgen van klimaatverandering. De kosten van eerdere onderbrekingen in de olievoorziening liggen in de orde van tienden van procentpunten BBP per jaar. Dat is veel lager dan de verwachte schade veroorzaakt door klimaatverandering.

Energiezekerheid kent verschillende dimensies. Onderbrekingen op korte termijn kunnen veroorzaakt worden door technologische storingen, extreme weersverschijnselen of terrorisme. Voorzieningszekerheid op lange termijn betreft de structuur van een energiesysteem en kan beïnvloed worden door politieke instabiliteit, beschikbaarheid van bronnen en geopolitieke relaties. De beschikbaarheid van olie en gas tegen redelijke en stabiele prijzen wordt beschouwd als een belangrijk aspect van lange termijn voorzieningszekerheid vanwege het effect van die prijzen op de wereldeconomie. Verwacht wordt dat de wereldeconomie tienden van procentpunten per jaar sneller gegroeid zou zijn als olie- en andere energieprijzen niet toegenomen waren sinds 2002. Om deze reden overschrijden mondiale economische invloeden van klimaatverandering op de lange termijn waarschijnlijk de regionale economische implicaties van onderbrekingen in de olie- en gasvoorziening op de korte en middellange termijn.

Er bestaan veel raakvlakken tussen beleid gericht op energiezekerheid enerzijds en dat gericht op een vermindering van klimaatverandering anderzijds. Deze worden voornamelijk zichtbaar in de potentiële toepassing van een scala aan innovatieve energietechnologieën. Er bestaan verscheidene redenen om aan te nemen dat technologische innovatie niet alleen voordelig zal zijn voor klimaat en voorzienigszekerheid, maar dat het ook de concurrentie tussen landen en industrieën zou kunnen stimuleren. Hieronder valt onder andere een mogelijke kostenreductie, de exploitatie van een concurrentievoordeel, verbeterde prestatie van traditionele technologieën, herinvestering van bespaarde kosten, en een verbeterde economische efficiency. Velen beschouwen het aannemelijk dat verdere technologische innovatie de productiviteit van de economie in de EU zal stimuleren. Hoewel dit een plausibel scenario is, lijken de huidige empirische bevindingen weinig houvast te bieden voor de claim dat innovatie van het energiesysteem de concurrentiepositie werkelijk zal verbeteren.

Er bestaat echter geen twijfel over het feit dat innovatieve energietechnologieën ten grondslag liggen aan de transitie naar een economie met een geringe koolstofintensiteit. Er is een breed scala aan technologieën beschikbaar die zich in verschillende stadia van marktrijpheid bevinden: technologieën in de R&D, demonstratie, of ontwikkelingsfase evenals commerciële technologieën. Veelbelovende (vrijwel) commerciële opties omvatten kernenergie, bioenergie

en wind. Daarnaast is verbetering van het rendement van gebouwen, apparatuur en industrie een belangrijke optie, net als tweede generatie biobrandstoffen.

Tenslotte zou het gebruik van zgn. ethanol flex-fuel voertuigen meer gestimuleerd kunnen worden. Om emissiereductie en energievoorzieningszekerheid op de middellange en lange termijn te realiseren, dienen verschillende technologieën op het gebied van CO_2-afvang en -opslag gestimuleerd te worden. Deze bevinden zich grotendeels in de demonstratiefase.

Een visie op klimaatbeleid, energiezekerheid en technologische innovatie
Om tot een geïntegreerde visie te komen op vermindering van klimaatverandering, verbetering van de energiezekerheid en technologische innovatie zijn twee scenarios uit de WETO-H2 studie geanalyseerd: een referentie- en een koolstofbeperkingsscenario. Deze scenarios zijn geselecteerd omdat zij actueel zijn, alsook consistent met EU-doelstellingen en voldoende gedetailleerd, en dat zij tegelijkertijd mondiale ontwikkelingen in ogenschouw nemen. Het koolstofbeperkingsscenario reflecteert een mondiaal emissiehandelsregime. Dit scenario gaat uit van een aandeel van 12% duurzame energie rond 2020 inclusief de EU-doelstelling om CO_2-uitstoot met 20% te reduceren. In beide scenarios wordt aangenomen dat de prijs van ruwe olie tot 2010 rond 40 US$05 per ton zal liggen en daarna zal toenemen tot 60 US$05/t rond 2025. Mondiale CO_2-emissies in de referentie- en koolstofbeperkingsscenarios nemen toe met respectievelijk 70% en 48% in 2050 vergeleken met 1990-waarden. Deze emissiewaarden worden in deze studie vergeleken met andere scenarios in het IPCC Fourth Assessment Report. Scenarios die een CO_2-emissietoename laten zien van 10 tot 60% halverwege deze eeuw over emissies in het jaar 2000 kunnen leiden tot atmosferische CO_2-waarden variërend van 485 tot 570 ppm. De CO_2-emissietoename in de WETO-H2 scenarios is van dezelfde orde en kan resulteren in vergelijkbare atmosferische concentraties.

Voor beide scenarios is de energiezekerheid beoordeeld door de zogenoemde Vraag/Aanbod Index te kwantificeren, alsmede de olie- en gasintensiteit van de economie en importafhankelijkheid. Zowel de vraag- als de aanbodkant van energiezekerheid zou profiteren van een mondiaal emissiehandelsregime. Desalniettemin heeft een kosteneffectief pakket van opties om CO_2-emissies tegen 2050 te reduceren naar relatief lage waarden (rond 50% van 1990-emissies) slechts een bescheiden invloed op energiezekerheid. De primaire energievoorziening zou beter gewaarborgd zijn onder een dergelijk regime wegens een grotere afhankelijkheid van nucleaire en duurzame energiebronnen rond 2050. Bij mondiale emissiehandel zouden olie- en kolenintensiteiten van de Europese economie op de lange termijn waarschijnlijk afnemen, net als kolenimport. De gasintensiteit zou echter licht toenemen in vergelijking met standaard ontwikkelingen. Een emissiehandelsregime zal echter niet resulteren in een grote omslag naar aardgastechnologieën. Daarnaast impliceert de grotere bijdrage van intermitterende duurzame energie aan electriciteitsproductie een groter risico op kortetermijnverstoringen in een scenario met een stricter mondiaal emissieregime.

De scenarioanalyse wees uit dat op korte tot middellange termijn (bijv. tot 2020) geen technologische doorbraken vereist zijn om emissies terug te brengen naar een niveau dat voldoende laag is om atmosferische CO_2 te stabiliseren naar 570 ppm of lager. De IPCC concludeerde in haar Fourth Assessment Report dat deze claim ook geldt voor lagere atmosferische stabilisatieniveaus. Echter, effectief beleid om bijna commerciële technologieën op de markt te brengen is noodzakelijk, en op de lange termijn (tot 2050) is voortdurende technologische innovatie essentieel voor een transitie naar een energiezuinig systeem.

EU energiebeleid en internationale samenwerking voor vermindering van klimaatverandering en voorzieningszekerheid
Een aantal ingrediënten is over het algemeen sleutel tot een effectief beleid voor een langetermijntransitie naar een koolstofextensieve en energiezekere economie. Ten eerste is dat een lange termijn horizon om bedrijven en consumenten het vertrouwen te bieden dat investeringen in klimaatvriendelijke technologieën die bijdragen aan de energievoorziening zichzelf uiteindelijk terugbetalen. Ten tweede zou een gevarieerde portfolio met innovatieve en veelbelovende technologieën gestimuleerd moeten worden om het uitsluiten van potentieel succesvolle technologieën tegen te gaan. Ten derde zou zgn. padafhankelijkheid in overweging genomen moeten worden. Dit kan complicaties met zich meebrengen wanneer bijvoorbeeld een

standaardisatie van processen, lange levensduur van technologieën of hoge investeringskosten een lock-in veroorzaken van suboptimale technologieën. Ten vierde moet de energie-efficiëntie in het huidige energiesysteem op de korte termijn gemaximaliseerd worden, door met name een scala van energie-efficiënte maatregelen in alle economische sectors. Ten slotte dient de overheid de ontwikkeling van veelbelovende technologieën te faciliteren door financiële ondersteuning te bieden, niches voor veelbelovende technologieën te creëren, de vraag ernaar te stimuleren door standaardisering of door economische impulsen, en door de uitwisseling en diffusie van kennis tussen belanghebbenden te stimuleren.

Hoewel de innovatieliteratuur ernaar neigt om de nadruk te leggen op bovengenoemde aspecten van het energiebeleid, beschouwen economen flexibele en marktinstrumenten essentieel voor het beperken van broeikasgasemissies. Het EU emissiehandelsysteem (EU ETS) wordt daarom beschouwd als de hoeksteen van EU klimaatbeleid. In januari 2008 heeft de Europese Commissie verschillende belangrijke aanpassingen voorgesteld met betrekking tot de emissiehandelrichtlijn, welke zouden leiden tot een versterking en uitbreiding van de doelstelling, inclusief een plafond voor de gehele EU tot en hoger dan 2020, en uitbreiding naar nieuwe industrieën en gassen. Tot op welke hoogte deze maatregelen zullen bijdragen aan het vaststellen van een voldoende hoog en voorspelbaar prijsniveau zal te zijner tijd geëvalueerd moeten worden. Uitbreiding van de doelstelling naar een mondiaal emissiehandelsregime, bestaande uit alle grote emitterende landen, zou de effectiviteit en de kostenefficiëntie bevorderen. Uiteraard is een beperking van de doelstelling dat deze sectoren buitensluit waarin omvangrijke CO_2-emissiereducties op respectievelijk de korte tot middellange en lange termijn denkbaar zijn, inclusief de residentiële en commerciële sector en de transportsector. Daarom zijn aanvullende beleidsinstrumenten om specifieke technologieën te stimuleren noodzakelijk.

Hoewel EU beleidsmaatregelen buiten het EU ETS verscheidene technologieën beoogt, zijn een aantal hyaten geïdentificeerd binnen de bestaande beleidsmix. Ten eerste bestaat er geen EU-beleid dat bijdraagt aan het overkomen van de hoge investeringskosten die het realiseren van grootschalige demonstraties van niet-commerciële technologieën met zich meebrengt, vooral CO_2-afvang en -opslag. Ten tweede bestaan er op EU-niveau geen substantiële kostenmaatregelen om met name transportgerelateerde technologieën in sectoren die buiten het EU ETS vallen, te promoten. Ten derde stuiten vele reductietechnologieën in de ontwikkelings- en marktrijpe fase op niet-financiële barrières. Barrières zoals een gebrek aan bewustzijn of ervaring bij consumenten zouden tegengegaan kunnen worden met behulp van maatregelen als standaardisering en prestatielabels in transport. Dergelijke maatregelen zouden kunnen helpen om consumentengedrag te sturen bij de aankoop van voertuigen. Kortom, een grotere emissiereductie op korte termijn kan worden bereikt als EU-beleid beter toegerust zou zijn om de barrières het hoofd te bieden waar koolstofarme energietechnologieën op stuiten op weg naar marktrijpheid, met name in sectoren buiten het EU ETS.

Tot slot communiceert de EU een tweeledige boodschap in haar externe relaties met landen die fossiele brandstoffen exporteren. Enerzijds streeft de EU ernaar om gas- en olieimporten uit producerende landen op de korte- en middellange termijn (i.e. tot 2030) te verzekeren, en goede verhoudingen met deze landen zijn van belang om de fossiele voorziening uit deze landen te waarborgen. Anderzijds probeert de EU haar fossiele import uit deze landen weg te diversifiëren – mede gemotiveerd door overwegingen op het gebied van voorzieningszekerheid. Op de langere termijn beoogt de EU zelfs de import uit deze landen substantieel te reduceren door een koolstofextensieve economie te promoten. Op deze manier worden noch investeringen in noodzakelijke nieuwe olie- en gastechnologie in producerende landen, noch de samenwerking met deze landen om tot een koolstofarme energietransitie op de langere termijn te komen, efficiënt gestimuleerd.

1 Introduction

Headlines of existing EU policies were proposed by the European Commission (EC) in the EU energy policy package in January 2007 (EC, 2007a) following a green paper on sustainable, competitive and secure energy (EC, 2006a). Ideally, such policies would contribute to mitigating climate change and enhance the security of energy supply at a reasonable cost. In addition, energy policies should contribute to a stronger competitive position of the European Union. Policy objectives were formulated in qualitative and quantitative terms for climate change mitigation, security of supply (Table 1.1). In January 2008, the EC tabled a number of proposals to should help to meet the formulated policy targets. These included an improved emissions trading system, an emission reduction target for sectors not covered by the ETS, and legally enforceable targets for increasing the share of renewable energy (see Section 4.3).

With regard to *climate change mitigation* quantitative targets were set in the 2007 Energy Policy Package. Greenhouse gas emissions should be reduced by 20%, and by 30% if other countries commit themselves to reduction targets as well. Additional targets have been set for renewable energy sources, biofuels and energy efficiency: 20% renewables in 2020, 10% biofuels in 2020 and 20% energy efficiency. The former two are binding, the latter is not. No official reduction objectives are set for the long term, although it has been recognised that reductions on the order of 60-80% halfway this century are needed for the EU to ready the 2°C target (EC, 2007b).

As to *security of supply* policy objectives in the Energy policy package (EC, 2007a) are qualitative and emphasise the importance of the internal energy market, external energy relationships, and mechanisms to ensure Member States solidarity. Fears for lack of supply security in Europe mainly refer to the increasing dependence on gas imports, which are expected to rise from a current 50% to 80% in 2020 (IEA, 2007a). The EU's fossil fuel dependence was demonstrated by incidents like the temporary cut-off of Russian gas supplies to the Ukraine beginning 2007 or the Russia-Belarus energy conflict at the beginning of 2007. Fears that energy will be used as a political lever by producing countries has put security of supply high on the European policy agendas (Tönjes, 2007). However, in the Energy Policy Package no timelines or specific actions were set for actions to improve supply security.

With respect to *competitiveness*, the proposal claims that a competitive market will inevitably lead to improved energy efficiency and investments. No specific actions or timelines were proposed in this respect.

The policy context for the competitiveness objective was set by the so-called Lisbon Agenda that was initiated at the Lisbon Council in 2000 to focus on growth and employment, was broadened to include sustainable development as an aspiration at the Gothenburg Council (2002), and was re-launched at the European Council in March 2005 refocusing priorities on jobs and growth. Competitiveness is a policy goal with two dimensions. On the one hand it refers to the aspiration to establish liberalised internal gas and electricity markets for power and gas, which materialised again in the Third Legislative Package on electricity and gas markets (EC, 2007c), on the other hand it regards the EU leadership in the market for renewable technologies. In the long run a range of innovative energy technologies may contribute to simultaneously curbing greenhouse gas emissions and improving the security of energy supply (e.g. MNP, 2004; MNP, 2006; Bradley and Lefevre, 2006) including energy efficiency technologies, capture and storage of CO_2 from coal-fired power generation, renewable energy sources, including biofuels in transport, and nuclear energy. The challenge for energy policies stimulating such technologies is to advance the transition towards low carbon energy systems that are no longer primarily based on fossil fuels. However, while further innovation and market diffusion of energy technologies are vital to accomplish emission reductions and to warrant supply security in the long term, it is uncertain if the presumed benefits for competitiveness will all materialise.

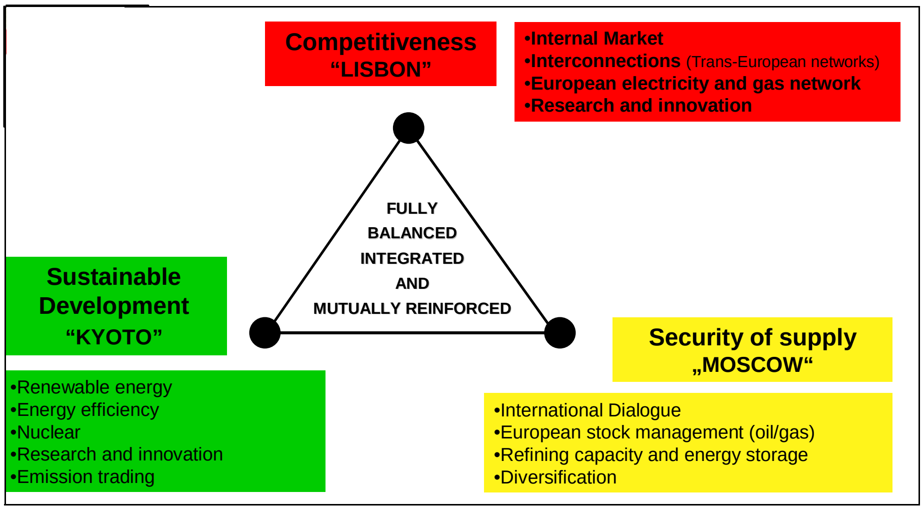
Table 1.1 EU policy objectives for climate change, security of supply and competitiveness

Climate change mitigation	"Energy accounts for 80% of all greenhouse gas (GHG) emission in the EU; it is at the root of climate change and most air pollution. The EU is committed to addressing this - by reducing EU and worldwide greenhouse gas emissions at a global level to a level that would limit the global temperature increase to 2°C compared to pre-industrial levels."…
	"An EU objective in international negotiations of 30% reduction in greenhouse gas emissions by developed countries by 2020 compared to 1990. In addition, 2050 global GHG emissions must be reduced by up to 50% compared to 1990, implying reductions in industrialised countries of 60-80% by 2050"…
	"An EU commitment now to achieve, in any event, at least a 20% reduction of greenhouse gases by 2020 compared to 1990."
Security of supply	"An effectively functioning and competitive Internal Energy Market can provide major advantages in terms of security of supply and high standards of public service."
	"The EU has effective energy relationships with traditional gas suppliers from inside the European Economic Area (EEA), notably Norway and outside, Russia and Algeria. The EU is confident that these relationships will strengthen in the future. Nevertheless, it remains important for the EU to promote diversity with regard to source, supplier, transport route and transport method. In addition, effective mechanisms need to be put into place to ensure solidarity between Member States in the event of an energy crisis."
Competitiveness	"A competitive market will cut costs for citizens and companies and stimulate energy efficiency and investment."
	"Boosting investment, in particular in energy efficiency and renewable energy should create jobs, promoting innovation and the knowledge-based economy in the EU."

Source: EC, 2007a.

Following the EC proposal, the European Council attached to its March 2007 Council Conclusions an action plan for European energy policy in the 2007-2009 period. The Action Plan comprises a number of priority actions, summarised in Table 1.2. Five priority actions are distinguished, which to some extent overlap. In the long list of actions measures to advance technological innovation only take up a minor share. While the importance of new technologies is underlined, the only action formulated to promote technological innovation is to strengthen R&D and the technical, economic and regulatory framework for CO_2 capture and storage by 2020.

Table 1.2 demonstrates that external relations have an important role in EU energy policy, in particular in securing energy supply. Strategic interests in gas and oil mainly stem from the fact that production and consumption of these fossil fuels are concentrated different geographical areas, while many oil- and gas companies are under close state control. While the main source of income of many fossil fuel producing countries is from the production of fossil fuels, they are engaged a lot less in international efforts to reduce greenhouse gas emissions, or in co-operative agreements to stimulate innovative energy technologies. EU Partnerships aimed at gas emission reduction and technology transfer are rather with countries where energy consumption is either large or growing sharply, including the US, China, India and Brazil.



Source: EC, 2007d

Figure 1.1 Schematic overview of main topics concerning the three EU energy policy objectives

Figure 1.1 depicts an EC diagram summarizing the various policy objectives. While listing a number of commonly used keywords, it does not provide insight into how exactly the various policy objectives interact and how synergies between policies to realise the objectives may materialise. The overall objective of having a ‘fully balanced, integrated and mutually reinforced’ energy policies in place will prove challenging.
This report aims to unpack the possible synergies and trade-offs between the three related policy goals, so as to arrive at recommendations for such policies. Obviously, those policies that jointly maximise all objectives are most attractive to policy makers. An obvious way to identify such policies would seem to quantify and compare costs and benefits of policies for climate change, supply security and technological innovation. This is not straightforward however. While the estimation of costs of policies may pose a range of methodological problems, the assessment of benefits for climate change mitigation, supply security and innovation is even more complex. A chief problem relates to the measurements of the various impacts of policies, in particular relating to energy security or technological innovation. Not only are these difficult to measure, the time scale at which benefits will become apparent also differs. Improvements in supply security through a reduced fossil fuel dependency will become visible within decades, but reduced impacts of climate change will take more time to become apparent.

For these reasons, this project will not seek to carry out an all-encompassing cost-benefit analysis that would provide insight into the costs of energy policies and their benefits for the global climate, EU energy security, and the EU’s competitive position. Instead, this project endeavours to shed light on the interactions between climate change mitigation policies, energy security and the role of innovative energy technologies therein. In particular, the study will:

1. Analyse the interactions between policies for climate change mitigation, energy security, and innovation and competitiveness.
2. Provide an outlook for climate change mitigation, long term energy security, and innovation and competitiveness.
3. Explore design options for European energy policies.

The study will focus on policies at the EU level and have a long term perspective, i.e. up to 2050. Climate change policies are taken as the starting point. The report sets out in *Chapter 2* with a discussion of the relative importance of climate change mitigation and energy security policies and a brief scan of costs and benefits of both climate change policies and supply security policies (Sections 2.1-2.3). This chapter also addresses the role of technological innovation in energy policies (2.4), including the implications of innovations for competitiveness, the challenges ahead, and the barriers to a further development of promising low carbon energy technologies. The table ends with an overview of the contribution of a range of innovative energy technologies to GHG emission reduction and energy security. In *Chapter 3* an outlook is presented on climate change policies, energy security and technological innovation. This outlook is based on two scenarios prepared for the European Commission, including a reference and a climate mitigation scenario (3.1). Using a number of indicators, including the Supply/Demand index (3.2) energy security in each of these scenarios is quantified and discussed (3.3). Next, the role of a host of technologies in the scenarios is assessed (3.4). *Chapter 4* then discusses EU energy policies and possibilities for international cooperation for climate change mitigation and security of supply. The need of an effective emissions trading scheme as well as complementary energy policies is discussed (4.2). Next, the present EU energy policy mix is evaluated in the light of all the energy technologies that need to be stimulated (4.3). Finally, the chapter assesses the possibilities for improving external relations with respect to energy and climate issues (4.4). The report ends in *Chapter 5* with a number of conclusions based on the report, and relevant policy recommendations.

Table 1.2 Priority actions and key points in European energy policy 2007-2009; European Council March 2007

Priority action	Key elements
Internal market for gas and electricity	– Implementation of legislation on opening up of energy markets – Appropriate investment signals, including development of regulatory framework – Separation of supply and production (unbundling) – Independence national energy regulators – Co-operation national regulators – Coordination network operation
Security of supply	– Diversification – Crisis response mechanisms – Transparency of data on oil stocks and supplies – Analysis of potential and costs of gas storage – Assessment of impact energy imports on MS supply securities – Establishment of Energy Observatory
International energy policy	– Negotiating of partnerships and cooperation agreements with Russia; – Strengthen relationships Central Asia, Caspian and Black Sea regions; – Intensify partnerships US, China, India, Brazil, and others for reducing GHG, energy efficiency, renewables, CCS; – Implement Energy Community Treaty, with possible extension to Norway, Turkey, Ukraine, Moldova – Use all instruments under the European Neighbourhood Policy – Enhance relationships Algeria, Egypt, others in Mashreq/Maghreb region – Build dialogue with and enhance decentralised renewables and energy access in Africa – Promote energy access in context of UN-CSD
Energy efficiency and renewable energies	– 20% efficiency improvement over 2020 level – Five priorities: transport, dynamic efficiency requirements of equipment, consumer behaviour , technology & innovations, buildings – Commission proposals for efficient lighting regulation – International negotiations for sustainable production and trade in efficient goods and services – Review of guidelines for State Aid – 20% renewables by 2020 – 10% biofuels by 2020 – Aim for framework with differentiated national targets and national action plans, and provisions for sustainable biomass production – Implementation Biomass Action Plan, especially for demonstration of 2nd generation biofuels – Analysis of potential for cross-border and EU-wide synergies and interconnection for reaching renewable target – Exchange of best practices
Energy technology	– Importance of generation efficiency and clean fossil fuel technologies – Strengthen R&D and technical, economic and regulatory framework for CCS by 2020 – Welcomes Commission’s intention of mechanism to stimulate realisation of up to 12 demonstration of sustainable fossil fuel technologies

2 The rationale for joint policies for climate change mitigation, supply security and technological innovation

2.1 Introduction

Analysing the interaction between the three main objectives of the European energy policy is not straightforward. It requires comparing phenomena that are hard to quantify and occur on widely different temporal and spatial scales. Although some of the effects of climate change are already evident the full consequences of a global temperature raise will not be fully apparent before the end of the century. Such a long timescale introduce a considerable uncertainty in estimating the magnitude of the adverse effects in different regions of the world. Moreover, in order to determine a course for action it is necessary to assign a present value to events far removed into the future and often hardly quantifiable.

The after effects of energy dependence pertain to different spatial and temporal dimensions. Supply disruptions such as blackouts and weather-related events are generally short-lived (lasting few hours or few days) and the consequences are experienced on a local or regional scale. Long-lasting supplies constrains, such as a persistently high and volatile oil prices, can have global consequences that last several years (e.g., economic downturns or geopolitical effects). Little interactions exist between short-term disruptions and climate change policies. On the other hand, some overlap may be detected between medium-term security of supply goals and climate change mitigation policies. While it is generally difficult to quantify the macroeconomic and geopolitical costs of energy dependence they generally outweigh greatly the economic consequences of short-term disruptions.

Similarly, it is not straightforward to evaluate the social and economic benefits of technological innovation. It is assumed that the technological changes stimulated by strong energy policies will bring about economic growth and new employment opportunities while stimulating growth. Indeed, renewable energy industries, such as wind energy and PV, have booked record growth in recent years. However, the overall impact on the economy of a transition to a low carbon energy system is still unclear. Decarbonising the economy will require both developing new technologies and implementing readily available low-tech solutions on a wide scale. The timeframe for deployment, the reduction potential and the interaction with the other policy objectives depends greatly on the technology considered.

If follows that an evaluation of the costs and benefits of climate change mitigation, energy security and innovation in a single framework is virtually impossible. Nevertheless, this chapter sets out to discuss the costs and benefits of policies for climate change mitigation and energy security, and the role of innovative energy technologies might play in this respect. Section 2.2 (and subsections within) reviews the estimates available in literature of the economic and social costs of climate change world wide. In Section 2.3 the various dimensions of energy security are analysed in order to quantify the consequences of disruption in energy supplies. Section 2.4 analyses the role of technological innovation in economic development and the barriers that prevent market penetration of alternative energy technologies. In Section 2.5 the synergy and trade-offs between different low-carbon technologies are examined.

2.2 Costs and benefits of climate change mitigation

2.2.1 Global impacts from climate change

A vast body of literature, by now allows for a better understanding of the implications of the predicted changes in the climate (Stern, 2007; Parry *et al.,* 2007). Some of the future repercussions that are considerate likely or very likely include:

- Impacts to the water cycle with melting of small glaciers, potential decrease of water availability in vulnerable regions, increased risk of serious drought in the south of Europe, disappearance major glaciers in the Himalaya affecting a large number of people in India and China.
- Changes in the food chain such as increased cereal yield in temperate regions, sharp decline in crop yield in tropical regions, acidification of the ocean with impacts on fisheries.
- Repercussion on human health: increase of mortality due to heat waves, exposure to malaria and other tropical diseases, malnutrition.
- Impacts on the land like permafrost towing, costal flooding, loss of dry land.
- Changes to the large ecosystems: bleaching of coral reefs, loss of artic tundra, extinction of a large number of species.
- Catastrophic events such as loss of the thermohaline circulation, complete melting of the Greenland ice sheet, complete melting of the West Antarctic ice sheet.
- Disproportionate effects on vulnerable regions and developing countries, depending in a non linear way on the global temperature increase.

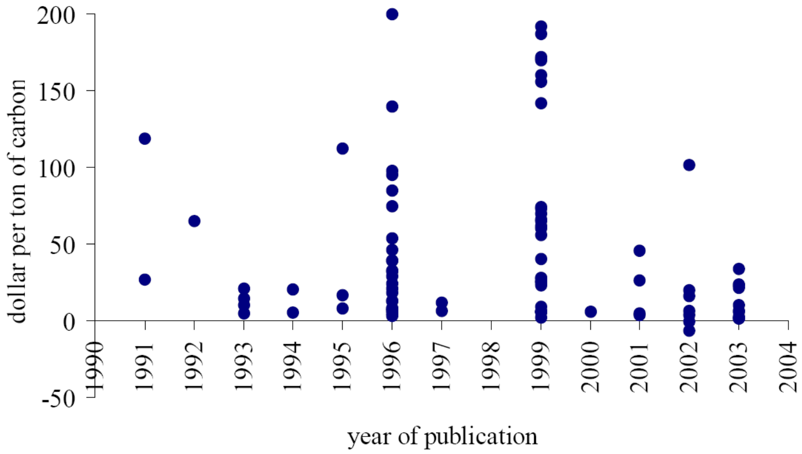
The confidence in predicting the possible effects of global warming varies considerably. Some, like increased frequency of hot days, are considered 'virtually certain' (Parry *et al.*, 2007) while on the occurrence of other events, such as major climate discontinuities, researchers are still uncertain. Likewise, the loss of welfare due climate change is easy to valuate only for a subset of impacts. For example the costs of costal protection in industrial countries are well known while it is difficult to valuate the loss of biodiversity. Watkiss et al. (2005) classify the impacts on the base of two criteria: the relative confidence in scientific predictions and the amenability to economic valuation. Figure 2.1 exemplifies the proposed classification.

Uncertainty in Predicting Climate Change	Uncertainty in Valuation			
		Market	Non Market	(Socially Contingent)
	Projection (e,g, sea level Rise)	Coastal protection Loss of dryland Energy (heating/cooling)	Heat stress Loss of wetland	Regional costs Investment
	Bounded Risks (e.g. droughts, floods, storms)	Agriculture Water Variability (drought, flood, storms)	Ecosystem change Biodiversity Loss of life Secondary social effects	Comparative advantage & market structures
	System change & surprises (e.g. major events)	Above, plus Significant loss of land and resources Non- marginal effects	Higher order social effects Regional collapse Irreversible losses	Regional collapse

Source: Watkiss et al, 2005.

Figure 2.1 Classification of the impacts of climate change

In order to appraise the consequences of climate change, a value has to be attached to each of the forecasted consequences. A monetary metric is most widely used to measure the market impacts implying, in the majority of cases, the use of a discount rate to calculate the net present value of the marginal damages of GHG emissions. The marginal costs of climate change estimated in 28 studies are plotted in Figure 2.2 alongside with year of publication. Analysis of the reviewed data show a considerable scatter among the estimates as well as a tendency towards lower values in recent years. The mean value for the marginal damage that was found was 25 €/tCO_{2e}. In another study Tol (2005) concluded that with standard assumption on discounting and aggregation the damage costs of carbon dioxide emission are unlikely to exceed 14 €/tCO_{2e} and are probably much smaller. In their analysis, Watkiss et al. (2005) conclude however that most of the impact studies conducted so far only account for a subset of the total impacts of climate change, specifically those in the top-left corner of Figure 2.1. For the remaining phenomena predictions becomes increasingly uncertain and economic valuation too complex and subject to arbitrary assumptions.

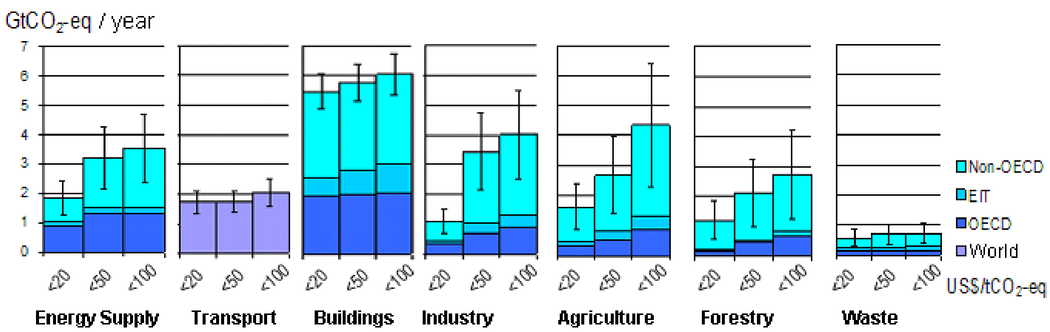


Source: Watkiss et al, 2005.

Figure 2.2 Marginal costs of climate change, review of 28 studies

2.2.2 Costs of climate change policies

These estimations of monetised impacts are close to the marginal abatement cost of emissions reductions needed for atmospheric stabilisation at low levels. Global greenhouse gas reduction potential under 20 US$/t$CO_2$ by 2030 is on the order of 9-18 Gt CO_2-eq/yr (Figure 2.3; Metz et al., 2007). This economic potential is larger than global reductions that would be needed as late as 2050 to stabilisation atmospheric CO_2 at a level between 440-485 ppm (-30 to +5% of the 27 Gt CO_2 emitted in 2000). Thus, the marginal cost of abatement needed for atmospheric stabilisation at low levels may will be close to or lower than the marginal damage of GHG emissions. By 2100 the costs of mitigating climate change are on the order of several percents of global GDP per year (Metz et al., 2007).



Source: Metz et al., 2007.

Figure 2.3 Estimated sectoral economic potential for global mitigation for different regions as a function of carbon price in 2030 from bottom-up studies

2.3 Costs and benefits of energy security

2.3.1 Dimensions of energy security

Energy security or security of supply is a broad concept that lacks a single definition. It has traditionally been associated with the securing of access to oil supplies and the issue of fossil fuel depletion. This preoccupation with oil stems most likely from the fact that gas and coal used to be mostly national fuels, often delivered through state owned enterprises exercising a monopoly. There might be occasional threats to continuity of supply, notably as a result of strikes; but these were issues to be resolved by negotiation between parties within the national industry who, ultimately, shared a common interest in continuity of supply (Priddle, 2002). Over the years however, the development of global markets, diversification, including the increased use of natural gas and the development of alternative supply technologies have all caused the concept to be redefined. A distinction is often made between short term security of supply and security of supply in the long term (Chevalier, 2005; Scheepers et al., 2007).

Long term supply security issues deal with fundamental aspects and structure of the energy system. Long lasting political instability, resource availability and geopolitical relations are but a few of the aspects typically related to long term security of supply. Physical shortages of oil are spread out over all consumers through an increase in price (IEA, 2007b; Toman, 2002). This has lead to a shift in the notion of security of supply from a purely physical definition to one that also incorporates the price of energy (Jenny, 2007). Moreover the scope has widened to also include other types of fuel (such as natural gas) and energy conversion and transport (Jenny, 2007; Scheepers et al., 2007).

Short term disruptions can be caused by various events that are hard to foresee such as strikes, sabotage, terrorism, but also climatic events such as hurricanes or extreme drought or rainfall. These are usually mitigated by demand restrained, temporary fuel switches, or delivery from strategic reserves (Chevalier, 2005; Scheepers et al., 2007). The liberalisation and deregulation of electricity markets in the European Union, intended to decrease vulnerability by increasing liquidity, efficiency and competitiveness through interconnectedness, has in fact led to a decrease in investments, which eventually may result in system failures (Chevalier, 2005). Problems related to underinvestment gradually build up over time. They become apparent however, through immanent system failure, usually in the form of a black out.

2.3.2 Regional historic impacts of oil and gas supply disruptions

Disruptions in fossil fuel supply become apparent by high and volatile prices, in particular for oil. Still one of the key components of the energy market worldwide, oil trade has long been characterised by supply disruption and volatile prices. Risks for security of oil supply include on the one hand a short-leaved increase in oil price caused by a significant loss of supply resulting, for example, from political instability, technical failures or weather related disruptions. On the other hand, long lasting prices increases may occur due to cartel behaviour of oil producing countries. Gas prices tend to be closely linked to oil prices, and particularly long lasting oil price increases are likely to affect gas prices as well. In this section an overview of historic developments in the global oil market will be provided, and the similarities and differences with the natural gas market will be outlined.

Table 2.1 and Figure 2.4 show major disruptions in oil production of the last 30 years and the price of oil in real value. The global oil market in the seventies was characterised by high prices, high volatility and frequent disruptions. During this period OPEC was successful in maintaining high prices and oil shocks of 1973 and 1979 lead to recession in most of the western economies. The adverse effects of the unstable market led to energy savings measures driving the economy of developed countries away from energy intensive activities. The energy intensity of Europe is currently almost 20% lower than in 1990 (EC, 2006c). The drop in energy intensity of the economy (the energy intensity of Europe is currently almost 20% lower than in 1990, DGTREN (2006), continuing a trend started in the early 70s) and explorations in other areas of the world, most notably in the North Sea, unlocked resources increasing production. Suring the 1980s OPEC lost part of its ability to influence prices, and the period from 1980 through the 1990s was characterised by lower oil prices and a lower frequency of substantial supply disruption (Joode et al., 2004). The reduced impact of supply disruption on the oil market is partly due to reduced oil intensity of industrialised countries. Furthermore, the development of spot and future markets enhanced the flexibility of market players to respond to (expected) disturbances and have reduced the vulnerability of economies to oil price peaks. The first decade of the 21st century was characterised by a surge in demand stemming from the boom of Asian economies, and by a decline of production in OECD countries. Both the average price of crude oil and the number of disruptions with a significant short term impact on price increased, indicating a tighter global oil market.

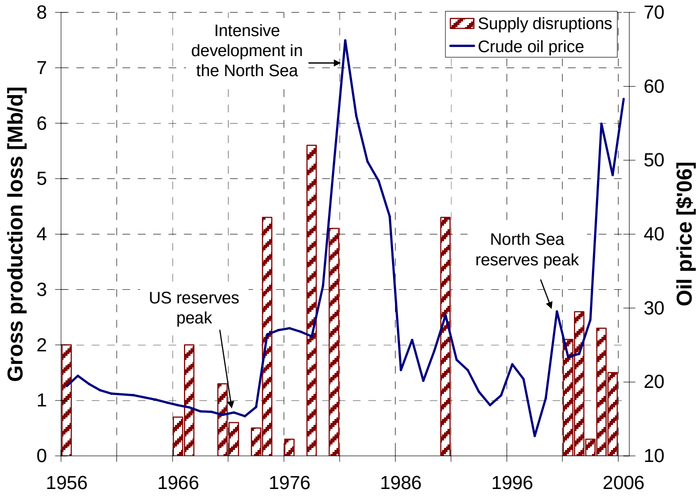
The adverse affects of high and unstable oil prices can be classified in direct costs and indirect effects on the economy. The direct cost of persistently high oil prices may be substantial. Given the current gross inland consumption of oil in Europe, a sustained price increase from 25 to 55 dollar per barrel of oil (approximately 23 €/b, similar to that experienced in recent years) amounts to approximately 1% of the EU25 2006 GDP. The indirect effects of high oil prices depend on the oil price elasticity of GDP. As a general rule, economic growth tends to slow down when oil prices increase, but it is difficult to exactly quantify the correlation. World economy would have grown slightly more rapidly had oil prices and other energy prices not increased - by 0.3 percentage points per year more than it actually did on average since 2002 (IEA (2006b). It has been estimated that for the United States the oil price elasticity of GDP was approximately 0.055 through the seventies and eighties, but it as been suggested that this relationship weakened considerably in recent years (Joode et al., 2004). Still, sudden oil shocks are cause of much concern as they can spark a widespread recession, has witnessed in 1973 and 1979.

Obviously, great care is needed in extrapolating historic results to the future. Considerable uncertainty exists in estimating both future oil prices and the impact, both in terms of both magnitude and frequency of disruptions. Currently, the oil market appears to be deteriorating due to a lack of investment in new oil production operations and an increased market power of oil producing countries. Nevertheless, the oil intensity of consumption and production, particularly for advanced economies, is now significantly lower than in the 1970s.

Table 2.1 Historic major oil supply disruptions (EIA 2007)

Date*	Duration [Months]	Average Shortfall [Million B/D]	Cause
3/51-10/54	44	0.7	Iranian oil fields nationalised May 1, following months of unrest and strikes in Abadan area
11/56-3/57	4	2.0	Suez War
12/66-3/67	3	0.7	Syrian Transit Fee Dispute
6/67-8/67	2	2.0	Six Day War
5/70-1/71	9	1.3	Libyan price controversy; damage to Tapline
4/71-8/71	5	0.6	Algerian-French nationalisation struggle
3/73-5/73	2	0.5	Unrest in Lebanon; damage to transit facilities
10/73-3/74	6	2.6	October Arab-Israeli War; Arab oil embargo
4/76-5/76	2	0.3	Civil war in Lebanon; disruption to Iraqi exports
5/77	1	0.7	Damage to Saudi oil field
11/78-4/79	6	3.5	Iranian revolution
10/80-12/80	3	3.3	Outbreak of Iran-Iraq War
12/02-2/03**	3	2.1	Venezuela strikes and unrest.
3/03-8/03	6	0.3	Nigeria unrest.
3/03-9/04***	19	1.0	Iraq war and continued unrest.

Source: EIA, 2007.



Sources: (based on) Joode et al, 2004; IEA, 2007a; WTRG, 2008.

Figure 2.4 Production losses due to major supply disruptions and inflation-adjusted oil price (annual average)

The natural gas market resembles the oil market to some extent. Reserves are concentrated in few countries with the three major exporters, Russia, Iran and Qatar, controlling 50% of the market. Import dependency for Europe is projected to rise as domestic production declines. By 2030 the EU25 will import as much as 80% of its natural gas. Moreover, natural gas price is generally linked to oil price exposing the market to the disruptions described in the preceding section. Unlike oil, however, there is little historical evidence of supply disruption or cartel behaviour from gas exporting countries. Indeed, Russia, the main natural gas supplier to Europe, remained a reliable commercial partner throughout the cold war. Another important difference between the oil and natural gas market is that the oil market is a global market whereas the natural gas markets are regional (i.e. Asian-Pacific, European and Atlantic market). Moreover, the main share of natural gas is transported through pipelines making importing countries in a greater extent bound to infrastructure and hence the exporters at the other side of the pipeline. The surge of LNG makes that regional markets become increasingly global, but the better economics of pipeline gas compared to LNG makes that liquidity will remain lower than in the oil market. This lower liquidity means that in case of a supply disruption fewer options exist to replace supply (Tönjes, 2007; Van der Linde et al., 2006).

2.3.3 Costs of supply security policies

A range of policies is available to limit the frequency and possible harmful consequences of supply disruptions. For instance, strategic oil stocks are an adequate instrument to cope with short-lived disruptions, and could compensate for the effect of a shock. After Katrina, the International Energy Agency decided in a few days to bring 60 million barrels of additional oil to the market. The emergency response system worked - the collective action helped to stabilise global markets (see also IEA, 2007b).

Measures to mitigate supply disruptions include furthermore an extension of the lifetime of oil and gas fields, or demand side management. Joode et al. (2004) performed cost-benefit analyses for a number of supply security policies. They found that a number of measures would most likely not be cost-efficient, including an extension of emergency oil stocks, limiting gas production in a major Dutch gas field to maintain swing capacity, incentives to invest in additional peak capacity, or taxing electricity use. The costs of those measures would be larger than the avoided economic damage. The general picture emerging from the study suggests that security of supply policy is hardly ever beneficial to welfare.

From an economic point of view it is preferable to accept the consequences of supply disruptions than to pursue supply security. The global risks from climate change mitigation are far more important than the regional supply security risks. Therefore, justification of energy policies is must primarily be founded on their contribution to curbing greenhouse gas emissions.

2.4 The role of technological innovation

2.4.1 Technological innovation and competitiveness

There are various reasons to believe that technological innovation will enhance the competitiveness of industries and countries. A number of reasons have been identified for the beneficial effects of innovation for competitiveness (Jochem and Madlener, 2003). Firstly, many new technologies, particularly for energy and material efficiency, will ultimately reduce costs, both for production processes and for consumers. Secondly, innovating industries and countries that enter new markets early have a competitive advantage, which they may exploit to increase profits. Thirdly, the introduction of new technologies will trigger efforts to improve the performance of traditional technologies. Fourthly, saved costs in a resource efficient economy will be re-invested. In many cases this will move capital from a few power generators and energy-industry industries to a range of small and medium enterprises in construction, consulting and other services. Finally, overall economic efficiency will benefit from increased recycling, improved capital and labour productivity, and intensified product use.

An EU-wide study estimated that renewable energy has the potential to create over 900,000 new jobs by 2020, including 515,000 jobs in agriculture and biomass fuel supply. Industry estimates endorse these levels of job creation. Already a number of countries are achieving high employment levels from renewable energy activities, particularly in the wind energy industry. Germany, for example, estimates that the turnover of the Germany wind energy industry reached 1.7 Bn Euro, providing 25,000 direct and indirect jobs (Ecotec, 2005).

Energy policies should typically yield a triple dividend, which is even more demanding than the double dividends at the time of the potential introduction of an EU carbon tax (Bovenberg, 1999). At that time the introduction of a carbon tax was supposed not only to be beneficial for the environment (weak dividend), but also for the labour market because tax revenues from energy taxes could be used to reduce (marginal) taxes on labour with more jobs as a result. Now the idea is that promoting new energy technologies would even be beneficial in a third dimension, i.e. by fostering economic growth.

Recently, these claims on the beneficial impacts from technological innovation on job growth and competitiveness were challenged. Green Roads to Growth, a programme of work carried out by the Danish Environmental Assessment Agency, explored the possible linkages between environmental policy and economic progress (IAA, 2006). From this assessment a number of conclusions can be drawn.

Firstly, green roads do not necessarily connect with roads to growth. Environmental policy not only brings benefits it will also bring costs to the economy. Environmental policies will probably normally not have a significant positive impact on economic growth and employment. Well-designed environmental policies are not likely to have any clear negative impact on growth or employment either. It seems unlikely that triple dividends exist.

Secondly, an ‘employment dividend’ is not likely to appear. In practice green taxes can probably significantly stimulate innovation - but more empirical evidence is desirable. The EU CO_2 trading scheme can provide interesting data on innovation impacts in the years to come - as can the increases in crude oil prices that we have seen over the last few years. The ‘best’ way to stimulate increases in employment is to reduce existing subsidies to competing activities - for instance subsidies to fossil based energy production. Internalise any negative environmental externalities in the same sectors. Remove other obstacles to a good functioning of the markets in question. Internalisation of externalities elsewhere in the economy 'automatically' triggers a desirable outcome in this regard, probably to a significant extent.

Thirdly, it does not seem likely that stimulation of biomass and renewable energy production will contribute significantly to higher economic growth or employment - at a national level. Any increases in employment in these sectors may to a large extent (if not fully) be offset by decreases in other sectors through competition in product and/or labour markets.

Fourtly, empirical findings seem to provide little support for the idea that environmental regulation might trigger 'win-win' situations at an aggregated level (Porter and Van der Linde, 1995). An increased R&D effort in the renewable energy technology sector may have negative implications on employment and growth as well. An important question is whether environmental regulation has a detrimental effect on aggregate productivity, for instance because of crowding-out effects on R&D (Smulders and De Nooij, 2003). When a given dollar of investment is spent on (research in) pollution reduction, other potentially more productivity-enhancing options are no longer possible. Capital intensive investments in promising environmental technologies may lower employment indirectly through the higher subsidies necessary to stimulate their (initial) penetration. Empirical evidence shows that abatement expenditures contribute little or nothing to production but also have no statistically significant effects on the productivity of non-abatement expenditures.

With respect to its potential positive impacts on overall economic growth the balance might seem more favourable, although again some trade-off might be inevitable here. Nevertheless increasing investments in the renewable energy technology sector might still be justified, in particular if the social benefit weighs up against the additional cost at the margin. This effect, however, is unlikely to be similar across all options and choices have to be made. For some options, such as wind, the balance might certainly be positive, for others, in particular biomass options, doubts seem to be justified.

2.4.2 Barriers to technological innovation

Over the past decades a host of low carbon technologies has become available that are in different stages of technological maturity: R&D, demonstration, upscaling and commercialisation, with performance of the technology improving over time and costs coming down. Various mechanisms contribute to this phenomenon of learning. These include economies of scale and learning by doing during production, as well as further product development. Furthermore, users will increasingly adopt a new technology as uncertainties related to costs and performance decrease. Learning by using and the emergence of user networks will further stimulate the uptake of a new technology. Each of these mechanisms provide grip for stimulating technological innovation and diffusion.

The barriers that low carbon technologies face on their way to commercialisation are described below (based on IEA, 2006a). At the end of the section Table 2.2 provides an overview of key barriers to low carbon technologies in different stages of maturity. Section 4.3 will then continue discuss to what extent existing EU policies address the various barriers that innovative energy technologies face on their way to commercialization.

2.4.2.1 Fossil fuel based technologies and nuclear

The age of *coal-based power capacity* in Europe will determine to a large extent the potential to reduce CO_2 emissions through improved coal technologies. Efficiencies may be improved to approximately 40 - 45%, compared to today's global average of 35%, by operating supercritical and ultra-supercritical steam plants. For Integrated Gasification Combined-Cycles (IGCC) capital costs are still high, and a range of technical issues requires improvement. Nonetheless, once integrated with CCS, IGCC can be a cost efficient option and nowadays there are approximately 10 plants operating in the world and more planned or under construction. As for

CCS, most of the components are proven technologies. Yet, a complete coal power plant with CCS needs to be demonstrated still. Major barriers include high upfront costs, uncertainty on the security of CO_2 storage reservoirs and the lack of a legal framework for storage. In the short-medium term the role of coal will be determined by a trade off between efficiency and capital cost (with the price of steel playing a significant role). In the long term, issues regarding security of supplies and the regulatory framework will determine the role of coal in the European electricity mix.

Uncertainty on future gas supply is the main barrier for a deeper penetration of *natural gas* power. Natural resources are concentrated in few countries with gas supplies depending on capital-intensive infrastructures. Recent developments of the gas market together with renewed tension in the bilateral relation with the Russian Federation, the main foreign supplier, have raised concerns for security of supplies. Petrochemical industries are investing massively in Liquefied Natural Gas infrastructure. LNG is generally more expensive than gas transported by pipeline, but allows diversification of supplies. Still, 63% of the gas consumed in the EU25 in 2004 was imported and dependency is estimated to rise considerably over the next decades due to depletion of the field in the North Sea.

A key barrier to nuclear energy is the opinion from the public, which particularly concerned about nuclear energy regard safety, disposal of waste and proliferation issues. These problems can be addressed to some extent by new designs of nuclear power plants. Designs exist for generation III and IV reactors that are safer and less suitable for production of nuclear weapons. A long term solution is still required for the safe disposal of radioactive waste. Innovative designs have been proposed to address these issues, but support for founding new reactors is still lacking.

2.4.2.2 Renewable energy technologies

Arguably the main barrier for further penetration of *bioenergy* is the lack of the economies of scale that characterise solid fossil fuels. Transport of biomass is costly due to the low energy density of the raw feedstock. Similarly harvesting and pre-treating the amount of biomass necessary for large scale operations is difficult and a cause of environmental concerns (e.g., competition with food crops). Smaller systems, tailored to the local feedstock availability, can benefit of further R&D. New business models, such as the biorefinery concept where the waste heat of a cogeneration biomass power plant is used to produce biofuels and other higher value chemicals, are envisioned for biomass.

Environmental and social concerns are a barrier for the development of the remaining large *hydropower* projects. Large dams may disturb ecosystems and may necessitate relocation of populations. Small hydropower projects face less resistance and recent developments have focused on environmental integration. Geothermal projects generally characterised by long development times and, upfront, it may be uncertain whether reservoirs can sustain long-term fluid and heat flows. Future development focuses on ways to exploit marginal areas that are currently uneconomic.

The vigorous growth of the *wind energy* industry in the last few years has caused some public resistance against wind turbines. Off shore wind farms would drastically reduce the environmental impact, but further cost reduction is needed for such installations to become profitable. The intermittency of wind is often cited as potential limit for the deployment of wind turbines. However, there is no clear consensus on the maximum amount of intermittent electricity that can be sustained by the grid. New infrastructures for better grid interconnections (such as very long distance DC power lines) will smooth out the effect of local variations.

Long payback times and lack of proper information are probably to blame for the unsatisfactory penetration of cost effective *solar heating* technologies. A consistent regulatory framework appears needed. The solar program in Cyprus succeeded in promoting widespread adoption of solar collectors (presently installed in more than 90% of private households). It appears possible to replicate extensively this success throughout Europe. As to *photovoltaics* modules, the task of bringing modules to the market appears particularly costly. While continued support for niche markets and new technologies is necessary, it is not expected for PV to have a great impact on emission reduction in the medium term. Silicon shortages caused the price of modules to rise making public support schemes considerably more expensive.

The harsh marine environment poses stringent reliability requirements to *ocean energy* systems. Tidal barrage systems use well established hydropower technology, but the available sites are limited. Ocean energy concepts might have a high potential and benefit of mass deployment, but the proposed systems are still in the development phase.

In order for *hydrogen* to become a competitive carrier in the transport sector consistent cost reduction has to be demonstrated. Several demonstration projects have been undertaken, but there is still no consensus on the cost reduction that can be achieved. Several technological barriers have to be addressed in particular regarding transport infrastructures and storage options.

2.4.2.3 Low carbon technologies in end use sectors

In *industry* large scale diffusion of CHP is still hampered by lack of homogenous regulation and dedicated policy support. Connection charges for electricity fed into the grid vary across the EU and sometimes discriminate against generators by charging the full costs upstream network reinforcement to the generator. Diffusion of efficient motor and steam systems is often limited by a lack of awareness about the potential energy savings, or reluctance to change familiar systems. Energy efficiency programs and sectoral agreements can promote the investments necessary to replace old equipment. A carbon price or an emission target can promote cost efficient investments while other innovations might require R&D support.

Key to reducing emissions from *households, services, and agriculture* is improvement of efficiency in buildings, in particular given the high potential for reduction and the long lifetime of buildings. Three major types of barriers are: high upfront costs/long payback time, lack of awareness and split incentives. Large insulation works involve high initial cost and there might be little awareness of the energy-saving potential. Another obstacle is posed by the split incentives for architects, advisers, and installers where benefits are not enjoyed by person that takes decisions. Similarly, for more efficient heating and cooling technologies, the initial cost and a lack of awareness may significantly limit penetration. District heating and cooling could result in important energy savings, but often requires large scale investments. Higher initial costs, lack of awareness, and split incentives also hamper diffusions of energy management systems, efficient lighting systems, and more efficient electric appliances. In this case the savings for the final user are sometimes too small to overcome the system inertia. The large potential for cost effective savings in the residential sector can be tapped by improving regulation. Equipment standards and regulations should undergo regular revision and update information should be made readily available to builders and architects. Adequate financial incentives, together with information campaigns, could help diffusion of advanced technologies with significant upfront costs. In the case of appliances and lighting, considerable success has been obtained through labelling and performance standards. In some case labelling can have significant transaction costs. In this case, banning the least efficient products should be carefully evaluated (e.g., retiring incandescent bulbs).

A range of policies and technologies is needed to further reduce CO_2 emissions from *transport*. It appears difficult to stimulate behavioural change on the scale needed to have an impact on global emissions. Efficiency improvements are compromised by an increasing market share of more powerful vehicles, and by adding energy consuming features. More stringent regulations on energy performance of vehicles can be a useful policy instrument. Voluntary agreements between the European Commission and car manufactures have been proved ineffective and binding regulations are under discussion. Tax reduction and incentives can promote diffusion of high efficiency vehicles such as hybrids, while for more advanced technologies (e.g., hydrogen) continued R&D support is needed. Alternative fuels face a number of challenges as well. Development of an adequate fuel supply chain, competition with food crops and negative environmental impact (in particular deforestation) are already concerns. A recent report discusses food price increases due to competition with biofuels for land use (OECD/FAO, 2007). Currently the focus is on development of 2nd generation biofuels (biofuels from lignocelluloses feedstock) that can be produced from a large variety of feedstock. Up scaling of the production process for these fuels is still in the demonstration phase.

Table 2.2 provides a summary of the hurdles that the energy technologies need to take on their way to commercial deployment. Effective energy policies need to address these. For the long term this necessitates stimulating immature and still costly technologies in the R&D and demonstration phase. For promoting innovative technologies on the shorter term a stimulation of private investments is required, for instance through subsidies or a tax reduction. In Section 4.3 we will evaluate to what extent the present EU policy mix effectively helps to overcome these difficulties.

Table 2.2 Overview of principal barriers to the uptake of technologies

	Technological	Cost	Other barriers
R&D PHASE			
Hydrogen fuel cell vehicles	×	×	
Ethanol (cellulosic), Fischer-Tropsch diesel (biomass-to-liquids)	×	×	Higher CO_2 reduction than 1st gen. ethanol not awarded
Hydrogen	×	×	Need for infrastructure
Industry - Process innovation basic materials	×	×	
Industry - Feedstock substitution	×	×	
Photovoltaics	×	×	
Ocean energy	×	×	Available sites
Stationary fuel cells	×	×	Need for infrastructure
CCS - oxyfuel combustion	×	×	
Nuclear generation IV	×	×	
DEMONSTRATION			
Industry - Material/product efficiency	(×)		No consideration life cycle env. impacts
Industry - CCS	(×)	×	
Concentrated solar power	(×)	×	
CCS - post/precombustion	(×)	×	
UPSCALING			
Hybrid vehicles		×	
Biodiesel from oil seeds, Ethanol (grain/starch, sugar)		×	Feedstock supply Food versus fuel competition
Fischer-Tropsch diesel (biomass-to-liquids)	×	×	
Industry - Fuel switch		×	
Industry - Cogeneration		×	
Wind on and offshore		×	Public resistance onshore Intermittency
Solar heating and cooling		×	Lack of information Lack of regulatory framework
Hydro		×	Env. & social concerns (large systems)
Biomass gasification, co-firing		×	Environmental concerns Food versus fuel competition
Geothermal		×	
COMMERCIAL			
Vehicle fuel economy & non-engine techn.			Consumer behaviour
Ethanol flex-fuel vehicles			Feedstock supply at gas stations
Industry - Motor and steam systems			Lack of awareness Lack of expertise
Buildings: miscellaneous efficiency measures			Lack of awareness Split incentives
Nuclear generation III			Safety Disposal of waste Proliferation Public opinion

Note: based on IEA, 2006a.

2.4.3 Costs and the role of learning

In order to assess the market potential of CO_2 reduction technologies it is useful to compare costs and emissions to the average EU fossil fuels mix in electricity generation. Table 2.3 shows costs and emissions factors of the most common power generation technologies. It should be noted that these cost estimates are quite uncertain and dependent on assumptions such as the fuel price.

Table 2.3 Cost and emission coefficient of common power generation technologies

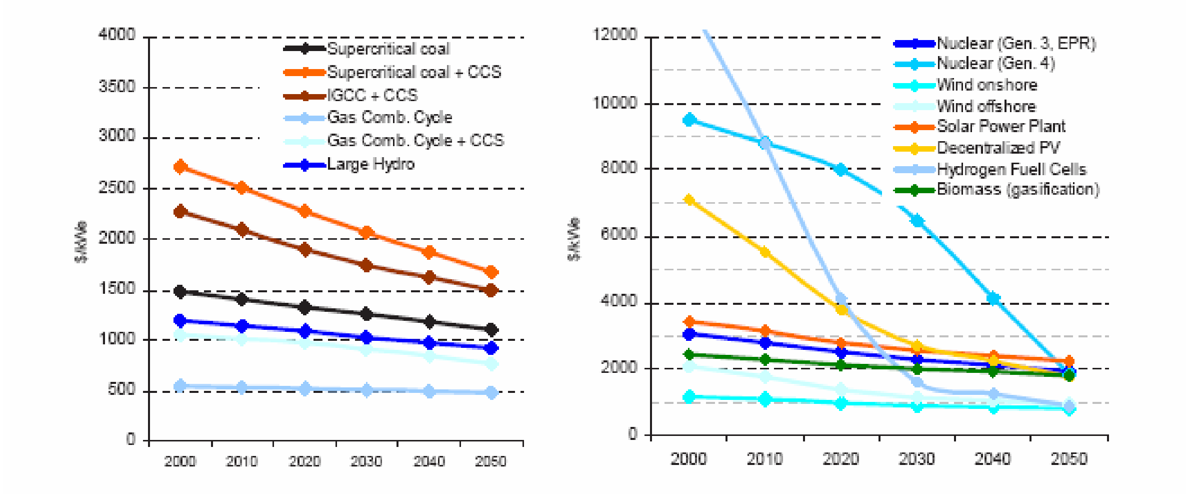
Source	Technology	Cost (2005) [€(05)/MWh]	Cost per t of CO_2 avoided* [€/tCO_2]	GHG emissions [kgCO_2e/MWh]	Efficiency [%]
Natural gas	Open cycle	45÷70	4.6 - 120	440	40
	Combined cycle	35÷45	-35 - 3.9	400	50
Oil	Diesel engine	70÷80	-	550	30
Coal	Pulverized coal	30÷40	-	800	40
	Fluidized bed	35÷45	-	800	40
	IGCC	40÷50	-	750	48
Nuclear	Light water	40÷45	-6.2 - 1.6	15	33
Biomass	Biomass plant	25÷85	-30 - 65	30	40
Wind	on shore	35÷175	-14 - 110	30	95
	off shore	50÷170	9.3 - 190	10	95
Hydro	Large	25÷90	-30 - 72	20	95
	Small	45÷90	1.5 - 71	5	95
Solar	PV	140÷430	170 - 690	100	

Note: based on EC 2007f.
* Cost per ton of CO_2 avoided is relative to the fossil fuel mix in EU25 power generation comprising 55% natural gas, 34% coal and 11% oil. For this mix the average generation cost is 44 €/MWh and the average emission factor is 657 kgCO_2/MWh.

Advanced natural gas technologies have a good potential for low-cost emission abatement, but obviously a switch to natural gas carries the cost of an increased dependence on foreign supplies. Among renewable technologies large hydropower, biomass co-firing and wind energy are clearly the cheapest options. The potential in Europe for large hydropower projects is all but exhausted while logistic problems (mainly in harvesting and transport) may hamper large scale diffusion for biomasses. The good potential of wind energy is one of the reasons for the strong growth of the industry in recent years. Conversely, PV modules are still expensive.

Cost reduction for innovative technologies is studied often by using learning curves (see Wene, 2000), which is a typical bottom-up perspective on the development and spread of new technologies. A learning curve typically represents cost reductions of a technology as a function of cumulative installed capacity. According to the learning curve concept, cost reductions for particular technologies arise out of a learning mechanism. Optimisation of repeated operations increases efficiency ultimately resulting in cost reduction. This learning-by-doing mechanism has been observed for many products and technologies and in particular for alternative energy technologies such as wind power and PV (Neij, 1997; Neij, 2003; Harmon, 2000). While the reliability and reproducibility of the learning-by-doing phenomenon are matters of ongoing study, it is generally well accepted that the cost of alternative energy technologies will decrease with deployment.

Decreases of investment cost of a range of low carbon technologies (comparable to 'learning curves') are presented in Figure 2.5 (EC, 2006b).



Source: EC, 2006b.

Figure 2.5 Projections of decreases in investment cost for some selected technologies in the WETO model

2.5 Synergies and trade-offs between innovative energy technologies

Table 2.4 gives an overview of various energy technologies and emission reduction options and provides the results of a first order assessment of their possible contributions to climate change mitigation and improving energy security, as well as their market maturity. The rational for the indications of market maturity is mostly given in Section 3.5. The scores in Table 2.4 are relative to baseline developments.

In general, any technology category included in the table includes measures between ‘very common’ and ‘very innovative’. The table therefore provides a first-order assessment only. As in any multi-criteria assessment, ratings are subjective to a certain extent.

Energy supply and conversion technologies are on the top of the table. Qualifications of the CO_2 reduction potential from these technologies are based on projections of the technical potentials (i.e. with abatement costs < 100US$/t$CO_2$) in the OECD (based on Metz et al 2007). Nuclear, hydropower and coal technologies can all be used to generate baseload electricity. These options are considered more beneficial for energy security than wind, which as an intermittent source can be used as a peak load options only. Other renewable options such as geothermal, concentrated solar power, PV and ocean energy will most likely contribute less to energy security than wind. Not only are they intermittent, their economic potential in the coming decades is also likely to be smaller than the potential of wind power. The contribution of stationary fuel cells to energy security will depend on the fuel used.

Buildings and appliances have a large potential to reduce energy consumption, and their CO_2 reduction potential and contribution to energy security is rated accordingly. Their potential *Industrial technologies* cover a wide spectrum. All abatement options will reduce CO_2, but the precise potential will depend on the particular sector and technology. Fuel substitution in basic commodity production will involve a larger consumption of natural gas and is taken to affect energy security negatively. Cogeneration in the Netherlands tends to favour the use of natural gas, and may in certain cases affect energy security only to a modest extent. CO_2 capture and storage will allow a cleaner use of coal, but will also require a greater fuel input, and does no necessarily lead to a greater use of solid fossil fuels over natural gas. For that reason it is rated 0.

Table 2.4 Low carbon technologies: potential contribution to climate change mitigation and security of energy supply, and technological maturity. Quantitative estimates for CO_2 reduction regard the OECD

	CO_2 reduction potential OECD [Gt]	Energy security	Innovation Phase
Energy supply and conversion	**0.9-1.7** [1]		
Nuclear generation II and III	++	++	Comm
Biomass gasification and co-firing	++	++	Upsc
Wind on and offshore	++	+	Upsc
(Small) hydro	+	++	Upsc
Solar heating and cooling	+	+	Upsc
Geothermal	0	0	Upsc
Coal and CO_2 capture	++	++	Demo
Natural gas and CO_2 capture	+	0	Demo
Concentrated solar power	0	0	Demo
Nuclear generation IV	++	++	R&D
Stationary fuel cells	0	0/+	R&D
Photovoltaics	0	0	R&D
Ocean energy	0	0	R&D
Buildings and appliances	**1.8-2.3** [1]		
Miscellaneous efficiency measures	++	++	Comm
Industry	**0.6-1.2** [1]		
Motor and steam systems	+	+	Comm
Cogeneration	+	+	Comm
Feedstock substitution	+	+	Upsc
Fuel substitution commodity production	+	-	Upsc
Process innovation in commodity production	+	+	Upsc/Demo
Material/product efficiency	+	+	Demo
CCS	+	0	Demo
Transport	**0.50-0.55** [1]		
Alternative fuels			
Ethanol (grain/starch, sugar)	+	+	Upsc
Biodiesel from oil seeds	+	+	Upsc
Hydrogen from fossil fuels	+	0	Upsc
Fischer-Tropsch diesel (coal-to-liquids)	-	0	Demo
Fischer-Tropsch diesel (biomass-to-liquids)	++	++	Demo
Ethanol (cellulosic)	++	++	Demo/R&D
Hydrogen from renewables	++	++	R&D
(Advanced) vehicles			
Ethanol flex-fuel vehicles	0/+	0/+	Comm
Vehicle fuel economy and non-engine technologies	0	0	Comm
Hybrid vehicles	0/+	0/+	Upsc
Plug-in hybrids	+	+	Demo
Electric cars	+	+	Demo
Hydrogen fuel cell vehicles	0/+	0/+	R&D

[1] *Source: Metz et al. (2007)*

Alternative fuels in most cases lead to lower emissions, with the important exception of coal-based Fischer-Tropsch diesel, for which an energy penalty on production affects emission negatively. Second generation biofuels (FT diesel from biomass and cellulosic ethanol) have a greater CO_2 reduction potential than conventional biofuels.
They contribute more to energy security as well, since they are based on woody materials rather than crops for which crop land may become scarce at a given point.

Advanced vehicles contribute to varying degrees to curbing greenhouse gas emissions and energy security. Vehicle fuel economy and non-engine technologies are all improvements to cars running on conventional gasoline and diesel, and are rated 0. Ethanol flex-fuel vehicles use conventional liquids and ethanol, hybrid vehicles use both conventional liquids and electricity, and the hydrogen used in hydrogen fuel cell vehicles may be produced from fossil fuels or based on renewable energy. Their ratings are therefore mixed (0/+). Plug in hybrids and electric cars will lead to a greater use of electricity in vehicles, which implies a greater efficiency than commonly found in conventional vehicles.

2.6 Conclusions

The assessment in this chapter highlights the uncertainty in the available estimates in valuating the negative impacts of climate change and supply disruptions. It is generally believed that if climate change is left untackled the final social costs will be higher than the costs of mitigation. The full costs of mitigation are estimated in several percentage points of the global GDP by the end of the century. While considerable uncertainties still exists, this value is probably the most accepted order of magnitude estimate of the ultimate costs of climate change.

The costs of short-lived supply disruptions appear modest when compared to the effort required to significantly cut emissions. The macroeconomic and geopolitical consequences of a sustained increase in energy price are consistent but difficult to valuate. An increase in fossil fuel prices generally spurs inflation and depresses economic growth, but the exact extent of the negative impacts depends on several factors, including the country-specific energy intensity of the economy, the duration and extent of the price increase and the general conditions of the economic cycle. Overall, the impact of temporarily high oil prices are estimated in few tens of percentage points of reduced growth for industrialized nations (IEA (2006b)). That is significantly lower than the costs of mitigating global warning. Moreover, while the costs of climate change will be fully apparent only in the very long term, past increases in the energy price have always been temporary, not lasting more than few years. In the light of these considerations it can be argued whether a joint policy is the most efficient instrument to tackle simultaneously the two objectives.

Evidence of positive effects of deploying new energy technologies on economic growth is scarce. While new industries are flourishing in the field of renewable energy and environmental services, including notably the trade of CO_2 as a commodity, the higher cost of more sustainable energy system will have a depressing effect in other areas of the economy. It is not know yet if the final balance will be positive or negative. The final economic outcome of the deep emissions cuts will depend, among other things, on the result of international climate change negotiations.

A range of low carbon technologies may contribute simultaneously to reducing CO_2 emissions and improving the security of energy supply, although this synergy will not always materialise. Fuel switching for instance will involve substitution of coal with gas, possibly leading to a greater dependency on natural gas imports, and coal-to-liquids will improve energy security, but affect CO_2 emissions negatively. A number of technologies may be stimulates as promising (nearly) commercial options on the short and medium term. In energy conversion these include in particular bioenergy and wind power, but also new technologies for generation III and IV nuclear power plants. Furthermore, end use efficiency in buildings and appliances and in industry is an obvious option, as are second generation biofuels. Finally, ethanol flex-fuel vehicles could be stimulated a lot more, considering the maturity of the technology. In order to reduce emissions and secure energy supply for the medium and longer term various technologies for CO_2 capture and storage need to be stimulated. These are mostly in the demonstration phase.

3 An outlook on climate change policies, energy security and technological innovation

3.1 Introduction

Current trends and projections for the future show that we are not on a pathway to meet energy objectives regarding climate and security. Important drivers governing future emissions and energy use are economic growth and developments in energy resources, energy prices and energy technologies. There are fundamental uncertainties regarding these drivers. A scenario analysis is a way to cope with these uncertainties. Most scenarios show that, in the absence of additional policies, energy use and greenhouse gas emissions will continue to rise. Growing energy demand, particularly in countries like Brazil, Russia, India and China, (BRICs) will be at odds with the limited number of oil and gas suppliers.

In order to provide a combined outlook for climate change mitigation, energy security and technological innovation, this chapter sketches developments in emissions and energy security. Two of the WETO-H_2 scenarios (World Energy Technology Outlook) are explored, which were generated using the POLES model (EC, 2006b), namely a Reference scenario and a Carbon Constraint scenario. The POLES model includes 46 regions in the world for which describes 22 energy demand sectors and 40 technologies. The main exogenous inputs are the population and economic growth and the estimated resources of gas and oil. Starting from the current trends, the model calculates the evolution of the energy system on the base of the expected improvements in competing energy technologies. The effect of a climate change mitigation policies is simulated attaching a price to carbon emissions in every sector that modifies the supply demand equilibrium. The WETO-H_2 scenarios were selected for use in this report because they were recent, consistent with the EU targets and at the same time including global developments, and detailed enough for our purposes.

Section 3.2 outlines assumptions on climate change policies and resulting CO_2 emission reductions in both WETO-H_2 scenarios examined. The implications for energy security are examined in Section 3.3. The role of innovative energy technologies in the scenarios is discussed in Section 3.3, and Section 3.4 concludes.

3.2 Outlook climate change mitigation

Two WETO-H_2 scenarios are discussed in the remainder of this chapter, namely a Reference and a Carbon Constraint scenario. Global CO_2 emissions in these scenarios rise with respectively 70% and 48% by 2050 over 1990 levels. The scenarios do not specify to what atmospheric levels such emissions correspond. However, to put these emission levels in context reference is made to some of the scenarios summarised in the IPCC's Fourth Assessment Report. Scenarios with global CO_2 emissions in 2050 10 to 60% over 2000 emissions (or 23-79% over 1990 emissions)[1] may lead to atmospheric CO_2 levels ranging from 485-570 ppm (CO_2-eq 590 to 710 ppm).

In both scenarios the price of crude oil is assumed to remain close to 40 US$('05) per barrel up to 2010 and increase thereafter to reach 60 US$('05)/b around 2025. These price levels are substantially below recent oil price levels, but at present no scenarios starting from 100 US$ per barrel are available. Higher fossil fuel prices will make renewable energy more competitive, but the same holds for non-conventional fossil fuels, such as oil from heavy tear sands.

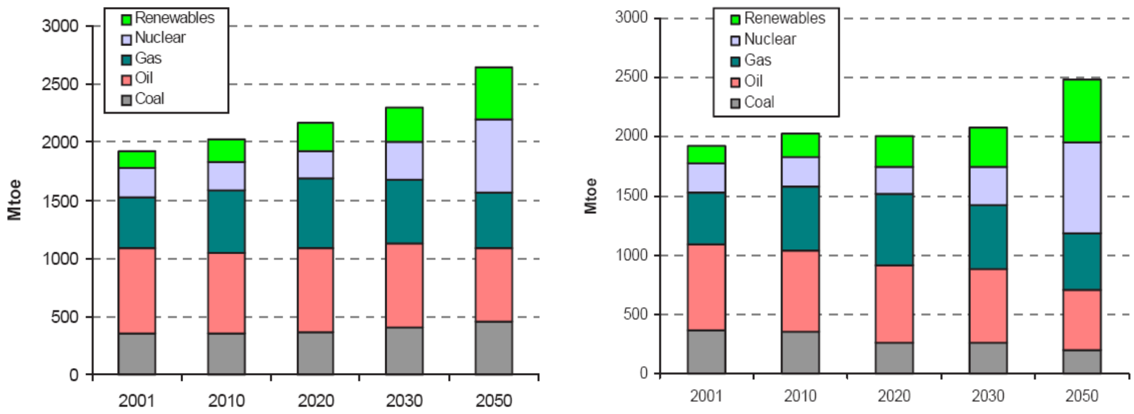
1 Global CO_2 emissions from fuel combustion between 1990 and 2000 rose by 12% (IEA, 2007e).

Key characteristics by 2020 in both scenarios are summarised in Table 3.1. The Carbon Constraint scenario suggests that eventually the CO_2 market will increase to 200 €/tCO_2 by 2050. Five options would contribute to CO_2 emission reductions in Europe: nuclear, renewables, fuel-mix changes, carbon capture and sequestration and efficiency improvements in demand. Primary energy demand until 2050 have been depicted for both scenarios in Figure 3.1.

Table 3.1 Key characteristics by 2020 in two WETO scenarios (EC 2006c). Global emissions by 2050 under the Reference and Carbon Constraint scenarios would be 120% and 26% over the 1990 level

	Reference	Carbon Constraint
CO_2 market price [€/tCO_2]	15	57.5
CO_2 emissions World 1990 [%]	70	48
CO_2 emissions EU over 1990 [%]	8	-20
Renewable energy EU [% GIC[1]]	11.2	12

[1] Gross Inland Consumption



Source: EC, 2006b.

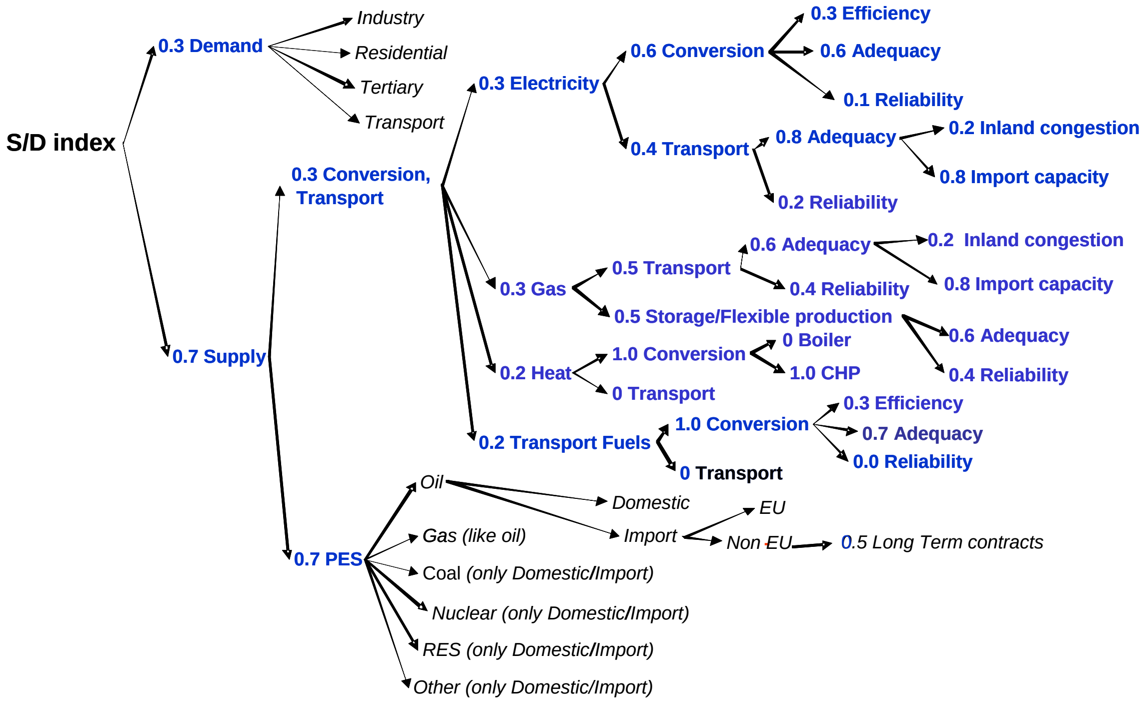
Figure 3.1 Primary energy supply in Europe, Reference and Carbon Constraint scenario

The scenarios suggest that eventually the role of innovative energy technologies in the EU would be more important under a regime with global trading. While biomass and waste in energy production in 2050 more than double compared to the 2001 level in the reference scenario, increase is almost threefold in an scenario with global emissions trading. Both scenarios suggest a 30-fold increase of wind energy by then. In 2050, solar power would be more than 40% from wind power in the reference, and nearly 70% in the global trading scenario. Hydrogen production in the reference and carbon constraint scenario would be on the order of 60 and 93 Mtoe respectively, to a major extent produced from renewable sources. CO_2 emissions from industry in the reference and under global emissions trading would be reduced by a third and half respectively. In households, services and agriculture they would remain constant in the reference and drop by one sixth under global trading, while in transport reductions would be by one fifth and a third in the reference and under global trading respectively. CO_2 sequestration would be on the order of 430 and 470 MtCO_2.

3.3 The Supply/Demand Index

In order to evaluate the security of supply in the WETO-scenarios, a number of indicators for energy security will be used. One of these is the so-called Supply/Demand Index (Scheepers *et al.,* 2006), which warrants some explanation. The S/D Index covers full energy supply and demand balances of a country and quantifies in a single number fuel mix, origin of primary energy sources, energy transport, conversions into secondary energy, and efficiency and structure of energy end use. It has proven to be a strong tool in comparing different aspects of a country's energy security, including supply, demand and energy conversion.

The S/D Index has a value between 0 and 100, with higher values representing more favourable energy security conditions. The index may be calculated on the basis of four types of inputs, two objective types and two types of a more subjective nature. Figure 4.1 shows the conceptual model of the elements considered in the overall S/D Index. Each individual aspect used in the model (i.e. at the end of the branches) obtains an index value between 0 and 100.



Source: Scheepers et al. (2006)

Figure 3.2 Weights (defaults, in blue) and shares (in italics) used in the Supply/Demand Index mode

The objective inputs concern the *shares* of different supply and demand types (i.e. for demand: industrial, residential, tertiary and transport use; for supply: oil, gas, coal, nuclear, renewables and other). The subjective inputs concern the *weights* that determine the relative contribution of the different components in the Index (such as the relation between supply and demand outputs in the Index, or the relation between EU imports and non-EU imports) and the *scoring rules* for determining various partial index values reflecting different degrees of perceived vulnerabilities (more weight/ higher score with increasing vulnerability). The weights for the various components of the index used by Scheepers *et al.* (2006) are depicted In Figure 3.2. Major scoring rules are in Box 1.

Box 1 Key scoring rules for the Supply/Demand index (Scheepers et al., 2006)

- Partial index values for each energy demand sector are calculated from the ratio between actual energy intensity and a benchmark figure. The benchmark is the average figure of energy intensities of the 5 best performing EU Member states. The maximum value will be 100 if the energy intensity is less (i.e. better) than the benchmark value. Weighing the four sectoral indices with the shares of each demand sectors relative to final energy demand results in the sub-index value for demand.
- The partial index value for primary energy supply (PES) is calculated on using various scoring rules for distinct sources:
  - Nuclear energy is valued 100 irrespective of the supply of origin (i.e. reliable export partners and unreliable export partners), because supply risk for uranium are relatively low.
  - Coal and renewables are valued 70 if the total supply is imported. The score will proportionally increase with decreasing imports.
  - Oil and gas are valued 0 if the total supply is imported from unreliable regions. The score for gas and oil equals the net share of domestic supplies plus the dependency on contracts from reliable export regions. Due to the weights of Supply (i.e. 0.7) and the PES (i.e. 0.7) herein the total S/D index is for almost 50% determined by the PES sub-index.

An important comment on the S/D index that has been raised in the past concerns the subjective nature of the indicator. Indeed, the weights chosen for aggregating the various components of the index may depend to a certain extent on user preferences. The same applies for the scoring rules, which determine the partial Index values for each of the components. Therefore, Scheepers et al (2006) conducted a sensitivity analysis to assess the impact of the most subjective parameters. They varied weights (by ± 0.1), benchmarks for energy intensities (by ± 20%) and parameters in scoring rules for partial index values (between -3% and +10%). For the UK and the Netherlands this resulted in uncertainty ranges for the S/D Index of about ±10%. In addition, Scheepers et al (2006) report other sensitivity analyses. Another remark is that the S/D index does not include the domestic energy reserve situation. Likewise, it does not take into account the domestic potential for renewable energy. The exploitation of domestic energy reserves and potential for renewables only materializes if the S/D Index is calculated from information in energy scenarios. If such exploitation is projected in a scenario, it will ultimately also be reflected in the value of the S/D Index in any particular year in the future.

3.4 Outlook energy security

Under a regime of global emissions trading, as in the Carbon Constraint scenario, a high CO_2 price is likely to provoke structural changes compared to baseline developments. The S/D index introduced above suggests that overall energy security will improve slightly under a global climate regime, albeit to a modest extent.

The demand side of energy security would benefit from a global climate regime. Under the Carbon Constraint scenario energy-intensities in five sectors improve. For the year 2050, energy-intensities and benchmark values are listed in Table 3.3. The benchmarks are based on the average figures of energy-intensities of the five best performing countries out of a group of EU Member states[2]. In the carbon constraint scenario the energy intensities fall due to more efficient use of energy. Therefore, the lower partial index for demand in the carbon constraint scenario compared to the reference scenario seems counterintuitive (Table 3.2). The explanation can be given by the downward shift of the benchmark values.

Primary energy supply would be more secure under a regime with global emissions trading, mostly due to a greater reliance on nuclear and renewable energy sources by 2050. Under such a regime oil and coal intensities of the EU economy in the long term are likely to decrease, as

[2] Great Britain, Germany, France, Spain, Italy, Poland, The Czech Republic, Sweden, The Netherlands, Belgium and Luxembourg

well as coal imports (Table 3.4), as well as coal imports (Table 3.5). Gas intensity however would increase slightly compared to baseline developments, while long term dependencies on oil and gas imported from outside the EU and Norway remain virtually unchanged (Table 3.5). This implies that care should be taken that an emissions trading regime will not result in too large a switch to natural gas technologies. Furthermore, the larger contribution of intermittent renewable energy to electricity production implies a larger risk of short term disruptions in a scenario with a more stringent global emissions regime climate.

The limited impact from climate policies on energy security is supported by earlier findings (MNP 2007). This study showed only modest effects on import dependency for oil and gas if emissions were reduced in a cost-efficient way. A policy to reduce European imports of oil and gas was shown to have modest impacts on emissions.

Table 3.2 Supply/Demand Indices, weights and partial index values for reference and carbon constraint (CC) WETO scenario (EC, 2006b) in EU25, according to methodology by Scheepers et al (2006)

	Reference -2001		Reference-2020		CC-2020		Reference-2050		CCC-2050	
	Weight	*PInd*	*Weight*	*PInd*	*Weight*	*PInd*	*Weight*	*PInd*	*Weight*	*PInd*
S/D index		**73.2**		**72.5**		**73.3**		**77.1**		**78.3**
Demand	*0.30*	**85.0**	*0.30*	**84.5**	*0.30*	**87.4**	*0.30*	**84.3**	*0.30*	**83.3**
Industry	*0.34*	91	*0.33*	92	*0.32*	90	*0.30*	91	*0.29*	91
Residential	*0.24*	74	*0.25*	83	*0.25*	88	*0.28*	84	*0.28*	80
Tertiary	*0.14*	85	*0.15*	88	*0.15*	87	*0.17*	86	*0.17*	83
Transport	*0.28*	87	*0.27*	75	*0.28*	84	*0.25*	76	*0.25*	79
Supply	*0.70*	**68.2**	*0.70*	**67.4**	*0.70*	**67.2**	*0.70*	**73.9**	*0.70*	**76.2**
C+T[1]	*0.30*	**72.7**	*0.30*	**82.7**	*0.30*	**82.7**	*0.30*	**85.4**	*0.30*	**85.4**
PES	*0.70*	**66.2**	*0.70*	**60.8**	*0.70*	**60.6**	*0.70*	**69.0**	*0.70*	**72.3**
Oil	*0.38*	44	*0.35*	33	*0.34*	34	*0.26*	30	*0.22*	30
Gas	*0.23*	56	*0.28*	49	*0.30*	49	*0.19*	44	*0.20*	44
Coal	*0.18*	90	*0.16*	87	*0.12*	87	*0.16*	85	*0.08*	86
Nuclear	*0.14*	100	*0.11*	100	*0.12*	100	*0.21*	100	*0.27*	100
Ren. ES	*0.06*	100	*0.11*	100	*0.12*	100	*0.18*	100	*0.23*	100

1) Conversion and transport. Data on average thermal efficiency and share of CHP in both scenarios were lacking. For reasons of consistency all values of those aspects were held constant over time.

Table 3.3 Energy-intensities for five economic sectors in 2050 in the reference and carbon constraint (CC) scenario

	Unit	Benchmark		Ref	CC
		ref	CC		
Industry	[toe/M€ added value]	88	77	97	85
Residential	[toe/cap]	0.6	0.5	0.7	0.6
Tertiary	[toe/M€ added value]	12	11	14	13
Transport goods	[toe/M€ added value)]	31	30	46	41
Transport passengers	[toe/Mtkm]	14	12	15	14

Table 3.4 Fossil fuel intensities in the reference and carbon constraint scenario

[% Gross Inland Consumption]	2001	2020		2050	
	Reference	Reference	Carbon Constraint	Reference	Carbon Constraint
Oil	38	33	33	24	21
Gas	22	28	30	18	19
Coal	19	17	13	17	8

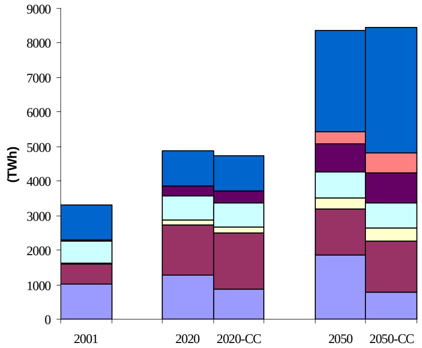
Table 3.5 Import dependencies fossil fuel resources in the reference and carbon constraint (CC) scenario

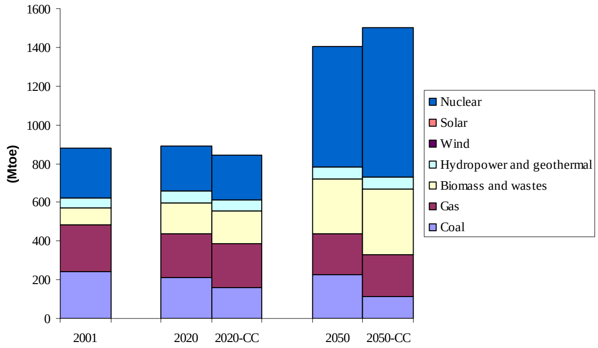
[%]	Reference-2001	Reference-2020	CC-2020	Reference-2050	CC-2050
Oil	77	87	87	92	92
Gas	52	75	75	83	84
Coal	34	42	37	50	45

3.5 Outlook technological innovation

There is high agreement and much evidence that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialized in coming decades, assuming appropriate and effective incentives are in place for their development, acquisition, deployment and diffusion and addressing related barriers (Metz et al, 2007).

An overview of the technology mixes used for electricity production, primary energy production and final consumption, as well as CO_2 emission in end-use sectors in the Reference and Carbon Constraint scenario is provided in Figure 3.3-3.6. In the following sections trends for the various energy technologies until 2050 are discussed.





Source: EC, 2006b.

Source: EC, 2006b

Figure 3.3 (Left) Electricity production in Reference and Carbon Constraint scenario

Figure 3.4 (Right) Primary energy production in Reference and Carbon Constraint scenario

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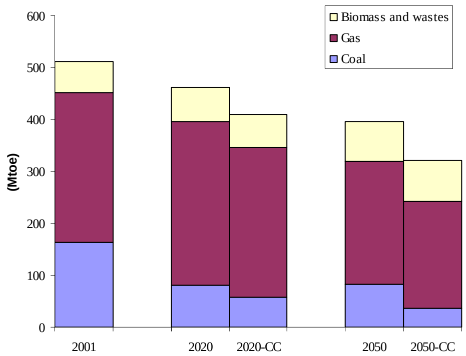
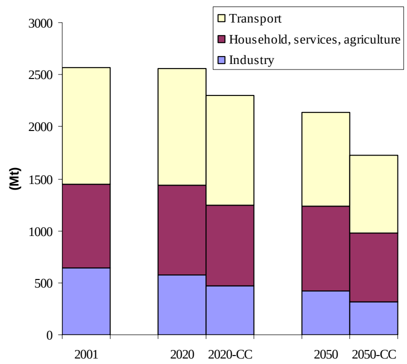




Source: EC, 2006b.

Source: EC, 2006b.

Figure 3.5 (Left) Final consumption in Reference and Carbon Constraint scenario

Figure 3.6 (Right) CO2 emissions in end-use sectors in Reference and Carbon Constraint scenario

3.5.1 Fossil fuel based technologies and nuclear

Coal technologies

Coal amounts for approximately 14% of the total primary energy supply (TPES) and 30% of power generation capacity in the EU in 2004. Under a regime of global emissions trading coal production and consumption in the European Union would drop by more than half.

While the average plant efficiency, currently around 35%, is modest, modern plant technology, especially Integrated Gasification Combined-Cycle (IGCC), promise to boost the efficiency to around 45-50%. This is still considerably lower that the state of the art for gas fired power plant, now approaching 60% overall efficiency. The cost of advanced technologies for coal combustion is dominated by the capital cost of the new installations, but further advancement is still possible through better plant integration. Increasing the efficiency of existing pulverized coal power plant has the potential to reduce considerably emissions in the short term, but the risk of lock-in effects should be considered carefully given the long lifetime of power plants. Carbon is the largest emitter of conventional pollutants (sulphuric acid, nitrogen oxides, particulate matter etc.) and, despite any foreseeable technological improvement, will remain the fossil fuel responsible for most emissions of acidifying and greenhouse gases as well as particulate matter. Concerning CO_2 capture and storage, highest costs are on the capture side. Several technical options have been proposed that can be deployed in combination with advanced coal technologies, including post-combustion, precombustion and oxyfuel technology. The extracted CO_2 has then to be transported and injected in underground saline aquifers or depleted oil and gas reservoirs. Overall, the technologies needed to develop CCS are well established but have never been deployed jointly or on a large scale. Successful demonstration and deployment of CCS can significantly increase this potential (IEA, 2006a).

Natural gas

In 2004 natural gas 24% of the TPES and 20% of electricity generation in the EU. The price of oil in the WETO scenario is set to rise steadily to accommodate a soaring demand. In the model the price for crude oil exceeds 100 US$ per barrel shortly before 2050. Natural gas price follows a parallel trend with prices steadily increasing. Under a regime of global emissions trading the share of natural gas will only drop to a limited extent, compared to the trend for coal.

The efficiency of the most advanced Natural Gas Combined Cycle (NGCC) power plants currently reaches 60% (although stand-alone turbines, the preferred choice to meet peak loads, achieve lower efficiencies). Capital costs can be as low as 1/3 compared to coal fired power plants with the cost of gas being the major cost component (60 to 85% of the total generation cost).

The combined effect of higher efficiency and lower carbon intensity significantly reduce CO_2 emissions from natural gas. A gas fired power plant emits as much as 50% less carbon dioxide compared to a coal counterpart. For this reason fuel switching from coal to gas has large reduction potential. Furthermore, gas is the cleanest of fossil fuels with reduced emissions of sulphur, nitrogen oxides, particulate matter and un-burnt hydrocarbon. The costs of power generated by natural gas, approximately 5 - 7.6 c€'06/kWh, is oftentimes competitive with coal (approximately 2.8 - 7.6 c€'06/kWh) (IEA, 2006a).

Nuclear

Nuclear energy today supplies approximately 31% of the electricity consumed in Europe. Nuclear power is being phased out or altogether abandoned in several EU countries. The WETO scenarios forecast a resurgence of nuclear energy through the construction of conventional nuclear power plants up to and, later in time, through deployment of the safer Generation IV power plants. The cost of nuclear electricity for base load generation is in many countries competitive with coal (depending on the local fuel cost). The cost of nuclear power is dominated by capital costs, the fuel cost playing only a marginal role. The energy density of uranium is hundred thousand times that of fossil fuel. For this reason supplies are forecasted to last several centuries and security of supplies is normally not considered a concern (IEA, 2006a).

3.5.2 Renewable energy technologies

Biomass and wastes

Bioenergy accounts for 4.5% of TPES in the EU27 in 2004. Production of energy from renewable sources, including biomasses, is set to soar in both scenarios. However, the Constraint scenario forecasts a more consistent growth of bioenergy for electricity production and of bioenergy in Europe. This indicates a deeper penetration of advanced conversion technologies including biofuels production.

Bioenergy conversion consists in combustion of renewable combustible and waste to produce heat and electricity and can be considered a well established technology. Co-firing dry biomass in a pulverized coal power plant (with concentrations up to 10 %) is the cheapest way to exploit bioenergy and the one that provides the most CO_2 emissions reduction.[The cost of power generation ranges between 1.5 and 4 c€/kWh assuming a feedstock cost of 0 - 2.5 €/GJ. At this cost bioenergy is cost-competitive with conventional whole-sale electricity prices. Wet biomass can be converted into biogas (a gaseous fuel with high concentration of methane) by anaerobic digestion. Advanced methods for conversion of biomass include gasification and co-gasification in IGCC power plants (which have a higher efficiency compared with pulverized coal power plants) (IEA, 2006a).

Hydropower and geothermal

Hydropower is a mature technology accounting for 1.5% of TPES in the EU25, and although installed capacity grows in every scenario, the share of hydropower in TPES remains below 3%. This trend essentially reflects the saturation of sites suitable for large hydropower projects. It is expected that the industry for small hydropower projects and geothermal energy will continue to grow, but the scale of deployment will be small compared with the currently installed hydropower capacity. Hydropower is in many cases one of the lowest cost power generation options with a cost of 3 - 5.2 c€'06/kWh. Small scale projects are generally more expensive with costs in the range of 5.2 - 80 c€'06/kWh. As to geothermal energy, generation costs remain highly site specific. Reported costs vary from as low as 2.6 - 5.2 c€'06/kWh to 31 - 47 c€'06/kWh (IEA, 2006a).

Wind

Wind power installed supplied 1.8% of the electricity in the EU25 in 2004. In the WETO scenarios wind energy is set to continue its dramatic growth becoming, in the long term, the second non-fossil electricity generation technology worldwide (after nuclear energy). In the Reference scenario the global installed capacity is expected to growth by two orders of magnitude in about two decades. Europe exhibits similar trends, but with slower growth in deployment. This suggests partial market saturation with most of the future opportunities lying outside Europe. The Constraint scenario shows similar trends, but on a shorter timeline.

At the best sites the cost of electricity from wind turbines is as low as 4.5 - 5 c€/kWh. However, both installation costs and wind speed ranges appear to be extremely site-dependent resulting in a range of costs. Although cost reduction is needed for wind power to become competitive in most markets and in off-shore installations, significant expansion is expected in the next decade. (IEA, 2006a).

Solar and ocean energy

The high carbon price in the Constraint scenarios facilitates deployment of solar power with the greatest share of growth taking place outside Europe. Generated electricity is 5 to 10 times more expensive than the average cost of fossil fuel power. Outside niche markets, the technology is not expected to become competitive before 2030 or 2040. Hybrid schemes have been demonstrated for combined solar-natural gas power plants and the technology has received renewed attention. Electricity generation in a solar thermal plant is a mature technology considered to be closer to the market. On the other hand, the use of solar energy for space heating and domestic hot water production is a well established and fully competitive

technology. In the central and north European regions 10 to 60% of the combined hot water and heating needs can be met with solar collectors at cost competitive prices.
Ocean energy is not deployed in the WETO scenarios. Some tidal systems have been operating economically for decades, but the potential appears limited. Other wave energy concepts presently at the R&D stage might have wider scope (IEA, 2006a).

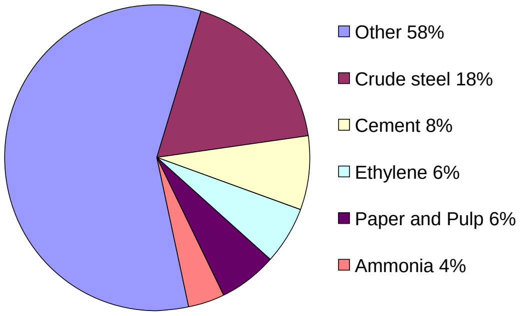
Hydrogen
Hydrogen is considered a promising energy carrier because it is potentially independent from the hydrocarbon market. For this reason, hydrogen is particularly appealing in the transport sector. Other niche markets can be important for developing the technology, especially stationary fuel cell installations for backup power or energy storage. Today hydrogen is produced in vast quantities (some 40 Mt/year worldwide) for chemical industry. The cost of technologies for energy application is still far too high for large scale deployment. The WETO scenarios suggest that hydrogen consumption production for energy purposes in the EU in 2050 will be comparable with the total amount produced today for the chemical industry in both scenarios.

The cheapest route for hydrogen production is currently through steam reforming of natural gas. These processes will require CCS in order to become a viable alternative (not taking into account concerns about security of supplies). The final cost of hydrocarbon reforming is currently projected at about 3 times that of gasoline (not including transport and storage). Hydrogen production via electrolysis of water is more appealing in the long term because it grants great flexibility, but is more expensive. The cost is approximately 10 times the current cost of gasoline, but vary considerably depending on the source of the electricity used (H_2 form off-peak electricity can be considerably cheaper, but the available capacity is limited). The cost of fuel cells has to decrease several orders of magnitude to be competitive with internal combustion engines for passenger car applications. For these reasons, even assuming successful cost reduction through R&D, deep penetration of hydrogen technologies is not expected before 2030-2005 (IEA, 2006a).

3.5.3 Low carbon technologies in end-use sectors

Industry
In 2004 the energy consumption in the industry sector reached 319 Mtoe in the EU25. CO_2 emissions from industry account for 16% in Europe. Energy consumption in industry is dominated by some large scale, energy intensive production. Source: IEA, *2006a.*
Figure 3.7 highlights the final energy use from some industrial sectors. For Europe and other industrialized countries, energy use in industry tends to level-off reflecting restructuring towards less energy intensive sectors, which appears to have a deeper impact on the energy intensity of industrialized countries than climate change policies.

Considerable scope exists for emissions reduction in industry through efficiency increase by upgrading motor and steam systems. Processes may be innovated further as well. Sector specific options include replacement e.g. feedstock substitution using biomass as raw material in the petrochemical industry, the production of biofuels on the basis of black liquor, a by-product of the pulp and paper industry. Combined heat and power generation (CHP) can deliver fuel savings in the range of 10 - 25% compared to stand alone systems. Emission reductions can also be achieved through from coal to gas, although the cost can be substantial depending on the local availability of natural gas. In general the saving potential and the investment required are highly site-specific (IEA, 2006a).



Source: IEA, 2006a.

Figure 3.7 Final energy use in industry in 2003

Households, services and agriculture

CO_2 emissions from households account for 12% of the total EU25 while 7% is emitted in service and agriculture. The use of energy in households, services and agriculture is forecasted to increase moderately in Europe. The high energy prices induce penetration of efficiency measures, restraining demand. In the Reference scenario the share of high efficiency building reaches 45% by 2050. The Constraint scenario is characterized by rapid and widespread diffusion of energy efficiency measures. The share of high efficiency buildings, for example, reaches 45% before 2030 and is almost 80% by 2050. Given the average lifetime of buildings this indicates retrofitting of existing dwellings. While energy use increases, emissions from households, services and agriculture decrease indicating fuel substitution.

A host of competitive and cost-efficient technologies is available to reduce energy consumption in this sector, including building envelop measures, such as double glazed windows or better roof insulation; advance heating and cooling techniques (active solar heating systems, condensing boilers, electric heat pumps and absorption chillers); efficiency improvements in domestic and commercial appliances, including reduction of standby losses and efficient lighting. Micro CHP is a promising technology, but is still in the development or demonstration stage (IEA, 2006a).

Transport

Energy consumption for transport accounts for approximately 350 Mtoe in Europe and 26% of GHG emissions. In spite of the high oil price the Constraint scenario projects only a moderate decrease of the energy needs for transport reflecting the inelastic nature of transport demand. CO_2 emissions drop more sharply due to penetration of alternative energy carries such as biofuels and electricity. Switching from oil to biofuels in transport may have complex implications for energy security due to the energy intensity of the transformation process. Based on the assumptions made, the gains in oil security are partly offset by a deterioration in gas supply.

The reduction potential of wide spread behavioural changes (e.g. to use public transport) is substantial, although fuel efficiency improvements may be even more important. Fuel efficiency of European vehicles has increased significantly since the early ’90 with average emissions now ranging between 170 and 220 g CO_2/km. Switch to diesel engines and downsizing allow modern engines to reach emissions levels of less than 120 g CO_2/km. Other cost effective measures include improvements in tyres, vehicle weight and aerodynamics can substantially contribute to increase average fleet performances. The reduction potential for biofuels changes considerably according to type and feedstock origin. Conventional biodiesel has a higher reduction potential than ethanol (40 to 60 %), but the potential is limited by the current availability of vegetable oil. Second generation biofuels such as lignocellulosic ethanol and Fischer-Tropsch biodiesel have a higher potential for CO_2 reduction (up to 90% compared to gasoline), but production is still at the demonstration stage. In the medium to long term radical developments can significantly alter the technological landscape for transport. Hybrid vehicles have already gained a solid niche market and are currently 25 to 30% more efficient than average cars. Second generation plug-in hybrids will allow for greater gains. Fuel cell vehicles are two orders of magnitude higher more expensive than conventional cars, and are not expected to achieve significant diffusion before 2030-2050 (IEA, 2006a).

3.6 Conclusions

The WETO-H_2 scenarios suggest that an increased efficiency and a portfolio of existing low-carbon technologies can bring about an emissions reduction of 20% below 1990 levels in 2020 (and 50% below 1990 levels in 2050). This conclusion is supported by other studies (e.g. MNP, 2006, Metz et al, 2007).

Scenario analysis showed that a cost effective package of technological options to curb emissions has only a modest impact on energy security. The WETO-H_2 scenarios suggest that oil and gas intensities under a global emissions trading regime are lower than otherwise, while import dependencies remain virtually the same. The Supply/Demand Index, indicates that under a global climate regime energy security would improve.

Implications for energy security of higher oil and gas price assumptions in the scenarios, e.g. starting from 100 US$/barrel today, are uncertain. While conventional fossil fuels might become more expensive, both renewable technologies and unconventional oil supplies might become more competitive and play a larger role in a secure energy system.

On the short to medium term the technologies that will contribute to achieving both targets are available today or in the final stages of development. No technological breakthroughs are needed in order to reduce greenhouse gas emissions to levels sufficiently low to stabilize atmospheric concentrations. On the long term however ongoing technological innovation and expansion of energy technologies are fundamental to a transition to a low carbon energy system. Major technological challenges for the future exist: for instance, second generation biofuels need to become competitive alternatives to fossil fuels, while CO_2 capture and storage needs to be demonstrated at an industrial scale.

4 EU energy policies and international co-operation

4.1 Introduction

Coherent energy policies are essential if the EU objectives are to be met. Effective domestic policies need to be combined with sound external relations to curb greenhouse gas emissions in the EU and worldwide, and to secure energy supply on the short and long term. This chapter looks into existing EU energy policies and the extent to which these policies realise the objectives of climate change mitigation and security of supply. It lines out the challenges for policies to advance the transition to a low carbon economy, and identifies shortcomings in the present policy mix. Section 4.2 discusses challenges energy policies face if they are to promote technological innovation, and the extent to which the EU ETS and other domestic instruments can be effective in this respect. Section 4.3 evaluates the present EU policy mix for stimulating a range of technologies in detail. The role of EU external relations in realising EU policy objectives is analyzed in Section 4.4. Finally, Section 4.5 draws some overall conclusions with respect to EU energy policies.

4.2 Towards effective EU energy policies

4.2.1 Challenges to technological innovation

It has been argued that current policy efforts may result in system optimisation rather than in a system change that would be required for a low carbon energy system. Conventional policies would imply a lock-in into fossil fuels (Sartorius and Zundel, 2005). Therefore, the challenge for energy policies to be able to realise the long term energy related objectives is to go beyond system optimisation and to make the transition towards new systems. Shifting from a fossil fuel intensive energy system to a low carbon energy system marks the energy transition. Although transition from a fossil fuel intensive energy system to a low carbon energy system requires also changes in regulations, infrastructures, habits, and capital flows, this report mainly focuses on technological change. Although there is relatively little insight in the nature and design of long term transition processes, many authors (e.g. Kemp, 2000; Geels et al., 2004; Suurs and Hekkert, 2005; Van Den Bergh et al., 2007; Satorius and Zundel, 2005) have reflected on fundamental ingredients for long term strategies for technological innovation. These are described hereafter. Early lessons from the Dutch Energy Transition Management Approach have been summarized in Box 2.

Provide and use a long term horizon - A long term horizon for energy policies is needed to provide companies and consumers with confidence that investments in climate friendly technologies that also secure supply of energy eventually will be paid back. Including a wide set of objectives to guide transitions in energy policies (not just climate domain, but also energy security) will help to achieve system changes. A long term target is important for instance in an emissions trading scheme, but also for other policies reducing the financial risk of investments, such as a feed-in scheme or a CO_2 price guarantee. A long term perspective will also increase the likelihood that research and development efforts in innovative technologies will be rewarded. The EU long term climate ambition is a rather soft commitment not yet providing enough certainty and trust - also because there is no global agreement on this. For energy security no long term targets has been set by the EU.

Allow for diversity, co-evolution and selection - Crucial to an effective strategy for a long term energy transition is a varied knowledge base and support for a diverse portfolio of innovative and promising technologies. This implies not picking a particular technology, e.g. biofuel or CO_2 capture system as a winner, but rather encouraging all of them. At the same it is necessary to set clear conditions for energy production and consumption consistent with long term objectives. This will allow so-called co-evolution and selection of candidate technologies over time. Future technological developments, cost reductions, and preferences among consumers and companies will then eventually resolve which technology will become dominant.

Consider path dependence - Path dependence refers to the fact that it may be difficult to replace technologies and infrastructures in place. Examples of factors contributing to path dependence include the standardisation of processes, especially when combined with economies of scale, long life-times of technologies and high investment costs of processes and infrastructures. This hampers the breakthrough of innovative, superior technologies and is referred to as the lock-in effect. Thus, prior to providing policy support to any existing energy technology implications for other promising but possibly less mature technologies should be considered. For instance, widespread deployment of micro CHP will reduce the potential for central CO_2 capture and storage; widespread deployment of CCS will continue reliance on fossil fuels and reduce the need for renewable energy.

Consider short term efficiencies in the framework of the long term - While in the long run a transition to a low carbon economy is imperative, this should not rule out opportunities for reducing emissions and improving supply security in the present energy system. Opportunities for such short term efficiency gains are numerous, including in particular a host of energy efficiency measures in all economic sectors. In other words, while system transition is under way, optimisation of the present system must be balanced with the long term ambitions. This raises the question of timing of policy efforts. Time aspects are often ill-considered in policy making and more long-term solutions often disregarded. To include time dimensions better into policy, Sartorius and Zundel (2005) recommend to design policy instruments with time in mind and set incentives for learning (time limits, digressive subsidies etc.) and to use specific socio-economic or political windows to further transition processes (such as the current high oil prices).

Facilitate **-** Finally, governments need to facilitate the development of a variety of promising technologies, essentially considering transitions as a learning process. This requires a broad perspective on actors and policy domains and action on different scales: are climate and energy security integrated throughout EU policies and part of the innovation agenda of the EU. Authorities may adopt a number of roles in this respect. Firstly, they may exert an innovation push by providing financial support and create special niches for promising technologies to prove themselves. Secondly, they may stimulate demand for new technologies by formulating environmental or technical standards or by providing economic incentives. Thirdly, they may involve a range of actors and promote the diffusion and exchange of knowledge among those.

Box 2 Early lessons from the Netherlands Energy Transition Management Approach

In the year 2000, the Netherlands set up an 'energy transition' policy, to stimulate the country's long-term transition to a low-carbon economy. Specific features of this policy are its long-term focus, its institutionalisation of public-private cooperation and the involvement of several ministries via a dedicated interdepartmental project team. Six public-private 'platforms' have been created to stimulate those themes that appear most promising for an energy transition in the Netherlands and that also complement the expertise of Dutch business. These are: 'new gas' & clean fossil fuels, green resources & feed-stocks, sustainable mobility, efficient energy chains, sustainable electricity, and energy efficiency in buildings. The Energy Transition Policy can only be judged on its results in achieving energy innovation. Being now only a few years after its start, tangible results of the energy transition - in terms of improvements in energy efficiency, increased application of renewable energy sources and cleaner use of fossil fuels - have not yet been realised.

Nevertheless, it is already possible to formulate some advantages and risks of this policy. Advantages lie particularly in the broad support that can be obtained by involving all relevant stakeholders and in the refusal to pick 'winners' - which might be good to stimulate, so as to prevent too high societal costs.; integration of all existing and new policies relevant to energy innovation via a dedicated, interdepartmental organisation; the use of a long-term horizon; and a focus on the innovation process rather than on specific technologies.

However, lessons learned from practical experience with the approach chosen in the Netherlands also bring to light some risks that have to be taken into account by any parties wishing to adopt a similar approach. Some of the main risks are, for instance, the question of who should take the lead, in other words, the possibility of 'much talking, but limited action'. This is particularly disadvantageous when it comes to the need of realising new energy infrastructures, such as for CO_2 or for hydrogen. Another risk is the detachment from short-term, practical policy, and the lack of clear criteria for success. The limited integration with foreign policy is another risk. Energy Transition activities have hardly been integrated into those of Foreign Affairs. In particular, in the field of development cooperation, where the government has committed funds to provide 10 million people with access to modern energy services, opportunities exist (de Jong et al., 2007; MNP, 2006).

4.2.2 The impact of environmental policies on innovation

Energy policies are important to the inducement and diffusion of low carbon energy technologies, either through emissions trading or other market-based instruments, (R&D) subsidies, and/or command and control (CAC) regulations. The effects of environmental policy are likely to differ across different policy instruments, such as emission restrictions through legislation or (changes in) taxes, subsidies or even tradable permits. Economists generally believe market-based instruments can provide stronger incentives than command and control (CAC) regulations to adopt cheaper and better technologies. CAC policies, like emission limits for installations, provide no reward for *exceeding* the requirements set by the regulations.

While subsidies have always met scepticism among economists (see Baumol and Oates, 1988), it is believed that in particular policies that affect relative prices tend to affect innovation and diffusion. However, few empirical studies exist that explicitly deal with differential impacts of environmental policy instruments. Popp (2002) is perhaps the most important recent study that confirms the role of prices in inducing technological change to date. This paper contains clear econometric evidence that the filing of US patents is sensitive to changes in relative prices. Popp shows that rising fossil fuel prices, in particular oil and gas prices, tend to induce patents (and citations) for energy-saving technologies, and that the availability of an endogenous existing knowledge stock is crucial in this respect.

Vollebergh (2006; 2007) surveys the empirical (economic) literature, asking whether there indeed is any evidence of different effects on the rate and direction of technological change associated with different environmental policy instruments. The study resulted in a number of conclusions. Firstly, environmental policies do impact on technological change. Not only does environmental regulation make life more difficult for existing firms, by increasing the (implicit) price of pollution; there is also a clear positive impact on invention and innovation of new technologies. Moreover, indirect evidence suggests that an increase in the implicit price of some emissions also boosts patents in complementary areas.

Secondly, higher energy prices lead to emission reductions. Emission reductions are triggered by higher implicit emission prices due to rising energy prices, because most fossil fuel use is closely linked to air pollution emissions. Such changes in energy prices have had strong impacts on invention, innovation and diffusion of more energy-efficient technologies which, in turn, have lowered emission levels as well.

Thirdly, financial incentives for technology development are usually stronger under market-based instruments (e.g. a tax). Moreover, technology-related information requirements for public authorities are much lower when using a tax compared to when using technology standards. In addition, taxes allow for more flexibility from the part of the regulated agent, reducing adjustment costs and optimising entry/exit and capital turnover rates.

The important role of prices of technologies suggest that there is good reason to believe that so-called market-based instruments can provide stronger incentives than command and control (CAC) regulations to stimulate reduce emissions.

4.2.3 The EU ETS as an effective and cost- efficient instrument

Well designed environmental policies are key in creating market conditions that promote innovation that takes society in the direction of cleaner technology. ‘Getting the prices right’ by internalisation of the social costs of environmental damages will provide incentives for innovations in the right ‘directions’. ETS is the cornerstone of the EU member states’ efforts to fulfill their emission reduction targets. The present system encompasses 45% of all CO_2 emissions and 30% of total greenhouse gas emissions in the EU. A cap-and-trade system like the EU ETS or similar economic instruments (like green taxes) in theory can provide a cost-effective option for abating emissions (static efficiency) and provide lasting incentives for technology development (dynamic efficiency).

In January 2008 the European Commission proposed a number of major amendments to the ETS Directive that should improve its effectiveness (EC, 2008a). An important modification that was proposed is a single EU-wide cap on allowed emissions, which will continue beyond the end of the third trading period (2013-2020), in line with the EU’s objective to reduce overall emissions by at least 20% by 2020. Furthermore, a much larger share of allowances will be auctioned, and part of the rights to auction will transferred from rich to poorer Member States in order to enable the latter to invest in climate-friendly technologies. In addition, the scheme will be extended to a number of new industries, notably aluminium and ammonia production, and two further gases, namely nitrous oxide and perfluorocarbons.

The proposed modification should contribute to a perspective on stable and sufficiently high CO_2 price under the EU ETS. Indeed, defining an EU wide cap in line with the EU’s emission reduction objective is crucial in view of the long life time of industrial installations. To what extent this will lead to predictable CO_2 prices and major investments in abatement technologies will need to be evaluated in due time.

Effectiveness and cost-efficiency of the EU ETS would be improved further if the scheme were to be extended to a global scheme. Global cooperation with at least major emitting countries, like Brazil, Russia, India, and China is needed to bring about the dramatic emissions reductions needed to meet the 2 degree stabilisation target. A global coverage would also help to limit the costs, as cheap abatement options can be found in developing countries. Steps towards global emissions trading are being taken through linking of EU-ETS with other schemes (e.g. US Regional Greenhouse Gas Initiative (RGGI), Japan, New Zealand, Norway etc.). A limitation of the scheme is further that only large industries and power generation (about 50% of the EU emissions) are covered, while large emitting large sectors like transport and households are not part of the system. Additional policies to put a price on emissions in these sectors are needed, and emission standards may be instrumental in this respect.

The EU ETS could significantly be optimized and also grow in scope and scale, especially geographically over time, resulting in a global policy diffusion and corresponding demand. In this case first mover advantages can be expected for the EU.

4.2.4 The need for complementary policies

Although the EU ETS and other emissions trading schemes arguably are effective instruments for reducing greenhouse gas emissions, their merits related to pulling technological innovation still need to be demonstrated in practice. What is more, the ETS can only establish the EU as a lead market for CO_2 reducing innovations if the mechanism delivers sufficient incentives to innovate. All in all this would appear plausible. So far the system has not proven particularly demanding with regard to CO_2 reductions, but this may change following the changes to the scheme proposed by the Commission in January 2008. In existing trading systems in the US, especially in the SO_2 trading system, innovation incentives of emission trading were limited to cheap technological or organisational solutions (Burtraw, 2000). Radical regime shifts and system innovations were not supported by these trading schemes. Incentives for further, more long-term oriented innovation efforts are difficult to identify in existing emissions trading schemes, depending largely on the underlying environmental targets (Rennings et al., 2004). It follows that the EU ETS may well need to be complemented by other policy instruments to stimulate technological change, including environmental or technological standards or (R&D) subsidies, particularly for sectors not covered by the scheme. Such complementary policies may well be effective.

There is an obvious case for the government to subsidise R&D, even though subsidising runs into a number of problems. Governments in the past have proven to be bad in picking winners, so a fundamental question always is what criteria exist for selecting research directions. Also, monitoring the results of research efforts is difficult and government-subsidised R&D may crowd-out research that would have been undertaken without a subsidy. Nevertheless, in the absence of subsidies firms are likely to under-invest in R&D. Not only may other firms imitate an innovation, the outcome of technological research is intrinsically uncertain and involves a financial risk. Furthermore, Hassett and Metcalf (1995) show that energy-conservation credits given to households have been successful in stimulating the penetration of modern energy-saving technologies. Jaffe and Palmer (1997) found that there is a significant correlation within industries over time between the rate of (lagged) expenditure on pollution abatement and the level of R&D spending, although the magnitude of this effect is small. Progress in wind turbine technology and the accumulated experience in producing wind turbines are likely to be affected by initial R&D subsidies and a gradual shift towards adoption subsidies to increase demand in a later stage.

4.3 Evaluation of the present EU energy policy mix

Apart from the EU ETS, a wide range of policy instruments are used in the EU to reduce greenhouse gas emissions. To a large extent these are applied to enhance introduction and diffusion of innovative energy technologies, and to overcome the barriers these technologies face on their way to commercialization (see 2.4.2). Below we will discuss to what extent the various EU policies manage to succeed in this respect.

Research and development of immature energy technologies are stimulated in the EU's Framework Programs. Furthermore, the EU Environmental Technologies Action Plan (ETAP) covers a spectrum of actions to promote the introduction and diffusion of environmental technologies, including innovative energy technologies (EC, 2004). The plan aims to promote R&D for such technologies, to mobilise funds, and to help drive demand and improve market conditions. In particular, the plan has resulted in a number of technology platforms for exchange of information and expertise. Finally, the Commission proposed to considerably enlarge the possibilities for Member States to support the introduction and diffusion of environmental technologies (EC, 2008b).

A range of measures has been taken to improve energy efficiency since the early 1990s. Implemented directives specify standards for energy efficiency in hot water boilers[3], domestic refrigerators[4], and ballasts in fluorescent lighting[5]. Furthermore, household appliances must have their energy efficiencies labelled[6]. Minimum standards for the energy performance of new and renovated buildings have been set, and certification of buildings and inspection of energy systems therein regulated[7]. The promotion of cogeneration in the internal energy market has been regulated[8], and a recent framework directive on eco-design requirements defines conditions for setting standards for energy-using appliances[9], including e.g. heating, water heating, electric motors, lighting domestic appliances, office equipment, consumer electronics, ventilation and air conditioning.

The promotion of renewable energy has also been taken up by the EU. To achieve the EU objective of having 20% of energy from renewable sources by 2020, the EC has proposed a Directive (EC, 2008c). This aims to establish national renewable energy targets that result in an overall binding target of a 20% share of renewable energy sources in energy consumption in 2020 and a binding 10% minimum target for biofuels in transport to be achieved by each Member State[10]. A Biomass Action Plan[11] and a Strategy for biofuels[12] were already formulated, although these do not hold specific measures or binding requirements. The former relates to the promotion of the use of biomass in heat production, electricity production and transport, the latter addresses in particular the possibilities to ensure the supply of sustainably produced biomass.

As for CO_2 emissions from transport, several measures and plans exist to reduce these. Voluntary agreements have been made with automobile manufacturers in Europe, Korea and Japan[13], to reduce average CO_2 emissions from vehicles to 140g CO_2/km in 2008, 2009 and 2009 respectively. A strategy to further reduce emissions to 120 g CO_2/km has been proposed[14]. The Commission also considers standards for rolling resistance, the promotion of tyre pressures, as well as more stringent rules on vehicle labelling. Plans have been developed to include aviation in the EU-ETS[15], and to connect ships to the electricity grid while they are in the harbour[16].

As a cross-cutting measure tax incentives can be a powerful tool. Commission plans to revise the Community framework for the taxation of energy products and electricity[17], and has proposed to tax private cars according to their pollution levels[18]. Nevertheless, taxation is as yet a Member State competence, which hampers the introduction of far-reaching green tax measures.

Clearly, a host of regulations is in place to stimulate energy technologies in the EU. Table 4.1 provide an overview of EU regulations applicable to a range of technologies. In spite of the scope of EU regulations in place, a number of gaps can be identified as well.

3 92/42/EEC
4 95/57/EC
5 2000/55/EC
6 92/75/EEC
7 2002/91/EC
8 2004/8/EC
9 2005/32/EC
10 COM(2008) 19 final
11 COM(2005)628
12 COM(2006)34
13 Resp 1999/125/EC, 2000/304/EC, 2000/303/EC
14 COM(2007)19
15 COM(2005)459
16 2006/339/EC
17 2003/96/EC
18 COM(2005)261

Firstly, no EU policies exist to assist in overcoming the high upfront costs that may be associated with realising large scale demonstrations of non-commercial technologies, notably CO_2 capture and storage. Technologies that are ready for demonstration at a commercial scale continue receiving R&D funding under the Seventh Framework Program, and in principle, the financial risk related to these technologies could also be reduced if they would be deployed by participants in the EU-ETS. Concentrated solar power could in addition benefit from tax exemptions[19]. However, the EU-ETS in its present form lacks the long term perspective for operators to invest in such capital-intensive operations.

Secondly, at the EU-level no genuine cost incentives exist to promote technologies in non-ETS sectors, notably transportation. European treaties only allow for fiscal and financial measures at the EU level to a limited extent. Hybrid vehicles, ethanol flex-fuel vehicles, or first generation biodiesel or ethanol transport, would all benefit from such financial incentives at the EU level, Member States are allowed to offer tax benefits to energy from renewable sources[20], and cost incentives do exist at the national level in many of the EU countries, as well as in the US and Japan. Nevertheless, EU-wide measures would have a larger geographical scope and are less likely to interfere with the internal market.

Thirdly, for many abatement technologies in the upscaling and commercialisation phase non-financial barriers need to be overcome. A large scope seems to exist for standard setting and labelling in transport. Such measures could help to steer consumer behaviour during the purchase of cars, and to address the lack of awareness or expertise in industry related to energy efficient technologies. Other non-financial barriers that have not been addressed at the EU level include e.g. the intermittency of renewable energy sources in the electricity grids.

Table 4.1 EU policies currently used for CO_2 abatement technologies in need of substantial R&D: the Seventh Framework Program (Council Decision 969/2006/EC) and the Environmental Technologies Action Plan (COM(2004) 38 final)

	R&D	
	FP7	**ETAP**
Transport vehicles		
Hydrogen fuel cell vehicles	×	×
Transport fuels		
Ethanol (cellulosic)	×	--
Hydrogen	×	×
Fischer-Tropsch diesel (biomass-to-liquids)	×	×
Industry		
Process innovation in commodity production	×	×
Feedstock substitution	×	--
Power generation		
Photovoltaics	×	×
Ocean energy	×	--
Stationary fuel cells	×	--
CCS - oxyfuel combustion	×	×
Nuclear generation IV	--	--

[19] Dir 2003/96/EC)
[20] 2003/96/EC

Table 4.2 EU polices currently used for CO_2 abatement technologies ready for demonstration at a commercial scale

	R&D		Demo	Upscaling		Commercial		
	FP7	**ETAP**	**Investment support**	**EU-ETS**	**Tax benefits[3]**	**Standards**	**Labelling**	**Other policies**
Industry								
Material/product efficiency	×	--	--	×[1]	--	--	--	--
CCS	--		--	×[2]	--	--	--	--
Power								
CSP	×	--	--	×	×	--	--	--
CCS post combustion coal	×	×	--	×[2]	--	--	--	--
CCS post combustion NGCC	×	×	--	×[2]	--	--	--	--
CCS - IGCC	×	×	--	×[2]	--	--	--	--

1 Dir 2003/87/EC
2 forthcoming
3 allowed under Dir 2003/96/EC

Table 4.3 EU policies currently used for CO_2 abatement technologies that need upscaling for further cost reduction

	R&D		Demo	Upscaling		Commercial		
	FP7	**ETAP**	**Investment support**	**EU- ETS**	**Tax benefits [2]**	**Standards**	**Labelling**	**Other policies**
Transport vehicles								
Hybrid vehicles	×	--	--	--	--	--	--	--
Transport fuels								
Biodiesel	×	--	--	--	×	×[3]	--	×[4]
Ethanol (grain/starch, sugar)	×	--	--	--	×	×[3]	--	×[4]
Industry								
Fuel switch commodity prod.		--	--	×[1]	--	--	--	--
Cogeneration	--	--	--	×		--	--	×[6]
Power								
Wind on and offshore	×	--	--	×	×	--	--	--
Solar heating and cooling	×	--	--	×	×	--	--	--
Hydro	×	--	--	×	×	--	--	--
Biomass	×	--	--	×	×	--	--	×[5]
Geothermal	×	--	--	×	×	--	--	--

[1] 2003/87/EC, [2] under Dir 2003/96/EC, [3] Biofuels Dir - 2003/30/EC, [4] EU Strategy Biofuels - COM(2006)34 final, [5] Biomass Action Plan- COM(2005)628, [6] 2004/8/EC.

Table 4.4 EU policies currently used for CO_2 abatement technologies facing other than cost barriers for wide scale deployment

3	R&D		Demo	Upscaling		Commercial		
	FP7	ETAP	Investment support	EU-ETS	Tax benefits[1]	Standards	Labelling	Other policies
Transport								
Ethanol flex-fuel vehicles	×	--	--	--	--	--	--	--
Vehicle fuel economy	--	--	--	--	--	--	--	--
Non-engine technologies	--	--	--	--	--	--	--	--
Industry								
Motor systems	--	--	--	×	--	--	--	--
Steam systems	--	--	--	×	--	--	--	--
Materials/product efficiency	--	--	--	--	--	--	--	--
Buildings & appliances								
many…	--	--	--	--	--	×[2]	×[3]	--
Power								
Nuclear II and III	--	--	--	--	--	--	--	--

1 under Dir 2003/96/EC;
2 92/42/EEC, 95/57/EC, 2000/55/EC, 2002/91/EC, 2005/32/EC
3 92/75/EEC, 2004/8/EC

4.4 Energy transition and international co-operation

Development of new energy technologies is an important element in a transition to a global low-carbon energy sector. However, as such a transition will have to involve at least a majority of, and preferably all countries worldwide, it will also need to strike a balance between a range of different political and economic interests of these countries. In particular, routes have to be identified in which current oil and gas dominated energy interests of most countries worldwide can give gradually way to low-carbon interests. Therefore strategic political aspects, in particular regarding energy security, will continue to play a role in a transition towards a low-carbon energy sector. This section examines some key international political aspects of a future energy transition and discusses to what extent the present EU foreign policy takes into account these elements.

4.4.1 Politics of a global energy transition

After the collapse of the former Soviet-Union in 1991, it was generally expected that a new world order would arise, in which market-oriented thinking, multilateralism and globalisation would prevail (see for instance Fukuyama, 1992). However, in practice this situation did not materialise. Rather, the present international political system can be characterised as ‘weak globalisation’, in which attempts for creating international markets and multilateral cooperation coexist with more state-directed and bilateral defence of national interests (Perlot and Hoogeveen, 2005).

This situation of ‘weak globalisation’ is also expressed in the energy sector, where national political interests play a key role alongside with more multilateral attempts for cooperation and market opening. An illustration of the process of market opening is for instance in the process towards an internal European energy market aimed at by the European Commission. A renewed interest in the defence of national energy interests can be noticed e.g. in the Russian-Shell ‘Sakhalin II’ dispute, or in the newly developed Chinese oil relations with African countries.

Whereas the importance of new technologies for the long term is stressed in this report, existing international political and economic interests are based predominantly on fossil fuels.

As global energy demand is foreseen to increase by some 50% until 2030 and some 80% of this demand might still be produced by fossil fuel capacity (IEA, 2007d), it is estimated that some 8.2 trillion dollars of investments in oil and gas infrastructure would be needed over this period, of which more than half concern exploration and production. This figure still by far outweighs the IEA estimation of 2.4 trillion dollars cumulative investments in new energy technologies that are needed until 2030 if all presently announced energy transition measures announced by governments worldwide were to be carried out[21].

The international strategic interests around these fuels mainly arise because demand and production do not coincide geographically. Reserves are concentrated in the Gulf countries for oil, and in the Gulf countries and Russia for gas[22], whereas main demand is concentrated in OECD countries and increasingly in large developing countries like India and China. With rising overall demand worldwide, increasingly an international political struggle is taking place for the remaining oil and gas reserves. Access to these reserves is also a main political issue because in many of the producing countries oil- and gas companies are state-owned or under close state control, which makes access subject to political considerations. Furthermore, with an estimated 40 to 60 years for oil and gas reserves to last, timing of this struggle more or less coincides with the timing of an energy transition that is pleaded for reasons of climate change[23]. Economic and political interests of fossil fuels therefore certainly have to be taken into account when considering an energy transition.

It should be noted also, that a global shift from fossil fuels to new energy technologies would certainly not make an end to international strategic energy interests. An improvement of security of supply in the EU as a result of transition to a low-carbon carbon economy that goes hand in hand with a destabilisation and reduced security of demand in oil and gas exporting countries does not necessarily result in an overall advancement in achievement of EU foreign energy and economic interests. A transition would result in a partition between countries that profit economically from the new situation, and in countries that would suffer from the changes. Economic winners from an energy transition would involve in particular those countries that already have created prosperous economies based on fossil fuels, who have almost fully exploited their own fossil fuel reserves, and who have taken the lead in developing low-carbon energy technologies. These countries are mostly united in the OECD. Winners might also be developing countries that already are investing in new energy technologies, such as most notably Brazil for biomass, or countries with coal reserves that manage to use these without emitting too much CO_2.

Losers on the other hand are likely to be in particular those countries that have built their economies on exports of oil and gas[24]. These countries include for instance the OPEC countries and Russia, but also countries in the Caspian Sea area which are just in the process of getting into oil and gas exports (Table 4.5). The sooner an energy transition takes place and the larger the percentage of non-fossil fuels it will involve, the larger the economic losses of these countries will be.

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21 The figure of 2.4 trillion dollars refers to the IEA Alternative Policies Scenario (IEA, 2007d), in which the effects of all presently announced climate change mitigation measures by governments worldwide are extrapolated until 2030.

22 According to the IEA (2007b) 62% of world's proven oil reserves are found in the Gulf countries, 56% of the global gas reserves in three countries Russia, Iran and Quatar.

23 The time span of 40 to 60 years refers to the 'proven-reserves-to-present-production-rate' (R/P ratio) as given for instance by BP (2006). This figure has to be taken as a rough approximation only, as new reserves can be found, and present production is foreseen to increase in future. According to Metz *et al.* (2007) main efforts to mitigate climate change have to be undertaken in 'the coming three decades'.

24 Nevertheless, there is also an option that oil and gas exporting countries actually might profit from a situation in which prices for oil and gas increase due to increasing scarcity. See e.g. Persson et al. (2007).

Table 4.5 Dependency of some selected states on oil and gas revenues

	Oil and gas export revenues [% of total export revenues]	Oil and gas export revenues [% of GDP]
Algeria	95	40
Iran	80-90	40-50
Kuwait	90	40-50
Libya	95	n.a.
Nigeria	90-95	n.a.
Saudi Arabia	90	n.a.
Russia	60	20
Azerbaijan	90	41
Kazakhstan	50	30

Source: EIA, 2007.

The timing of depletion of fossil fuels in relation to the timing of transition for climate change reasons is therefore an important variable for international politics relating to energy transition. Economic deterioration in fossil fuel exporting countries might quite well result in political destabilisation on an international level. With the Middle East becoming an even more politically sensitive area, or the nuclear power Russia getting into an isolated position, a global energy transition could become very hard to achieve - despite the fact that these countries are not world's largest CO_2 emitters per se.

It is within this international constellation, where short- and middle term political and economic interests concerning fossil fuels play a very important role, that efforts towards a long-term global energy transition have to take place. EU external relations therefore should take into account these shorter term economic interests in order to prepare for a longer term transition. In the next section, it is examined to what extent the EU foreign policy does so indeed.

4.4.2 EU external policies and energy transition

EU external relations involve many different policies, of which energy is only one. Main actions and instruments for improving the security of supply are outlined in the conclusions of the European Council meeting in March 2007 (European Council, 2007). Short-term measures will be taken to face supply disruptions. Furthermore, to increase diversification of energy supply, new gas pipelines and LNG infrastructure have to be build. Also, a common European voice and a framework for new partnerships have to be developed. The Energy Dialogue with Russia and the Energy Community Treaty with South-East Europe are mentioned explicitly as actions to be taken further. Regional cooperations of the EU exist in particular with the Caucasus/ Central Asia region ('Baku Initiative'), Baltic Sea region (BASREC), Southern Mediterranean (EUROMED) and South East Europe ('Energy Community Treaty'). More recently, also an EU - Africa energy dialogue has started. Aim of these cooperations is on one hand to assure flows of gas and oil to Europe (in particular from the Caucasus region and Northern Africa), on the other hand to stimulate market opening similar to that in the European Union in neighbouring countries. Recent involvement of China in Africa has also spurred the EU - African energy relations, which partly overlap with development cooperation but are also meant to give Europe access to Africa's fossil energy resources. Important bilateral energy cooperations exist furthermore with China, India, Norway, Russia, Ukraine and the USA. These countries are either main producers of fossil fuels (Norway, Russia), crucial transit routes (Ukraine) or main consumers of energy (United States, China, India).

However, energy has become more important in recent years, as for instance stressed by the fact that in 2006 for the first time a separate EU document was published on external energy relations. This joint paper of the European Commission and the High Commissioner was presented to the European Spring Council 2006[25]. In the paper, main guidelines were presented for EU external energy policies (Box 3).

Box 3 Guiding principles of EU external energy policy

1. Improving production and export capacities in producer countries and developing and upgrading energy transportation infrastructure in producer and transit countries.
2. Improving the climate for European companies' investments in third countries and opening up the production and export of energy resources to EU industry.
3. Improving conditions for trade in energy through non-discriminatory transit and third party access to export pipeline infrastructure.
4. Enhancing physical and environmental security as well as the energy infrastructure safety.
5. Encouraging energy efficiency, use of renewable energies including bio fuels, low emission technology and rational use of energy worldwide.
6. Implementing the relevant Kyoto Protocol mechanisms.
7. Diversifying energy imports by product and country.
8. Creating an international regime for the supply of enriched uranium to countries that have chosen the nuclear option, in line with non-proliferation commitments and taking into account the EURATOM treaty provisions.
9. Promoting strategic reserve stocks and encouraging joint stock holding with partner countries.

Source: European Council, 2006.

Looking at the balance between the energy policy objectives 'affordable, clean, secure', it appears that the guiding principles of EU external energy policy are directed mainly to serve the objective of energy security. The first principle refers to 'producer' and 'transit' countries, obviously meaning 'oil and gas producing- and transit countries'. Of the other eight principles, five refer directly or indirectly to fossil fuels, one is directed at nuclear energy, one at new energy technologies in the fields of energy efficiency and renewables, and one at the Kyoto mechanisms.

Although all principles are formulated in a more or less general sense, it is striking that in particular the principles on new energy technologies and on the Kyoto mechanisms are formulated in a very broad and general sense, speaking about 'encouraging' and 'implementing' only. There is no vision embedded in the principles of EU external energy policy on how international diplomacy can be applied to achieve a long-term gradual replacement of fossil fuels by new energy technologies. Neither is there an idea formulated how this can be done in such a way that an interest is created for potential 'losers' of an energy transition to participate in the formulation of new international energy policies.

EU external policies also involve climate change policies as a topic. Guidelines for climate change policies are given in the Commission Communication "Winning the battle against global climate change" (Box 4). Two statements that are particularly relevant to EU external policies are that "action against climate change has to be extended to all polluting countries" and that a "stronger cooperation with third countries at the scientific level" has to be realised. In practice, efforts concerning the fist action principle mainly involve efforts to engage countries that haven't signed the Kyoto protocol in binding emission reduction obligations for the period after 2010. The second action principle has led to many international cooperations to develop new energy technologies (Box 5).

[25] Paper from the European Council /SG/HR, 'Facing External Energy Risks', European Council, 15-16 June 2006.

Box 4 Guiding principles for EU climate change policies (EC, 2005)

"A strategy to combat climate change represents a four-fold challenge: the climate risk itself and the political will to face up to it, international participation in efforts to tackle climate change, the innovation needed for changes in the production and use of energy, and adaptation of countries to the unavoidable effects of climate change.

Accordingly, any strategy should include:

- Extension of action against climate change to all the polluting countries (with common but differentiated responsibilities) and sectors involved (all modes of transport, deforestation etc.);
- Enhanced innovation, which includes the implementation and deployment of existing technologies and the development of new technologies (in particular by means of active support policies which take advantage of normal capital replacement);
- Use and development of market-based instruments (such as the emissions trading system introduced by the EU);
- Harnessing of preventive and remedial efforts to adapt to climate change based on the most affected regions and economic sectors.

Consideration could be given to these elements through the following actions:

- *Immediate and effective implementation of agreed policies in order to meet the target of the 8% reduction in greenhouse gas emissions (compared with 1990 levels) agreed in the Kyoto Protocol . The measures concerned include those identified in the Green Paper on the security of energy supply and the White Paper on transport policy , as well as measures to promote climate-friendly technologies, such as the ecotechnologies ;*
- *Increased public awareness to encourage people to change their behaviour, i.e. through the launching of an EU-wide awareness campaign;*
- *More and better focussed research to further improve knowledge on climate change and its global and regional impact and to develop cost-effective climate change adaptation and mitigation strategies (in particular in the energy and transport sectors, but also in agriculture and industry);*
- *Stronger cooperation with third countries at the scientific level and through climate-friendly technology transfer as well as through specific measures with developing countries to draw up climate-friendly development policies and strengthen the adaptive capacity of the most vulnerable countries. The EU should therefore maintain its role of a driving force in international negotiations in this area;*
- *A new phase of the European climate change programme in 2005 in order to determine new measures to be taken in synergy with the Lisbon strategy , particularly in relation to energy efficiency, renewable energy, the transport sector and carbon capture and storage."*

However, again referring to the three energy policy objectives 'clean, affordable and secure', the actions in order to push the 'clean' objective do not seem to be very well integrated with actions regarding the other two objectives. Whilst much action is directed at involving the largest emitters of CO_2 worldwide in any new international emission reduction arrangements, it is still an open question how the relations to oil and gas exporting countries will develop if the EU sends out a double message of on one hand striving to secure oil and gas imports from these countries as long as possible, while at the other hand pushing for an energy transition in which these countries no longer will be needed.

In the EC energy policy package (EC, 2007a) costs, security of supply and climate change issues related to energy were addressed in a comprehensive approach. The package focused particularly on internal issues, but also contained some directions for external policies. Regarding relationships with producing countries it was remarked that "To enhance relations with our external energy suppliers, further developing comprehensive partnerships based on mutual interest, transparency, predictability and reciprocity". No mention was made however of how to involve these countries in a future energy transition.

Climate change mitigation and supply security in the EU will both benefit from ongoing international collaboration to further develop innovative energy technologies. However, the development of new technologies outside the European Union may have a bearing on the competitiveness between the EU and other regions. While the EU would like to welcome other regions to participate actively in an international climate regime or to contribute the supply security, it is keen to develop lead markets for innovative technologies within in its own borders.

Box 5 Main EU International Technology Collaborations

IEA Energy Technology Implementing Agreements

41 agreements with varying participation, ranging from advanced fuel cells to wind energy systems
Participants: 26 IEA member countries (mainly OECD countries) and the European Commission

Carbon Sequestration Leadership Forum

21 countries and EU participating, aim is to stimulate research, demonstration and development of carbon capture and storage technologies
Participants: Australia, Brazil, Canada, China, Colombia, Denmark, European Commission, France, Germany, Greece, India, Italy, Japan, Korea, Mexico, Netherlands, Norway, Russia, South Africa, Saudi Arabia, United Kingdom, United States

International Partnership for the Hydrogen Economy

16 countries and EU participate, goal is to accelerate the transition to a hydrogen economy. Participants: Australia, Brazil, Canada, China, European Commission, France, Germany, Iceland, India, Italy, Japan, Republic of Korea, New Zealand, Norway, Russian Federation, United Kingdom, United States

Renewable Energy and Energy Efficiency Partnership (REEEP)

Public private partnership backed by more than 200 organisations, including governments, businesses and NGOs. Its aim is to structure policy and regulatory initiatives for clean energy, and facilitates financing for energy projects.

Methane to Markets Partnership

Partnership of 20 countries with high methane emissions. Aim of the cooperation is to reduce methane emissions in particular in agriculture, coal mines, landfills and oil and gas systems.
Participants: Argentina, Australia, Brazil, Canada, China, Colombia, Ecuador, Germany, India, Italy, Japan, Mexico, Nigeria, Poland, Republic of Korea, Russia, Ukraine, United Kingdom, United States, Viet Nam

World Bank Gas Flaring Reduction Initiative

Cooperation of 5 donor countries and EU, 12 target countries, 9 oil companies and 2 multilateral organisations (OPEC, World Bank) aiming to reduce gas flaring at oil production. Donor Countries: Canada, France, Norway, United Kingdom, United States. Target countries: Algeria, Angola, Cameroon, Chad, Ecuador, Equatorial Guinea, Indonesia, Kazakhstan, Russia, Nigeria, Norway, United States.

Extractive Industries Transparency Initiative

Initiative in which presently 20 countries participate that support improved governance in resource-rich countries through the verification and full publication of company payments and government revenues from oil, gas, and mining. Donors include the EU, Canada and Australia. Participants: Cameroon, Chad, Democratic Republic of Congo, Republic of Congo, Equatorial Guinea, Gabon, Ghana, Guinea, Liberia, Madagascar, Mali, Mauritania, Niger, Nigeria, Sao Tome and Principe, Sierra Leone, Azerbaijan, Kazakhstan, Kyrgyz Republic, Mongolia, Timor-Leste, Bolivia, Peru, Trinidad & Tobago, Yemen

ITER Nuclear fusion Project

ITER is a joint international research and development project in which 7 partners cooperate. It aims to demonstrate the scientific and technical feasibility of fusion power
Participants: European Union, United States, Russia, China, Japan, India, Korea

From the previous discussion it follows that if a long-term global energy transition is indeed a trajectory that the EU considers useful to follow, a balanced foreign energy policy approach is needed. In particular, the EU should consider how the relations to the current fossil fuel exporting countries relate to a long-term energy transition. A constructive dialogue with these countries on how they could profit as well from such an energy transition could be a way to remove possible roots of future international conflicts and could even be a two-sided sword for the EU: by linking international fossil fuel relations to renewables and energy efficiency, the EU could also export its knowledge and assets in this field, and thus convert a one-sided import dependency into a trade relation on an equal basis.

International collaboration, which encourages both information and cost-sharing could greatly enhance the effectiveness of policies for technology innovation, development and dissemination. Technology transfer to the developing world is likely to play a critical role in controlling global emissions. International technology agreements could help support additional efforts to promote technology innovation, development and diffusion. They could complement agreements to achieve shorter-term emission limitation or reduction objectives.

4.5 Conclusions

From the arguments brought forward in this chapter, it appears that current EU policies to mitigate climate change and secure energy supply are most likely insufficient to ultimately realise these goals by 2050. The EU emission trading system is a useful, market-based and flexible instrument to reduce greenhouse gas emissions, but in its present form most likely will not provide sufficient incentives for major investments in new technologies. In addition to the ETS, specific barriers to the introduction and commercialisation of low-carbon energy technologies should be addressed. Regarding EU foreign relations, an integrated short- and long-term approach would be beneficial to energy transition, in particular if this policy would more explicitly address the present bifold message sent out to oil and gas producing countries - stimulating on one hand medium-term contracts for oil and gas delivery with these countries (‘security of supply’), whilst on the other hand expressing the wish to become independent of these oil and gas supplies in the long run (‘climate change’).

5 Conclusions and policy recommendations

In this chapter we assessed adequacy of the EU energy policy mix for meeting the three objectives of the EU energy policy, as formulated in the EC's energy policy package: climate change mitigation, a secure energy supply, and competitiveness. Two principle conclusions and a series of underlying findings are derived from this study.

5.1 Conclusions

1. *The synergy between climate change mitigation, energy security and competitiveness suggested by the three-fold objective of EU energy policies is not straightforward.*

a) *Monetised global impacts from climate change in the long term most likely outweigh the economic implications of oil and gas supply disruptions for the EU, both in the short and medium term.* Sectoral and regional impacts of both climate change and energy supply disruption may not follow this general pattern. In its latest assessment IPCC avoids concluding on the economic value of climate change impacts, because existing projections do not include key phenomena for which projections are too uncertain, such as extreme weather events, or economic valuation too complex, as for impacts on human health or ecosystems. Nevertheless, the financial implications of climate change impacts are presumed to exceed the costs of mitigating climate change. Therefore, mitigation costs, which by 2100 are estimated on the order of several percents of global GDP per year over business as usual, could be used as a lower bound for the damage cost of climate change. The costs of past oil supply disruptions have been on the order of tenths of percents of GDP per year i.e. much lower than the expect damages caused by climate change.

b) *Evidence that innovative energy technologies will improve competitiveness of the EU is not very robust.* Markets for innovative energy technologies are undoubtedly important, and many consider it likely that further technological innovation will increase overall total EU productivity. Yet, empirical evidence for this presumption is scarce. Likewise, the impacts from environmental policies with respect to broader goals of economic growth and employment are uncertain. While the stringency of environmental standards and competitiveness of industries may be correlated, this does not necessarily imply a causal relationship between the two. In this respect it should be recognized that energy and climate policies not only bring benefits, but also involves costs, with costs of climate mitigation policies by 2030 up to several percents of global GDP.

c) *A range of low carbon technologies may contribute simultaneously to reducing CO_2 emissions and improving the security of energy supply.* Important exemptions to the exist as well, such as a switch from coal to natural gas technologies or coal-to-liquids technology. (Nearly) commercial technologies that should be stimulated in view of the EU's climate change and energy security objectives include in particular wind and bioenergy, as well as end use efficiency in buildings, appliances and in industry. Ethanol flex-fuel vehicles could be stimulated a lot more, considering the maturity of the technology. In order to reduce emissions and secure energy supply for the medium and longer term further development of second generation biofuels and demonstration of various technologies for CO_2 capture and storage need to be stimulated. Finally, nuclear energy could also play a role in meeting both objectives.

d) *A cost effective package of options to curb CO_2 emissions by 2050 to relatively low levels (i.e. on the order of 50% of 1990 emissions) has only a modest positive impact on energy security.* The implementation of such a package could be induced by an emissions trading scheme, as in the carbon constraint scenario evaluated in this study. However, not only might the EU ETS stimulate the use of natural gas technologies, a trading regime is also unlikely to comprise the transportation sector, which at present very much depends on a secure oil supply. Gas intensity might increase under an emissions trading regime. This implies that care should be taken that an emissions trading regime will not result in too large a switch to natural gas technologies. Furthermore, the larger contribution of intermittent renewable energy to electricity production implies a larger risk of short term disruptions in a scenario with a more stringent global emissions regime climate.

e) *On the short to medium term no technological breakthroughs are needed in order to reduce greenhouse gas emissions to levels sufficiently low to stabilise atmospheric CO_2 concentrations below 570 ppm.* The IPCC in its Fourth Assessment Report concluded that this statement also holds for lower stabilisation levels. Nevertheless, effective policies to bring nearly commercial technologies to the market are imperative, and on the long term ongoing technological innovation and expansion of energy technologies are fundamental to a transition to a low carbon energy system.

2. *Current EU energy policies to stimulate (nearly) commercial and immature technologies are most likely insufficient to mitigate climate change and secure energy supply up to and beyond 2050.*

a) *Flexible and market-based instruments are key for limiting greenhouse gas emissions, the EU Emission Trading System being a prime example.* Extension of the EU ETS to a global emissions trading regime, encompassing all major emitting countries would increase both its effectiveness and its cost-efficiency. It would also help to avoid that certain emitting countries would benefit from the mitigation efforts from others.

b) *So far the EU ETS has not provided the incentive for major investments in innovative energy technologies which eventually are needed for a transition to a low carbon economy.* In January 2008 a number of major modifications were proposed, including a single EU wide cap on allowances up to and beyond 2020, a substantial role for auctioning of allowances, and an extension of the scheme to include more sectors and gases. To what extent these measures will help to bring about a sufficiently high and stable CO_2 price level will need to be evaluated timely. The scheme excludes the residential and commercial sectors, as well as the transportation sector. In these sectors major CO_2 emission reductions are conceivable on respectively the short to medium and long term. For these reasons, complementary policy instruments for stimulating specific technologies are necessary.

c) *In the short term, more emissions could be reduced if EU policies would be better tailored to address the barriers low carbon energy technologies face on their way to commercialisation, particularly in non ETS sectors*. A large scope seems to exist still for commercial technologies facing barriers of limited information or awareness, or split incentives. These include standard setting and labelling in the residential sector and transport, stimulating also hybrid and flex-fuel vehicles. Furthermore, targeted support for technologies in need of large-scale demonstration (notably CO_2 capture and storage) would help them to finance the major investments required for these operations.

d) *The EU in its external relations sends out an ambiguous message to fossil fuel exporting countries.* The EU seeks to assure gas and oil imports from producing countries on the short and medium term, and good relations with these countries are important to secure fossil supply from these countries. On the other hand, the EU tries to diversify its fossil imports away from these countries - also motivated by security of supply considerations. On the longer term the EU even wants to significantly reduce imports from these countries by pushing for a low-carbon economy. Neither investment in much needed new oil and gas technology in producing countries at this moment, nor their cooperation in a low-carbon energy transition on the longer term are efficiently stimulated in this way.

5.2 Policy recommendations

In view of the conclusions based on the present report, a number of recommendations may be formulated that may be of use to national and European policy makers alike.

1. Firstly, energy policies should be designed in the first place to protect the environment and secure supply of energy. The formulation of quantitative targets for energy security in the EU may advance the formulation of effective policies. A combination of indicators may well prove most informative in this respect. Indicators could include *inter alia* the Supply/Demand index, oil and gas intensity of the economy, import dependency for oil and gas, and the number of countries from which fossil fuels are purchased.
2. Secondly, the EU ETS needs a long term perspective on a stable and predictable CO_2 price level, which implies long trading periods and a low overall emission ceiling. Extension of the EU ETS to a global emissions trading regime encompassing all major emitting countries would increase both its effectiveness and its cost-efficiency. While a truly stringent emissions trading regime may advance a switch to natural gas technologies, corrective measures such as an increase of natural gas stocks suppliers may need to be anticipated to secure natural gas supply.
3. Thirdly, energy efficiency in buildings and appliances, promotion of hybrids and flex-fuel vehicles should be stimulated further. Bioenergy and wind energy are technologies that should also be promoted on the short and medium in view of the EU's climate change and energy security objectives. In order to curb emissions and secure energy supply on the medium to long term stimulation of CO_2 capture and storage demonstration must be recommended as well. In the light of climate change mitigation and energy security nuclear energy is a worthwhile option to consider, although concerns about nuclear proliferation, waste, and risks of nuclear power generation for some may outweigh the benefits of nuclear power.
4. Fourthly, short and medium term supply security and long term technological change could both be improved if the EU would engage in a more substantial dialogue with fossil fuel exporting countries on the question how they could benefit from a transition to a low-carbon economy. The EU should contribute to diversifying the economies of oil and gas producing countries away from a dependency on solely export of fossil fuels. Meeting domestic energy demand in an efficient way while using their renewable (e.g. solar!) potential should be an integral and substantial part of the EU external relations with these countries.
5. Fifthly, a long term vision as to how the present energy system would eventually evolve into a new intrinsically low carbon and secure energy system needs to be developed. A paradigm shift is needed to develop such a long term view on future energy supply and demand in the EU. In particular, a better understanding is needed as to how national political and economic interests in fossil fuels can gradually give way to low-carbon interests, and to what extent EU external relations and diplomacy can contribute to such a shift. Furthermore, insight would be required as to how innovative technologies could be accommodated by existing and new energy infrastructures, including the electricity grid, a hydrogen distribution network, or a CO_2 pipeline network. The role of industries, the European Commission, national governments, financial institutions, and external relations, as well as timing of required actions would need to be addressed in a long term energy strategy for the EU.

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List of Abbreviations

BERD	Business Expenditure on R&D
BRIC	Brazil Russia India China
CAC	Command and Control (regulation)
CC Index	Crisis-Capability Index
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power (generation)
CSP	Concentrated Solar Power
EC	European Commission
EEA	European Economic Area
ESI	Energy Security Index
ETS	Emissions Trading Scheme
EURATOM	European Atomic Energy Community
FED	Final Energy Demand
GDP	Gross Domestic Product
GERD	Gross (domestic) Expenditure on R&D
GHG	Green House Gas
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	International Panel on Climate Change
LNG	Liquefied Natural Gas
MA	Mitigation Assessment (Index)
MS	Member States
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of Oil Producing Countries
PES	Primary Energy Sources
PV	Photo-Voltaic
RA	Risk Assessment (Index)
RET	Renewable Energy Technology
RGGI	Regional Greenhouse Gas Initiative
S/D Index	Supply-Demand Index
toe	Ton of Oil Equivalent
TPSE	Total Primary Energy Supply
UN-CDS	United Nations Commission on Sustainable Development
WETO	World Energy Technology Outlook

Appendix A Other indicators of energy security

In Section 4.3 the so-called Supply/Demand Index was introduced as one of a set indicators used to evaluate energy security in the WETO-scenarios. Below a number of alternative indicators are introduced.

A1 Simple indicators of energy security

Useful and simple indicators of energy security in a country or region are oil and gas import dependencies and fossil fuel intensities. Reduction of fossil fuel import dependency was also the leading indicator in a qualitative assessment of supply security by MNP (2006), which is described in Section 2.5, where technology options were scored '+','0' or '-' based on their contribution to reducing imports of oil and gas into the EU. Examples of simple indicators include the share of imports in total primary energy supply, possibly weighted with fuel diversity (Kendell, 1998; APERC, 2007), the share oil imports in total oil demand (Alhajji and Williams, 2003), the share of middle East oil imports in total oil demand (ARPEC, 2007) or the share of oil or energy imports in GDP (World Bank, 2005, Percebois, 2006).

Although seemingly instructive, these indicators do not provide any insight into the vulnerability to - or impacts of - a supply disruption. It has been argued that a measure of vulnerability of impacts would provide much more guidance in establishing a comfortable level of energy security (Percebois, 2006; Kendell, 1998). The extent to which an economy relies on energy offers an indication of the potential impacts of a supply disruption. To this end, one may look at the *energy intensity of an economy*, expressed in units of energy per units of GDP. To transform this physical measure into a purely economic one, the *energy expenditures per unit of GDP* can be used. Additionally, this could be further disaggregated into specific fuel intensities, of which the oil intensity is the most instructive one. With oil the main energy carrier in most economies, and its price the most volatile one, it forms an indication of the impacts of disruptions. The *oil consumption* or *oil expenditures per unit of GDP* can therefore serve as a straightforward indicator (Kendell, 1998). A physical counterpart of this measure could be provided by the *oil use per capita*. With respect to oil, the transport sector is especially vulnerable, as for example in Europe, oil accounts for 98% of energy use in the transport sector (EC, 2007e). A more specific indicator could therefore be *the share of oil used in the transport sector*. Although overall oil intensity may be low, the transport sector in many economies serves at pivotal point, impacts on which can have profound effects on other sectors.

A2 The Crisis Capability Index

The Crisis Capability Index (Scheepers *et al.,* 2006; 2007) assesses the risk of sudden unforeseen short-term supply interruptions and its potential impact (Risk assessment: RA) and the capacity to manage them (Mitigation assessment: MA). The RA includes the profitability of specific risks as well as the impacts of these risks. The impacts comprehend the direct effects for consumers and producers and indirect impacts on the national economy and society as a whole. It is sometimes difficult to separate risks from mitigation measures. Redundancy of components and back up systems are reducing the risks of supply interruptions. These measures to mitigation risks should be taken into account when the assessment is carried out, i.e. the remaining risk for supply interruptions should be assessed.

In the risk assessment domestic production, import, energy conversion & transport are all assessed for their different risks of short-term interruptions. Included are for example climate risks that could trigger activity interruptions in oil refineries or in LNG-terminals and regas-facilities. Three types of risks and associated impacts may be distinguished: (1) technical and organisational failures, (2) human factors (incl. human failures and deliberate actions such as terrorist attack and political factors and (3) natural events. The risk can be valued by country

experts with a figure indicating no (0), low (1), medium (2) or high risk (3). Scores on each of the risks are weighed according to shares in primary energy, final energy demand or total energy import., and added up to obtain a value between 0 and 100 for the RA sub-index.
In the mitigation assessment, five groups of mitigation & emergency measures are distinguished: (1) strategic or emergency stocks, (2) demand restraint (including rationing), (3) fuel switching capabilities, (4) reserve capacity and (5) locked-in production capacity. Management of short-term sudden supply interruptions is in place in many EU Member States on the basis of international commitments such as the IEA Treaty and/or national contingency planning. Measures may be rated as not available (0), implemented (1), or implemented and tested (2). The scores are multiplied by the share relative share in primary energy sources (PES) or final energy demand (FED) similar as in the Risk Assessment checklist. The value of this Mitigation Assessment (MA) sub-index can be calculated when the total score of the checklist is multiplied by 10, resulting in an index value between 0 and 100.

Whether a country has an adequate capability to handle sudden energy supply interruptions can be judged by comparison of the MA sub-index to the RA sub-index. Although this comparison does address a country's capability to mitigate specific supply interruptions, it gives an overall indication of how well a country is prepared in comparison to its risk exposure. If the RA sub-index is equal to or lower than the MA sub-index the crisis capability of a country may be considered sufficient, and the CC Index will be 100. If the RA sub-index exceeds the MA sub-index more emphasis should be put on the measures to mitigate an energy supply security crisis. In that case the CC Index can be calculated with the formula:

If RA > MA: $$CCIndex = \frac{MA}{RA} * 100$$

Note that if the MA sub-index is much higher than the RA sub-index the costs associated with crisis capability measures may be exceeding the probability and costs of sudden supply interruptions. In other words, comparing MA and RA may show the extent to which preventive measures are commensurate with the disruption risks.

A3 The Energy Security Index

Bradley and Lefevre (2006) developed two indices to quantify the energy security implications of resource concentration. The Energy Security Index price (ESI_{price}) focuses on the price component of energy security, and consists of two elements: a measure of market power for international fossil fuel markets, and the level of exposure of a country to such risks. The Energy Security Index volume (ESI_{volume}) measures a country's risk of physical unavailability.

Although energy security concerns tend to be based on considerations of both price and physical availability, the relative importance depends on the market structure, and in particular the extent to which prices are set competitively or not. Prices on the coal and oil market are assumed to reflect market fundamentals, and consequently, the price mechanism will reduce the risk of physical unavailability. A shortfall in supply will induce more expensive suppliers to enter the market and at the same time trigger consumers to switch to alternative fuels. Ultimately, the main energy security concern in the international coal and oil market will be to have a price being set at uncompetitive levels.

On the other hand, if there is no (properly functioning) liberalised market to spread the effect of shortages or disruptions over all consumers in an economic manner, physical shortages may occur as a result of supply disruptions. In the case of (parts of) the European gas market for instane, gas contracts are negotiated bilaterally and prices determined periodically, usually indexed to oil. In those cases, supply shortages are not spread out over the market and mitigated by price increases. Physical unavailability is a major concern in such a market where domestic natural gas resources could be more safely relied upon than imports. Measuring the ESI_{volume} is therefore useful predominantly in gas markets.

A4 Comparing indicators for the security of supply

The indicators introduced above have all their strengths and weaknesses. Simple indicators such as import dependencies and fossil fuel intensities of an economy clearly indicate key differences between countries and trends over time. Individual policy measures may be scored in a semi-quantative manner on their contribution to reducing import dependency from oil and gas.

The principle asset of the approach elaborated by Bradley and Lefevre (2006) seems to be the distinction made between dependency from oil and gas. The notion that in the geopolitical playing field dependence on oil imports will have quite different implications than that of gas imports appears important. The calculation scheme used to quantify the price and volume indices of the Energy Security Index is not readily available though, which complicates its use in the present study.

The most sophisticated analysis underlies the S/D index developed by Scheepers *et al*. (2006; 2007), looking in detail into countries' supply and demand balances, crisis capabilities as well as into political abilities and willingness to act regarding energy supply security. However, the S/D Index analysis can not be applied to individual policy measures, but may be used to analysis energy security trends in scenarios.

In order to arrive to a detailed picture of the consequences of security of supply measures, it is proposed to use a range of complementary indicators. In this report we aim to assess energy security implications of two climate mitigation scenarios, and for these we will have quantified import dependencies and fossil fuel intensities, as well as the Supply/Demand index.

Appendix B Indicators for technological innovation

This section provides an overview of indicators for innovation and innovation capacity. In practice, many indicators exist and are deployed to measure innovation. A distinction can be made between innovation input and output indicators. Input indicators measure the efforts, often in monetary terms, put into stimulating innovation. Output indicators measure the actual outcome of the innovation process, in other words, the impact of innovation. Furthermore, some indicators can give an idea of the 'climate' for innovation in a country, i.e. the likeliness that innovations can take place, or innovation capacity. This innovation capacity reflects the incentives people and companies get to innovate, as well as the probability and speed that innovations will be adopted. Tables B1, 2, 3 give an overview of the various types of indicators.

Increasing competitiveness of a country relative to main competitors has to contribute to economic growth and job creation. For economic growth and job creation to occur, however, inventing a new product, process or service as such is not enough. The product or process has to be sold in order to be of any impact on the economy. It is therefore the *output* of innovation that actually matters to competitiveness. However, since measuring the actual outcomes of the innovation process is far more difficult than looking into inputs, the number of output indicators of innovation is far more limited than the number of input indicators. In fact, the 'number of patents' is the most commonly used indicator for the latter purpose. Therefore, ideally also input indicators for innovation have to be considered, as well as indicators for the innovation capacity of a country. Even if all these indicators are taken into account, it has to be kept in mind that the relation of these indicators to the competitiveness of a country remains complex. A positive value for all innovation indicators is by no means an absolute guarantee that this is translated directly into economic growth and job creation.

From the above, two conclusions can be drawn. Firstly, output of innovation is most important to examine for competitiveness. Secondly, the number of output indicators is limited, so that also input indicators and innovation capacity indicators have to be taken into account. Furthermore, none of the indicators introduced above can be used to assess technological innovation in the scenarios studied in this report. Therefore, we have not used them for the quantification of technological innovation in this report. Instead, technological innovation in the scenarios was described based on general trends of primary production and final consumption of fossil fuels, and of the composition of the electricity production portfolio.

Table B.1 Innovation input indicators

Indicator	Source
Amount of public and private R&D investment	*(Veugelers, 2006)*
Stock of Science & Technology researchers	
Proportion of population in tertiary education	
Funding allocated to education	
Migration of researchers	
Gross domestic expenditure on R&D (GERD)	*(OECD, 2006)*
Business enterprise expenditure on R&D (BERD)	
GERD or BERD as percentage of GDP	
Public expenditure on R&D (GERD - BERD)	
Public expenditure on R&D as percentage of GDP	
Total researchers (fte) per thousand total employment	
Public research spending as part of GDP	*(EC, 2006d)*
Public research spending as part of researchers	
Co-existence of national and EU-funded research activities	
Total innovation expenditures	*(OECD, 2006)*
Sales of imitative and innovative products	
New product announcements	
Significant (or basic) innovations	
R&D-man years	

Table B.2 Innovation output indicators

Indicator	Source
Number of patents High technology exports per capita	*(EC, 2006d)*
Number of patent families per thousand capita population	*(OECD, 2006)*

Table B.3 Success factors for innovation capacity

Factor	Source
Diversity Leadership Tolerance for failure Entrepreneurship Time Share of knowledge	*(Gasperz, 2005)*
Factors related to innovation policy: Excellence in basic research (by government funding) Protection of property rights Availability of venture capital for innovative projects Degree to which antitrust enforcement encourages innovation-based competition Openness of the economy to trade and investment Supporting factors: Effectiveness of intellectual property protection Ability of a country to retain scientists and engineers Size and availability of R&D tax credits for the private sector Sophistication and pressure from buyers to innovate Presence of suppliers of specialised research and training Overall quality of scientific research institutions Information infrastructure	*(Furman* et al.*, 2002)*

Appendix C Summary expert workshop 'Balancing European energy policy objectives'

24 May 2007, Clingendael Institute, The Hague

Participants

Experts:	Nicola Kirkup (DTI, UK); Fredrik Hedenus (Chalmers University), Cedric Philibert (IEA), David Reiner (Cambridge University); Ferenc Toth (IAEA).
Project team:	Ton Manders (PBL), Marcel Kok (PBL), Stephan Slingerland (CIEP), Stijn van den Heuvel (CIEP), Bas Wetzelaer (ECN), Francesco Ferioli (ECN), Heleen Groenenberg (ECN).
Steering Committee:	Erwin Mulders and Merrilee Bonney (both Ministry of Public Housing, Spatial Planning and the Environment (VROM)).

Background and setup of the workshop

The expert workshop, held the 24th of May at the Clingendael Institute in The Hague, was part of the project "Balancing European Energy Policy Objectives", which is carried out by ECN Policy Studies, PBL Netherlands Environmental Assessment Agency and the CIEP Clingendael International Energy Programme. The project started in January 2007 and will end at the end of 2007 with an international seminar. The objectives of the project are threefold:

1. Analyse the interactions between policies for climate change mitigation, energy security, and innovation and competitiveness;
2. Analyse quantitative methods for the evaluation of policies with respect to climate change mitigation, long term energy security, and innovation and competitiveness
3. Explore options for international co-operation with respect to climate change mitigation and the security of energy supply.

The informal policy workshop was meant as a first milestone in the project, which would allow the project team to benefit from the expertise of international researchers and policy makers. It consisted of four sessions:

I. Security of Supply and Climate Change
II. Innovation and links to climate change, security of supply and competitiveness
III. Policy instruments and scenarios
IV. Balancing EU energy policy objectives.

In each of the sessions, experts gave their views on the approach proposed by the project team. The workshop ended with a discussion on how to take the work in the project forward, which resulted in a number of recommendations.

Introduction

Ton Manders introduced the project and the expectations for the workshop briefly to the workshop participants. Francesco Ferioli presented the first results of the project. He showed how a baseline scenario and a mitigation scenario from both the PRIMES and the POLES models differed in terms of CO_2 emissions, contribution of renewable energy supply, and import dependency. In addition, supply security was quantified using the Supply/Demand-Index developed by Scheepers et al (2006). The role of innovation was presented in terms of production of renewable energy, and the forecasted shares of nuclear, renewable energy, CO_2 capture and storage, and hydrogen production in major world regions. It turned out that in particular nuclear and renewable technologies have a strong potential in Europe. Finally it was concluded that additional policies would be needed on top of the EU-ETS, to reach renewable energy targets.

Comments on the presentation:

- The approach taken in this project to compare a small number of existing scenarios from two different models was rejected.
- The SD indicator taking into account energy demand was considered to be a useful step forward. However, choices made were considered to be arbitrary and some relevant aspects remain hidden in the aggregate index (see below).

SESSION I: SECURITY OF SUPPLY AND CLIMATE CHANGE

(Nicola Kirkup; Fredrik Hedenus)

Main points made in this session were:

- Lowering consumer demand is the most straightforward way to improve both SoS and CC. Creating consumer demand for climate change mitigation (e.g. clean energy, energy efficient electronic devices, etc.) is likely to be more powerful than trying to change energy consumption directly[26].
- Four general themes are of special importance with regard to security of energy supply:
  1. Reliability of imports
  2. Diversity
  3. Spare capacity[27]
  4. Market responsiveness
- Spare capacity as a measure to improve SoS should be differentiated with regards to the type of technology. The intermittent character of renewables reduces the positive contribution (less import dependence) to the security of energy supply. As a consequence, baseload fossil fuel capacity cannot be replaced simply by renewables. To secure supplies, additional power stations that only run when there is e.g. not enough wind are needed. This extra capacity leads to high costs.
- Emergency planning for short term disruptions in energy supply can be used to improve a countries' resilience to supply shocks and hence decrease the possibility of energy stress. Such measures should therefore always be aimed for and stimulated if market forces do not bring about the desired level of emergency capacity.
- High oil prices tend to bring investments on stream in exploration and production and in alternative energy sources. In general it can be said that the price level as such is not the main problem of SoS, but rather the volatility of prices.

Supply/Demand Index

- Considerations of the security of supply often only focus on import dependency. This may lead to unwanted policy responses without solving the problem. The Supply/Demand Index takes account of a more complex set of drivers, in particular demand-side interactions and therefore is a useful indicator for measuring energy security. Improvement of conversion efficiency would, for example, not be taken into account when only import dependency was used as an indicator.
- The exact meaning of a value of the SD index is not clear, nor is it clear what the sensitivity of the index is. It would be interesting to be able to relate the level of the SD-index to the cost of bringing about a change in the level of the index. For example, a 2% improvement of the index might be worthwhile when it has a cost of €20 million, but is this still the case when the costs are €20 billion?
- In order to find an answer to this question, a risk-based approach would be needed. Such an approach can assess the impacts of a reduced energy security (i.e. the cost of not having enough energy per period of time) by attaching a cost to each MWh of lost energy. This

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[26] The 23rd of May, the UK government presented a white paper on energy policy: '*Meeting the Energy Challenge'*. In this paper many ways are discussed to tackle the twin challenge of climate change and energy security. Although it is not the role of the government to pick technologies, the existing market failure of not internalising costs of climate change (CC) and a limited security of energy supply (SoS) legitimate government action.

[27] With regard to electricity, spare capacity seems to be the most important measure to prevent that the lights turn off.

approach should differentiate between segments of users (degree of vulnerability) and the duration of lost energy into account. The impacts of a disruption should then be related to the likelihood of an energy supply failure should be taken into account. The concept of ‘expected energy not served’ is a useful risk measure. It can be used to estimate the required level of storage, the required over-capacity and the resulting (in)dependence of import.

Oil sector perspective

- To assess security of supply of the gas market, it is interesting to have a look at the oil sector. With the emergence of LNG the gas and oil sector might show stronger parallels within 20- 30 years than today.
- The Middle East will continue to control world oil supplies to a large extent into the future. A policy approach could therefore include a strategy that reduces the market power of the Middle East / OPEC. Currently, world energy demand continues to rise, while supplies of fossil fuel seem to become less reliable and secure as a result of the increased competition between consuming regions. This leads to higher prices and in the future possibly to physical shortages.
- High oil prices can have a positive influence on SoS. In the first place a high price makes the search for unconventional resources like tar-sands, and high-cost exploration projects, economically feasible. Secondly, the cheapest oil is located in Middle East a low price increases the dependency on this region, which is conceived to be bad for security of supply. In the third place, a high oil price makes the gap with alternatives to oil smaller. Coal to liquids, biofuels or ethanol[28] can compete better with high prices. Moreover, new and possibly cleaner technologies require a lower level of government funding to reach a commercial stage in a high oil price situation.
- Unclear why import of oil is relevant given the global oil market. More relevant to focus on oil intensity or energy intensity.

SESSION II: INNOVATION AND LINKS TO CLIMATE CHANGE, SECURITY OF SUPPLY AND COMPETITIVENESS

Main points made in this session were:

- Innovation as such is not a primary goal of European energy policy and should not be assessed at the same level as CC and SoS policy. Rather, competitiveness is a main policy objective in general. The potential outcome of the innovation process, an increase in jobs and economic growth caused by a competitive European industry (in terms of prices of industrial goods and technological leadership leading to export potential) relates to other EU policy objectives, like the Lisbon strategy. So when assessing innovation, it is first important to realise, why do we want to innovate? To increase competitiveness of the industry, to support economic growth, to reform the economy in a greener way or to develop new technologies? In relation to energy innovation can more specifically aim greater deployment of current technologies, incremental improvements or radical breakthroughs for the longer term.
- Different stages in the innovation process require different types of funding. In the research stage, public money often plays an important role. In the ‘exploratory’ stage there is a need for venture capital to be able to scale-up. When the commercial / diffusion stage is reached investments and financing should be done by the market. In general it can be said that the closer one comes to deployment, the more expensive financial support becomes.
- The third energy goal of the European Union, creating a competitive internal energy market, has made effective policies for climate change mitigation and energy security more difficult. Liberalised markets have taken away a lot of levers to influence the energy industry.
- Technologies to combat climate change should preferably be put in place in different countries and regions across the globe. Such policies, however, may lead to concerns on

[28] With regard to ethanol it should be noted that in general it does not lower import dependence. It can however improve diversification of suppliers both in terms of the number of suppliers and the perceived reliability.

domestic competitiveness. One example is the proposal of the US administration to provide clean coal technologies to other countries. The congress refused this plan because of fears that the technology would be copied and the competitive position of the US industry would be damaged. So it is be very important to assess how technological development relates to a region's own needs, as the risk of leakage can be substantial. Europe has strongly bought into the Porter Hypothesis[29], but it is far from evident that this will provide the desired results.

SESSION III: POLICY INSTRUMENTS AND SCENARIOS

Main points made in this session were:

- Several policy instruments exist to promote diffusion of renewable technologies, each with specific advantages and drawbacks. Several countries and several US States adopted renewable energy portfolio standards. Advantages include that this instrument leads to a least cost solution (as it is left to utilities how to implement it) and that the environmental outcome is certain. Informing and persuading the public to behavioural changes is another policy direction. It might, however, be more expensive than imposing obligations and the outcome is less certain. A drawback of obligations is that it makes it unlikely that a higher level of renewable sources than the obligated level will be produced. Moreover an obligation does not foster the development of technologies that have a strong potential in the long-term (and in fact might be needed to reach the long-term policy goals), but have not yet reached a competitive stage in terms of costs. Many European countries adopted the feed-in tariff system. This system has the evident advantage that it enables governments to differentiate technologies and hence stimulates both short- and long-term alternatives.
- Mandatory measures can be a strong instrument, e.g. by obliging all fossil fuel power plants to be equipped with CCS after 2020. Technologies such as CCS will only emerge when there is climate policy in place (i.e. carbon has a price), as using it will always imply a cost.
- It is often debated if new technologies are needed to tackle climate change or that improvements in existing technologies can be enough. The IEA projects that in 2050 emissions can be brought back to the 2003 level with current technologies. In between there will however be an overshoot of emissions. To reach the 2003 level in 2050 further (incremental) innovation is in cost reductions is still required. The assessment shows that no further radical innovations are needed to reach the 2003 emission by 2050[30].
- The potential of innovative technologies can be analysed by looking at learning curve data and the position of individual technologies on the experience curve. A combination of expansion of markets and development in science is needed to achieve necessary cost reductions. An option can be to stimulate niche markets for technologies that leave the R&D phase.

SESSION IV: BALANCING EU ENERGY POLICY OBJECTIVES

Main points made in this session were:

- How to bring about international cooperation in the field of climate change should be an important part of European policy, next to changes in the domestic energy system. Currently Europe accounts for 15% of global emissions, by 2020 possibly only for 9%. So even when European emissions would be cut to zero, the climate problem is not solved. This section therefore deals with international agreements and post-Kyoto design.
- The way of allocating emission allowances to the industry can lead to different environmental outcomes. Two common options are free allocation by the government or auctioning. Free allocation based on grandfathering may lead to windfall profits for participants in the trading scheme and may be a disincentive to further cost reduction and innovation. Auctioning is

[29] According to the Porter Hypothesis strict environmental regulations can induce efficiency and encourage innovations that help improve commercial competitiveness.

[30] This implies that reaching the climate goals of decreasing emissions with 50% by 2050 requires a very large amount of innovation.

better for innovation and technological change as it really makes companies think of what alternatives they have from emitting.

- A global carbon tax is unlikely to come into place, but alignment of national energy taxes seems to be more realistic. Long term certainty on energy policies, be it a carbon tax, a trading scheme, or another instrument will increase the required certainty to actors to invest in emission reducing technologies.
- Another policy option could be to pursue lead markets: groups of countries that want to collaborate in certain technological areas. The Strategic European Technology Plan foresees in such a structure with its aim to reduce overlap in research by coordinating research collaboration at the Commission level for different technological areas.
- If the climate problem becomes really severe you might prefer a quantity system to a tax system, as the outcome of a quantity system is secure, while the outcome of a tax system is left to the market and hence more uncertain.

Main recommendations of experts for the project

- The use of models in the project is at this moment not yet clear. Why are these scenarios used and what new is to be learned from these scenarios? If you do not dispose of a model to produce scenarios yourself, perhaps you should focus on a range of scenarios from a single model and not make comparisons between mitigation scenarios from different scenarios.
- An alternative to a cost-benefit framework for the assessment of energy policies or technologies would be to group and rank technologies and policies: put policies and/or technologies into groups of more or less similar contributions to climate change mitigation; next, rank the policies and/or technologies in each group with respect to their contribution to energy security.
- There is an order of magnitude difference between climate impacts and SoS impacts. It is not easy to add up across these dimensions. Cluster options with a similar effect on reductions and as a next step look at SoS impacts.
- Perhaps use the Supply/Demand Index to compare current energy security situations in (a selection of) EU Member States.
- Make clear what the goal of innovation and its relation to competitiveness and climate change mitigation is, before trying to quantify it.
- Distinguish between the different dimensions of energy security: risk of insufficient imports (resources) versus risk of black-outs.