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Energy security of supply under EU climate policies

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ECN-E--06-061 December 2006

Acknowledgement

The present study has been financed by the Ministry of Economic Affairs in the Netherlands. The responsibility for the contents of the report lies fully at the project team of the Energy Research Centre of the Netherlands (ECN).

This project is registered at ECN under number 7.7728. For information on the ECN contribution to the project you can contact Heleen Groenenberg by email (groenenberg@ecn.nl) or by telephone (+31 22456 4516).

Abstract

The implications of various climate policies for the security of supply in the EU-25 were investigated. The security of supply was quantified using the Supply/Demand (S/D) Index. This index aggregates quantitative information on a country's energy system into one single figure. It takes a value between 0 and 100, with higher values indicating a more secure energy system. The S/D Index was calculated for the year 2020 based on the information in a series of policy scenarios, including a baseline (S/D Index 50.7), an energy efficiency scenario (53.8), two renewable energy scenarios (52.6 and 53.3) and two scenarios with combined policies (55.9 and 55.6).The S/D Index proved a useful indicator for assessing the implications of climate policies for the security of supply. As climate policies become more stringent, CO_2 index fall, and the S/D index increases. The magnitude of the changes in the two indices is not always similar however. Major falls in CO_2 indices in the order of 20% for two scenarios with combined energy efficiency and renewable energy polices lead to less noteworthy improvements in the associated S/D indices. Nevertheless, this combination of policies leads to the greatest improvements in the security of supply.

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Summary

In this study the implications of various climate policies for climate change mitigation and for the security of supply in the EU-25 were investigated. This security of supply (SoS) was quantified using the Supply/Demand (S/D) Index as a proxy measure to assess the SoS. This index aggregates quantitative information on a country's energy system into a single figure. It takes a value between 0 and 100, with higher values indicating a more secure energy system. The S/D Index was calculated for the year 2020 based on the information in a series of climate policy scenarios developed by the National Technical University of Athens and supported by the Directorate-General for Energy and Transport (DG TREN). These scenarios included a baseline scenario ('Trends to 2030') and five scenarios with policies for stimulating measures for energy efficiency and renewable energy.

The 'energy efficiency' (EE) scenario assumes full implementation of existing EU directives related to energy efficiency. The '12% renewables in 2010' (RES-12) scenario takes into account policies that are required for achieving a 12% share for renewable energy in the EU's energy supply in 2010, and a continuation of similar policies thereafter. The 'high renewables' (HIRES) scenario also includes the 12% target in 2010, but assumes more stringent policies thereafter to achieve a 20% share of renewables in 2020. The EE&RES-12 and EE&HIRES scenarios comprise combinations of policies for energy efficiency and for renewable energy.

Energy efficiency policies in the scenarios assessed in this study have a more marked impact on CO_2 emissions than policies for renewable energy. Emissions fall by almost 10% below the 1990 level if existing directives on energy efficiency are implemented. Emissions decrease by 6 and almost 9% in the scenarios with policies for renewable energy (respectively RES-12 and HIRES). Major reductions in the order of 20% can be realized if policies for energy efficiency and renewable energy are combined.

Policies for renewable energy will lead to an improvement of supply security in the EU. Calculated values for the S/D Index in 2020 were 53 both for the RES-12 and HIRES scenarios, vs. 51 in the baseline. Policies for energy efficiency have a more pronounced effect on the security of supply, with an index value of 54. Obviously, combinations of policies lead to the greatest improvements in the security of supply, as shown by S/D Index values of 56 for both the EE&RES-12 and EE&HIRES scenarios respectively. Nevertheless, these improvements are not as noteworthy as the sharp drop in CO_2 emission reductions achieved by a combination of policies.

The S/D Index proved a useful indicator for assessing the implications of climate policies for the security of supply. However, the range of calculated values in the six scenarios was 5.1. This range overlaps with the uncertainty range of ± 10%, estimated in a previous study. Consequently, if the S/D Index is to support decision making on climate and supply security policies, it is imperative that users agree on the assumptions underlying the index.

1. Introduction

1.1 Background

Energy security, defined as continuous and uninterrupted availability of energy, has become an important matter of concern both in the Netherlands and the European Union. The EU has become increasingly dependent on the import of fossil fuels, sometimes from politically unstable regions in the world. This concern is being felt in a time where the reduction of greenhouse gas emissions has become a chief objective of environmental policies.

While detailed climate change mitigation policies have been elaborated in many countries, policies for the security of energy supply are still underdeveloped. Many climate change policies however are beneficial for a secure energy supply. Different forms of renewable energy, including alternative transport fuels, low emission fossil fuel based power plants, or energy savings in buildings will all reduce pressure on scarce supplies of fossil fuels.

Although a range of climate policies may improve the security of supply, it is still unclear what technology or policy would be most helpful in meeting objectives for both climate change mitigation and supply security. This would require a quantitative insight into the benefits of such policies for the global climate and for the supply security in a region. While benefits for mitigating climate change are commonly measured as the volume of CO_2 avoided, a good indicator for the security of supply is still lacking. Such a measure is vital however for evaluating implemented policies and formulating new ones.

1.2 Previous work

In a 2004 study on ‘Energy Supply Security and Geopolitics’ which was prepared for the European Commission’s directorate for transport and energy (DG TREN), Clingendael International Energy Programme recommended developing an EU standard for energy supply security (CIEP, 2004). Such a standard would help to assess supply security in the EU and its Member States while taking account of national circumstances. It would be instrumental in formulating and evaluating policies in Member States.

A range of quantitative indicators for energy security has been proposed in the past (see Jansen et al., 2004, Scheepers et al. 2004, Van Werven et al. 2005, Van Oostvoorn (ed) 2003, Kessels and Bakker, 2005; IEA, 2006). Many indicators focus on the energy supply of one or several primary energy sources. An assessment of supply security should also include demand however. Also losses during energy conversion and transport have a negative effect on the security of supply. Therefore, Scheepers et al. (2006) developed a new indicator for the medium and long term security of supply, the Supply/Demand Index (S/D Index). The S/D Index aggregates quantitative information on a country’s energy system into one figure, and takes a value between 0 and 100. The authors suggested the development of benchmarks based on the S/D Index to assess the security of supply in a country or region. Today’s S/D Index was calculated for a number of selected EU Member States and the EU-25. The S/D Index proved a useful indicator for obtaining insight in the supply security situations in various Member States. It was recommended that further development as well as practical experience with the indicator be gained. The update and further development of the S/D Index model and its application for the EU27 as an aggregate and for the 27 individual Member States will be published in (Scheepers et al., 2007). Both today’s S/D Index (‘2005) and the year 2020 value based on the ‘Trends to 2030’ scenario is part of that quantification.

The S/D Index has also been used in two recent ECN studies. The first included an assessment of the Biofuels Directive on the SoS (Londo *et al*., 2006, confidential) and the quantification of the S/D Index for Ireland (SEI, 2006).

1.3 Objectives

This study aims to further explore the use of the Supply/Demand Index as a tool to compare synergies and tradeoffs between climate change mitigation policy and the security of energy supply. Supply security in this report is considered as a shortage in energy supply, either a relative shortage, i.e. a mismatch in supply and demand inducing price increases, or a partial or complete disruption of energy supplies. These shortages refer to security of supply risks. In particular, the S/D Index will be used to assess the benefits of various climate change policies for the security of supply by the year 2020 in the EU-25. It will compare the benefits of such policies for climate change mitigation with benefits for the security of supply. Policies considered include incentives for renewable energy, energy efficiency policies, and combinations of these. The impacts of these policies on energy supply and demand in the EU-25 have been laid down in a series of climate policy scenarios developed by the National Technical University of Athens (NTUA) and supported by DG-TREN (2006b). These scenarios will be the basis for the analysis in this study.

Chapter 2 explains how the S/D Index can be calculated based on objective information on energy supply and information, and more subjective inputs concerning the weights that are assignned to different components of the index. Chapter 3 introduces the energy scenarios describing the impacts of climate change policies. Next, the S/D Index in the EU-25 in the year 2020 are calculated for each of these scenarios. Results are presented and analysed in Chapter 4. Chapter 5 discusses the values and drawbacks of the S/D Index and identifies routes for further research. Chapter 6 concludes.

2. Methodology

2.1 The S/D Index Model

The S/D Index has been recently developed and can be used to assess security of supply on a EU level, for EU Member states separately, but also to assess the supply security situation for a sub-region of a few EU member states (Scheepers et al., 2006). This chapter outlines the essence of the S/D Index model, largely based on Chapter 4 of the aforementioned (Scheepers et al., 2006). The S/D Index includes all three parts of the energy system: final energy demand, energy conversion and transport and primary energy supply. It is suited in particular for assessing today's energy security as well as security in the medium and longer term. The index will rate the energy security of supply with a value between 0 and 100.

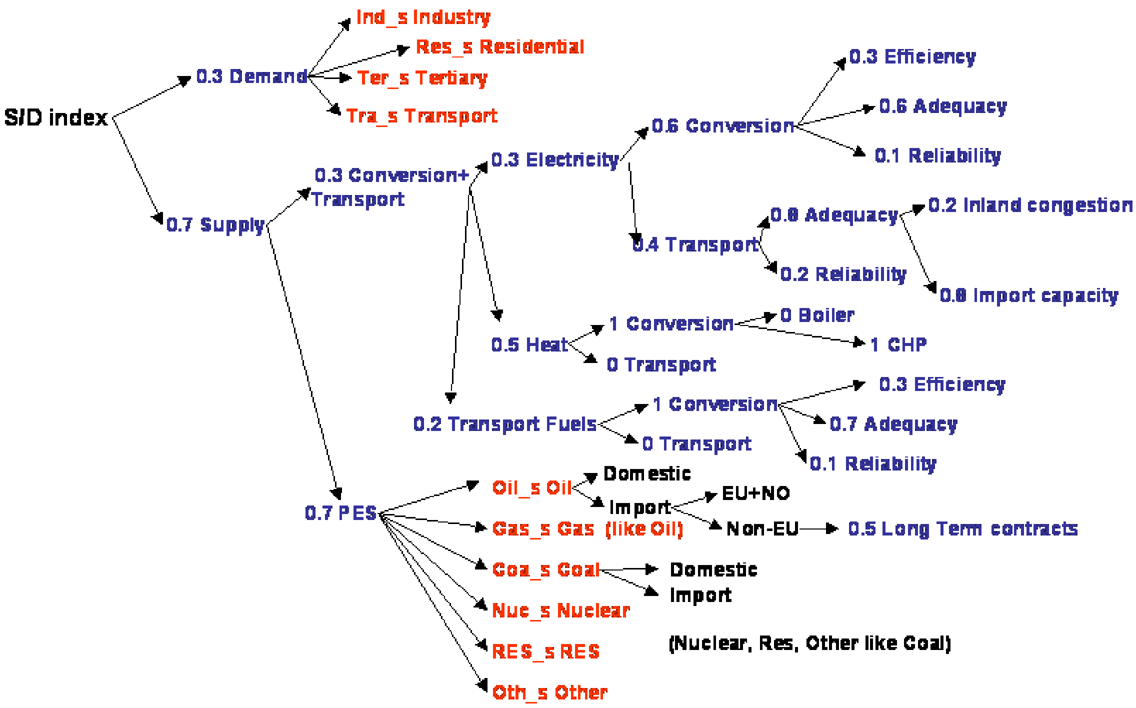

Figure 2.1 *Components of the S/D Index. Weights for aggregating the components are indicated*

Note: Objective shares are coloured in red, and subjective weight factors are coloured in blue.

For the calculation of the S/D index a spreadsheet has been elaborated, which includes a database with a range of energy parameters. These parameters represent the energy demand and supply structure of EU Member States, the whole EU or a sub-region of the EU. Figure 2.1 shows the components of the energy system included in the index. The index includes the most important aspects of the energy system to provide good insight into the security of supply. An overload of details is avoided, to warrant transparency of the index.

The S/D Index uses four types of inputs:
1. *Shares* indicating the structure of energy supply and demand.
2. *Parameters* characterising capacity and reliability of the energy system.
3. *Weights* determining the relative contribution of different components of the index.
4. *Scoring rules* determining the index value of each individual aspect contributing to the S/D index.

The first two types of inputs are objective and based on physical parameters of the energy system. The shares represent the contributions of various economic sectors in energy demand, and of different primary energy sources in energy supply. This information is readily available in energy balances or scenario projections. The parameters used are further explained for demand in Section 2.2, for primary energy sources in Section 2.3 and, for conversion and transport, in Section 2.4.

The latter two types of input, weights and scoring rules, are of a more subjective nature and based on expert judgement. The establishment of those weights or scoring rule criteria might also be the outcome of the conceptual phase in the process of deriving 'EU Standards for energy SoS' as proposed in (Scheepers et al., 2006). Weights are used to aggregate the various components into one single index. The weights parameters have been chosen in relation to the contribution of components to a secure energy system. A high weight of a component indicates that it increases vulnerability of the system.

Each individual component in the index (i.e. at the end of the branches) will have an index value between 0 and 100. The next sections discuss in more detail the calculation method of the individual indexes for each of the three parts of the model (energy demand, conversion and transport, primary energy sources). Default values are introduced for weights determining the relative contributions of the individual index values to the overall S/D Index. They are also listed in Figure 2.1.

2.2 Final Energy Demand

As was stated earlier, the S/D Index includes final energy demand, i.e. the amount of electricity, gas, heat and transport fuels used by energy consumers. The index seeks to value the degree in which the energy demand is kept as low as possible. This is done by a series of energy intensity factors.

The S/D Index includes five energy intensity factors to allow for differences in Member State demand structures:

1. Energy intensity of the residential sector (ton-oil-equivalents/capita).
2. Energy intensity on added value for the industrial sector (ton-oil-equivalents/M€).
3. Energy intensity on added value for the tertiary sector (ton-oil-equivalents/M€).
4. Two energy intensities for the transport sector (ton-oil-equivalents/M-ton-km for goods and ton-oil-equivalents/M-passenger-km for passengers).

The partial index value for each energy demand sector is calculated from the ratio between the EU's or Member States' energy intensities and benchmark values. As default proposed and as a general rule, the benchmark values are the average figures of energy intensities of the five best performing EU Member States. No corrections are made for climate differences (residential sector), differences in energy intensive industries (industrial sector) and population density (transport sector). This will keep the model simple and more transparent. Moreover, corrections would obscure the vulnerability of certain sectors to a disruption of energy supply. Weighing the four partial index values (one for each economic sector) with the shares of each demand sector results in a partial index value, the so-called Demand Sub-index, for energy demand as a whole.
It should be noted that establishment of the benchmark values is also part of the conceptual phase possibly leading to 'EU Standards for energy SoS'.

2.3 Primary Energy Supply

For calculating the partial index value on primary energy supply, a close look at the origin of primary energy sources is needed. A number of factors is distinguished (see Figure 2.1):

- Domestic primary energy production versus imports from other EU Member States.
- Imports from inside the EU (including Norway[1]) versus imports outside of the EU.
- Imports from outside the EU warranted by long-term contracts versus short-term contracts.

The distinction between domestic production versus import from other Member States may seem redundant. The internal market should assure non-discriminatory trade and respect of import contracts. However, questions have been raised whether existing import contracts for gas or power should always be honoured, even in times of immediate shortfalls. Although politicians have assured not to interfere in existing contracts when there are short-term supply interruptions, it is uncertain whether this will always be the political reality. Therefore, the model allows for making a slight difference in rating supply relations that are purely national versus those that are intra-EU based.

Energy trade relations for imports from outside the EU will also be based on contracts, i.e. on the rule of law, and sometimes on multilateral or bilateral treaties. EU energy imports basically cover crude oil, oil products, gas (including LNG), coal, uranium and renewables (mainly biomass). As for oil and gas the S/D Index distinguishes between import from EU Member States and supply from outside the EU. This does not only arise from heavy geographic concentrations of these energy sources, but also from the increasing awareness of geopolitical concerns that are adding to supply risk perceptions. Although several methods are available that allow for differences in geopolitical circumstances in supply regions, it was decided not to make further refinements in this respect, because of the poor data availability on future supply origins and in order to avoid a too high degree of complexity. It would seem that coal, uranium and renewables energy sources do not ask for a specific assessment because of a sufficiently diverse supply base from a number of secure sources.

Oil and gas supplies based on long-term contracts will give higher assurances of interrupted supply than short-term contracts. Therefore, the model allows for this type of differentiation. Oil and especially gas that originates from areas where national oil or gas companies together with international energy companies have made some heavy long-term investments, and thus have created strong economic interests in secure and reliable long-term energy flows, could be considered as more secure because it is mitigating supply risks for consumers and demand risks for producers.

The factors above are included in the calculation of the partial index value on primary energy supply. For the six primary energy sources the following scoring rules apply (see also Figure 2.2):

- Nuclear energy will have a value of 100 irrespective of the supply origin because supply risks for uranium are relatively low.
- The indices for coal, renewable energy (mainly biomass) and other energy supplies have a minimum value of 70 if the total supply is imported and will increase proportionally with decreasing imports. This is because these sources are originate from various regions and reduce a vulnerability of energy supply. Some may argue that coal is at least as good for the security of supply as nuclear; in that case the minimum score for coal would be 100.
- The index for gas and oil will be zero until the net share of domestic supplies exceeds a level of 30%[2]. Above this level the index will increase proportionally with increasing domestic supplies. The threshold of 30% will become lower when the share of long-term contracts in non-EU imports increases (i.e. in Figure 2.2 the point of intersection of the gas/oil line with the x-axis will move to the left). Next to the net share of domestic supplies, the

[1] Norway is since 1994 legally committed through the Agreement on the European Economic Area (EEA) to apply the EU's energy market rules. This being the case, there is no reason to treat energy imports from Norway different from imports from within the EU.

[2] These thresholds have been set to 0% (hence, no thresholds) in the quantification in the fortchcoming (Scheepers et al., 2007), as a result of discussion with policy makers in a few MS with interest in using the S/D Index.

import part will only get a positive score if the import share from EU + Norway and a weighted share from non-EU governed by long term contracts exceeds a level of 30% again.
- Domestic oil and gas production will only result in a positive score if the domestic share is above a certain minimum (30%). Furthermore, the import part will only get a positive score, if the import share from the EU and Norway and a weighted share from non-EU imports governed by long term contracts is above certain minimum (30%) (see Scheepers et al. 2006).

The partial index value for primary energy sources ('PES sub-index') is calculated on the basis of the score of each of the primary energy sources, and their relative shares in the total primary energy supply.

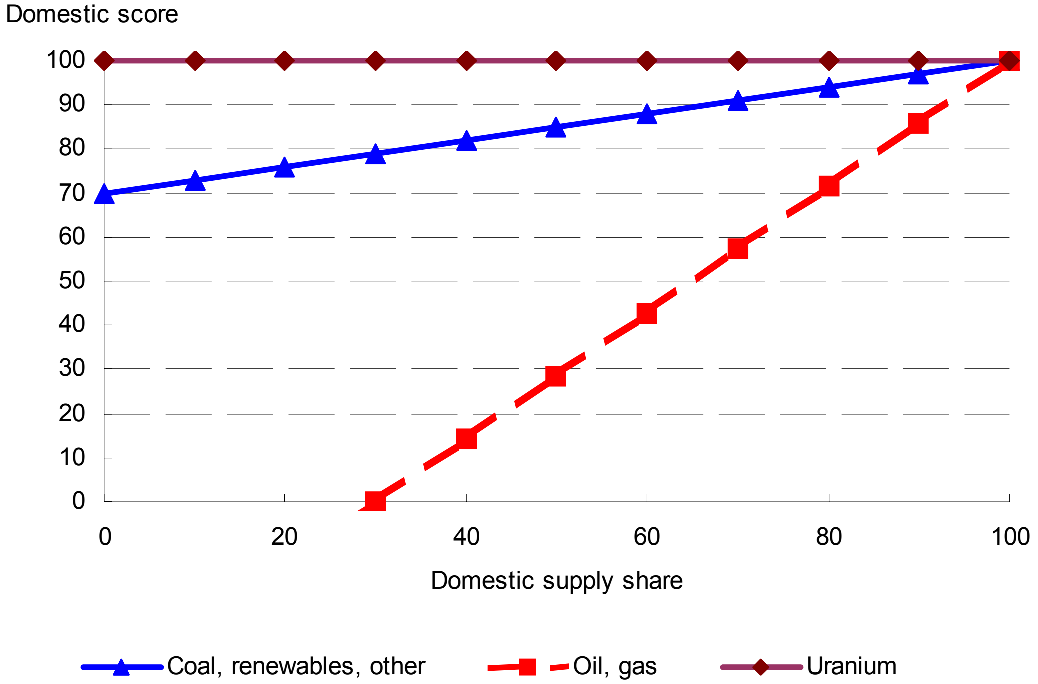

Figure 2.2 *Scoring on primary energy sources as a function of domestic supply*

2.4 Energy Conversion and Transport

Whether final energy demand can be covered by primary energy sources depends partly on the adequacy and reliability of energy conversion and transport infrastructures. For conversion and transport of energy three secondary energy carriers are used: electricity, heat and transport fuels[3]. For some of these aspects reliable data are lacking, in particular in future energy scenarios, or the aspects are perceived as less important for energy supply security. These aspects are: power generation reliability, adequacy for the inland electricity network, electricity network reliability, heat transport, refinery reliability and fuel transportation. For reasons of consistency these aspects are kept in the model, but the default value is set to 100.

The scoring rules on components for energy conversion and transport aspects are as follows:
- *Efficiency power generation*: if the average electricity generation park efficiency is less than 35% the index value is zero. The index value is 100 if the average efficiency is 50% or above. Between 35% and 50% the index value is proportional. These values are based on the present state of the technology.

[3] The updated S/D Index model (Scheepers et al., 2007) includes also gas as a separate branch.

- *Power generation adequacy*: the index value is based on the so-called reserve factor, i.e. the power generation capacity exceeding the level of peak demand. If the reserve factor is 1.2 or above the index value is 100. The index value is zero when the reserve factor is less than 1 and proportional if the reserve factor is between 1 and 1.2. These values reflect present industry practices, including the role of mothballing.
- *Power generation reliability*: The default index value is 100, assuming that on average the reliability of power plants is sufficient. Alternatively, the power generation reliability can also be included in power generation adequacy.
- *Electricity network adequacy*: The index value for import capacity consists of combining a value relating import capacity to domestic capacity and one including a reserve factor including both domestic and import capacity. The import capacity value is proportional to a ratio between 0 en 5%, and the value for the 'combined' reserve factor is proportional if its value lies between 1 and 1.2. Instead of the 5%, one could also choose the so-called 'Barcelona target' (EC, 2003a) according to which interconnection should cover at least 10% of a Member State's installed capacity. The value of 5% has also been subject of the NL/UK sensitivity analyses reported in (Scheepers et al., 2006). For the Netherlands it appears not to be important (as the import factor is about 19%), while for the UK it is somewhat more important (as the import factor is only 3%).
- *Electricity network reliability*: For this component statistics on network reliability in terms of the average time of outages per year can be used. However, data on future network reliability is not available. For the moment the default index value is 100.
- *Heat generation efficiency:* The boiler efficiencies are not used here because of lacking information on this aspect. But even more relevant for efficiency of heat production is the share of heat generated by combined heat and power (CHP). However, since these figures are difficult to acquire, the share of CHP in electricity generation is used instead. The index value is proportional to this share and will reach the value of 100 when 25% or more of national annual electricity production is generated by CHP, a figure reflecting national practice in the Netherlands and Denmark.
- *Refineries efficiency:* The efficiency of refineries is determined by the ratio of the energy value of transport fuels and those of crude oil and biofuels, due to the importance of oil products for the transport sector. The fuel efficiency in terms of crude oil (and biofuels) input versus oil products output is relatively high (typically about 94%) and not really discriminating. Moreover, supporting data cannot be obtained easily; therefore, a score of 100 is assigned in all cases. Otherwise, a similar rule such as for power generation efficiency could be applied.
- *Refineries adequacy:* The index value is 100 if the refinery capacity in use is 80% or lower compared to the total domestic refinery capacity. If this figure exceeds the value of 95% the index value is dropping to zero. Between these two figures, which again reflect industry practice including mothballing, the index value is proportional to the ratio of refinery capacity in use.
- *Fuel transportation:* The capacity for transporting automotive fuels will seldom be constrained, because there are several alternatives (by truck, ship, train or pipeline). Therefore the default index value is 100.

3. EU Climate Policies

The S/D Index will be used to study the security of supply under various climate policies. In particular, the consequences of policies on energy efficiency and renewable energy will be assessed. The effects of such policies on the energy system and on CO_2 emissions have been projected in a series of scenarios designed by the NTUA and published by the European Commission (DG TREN 2006a, b). Apart from a baseline scenario 'Trends to 2030', five scenarios on energy efficiency and renewable energy were constructed to assess the effects of additional policies. The baseline scenario will be used as the reference for these scenarios. It will be presented in the following section. Next, the policy scenarios will be discussed in Section 3.2 to 3.6 and illustrate possible alternative pathways for the evolution of the EU energy system in the horizon of 2030.

3.1 The baseline scenario

The baseline scenario of the EU-25 energy and transport case to 2030 examines energy, transport and CO_2 developments. A clear and exhaustive description of a baseline scenario is of major importance for two reasons: the first is the need to understand the key drivers of the trend projections, and the second is to ensure the basis for further policy analysis. As noted above, the baseline scenario can be considered as the reference for additional policy scenarios. In that way, policy makers are better able to evaluate alternative pathways addressing issues such as an increase in nuclear capacity, energy efficiency measures, rising energy import prices, or alternative fuels in transport. Major assumptions on population, climate, economic growth and technological progress are presented below (DG TREN, 2006a).

3.1.1 Demographic and climate assumptions

In order to determine both energy trends and overall economic performance, projections for the evolution of population in the EU Member states are essential. Following EUROSTAT figures, the EU-25 population is projected to increase by some 11 million people between 2005 and 2030.

Household size has an important effect on energy demand. In spite of the rather small increase in EU-25 population, UN projections and the PRIMES-model[4] indicate that a significant growth in the number of households (+ 0.8% per year in 2000-2030) can be expected. This growth figure is one of the key drivers of energy demand in the residential sector. As is shown in Table 3.1, energy demand in the residential sector is projected to increase from 295 Mtoe in 2005 to 339 Mtoe in 2020.

Weather conditions determine both the intensity and the overall pattern of energy use, in particular related to heating. Climate is assumed to remain stable over the projection period, which means the degree-days parameter is taken as constant at 2000 levels.

[4] According to NTUA (2000) PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand in the EU member states. The model determines the equilibrium by finding the prices of each energy carrier such that the quantity producers find best to supply match the quantity consumers wish to use. In addition, PRIMES is a general purpose model. It is designed for forecasting, scenario construction and policy impact analysis. The dynamics, as stimulated by the model, influence the penetration of new technologies.

3.1.2 Macroeconomic assumptions

The baseline scenario foresees a continuation of policies on the Lisbon agenda, launched in 2000, and the completion of the internal energy market. In addition, the EU-25 is projected to benefit from economic and monetary unification as well as from a continued increase in world trade. Increases in commodity prices and inflation are assumed to remain modest.

However, in view of the weak state of the economy in many EU Member States seen in the last few years, lower GDP figures than those shown in the baseline scenario (see Table 3.2) are also possible. The projected GDP growth for the EU-25 are mainly determined by the evolution of the EU-15 economy. Although economic growth is faster in the New Member States (NMS), the size of the economy in these countries remains rather limited compared to the rest of the EU-25. The existing structural disparities between the EU-15 and the NMS economies in 2005, are not forecasted to be fully eliminated by 2030. As an example, the NMS-economies are projected to remain more reliant on industry than EU-15 economies. Consequently, as is shown in Table 3.1, energy demand in the industrial sector is projected to increase from 339 Mtoe in 2005 to 382 Mtoe in 2020.

Table 3.1 *Overview of baseline and climate policy scenarios*

	Baseline 2005	Baseline 2020	RES-12	HIRES	EE	EE&RES-12	EE&HIRES
Final Energy Demand [Mtoe]				**(%change from baseline)**			
Industry	339	382	0.7	0.7	-3.1	-2.4	-2.5
Residential	295	339	0.3	0.3	-17	-18	-18
Tertiary	174	211	-0.7	-0.8	-22	-22	-23
transport	361	406	0.0	0.0	-9.3	-9.3	-9.3
total	1170	1340	0.2	0.1	-12	-12	-12
Installed capacity [GW]				**(change from baseline 2020 in GW)**			
Nuclear	138	117	-5.5	-5.5	-8.9	-11	-11
Renewable	138	241	89	107	-22	50	71
Hydro	100	109	3.0	3.0	-2.3	1.8	1.9
Wind	38	128	70	81	-19	46	63
Solar	0.8	4.9	16	23	0	2.2	6.8
Thermal	450	585	-27	-30	-107	-112	-108
Solids	187	157	-42	-45	-35	-64	-65
Oil	75	48	-5.3	-6.0	0.5	-0.1	0.1
Gas	171	321	-34	-41	-62	-85	-88
Biomass-waste	16	57	50	58	-10	34	41
Geothermal	1.3	1.5	3.8	4.2	0	3.3	3.7
Total	726	943	56	71	-137	-73	-48
Import dependency [%]				**(percentage points difference from baseline)**			
Solids	51%	50%	*0.8*	1.7	0.6	*-1.4*	0.4
Liquids	38%	96%	*-0.1*	-0.4	-0.5	*-0.3*	-0.8
Natural gas	83%	81%	*-1.5*	-1.7	-2.6	*-4.5*	-5.0
Total	53%	64%	*-4.2*	-5.3	-0.4	*-7.8*	-5.8
GDP G€$_{2000}$)	9716	13656	13656	13656	13656	13656	13656
CO_2 index (1990 = 100)	100.7	104.0	93.9	91.3	90.1	80.9	78.6
S/D Indicator	52.8	50.7	52.6	53.3	53.8	55.8	55.6

Source: *DG TREN, 2006a b.*

3.1.3 International energy prices

In the baseline scenario high market prices are foreseen for crude oil, natural gas and to a lesser extent for coal. Oil prices would fall over the next few years from their high 2005 level of 55 $\$_{2005}$. The projection for the 2010 oil price is almost 45 $\$_{2005}$, from where it grows steadily to reach nearly 58 $\$_{2005}$ by 2030. Natural gas prices are estimated to reach 34 $\$_{2005}$ per barrel of oil equivalent in 2010 from roughly 30 $\$_{2005}$ in 2005. This implies that the oil–gas price gap becomes smaller in the medium term (horizon to 2010). However, outcomes from the Prospective Outlook of Long-term Energy Systems (POLES) model, which have been used in the scenarios published by DG TREN, suggest that beyond 2015 the shift from regional gas markets towards a more global gas market generates increasing competition between gas-exporting countries. As a consequence, gas prices are decoupled from oil prices in the second part of the projection period (2015-2030) and the difference between both prices becomes larger with a lower increase of the gas price. As for coal, prices decline from approximately 13 $\$_{2005}$ in 2005 to reach 12.5 $\$_{2005}$ in 2010, and rise slowly thereafter to reach 15 $\$_{2005}$ in 2030.

3.1.4 Other assumptions

The baseline scenario assumes that all current policies and those in the process of being implemented at the end of 2004 will continue in the 2005-2030 period. Indicative targets as set out in various EC Directives (e.g. Directive 2001/77 EC on electricity production from renewable energy sources or Directive 2003/30 EC on the promotion of the use of biofuels or other renewable energy fuels for transport) are not assumed to be necessarily met. For example, renewables shares in 2010 are outcomes of the PRIMES model: they reflect implemented policies rather than targets. In addition, no new CO_2 abatement policies are assumed for the post-Kyoto period. However, the baseline scenario does take into account the developments listed below.

- technological progress
- restructuring of the sectoral pattern of economic growth (see 3.1.2)
- completion of the new internal electricity market and gas markets in EU-25
- restructuring in power and steam generation
- shifting primary energy production patterns (closure of unprofitable coal mines)
- continuation of gas infrastructure projects
- nuclear phase-out policies in some EU-25 Member States
- low impact on consumers prices of blending gasoline and diesel with biofuels
- CO_2 market price 5 $€_{2000}/tCO_2$
- stringent regulation for acid rain pollutant
- execution of existing decommissioning and investment plans in power generation
- differentiation of discount rates.

Most of the assumptions have been elaborated in the DG-TREN report (2006a**).** As for the assumptions on investment and decommissioning, all plans made for capacity investment and decommissioning plants are executed as indicated in the EURPROG report of EURELECTRIC (ref. ?) and other statistical sources. For nuclear energy this means that decommissioning occurs on the basis of technical lifetime and agreements on policies on nuclear phase-out. Finally, the discount rate is a key element in the determination of investment decisions of energy using applications. Three (real) discount rates are used in the model to assess EU climate policies: 8% for large utilities, 12% for large industrial and commercial entities and 17.5% for households in determining their expenditures for transportation and household applications.

3.2 Energy efficiency (EE)

The energy efficiency (EE) scenario incorporates improvements that together yield significant energy and cost savings. Several directives have been adopted, including a directive on energy performance in buildings (2002/91/EC, EC 2002), on eco-design requirements for energy using products (COM (2003) 453 final 2003/0172, EC 2003b) and on end-use energy efficiency and energy services (COM (2003) 739, final 2003/0300, EC 2003c). The energy efficiency scenario assumes full implementation of these directives. Accordingly, efficiency measures are more focused on the residential sector and tertiary sector than on transport sector and industrial sector.

This, in turn, is reflected in relatively large projected changes for final energy demand in residential sector (-17% compared to baseline projections by 2020) and tertiary sector (-22% compared to baseline projections in 2020). The industrial sector and transport sector only achieve limited energy savings of respectively -3.1% and -9.3%.

Installed generation capacity for all energy forms (nuclear, renewables and solid fuels) is 137 GW lower than in the baseline. Table 3.1 shows that the biggest fall is projected for gas-fired installations, solids-fired installations and wind power installations, by -62 GW, -35 GW and -19 GW respectively in 2020. Lower electricity needs, adoption of more efficient power generation technologies in the EU-25 and a larger exploitation of co-generation options in the power generation sector all contribute to this decrease.

In the short (2010) to medium (2020) term projections for import dependency are slightly lower than in the baseline scenario (-0.4 percentage points in 2020, see Table 3.1). This can be explained from a lower electricity demand produced from nuclear and (indigenous) solid fuels. In 2030, this lower exploitation of EU-wide energy sources even offset the decline in primary energy production. As a consequence, projections for import dependency are a little higher in the long run.

As a result of lower energy demand and a more efficient production of electricity, CO_2 emissions from the power generation sector are lower. According to Table 3.1, CO_2 emissions are 10% below the 1990 level.

In brief, the energy efficiency scenario foresees a much more sustainable development of the EU-25 energy system than the baseline scenario. Strong action to reduce gas and solid-fuels installed generation capacity allow for a improvement in the carbon intensity, which in combination with the downward changes in final energy demand brings about a favourable trend in CO_2 emissions. Furthermore, energy efficiency policies may lead to a smaller exploitation of the potential for electricity generation from renewable energy, in particular wind power. Thus, energy efficiency measures result in a more modest increase of the share of renewable energy in the medium and long term energy mix.

3.3 12% renewable energy in 2010 (RES-12)

Within the EU, many policy developments underline the key role of renewable energy in ensuring sustainable energy supplies. Moreover, new renewable energy policies reinforce social and economic cohesion, generate new impulses for the European industry and contribute to job creation. Especially the introduction of the 1997 White Paper 'Energy for the Future: Renewable Sources of Energy'[5] established a basis for renewable energy in the policy landscape of the EU.

The '12% renewable energy in 2010' (RES-12) scenario explores the evolution of the EU-25 energy system until 2030 with supporting policies for renewable energy forms remaining constant over the projection period at the levels needed for the achievement of 12% share in 2010. As a consequence, the fuel mix in the EU-25 energy system undergoes significant changes. This insight is reflected in the changes in installed capacity compared to the baseline scenario. The projection for the generation capacity for renewable energy sources (hydro, wind and solar) is estimated at 330GW in 2020. This is 33% of total installed capacity, which is higher than the 28% in the baseline scenario. The strong increase of renewable energy sources in the fuel mix has an effect in particular on solid fired power plants. In 2020 the installed capacity is -41.8 GW lower than in the baseline (see Table 3.1). A major part of the increase in renewable energy use can be attributed to biomass and waste, whereas the contribution of other renewable energy sources, such as hydro, wind, solar and geothermal energy, is less significant.

5 In November 1997 the White Paper put forward the long standing indicative objective of increasing the share of renewables in gross inland consumption to 12% in 2010.

The increase in the use of indigenous energy forms under this scenario is also reflected in the foreseen evolution of the import dependency within the EU-25 (Table 3.1). Import dependency grows more slowly than in the baseline (-4.2 percentage points from baseline levels in 2020). Thus, the 11 percentage points rise in import dependency in the baseline is reduced to 6.3 percentage points in the RES-12 scenario.

Finally, the transformation of the energy system under the RES-12 scenario leads to a significant reduction of CO_2 emissions in EU-25 over baseline levels. Total CO_2 emissions are over 200 Mt lower than the baseline level in 2010 and almost 440 Mt lower in 2030.

3.4 High Renewables (HIRES)

The ‘High Renewable’ (HIRES) scenario foresees at a 12% share of renewable energy in 2010, similar to the assumption in the RES-12 scenario. Contrary to the RES-12 scenario however, the share of renewable energy increases to 20% in 2020. The installed capacity for renewable energy in the EU-25 energy system increases by 107 GW over baseline levels (see Table 3.1).

While market share of nuclear energy and fossil fuels are lower than in the baseline, indigenous energy supplies are higher in the HIRES scenario than in the baseline, following a larger exploition of renewable energy. As a result, import dependency falls below baseline levels in the next 25 years. Import dependency in 2020 is limited to 58%, which compares favourably to the 64% in the same year in the baseline scenario.

The depicted changes in the energy fuel mix lead to a reduction of CO_2 emissions from the power generation sector, with a projected CO_2 index of 97.3 in 2010. As can be seen from Table 3.1, CO_2 emissions in 2020 are with an index of 91.3 lower than the 1990 level. In 2030, emissions are even 11% below the 1990 Kyoto-based level.

In brief, the HIRES scenario projects significant improvements in the future evolution of the EU-25 energy system compared to the baseline scenario, both in terms of security of supply and in reduced CO_2 emissions.

3.5 Energy efficiency and 12% renewables in 2010 (EE&RES-12)

The ’energy efficiency and 12% renewable energy in 2010’ (EE&RES-12) scenario combines the policies foreseen in the EE and the RES-12 scenarios. This results in marked effects on the market share for renewable energy, and in particular in declining CO_2 emissions. The former indicator shows that the share of renewable energy sources in total primary energy needs increases from 7.9% in the baseline to 11.7% in the EE&RES-12 scenario. The latter indicator drops continuously in the coming decades. In 2020 projected CO_2 emissions are -19% lower than in 1990 (Table 3.1).

Important changes are projected for electricity and steam generation. Obviously, renewable energy sources increase their market shares, thus diminishing the shares of gas and solid fuels (Table 3.1), while overall electricity generation declines significantly from baseline levels (-4.7% in 2010, 26% in 2030). In 2020, 11% of electricity and steam generation capacity would originate from biomass and waste, wind would contribute 25%, hydro would contribute 13% and solar would take account of 0.8% of total capacity.

This scenario implies a significant decline in energy demand, i.e. by –12% over the 2020 baseline level. This decline is manifest particularly in the tertiary (-22%) and residential sectors (-18%), while the effect on demand in industry is rather limited (-2.4%). Energy efficiency policies are mostly targeted at the residential and tertiary sectors. Policies for improvements in buildings' thermal integrity and demand side management, which constitute the main focus of efficiency policies, only allow for significant energy intensity gains in residential and tertiary sectors and have limited impacts in industry.

3.6 Energy efficiency and high renewables (EE&HIRES)

The 'combined energy efficiency and high renewables' (EE&HIRES) scenario combines the assumptions of the EE and the HIRES scenarios. It emphasises exploiting the promising synergies and trade-offs of policies promoting energy efficiency and renewable energy forms simultaneously, regardless of any specific targets. Renewable energy forms that are of specific importance in this scenario are the higher penetration of biomass and waste, including the increased share of biofuels used in the transport sector.

In 2020 renewable energy is projected to account for 20% of primary energy needs in the EU-25 energy system, which is 0.6% higher than in the HIRES scenario. This modest increase can be explained from lower energy requirements. Demand for all other energy forms, especially nuclear energy, is projected to fall under baseline levels. The prominent decline in nuclear energy limits the share of carbon extensive energy sources in primary energy needs. Furthermore, import dependency, especially for natural gas, would be lower than in the baseline, i.e. 58% in 2020, which is -5.8 percentage points under the baseline level (Table 3.1).

CO_2 emissions are projected to decline -21% from the baseline level in 2020, as a result of the upward shift of the renewables share in the fuel mix and the much lower energy requirements in the EU-25 Member States. Among the scenarios explored in this study, the most favourable development of CO_2 emissions is achieved in the EE&HIRES scenario.

4. Resulting Supply/Demand Indices

4.1 Baseline

As set out in Section 3.1, the baseline scenario represents current trends and policies as implemented in the Member States up to the end of 2004. It does neither take into account possible additional action in the Member States for meeting their Kyoto commitments nor any new policies after 2012. Under such a scenario, the security of energy supply in the EU-25 will deteriorate. The S/D Index drops between 2005 and 2020 from 52.8 to 50.7, more than 2 points.

Table 4.1 gives insight into the drivers behind this development. The table shows the overall S/D Index and partial index values in bold. The first and third column present the weights that were assigned to the components of the S/D Index, according to the methodology set out in Section 2. In the baseline scenario energy demand falls steadily. This is reflected in the lower partial index value on the demand indicator. An increase in residential energy demand intensity is the most important driver behind this development. Energy intensity in this sector is projected to increase from 0.60 to 0.72 toe/cap. On the other hand, energy intensities in the tertiary sector will decrease until 2020, from 27 to 20 toe/€ added value. This has a minor impact on the demand partial index though.

Conversion and transportation of energy will become more efficient in the baseline scenario. Average thermal efficiency increases from 38 to 45%, while the share of heat in electricity production increases from 16 to 22%. Yet the most important driver behind the deteriorated energy security in the baseline is the reduced security of primary energy supply. Both coal and nuclear will face a drop in their shares in primary energy supply, although renewable energy will contribute more. In particular the supply of gas will become less secure, with the net domestic share of gas in primary energy consumption falling from 47% to 19%.

Table 4.1 *Supply/Demand Index, partial index values (bold) and weights (italics) for the EU-25 in the baseline scenario*

	2005		**2020**	
	Weight	**Index**	***Weight***	**Index**
S/D index		52.8		50.7
Demand	***0.3***	59.2	***0.3***	56.3
Industry	***0.28***	**40**	***0.29***	**39**
Residential	***0.27***	**58**	***0.25***	**48**
Tertiary	***0.15***	**57**	***0.16***	**55**
Transport	***0.30***	**80**	***0.30***	**80**
Supply	***0.7***	50.0	***0.7***	48.3
C+T	***0.3***	65.6	***0.3***	79.2
Electricity	***0.3***	**61**	***0.3***	**70**
Heat	***0.5***	**66**	***0.5***	**87**
Tr. Fuels	***0.2***	**72**	***0.2***	**72**
PES	***0.7***	43.4	***0.7***	35.1
Oil	***0.37***	**0**	***0.36***	**0**
Gas	***0.24***	**27**	***0.28***	**4**
Coal	***0.18***	**89**	***0.14***	**85**
Nuclear	***0.15***	**100**	***0.12***	**100**
Ren. ES	***0.06***	**100**	***0.10***	**98**

4.2 Climate policies

The development of the energy security under the baseline scenarios may be curbed following climate change mitigation policies. Such policies typically lead to improved energy intensities or a larger share of renewable energy in primary energy supply, which is beneficial for the energy security situation. Table 4.2 presents the S/D index for the baseline scenario in 2020, as well as for five climate policy scenarios in the same year.

Each of the climate policy scenarios will lead to an improved energy security situation, albeit not all to the same degree. The RES-12 and HIRES scenarios will lead to an increase in the S/D Index by 1.9 and 2.6 points respectively. Policies for energy efficiency will lead to an even larger improvement of 3.1points compared to the S/D Index in the baseline scenarios. Combining energy efficiency and renewable energy policies, as in the EE&RES-12 and EE&HIRES scenarios, result in scores that are almost the same (5.1 and 4.9 points respectively over the baseline value in 2020. In the following sections we will unravel the overall scores on the S/D Index for each of the five climate policy scenarios. We will discuss the partial scores on demand, on conversion and transport, and on primary energy supply.

Table 4.2 *Supply/Demand Indices in 2020 and breakdown for baseline and five climate policy scenarios*

	Baseline		**RES-12**		**HIRES**		**EE**		**EE&RES-12**		**EE&HIRES**	
	Weight	**Index**	***Weight***	**Index**	***Weight***	**Index**	***Weight***	**Index**	***Weight***	**Index**	***Weight***	**Index**
S/D index		50.7		52.6		53.3		53.8		55.8		55.6
Demand	***0.3***	56.3	***0.3***	57.9	***0.3***	57.9	***0.3***	63.5	***0.3***	65.5	***0.3***	63.6
Industry	***0.29***	**39**	***0.29***	**39**	***0.29***	**39**	***0.31***	**40**	***0.32***	**40**	***0.32***	**40**
Residential	***0.25***	**48**	***0.25***	**48**	***0.25***	**48**	***0.24***	**59**	***0.24***	**59**	***0.24***	**59**
Tertiary	***0.16***	**55**	***0.16***	**66**	***0.16***	**66**	***0.14***	**70**	***0.14***	**84**	***0.14***	**71**
Transport	***0.30***	**80**	***0.30***	**80**	***0.30***	**80**	***0.31***	**88**	***0.31***	**88**	***0.31***	**88**
Supply	***0.7***	48.3	***0.7***	50.4	***0.7***	51.4	***0.7***	49.6	***0.7***	51.6	***0.7***	52.1
C+T	***0.3***	79.2	***0.3***	79.3	***0.3***	79.6	***0.3***	85.0	***0.3***	84.3	***0.3***	84.3
Electricity	***0.3***	**70**	***0.3***	**68**	***0.3***	**68**	***0.3***	**68**	***0.3***	**66**	***0.3***	**66**
Heat	***0.5***	**87**	***0.5***	**89**	***0.5***	**90**	***0.5***	**100**	***0.5***	**100**	***0.5***	**100**
Tr. Fuels	***0.2***	**72**	***0.2***	**72**	***0.2***	**72**	***0.2***	**72**	***0.2***	**72**	***0.2***	**72**
PES	***0.7***	35.1	***0.7***	38.0	***0.7***	39.3	***0.7***	34.4	***0.7***	37.6	***0.7***	38.5
Oil	***0.36***	**0**	***0.35***	**0**	***0.34***	**0**	***0.37***	**0**	***0.36***	**0**	***0.35***	**0**
Gas	***0.28***	**4**	***0.26***	**4**	***0.26***	**4**	***0.28***	**4**	***0.26***	**4**	***0.25***	**4**
Coal	***0.14***	**85**	***0.11***	**85**	***0.11***	**85**	***0.13***	**85**	***0.10***	**86**	***0.10***	**85**
Nuclear	***0.12***	**100**	***0.11***	**100**	***0.11***	**100**	***0.12***	**100**	***0.11***	**100**	***0.10***	**100**
Ren. ES	***0.10***	**98**	***0.17***	**98**	***0.19***	**98**	***0.11***	**98**	***0.18***	**98**	***0.20***	**98**

4.2.1 Demand

The partial index values on demand in the six scenarios can be divided into two groups. The scenarios that take into account energy efficiency policies (EE, EE&RES-12, EE&HIRES) have substantially higher scores, i.e. 63.5 to 65.5, than the baseline and the renewables scenarios without efficiency policies, with scores in the order of 57.9. Differences can be explained from the energy-intensities in five sectors. These are listed in Table 4.3, both for the baseline and the energy efficiency scenarios. It also shows benchmark values for energy-intensities in these sectors. The benchmarks are based on the average figures of energy-intensities of the five best performing EU Member States. Energy-intensities in the RES-12 and HIRES scenarios are mostly similar to those the baseline scenario, although energy-intensities in the tertiary sectors are somewhat lower. Likewise, energy-intensities in the scenarios with combined policies

(EE&RES-12 and EE&HIRES) are mostly similar to those in the energy efficiency (EE) scenarios, with values for the tertiary sectors somewhat lower.[6]

Table 4.3 *Energy-intensities for five economic sectors in 2020 in the baseline and energy efficiency (EE) scenario*[7]

	Unit	Benchmark	Baseline	Energy efficiency
Industry	[toe/M€ added value]	60.2	155.8	151.0
Residential	[toe/cap]	0.350	0.722	0.597
Tertiary	[toe/M€ added value]	12.3	22.6	17.7
Transport goods	[toe/Mpkm]	45.0	53.7	49.1
Transport passengers	[toe/Mtkm]	25.5	32.7	29.6

4.2.2 Conversion and Transport

Climate policies affect performances in the conversion and transport of energy. Average thermal efficiency and the share of CHP are affected by the policies assumed in these scenarios. The resulting partial index values on conversion and transport are listed in Table 4.4, with higher scores for the 'combined' and for the energy efficiency scenarios (EE, EE&RES-12, EE&HIRES). They are explained to a large extent by the share of CHP in electricity production. The highest score is for the energy efficiency scenario, which has a better average thermal efficiency than the 'combined' scenarios and a higher share of CHP. The low average thermal efficiency of the three efficiency scenario in comparison to the baseline scenario may seem counter-intuitive. A possible explanation can be given by the significant contribution of new fossil fuel capacity in the baseline scenario 2020. A higher dependence of these sources may increase the average thermal efficiency. In the three efficiency scenarios installed capacity declines, whereby the dependence of renewable energy sources increases and thermal energy-based installlations are not easily improved.

Table 4.4 *Partial index values on Conversion & Transport, average thermal efficiency and share of CHP in electricity production*

	C+T score	Average thermal efficiency [%]	Share CHP [%]
Baseline	79.2	45.3	21.8
RES-12	79.3	43.3	22.2
HIRES	79.6	43.2	22.4
EE&RES-12	84.3	41.8	27.1
EE&HIRES	84.3	41.7	27.9
EE	85.0	43.8	28.2

4.2.3 Primary Energy Supply

Table 4.5 provides an overview of the partial index values on Primary Energy Supply and the composition of the primary fuel mix. The partial index values are explained by the composition of the primary fuel mix and the ratings of the different energy sources. Nuclear and renewable energy both index value 100, while coal is rated 85 or more. Gas is rated considerably less, de-

6 Energy-intensities in the tertiary sector for the RES-12, HIRES12 and EE&RES-12 scenarios could not be easily determined in comparison to the energy-intensities in the tertiary sector for the Baseline, EE&HIRES and EE scenarios. For the latter group, detailed Primes energy model results are used to determine the energy-intensities in the tertiary sector. For the former group, this report relies on efficiency improvement proxies.

7 Note that due to the quantification of and extension to all 27 EU MS and due to the use of the individual MS scenario results, the benchmark values for both 2005 and 2020 (Baseline) have been changed in the update (Scheepers et al., 2007).

pending on its share in domestic energy supply. The rating for oil is 0 due to the large import dependency and the origins of the imports (most not from Norway; Norway is considerd as secure as EU domestic). Most climate scenarios have a higher partial index value on PES than the baseline. Only the energy efficiency (EE) scenario has a lower index value, since in this scenario a larger share of oil is foreseen.

The EE&RES-12 scenario foresees a lot more coal and renewable energy than the baseline scenario, and has a higher partial index value on PES. The RES-12 scenario, which does not include efficiency policies, has an even larger share of coal. In addition, its share of oil in primary fuel mix is smaller. Therefore, the index value on PES is higher in RES-12 scenario than in the EE&RES-12 scenario.

The HIRES scenarios includes a somewhat smaller contribution from coal and nuclear, but a much larger share of renewable energy than the RES-12 scenario. Consequently, its index value on PES is higher. The highest index value on PES, can also be found in the HIRES scenario and not in the EE&HIRES scenario, although the difference of 0.8 points is not significant. The EE&HIRES scenario foresees the largest share of renewable energy and the smallest share of natural gas.

Table 4.5 *Partial index values on Primary Energy Supply and fuel composition*

	Partial index	Oil	Gas	Coal	Nuclear	Renewables
EE	34.4	36.5	27.9	12.9	12.1	10.5
Baseline	35.1	35.5	28.1	13.8	12.1	10.4
EE&RES-12	37.6	35.8	25.7	10.0	10.7	17.7
RES-12	38	34.6	26.2	10.9	11	17.2
HIRES	39.3	33.8	25.8	10.5	10.5	19.3
EE&HIRES	38.5	35.2	25.3	9.6	9.9	19.9

4.2.4 Security of supply

The scores on Conversion and Transport and on PES are combined in a partial index value on Supply. Security of supply is better in scenarios that foresee an important share of renewable energy than in other scenarios. The scenarios that in addition include improvements in conversion and transport have the highest partial index value on supply.

4.2.5 S/D Index and CO_2 emissions

An interesting question is whether improvements in the security of supply go in step with reductions in CO_2 emissions. This question may be answered by studying the overall S/D Index values and CO_2 index values (Table 3.1) simultaneously.

As climate policies become more stringent, CO_2 emissions and the CO_2 index fall, and the security of supply improves, i.e. the S/D Index increases. The magnitude of the changes in the two indices is not always similar however. This is shown in the table. The introduction of policies on renewables, as in the RES-12 scenario, leads to a sharp drop in CO_2 emissions. The security of supply situation improves only moderately, i.e. with 1.5 point in the S/D Index. More stringent policies on renewables, as in the HIRES scenario, lead to minor further CO_2 emissions reductions only. The same pattern occurs in the EE and RES-12EE scenarios. When energy efficiency policies are complemented by policies to achieve 12% renewables, CO_2 emissions drop considerably, but the security of supply improves only moderately.

Table 3.1 also shows the effect of energy efficiency policies. We compare the effects of such policies with those of policies on renewable energy. The impact of energy efficiency policies on

CO_2 emissions outweighs even the most stringent policies on renewables. In addition, energy efficiency policies improve the security of supply to a larger extent than policies on renewable energy.

CO_2 emissions in different economic sectors under the six scenarios are presented in Figure 4.1. The sharp reduction in CO_2 emissions under policies for renewables is realised in particular in the power generation sector. This can be explained from the composition of installed capacity in power generation under various scenarios, presented in Figure 4.2. The figure presents changes in installed capacities relative to the baseline for the most important sources. Installed capacities can be lower for all sources in the EE scenario, since final energy demand is lower. Under policies for renewables installed capacities of biomass and waste capacity increase by 50 and 58 GW in 2020 for RES-12 and HIRES respectively. Capacities for other renewable energy increase by 89 and 107 GW respectively.

Figure 4.1 provides insight into the synergies between climate change mitigation policies and the security of energy supply. Almost all climate policies scenarios explored in this study show a simultaneous decrease in CO_2 emissions and an improvement in the supply security, as indicated by the S/D index. The only exception is the EEHIRES scenario. In this scenario a higher deployment of renewable energy relative to the EERES-12 scenario does lead to a further CO_2 emission reduction, but to a small deterioration of the supply security.

Note that trade-offs between climate change mitigation and supply security are conceivable as well. For example, a switch to natural gas, without capturing and storing the CO_2, will reduce CO_2 emissions, but imply a greater reliance on natural gas imports. Another somewhat hypothetical example would be a large scale switch to biomass imported from outside the European Union.

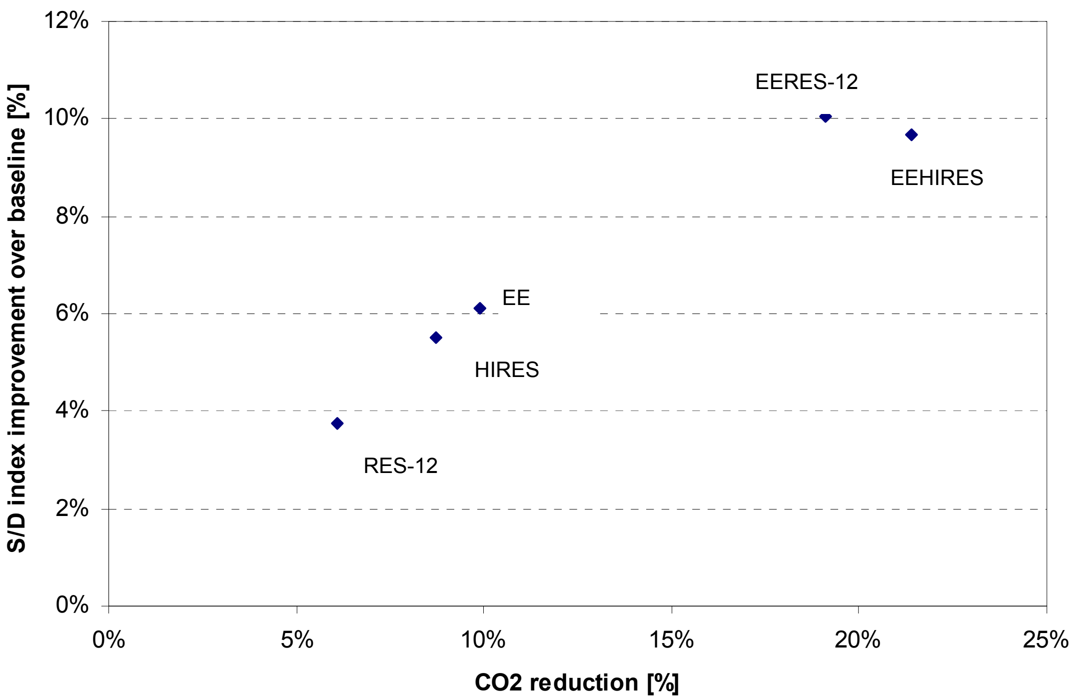

Figure 4.1 *CO_2 reductions in 2020 relative to 1990 and improvements in the S/D index compared to baseline in five climate policy scenarios*

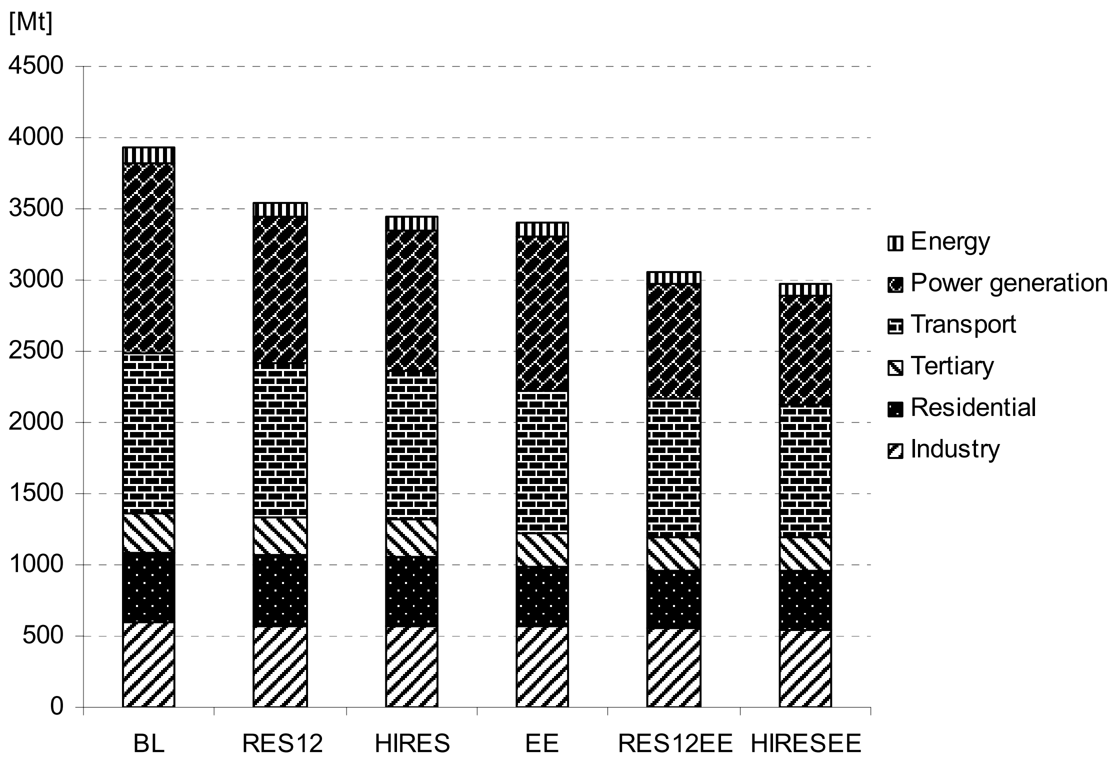

Figure 4.2 *CO_2 emissions in 2020 under a baseline and five climate policy scenarios*

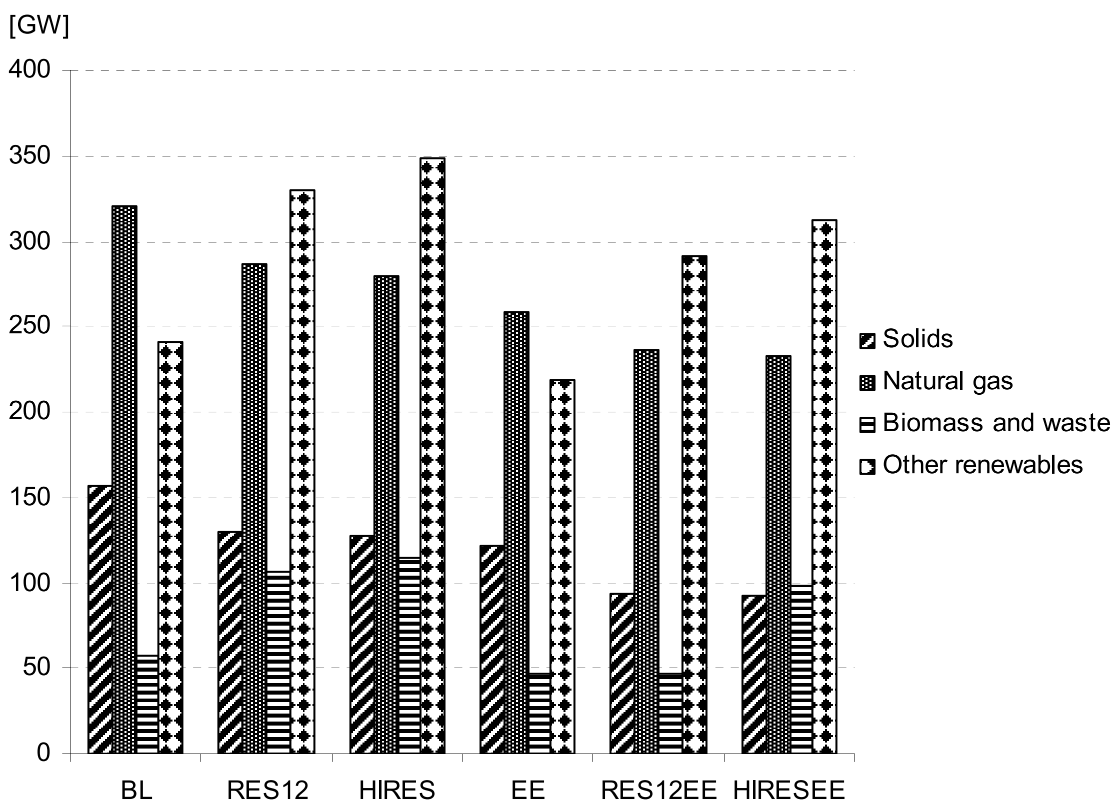

Figure 4.3 *Installed capacity power generation for four primary sources in 2020 under a baseline and five climate policy scenarios*

5. Discussion

This study endeavoured to explore the merits and limitations of the Supply/Demand Index as tool to compare synergies and trade-offs between climate change mitigation policies and security of energy supply. It must be noted that the results from this study were obtained using an earlier version of the S/D Index (Scheepers *et al.* 2006). Recently, an update of the S/D index was elaborated (Scheepers *et al.* 2007), in which alternative scoring rules for oil and gas in primary energy supply are used, and adequacy and reliability of gas conversion and transport are included.

Merits of the S/D index
In this study the S/D index proved a useful tool to compare security of supply in some future year with today's state of affairs. We showed that it may be used to explore the impact of policies in various mitigation scenarios on supply security. To our knowledge the index is the only existing indicator covering the entire energy system. Its breakdown in partial indices allows for identification of causes of deterioration and improvement, and to identify on what technologies and economic sectors energy policies need to be focused.

Other dimensions of supply security
Security of energy supply has a range of aspects, and not all of these are covered in the S/D index. Salient elements that are not considered include political stability in fossil fuel exporting regions, as well as height and volatility of fossil fuel prices. Jansen et al. (2004) included political stability as one of several inputs in an update version of the Shannon index. However, not only is it awkward from a scientific point of view to quantify political stability, in addition it is politically almost impossible to reach consensus on the evaluation of this aspect of supply security. It seems difficult therefore to upgrade the S/D index by including political stability in one way or the other. Height and volatility of fossil fuel prices on the contrary are not easy to project, but it may prove more feasible from a scientific perspective to reach a common ground for an approach to include these aspects in the index. In fact, IEA(2006) has already endeavoured to capture this element of supply security in an indicator. This indicator aims to measure market concentration in fuel markets. Market power or 'the ability to set prices above competitive levels and for this to be profitable' is argued to be the largest risk to security of supply in liberalised markets. It must be noted though that gas prices in large parts of the world are indexed to oil prices, and market power to set gas prices is limited to long term supply contracts. Nevertheless, the role of fossil fuel prices is important to consider in the evaluation of a region's supply security, and the S/D index does not reflect it.

Subjective nature of weights and criteria: need for consensus?
A range of possible controversies regarding the S/D Index was addressed earlier by Scheepers et al. (2006). An important comment that has been raised in the past concerns the subjective nature of the indicator, which is a problem in particular when the index is used to compare supply security between different EU Member States. Use of the S/D Index for a particular Member State or the EU as an aggregate, with the aim to compare the current situation to future developments, as has been done in this report is less controversial. 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; 2007) report other sensitivity analyses.

No sensitivity analyses were conducted in the study reported here. Nevertheless, uncertainty ranges for the S/D Index for the EU under various scenarios will most likely have the same magnitude. This implies that the differences in the values of the S/D Index in various scenarios calculated in this study are within the uncertainty range. It follows that the subjectivities should be made explicit. The S/D Index can only support the policy making process regarding supply security if users agree on the assumptions underlying the index. Thus, the merits of the S/D Index are not so much that it would provide an accurate and irrefutable impression of the security of supply in a country. It may rather be instrumental in elucidating national, economic and political interests.

User-friendly tool
If the S/D Index is to play such a role, it is essential that a user-friendly tool be developed. Such a tool would allow users to specify which components of an energy system they would perceive as most vulnerable. It would also provide the possibility to incorporate other perceptions in the index, e.g. views on the contribution of primary energy sources to supply security or on the import of adequacy and reliability of the energy conversion. In this way the S/D Index may become an acceptable indicator for policy makers across the EU Member States with a range of political and economical preferences.

Domestic energy reserve situation
Another remark regarding the S/D Index is that it 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. Indeed, this study showed that scenarios including policies for renewable energy resulted in higher values for the S/D Index. Thus, if domestic energy reserves and potential for renewables are to be evaluated, the S/D Index will need to be used in a scenario context. Domestic reserves and potential for renewables may also be revealed by e.g. higher import dependencies and origins outside the EU/Norway in long term scenarios.

However, if the index is to compare the security of supply in different countries at a given moment, it cannot account for the possible exploitation of reserves or potentials in the future. In that case the S/D Index ideally would consider differences between the supply systems of countries. For example, if countries A and B have identical energy systems, and A, unlike B, disposes of large gas reserves, than the S/D Index should reveal this. Including energy reserves and potential for renewable energy may result in a higher complexity and less transparency of the model. Nevertheless, future work on the indicator may also explore ways to include domestic energy reserves and the potential for renewable energy. Alternatively, the domestic reserves issue could be addressed by ‘what if’ analyses. Declining domestic reserves will most probably result in both higher import dependences and origins of import outside EU/Norway in the long term.

In this report the consequences for supply security of a limited set of climate policies was explored. Only policies on energy efficiency and on renewable energy were assessed. As suitable scenarios including alternative policy mixes and technologies in the EU-25 become available, these may be assessed as well. In particular, the extension of nuclear energy or clean coal options and its implications for the security of supply would be interesting to explore.

Cost-effectiveness and trade-offs?
Lastly, this study has not addressed the costs of climate policies. The reason for this omission was mostly practical: the scenarios assessed in this study did not contain any information on the overall costs of the policy packages. Yet, consideration of costs would constitute interesting additional information. It would shed light on the average cost-effectiveness of policy packages, both with respect to climate change mitigation and the security of supply. Cost-effectiveness

would then be expressed as costs per tons avoided CO_2, or costs per S/D Index point. This may be useful additional input into the decision making on climate and supply security policies.

6. Conclusions

In this report the implications of various climate policies for climate change mitigation and for the security of supply in the EU-25 were investigated. This security of supply was quantified using the Supply/Demand (S/D) Index[8]. From the study a number of conclusions can be drawn.

Although the quantification of the various climate scenarios should be considered as indicative only, some interesting conclusions with regard to EU policies up to 2020 are:

- The baseline scenario shows a small drop in the S/D Index value from 53 in 2005 tot 51 in 2020.
- The energy efficiency policies assessed in this study have a more marked impact on CO_2 emissions than the policies for renewable energy.
- Major CO_2 emission reductions in the order of 20% can be realised if policies for energy efficiency and renewable energy are combined.
- The policies for energy efficiency included have a more pronounced effect on the security of supply than the policies for renewable energy that were incorporated in this study.
- Combinations of policies for energy efficiency and for renewable energy lead to the greatest improvements in the security of supply. Nevertheless, these improvements are accompanies by a sharp drop in CO_2 emission reductions achieved by such policy mixes.
- The calculated values for the S/D Index for the year 2020 in the six scenarios range from 51 (baseline) to 57 (EE&HIRES), so the S/D Index shows marked differences for the various policy scenarios. All policy scenarios have a higher index value in 2020 than the baseline value in 2005 (53).

With regard to the use, merits and limitations of the S/D Index as tool to assess the energy security:

- The S/D Index proved a useful indicator for assessing the implications of climate policies for the security of supply.
- If the S/D Index is to support decision making on climate and supply security policies, it is imperative that users agree on the assumptions underlying the index.
- Comparing future CO_2 reductions against future developments in the S/D Index value may show the extent of synergy between climate policies and their impact on the energy security of supply and possible trade-offs.
- Future work on the S/D index may consider the role of market power as well as height and volatility of fossil fuel prices.

[8] Based on the old S/D Index (Scheepers et al., 2006). The updated S/D Index reported in (Scheepers et al. 2007) will reveal other absolute figures, but similar findings in a qualitative and relative sense.

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