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Designing indicators of long-term energy supply security

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Abstract

To our knowledge, so far amazingly little research work has been undertaken to construct meaningful indicators of long-run energy supply security for a particular nation or region. Currently, in addressing energy supply security, policy makers tend to emphasise short-term supply disruptions. In contrast, this pre-study accords with the broader Sustainability Outlook in considering the long-term perspective. This report starts with taking stock, in a concise way, of the official EU energy outlook and issues related to the opportunities to administer changes in the energy mix at the level of major energy use categories. Then a brief survey of relevant literature is made on long-term strategies to ensure survival of systems - be it biological, social, etc. - in an environment largely characterised by high uncertainty and a lot of unchartered territory. We found the work of Andrew Stirling very inspiring in this context. Based on his work and considering the limitations of the present research activity, we retained the Shannon index as the best 'simple' indicator of diversity.

In the core of the report, the Shannon index is elaborated into four indicators of long-term energy supply security. Stepwise, additional aspects of long-term energy supply security are introduced. These aspects are:
- Diversification of energy sources in energy supply.
- Diversification of imports with respect to imported energy sources.
- Long-term political stability in regions of origin.
- The resource base in regions of origin, including the home region/country itself.

After small adjustments to allow for data availability, these indicators were applied to the reference year 2030 of four long-term scenarios with data of base year 1995 and projections for underlying variables provided by the Netherlands Environmental Assessment Agency (MNP). Preliminary interpretation of the results suggests the usefulness of the indicators presented in this report.

A second activity undertaken in this report was identifying possible long-lasting disruptions in the supply of natural gas to Europe and their potential effects. Three examples have been elaborated in the Annex.

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SUMMARY

The MNP, in collaboration with CPB, is preparing a long-term scenario study with year 2040 as time horizon for a 'Sustainability Outlook' (Mooij and Tang, 2003). To that effect four global scenarios are being investigated, with the world divided into 17 regions in line with the TIMER model, an energy module of the IMAGE model. OECD Europe is one of the regions. One of the main topics to be addressed in the upcoming Sustainability Outlook is energy supply security.

The MNP has requested ECN to undertake a brief pre-study on the energy supply security issue with a focus on OECD Europe (with the EU forming the core). This pre-study focuses on two research questions:

1. Is it possible to design a macro indicator for long-run energy supply security and, if so, how could this be done?
2. Which forms of (long-term) disruptions in the supply of natural gas and which response patterns can be expected, and what would be the order of magnitude of attendant costs?

The main text of this report deals with the first research question. The second question is addressed in Annex A of this report.

To start with, the energy supply situation in the EU-15 is briefly reviewed. Unexpected sustained disruptions in oil and, to a lesser extent, gas supply would seem the most serious by far from the perspective of end users in the EU. Particularly in the transportation sector, substitution of current, petroleum-based energy carriers is difficult to effectuate. Furthermore, increasing dependency in the power sector on natural gas would imply high stranded costs in case of responsive adjustment to unexpected, serious long-term disruptions in the supply of natural gas. In other areas of energy services, current energy carriers can be substituted in the long run with relative ease, if in a number of cases at substantial short-term adjustment costs.

In the face of large blind spots of ignorance on long-term future socio-economic developments, well-designed diversity strategies with regard to the portfolio of long-term energy supply options appear to hold out the best promise of energy supply security. Diversity can be considered from different angles, notably *variety* (the number of available options, categories, species), *balance* (the spread among options) and *disparity* (the nature and degree to which options are different from each other). Stirling (1999) has shown that the Shannon diversity index is the most attractive simple index reflecting both variety and balance in an even way. Inclusion of disparity remains cumbersome. For the purposes of the present report we have retained the Shannon index for further elaboration.

Four long-term energy security indices have been conceived, allowing for an increasing number of long-term supply security aspects. Aspects introduced in our indicators on a stepwise additional basis are successively:

- Diversification of energy sources in energy supply (I_1).
- Diversification of imports with respect to imported energy sources (I_2).
- Long-term political stability in import regions (I_3).
- The resource base in regions of origin, including the home region itself (I_4).

After some small adjustments owing to data availability, the indicators referred to above have been applied to reference year 2030 of four MNP-CPB long-term sustainability outlook scenarios. These indicators proved quite well amenable to making projections of long-term development of energy supply security for a particular region. We have endeavoured to make some preliminary interpretation of the results under the four MNP-CPB scenarios. The results presented

seem encouraging for emulation in other applications and for conducting follow-up research on the design of energy supply security indicators

As for indicator I_4 - the indicator allowing for all four aspects considered of the extent of long-term energy supply security - the projected scores in year 2030 on a 0-100 scale are as follows:

- *Global Economy*: 34.9. The Global Economy scenario accounts for the lowest score, mainly because of (i) poor fuel diversification and, less so, (ii) high dependency on imports from political unstable regions and (iii) high dependency on fuels from regions characterised by relatively fast depletion of these fuel resources.
- *Transatlantic Markets*: 40.9. This relatively high score owes especially to the relatively good fuel import diversification in terms of regions of origin.
- *Strong Europe*: 35.1. Very poor import diversification in terms of regions of origin is a major factor explaining the poor score of this scenario.
- *Regional Communities*: 39.6. This scenario performs relatively well on aspects such as fuel diversification and (relatively low) dependency on fuel imports from regions with potentially unstable political conditions.

In Annex A we identify three possible sources of long-lasting disruptions in the supply of natural gas to Europe and analyse their potential effects. First, disruption of transit of Russian gas via the Ukraine serves as an example of political risk. Second, a European ban on LNG trade could be a technological risk, e.g. following an explosion in a LNG terminal or container. Finally, a potential economical or market risk is a structural high gas price, e.g. as a result of monopolistic market power.

1. INTRODUCTION

The MNP, in collaboration with CPB, is preparing a long-term scenario study with year 2040 as time horizon in the framework of her publication 'Sustainability Outlook', due early 2004. To that effect 4 global scenarios are being investigated, with the world divided into 17 regions in line with the TIMER model, an energy module of the IMAGE model. OECD Europe is one of the regions. One of the main topics to be addressed in the upcoming Sustainability Outlook is energy supply security.

The MNP has requested ECN to undertake a brief pre-study on the energy supply security issue with a focus on the EU (or, alternatively, OECD Europe). This pre-study focuses on two research questions:

1. Is it possible to design a macro indicator for long-run energy supply security and, if so, how could this be done?
2. What could be forms of (long-term) disruptions in the supply of notably natural gas, which response patterns can be expected, and what would be the order of magnitude of attendant costs?

The main text of this report deals with the first research question. The second question will be dealt with in the form of draft text boxes in Dutch dealing with three distinct case studies. These are reported upon in Annex A of this report.[1]

The project team has been requested by the MNP to give special attention to a number of possible indicator attributes, associated with energy supply security. In the ToR mention is made of:

- Net import dependency, whether or not weighted by type and intensity of use of primary energy source (PES). The following five categories are suggested: Oil, Natural Gas, Coal, Nuclear, and Renewables.
- Import source (by TIMER region).
- Geopolitical stability of sources of origin.
- With respect to exhaustible resources: world reserves situation.

And possibly:

- Differences in energy demand and demand preferences.
- The degree of collaboration between nation states (within the EU; EU and major trading partners).

In a meeting on 30 July last at RIVM additional attributes for further consideration were suggested on the part of MNP. That is:

- Transport distance of imported energy resources.
- Transport mode for Oil (pipeline, ship), and Natural Gas (pipeline, LNG).
- Marginal supply costs for each distinct PES.

In the various briefings the project team has been requested to provide information on useful concepts and approaches that would provide insight into assessment of the degree of energy supply security. Furthermore, any suggested macro indicators of energy supply security should be acceptable to the stakeholders concerned, including ECN itself.

[1] The division of work has been as follows. Jaap Jansen acted as project leader and prepared the main text of the present report. Maroeska Boots prepared Annex A with three case studies on long-term disruptions of natural gas supply (written in Dutch in accordance with the research contract). Wim van Arkel conducted data research in support of Chapter 2.

The outline of this report is as follows. Chapter 2 briefly reviews the official EU energy outlook and issues related to the opportunities to administer changes in the energy mix at the level of major energy use categories. In Chapter 3 a brief survey of relevant literature is made on long-term strategies to ensure survival of systems - be it biological, social, etc. - in an environment largely characterised by ignorance. The Shannon index is retained as the best ‘simple’ indicator of diversity. In Chapter 4 the Shannon index is elaborated into four indicators of long-term energy supply security. In the final chapter, Chapter 5, slightly adjusted variants of these indicators are applied to four long-term scenarios for the ongoing MNP/CPB Sustainability Outlook main study.

2. MAIN PRIMARY ENERGY SOURCES: EU SUPPLY PATTERN AND SUBSTITUTION POSSIBILITIES

2.1 Introduction

This chapter provides a brief overview of the five PES categories considered. Firstly, the relative importance of each PES category in total energy supply (gross inland energy consumption) of the EU is considered. Secondly, some broad observations are made on main applications and ease of substitution.

2.2 Energy supply patterns in the EU

For providing some background to projection exercises of energy futures in the OECD Europe area, it is useful to review the most authoritative scenario study that has been used for policy formulation in the EU over the last 4 years. The EU-15 in fact is the core region of the OECD Europe area. One of the major tools currently used by the European Commission for energy scenario projections, is the PRIMES model of the National Technical University of Athens (NTUA). [2]

Table 2.1 below reproduces some key baseline projections published in the quite influential publication (EU, 1999).[3] The baseline scenario is based on the assumption that EU policies in place at the time of writing (1999) will be continued. These include, among other policies, the continuation of support for renewables and co-generation and the extension of the lifetime of nuclear plants to 40 years. The baseline does not include any policies that specifically address the climate change issue.

NTUA's baseline scenario (EU, 1999) projects for the EU-15 a total primary energy supply in year 2010 of 65 EJ compared to 57 EJ in base year 1995 (0.9% growth per year). Growth in total energy supply would decelerate subsequently to 0.4% per year with an annual energy supply level reaching 67.5 EJ in 2020. Moderate economic growth, structural changes of the EU-15 economy towards low-energy-intensity services and energy efficiency improvement are major factors at play. If the pertinent lifetime extension assumption holds true, most current nuclear power plants will be decommissioned between 2015 and 2030. This would provide for new opportunities to coal (solid fuels) after 2015 to fill part of the nuclear power gap. NTUA's baseline scenario envisages a gradually subsiding 'dash for gas' trend due to an increasing relative price of gas. European importers of gas from Russia and Central Asia could face competitive pressures from rising gas demand in East and South Asia. Increasing demand for oil in transportation would be almost offset by plummeting demand for non-renewable liquid fuels in other sectors.

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2 The information on energy supply and consumption in the EU presented hereafter is based on Eurostat data. The latter source is adhered to for the sake of convenience: EU renewable energy policy targets are based on Eurostat data. Typically the 'Eurostat Convention' on energy statistics tends to indicate a lower contribution of RES to total primary energy supply than, e.g., IEA statistical conventions. Major reason is that Eurostat assesses primary energy contribution of primary electricity sources (e.g., hydro power, wind power) at its calorific value (1 kWh = 3.6 MJ). IEA uses a much higher notional fossil-fuel replacement value to assess the primary energy quantity per kWh of primary electricity, applying a standard rate of notional conversion efficiency.

3 At the time of completing the final draft for this chapter, an updated NTUA study *European Energy and Transport 2030* (EU, 2003) has appeared. The major conclusions relevant to this study, do not seem to have materially altered.

Primary energy supply based on renewable energy sources (RES) would rise gradually from a rather low base. NTUA's baseline envisages for the EU-15 a RES-based energy supply in 2010 and 2020 on the order of 2.34 EJ and 2.49 EJ, against 1.95 EJ in base year 1995. Renewable energy would grow over the periods 1995-2010 and 2010-2020 by rather modest rates of 1.4% per year and 1.2% per year respectively. In 2010, under the baseline scenario renewables would contribute a mere 5.7% to total energy supply, that is no less than 6.3% short of the 12% indicative target, officially adopted by the EU. In the same year, among all renewables biomass and hydro electricity would contribute most, that is 3.4% and 1.7% respectively. Wind would be the fastest runner-up with a still modest share in 2010 of 0.3%.

NTUA (EU, 1999) projects the impact of Climate Change policy to have a mildly stimulating impact on renewables. The most stringent carbon-constrained scenario, S6, would lead to a carbon price (annual marginal abatement cost) of 102 $€_{1990}$ per tonne of carbon in year 2010 and 115 $€_{1990}$/tC in year 2020. The S6 scenario would push up the renewables share in total energy supply to 8.4% in 2020[4] as against 6.2% in the baseline scenario.

At the time of completing the final draft for this chapter, an updated NTUA study on the European Energy Outlook 2030 has appeared. At first glance, the major conclusions do not seem to have materially altered.3

Table 2.1 *Baseline scenario projections of total primary energy supply by source in the EU-15, stated in the Energy Outlook 2020; 1995-2020*

	TPES				TPES		Annual growth	
Primary energy	1995	2010	2020	1995	2010	2020	1995-2010	2010-2020
Source	Base yr	Proj.	Proj.	Base yr	Proj.	Proj.	Proj.	Proj.
	[EJ]	[EJ]	[EJ]	[EJ]	[%]	[%]	[%]	[%]
Non-RES								
Solid fuels	9.96	7.62	9.13	17.4	11.7	13.5	-1.8	1.8
Liquid fuels	24.20	27.42	27.75	42.3	42.1	41.1	0.8	0.1
Natural gas	11.47	16.79	18.04	20.0	25.8	26.7	2.6	0.7
Nuclear	8.58	9.50	8.33	15.0	14.6	12.3	0.7	-1.3
Subtotal	*54.21*	*61.32*	*63.25*	*94.7*	*94.2*	*93.7*	*0.8*	*0.3*
Non-EU electricity	*0.04*	*0.08*	*0.13*	*0.1*	*0.1*	*0.2*	*4.7*	*4.1*
RES								
Biomass	1.85	2.20	2.37	3.2	3.4	3.5	1.2	0.8
Hydro	1.05	1.11	1.20	1.8	1.7	1.8	0.4	0.8
Wind	0.01	0.22	0.44	0.0	0.3	0.7	20.9	7.3
Solar	0.01	0.03	0.04	0.0	0.0	0.1	7.6	4.1
Geothermal	0.10	0.14	0.13	0.2	0.2	0.2	2.3	-1.2
Marine energy	0.00	0.00	0.00	0.0	0.0	NA	0.0	0.0
Hydrogen	0.00	0.00	0.00	0.0	0.0	NA	0.0	0.0
Subtotal	*3.01*	*3.69*	*4.17*	*5.3*	*5.7*	*6.2*	*1.4*	*1.2*
Total	57.26	65.13	67.48	100	100	100	0.9	0.4

Source: Adapted from (EU,1999: Tables 3-3 and 3-9; base year data derived from Eurostat data)

2.3 Coal

Main applications

Main applications of coal in Western Europe are in the power sector. Furthermore, a much less important application is cooking coal used in the steel industry.

4 and presumably to a share in between 5.7 % and 8.2 % in year 2010. No details on 2010 projections have been presented for the S6 scenario. C.f. (EU, 1999: p.97, Table 4-24).

Flexibility and substitution possibilities

In a sustainability-oriented society the application of coal for combustion purposes has some serious environmental drawbacks, especially in terms of pollutant emissions. Among fossil fuels, the combustion of coal yields the highest GHG emission burden per unit of energy. For example, CO_2 emission factor for coal is 94 kgCO_2/GJ against 56 kgCO_2/GJ for natural gas. For coping with local pollutants, a variety of abatement options exist, mainly end-of-pipe options, with a fairly affordable price tag. However, no easy options to abate GHG emissions are at hand. Options include:

- CO_2 removal and storage (geological sequestration). Relevant issues when resort to this option is to be had, are the environmental integrity issue and the issue of (acceptable) additional costs.
- Biomass co-firing. This raises the questions as to how to ensure adequate supply of biomass at acceptable costs, and how much biomass can be used without disrupting the operation of the power plant(s) concerned.

With regard to substitution of coal, power plants are typically equipped to use a second fuel. Older plants can typically readily convert to fuel oil. Coal-fired plants of a recent vintage in areas with a gas distribution infrastructure can typically readily convert to natural gas. Conversion to fuel oil would lead to a CO_2 reduction on the order of 20 to 25%, against 40% for conversion to natural gas. In the iron and steel industry coke coal is used for combustion at the required high temperatures. No easy substitute exists.

2.4 Oil

Main applications

The bulk of oil products is for use in transportation (light and middle distillates). More than 99% of today's energy supply for road transport in OECD-countries stems from crude oil (69% gasoline and 30% diesel), while the currently most important alternative fuels hold minuscule shares; that is, LPG 0.9% and natural gas 0.05% (IEA/AFIS, 1999). In developing countries the relative importance of middle distillates (automotive diesel) tends to be much more pronounced than in the OECD area. LPG can be produced from oil as a by-product in oil refineries and as a valuable by-product from gas separation (treatment) plants near natural gas production fields.

Much less significant applications of middle and, notably, heavy distillates are for heating applications in industry and power (process heat for, among others, boilers), and in the household and services sectors (space heating).

Furthermore, non-energy applications in the chemical sector are quite significant for applications such as plastics, PVC, etc.

Flexibility and substitution possibilities

Short-term to medium-term options to reduce the oil-share in favour of natural gas are LPG and CNG. Infrastructure requirements are fairly demanding, especially for the introduction of CNG. As for LPG, it can be either a by-product of oil refining (no oil substitution) or can be produced from condensates extracted from cleaning of natural gas near gas production fields (gas-for-oil substitution). Up to some 5-10% of oil requirements for road transportation might be replaced by gas-based fuels, such as CNG and (in part) LPG in the medium to long run, say by year 2015 at the earliest. A long-term option to reduce the oil-share in the transport fuel market by up to some 15% by, say year 2025 at the earliest, is consisting of bio-fuels. These include bio-diesel (based on vegetable oil energy crops like rape seed and sunflower or spent cooking oil form the food industry) and ethanol (based on starchy plants such as sugar beet, sugar cane, wheat, barley or on cellulose from wood or biomass waste like stalks). In addition, there are methanol biofuels routes based on woody biomass. For reasons of availability of moderately priced biomass, the best long run prospects seem to be with the ones based on woody biomass. The conversion routes concerned, though, need further technological development with prospects for significant reduction of the conversion process costs within a ten years time period.

Furthermore, a very long-term substitution option is the use of hydrogen in fuel cells based on natural gas or renewables. This option may become cost competitive at any significant scale for natural gas by 2030. For renewables-based hydrogen production this would be the case by 2040 at the earliest.

For non-transport energy options, generally substitution options into direction of coal, gas, and biomass tend to be readily available. Abrupt disruptions in oil supply may cause short-term adjustment problems though.

Generally, for most non-energy oil-based products, substitutes tend to be readily available but with an appreciably higher price tag. Abrupt oil supply problems will cause serious transitional adjustment problems on the short term but less so in longer time frames.

2.5 Gas

Main applications
The share of natural gas in TPES of OECD Europe (=EU-15 plus Czech Republic, Hungary, Poland and Slovakia) has grown from 9.7% in 1973 to 22.6% in 2001.

The residential sector is the largest consuming sector of natural gas, followed by the industrial, electricity and commercial sectors. The use of gas in power generation is growing rapidly.

Flexibility and substitution possibilities
In gas markets, demand is generally not very flexible. Most residential and commercial customers are unable to switch easily to alternative fuels (furthermore, they cannot store gas). Industrial customers and power generators with bi-fuel equipment usually have little incentive to maintain this costly equipment because the price of gas is often linked to the price of alternative fuels. Coal is generally the most important alternative fuel for natural gas multi-fuel equipment in power generation (14% of net electricity generating capacity with combustible fuels (excluding nuclear and renewable) in OECD Europe). However kerosene and oil are also used as alternative fuels for natural gas in power generation.

In 1998 the net maximum electricity generating capacity in OECD Europe was 621.17 GW, of which 321.52 by combustible fuels. From the generating capacity with combustible fuels, 12% is single natural gas fired, respectively 14% and 2% is dual natural gas fired in combination with solid fuel or liquid fuel. Another 5% is multi fired combining the three types of fuel.

2.6 Nuclear energy

Main applications
The only major application is in power generation.

Flexibility and substitution possibilities
A broad range of options based on all other primary energy sources can readily substitute nuclear-based electricity. Short-term adjustment problems relate to the stranded costs associated with pre-planned closure of nuclear power plants, including the earlier needs for financing the relatively large exit (decommissioning) costs.

2.7 Renewable energy sources

Main applications
Main applications are in power generation (hydro, wind, biomass co-firing) and in a variety of industrial and household heat applications. Production of liquid and gaseous fuels from biomass for application in transportation and in heat applications is still small but picking up. In developing countries biomass use for especially cooking and - less so and quite site-specific - heating in households and small-scale enterprises.

Flexibility and substitution possibilities
Apart from large hydropower and niche markets in isolated areas the renewable energy applications tend to be relatively expensive. Substitution possibilities are readily available. Following abrupt disruptions in the supply of renewable energy sources, in niche markets in isolated areas short-term adjustment problems might be faced. On the other hand, none of the five PES categories is as diverse in terms of the nature of sources it encompasses, harnessing technologies applied, and regional incidence. When the renewable energy resource base of a region under consideration, this feature bestows on renewable energy a strong innate resilience against supply disturbances with respect to one particular source of renewable energy. Generally favourable environmental impact features increase the attractiveness of renewable energy form a sustainability perspective.

2.8 Conclusions

Among the five PES categories discerned, unexpected sustained disruptions in oil and, to some lesser extent, gas supply would seem the most serious by far from the perspective of end users in the EU. The energy field in which even in a long-term framework substitution of current, petroleum-based energy carriers is the hardest to effectuate is the transportation sector. Furthermore, increasing dependency in the power sector on natural gas would imply high stranded costs in case of responsive adjustment to unexpected, serious long-term disruptions in the supply of natural gas. In other areas of energy services, current energy carriers can be substituted in the long run with relative ease, if in a number of cases with high short-term adjustment costs.

3. DIVERSITY TO ENHANCE ENERGY SUPPLY SECURITY: SOME THEORETICAL CONSIDERATIONS

3.1 Conceptualisation of long-term energy supply security

This pre-study is concerned with the measurement of the extent a particular study region can ensure meeting ex ante demand for energy services at affordable prices of over long time frames ahead up to year 2040. The measuring rod to be designed should focus on long-term threats to the energy supply and delivery system of a region, notably sustained fuel supply disruptions, and attendant long run hedging approaches. Supply disruptions of short duration that do not pose a long-term challenge to the regional energy system will be disregarded. An essential feature of ensuring long-term energy supply security is conceived of the determination of efficient portfolios of primary energy sources. Efficiency in the aforementioned context refers to the trade-off between reducing serious threats to sustained provision of energy services - including notably threats in currently uncharted territory - and average unit costs of (primary) energy supply for a given portfolio.

The indices to be designed should at least provide an ordinal ranking of alternative socio-economic development scenarios with respect to the extent that long-term energy supply security is ensured under the distinct alternative scenarios and their projected portfolios of energy supply options.

3.2 Risks and diversity concepts with associated hedging approaches[5]

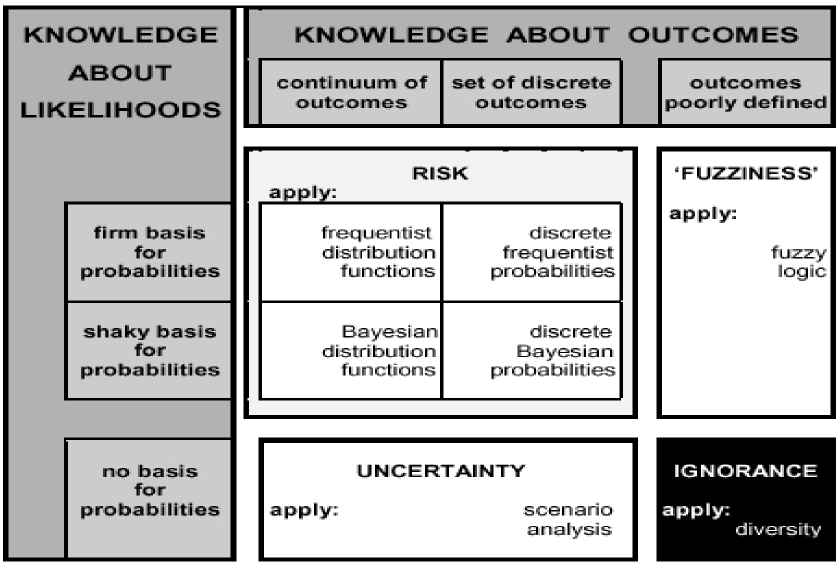

Figure 3.1 *Andrew Stirling's classification of risk and diversity concepts and attendant approaches*
(Source: Stirling, 1999: Box 2)

The logical complement of energy supply security is energy supply insecurity. For designing relatively effective hedging strategies a first question to be answered is what is our state-of-the-art knowledge of Figure 3.1.

[5] Sections 3.2 and 3.4 borrow from Stirling (1999).

Types/events of long-term energy insecurity, a region such as the EU does face over long time frames ahead? In a number of seminal publications (*inter alia*, Stirling 1994; Stirling 1999) Andrew Stirling has developed some quite revealing insights to this question, which we like to briefly review in the remainder of this section. In Stirling (1994) he distinguishes three basic states of 'incertitude':

i. *risk.* A probability density function may meaningfully be defined for a range of possible outcomes;
ii. *uncertainty.* No basis for the assignment of probabilities exists;
iii. *ignorance.* No basis for the assignment of probabilities to neither outcomes, nor knowledge about many of the possible outcomes themselves exists.

In Stirling (1999) Andrew Stirling elaborates 'incertitude' into four fundamental categories of 'incertitude' by way of a dichotomy of 'knowledge about likelihood's' and 'knowledge about outcomes' as depicted in Figure 3.1. Risk, properly defined, is a measure where a probability density function may meaningfully be defined for a range of possible outcomes (Stirling 1994). Financial analysts tend to focus on the downside of risk, for instance on the exposure to the chance of loss or 'unpleasant surprises'. The word 'chance' suggests that these analysts deem that for the cases considered downside risks can be captured in terms of probabilities. In the strict case of *risk* the top left-hand corner of the top left-hand quadrant would apply. *Probabilistic approaches* would lend themselves in addressing risk in a world that would develop along patterns predictable from past trends. We will discuss some of these approaches in the next section.

However, it would seem that great blind spots exist in our knowledge on even the very nature of defining future events, let alone their probabilities. This renders at least complete, and perhaps even partial, reliance on probabilistic hedging approaches to the extremely complex issue of long-run energy supply security questionable. The same may well apply to *Bayesian approaches*, assigning subjective probabilities to a presumably exhaustive set of significant events by way of Delphi-like methods to compile 'weighted expert opinions'. The famous economist Friedrich Hayek paraphrased such approaches as the 'pretence of knowledge'.

Another framework for incertitude conditions is phrased by Stirling *fuzziness*. This state refers to the situation under which the various possible outcomes do not admit discrete definitions, but where the degree to which they are actually manifest can be expressed in numerical terms akin to the assignment of probabilities (Stirling, 1999: 16-17). Also this framework does seem to offer limited attractiveness to the issue at stake in this report.

Of perhaps greatest importance for the purposes of the present report is the condition, dubbed by Andrew Stirling, *ignorance*. This is a state under which there exist neither grounds for the assignment of probabilities, nor even a basis for the definition of a comprehensive set of outcomes. This is depicted in the lower right hand of Figure 3.1. 'It emerges especially in complex and dynamic environments where agents may themselves influence (in indeterminate ways) supposedly exogenous 'events' and where the very identification of particular courses of action can exert a reflexive influence on the appraisal of alternatives.' Stirling recites suitable dictums ascribed to Pliny and Lao Tzu respectively: 'The only certainty is that nothing is certain' and 'Knowing ones ignorance is the best part of knowledge' (Stirling, 1999: 17 and 19).

From several sciences the insight emerges that in a state of ignorance *diversity* provides resilience to systems exposed to incertitude. For instance, Darwin brought out that diversification through evolution facilitates creation, and consequently survival, of the fittest species, and by implication of the biodiversity system. Also in the science of technology dynamics, the idea not to put all (R&D expenditure) eggs in one basket mitigates the negative impact of technological lock-in. Yet in keeping with Milton Friedman's adage 'there is no such thing as a free lunch': diversity has its costs, e.g. in terms of foregoing certain cost reduction advantages related with economics of scale and standardisation. Given new information technology developments, though, the diversity optimum may shift over time toward more diversity. We revert to the ignorance framework and diversification strategies in Section 3.4.

3.3 Some probabilistic approaches

In the insurance business sector ample resort is taken to probabilistic approaches to predict *fair* insurance *premiums* at which for the population of insured agents, on aggregate, neither loss or gain is expected from shifting the damages risk of a defined occurrence to the insurer concerned. Insured agents are even prepared to accept *premium loadings* from which the insurer can recover its costs and make a reasonable profit. This relates to risk-averse utility functions of individual entities, while an insurer is able, in principle, to reduce risk through risk pooling under prevalence of 'the law of large numbers'. This is subject to several conditions (Skipper, 1998):

- Adequate information should be available to identify the nature of damage risk events covered by a certain policy and to make an adequate prediction of the future loss probability distribution function. Parametric values have to be periodically monitored and adjusted.
- Absence of conditions of adverse selection (only high-risk agents from a certain target population insure themselves based on asymmetric knowledge).
- Loss events should be mutually independent. Note that this condition may be violated at times of catastrophic events.
- Over-exposure risks should be re-insurable (capable of being transferred to re-insurers at a re-insurance premium).

Key to the insurance business is that the risks covered by insurance policies are clearly identifiable and susceptible to ample statistical documentation to make reliable predictions on future damages trends. These type of conditions do not hold for the unknown set of future 'surprise events' from the perspective of present-day analysts, that will help shaping future energy supply systems.

Another approach that by the end of the 1990s has gained increasing popularity in banking and assets and liabilities management applications is Value-at-Risk (VaR) approaches. This approach can be applied to any portfolio of assets and liabilities, whose market values are available on a periodic basis. To implement it, the probability distribution of price changes for each portfolio instrument should be known. Typically, normal distributions are assumed with values for price volatility (δ), based on past statistics. Using calculated parameter values for the whole portfolio, the maximum portfolio loss can be projected provided a specific unlikely event does not occur, for example a 5% chance adverse price movement within the next holding period. The result of this calculation is the value at risk. This may help to set trading risk limits. For example, for the next trading day for a certain trader a VaR limit of €1 million on his stock of trade commodities might be set. However, the VaR approach depends critically on reasonable estimates of price volatility and correlations among financial assets as well as the assumed distribution of price changes (Levich 2001: 633-638). Lately, as a result of unexpected falls in share values sophisticated VaR applications by asset and liability management specialists fell short of preventing portfolio values of many pension schemes in the Netherlands and elsewhere from diving well below mandatory liability-coverage rates, set by financial markets regulators.

The last application of a probabilistic approach to be reviewed here is the Markowitz's portfolio theory to the portfolio of electricity generating assets. Shimon Awerbuch has pioneered this specific application. The main idea in this application is to determine the *efficient frontier*. This graph visualises the set of optimal portfolios (with optimal shares for distinct asset categories). Optimality refers to Pareto optimality in the trade-off between portfolio risk and portfolio return. For each portfolio on the efficient frontier:

- The expected portfolio holding period return (HPR) cannot be improved without increasing expected portfolio HPR risk.

- The expected portfolio HPR risk cannot be reduced without reducing expected portfolio HPR.

Awerbuch defines portfolio return in the case of electricity generating assets as the reciprocal of unit generating cost (reciprocal of cost per kWh) and price risk in terms of price volatility per holding period (δ per year). The latter is based on statistics of performance over past years and predicated on the assumption that past performance patterns have predictive value for future performance.

Awerbuch (Awerbuch, 2000) has applied the portfolio theory to the U.S. case with a simplified portfolio of 3 generating technologies. In an extension to EU generating mixes, Awerbuch and Berger (Awerbuch and Berger, 2003; Berger, 2003) have extended the model to 11 technologies and several cost components. To further enhance the practical value of portfolio theory applications for energy policy makers:

- The portfolio basket of generating technologies could be extended further, notably with respect to renewables-based technologies.
- Environmental constraints need to be introduced.
- Applications can be further extended to the portfolio of primary energy supply for meeting a region's demand for energy services.

In doing so, for each major power generating technology plausible projections of unit costs and cost volatility per major cost item would have to be made. In discounting future cash flow projections of generating costs, due allowance will be made for price (volatility) risk, cost-reducing technological advances, and inclusion of costs of environmental damages to an extent compatible with preferences of EU policy makers. Based on projected unit costs and volatility co-variation patterns, 'efficient' (i.e., optimal) portfolios of generating assets can be determined, reconciling policy concerns on generating power at least cost, energy supply security and environmental protection. Under current conventional energy system cost calculations, inadequate allowance is made for notably energy supply security concerns. For the EU, being a major importer of fossil fuels, these concerns would seem to have a high political urgency (EU, 2000). Considerations on risk aversion and implementation constraints, notably with regard to renewables, will reduce the relevant part of the efficient frontier for policy makers.

3.4 Stirling's ignorance approach

In order to design optimum diversity strategies in the face of conditions of ignorance, diversity needs to be characterised. Stirling uses *diversity* as an overarching concept with three subordinate properties (Stirling 1999: 39):

- *Variety*. Refers to the number of categories into which the quantity in question can be [or rather: is] partitioned. For example, in our case the quantity may be defined in terms of primary energy (e.g. EJ) and the categories may denote PES (primary energy sources) categories or, in a more refined analysis, major energy conversion technologies. Variety is a positive integer. All else being equal, the greater the variety of a system, the greater the diversity.
- *Balance*. Refers to the pattern in the apportionment (spread) of that quantity across the relevant categories. Given the number of categories, the more even the spread, the greater is the diversity.
- *Disparity*. Refers to the nature and degree to which the categories themselves are different from each other. For example, it would appear that the categories Oil and Natural Gas are less disparate than Oil and Renewables, considering the heterogeneity of the latter. Disparity, though, is an intrinsically qualitative, subjective and context-dependent aspect of diversity.

Stirling has addressed the question as to whether and how diversity can be captured in a simple and robust quantitative index. His threefold variety-balance-disparity concept of diversity is non-parametric in the sense that the system is not ex ante stylised by a structural model, for example a normal distribution, or theoretical framework. Based on a review of non-parametric measures of ecological diversity, he could not identify any that addresses the complex and fundamentally subject concept of disparity. As Hill has demonstrated the two most prominent dual concepts, marrying variety to balance, are subject to same general form:

$$\Delta_a = \sum_i (p_i^a)^{1/(1-a)}$$

Setting a=1, the Shannon-Wiener index (henceforth briefly ‘Shannon index’) can be obtained:

$$\Delta_1 = - \sum_i (p_i) \ln p_i$$

Setting a=2, the reciprocal of the function, referred to in ecology as the Simpson diversity index and in economics as the Herfindahl-Hirschman concentration index, (henceforth ‘Simpson index’) emerges:

$$\Delta_2 = 1 / \sum_i p_i^2$$

Stirling’s preferred dual concept diversity index is the Shannon index. Arguments are:

- *Sensitivity of final ordering*. Changes of the base of logarithms used in Shannon (Stirling uses by natural logarithms by default) do not change the rank orderings of different systems and, by implication, do not lead to different relative sensitivities to variety and balance. In contrast, using another exponential power (than 2) in Simpson may lead to different rank orderings. There does not seem to be a clear reason why only exponential power 2 should be chosen in the case of Simpson.
- *Additivity property in case of refining the taxonomy*. Given the subjectivity in classifications (referring to the subordinate property of disparity), a diversity index would be more robust if it holds the following property. Its value for a system of options, which has been disaggregated according to a combined taxonomy, should be equal to the sum of the index values obtained for the same system classified under each taxonomy individually. Shannon, as distinct from Simpson, exhibits this property.

No easy way to capture disparity presents itself. The way in which options are disaggregated determines the results that are obtained in any analysis of dual concept diversity. Comparing two systems with same variety and balance, the more disparate system will be the more diverse as well. A dual concept index, though, would indicate the same diversity value. A practical approach to address the diversity challenge is to adopt a classification, which is conservative with respect to the particular hypothesis investigated. For example, in Stirling (1994) Andrew Stirling investigated the strength of the diversity argument prominently used by the U.K. government to sanction enhanced reliance on the option Nuclear in the U.K. power supply system. He adeptly showed that the option Renewables would held out the same or more diversion benefits at an appreciably lower ‘diversity premium’. This in spite of a conservative classification scheme (Renewables would seem much more heterogeneous than Nuclear) and conservative cost assumptions favouring Nuclear.

Stirling (1999) enumerates the properties of his ideal diversity index as follows:

- Being *complete*. It should address at the same time the variety, balance, and disparity components of diversity.
- Being *parsimonious*. Involving only those types of variable or operation, which are already required in the appraisal of contending options.
- Being *transparent*. Requiring a minimal number of hidden assumptions concerning the natures and structures of the systems under scrutiny.

- Being *robust.* The orderings obtained should not be sensitive to changes in the value of those parameters that are included.
- Being *consistent.* The principle elements of consistency are:
  - *(i)* Given balance and disparity, the index should increase monotonically with variety.
  - *(ii)* If variety is equal to one, the index should take a value of zero.
  - *(iii)* Given variety and disparity, the index should increase monotonically with the degree of balance in the spread of option contributions.
  - *(iv)* Given variety and balance, the index should increase monotonically with the aggregate distance between options in the 'disparity space'.
  - *(v)* Where this aggregate distance is zero (i.e., where all options are effectively identical), the diversity index should take a value of zero.

The 'most ideal' dual concept diversity index, Shannon, possesses all properties just mentioned, except for *completeness* and elements *(iv)* and *(v)* of *consistency*.

Stirling proposes an 'integrated multicriteria diversity index', *M*, possessing all ideal properties:

$$M = \sum_{ij} d_{ij} \cdot p_i \cdot p_j$$

Where: p_i = the proportional representation of option i
d_{ij} = the distance in a Euclidean disparity-space between options i and j.

And:

variety:	$V = \sum_i p_i^0$	(high *V* indicates high diversity)
balance:	$B = (1/V)\sqrt{[\sum_i (p_i - 1/V)]}$	(low *B* indicates high diversity)
disparity:	$D = \sum_{ij} d_{ij}$	(high *D* indicates high diversity)

He further refines the *M* index into an 'interaction matrix', ***M'***, by allowing for a range of factors relating to complex (positive or negative) interactions between options. For example, the inflexible operating characteristics of Nuclear do not go along well with intermittent Renewables such as Wind or PV but can be conveniently reconciled with the flexible operating characteristics of CCGT (combined cycle gas turbine) technology. Using a Monte-Carlo technique and matrix optimisation procedures, Stirling provides an example of an application of ***M'*** with proprietary software to explore trade-offs between diversity and other aspects of performance in a multi-criteria analysis mode of research.

3.5 Conclusions

Hedging against potential threats to long-run energy supply security can be modelled by way of probabilistic approaches. A potentially attractive one is application of Markowitz's portfolio theory in a fashion pioneered by Awerbuch. For the portfolio of PES options, one would need to project over the time frame with horizon 2040 the development of:

- Unit costs for the distinct PES options, whether or not broken down into major cost components.
- Cross-correlations of unit costs.
- The shares of distinct PES in total primary energy supply.

The assumption that past trends have predictive value for the future is a rather heroic one over the long time frame considered. Nor is all required information on past price volatility readily available. It would seem though, that past price volatility performance with respect to the distinct PES indicates evolving market expectations on future supply uncertainties. Uncertainties reflected in historical market clearing price volatility include changing perceptions on aspects such as political risks, resource depletion and carbon constraints. Moreover, sharp fuel movements appear to occasion notable asymmetric macroeconomic shocks (Sauter and Awerbuch, 2002).

In the face of large blind spots of ignorance on long-term future socio-economic developments, well-designed diversity strategies with regard to the portfolio of long-term energy supply options appear to hold out the best promise of energy supply security. Stirling (1999) has shown that the Shannon diversity index is the most attractive dual concept diversity index, reflecting both variety and balance in an even way. Inclusion of disparity remains cumbersome. One could apply a relatively simple optimality analysis, comparing scenario scores with respect to the Shannon index to a single performance criterion, for example unit energy cost (see Stirling 1994), or apply complex multi-criteria analysis methods (Stirling 1999) to identify Pareto-optimal scenarios.

For the purposes of the present report we will retain the Shannon index for further elaboration. The 'integrated multi-criteria' index *M* and 'interaction matrix' *M'* seem too complicated and prone to methodological caveats, although the latter indices would certainly seem worthy of further exploration in a large future research project.

4. DESIGN OF INDICATORS

4.1 Introduction

In the present chapter some indicators of long-term energy supply security will be developed, starting out from the Shannon diversity index, introduced and discussed in the previous chapter. The index is applied to the portfolio of sources for primary energy supply. Subsequently, it is set out to capture several aspects considered of major relevance on a step-by-step basis. These aspects include:

- Import diversity without allowance for political stability;
- Further elaboration of import diversity with allowance for the extent of political stability in regions of import origin;
- Considerations on depletion of natural energy resources.

4.2 Basic indicator

The basic indicator will be denoted by the Shannon diversity index for the portfolio of sources for primary energy supply (PES). The formula is:

$$I_1 = -\sum_i \left(c_i^1 p_i \ln p_i\right) \qquad (4.1)$$

where:
I_1 = energy supply security indicator no. 1
p_i = share of primary energy source i in total primary energy supply
i = 1…….M: primary energy source index (M sources are distinguished).
c_i^1 = correction factor to p_i for indicator I_1. All these correction factors are equal to unity in case of the first indicator. Yet indicators nos. 2-4 to be explained below will be variants of this first one, by elaboration on the correction factor.

Given eight categories of PES (coal, oil, gas, modern biofuels, traditional biofuels, nuclear, renewables not elsewhere specified, hydro power), the maximum value that I_1 can take on indicating maximum diversity in terms of variety and balance is approximately 2.079 (-ln1/M; M=8). The minimum value if all energy services would be driven by only one primary source is 0. Thus, a lower value of I_1 suggests a worse energy supply situation than a higher value.

4.3 Allowance for energy import dependency

The second indicator provides for an adjustment of the basic indicator for net import dependency. The Shannon diversity index is applied to the portfolio of sourcing regions in total imports of energy source i from region of origin j. Subsequently, the ratio of the corresponding actual diversity value to the corresponding maximum value is determined. In case of 16 potential (foreign) regions of origin, the corresponding maximum value would be approximately 2.77 (-ln 1/N; N = 16). The next step is to adjust the portfolio shares of the distinct primary energy sources by multiplication with a corresponding fraction which is in between zero and unity. This fraction is relatively low if for the region concerned (say OECD Europe) the import dependency for source i is relatively high and, at the same time, very poorly diversified.

The second indicator is:

$$I_2 = -\sum_i \left(c_i^2 p_i \ln p_i\right) \tag{4.2}$$

Subject to:

$$c_i^2 = 1 - m_i\left(1 - S_i^m / S_i^{m,\max}\right) \tag{4.3}$$

where:
I_2 = energy supply security indicator no. 2 accounting for import of energy resources
c_i^2 = correction factor to p_i for indicator I_2
m_i = share of net import in primary energy supply of source i

S_i^m = Shannon index of import flows of resource i

$$S_i^m = -\sum_j \left(m_{ij} \ln m_{ij}\right) \tag{4.4}$$

m_{ij} = share of imports of energy resource i from region j in total import of source i

j=1….N: index for (foreign) region of origin. A total number of N regions of origin are distinguished.

$S_i^{m,max}$ = Maximum value of Shannon index of import flows of resource i (equal to 2.77 for 16 regions of origin, excluding the home region)

In the case of oil and gas a further refinement could be introduced by classifying import sources according to region of origin and *transport mode* (pipeline, tanker/LNG container ship), which would in theory double the options from 16 to 32. In practice, this refinement would seem to make a minor difference. In some long-term scenarios, OECD Europe might import from major oil & gas exporting regions (e.g., the region including Russia and the one including the Middle-East) in hybrid mode (pipeline, tanker).[6]

4.4 Allowance for import dependency and long-term socio-political stability

The third additional adjustment accounts for the level of long-term political stability in regions of origin. It is assumed that political stability in the 'home' region (that is, OECD Europe in Chapter 5's application) is not an issue.

It is proposed to use the UNDP Human Development Indicator (HDI) as index for long-term socio-economic stability. Presumably, there will be a high correlation between countries with long-term future political stability and countries with a high current HDI score. The HDI index has the following advantages:

- It is an authoritative index, compiled for each country with a convenient range between zero (lowest value) and unity (highest value). The index stands for the extent to which people

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[6] Christian von Hirschhausen and Anne Neumann made a presentation on the INDES Workshop, Amsterdam, 6-7 May 2003 on security of gas supply(Hirschhausen and Neumann, 2003). There they referred to two "Shannon Weiner-Neumann" indices of gas supply security:
SW1 = $-\sum x_{Ii} \ln x_I b_i$ and SW2 = $-(\sum x_i \ln x_i b_i)(1+g_i)$ where:
x_i = market share of supply country I
b_i = index of political stability
g_i = share of indigenous production (%).
Anne Neumann communicated in an e-mail exchange with one of the authors that these formulae should be read as:
SW1 = $-\sum x_i(\ln x_i)\, b_i$ and SW2 = $-\sum x_I (\ln x_i) b_i(1+g_i)$

can develop their full potential and lead productive, creative lives in accord with their needs and interests.

- This index is periodically updated and is easily accessible online[7] and through publications (UNDP 2003).
- Political risk indices compiled by rating organisations such as Moody's, S&P, Fitch, etc., are extremely vulnerable to - unpredictable and sometimes frequent - shifts in ideological denomination of political regimes, whereas it appears that the HRI index provides a better indication for long-term socio-economic stability in a country or region. Moreover, data of commercial rating agencies tends to be proprietary.

The third index can be determined as follows:

- Compile, for the most recent year that HDI values are available (UNDP 2003: 237-241), HRI values at the regional level, weighting national values by population numbers.
- Assume in first instance that HRI values will develop in line with real regional GDP per capita. As a next step, determine the resulting region score. The projected HDI value for import region j, h_j, is equal to the square root of the ratio between the score of the region considered and the highest region score for the projection year concerned. In fact, this procedure is fairly similar to projection of the HRI, making allowance of one of its three components (real per capita income) only.
- Determine correction factors c_i^3 by multiplication of all coefficients, m_{ij}, in Equation 4.4 above by HDI values h_j.
- Emulate the procedure for calculating index 2 inserting c_i^3 for c_i^2 in Equation 4.2 above.

In formulae, this can be stated as follows:

$$I_3 = -\sum_i \left(c_i^3 p_i \ln p_i\right) \tag{4.5}$$

where:
I_3 = energy supply security indicator 3 accounting for energy imports and the extent of long-term socio-political stability in regions of origin

$$c_i^3 = 1 - m_i\left(1 - S_i^{m*} / S_i^{m*,\max}\right) \tag{4.6}$$

$$S_i^{m*} = -\sum_j \left(h_j m_{ij} \ln m_{ij}\right) \tag{4.7}$$

h_j = extent of political stability in region j, ranging from 0 (extremely unstable) to 1 (extremely stable)

S_i^{m*} = Shannon index of import flows of resource i, adjusted for political stability in the regions of origin

$S_i^{m*,max}$ = Maximum value of aforementioned Shannon index (equal to value 2.77 for 16 foreign regions of origin)

4.5 Additionally: allowance for resource depletion

The fourth indicator allows for the level of resource depletion on an additional basis. Theoretically, resource depletion can play a role for coal, gas, oil, nuclear (uranium), and biomass (unsustainable biomass extraction). In practice, over the time span relevant for this study (up to

[7] http://www.undp.org/hdro/

year 2040) sustained energy supply disruptions because of resource depletion is only likely to play a role for oil and, perhaps, gas. This would seem the case, considering:

- The very high Reserve/Production ratios (R/P) for coal and the primary resource for nuclear.
- The relatively low cost share of the primary resource in electricity from nuclear power plants.
- The share of modern biomass in total primary energy supply of OECD Europe in the long-term up to 2040, which is poised to remain relatively modest.
- The share of coal which is poised to recede in a carbon-constrained future.

We expect the market to react to information on proven reserves rather than speculations on (changes in) ultimately recoverable reserves. Information on currently proven reserves of coal, oil and gas is readily available, e.g. from BP's website.[8] We assume that fuel markets will primarily respond to new information on proven reserves when reserve-production ratios have reached values below 50 and propose to make allowance for resource depletion in the following manner:

$$I_4 = -\sum_i c_i^4 p_i \ln p_i \qquad (4.8)$$

Where:
I_4 = indicator 4 accounting for energy imports, political stability in producing regions and for the proven regional reserves with respect to the annual production in the region concerned.

$$r_{ij} = Min\left\{\left[\frac{(\mathrm{R/P})_{\mathrm{ij}}}{50}\right]^{\mathrm{a}};1\right\} \quad (\mathrm{a} \geq 1) \qquad (4.9)$$

$$c_i^4 = \{1-(1-r_{ik})(1-m_i)\} * \{1-m_i(1-S_i^{m**}/S_i^{m**,\max})\} \qquad (4.10)$$

$$S_i^{m**} = -\sum_j (r_{ij} h_j m_{ij} \ln m_{ij}) \qquad (4.11)$$

r_{ij}= depletion index for resource i in import region j

r_{ik}= depletion index for resource i in home region k, for which the indicators are determined (that is, OECD Europe in our applications in Chapter 5 of this report)

$(R/P)_{ij}$ = proven reserve-production ratio for resource i in region of origin j

The proposed indicator I_4 not only allows for resource depletion in the import regions. In Equation 4.10 the factor $\{1 - (1-r_{ik})(1 - m_i)\}$ allows for resource depletion in the home region, k, taking account of the local sourcing quote $(1-m_i)$, while the factor $\{1-m_i(1 - S_i^{m**}/ S_i^{m**,max})\}$ makes allowance for the resource depletion situation in the foreign regions of origin.

The higher value for parameter *a* in Equation 4.9 is taken, the quicker the depletion index value will approach the lower bound zero when R/P runs from 50 to zero. We propose the convenient - but admittedly arbitrary - value of *a* = 2.

8 http://www.bp.com/centres/energy/index.asp

To conclude this section, we like to consider the relationship between the four indicators designed above. Generally, the following relationship for the indices developed above holds in a consistent way:

$$S_4 \leq S_3 \leq S_2 \leq S_1 \tag{4.12}$$

4.6 Conclusions

In this chapter we have designed four long-term energy security indices allowing for an increasing number of major factors. These indicators are elaborations of the simple dual concept Shannon diversity index. Aspects having been introduced in our indicators on a stepwise additional basis are successively:

- Diversification of energy sources in energy supply (I_1).
- Diversification of imports with respect to imported energy sources (I_2).
- Long-term political stability in import regions (I_3).
- The resource base in regions of origin, including the home region itself (I_4).

5. CASE STUDY: APPLICATION TO SUSTAINABILITY SCENARIOS

5.1 Brief introduction of the scenarios

MNP and CPB[9] have designed four sustainability scenarios covering the period 2000-2040 with year 2000 as base year. A succinct description of these scenarios follows suit. For a detailed description reference is made to a publication of CPB (Mooij and Tang, 2003).

Global Economy (GE, A1). Economic agents make, on balance, the proper decisions to keep the energy supply system reliable and affordable. With economic liberalisation as dominant paradigm and increasingly high-tech and affluent life styles, energy intensities decrease at a steady rate. Kyoto is deemed too expensive. Penetration of renewables does not meet ex ante expectations. OECD Europe witnesses increasing dependence on oil and gas from the Middle East and the FSU.

Transatlantic Markets (TM, A2). Increasing disparities at global level lead to increasing political tensions with low economic growth, ascending economic regionalism, and relatively slow technological progress as a result. In spite of regionalised liberalisation and bilateral trade agreements energy prices surge. This translates into sobering life styles for low-income population strata. In spite of rising protectionism, dependence on oil and gas from the Middle East and the FSU does not wane.

Strong Europe (SE, B1). Substantial public intervention occurs to internalise environmental impacts in a mode of cordial global co-operation. Access by the poor to basic energy services ranks among the policy priorities pursued by 'responsible' governments. The policy response to the Kyoto Protocol in place becomes increasingly strong. The role of natural gas at global level steadily increases at the expense of oil. Automotive biofuels achieve a remarkable penetration on the market for motor fuels. Likewise, renewables and steady progress in gas combined cycle technology are conspicuous features of the B1 scenario.

Regional Communities (RC, B2). This scenario is characterised by the ascend of the "small is beautiful" paradigm with an expanding informal sector and increasing reliance on regional or rather local sourcing. Distributed generation and increasing deployment of renewables stand out under the B2 scenario. Yet the absence of global co-operation to address mounting environmental challenges lead to serious environmental problems and energy price volatility at local and regional levels.

5.2 Adjustment of the indicators

Because of data availability some adjustment of the four proposed indicators for application to the aforementioned scenarios was necessary. The following adjustments were made:

Indicator I_1. No adjustment.

Indicator I_2. No adjustment.

Indicator I_3. Projections of the HDI indicator were not readily available but projections of real GDP per capita were, whilst the HDI indicator is highly correlated with a normalised value of

[9] The Dutch acronym of the Netherlands Bureau for Economic Policy Analysis, The Hague.

the square root of real GDP per capita. We took the latter variable as a proxy. Normalisation was done dividing the distinct regional values by the highest regional value of the same year

Indicator I_4. No projections of proven reserves to yearly production ratios were available. In fact, these ratios are hard to project given the partly political character of these ratios. Some OPEC countries have tended to cut back upward revisions of official statistics on proven reserves in bullish market conditions, while presenting a more rosy reserves situation in lean times to attract foreign investments. Therefore, we used projections of ultimately recoverable reserves, and substituted for the aforementioned ratio the quotient of the ultimately recoverable reserves of the region concerned in the projection year and the corresponding variable in the base year, i.e. year 1995, or one if the latter number would exceed unity. Typically, the ratio used will cause less pronounced adjustments and will be a correspondingly less good predictor of imminent upward price pressure or high price volatility than the ratio suggested in Chapter 4. This would probably hold true *a fortiori* for retaining R/P ratios but substituting projections of ultimately recoverable reserves for projections of proven reserves. For many regions the latter ratio is poised to exceed 50 for quite some time, even in the case of Oil.

5.3 Numerical results

We have applied the four energy supply security indicators described in Chapter 4 and Section 5.2 to the scenarios, briefly outlined in Section 5.1 above. The primary data for this application was delivered by RIVM. The results are shown in Table 5.1

Table 5.1 *Projected numerical values of normalised long-term energy supply security indicators to the four MNP/CPB sustainability scenarios; year 2030*

Scenario	Year	Indicator			
		I_1	I_2	I_3	I_4
(Actuals)	1995	64.3	54.3	49.3	49.3
GE (A1)	2030	*62.6*	*43.3*	*36.7*	*34.9*
TM (A2)	2030	*69.3*	*49.0*	*42.9*	*40.9*
SE (B1)	2030	*69.9*	*43.1*	*36.7*	*35.1*
RC (B2)	2030	*72.3*	*46.3*	*40.9*	*39.6*

Source: authors' calculations, based on RIVM data

The relative changes occasioned by each elaboration step also contribute to the explanation of the numerical results. These are shown in Table 5.2. The projected relative changes in indicator scores for 2030 suggest that long-term energy supply security will be most negatively affected by relatively poor supply diversification among resources (I_I – 100%) and dependency on relatively poorly diversified foreign regions of origin (I_2 over I_1). Political instability in foreign regions of origin (I_3 over I_2) and, even more so, resource depletion (I_4 over I_3) would denote less negative factors. As for the latter we refer to the caveat made on indicator I_4 in the previous section.

Table 5.2 *Projected relative changes in the value of successive long-term energy supply indicators for four MNP/CPB sustainability scenarios; year 2030*

Scenario	Year	Relative change in projected score [%]			
		I_1 over 100%	I_2 over I_1	I_3 over I_2	I_4 over I_3
(Actuals)	1995	-35.7	-15.6	-9.2	0.0
GE (A1)	2030	*-37.4*	*-30.8*	*-15.1*	*-5.1*
TM (A2)	2030	*-30.7*	*-29.4*	*-12.5*	*-4.7*
SE (B1)	2030	*-30.1*	*-38.3*	*-14.9*	*-4.3*
RC (B2)	2030	*-27.7*	*-35.9*	*-11.7*	*-3.3*

Source: authors' calculations, based on RIVM data

In all four scenarios the energy supply security situation is projected to worsen substantially relative to base year 1995 (See Table 5.1, last column). The scenarios Global Economy and Strong Europe yield the lowest projected score for the most elaborated indicator, that is I_4, whereas Transatlantic Markets and Regional Communities yield the best projected score in reference year 2030. Let us consider the indicator projection results in somewhat more detail for each scenario.

Global Economy. Wide-ranging liberalisation and high economic growth are some main features of this scenario. This scenario yields the lowest score for composite indicator I_4 in year 2030, 34.9. This scenario scores very low in resource diversification in energy supply. This can be gauged by comparing the I_1 scores, shown in Table 5.1 or the I_1 over 100% score in Table 5.2. On the aspect diversification of energy imports, this scenario - assuming smooth global trade liberalisation - performs relatively well, compared to the other ones. This is inferred from a comparison of the relative change in projected scores from I_2 over I_1 (Table 5.2). Differences between the scenarios considered in relative changes of projected I_3 over I_2 scores indicate that under scenario Global Economy relatively much energy imports are made from politically less stable regions. Moreover, the projected regional portfolio of energy supply to OECD Europe is under this energy-guzzling scenario most prone to depletion of the resource base as reflected by projections of ultimately recoverable resources. This is borne out by comparison of the lower four scores in the last column of Table 5.2.

Transatlantic Markets. Some key features of this scenario are increasing welfare disparities and economic regionalism. It scores much better than Global Economy on diversification of energy sources and scores the best of all scenarios on energy import diversification. Moreover, on political stability in import regions this scenario - emphasising less dependency on imports - does relatively well, while the opposite holds for resource depletion weighted by the share of its regions of origin.

Strong Europe. This scenario depicts harmonious global co-operation on, among other global policy issues, Climate Change. Strong Europe scores relatively well on the energy mix spread. However, its performance is quite poor on diversification of energy imports. Also the performance of this scenario on reduction of imports from potentially less stable regions is poor. The assumed global political situation under the Strong Europe scenario facilitates this outcome. Its performance on resource depletion is better than Global Economy and Transatlantic Markets. Especially the outstandingly poor score on energy import diversification makes for the low score on composite indicator I_4.

Regional Communities. Regional Communities - emphasising local sourcing - yields a relatively modest overall deterioration of projected energy supply security as depicted by the projection for indicator I_4 in year 2030, that is 39.6. Diversification of the energy mix is projected to evolve quite favourably under this scenario. However, the portfolio of energy import regions would develop more unfavourably than the scenarios Transatlantic Markets and Global Economy. Regional Communities scores quite well on political stability in the import regions of energy resources destined for OECD Europe.

5.4 Concluding remarks

After some small adjustments owing to data availability, the designed indicators proved quite well amenable to making projections of long-term development of energy supply security for a particular region. We have endeavoured to make some preliminary interpretation of the results under the four MNP-CPB scenarios.

As for indicator I_4 - the indicator allowing for all four aspects considered of the extent of long-term energy supply security - the projected scores in year 2030 on a 0-100 scale are as follows:

- Global Economy: 34.9. The Global Economy scenario accounts for the lowest score, mainly because of (i) poor fuel diversification and, less so, (ii) high dependency on imports from political unstable regions and (iii) high dependency on fuels from regions characterised by relatively fast depletion of these fuel resources;
- Transatlantic Markets: 40.9. This relatively high score owes especially to the relatively good fuel import diversification in terms of regions of origin, associated with Transatlantic Markets;
- Strong Europe: 35.1. Very poor import diversification in terms of regions of origin is a major factor explaining the poor score of this scenario;
- Regional Communities: 39.6. This scenario performs relatively well on aspects such as fuel diversification and (relatively low) dependency on fuel imports from regions with potentially unstable political conditions.

With better scenario knowledge, the interpretation of the outcomes of the present application can probably be further improved upon. Yet the results presented would seem encouraging for emulation in other applications and for conducting follow-up research on the design of energy supply security indicators.

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ANNEX A MOGELIJKE ONDERBREKINGEN VAN DE AARDGASVOORZIENING

In tegenstelling tot de olie- en elektriciteitsvoorziening, zijn grote verstoringen van de aardgasvoorziening tot nu toe nog niet voorgekomen. Grotere risico's zijn in de toekomst echter denkbaar. Het aandeel van gas in de energievoorziening stijgt terwijl productie in Europa afneemt, waardoor aanvoer over langere afstanden nodig is.

Aan de hand van concrete voorbeelden uit de aardgasproductie- en distributieketen worden mogelijke incidentele discontinuïteiten in de fysieke levering van aardgas geïllustreerd en worden de mogelijke risico's beschreven. De voorbeelden zijn zodanig extreem gekozen dat er sprake is van een langdurige (> 1 jaar) onderbreking van de gasvoorziening. De kans dat dit soort onderbrekingen zich voordoet is misschien niet erg groot, maar toch reëel en heeft waarschijnlijk veel impact. Hieronder worden drie voorbeelden uitgewerkt, waarbij de mogelijke effecten in 2020 voor de EU-30 worden beschouwd.

A.1 Stagnatie doorvoer Russisch gas via de Oekraïne

Als voorbeeld van politieke risico's beschouwen we het (onverwachts) afsluiten van de belangrijkste doorvoerroute van Russisch aardgas via de Oekraïne naar Europa. Het politieke regime in de Oekraïne kan zodanig verslechteren dat de toch al moeizame gasdoorvoer stagneert. Enerzijds omdat geen geld wordt vrijgemaakt voor het onderhoud en de uitbreiding van het gastransit netwerk. Anderzijds omdat de politieke ver(stand)houding tussen de Oekraïne en Rusland en tussen de Oekraïne en Europa tot een dieptepunt zakt. Voor de afzet van Russisch aardgas hoeft dit geen groot probleem te zijn, omdat de gasmarkt in Azië sterk groeit. Het Russisch gas dat voor de stagnatie naar Europa ging kan dus in Azië worden verkocht, mits de infrastructuur daarvoor voldoende aanwezig is (op dit moment een enkele pijplijn naar China en India).

De gastransit mogelijkheid door de Oekraïne is momenteel zo'n 130 bcm[10]. Rekening houdend met investeringen zal deze capaciteit in 2020 circa 148 bcm zijn. Hiervan wordt 109 bcm (ruim 70%) gebruikt voor transit van Russisch gas en de rest voor gas uit de Kaspische Regio (Azerbeidzjan, Kazakstan, Turkmenistan en Oezbekistan). We veronderstellen dat alleen de doorvoermogelijkheid van het Russische gas wegvalt[11].

De effecten van deze interruptie kunnen worden onderscheiden naar de termijn waarop ze zich voordoen. In de dagen en maanden direct na de onverwachte interruptie (korte termijn) zijn de gevolgen het grootst en meest voelbaar omdat er enige tijd nodig is voor aanpassingen en wijzigingen die op de middellange termijn (tot circa 2 jaar na de interruptie) en lange termijn (> 2 jaar na interruptie) nodig zijn om het weggevallen aanbod (deels) te kunnen compenseren.

Effecten op korte termijn
Op de korte termijn zullen landen, die direct Russisch gas via de Oekraïne importeren[12] en geen of weinig aardgas op voorraad hebben, (een deel van) hun aardgasverbruik drastisch moeten inperken, zeker als de interruptie zich 's winters voordoet. Daarnaast speelt de mate waarin het

[10] 1 bcm = 10^9 m^3
[11] Doorvoer van gas uit de Kaspische Regio wordt niet aangetast. Dit is natuurlijk vreemd als je ervan uitgaat dat het knelpunt in de Oekraïne ligt. Waarom zouden ze daar onderscheidt maken naar herkomst, als dat fysiek al mogelijk is?
[12] Duitsland, Italië, Frankrijk, Roemenië, Polen, Hongarije, Tsjechië, Oostenrijk en Slowakije importeren direct Russisch gas via de Oekraïne.

gasverbruik afschakelbaar is (technisch of contractueel) en de toepassing van gas (welke sectoren) een rol.

De huidige gemiddelde afschakelbaarheid in Europa is 21%. Gas uit opslag kan voor circa 2 maanden in het gemiddelde verbruik voorzien. In 2020 zullen deze waarden waarschijnlijk wat gunstiger zijn. Tegen die tijd zal de elektriciteitsproductiesector de belangrijkste gasverbruiker zijn, daar waar dat nu nog de kleinverbruikers zijn.

In bijvoorbeeld Duitsland wordt veel gas verbruikt door huishoudens, die doorgaans weinig mogelijkheden hebben om op korte termijn te switchen naar een andere brandstof. Een deel van de Duitse huishoudens gebruikt echter nog olie voor ruimteverwarming (nu ca. 35%, maar in de toekomst minder). Circa 26% van de Duitse gasgestookte elektriciteitsopwekking kan technisch makkelijk overgaan op een andere brandstof. Gecombineerd met contractuele afschakelbaarheid is in totaal ongeveer 70% van het Duitse gasverbruik door de elektriciteitssector afschakelbaar. Industrieel gasverbruik is voor ongeveer 25% afschakelbaar. Als volledig van deze afschakelbare opties gebruik wordt gemaakt, dan kan Duitsland zijn huidige gasverbruik nog ruim drie maanden volhouden door de gasvoorraden aan te spreken[13]. De situatie in Frankrijk, Italië, Hongarije en Tsjechië is vergelijkbaar met die in Duitsland. Met name Slowakije en Oostenrijk hebben veel gasopslag (4,5 maand). Roemenië en Polen hebben relatief weinig gasopslag mogelijkheden (1 maand) en de consumptie is nauwelijks afschakelbaar. Vooral het industriële gasverbruik is daar hoog. Over het algemeen is de gasvraag in de Centraal- en Oost-Europese landen meer seizoen- en temperatuurafhankelijk dan in West-Europa.

De gevolgen zullen echter ook van het overheidsbeleid/ingrijpen ten tijde van de interruptie afhangen. De overheid kan bijvoorbeeld voorrang geven aan de elektriciteitsproductie (evt. na afschakeling) en beslissen dat huishoudens het maar een tijd zonder gas moeten doen. Met name in de zomer en in landen zoals Roemenië en Oostenrijk waarin huishoudens (nog) relatief weinig gas verbruiken kan zo'n beslissing worden genomen. Voor verwarming zijn met name olie (bijv. Oostenrijk en Duitsland) en in veel mindere mate kolen (Polen), belangrijke alternatieven[14]. Voor warm water en koken kan gas redelijk makkelijk worden vervangen door elektriciteit.

Het spreekt voor zich dat aan deze maatregelen kosten zijn verbonden en dat prijseffecten dus niet uit zullen blijven. Naast de oplopende gasprijs wegens schaarste en hogere transport- en opslagkosten vanwege bijvoorbeeld congestie, zullen de alternatieve brandstoffen duurder worden, zodat elektriciteit en industriële producten ook duurder worden.

Effecten op middellange termijn (met name gebaseerd op onze modeluitkomsten)[15]
Bij het wegvallen import van Russisch gas via de Oekraïne zullen in eerste instantie bestaande, alternatieve toevoerroutes worden benut, zoals de Bluestream leiding van Rusland naar Turkije met een totale capaciteit van 16 bcm in 2020[16], de nieuwe Baltische leiding naar Duitsland (capaciteit 30 bcm in 2020) en export van Russisch LNG (Rusland voorziet een LNG export capaciteit van 13 bcm in 2020). We mogen echter verwachten dat deze (en andere, zoals via Wit-Rusland) transportcapaciteiten al volledig door lange termijn contracten zijn vastgelegd. Al met al kan maximaal 10 bcm (9%) hierdoor worden opgevangen.

Voorts kan bestaand productie- en exportpotentieel van de Kaspische regio (via Turkije) en Noorwegen, en het wereld LNG-exportpotentieel worden gebruikt om het weggevallen Russisch aanbod aan te vullen. De laatste optie, LNG, heeft waarschijnlijk de meeste ongebruikte termi-

[13] Vòòr gebruikmaking van afschakelbaarheid kan het gasverbruik nog 2,5 maanden worden volgehouden. Dit zijn gemiddelde cijfers voor de situatie in 2000. In een (strenge) winter ontstaan er al eerder problemen.
[14] In Spanje wordt elektriciteit veel gebruikt voor verwarming (> 70%), maar Spanje ondervindt nauwelijks korte termijn effecten in dit voorbeeld.
[15] Zie o.a. (Oostvoorn, 2003).
[16] Doorvoermogelijkheden van Turkije verder Europa in zijn echter beperkt.

nal capaciteit beschikbaar (het aantal tankers is hier misschien de bottleneck), maar is gelijk ook het duurste alternatief. In totaal kunnen deze opties maximaal 40 bcm (37%) van het weggevallen aanbod compenseren.

In heel Europa zal het effect van deze interruptie merkbaar zijn. Op de korte en middellange termijn kan een groot deel van het weggevallen Russische aanbod niet worden aangevuld. De consumptie van aardgas zal moeten dalen met zo'n 8% gemiddeld in Europa terwijl de gasprijs circa 40% stijgt. De Centraal- en Oost-Europese landen, die traditioneel in hoge mate afhankelijk zijn van de invoer van Russisch gas, zullen te maken krijgen met de grootste prijsstijgingen (40-80%). Maar ook de landen die niet direct Russisch gas importeren kunnen flinke stijgingen van de gasprijs verwachten (15-35%). Omdat LNG export waarschijnlijk het enige alternatief is met een significante reservecapaciteit, zullen met name die landen die geen (additionele) LNG import capaciteit beschikbaar hebben, lijden onder de stagnatie van toevoer van Russisch gas via de Oekraïne.

Lange termijn effecten
Als de doorvoer van Russisch gas via de Oekraïne niet kan worden hersteld op de langere termijn, moeten nieuwe pijpleiding(en)[17] en gasvelden uitkomst bieden. Echter, in de tussentijd kan gas structureel zijn vervangen door andere brandstoffen, waardoor het risico van investering in nieuwe infrastructuur groter is. Als we aannemen dat er verder geen belemmeringen zijn (bureaucratie, financiering, toegankelijkheid van land/grond), dan duurt het zeker twee jaar, maar meestal veel langer, voordat een nieuwe gaspijpleiding in gebruik kan worden genomen. De hoge gasprijzen leiden tot gunstige financieringsmogelijkheden voor deze nieuwe infrastructuur.

In tijden van hoge gasprijzen neemt de exploratie en productie van gas doorgaans toe. Ook duurdere aardgasopties, zoals moeilijk winbare reserves en gashydraten, en substituten zullen eerder worden geëxploiteerd en benut. Nieuwe velden zullen versneld ontdekt en in gebruik worden genomen. Nabije gasreserves zijn echter beperkt, het ‘nieuwe’ gas moet dus over langere afstand naar Europa worden vervoerd, wat ook weer hogere investeringen in infrastructuur met zich mee brengt.

De Nederlandse en andere Europese gasproductie en -export kan enigszins worden vergroot door deze ontwikkelingen. De verwachte winbare reserves zijn echter niet voldoende om substantieel bij te dragen aan het herstel van de gevolgen van de interruptie.

A.2 LNG in de ban

Een grote ontploffing in een LNG-invoerhaven (al dan niet als gevolg van een terroristische actie), geldt als voorbeeld van technische risico’s. Zo'n eenmalig incident hoeft op zich geen grote kentering in de gasvoorziening te betekenen. De jaarlijkse capaciteit van een enkele LNG haven is immers niet groter dan circa 10 bcm. Een ontploffing van een LNG-invoerterminal of schip, met daarbij veel slachtoffers, kan echter leiden tot een volledige omslag in de publieke opinie ten aanzien van LNG. LNG wordt niet (meer) als veilige aardgasoptie gezien en daarom volledig verboden in Europa.

De huidige LNG-ontvangstcapaciteit in Europa is 43 bcm, terwijl de daadwerkelijke import van LNG in 2000 34 bcm bedroeg[18]. Met name Frankrijk, Spanje, Italië en België zijn afhankelijk van de invoer van LNG. Als rekening wordt gehouden met alle bestaande uitbreidings- en nieuwbouwplannen, dan zal de ontvangstcapaciteit in 2020 ongeveer 130 bcm zijn, waarvan

[17] Het is maar zeer de vraag of Rusland het productieoverschot dat ontstond na de interruptie, na een onderbreking van een aantal jaar, nog steeds bereid is te leveren aan Europa. Ondertussen kan een alternatieve markt in bijvoorbeeld Azië prioriteit hebben.
[18] Het verschil wordt geheel veroorzaakt door Spanje, waar de capaciteit vooruitloopt op de sterke groei van import.

echter maar zo'n 60% (bijna 80 bcm) wordt gebruikt[19]. De opvallendste nieuwbouw en import vindt plaats in Engeland (wordt netto importeur van gas).

Korte termijn effecten
De toepassing van LNG is in principe gelijk aan die van pijpleiding gas. De maatregelen die op korte termijn (vlak na het abrupt stoppen van de LNG-toevoer) kunnen worden genomen zijn daarom in principe dezelfde als in het vorige interruptievoorbeeld besproken. De omstandigheden betreffende gasopslag en afschakeling zijn in Frankrijk en Italië het gunstigste. Zij kunnen nog ruim drie maanden het normale gebruik van gas, na afschakeling van de grootverbruikers, voortzetten. In België en Engeland is dat korter dan een maand, hoewel Engeland druk doende is om de gasopslagmogelijkheden uit te breiden, zodat de situatie in 2020 iets gunstiger kan zijn.

Middellange termijn effecten (met name gebaseerd op onze modeluitkomsten)
Een radicaal verbod op LNG betekent een daling van bijna 80 bcm in de aanvoer van gas[20]. Algerije, Libië, Iran en andere LNG-producenten moeten hun LNG productie staken. Er zit geen rek meer in de pijpleidingen om dit gas alsnog naar Europa te transporteren. Ook de productie- en transportcapaciteit vanuit andere regio's (Noorwegen, Rusland) is niet toereikend. Consequentie hiervan is dat zowel de productie als de Europese consumptie van gas minimaal 10% daalt. De gemiddelde Europese gasprijs stijgt met circa 30%.

De effecten zijn echter zeer ongelijk verdeeld. Afhankelijk van het aandeel LNG, zijn Spanje, Engeland[21], Frankrijk, België en Italië genoodzaakt de gasconsumptie met 10 tot 30% in te krimpen. Als gevolg van de schaarste zullen de gasprijzen daar sterk stijgen (40 tot 100%). De rest van Europa zal slechts met iets hogere gasprijzen te maken krijgen (0 tot 3%). De ongelijke verdeling heeft vooral te maken met de specifieke LNG-infrastructuur, en dus de afwezigheid van additionele aanvoermogelijkheden via pijpleidingen.

Lange termijn effecten
Ook een lange tijd na het verbod op LNG zullen de effecten nauwelijks kunnen worden verzacht. De LNG-infrastructuur in bijvoorbeeld Spanje en Engeland is vooral ingegeven door de ongunstige locatie van deze landen ten opzichte van belangrijke leveranciers. Spanje zou bij een verbod op LNG grote investeringen moeten doen in de aanleg van nieuwe pijpleidingen vanuit Algerije, waar de productiecapaciteit in principe nog voorhanden is. Voor Engeland daarentegen heeft het nauwelijks zin om extra aanvoer vanuit Noorwegen mogelijk te maken omdat het Noorse productiepotentieel gering is. Additionele pijpleidingen naar het continent zijn wel mogelijk, maar voor de toevoer van bijvoorbeeld Russisch gas dient het netwerk in heel Europa te worden uitgebreid.

A.3 Extreem hoge gasprijzen

Een voorbeeld van economische risico's is een extreme stijging in de prijs van aardgas, als gevolg van een monopolistische gasmarkt, bijvoorbeeld door de macht van een GASPEC, terwijl de beschikbaarheid van gas beperkt is[22]. Als de huidige snelle groei, vooral bij elektriciteitspro-

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[19] Dit is het gevolg van onze modelberekeningen waarin een bilaterale (spot) markt wordt verondersteld. De duurste marginale optie LNG wordt daarin niet volledig gebruikt. Er wordt dus geen rekening gehouden met (lange termijn) contracten waarin een groot deel van de capaciteit al is vastgelegd.

[20] Een verbod op LNG vanuit overheidswege zal waarschijnlijk geleidelijk worden ingevoerd zodat maatregelen tijdig kunnen worden genomen. Korte en middellange termijn effecten zullen in dat geval een stuk gunstiger zijn dan hier besproken.

[21] Engeland wordt een belangrijke importeur van LNG in 2020.

[22] Gasprijzen zijn echter niet zo makkelijk te manipuleren als olieprijzen. Gasmarkten zijn nog steeds (en blijven?) vooral regionaal georiënteerd, er bestaat geen wereld gasmarkt, hoewel de LNG-markt zich wel ontwikkelt in die richting. In een (regionale) markt met een snel stijgende vraag en beperkte transportcapaciteit zoals bij gas het geval is, is een kartel niet nodig. Bovendien streeft de OPEC naar een stabiele olieprijs (rond $25/vat = $4,3/GJ), en niet zozeer naar maximale prijzen. Hetzelfde zou gelden voor gas. Daarnaast delen gasproducenten met name belangen als het gaat om technische aspecten die productiekosten kunnen verlagen.

ductie, zich stabiliseert, zijn prijsmanipulaties in de aardgasmarkt op de lange termijn niet ondenkbeeldig. Wanneer de Europese economie in belangrijke mate afhankelijk is geworden van aardgas en dus niet flexibel is qua energiesubstitutie, kan zo'n structureel hoge gasprijs grote gevolgen hebben voor Europa.

We veronderstellen dat de gasprijs structureel circa 50% hoger is dan normaliter. Vanwege de relatief matige substitutiemogelijkheden, zal de vraag naar aardgas op korte termijn niet veel lager zijn dan bij de oorspronkelijke gasprijs. Duurdere aardgas opties, zoals moeilijk winbare reserves en gashydraten, en substituten zullen echter eerder worden geëxploiteerd en benut. Dit geldt ook voor de Nederlandse (kleine) velden. Hierdoor kan het aanbod van gas en substituten op langere termijn toenemen en de prijs geleidelijk weer wat dalen. Eer het echter zover is zullen met name de landen die voor een groot deel van hun primaire energiebehoefte afhankelijk zijn van gas en die netto importeren de gevolgen voelen.

De hoge gasprijs heeft niet alleen een effect op het directe gasverbruik, maar ook op de prijs van producten die met behulp van aardgas worden gemaakt. Elektriciteit is natuurlijk het meest sprekende voorbeeld, maar veel industriële productie is ook afhankelijk van aardgas. Daarnaast wordt gas gebruikt voor ruimteverwarming. Een hoge gasprijs zal daarom resulteren in een algehele inflatie. Het gebruik van afschakelmogelijkheden, brandstofsubstitutie en ander beleid is hierop van invloed.