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Natural Gas in Europe

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Foreword

The IIASA International Gas Study analyzed the long-term prospects for natural gas demand, supply, and trade in European energy markets. The small IIASA study team cooperated informally with institutions and individuals involved in the broader aspects of natural gas research. A number of workshops, organized and held at IIASA, were instrumental in communicating the IIASA activities to experts from the gas industries and cooperating scientific institutions.

This paper summarizes the general approach of the study and reports on the results of this mathematical modeling effort.

We thank Academician M. Styrikovich, Leader of the Working Consulting Group to the President of the Soviet Academy of Sciences on Long-Term Energy Forecasting for reviewing this paper.

Hans-Holger Rogner
Leader
International Gas Study

Contents

NATURAL GAS IN EUROPE

Sabine Messner, Anatoli Golovine and Manfred Strubegger

Introduction

During the last 10 to 15 years a number of energy studies with varying regional and substantive focus were conducted at IIASA. Among them was the comprehensive analysis of the global energy situation *Energy in a Finite World* (Häfele 1981), as well as regional (Nakicenovic and Messner 1982, Sassin et al. 1983) and country-specific studies (Rogner and Strubegger 1982 , DiPrimio and Strubegger 1981). An update of the model runs from Energy in a Finite World, the *IIASA '83 Scenario of Energy Development* (Rogner 1984), pointed to the increased relevance of natural gas as internationally traded fuel. Gas would, according to this analysis, become the next major source of energy. This was already earlier concluded by C. Marchetti, who based his findings on a very different methodological approach—the logistic substitution model (Marchetti and Nakicenovic 1979).

These considerations, together with the nature and complexity of the problems related to gas extraction, transport and trade, lead to the initiation of the IIASA International Gas Study.

The focus of the IIASA gas study was Europe, because, out of the regions with substantial gas use, it shows the highest complexity in international relations and energy trade options. Other reasons are the high degree of economic development, allowing for the capital intensive build-up of a gas infrastructure, and the obvious necessity to step up energy imports in the future.

One important issue is the competitiveness of natural gas against other energy sources. Therefore a systems perspective was chosen, i.e. the energy system is seen as an entity—natural gas is not singled out and treated separately as in many other gas studies. To be able to study substitution processes and to cover other important aspects, like the build-up of new infrastructures and the implementation of new end-use technologies—all of them being relatively slow processes—the time horizon had to be extended well into the next century. But also the need to get a clear picture of the situation regarding the availability and consumption of resources necessitates an extended time horizon. Thus the study allows to shed some light on the period around 2010, when present contracts expire and when most of the currently operated fields will be exploited.

The systems perspective—together with the long time horizon--shows the problems incurred by simply extrapolating the structure and dynamics of our present energy system. When looking some 20 to 30 years ahead, like in many other studies, structural problems do not yet have major consequences. Looking 50 years ahead, these problems cannot be overseen any more—they have to be considered in some way. The main point here is, however, that these changes are dynamic processes taking place continuously, also in the next 20 years. By looking far ahead we try to cover shifts and changes that cannot be seen easily in shorter view.

For similar reasons it was necessary to refrain from simply using published figures on proven reserves, which, as also indicated later in this paper, vary considerably over time. Consequently, the resources recoverable in the next decades, as well as the cost of extraction, had to be re-evaluated for this study.

The regional disaggregation was chosen with respect to degree of economic development, present use of gas, existing infrastructure, and geographic coherence. Basically there are two types of regions: net importers and net exporters of natural gas. The importers are located in Europe and grouped in five regions: *Central Europe*, comprising the EC-9 except Italy plus Austria and Switzerland, *North Europe* representing Scandinavia, *South West Europe* (Spain and Portugal), *South East Europe* (Italy, Greece, Yugoslavia and Turkey), and *East Europe* consisting of the CMEA countries excluding the Soviet Union.

The sources of natural gas are domestic extraction in each region and gas bought from the exporting regions. These exporters are the *Netherlands*, *Norway*, the *Soviet Union*, *North Africa* and the *Middle East*. They cover all presently conceivable sources of natural gas imports for Europe with a longer time perspective. Figure 1 shows the flows of natural gas envisaged between the trading partners.

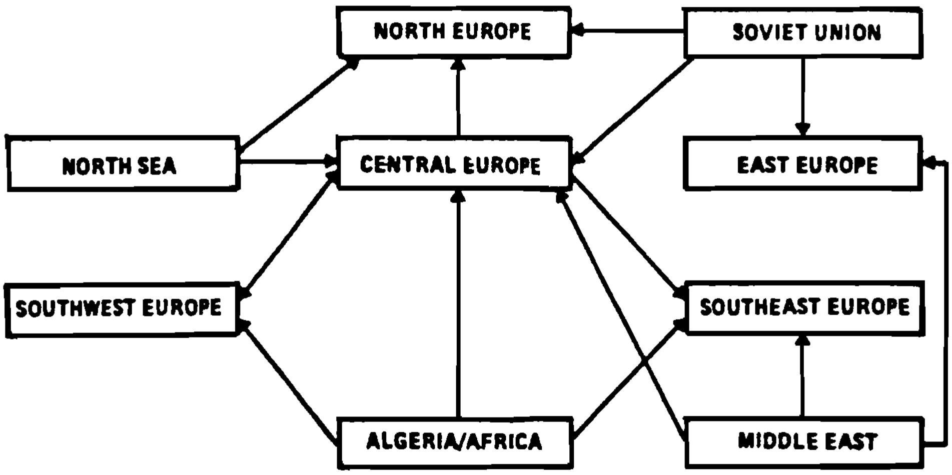

Figure 1. Possible Gas Trade Flows.

The methodological backbone of the study is a system of models which analyze the development of energy demand, production and resource depletion, and international trade. They were mainly based on the demand model MEDEE-2 (Lapillonne 1978) and the energy supply and utilization model MESSAGE II (Messner 1984, Strubegger 1984). Additional tools, like an interactive model for the analysis of gas trade options (Messner 1986), and a code to investigate the effects of various investment strategies on the production pattern of gas fields, were developed.

This paper gives a short overview on the development of the gas industry, the setup of the study and the models used, and describes the most important results obtained. A full report is in preparation and will appear in due course.

Historic Perspective

First uses of natural gas are reported from China around 900 B.C. for the production of salt and from Baku at the Caspian Sea, where gas was used at the Temple of Zarathoustra (Brecht 1984). The first reported use of natural gas in our societies was in 1821 in the United States of America (Peebles 1980). While in the US natural gas and manufactured gas industries developed in parallel, in Europe manufactured gas produced from coal paved the way for the natural gas industry.

In East Europe—here including, for statistical reasons, Tsarist Russia—commercial natural gas production started around 1915, while production in West

Europe commenced by 1945. At that time East Europe had already reached a production level of more than 5×10^9 m^3 per year. The biggest producer was, however, North America with a production of 110×10^9 m^3 in 1945 (see Table 1).

Table 1. Development of World Commercial Gas Production, 1900-1985 (10^9 m^3/yr).

	North America	Latin America	West Eur.	East* Eur.	Africa	Middle East	Asia Oceania	World
1900	6.7	-	-	-	-	-	-	6.7
1905	10.0	-	-	-	-	-	-	10.0
1910	14.6	-	-	-	-	-	-	14.6
1915	18.4	-	-	0.1	-	-	-	18.5
1920	23.4	-	-	0.2	-	-	-	23.6
1925	34.8	-	-	1.1	-	-	-	35.9
1930	56.7	0.2	-	1.9	-	-	-	58.8
1935	56.5	0.5	-	3.8	-	-	0.1	60.9
1940	74.5	1.6	-	6.2	-	-	0.2	82.5
1945	109.8	2.3	0.1	5.5	-	-	0.1	117.8
1950	170.6	3.7	0.9	9.0	-	0.1	0.3	184.6
1955	256.4	6.6	5.1	15.8	-	1.3	0.5	285.7
1960	358.6	13.0	11.9	56.7	-	2.7	3.6	446.5
1965	464.4	24.5	19.2	148.2	1.9	4.5	15.9	678.6
1970	651.8	34.5	78.5	234.5	3.4	19.5	25.4	1047.6
1975	619.7	43.7	171.4	341.9	12.5	37.6	46.0	1272.8
1980	624.4	65.5	195.6	490.8	27.2	44.9	80.6	1529.0
1984	565.7	77.5	185.2	653.4	47.6	57.4	107.2	1679.4
1984	552.4	76.6	192.1	709.0	52.9	67.5	119.6	1770.1

Source: Valais et al. 1982, Cedigaz 1985, PE 8/86.
*Includes Russia and later the Soviet Union.

East European extraction of gas has been growing ever since the end of World War II, reaching a share of 33% of world production in 1980. West European production got its first push after the discovery of the large and cheap Groningen gas field in 1959, the second one by the extraction of North Sea oil and the associated gas. Production of oil and gas in the North Sea became economic after the two oil price increases in 1973 and 1979, while the present slump in oil prices endangers many projects in the North Sea. A prerequisite for the exploitation of the Dutch Groningen field was the initiation of international trade of natural gas to be able to utilize the high production capacity. The first importer was the FRG in 1963, followed by Belgium (1966), France and Luxembourg (1967).

The Soviet Union started its natural gas exports by delivering gas to Poland already in 1946—a situation that was due to the change in the national territories after World War II. When constructing the Bratstvo pipeline for export to Western Europe, the Soviet Union also started to export gas to Czechoslovakia (1967). West European imports of Soviet gas started in 1968 to Austria, only in 1973 the FRG and later on Finland, Italy and France followed. In 1984 Western Europe imported 33×10^9 m^3—28% of the total gas imports—from the Soviet Union (Cedigaz 1985).

Already before the Soviet Union entered the West European gas market, Algeria started to export LNG to the United Kingdom and France. These deliveries, the world's first commercial LNG shipments, started in 1964 to the UK and in 1965 to France. Later on, LNG was also exported to Belgium, Spain and Italy. In 1981 a pipeline through the Mediterranean Sea, connecting Algeria with the European gas market (the Trans Mediterranean pipeline), was finished.

The newest actor on the European gas scene is Norway which has started oil production in the North Sea in the early 1970s and entered the gas market in 1977, when the transport of associated gas from the Ekofisk field to Emden, FRG, began. At the same time the gas field Frigg, 60.82% of which belong to Norway and 39.18% to the UK, came on stream and supplies gas to the UK via St. Fergus. In 1984 Norway produced 26 billion m^3 gas or 11% of the gas used in Western Europe (22% of the imports of this region).

Due to the high capital intensity and physically fix structure of gas transport equipment, trade with natural gas is rather bilateral than international. On the West European side usually a consortium of buyers, lead by Ruhrgas of the FRG, negotiates with the counterparts from the exporting countries (Statoil from Norway, Sonatrach from Algeria, Soyuzgazexport from the USSR and Gasunie from the Netherlands). The latest contract was signed between the Norwegians and the European Consortium on the import of 450×10^9 m^3 of gas from the North Sea fields Sleipner and Troll over 27 years, according to which deliveries will start in 1993 (*Petroleum Economist* 7/86).

The Resource Base

Presently the Soviet Union holds 39% of the world's proven reserves of natural gas, while the share of all West European countries together is 6% (Cedigaz 1985). Since 1970 world proven reserves have grown at an annual average rate of 6% (see Table 2). The biggest increase of roughly 25 trillion m^3 is to be attributed to the Soviet Union, the Middle East gained some 19 trillion m^3 since 1970. The only region of the world with declining reserves is the US—a fact which could partly reflect the regulatory policies of setting low well-head prices which slow down exploration.

Table 2. Development of World Proven Gas Reserves, 1940-1986 (10^{12} m^3) and Shares.

	North America	Latin America	West Eur.	East Eur.	Africa	Middle East	Asia Oceania	World
				Total				
1940	2.6	0.2	0.0	0.0	0.0	0.5	0.2	3.5
1950	5.3	0.7	0.1	0.1	0.0	1.8	0.5	8.5
1960	8.1	1.4	0.3	1.8	0.6	4.4	0.5	17.0
1965	9.2	1.7	1.5	3.1	1.9	5.8	0.9	24.2
1970	9.4	1.9	3.6	12.6	3.8	6.8	1.5	39.6
1975	8.5	2.4	4.0	24.3	5.2	15.5	3.4	63.3
1980	8.0	4.4	3.9	31.6	5.7	18.7	4.8	77.0
1984	8.3	5.3	5.4	36.6	5.9	22.4	6.4	90.4
1985	8.3	5.5	5.6	38.1	5.9	25.6	7.2	96.2
1986	8.1	5.5	5.4	39.1	5.9	26.2	7.5	97.7
				Shares				
1940	74.3	5.7	0.0	0.0	0.0	14.3	5.7	100.0
1950	62.4	8.2	1.2	1.2	0.0	21.2	5.9	100.0
1960	47.6	8.2	1.8	10.6	3.5	25.9	2.9	100.0
1965	38.0	7.0	6.2	12.8	7.9	24.0	3.7	100.0
1970	23.8	4.7	9.0	31.8	9.7	17.1	3.9	100.0
1975	13.5	3.7	6.3	38.4	8.3	24.5	5.3	100.0
1980	10.4	5.7	5.0	41.0	7.4	24.3	6.2	100.0
1984	9.2	5.9	6.0	40.5	6.6	24.8	7.1	100.0
1985	8.7	5.7	5.8	39.6	6.1	26.6	7.5	100.0
1986	8.3	5.7	5.5	40.0	6.1	26.8	7.5	100.0

Source: Valais et al. 1982, Cedigaz 1985, PE 8/86.

But also the Soviet Union, despite the numerically very high resource base, faces a complex situation. Most of the newer gas finds are located in the Asian part of the country, far away from potential consumers. Table 3 shows the development of the distribution of USSR's gas reserves over the period 1955 to 1985. While in 1955 more than 90% of the known reserves were relatively near to the consumption centers in the European part of the country, the situation is reversed in 1985. Presently only 13% of the known reserves are in Europe, the rest is located in Asia in climatically unfavorable and geographically remote areas.

The distribution of gas resources among the nations in both East and West Europe stresses the necessity of natural gas trade. While in East Europe the Soviet Union owns basically all natural gas reserves (1.1.85: 98.5%, see Table 4), in Western Europe three countries have a considerable potential: The Netherlands (35%), the United Kingdom (13%) and Norway (40%). The United Kingdom with a

Table 3. Natural Gas Reserves (A+B+C1) of the Soviet Union (10^9 m^3).

	Europe	Asia	Whole USSR
1955	642	50	692
1965	1803	1763	3566
1975	4200	21600	25800
1980	4570	28520	33090
1985	6080	42050	48130

Source: Stern (1984) and Databook: Natural Gas and Condensate Deposits, 1983 (updated).

Table 4. Development of Proven Gas Reserves in Selected Regions, 1960 - 1986 (10^9 m^3).

	Nether-lands	United Kingdom	Nor-way	Alge-ria	Soviet Union	Middle East
1960	10	-	-	600	1700	4360
1965	1100	-	-	1700	2786	5830
1970	2042	850	-	2875	9300	6790
1975	1963	762	550	2840	19820	15570
1980	1626	754	828	3700	25750	18690
1985	1890	725	2236	3087	37500	25609
1986	1855	648	2228	3030	38500	26150

Source: Valais et al. 1982, Cedigaz 1985, PE 8/86.

reserve to production ratio (R/P) of 16 years in 1984 does not plan to export natural gas, it rather imports North Sea gas from Norway. The Netherlands with a R/P ratio of 25 years and nearly stable reserves since 1970 are starting to handle their resources with growing caution. Norway has, within Europe, by far the largest resource base. These gas resources do, however, lie to a large extent far up in the North Sea and are costly to exploit. This leads to similar problems as incurred with long distance gas transport: the share of investments in total gas production costs is unfavorably high (77% for North Sea oil and gas according to Lorentsen et al. 1984).

Algerian reserves started to decline around 1980. This situation could be the result of the political and economic targets of the country at that time. Algeria tried to enforce oil price parity in the price of gas exports, which resulted in lower takes from the importing countries. Lately, specially with the falling oil price, the Algerian position seems to adapt to reality.

Besides the present exporters to Europe, also the large dry gas reserves in the Middle East, specially in Iran (proven reserves beginning of 1986: $13.9 \times 10^{12} m^3$) and Quatar ($4.4 \times 10^{12} m^3$), could be used for export to Europe, either as LNG or via a pipeline through Turkey. Even conversion to other liquid products like methanol or middle distillates seems feasible. The proven reserves in this region are, although hardly any prospective efforts are undertaken, growing fast and are in the same order of magnitude as in the Soviet Union.

The Status Quo

Table 5 summarizes reserves, domestic production and consumption for the countries considered, grouped according to the aggregation used in the IIASA Gas Study. Proven gas reserves are, as already mentioned, distributed very unevenly among the nations. But also the degree of gas utilization varies considerably.

Some countries, like Turkey and Sweden, did not use any natural gas in 1984. However, Sweden started to import gas from Denmark in the summer of 1985, and Turkey just signed a contract with the Soviet Union to buy up to $6 \times 10^9 m^3$ of gas per year starting in 1987. It will be transported via a pipeline from the Soviet Union through Bulgaria, across Thrace and the Sea of Marmara to Gemlik and Ankara (PE 3/86). The largest users of natural gas are the Netherlands with a gas share in primary energy use of 47% and the United Kingdom with 24% in 1984. Both belong to the nations with relatively large reserves, but only the Netherlands are self-sufficient in gas supply.

In East Europe Romania has the largest resource base in terms of both liquid and gaseous hydrocarbons. In comparison, however, the gas reserves are only in the same range as the reserves of the FRG. All East European countries depend on gas imports from the Soviet Union.

For the aggregated regions of West Europe, Table 6 gives the overall energy consumption mix for 1984. The dependence on oil varies between 38% for the northern countries and 58% for South West Europe. There are only a few nations where oil is not the single most important source of energy, namely Norway with 70% hydropower, the Netherlands with 47% gas, and Yugoslavia with 35% coal in the energy supply mix.

On the average, natural gas supplies 15.6% of the primary energy consumed. In the region North Europe, Finland was the only consumer of gas in 1984. Therefore the average share of gas was below 1%, while in central Europe only Belgium

Table 5. Some Characteristic Figures for Natural Gas in the Nations of Europe, 1984 (10^9 m^3).

	Proven Reserves 1.1.85	Marketed Production 1984	Domestic Consumption 1984	Net Imports 1984
North Europe				
Finland	0	0.00	0.77	0.77
Norway	2236	27.28	1.04	-26.24
Sweden	0	0.00	0.00	0.00
Total	2236	27.28	1.81	-25.47
Central Europe				
Austria	18	1.27	5.34	4.07
Belgium-Lux.	0	0.00	9.30	9.30
Denmark	100	0.32	0.62	0.30
FRG	191	18.57	54.00	35.43
France	40	6.26	28.88	22.62
Ireland	32	2.34	2.34	0.00
Netherlands	1890	75.14	40.81	-34.33
Switzerland	0	0.00	1.60	1.60
UK	725	40.16	53.76	13.60
Total	2996	144.06	196.65	52.59
South East Europe				
Greece	3	0.06	0.06	0.00
Italy	250	13.62	32.82	19.20
Turkey	35	0.00	0.00	0.00
Yugoslavia	88	2.05	5.67	3.62
Total	376	15.73	38.55	22.82
South West Europe				
Portugal	0	0.00	0.00	0.00
Spain	26	0.17	2.18	2.01
Total	26	0.17	2.18	2.01
East Europe				
Bulgaria	5	0.10	5.15	5.05
Czechoslovakia	10	0.74	10.30	9.56
GDR	115	12.37	19.02	6.65
Hungary	120	6.90	11.15	4.25
Poland	110	6.00	11.70	5.70
Romania	210	37.90	39.50	1.60
Total	570	64.01	96.82	32.81
West Europe	5634	187.24	239.19	51.95
Total Europe	6204	251.25	336.01	84.76

Source: Cedigaz 1985.

Note: For the model calibration, specially for East Europe, other statistical bases were included, resulting in different figures for consumption and production.

Table 6. Primary Energy Consumption in West Europe, 1984 (10^{18} J) and Shares.

	Oil	Gas	Coal	Hydro	Nuclear	Total
Primary Energy						
North	1.61	0.03	0.25	1.51	0.51	3.91
Central	16.62	7.00	8.21	1.36	3.20	36.40
South East	5.73	1.37	2.14	0.85	0.14	10.23
South West	2.39	0.11	0.89	0.40	0.22	4.01
West Europe	26.35	8.51	11.49	4.12	4.06	54.54
Shares per Region						
North	41.22	0.80	6.30	38.57	13.12	100.00
Central	45.67	19.25	22.55	3.74	8.79	100.00
South East	56.07	13.35	20.97	8.28	1.33	100.00
South West	59.56	2.68	22.24	10.09	5.43	100.00
West Europe	48.32	15.60	21.07	7.55	7.45	100.00
Shares per Energy Carrier						
North	6.11	0.37	2.14	36.60	12.62	7.17
Central	63.08	82.33	71.45	33.02	78.68	66.74
South East	21.76	16.04	18.66	20.57	3.35	18.75
South West	9.05	1.26	7.75	9.81	5.35	7.34
West Europe	100.00	100.00	100.00	100.00	100.00	100.00

Source: British Petroleum 1985.

Note: Hydro and nuclear are given as primary energy equivalent, calculated with an efficiency of 37%.

and Switzerland supplied less than 15% with gas in 1984. Hydropower provides roughly the same amount as nuclear energy, mainly because of the large potential in North Europe—37% of hydroelectricity is produced in North Europe, while 79% of the nuclear electricity comes from Central Europe (37% from France alone).

The Determinants of Gas Consumption

The role of natural gas in the future can, as with any other energy carrier, only be assessed using a systems wide approach. It is influenced by the overall energy consumption of the society and the relative competitiveness and availability. Total energy use is primarily determined by the size of the population and the economic activity in the region. They influence private and industrial/commercial consumption of energy.

Energy Demand

The projections of population growth were taken from Keyfitz and Just (1982), while the development of the gross domestic product (GDP) represents a continuation of the present sluggish performance well into the 1990s, a revitalization of economic development thereafter, followed by a slow-down later next century. Additionally, a differentiation in economic development from North to South was assumed, with the Southern countries showing a more dynamic development. Table 7 gives the aggregate figures for population and economic activity for the years 1985, 2000 and 2030 for the regions considered. Analyses of industrial structural change, energy intensiveness in the industrial branches, development of specific space heat requirements and energy conservation measures lead to a scenario about the future energy requirements of industry, households, the service sectors and transport.

Table 7. European Regional Development of GDP and Population, 1985 to 2030.

	1985	2000	2030
Population [*million*]			
North	17	18	18
Central	222	232	242
South East	142	162	190
South West	50	56	64
East	113	120	129
GDP [10^9*US$'*80]			
North	233	313	519
Central	2732	3786	6858
South East	606	878	2010
South West	253	372	759
East	545	778	1633

The framework used for the construction of the regional demand scenarios is MEDEE-2 (Lapillonne 1978). This model requires information on specific energy use for various processes, like passenger or freight transport, steel production, space and process heat production. Additionally, MEDEE-2 considers structural changes between important industrial sectors and behavioral factors like the load factor of cars, the distance driven per person per year, or the size and insulation level of newly-built housing stock. This information is combined with the general assumptions regarding population and economic activity to give a picture of the demand development, disaggregated into specific electricity and liquid fuels, useful thermal heat in three temperature ranges, and space and water heat. These demands serve as import to the supply model.

Energy Supply

For the analysis of energy supply a techno-economic approach was taken. A dynamic linear programming model was used to minimize the overall cost of supplying useful energy under technical, economic and ecological considerations and constraints. This model depicts the whole energy supply chain from domestic extraction and imports via transport and conversion to distribution and consumption of final energy.

In the present application special emphasis was given to the economics of gas use that varies with consumption density and distance to the main line due to the capital intensive transport. The competition with district heat on the space heating market, different economics for different industrial applications and technological improvements like high-efficient combined cycles and, as a representative of qualitatively new technologies, heat pumps were taken into account. The energy supply model derives a supply strategy for given energy import prices. Sensitivity analyses on the oil price development and the gas and coal prices in relation were undertaken, as well as investigations of the effects of lower emissions in the whole regions on the energy system and the related costs, or a ban on nuclear energy.

On the basis of the structure of primary energy supply in the European regions, the international supply of gas is determined. This requires considerations on supply security, resource bases and extraction costs of the exporters, investment necessities and transport infrastructure. Table 8 shows the natural gas and oil resources considered for the major European producers. Based on the distribution of known gas fields, historic development of known reserves and expectations about finding rates, the ultimately recoverable resources—distributed to cost categories—were estimated*. Similar estimates were derived for all regions and all energy sources considered.

For the Soviet Union, Table 9 shows the distribution of the resources (proven plus probable in known fields) over the depth. Presently, most of the reserves are in depths between 1.1 and 3 km. This is certainly related to drilling technology and experience. Recently the USSR launched a deep drilling programme, expressing the trust that major new oil or gas fields will be discovered in deeper strata than currently explored. This, and intensified exploration in yet untouched areas will almost certainly lead to increases in the USSR's gas reserves. The distribution of

* For Norway, the estimate could be higher, but the model results would be influenced only marginally due to the already now high proven reserves.

Table 8. Natural Gas Resources and Extraction Costs Considered for the Major Producers of Western Europe.

	Category	Extraction Cost [US$/1000 m^3]	Resource [10^9 m^3]
Norway	Frigg etc.	26.2	370
	Sleipner etc.	48.2	385
	Troll etc.	89.6	1154
	North of 62nd	141.4	1538
United Kingdom	Proven southern North Sea	18.5	585
	Proven northern North Sea	40.6	692
	Additional southern North Sea	60.0	846
	Additional northern North Sea	129.0	1538
Netherlands	Groningen	10.9	1422
	Additional Onshore	20.2	248
	Proven Offshore	16.0	338
	Additional Offshore	52.8	808

Table 9. Reserves of Natural Gas as of 1986-01-01, USSR (billion m^3).

	Depth [km]				
	< 1.1	1.1-3.	3.-5.	>5.	Total
USSR (total)	11040	28900	7890	300	48130
European Part	250	3800	1740	290	6080
Asian Part	10790	25100	6150	10	42050

Source: Data Book: Natural Gas and Condensate Deposits, 1983 (updated).

the resources to depth, together with field sizes and investment strategies over the life of the fields that lead to the required production profile, are used as indicator for the investment costs for gas extraction.

The Base Case

Based on the demand development, domestic resource availability and a scenario on the future development of the oil prices, which was developed by Dr. A. Papin at the Siberian Energy Institute (SEI)* on the basis of the IIASA '83 Scenario (Rogner 1984), the Base Case gives a picture of the European energy supply in a surprise-free future.

* This price would, from a level of 15$/bbl, increase at an annual average rate of 2%.

Western Europe

Primary energy consumption in West Europe would stagnate until 1990, and thereafter resume growth at a rate below 1% per year, reaching 60 EJ in 2000 and 75 EJ in 2030. Nuclear energy would expand from presently 7% of primary energy to 12% in 2000 and 18% in 2030, some 230 GW(e) (see Figure 2). Hydroelectricity would grow slowly, just keeping its share roughly constant at 7%, while the use of oil (52% in 1980) would decline to 37% in 2000 and 25% in 2030. The market of natural gas grows by 40% up to 2000, from 8.5 EJ in 1984 to 12 EJ in 2000. By 2030 gas consumption doubles, reaching 16.4 EJ and constituting 22% of primary energy. The use of coal does also show considerable growth. However, percentage wise it stagnates around 21% of primary energy until 2010 and reaches 22.7% by 2030.

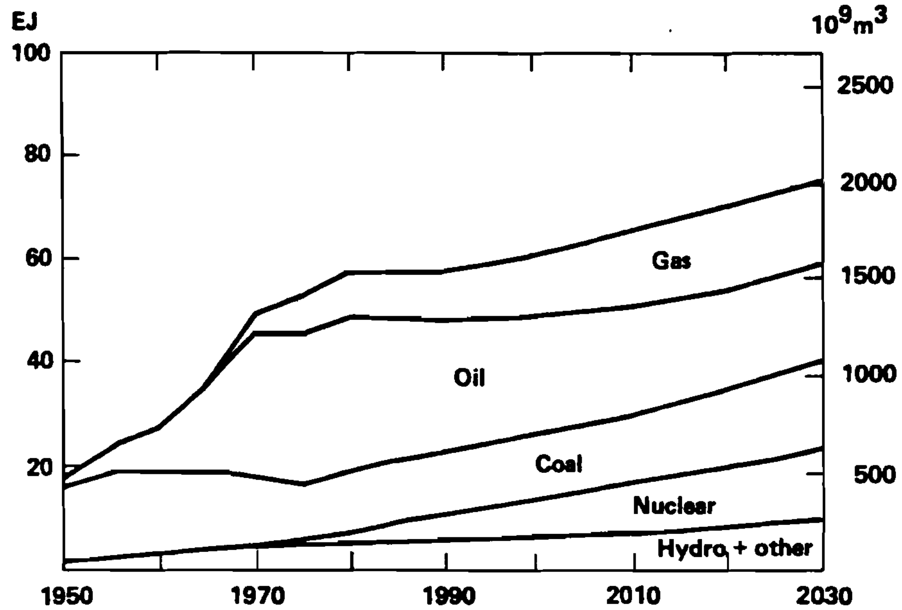

Figure 2. Primary Energy Consumption in Western Europe, Base Case, 1950-2030.

Table 10 shows the structure of primary energy consumption on a regional basis. For all regions an increase in diversification and thus higher resilience of energy supply is noticeable. By 2030, the highest share of a single source of energy is hydropower with 32% in north Europe. All other sources of energy in the north and all sources in the other regions contribute less than 30% of primary energy in 2030.

The development of final energy use is rather stable. Up to 2000, the use of coal is constant, while oil products are substituted by gas. The growth in consumption is basically supplied (or created) by electricity and some district heat.

Table 10. Base Case: Primary Energy Consumption in the Regions of Western Europe, 1990 to 2030, in Shares and Total (10^{18} J).

	Hydro	Nuclear	Coal	Oil	Gas	Other	Total
Western Europe							
1990	7.69	8.80	20.59	43.62	17.61	1.70	57.84
2000	7.62	12.27	21.23	36.82	19.61	2.44	60.78
2030	7.11	17.68	22.65	24.78	21.74	6.04	75.47
North Europe							
1990	32.66	13.61	17.79	32.32	3.36	0.26	4.69
2000	32.51	15.27	21.23	25.22	5.30	0.47	4.71
2030	32.27	20.40	16.60	17.77	7.20	5.76	4.75
Central Europe							
1990	3.72	10.48	21.21	42.85	20.69	1.05	37.68
2000	3.69	13.58	21.06	37.88	22.29	1.49	38.01
2030	3.57	20.64	21.10	27.05	25.51	2.13	40.94
South East Europe							
1990	9.52	2.20	19.61	45.93	17.84	4.90	11.29
2000	8.70	7.81	19.78	34.87	22.55	6.31	13.13
2030	7.26	12.80	26.12	19.31	21.33	13.18	22.16
South West Europe							
1990	24.91	14.38	35.60	11.58	12.49	1.04	1.76
2000	18.71	18.58	29.07	23.52	7.94	2.18	2.97
2030	13.24	18.94	29.84	13.87	15.62	8.49	5.75

In 2000 gas supplies 20% of final energy (presently 15%), by 2030 the market grows by only 1% to 21% of final energy. The structure of the gas market can be seen in Figure 3. The low growth of gas used as final energy carrier after 2000 can be attributed to the introduction of new, energy saving technologies—here represented by heat pumps. The major growth of gas consumption does also come from a new technique, the introduction of highly efficient combined cycle turbines, representing 25% and 33% (130×10^9 m^3) of the gas market by 2000 and 2030, respectively.

Overall energy imports can be nearly stabilized up to 2000, thereafter they grow at roughly 1% per year. Oil imports decline to 17 EJ by 2000, while imports of gas grow from slightly above 100×10^9 m^3 in 1984 to 200×10^9 m^3 in 2000. The further growth of gas imports, which is, as mentioned above, induced by gas-fired electricity generation and, eventually, co-generation of electricity and heat, leads to imports in the range of 300×10^9 m^3 after 2010 and 350×10^9 m^3 by 2030. But also the supply of sufficient coal has to be secured by considerable imports. By 2030, 55% of the coal used has to be imported. It should be noted that there is sufficient coal available in Western Europe. However, due to high production costs and the high sulfur content it is, from an economic and environmental viewpoint, preferable to import coal.

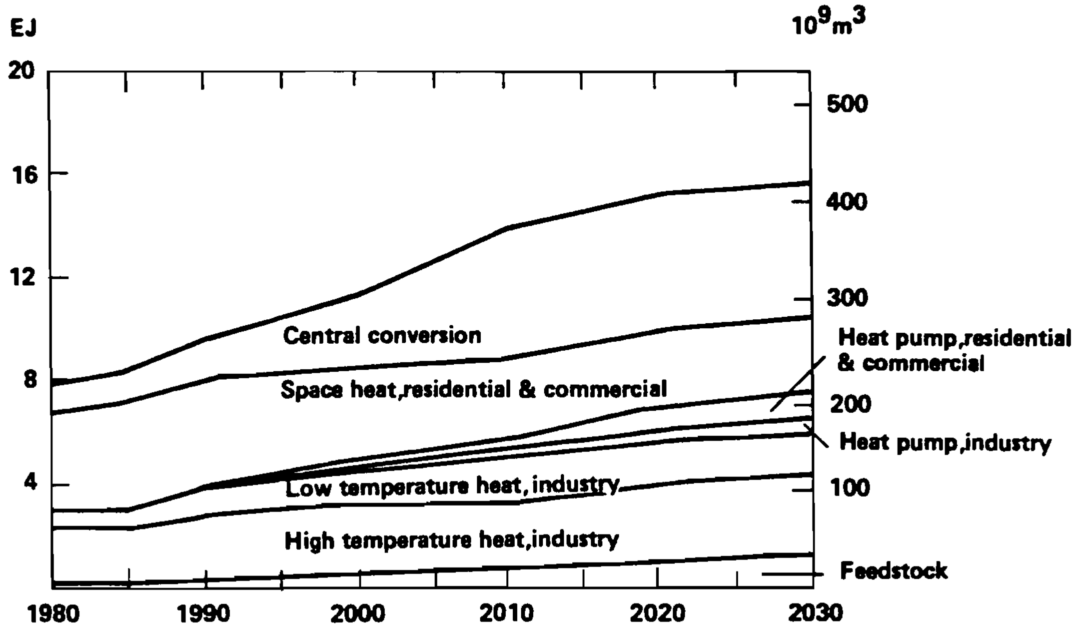

Figure 3. Uses of Natural Gas in Western Europe, Base Case, 1980-2030.

Domestic supply of natural gas is secured mainly by the Netherlands and the United Kingdom. A crucial assumption in this respect is the amount of natural gas recoverable in the UK continental shelf. The real development will be heavily influenced by the incentives given for exploration by the tax regime and other government measures.

The extraction profile envisaged for the UK under the conditions outlined for the Base Case—specially the price development—is shown in Figure 4. Supplies from the presently proven fields will, after a peak around 1995, decline drastically. Gas production in the Netherlands will, after a steady decline, level out around 35×10^9 m^3, the domestic consumption level (Figure 5).

East Europe

The East European situation differs substantially from Western Europe in the present supply mix. More than 50% of primary energy is supplied from—mostly domestic—coal (see Figure 6). It will not be possible to maintain this high share of domestic coal, since extraction is reaching its limits. Of the 11.9 EJ of coal foreseen for 2030 roughly 2.8 EJ are imported.

The use of oil could be reduced slightly, while gas use can, due to the necessity to build up new infrastructures, be increased only slightly by 2000. Thereafter the growth potential is larger, with an annual average growth of 2.2%

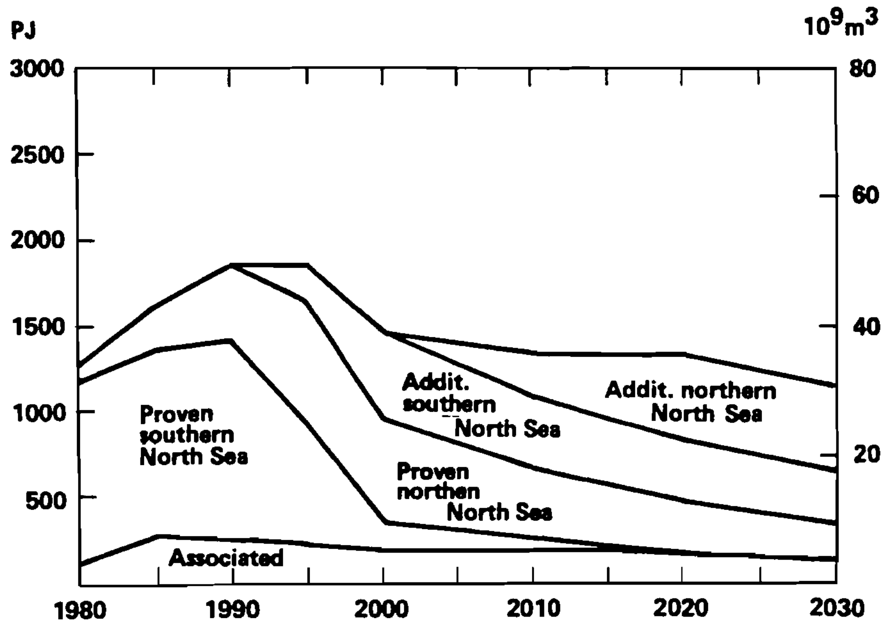

Figure 4: Natural Gas Extraction in the United Kingdom, Base Case, 1980-2030.

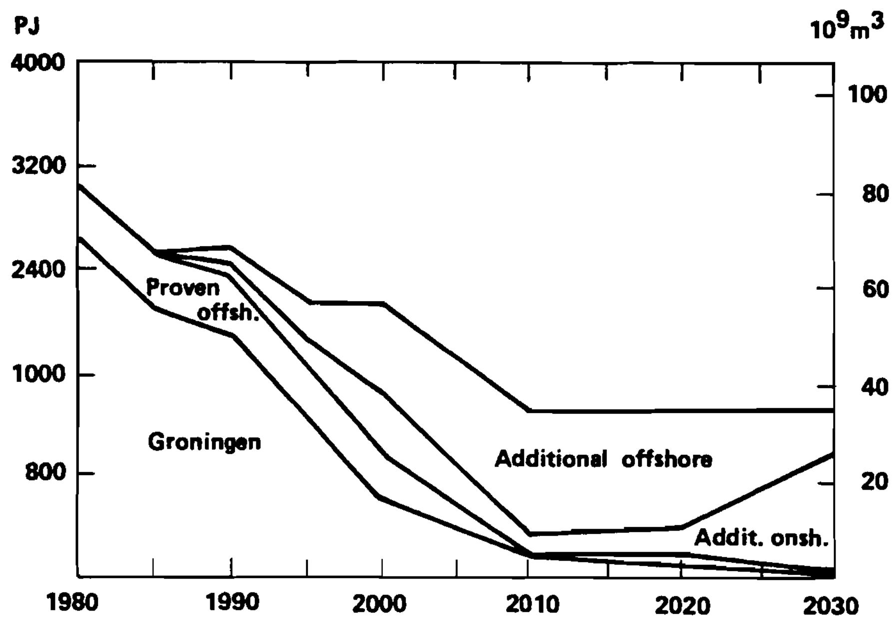

Figure 5: Natural Gas Extraction in the Netherlands, Base Case, 1980-2030.

between 2000 and 2030, supplying 20% of primary energy then. Nuclear energy would supply 8% in 2000 and 21% in 2030.

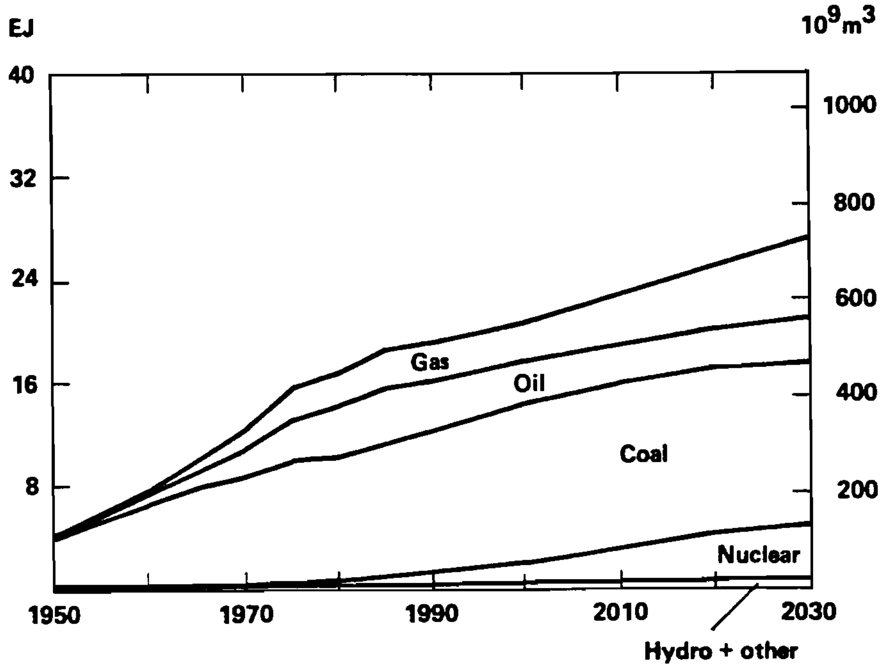

Figure 6. Primary Energy Consumption in East Europe, Base Case, 1950-2030.

The supply of liquid fuels would, after 2000, be secured by the conversion of coal to methanol. This implies the build-up of capital intensive processes to decrease foreign currency expenditures (or export of equivalent goods) for energy imports. By 2030 14% of the liquid fuels consumed would be derived from coal.

Import requirements, at present basically oil, would increase from 25% of primary energy use to 27% in 2000 and 41% in 2030. At that time 44% of the energy imports would be in the form of gas and 25% or nearly 200 million tons of coal equivalent per year in the form of coal.

Gas Exporters

The Netherlands will, as already mentioned, supply declining amounts of gas to the customers and stabilize production at the level of domestic consumption around 2010. By this time the cheap Groningen field will—optimizing discounted gains from exports minus extraction costs and disregarding other considerations—be nearly completely exploited.

Norway would, by 1990, produce 8 $\times 10^9$ m^3 per year from Sleipner and similar fields, reaching a peak of 13 $\times 10^9$ m^3/yr by 2000 (see Figure 7). In 2000, Troll would already supply 10 $\times 10^9$ m^3 per year to the European market. The overall Norwegian production in this year would be 42 $\times 10^9$ m^3, 13% of the gas consumed in Western Europe in this year. Including the expensive gas from north of the 62nd parallel, Norwegian gas production would reach 47 $\times 10^9$ m^3 in 2030 (10% of the West European market).

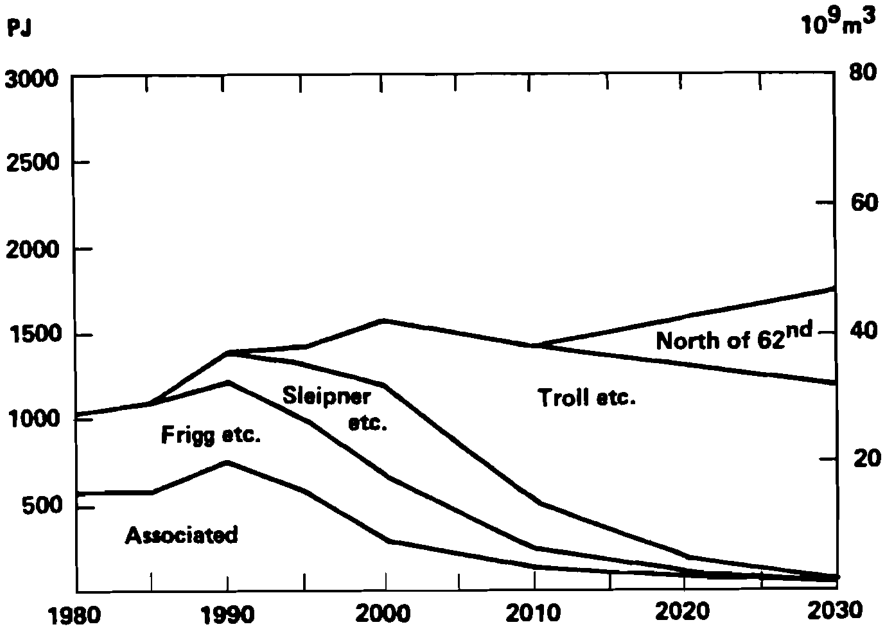

Figure 7. Natural Gas Extraction in Norway, Base Case, 1980-2030.

The resulting net gas import requirements of Western Europe amounts to 73 $\times 10^9$ m^3 in 1990, 137 in 2000 and 295 in 2030 (see Table 11). Assuming that a maximum of one third of the imports can come from a single source, in 1990 48 $\times 10^9$ m^3 could come from the Soviet Union, the rest from North Africa. For 2000 the Figures would be 67 and 69 $\times 10^9$ m^3. Applying the rule also to North Africa would leave another 2 $\times 10^9$ m^3 to other suppliers, e.g., the Middle East.

In 2030 the maximum for a single supplier would be 114 $\times 10^9$ m^3 and would apply to both regions, the Soviet Union and North Africa, leaving 67 $\times 10^9$ m^3 for other suppliers. Up to 2000 these supply figures seem technically and resource-wise feasible. Including exports of 60 to 65 m^3 to East Europe and a domestic consumption of 740 to 840 m^3 for the Soviet Union, the total production would have to reach 890 to 1000 m^3 (Main Directions, 1986). It is possible to sustain the production level with present proven reserves for twenty years after 2000. However, there is evidence that the proven reserves of the USSR will increase considerably

Table 11: Possible Development of Consumption and Supply of Natural Gas, 1990 to 2030 (10^9 m^3).

	1990	2000	2030
Gas Consumption			
Western Europe	273.0	320.0	440.0
East Europe	68.2	76.5	146.4
Soviet Union	609.3	766.5	732.7
Gas Production			
Western Europe	44.3	44.8	32.8
Netherlands	68.5	57.5	35.0
United Kingdom	49.8	39.0	30.8
Norway	37.4	42.2	46.7
Total Western Europe	200.0	183.5	145.3
East Europe	19.9	14.1	14.2
Net Demand			
Western Europe	73.0	136.5	294.7
East Europe	48.3	62.4	132.2
30% Rule for Gas Imports			
Soviet Union to Western Europe	48.0	67.1	113.8
North Africa to Western Europe	25.0	67.1	113.8
Middle East to Western Europe	0.0	2.4	67.1
Production Soviet Union	705.5	896.0	978.7
30% Rule for Total Gas Consumption			
Soviet Union to Western Europe	73.0	106.7	146.7
North Africa to Western Europe	0.0	29.8	146.7
Middle East to Western Europe	0.0	0.0	1.4
Production Soviet Union	730.5	935.6	1011.6

over time, making a ceiling of 1100×10^9 m^3 or even more feasible even over an extended period of time.

Exports from North Africa at a level of 67×10^9 m^3, as foreseen for 2000 could, alone by Algeria, be sustained for 47 years. On this basis a production of 114×10^9 m^3, as indicated for 2030, seems unlikely under present conditions. The Middle East as source, with proven reserves of 25600×10^9 m^3 and a low probability of a high level of domestic gas consumption, is a virtually infinite source of natural gas. Problems related to this source are the very long distance to be covered and the fact that this region also supplies a large share of the oil imports. For economic reasons it is conceivable that gas from the Middle East is rather exported as liquid fuel, e.g., converted to methanol, than in the form of gas (Strubegger and Messner 1986).

Another interpretation of the 30% rule would allow imports from a single source up to one third of total gas consumption. Under this condition, the gas production of the Soviet Union would reach roughly 935×10^9 m^3 by 2000, still below the target. The production in 2030 would be 1012×10^9 m^3, which would be a feasible production path if the existing resources are upgraded by some 5 to 10%.

The gas consumption figures for the Soviet Union are based on the assumption that total energy use would grow by 2% per year between 1985 and 2000, and by 1.3% per year thereafter. Compared to historic growth rates (1950 to 1970: 11.6% per year, 1970 to 1980: 5.7% per year, 1981 to 1985: slightly below 3% per year), these low growth rates can be considered fairly realistic. Recent changes in the setting of economic targets, like the change from quantity to quality in the measurement of production, allow optimism in this respect.

Present trends in the energy consumption of the USSR show a strong tendency to substitute coal and fueloil by natural gas. By the end of the century this substitution will mainly take place in industrial energy use, the fields of electricity generation and district heating, and to some extent in the use of energy sources for non-energetic purposes (e.g., as chemical feedstock). Similar trends are expected for the period from 2000 to 2030, with some changes in scale and directions. The design of the energy consumption scenario for the USSR after 2000 is based on the following assumptions:

- small and medium-scale heating, feedstocks and other non-fuel consumers of primary energy sources will remain important and consume fossil energy;
- increases of energy demand in the fields mentioned above will be covered by natural gas, with the exception of small consumers in remote areas which will be supplied by solids, liquids or electricity;
- the strong trend to use natural gas for district heating will be complemented by the possibility to supply medium temperature industrial heat from *combined cycle co-generation* units; and
- despite the increasing growth of nuclear power generation capacities, electricity generation will still rely heavily on fossil fuels; only the oil products will be substituted by natural gas, and later on by coal (in central Siberia and other areas with cheap local coal resources).

The above assumptions are reported to be the key trends in the national energy development in the Soviet literature (e.g., Energy Complex, 1983).

Following these assumptions gas use would, in our scenario, increase from presently (1985) 32% of primary energy to 38% in 2000, mainly substituting oil products, which would decline from 36% in 1980 and 32% in 1985 to 19.6% in 2000. Until 2030 oil consumption would further decrease from 7-9 EJ or 6-8% of primary energy use. The share of natural gas would also decline again from 24-27%. The major suppliers would then be nuclear energy and coal with 30% and 36% of primary energy, respectively. Roughly 33 EJ of thermal energy from nuclear sources would be used for heating, process heat and electricity generation. The use of coal would be around 40 EJ (1370 tce), nearly 2.8 times the amount used in 1980 (see Figure 8).

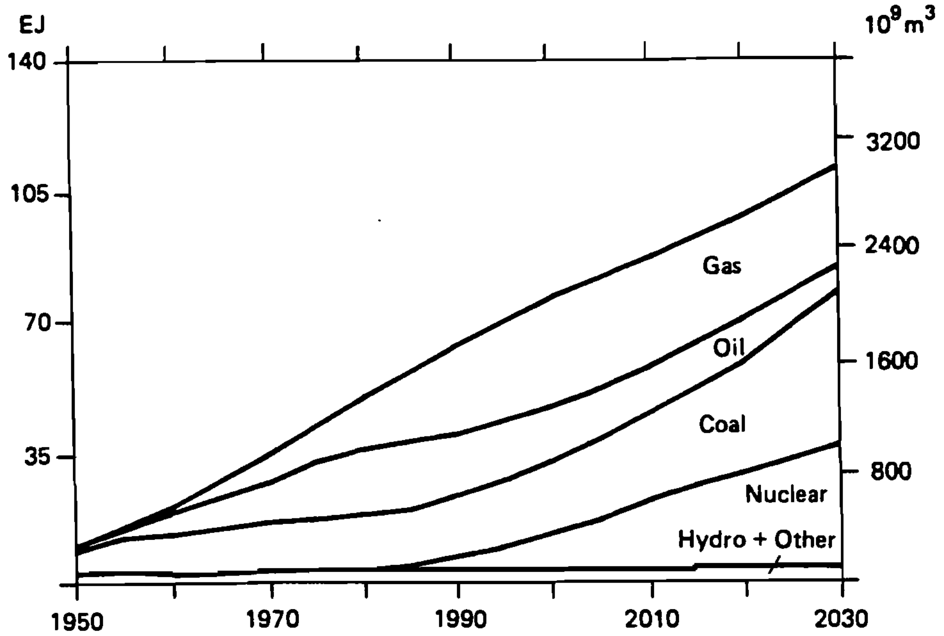

Figure 8. Primary Energy Consumption in the Soviet Union, Base Case, 1950-2030.

Compared to other studies, the assumptions for the supply of nuclear energy and coal are not unrealistic. In a scenario developed by Sinyak (1984), the growth rates for nuclear energy up to 2000 are in the same range: nuclear thermal energy supply increases from roughly 1.5 EJ in 1985 to 8-10 EJ thermal nuclear energy in 2000. Even more optimistic are Sinyak's assumptions on the production of coal, which will reach up to 58 EJ by 2030. These high coal production and consumption levels could be reached by large projects devoted to the large-scale development of such enormous coal basins as Kuznetsk and Kansk-Achinsk. Along with conventional coal technology, allothermal processes for the conversion of coal to liquids, which would be based on heat from high temperature reactors, are under investigation. If these plans materialize, more coal could be available and utilized domestically, either increasing the domestic consumption or setting more energy free for export.

Concerning the level of internal natural gas consumption in the USSR, there are good prospects for its stabilization at a level of 750 to 800 m^3 per year over the period 2000 to 2030. The main reasons for this constant natural gas consumption level are the fast growth of nuclear and coal production (including coal conversion) and the completion of the oil-to-gas substitution process by the year 2000. An extreme option would be the enhanced switch of internal consumption to nuclear and coal in order to increase the gas export potential. If efforts in this direction succeed, the export potential of gas after 2000 could be in the range of 250 to 400 $\times 10^9 m^3$ per year.

Lower Oil Prices

Following recent developments on the international oil markets, investigations on the long-term effects of lower oil and, consequently gas and coal, import prices were undertaken. All these prices were maintained at the low level of 1985/86 for the whole time horizon. The effect up to the year 2000 would be relatively small. Compared to the Base Case the use of coal is reduced by 10% (1.2 EJ), oil consumption increases by 5.7% (or 0.92 EJ) (see Figure 9). The use of gas is by $7 \times 10^9 m^3$ (0.3 EJ) higher than in the Base Case.

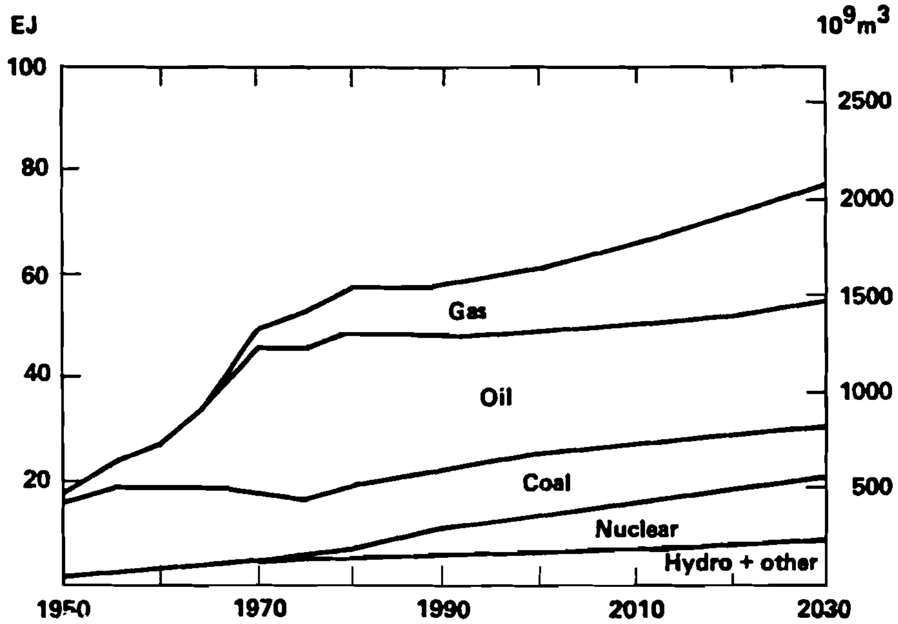

Figure 9. Primary Energy Consumption in Western Europe, Low Oil Prices, 1950-2030.

By 2030, a difference in the build-up of expensive hydropower and the construction of nuclear power-plants (roughly 20 GW(e) or 10% less) is noticeable. The use of coal would, due to the high capital intensity and adverse environmental influences, be reduced after 1995, reaching less than 10 EJ or 13% of primary energy in 2030. Crude oil would reach a share of 32% (compared to 25% in the Base Case), and natural gas 30% or 600×10^9 m^3.

Possible supplies for this huge gas consumption are more difficult to assess than in the Base Case. Higher imports from European sources or the Soviet Union seem rather problematic as well as additional supplies from North Africa. Future options for the supply of natural gas would be imports from the Middle East as LNG, or even converted to other liquid fuels. Other considerations suggest that virtually unlimited amounts of natural gas from abiotic origin can be found at many locations, if drilling reaches the appropriate depth (Gold and Soter 1980, Gold 1985).

In summary, constant energy supply prices over the next 50 years seem inconsistent with present knowledge about resource availability and regional distribution. They would lead to increases in consumption, which would, in the longer term, initiate a new price hike. The model runs with low import prices should therefore just be viewed as sensitivity analysis and investigation of the maximum potential under favorable conditions.

The IIASA Study in Perspective

Comparing the results of the IIASA gas study with two studies finished recently (a study by the International Energy Agency *Natural Gas Prospects* (IEA 1986) and a study of the Working Consulting Group of the President of the Soviet Academy of Sciences on Long-Term Energy Forecasting (WCG) *International Natural Gas Market* (Styrikovich 1986)) opens some interesting aspects. Both studies focus mainly on natural gas, but both use a different methodology and time frame and report different types of results. Whereas the IIASA gas study looks at the complete energy system--including all energy carriers and total energy demands--the other two studies focus solely (IEA) or mainly (WCG) on gas. The IEA study comprises the information gathered from the member countries. The IIASA and WCG studies are based on mathematical models.

A common basis can be found in the use of gas in Western Europe from 1990 to 2010 for the IEA study and to 2020 for the WCG study (see Table 12). The WCG developed three demand scenarios relating to different oil price developments, for each of which some trade alternatives are analyzed. In our comparison we use the trade scenarios resulting in the highest use of gas. The IEA developed two price related demand scenarios, for which only the gas demand is reported.

Table 12. Comparison of Natural Gas Consumption in Western Europe for the IEA, the WCG and the IIASA Gas Studies, 1990 to 2020 (10^9 m^3).

	1990	2000	2010	2020
WCG-low	245	290	250	285
WCG-medium	245	290	255	295
WCG-high	245	280	265	290
IEA-low	224	248	258	-
IEA-high	244	280	305	-
IIASA	273	320	392	434
IIASA - electricity	233	246	259	292

Comparing the overall gas use, the IIASA Base Case has by far the highest consumption of natural gas. This can, however, be attributed to a large extent to the high penetration of the electricity market. Without electricity, the Base Case resembles very much te IEA low scenario. Striking about the WCG scenarios is the slump of gas use after 2000, which is due to optimistic assumptions in the growth of nuclear power.

Comparing the sectoral gas use between the IEA scenarios and the Base Case shows another significant difference (besides the use for electricity generation, see Table 13). The IIASA Base Case sees the industrial sectors (including feedstocks, but also process heat production) as growth markets for natural gas, while improved technology, competition with district heat and conservation reduce the potential in the residential and commercial markets. Thus, in the IIASA study gas comes up as a competitive fuel conquering the industrial and electricity generation markets, while the IEA views it as fuel mainly sold by the utilities to private consumers.

Table 13. Comparison of Structure of Natural Gas Consumption in Western Europe for the IEA and the IIASA Gas Studies, 2000 (10^9 m^3).

	IEA-Low	IEA-High	IIASA
Industry	84.0	102.0	123.2
Residential	130.0	133.0	103.3
Conversion	34.0	45.0	75.3
Total	248.0	280.0	301.8

Conclusions

In contrast to many other energy studies, the IIASA International Gas Study shows a substantial potential for an increased utilization of natural gas in Europe. However, this requires the anticipation of technological progress in many fields and the penetration of all possible markets. Whereas most other studies see the growth potential for natural gas in the domestic heating sector, the IIASA study sees good prospects for an increased use of gas in the industrial and power generation sectors.

The introduction of natural gas into the power sector is to a large extent due to the long-term perspective of the analysis. During the next decades it will become increasingly difficult to build coal harbors, transportation systems and power plants. Nuclear generated electricity will, due to public resistance, at least take more time than expected to penetrate the electricity market. Other options are to continue the use of fuel oil, a very unprobable alternative, to generate electricity from renewable sources (other than hydropower), a very expensive alternative, or to reduce the growth of electricity consumption, an inconvenient solution. Continuing the growth of electricity use is essential for a restructuring of our industries toward more intelligent products—away from the smokestack industries using fuels for thermal processes. Residential electricity use will also continue to grow for some time, specifically in the less industrialized countries in the south of Europe. This increased need for electricity could, as the IIASA study indicates, well be supplied by highly efficient gas turbines and combined cycle power plants.

Another result of the study is the limited potential of gas use in the residential sector, when compared to the IEA study. Conservation, together with the expectation of technological improvement, and the consideration of the competition from district heat—so to say a by-product of thermal generated electricity—let the potential of natural gas in this market decline after 2000. This leaves, besides central conversion, the industrial consumers as major customers for the gas utilities. If natural gas is priced competitively, its cleanliness and—in relation to coal—low associated investment and operation costs make it an ideal fuel for high temperature processes (with electricity as major competitor). In steam and process heat generation the boiler size, i.e. the relation between fuel and investment costs, is the main basis for a decision for natural gas or coal. Considering present and future environmental problems the investments in coal burners will increase in order to reduce the emissions, resulting in an increased competitiveness of natural gas.

For East Europe the analyses showed that, due to the poor endowment with hydrocarbons besides coal which mostly has a low calorific value, import requirements will continue to grow. The expenditures for these imports could be reduced by using domestic capital goods to substitute for high-quality fuel imports. The production of liquid fuels like methanol from domestic or even imported coal would be a viable option. But the shortage of clean domestic fuels, together with the necessity to improve environmental standards, imposes a heavy burden on the economies of East Europe. District heating systems have to be introduced or enlarged, town gas grids have to be converted to natural gas and new ones constructed, and the nuclear capacity has to be increased. Adequate energy supplies will remain an urgent problem in East Europe.

Obviously many other internally consistent energy futures could be constructed for Europe. However, a number of reasons indicate that the outcome of this study—a substantial increase in the use of natural gas--points into the right direction. Not only did the increased efforts to find natural gas lead to important technological improvements in offshore and deep drilling, keeping gas production costs within reasonable limits; research to improve end use devices also showed that natural gas can be used at much higher efficiencies than other primary fuels. Additionally, besides SO_2, also significantly lower NO_x and CO_2 emissions can be reached than with burning other fossil fuels. Natural gas can help to reduce the environmental burden imposed by an increased utilization of coal, since it does not face public resistance like, e.g., nuclear energy. As the estimates of gas resources keep growing, it could well be the dominant fuel in Europe's energy system at the beginning of the next century. It would then play an important role in the way toward a sustainable energy future.

Final Remarks

Recent developments, like the continuous renegotiations and government interventions in gas trade between European nations and Algeria, have shown that contracts are not strictly binding for future developments in international gas trade. The rapid build-up of Soviet gas export capacity proved that infrastructural limitations also do not play a major role, when thinking in terms of decades. Both countries, Algeria and the USSR, and their major trade partners in Western Europe (France and the FRG, respectively) have strong political interests behind their trade relations, making purely economic analyses a hazardous undertaking.

Finally, the agreement on the Troll deal, signed in June 1986 for gas priced well above the present market value, underlines the influence of not purely economical considerations--including the expectations that oil and gas prices will rise well above $20/bbl by the middle of the 1990s. The European buyers know very well the importance which North Sea gas exploration and production has for Europe's industry, the standing in international competition and technological progress. With the Troll deal they keep some of the know-how gained in the North Sea operations, inhibiting the death of a very lively and technology-intensive industry. But also security of supply and diversification play a major role. The Troll field is, after the Groningen field, the second largest and important "domestic" West European source of gas.

All these facets seem to point in the direction of a supply picture for natural gas with a high degree of diversification. Like Japan, which encourages any conceivable LNG export project, the European buyers boost their potential sources of natural gas in order to increase their future options to choose. An open question still is if, as the gas markets and grid systems get more and more integrated, a spot market for gas could evolve. The present overcapacities for supply together with the Groningen field, which could serve as peak supplier or, later, as storage, would leave room for such a development.

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