TWO ALTERNATIVE SOLAR ENERGY SCENARIOS FOR WESTERN EUROPE

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ABSTRACT

The paper describes two limiting scenarios that lead to a sustainable energy system in Western Europe toward the end of the next century. The scenarios consider exclusively solar energy futures--one based on centralized solar technologies (Hard scenario) and the other on decentralized user-oriented technologies (Soft scenario). While both scenarios eliminate Western Europe's dependence on domestic and foreign fossil energy sources, the Hard Solar scenario requires substantial imports of solar produced hydrogen. Fundamental but different changes of the whole energy system, economic structure and lifestyles are necessary in order to achieve sustainable solar energy futures in the scenarios.

energy, solar energy, energy scenarios, long-term, energy options, Western Europe

INTRODUCTION

This paper describes two limiting scenarios of possible, though not necesssarily probable, transition path to a sustainable energy future for Western Europe (Ref. 1). By the term sustainable energy future we mean that continued energy supply is assured from practically infinite energy sources, and not necessarily that import independence is achieved, rather it implies a transition away from domestic and imported fossil energy sources. The scenarios consider exclusively solar energy futures [illegible] based on centralized solar technologies (Hard scenario) and the other on decentralized, user-oriented technologies (Soft scenario). They are based on dynamic balances of energy demand and supply using detailed models to achieve consistency. The overall implications of each scenario are that fundamental changes of the whole energy system, economic structure and lifestyles are necessary in order to achieve sustainable solar energy futures.

ENERGY DEMAND AND SUPPLY

Here, Western Europe refers to continental Europe and Asia Minor excluding the COMECON countries; it represents a developed world region with little endogenous fossil resources, and low population growth. Thus, an achievement of a sustainable energy system means a transition to alternative energy sources such as nuclear, solar and renewable energy. However, the IIASA Global Study (Ref. 2) showed that sustainable energy systems could not be achieved by 2030. In order to allow enough time to complete the transition away from fossil to solar energy sources, the time horizon of the study is longer than 100 years, reaching to the year 2100.

The future energy outlook for Western Europe depends on a multitude of interdependent factors--most important among these are the economic development and population growth. Therefore, the future evolution of Gross Domestic Product (GDP) and population are the two basic assumptions in the scenarios. The population evolution is based on projections developed by Keyfitz (Ref. 3) and is shown in Figure 1a, which indicates that Western Europe would reach a stable population of 570 million people by the end of the next century.

The projection of the GDP evolution in the scenarios is based on the GDP growth in the Low scenario of the IIASA Global Study. Figure 1b shows the GDP evolution in Western Europe, implying an average 1.6 percent per year growth rate, which may appear to be a low figure. However, this growth rate should be viewed as a sustainable long-term trend, and should be compared with a much lower population growth rate of 0.3 percent per year. On the average it leads to more than a five-fold increase in GDP per capita levels by the end of the next century.

Based on these population and economic growth projections, the scenarios provide two extreme alternatives for achieving a sustainable energy future. Together, these scenarios identify a *region of feasibility* within which more likely and less extreme sustainable energy futures for Western Europe could be found. Any future that is between these extreme possibilities could be viewed as achievable. Thus, although the assessment of *the* future is impossible, the scenarios delimit the possibilities against the background of our assumptions.

Two sets of assumptions were used to result in two different energy demand projections, a higher one for the Hard Solar scenario and a lower one for the Soft scenario, both of them based on the same population and GDP projections described above. The large differences between the two are due to

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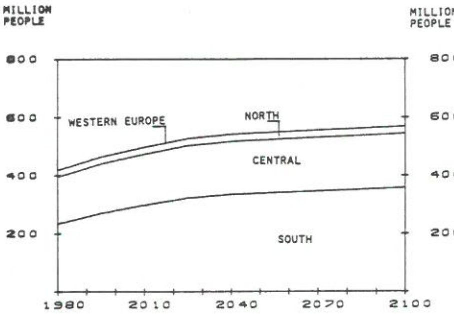

Figure 1a. Population projection.

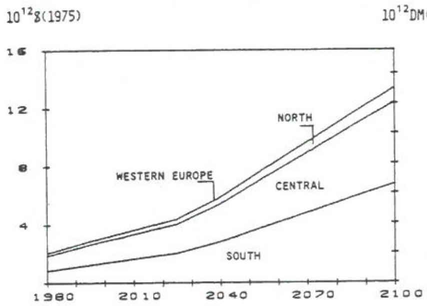

Figure 1b. GDP projection.

different lifestyle changes and energy use efficiency improvements. That is, different energy demand patterns and levels, at the same GDP, are possible since the GDP index will actually measure different things as the economic structure and lifestyles change over time. The typical basket of goods associated with the Hard Solar scenario will be different from that of the Soft scenario. These different material needs associated with the same GDP (i.e. economic activity) level are assessed in the MEDEE-2 model in physical terms and, in conjunction with energy use efficiency improvements and lifestyle changes, result in specific demands for energy.

The energy demand levels are assessed in the MEDEE-2 model for all sectors of the economy, e.g. industry, transport, households and services, and within each sector by demand category. For those demand categories where a number of final energy forms (usually each with a different efficiency) could provide a given service the demand levels are specified in terms of the required useful energy or energy services. Where only one specified form of final energy can provide the service, the demand levels are specified in terms of final energy, e.g. hydrocarbons for feedstocks in chemical industry. The energy supply model MESSAGE II then determines the structure of an energy supply system that is capable of providing the demanded energy according to each specific use. The energy system configuration is specified by MESSAGE II so as to provide a cost minimal energy mix that meets demands under the constraints of maximal build-up rates for technologies and resource constraints.

Starting from the energy system level closest to the consumer, the first energy balance that has to be fulfilled is that the delivered final energy must meet the demanded energy uses. Table 1 shows such a final energy balance in Western Europe for the base year of the study, 1975, and the final energy balances of the Hard and Soft Solar scenarios in the year 2100.

The first thing to observe is that exactly the same energy use categories are satisfied by final energy supply in the scenarios as in the base year. However, the structural shifts between today and the year 2100 go beyond substitution among solid, liquid, gaseous fuels and electricity and even beyond the substitutions of various forms of final energy within each of these categories; the actual use of final energy forms changes.

In the Hard Solar scenario, the final energy more than doubles compared to the current final energy use, while it remains practically constant in the Soft Solar scenario during a period of more than 100 years. These relatively small increases in the final energy use in the Soft Solar scenario, and even the greater increases in the Hard scenario, illustrate the substantial energy efficiency improvements and overall conservation measures in the scenarios. Recalling that the GDP grows more than seven-fold during the same period implies as a result extremely low final energy to GDP elasticities of 0.43 in the Hard and only 0.08 in the Soft Solar scenario compared with historical elasticity of 0.79 (for the period 1950 to 1975). The overall energy use per unit of GDP is reduced by two thirds in the Hard Solar scenario and by more than 80 percent in the Soft Solar scenario (from 0.7 W/$(1975) in 1975 to 0.2 and 0.1 W/$(1975) in 2100, respectively). This could be achieved as a result of substantial changes throughout the economy and within each economic sector in addition to a change in lifestyles (e.g. reduced plane travel, user orientation in energy conversion) and enormous efficiency improvements of energy end use technologies. Moreover, the energy use reductions were larger in the Soft Solar scenario than in the Hard scenario, the Soft Solar scenario being consistent with the lower demand projection and the Hard Solar scenario with the higher demand projection.

Table 2 shows the final energy supplies in the scenarios by final energy form. Both scenarios lead to sustainable energy use by 2100, but in 2030 the reliance on fossil energy supplies is still strong, a result that confirms the necessity of using a long time horizon of more than 100 years for the analysis of sustainable energy futures. By 2100, the Soft Solar scenario relies mostly on on-site energy generation contributing 41 percent of all final supplies. In addition, the local energy sources such as district heat co-generation and wind and photovoltaic plants contribute in the form of electricity 14 percent of final energy compared to the total of 18 percent of final energy delivered as electricity. The remaining electricity originates from hydropower. Only 15 percent of all final energy is delivered in the form of thermolytic hydrogen originating from large solar power plants in South Europe. Thus, the Soft Solar scenario is based on at most one fifth of all final energy from large centralized energy generation systems.

In the Hard Solar scenario the opposite is the case. On-site energy generation is not used at all. 52 percent of all final energy is delivered in the form of thermolytic hydrogen and 27 percent as electricity, both energy forms originate from large solar plants placed in sunny areas of the South and require long-distance transport and hydrogen storage. Thus, altogether in the Hard Solar scenario about 80 percent of all final energy is delivered from centralized energy conversion technologies and in the Soft Solar scenario the same relative share is delivered from user-oriented, local or on-site systems.

Table 1A. Final energy by form and use, base year 1975 (GWyr/yr)

Final Energy Form	Final Energy Use: Thermal Low	Thermal High	Coke	Feed-stocks	Motor Fuels	Elec-tricity	Total
Coal	48.7	28.8	43.5				121.0
Oil Products	335.9	52.6		81.2	239.9		709.6
Natural Gas	109.1	86.7					195.8
Electricity						141.2	141.2
Biomass	26.4						26.4
Total	520.1	168.1	43.5	81.2	239.9	141.2	1194.0

Table 1B. Final energy by form and use, Hard Solar scenario, 2100 (GWyr/yr)

Final Energy Form	Final Energy Use: Thermal Low	Thermal High	Steel Production	Feed-stocks	Motor Fuels	Elec-tricity	Total
Coal			2.0				2.0
Electricity	68.2				31.6	644.0	743.8
Biomass	87.9						87.9
Methanol				518.0			518.0
Hydrogen	689.6	315.0	59.9		390.2		1454.7
Total	845.7	315.0	61.9	518.0	421.8	644.0	2806.4

Table 1C. Final energy by form and use, Soft Solar scenario, 2100 (GWyr/yr)

Final Energy Form	Final Energy Use: Thermal Low	Thermal High	Steel Pro-duction	Feed-stocks	Motor Fuels	Elec-tricity	Co-genera-tion	Total
Coal			1.0					1.0
Electricity	16.1	50.6			20.9	160.1		247.7
Biomass	13.8						96.2	110.0
Methanol				216.3				216.3
Hydrogen		1.7	31.2		173.5			206.4
District Heat	34.4							34.4
On-Site	344.7	70.5				156.5		571.7
Total	409.0	122.8	32.2	216.3	194.4	316.6	96.2	1387.5

Table 2. Final energy shares by form, Soft and Hard Solar scenarios, 1975 to 2100 (%)

Form	Base Year 1975	Scenario: Soft Solar 2030	Soft Solar 2100	Hard Solar 2030	Hard Solar 2100
Coal	10.1	4.6	0.1	14.5	0.1
Oil	59.5	6.6	0	15.2	0
Gas	16.4	4.2	0	21.8	0
Electricity	11.8	18.9	17.8	23.4	26.5
Biomass	2.2	9.8	7.9	5.3	3.1
Methanol	0	2.4	15.6	5.7	18.5
Hydrogen	0	13.5	14.9	14.1	51.8
District Heat	0	2.9	2.5	0	0
On-Site	0	37.1	41.2	0	0
Total (TWyr/yr)	1.19	1.17	1.39	1.82	2.81

The final energy deliveries that meet the demands result in primary energy requirements. In between are the various stages of energy conversion, storage in the case of hydrogen, transport and distribution. The final energy demands in the year 2100 of 1.4 TWyr/yr of the Soft Solar scenario and 2.8 TWyr/yr of the Hard Solar scenario result in primary energy requirements of 3.2 TWyr/yr and 5.8 TWyr/yr, respectively. Table 3 shows how these primary energy requirements are distributed among different energy sources. Thus, from the structure of energy supply, the Soft Solar scenario is over 70 percent "soft", the Hard scenario relies to more than 80 percent on centralized solar conversion technologies.

The general approach is that all energy conversion, transportation and distribution technologies can compete to meet demands in all scenarios. We have assumed that technologies compete primarily on a cost basis, the cheapest technology available being used first. But there are constraints on the rates at which resources and potentials can be exploited, on the rate at which new facilities are built and implicitly on the total amount of any single activity that can be used. All of these numerous constraints affect decisions which would otherwise be dominated by cost considerations alone. Together they can be seen as deliberately forcing the energy system to maintain flexibility during the transition to a sustainable future--to provide diversity in order to cope better with unexpected changes. In fact, to the extent that the scenarios represent extreme future energy systems, they delimit the flexibility. For example, a future with lower energy use than in the Soft Solar scenario is perhaps possible, but within our analysis not by a smooth "surprise-free" transition from the current energy system.

ENERGY IMPORT COSTS AND CAPITAL REQUIREMENTS

In 2030, during the transition period to sustainable energy supplies, the scenarios rely on fossil energy sources. Due to the lack of sufficient endogenous fossil sources in Western Europe

Table 3. Primary energy (equivalent) shares, Soft and Hard Solar scenarios, 1975 to 2100 (%)

Energy Source	Base Year 1975	Scenario Soft Solar 2030	Soft Solar 2100	Hard Solar 2030	Hard Solar 2100
Coal	22.1	2.4	0	12.6	0
Oil	52.5	3.6	0	9.5	0
Gas	13.2	2.3	0	13.7	0
LWR	2.4	4.6	0	0.8	0
FBR	0	0	0	9.5	0
HTR	0	0	0	0	0
(Nuclear Total)	(2.4)	(4.6)	(0)	(10.3)	(0)
Hydropower	8.1	10.6	8.5	7.7	4.3
Biomass	1.7	8.4	15.1	10.1	9.4
Windpower	0	34.8	33.9	0	0
Wavepower	0	1.8	1.4	0	0
Photovoltaics	0	6.0	9.4	0	0
On-Site Sources	0	25.4	28.3	0	0
("Soft" Total)	(0)	(68.0)	(73.0)	(0)	(0)
Solar-Electric	0	0	0	19.9	3.4
Solar-Hydrogen	0	0.1	3.4	16.2	82.9
("Hard" Total)	(0)	(0.1)	(3.4)	(36.1)	(86.3)
Total (TWyr/yr)	1.53	2.36	3.16	3.20	5.76

most of these energy needs are balanced by energy imports. However, the relative shares of fossil energy sources are much lower even during the transition than today, so that the import dependence is reduced in both scenarios by 2030. In 1975, 53 percent of all primary energy consumed in Western Europe originated abroad. By 2030, only two percent of all primary energy is imported in the Soft Solar scenario. A relative reduction of energy imports to 31 percent of all primary energy is also achieved in the Hard Solar scenario. The reason for the relatively high import dependence of the Hard Solar scenario is that in addition to fossil energy imports most of the solar thermolytic hydrogen must be imported because the endogenous solar thermal potential of Western Europe is practically exhausted by electricity production. Moreover, after 2030 the energy import dependence increases again in the Hard Solar scenario due to increased hydrogen needs. In the Soft Solar scenario energy imports are completely eliminated after 2060.

In the Hard Solar scenario it is assumed that hydrogen is imported from the Sahara since this is a sustainable source of energy, although of a non-European origin. Setting aside the political issues involved, we have assumed that the total production and investment cost of this scheme would be carried by Western Europe, so that these costs are included in the scenario. The total energy import bill increases from less than 5 percent of the total GDP in 1980 to a maximum of almost 7 percent by 2025. After 2060 fossil energy is completely phased out so that all of the imported energy by 2100 is in the form of hydrogen, reducing the energy import bill to less than 5 percent of GDP again. For example, in 2030 73 percent of the import bill is due to fossil energy imports and the remainder due to hydrogen imports from the Sahara.

In the Soft Solar scenario less than one percent of total GDP goes for energy imports by 2030, and by 2100 no energy is imported. This gradual decrease of the relative share of the energy imports and eventual import independence in the Soft Solar scenario can only have positive effects on the total balance of payments and overall economic growth. However, even in the Hard Solar scenario the relative share of energy imports in GDP increases less than 50 percent over a period of more than 50 years, and in the long run decreases below the current level. This should probably not cause any critical problems. It represents at most a doubling over the current energy import bills of most of the Western European countries (e.g., in the FRG the share of energy imports in GDP was 3.1 percent in 1975).

However, problems occur if payments for energy, foreign and domestic, clash with the increasing demands for highly capital intensive energy conversion and end use technologies.

Only some of these considerations are reflected in the capital requirements of the scenarios. Figure 2 compares the total investments in the energy system for the two scenarios. In the Hard Solar scenario the energy investment share in GDP increases to over 5 percent in 2030 and gradually doubles by 2100. In the Soft Solar scenario it increases somewhat up to 2030 and slowly reduces to below 3 percent of GDP by 2100. Thus due to the continuous economic growth, the energy investment share in GDP even in the Hard Solar scenario appears not to be too critical, although in absolute terms the energy investment requirements increase by a factor 13 in the Hard Solar scenario and by a factor 5 in the Soft Solar scenario. These total investments in the energy sector are based on the capital requirements of all technologies employed in the scenarios and are expressed in 1975 price levels and exchange rates in U.S. dollars.

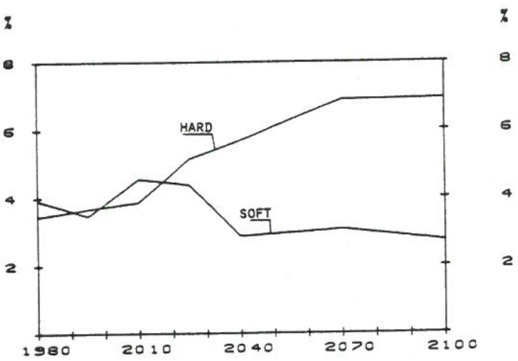

Figure 2. Capital requirements as share of GDP, Hard and Soft Solar scenarios.

In both scenarios energy transportation and distribution capital requirements are comparatively low and their relative shares decrease as energy conversion and end use become more complex during the next century. It should be observed that in the Hard Solar scenario the central conversion capital requirements increase proportionally more than those of end use. In the Soft Solar scenario the on-site energy technologies become the most capital intensive part of the energy system, accounting for almost one half of all capital requirements. Thus the structure of capital needs of the energy sector shows a different evolution in the two scenarios.

The higher capital requirements for end use and on-site technologies illustrate that both energy conservation and user orientation could relieve many of the traditional energy supplies from centralized energy systems. Thus higher investments can help to reduce the increase of the total energy bill by reducing energy demand and increasing the amount of energy generated locally. However, there is an additional factor implied by the scenarios that is not explicitly reflected in the capital needs: namely, the indirect capital needs that would result from lifestyle changes and infrastructural changes. However, these structural changes are so numerous in the scenarios that they cannot all be accounted for in monetary terms.

The analysis of the energy systems in the scenarios has demonstrated that a consistent energy supply and demand balance can be achieved in a sustainable energy future of Western Europe if appropriate changes in lifestyles and economic structure are consistent and possible.

CONCLUSION

The study shows that after a period of some 100 years virtually all energy demand categories could be supplied on a sustainable basis from solar and renewable energy sources. Thus it would be tempting to conclude that such a future is within our reach. But the analytical approach could only designate technical and techno-economic solutions that indicate how such a transition could be achieved. Behind these solutions, however, are the two sets of normative assumptions that specify a parallel, and within scenarios necessary, evolution of lifestyle patterns and economic structure. In other words, it was possible to determine what types of structural changes are necessary in order to achieve a balance within the energy system, but it is not possible to assess the quantitative feedbacks throughout the society in the same manner as within the energy system. It is simply not possible to compare different economic structures and consumer habits with current measures. For these reasons the scenarios should not be viewed as predictions of a likely future for Western Europe. The scenarios cannot be viewed as immediate alternative options for Western Europe as it exists today either, since each scenario necessitates complete but different changes of the current socioeconomic structures. Rather, they represent "yardsticks" that delimit the range of feasible and consistent futures given the assumptions. A choice between the scenarios would certainly not depend on preferences for certain technologies but on social, cultural as well as political preferences. These changes of preferences would affect Western Europe as it exists today more dramatically than the associated technological changes of the energy system, although in the scenarios both are necessary.

REFERENCES

1. Energy Systems Group of the International Institute for Applied Systems Analysis 1982, *Die zukünftige Nutzung der Sonnenenergie in Westeuropa*, Report to the Federal Ministry for Research and Technology of the FRG, Project ET 4359A. Written by N. Nakicenovic and S. Messner, translated by I. Teply-Baubinder (in print).

2. Energy Systems Program Group of the International Institute for Applied Systems Analysis, W. Häfele, Program Leader, 1981, Vol.1: *Energy in a Finite World. A Global Systems Analysis;* and Vol.2: *Energy in a Finite World. Paths to a Sustainable Future* (written by J. Anderer with A. McDonald and N. Nakicenovic). Cambridge, Mass., Ballinger Publishing Co.

3. Keyfitz N 1979, *Population of the World and Its Regions, 1975-2050.* WP-79-119, Laxenburg, Austria, International Institute for Applied Systems Analysis.