THE POTENTIAL OF RENEWABLE ENERGY SOURCES

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ABSTRACT

The solar light radiation intercepted by the earth represents an energy flow more than four orders of magnitude larger than the present global energy demand. On the earth's surface, one third of this flow is available for the energy supply of man, mainly in the form of light, but also in substantial quantities as wind-energy, wave-energy, hydroenergy and biomass. The utilization of this energy-income requires the development and construction of installations ranging from simple domestic hot water systems and small photovoltaic generators to huge solar power towers and ocean thermal energy converters. Additionally, the social, economic, financial and legal structures associated with the supply and consumption of energy will have to be revised.

INTRODUCTION

It is impossible to foretell the future and consequently, there is no intention to try to do so in this presentation. Yet, it makes little sense to talk about the potential of renewable energy sources without discussing future developments. What then can be the significance of any statements that will be made in this paper? In this connection it is useful to distinguish between various levels of certainty that can be attached to the occurrence of coming events:

- The highest level of certainty can obviously be given to those future events which are based on physical laws and scientifically well established facts; e.g. efficiencies of equipment will never surpass the limits set by thermodynamics and the intensity of solar radiation can safely be taken to vary little for many centuries to come.
- A somewhat lower, but still acceptable degree of certainty can further be attached to developments which are already under way and are very unlikely to be stopped. The gradual depletion of oil and gas resources and the growth of the world population to between 10 and 15 billions sometime in the next century are developments of this nature.

- And, finally, a large group of events can be identified which may or may not happen. Many cultural and political developments belong to this group, but also the speed and degree of the progress in science and the breakthrough of new social attitudes should be included.

It is with this mixture of certainty and uncertainty that calculated guesses, or guessed calculations of the potential of the renewable energy sources will have to be made. Accordingly, although the results are presented in definite figures, they will have a corresponding degree of uncertainty. With this reservation in mind, the results might be designated as a conditional model for the Netherlands for the middle of the next century, the main condition being that the political and cultural changes required for its implementation are actually realised.

THE GEOPHYSICAL POTENTIAL OF RENEWABLE ENERGY SOURCES

Almost all renewable energy sources derive their energy from the tiny fraction (one part in two billion) of the solar radiation flow that is intercepted by the earth. On the average this intercepted light energy flow amounts to 172.5 PW. (1) and thereby surpasses the current commercial energy use of nearly 10 TW (2) by four orders of magnitude. The clouds and the atmosphere re-radiate 41.4 PW of light power back into space, and an additional 41.4 PW are absorbed in the atmosphere and converted into sensible heat (the equality of the numbers is fortuitous). This leaves a light power of 89.7 PW reaching the earth's surface, corresponding with an average flux of 176 W m^{-2} . As the energy use of mankind is almost exclusively land-based it seems appropriate to consider only the light power reaching the 148 million km^2 of land surface as utilisable energy. This brings the geophysical potential of this renewable energy sources (RES) down to about 26.0 PW, corresponding to 1/7 of the flow intercepted by the earth (the potential, by the way, still includes the insolation on rivers, lakes etc.). Not all the light energy converted into sensible heat in the atmosphere or in the oceans is lost as a RES. The evaporation, temperature differences and natural convection phenomena resulting from the conversion lead to new, be it indirect ways, for the utilization of solar energy. As borne out by fig. 1, the geophysical potentials of these indirect sources are two or more orders of magnitude smaller than the potential of the light radiation itself. Even the largest of them hardly surpass the present global commercial energy use by more than one order of magnitude. Practically speaking, this excludes all indirect RES from playing more than a regional or secondary role in the solution of the energy problem.

Fig.1. Origin and geophysical potential of the various renewable energy sources, related to the present global commercial energy use (10 PW approximately); with use of (1) and reduced to land based utilization.

Actually two groups of indirect RES can be distinguished: the three larger are biomass, hydropower and windenergy (and maybe in the future OTEC), for which such a role is conceivable, and the group of the small are wave-, tidal-, and geothermal energy, which are bound to remain of only local significance. It should be pointed out that the geophysical potentials given so far represent only the upper and still theoretical limits of the power that can be derived from each of the different RES. Factors such as uneven distribution (60% of the biomass grows in the tropical and subtropical forests), bad accessibility (windenergy at heights above 200 m), and low efficiencies in subsequent conversions (less than 3% for OTEC) invariably cause a substantial reduction in the power output that can actually be realised. For hydropower the reduction amounts to only one order of magnitude (1) but in most other cases, a reduction within two orders of magnitude is a better first estimate.

It needs no comment that tidal- and geothermal energy do not have their origin in solar radiation. However, it may be useful to note that the utilization of the heat from underground bodies of hot water, as was considered in Spijkenisse near Rotterdam, is not a RES because the heat is depleted in a short period, say 25 years, and is only very slowly replenished from the interior of the earth. The geothermal energy as a RES only refers to hot springs and similar phenomena occurring in areas of high volcanic activity.

THE CONVERSION OF THE PRIMARY RENEWABLE ENERGY

All renewable primary energy sources require one or more conversion steps in order to obtain energy in a form suitable for final use. Preferably such a conversion route should encompass (at least) one storage component for adjustment of supply and demand. As the power level of most of the renewable energy sources is fluctuating by nature, the storage of energy plays a much more important role in renewable energy systems than in the conventional, fossil-fuel based systems, in which the fuels virtually provide all storage that may be required.

In the framework of this paper it makes little sense to discuss conversion steps and storage methods that are already well known in the current energy technology. As Ocean Thermal Energy Conversion and the Potentialities of Wind-energy will be adequately covered in two other papers in this volume, and information on the bioconversion of waste and on alcohol fuels are also included, it suffices here just to mention these options. However, for the sake of completeness they are listed in the conversion and storage surveys in Figs. 2a and 2b.

SOURCE	CONVERSION DEVICE	PRIMARY PRODUCT	MAX. EFF.	STORAGE DEVICE(S)
LIGHT	FLAT PLATE COLLECTORS EVACUATED COLLECTORS	HEAT 40-150°C	70%	WATER, ROCK SALTS
	CONCENTRATING COLLECTORS FOUSSING COLLECTORS	HEAT 150-800°C	60%	SALTS, SODIUM
	PHOTOVOLTAIC CELLS	ELECTRICITY (LOW VOLTAGE)	12%	BATTERIES HYDROGEN
	PHOTOCHEMICAL-, PHOTOELECTROCHEMICAL-, AND PHOTOBIOCHEMICAL CELLS	FUELS AND/OR ELECTRICITY (LOW VOLTAGE)	5 - 10%	FUEL AS SUCH BATTERIES HYDROGEN

Fig.2a. Ways for the direct conversion of light energy into a utilisable energy form; with use of (1) and (5).

As shown in Fig. 2a, there is a large number of ways along which light energy can be converted into a utilisable energy form. The maximum conversion efficiencies that can presently be attained are fairly high for the well developed conversion into heat. It should be noted, however, that the listed efficiencies are first law efficiencies and do not take into account the quality of the energy. Moreover, they are the instantaneous peak efficiencies and do not include the often considerable system and operational losses occurring in practice. In flat plate and evacuated collectors, the light energy is absorbed and transformed into heat by means of black metal or plastic plates exposed to the light radiation. The plates are thermally shielded from the environment by some envelope with a

transparent front cover. For the so-called evacuated collectors, this envelope usually is a glass tube which is evacuated in order to eliminate the convective heat losses. The radiative heat losses from the absorber can be eliminated for the greater part by the application of a so-called spectral selective coating on the absorber. The heat developed in the absorber plate is removed by some cooling fluid, passing through ducts attached to the absorber plate. Water and air are the most widely used cooling media and, correspondingly, water and rocks are the media most widely used for the storing of the heat.

The energy density of the light incident on the earth is rather low, only 1 kW m^{-2} in bright sunshine. This sets a limit to the operational temperatures that can be reached with simple flat plate collectors. Concentrating the light radiation by means of an array of mirrors or lenses is the obvious method for shifting this limit upward, and a wide variety of schemes has been proposed to this end. The better and more accurate the focussing, the higher the operating temperature that can be attained, but also the higher the costs of the mirror array. Nevertheless, fairly realistic installations have been and are being constructed in which solar energy is used to produce high pressure steam for the generation of electricity. They are generally designated as "power towers", after the central tower, which carries the boiler in the focussing point of the mirror array (20). In moist and cloudy climates, like the Dutch, where most of the light is scattered in the atmosphere (up to 70% (1)), such highly concentrating devices are unsuitable because scattered light can not be focussed. Consequently, only weakly concentrating mirrors with a concentrating ratio of 2 to 4, are applicable here.

Within the past few decades much progress has been made in the direct conversion of light into electricity by means of photovoltaic cells. Conversion efficiencies of 12% are common practice by now and the costs have been reduced by more than a tenfold to about 3000 US \$ per m^2 of solar panel, including installation and a 24-hour battery storage (3). A further reduction in cost, by a factor of 5, is expected by the year 1985 and large additional improvements are projected for the years thereafter. In laboratory experiments efficiencies of almost 30% have been attained and theoretical studies have shown that an efficiency of 60% is not beyond reach (4). However, much research and development work will be required before cells with such performances can actually be marketed. This counts even more for the photochemical, photoelectrochemical and photobiochemical conversion methods, mentioned last in Fig. 2a. The theoretical first law efficiencies for these methods reach up to 40% (1) but all methods are still in the laboratory phase. How attractive the direct production of fuels from sunlight may appear, and how vast the number of candidate photochemical reactions may be, it should always be kept in mind that usually only one out of every hundred laboratory accomplishments turns out to be feasible in practice.

SOURCE	CONVERSION DEVICE(S)	PRIMARY PRODUCT	MAX. EFF.	STORAGE DEVICE(S)
HYDROPOWER	WATERTURBINE	MECH. ENERGY	90%	FLYWHEEL, ELEVATED WATER
BIOMASS	INCINERATION, FERMENTATION	HEAT, FUELS	70%	BIOMASS & FUELS AS SUCH
WINDENERGY	WINDMILL	MECH. ENERGY	50%	FLYWHEEL, ELEVATED WATER
OCEAN THERMAL ENERGY	LOW TEMPERATURE RANKINE CYCLE	MECH. ENERGY	3%	NOT REQUIRED
WAVE ENERGY	PNEUMATIC OR OSCILLATING CONVERTORS	MECH. ENERGY	70%	NOT APPLICABLE
TIDAL ENERGY	WATERTURBINE IN DAM STRUCTURE	MECH. ENERGY	90%	NOT APPLICABLE
GEOTHERMAL ENERGY	NOT REQUIRED	HEAT UP TO 300 °C	90%	NOT REQUIRED

Fig.2b. Ways for the conversion of the indirectly renewable energy sources into a utilisable energy form. Storage of mechanical energy as such is not envisaged for wave- and tidal-energy; with use of (1).

In actual use for centuries - on the contrary - are most of the conversions for the indirectly renewable sources, summarised in Fig. 2b. Only the ocean thermal energy conversion and the utilization of wave energy are new and even here some earlier experiments can be found in the history of science. Generally, the environmental care and the energy crises have greatly improved the economical viability of all these conversion methods. In particular, biomass features high in the RES models and scenarios that have been put forward in various industrialised countries. In this connection, however, it should not be overlooked that wood still accounts for about 8% of the global energy production (2). Here also is an appreciable extension and upgrading of an existing technology, more than a new technology. There are some opportunities here for industries in which the spirit of enterprise has not yet been pensioned off.

REGIONAL DIFFERENCE

Up to now, mainly the potential of RES from a global point of view has been considered. To complete this picture several regional differences have to be taken into account, some of which are obvious. For example, tropical climates are favorable for the utilization of biomass, which explains Brasil's leading role in the field of alcohol fuels. In a similar way the high average wind speed in the coastal areas of Denmark and the Netherlands offers an excellent opportunity for the foundation of an internationally leading windmill industry.

For the most important RES, light radiation, the consequences of the regional differences are rather more difficult to assess. A high population density usually goes with a high energy use density, but also with a lack of space for the accommodation of large solar collector arrays. Moreover, in the centers of

larger cities the energy use density often surpasses the average density of the solar radiation, implying that the demand can not be met with the local radiation. A similar argument holds for the concentrated energy use in heavy industries.

In order to obtain some insight in these matters, Fig. 3 has been prepared showing the solar radiation and the energy use in W/m^2 of land for various countries.

COUNTRY	AREA	POP'N D'TY	ENERGY USE (1978)	RADIATION			ABUNDANCE RATIOS		
				JUNE	DEC	AVER			
NETHERL'S	0.041	328	2.10	212	21	108	101	10	51
U.K.	0.245	229	1.12	225	25	110	200	22	98
F.R.G.	0.248	249	1.46	225	25	120	155	17	82
FRANCE	0.547	95	0.46	250	35	140	540	76	300
SWEDEN	0.450	18	0.125	250	8	115	2000	64	910
U.S.A.	9.360	22	0.25	280	100	210	1120	400	850
JAPAN	0.372	290	1.25	180	75	160	145	60	130
BRASIL	8.512	12	0.0125	175	240	225	—	—	18000
GLOBAL	148	27	0.068	—	—	176	—	—	2600
UNITS	10^6 KM^2	KM^{-2}	WM^{-2} (HORIZONTAL)				—		

Fig.3. Seasonal and average solar radiation density in comparison to energy use density for various countries, with use of (5-7). Demographical data for 1977 (countries) or 1980 (global). The figures are approximate; lakes, rivers etc. are included in the area.

The three figures in the fourth column refer to mid-summer, mid-winter and (yearly) average radiation, respectively; the energy use is assumed to be approximately uniform over the year. It appears that the abundance ratio, i.e. the ratio between the light radiation and the energy use, varies over almost two orders of magnitude. Thinly populated countries, such as Sweden, U.S.A. and Brasil, feature highest and the densely populated ones, like Japan and the Western European countries, lowest. The population density obviously is a more important factor than the climate and the geographical position of the country; the spread in the average solar radiation hardly exceeds a factor of 2. As was to be expected, the countries at high latitudes show a large summer to winter variation of the abundance ratio. It is not surprising that such high latitude countries show a

particular interest in the season to season storage of solar energy. In the Netherlands, the midwinter abundance ratio even goes down to only 10, the lowest figure in the last column. But also for the average abundance ratio, the Netherlands rank as the most unfavorable country for the application of solar energy, probably sharing this position with some densely inhabited areas in other countries, e.g. the German Ruhr district and the region around London.

WHY RENEWABLE ENERGY SOURCES?

For many reasons the geophysical potential of the RES discussed so far can not fully be utilized. The degree to which this is possible depends not only on a large variety of technical and economical restrictions but also, and to a much larger extent, on the time horizon which is used in the assessment. Only a sufficiently distant time horizon makes it possible to discriminate among the objectives that are realistic in the long run and the solutions that will not last for longer than a few decades and should better not be pursued. The building up of a fundamentally new energy supply system for an industrialised society requires a period of the order of a century, simply, because it implies complete reconstruction of the societal infrastructure. Considering the multiple interactions between e.g. the private car and the structure of industry, roads and streets, and the retail shop system suffices to prove this point.

An other interesting figure in this context is that the mean lifetime of the present dwellings in the Netherlands is no less than 83 years (11). As a consequence, the real potential of renewable energy sources can only be estimated on such a long term. This condition makes it necessary to sketch, at least in broad lines, a picture of the future world, somewhere in the middle of the next century. Fairly certain this world will differ from the present one in the following respects (among others):

1. The world population will have increased by about a factor of 3, to say, 13 billion people, mainly by an increase of the population of the Third World, in particular in south and east Asia.
2. Technology, science and information will have penetrated into daily life all over the world; on this basis, starvation may have been overcome in many areas
3. The center of world trade will have shifted from the western countries to south-east Asia, as will the political and economic power; most probably China will be the most powerful nation in the world.
4. The energy efficiency will be high compared to present standards, but much energy will be required for both environmental care and preparation of low grade ores and for recycling. Consequently the global energy use will have increased considerably, say about fivefold (corresponding to roughly 4 kW per capita, presently 2.2 kW). As yet, it is uncertain to which extent nuclear energy will contribute in meeting this demand.

5. The oil, gas and many high grade mineral resources will be all but depleted (7). This applies in particular to the indigenous resources of Western Europe and Africa. Because of the high global demand the prices of raw materials will be very high, also for coal.

The conclusion to be drawn from this sketch is not only that Western Europe is gradually moving into a highly energy and raw materials dependent situation, but also that in the next century mankind as a whole, by the sheer impact of its number, is going to draw on its finite resources in an unacceptably strong and fast way, at the same time creating a most difficult waste problem. This is the main reason why a fundamental change in the global energy supply system is necessary and why the potential of RES will have to be explored and exploited to the fullest possible extent.

It is, by the way, not the first time in history that mankind faces a challenge of this nature. Long ago, the Neolithic hunter and collector was forced to adapt his food supply system to the steadily increasing population density in a similar way. This led man into the agricultural revolution from which the sedentary societies and the ancient civilisations have emerged. Since then, the world population has increased by two orders of magnitude.

RES MODELS FOR VARIOUS COUNTRIES

The revolutionary character of the energy situation has earlier been indicated in various ways. It is implicitly detectable in the well known report "Limits to Growth" to the Club of Rome and very outspoken in the many publications of Amory Lovins (e.g. 12). Most concretely it is expressed in the RES models that have been constructed for various countries or regions (8, 9, 13, 14). Most of these models are still of a rather primitive nature, depicting only a single combination of possibilities for a delimited area. The economic factors are taken into account in only an approximate way, because many data are still lacking. On the other hand, most models may be called realistic, in the sense that the basic energy needs for industrial activities, transport, communications and space heating, are well accounted for. For obvious reasons energy efficiency is an essential element in all the models.

To illustrate the character of these models, two of them are schematically depicted in Fig. 4. The RES model for Scandinavia (8) is interesting because it incorporates the exchange of renewable energy between Norway, Sweden and Denmark.

The low population density in Sweden and Norway, in combination with the large potential of hydroelectricity in the latter and of biomass (forests) in the earlier mentioned country, turn energy export to Denmark into a good commercial proposition. The energy use per capita is assumed to remain constant at a fairly low level, all energy efficiency serving a modest increase of the material standard of living.

Fig. 4. Renewable energy source models for Scandinavia (8) and the U.S.A. (9).

The U.S.A. RES model, on the contrary, includes energy conservation as an essential element (9). Also, the direct conversion of solar energy plays a more important role than in the Scandinavian model. This implies a rather optimistic view on the possibilities of storage. It should be noted that both RES models are related to thinly populated areas with an average abundance ratio beyond 500 (see Fig. 3).

A report on the short term prospects of renewable energy in the U.S.A. has recently been published by the U.S. Department of Energy (10). The main results for the year 2000 are shown in Fig. 5. Under the assumption that the State and Federal policies are used to accelerate solar use, but also taking into account economic restrictions, it is concluded that the share of RES in the U.S.A. energy supply may increase from 6% in 1977 to nearly 20% in the year 2000, notwithstanding an increase of 25% in the total energy demand. This fully agrees with the estimates for the initial period in the RES model for this country.

SOLAR TECHNOLOGY	CONTRIBUTION
ACTIVE HEATING AND COOLING	2.0
PASSIVE HEATING AND COOLING	1.0
INDUSTRIAL AND AGRICULTURAL	2.6
BIOMASS	5.4
PHOTOVOLTAIC SYSTEMS	1.0
WIND SYSTEMS	1.7
SOLAR THERMAL POWER	0.4
OCEAN THERMAL	0.1
HYDRO POWER: HIGH HEAD	3.5
: LOW HEAD	0.9
TOTAL (QUADS) IN THE YEAR 2000	18.5

1 QUAD = 10^{15} BTU = $1.055 \cdot 10^{18}$ J. TOTAL U.S.A.
 ENERGY USE ESTIMATED TO INCREASE FROM THE PRESENT
 78 QUADS TO 95 QUADS IN THE YEAR 2000.

Fig.5. D.O.E. estimate of solar contributions by the end of this century, under the assumption that State and Federal Policies are used to accelerate solar use (10).

ASSUMPTION FOR A CONSERVATION AND RENEWABLE ENERGY SOURCE MODEL FOR THE NETHERLANDS

As illustrated before, the Netherlands is one of the most unfavorable countries for renewable energy sources in the world. Moreover, it is surrounded by countries in which the RES situation is not substantially better, except maybe in France (see Fig. 3). The latter circumstance makes it significant to investigate the possibilities of RES for the Netherlands without any regional exchange, at least in first instance. Additionally, a Dutch RES model may procure valuable indications regarding the options for the surrounding countries. Energy efficiency has to be an essential element in any energy plan for an industrialised country, if only because of increased energy prices. As a consequence, the starting points for the construction of the model is subdivided in two groups:

- starting points related to the future developments and improvements of the various solar energy conversion methods,
- and
- starting points related to the long term effects of energy conservation.

In order to express these two aspects in the name of the model it will further be called a conditional or CRES model. As regards the efficiencies of solar energy conversion, the following six long term (75 years) assumptions are conservative.

1. Because of the required space, solar energy conversion methods with an efficiency below 10%, such as energy plantations, are not applicable to a significant degree in densely populated areas like the Netherlands. Only waste materials can be excluded from this general rule.

2. The efficiency of low temperature photothermal conversion devices can be raised to 45%, as an annual average. As a consequence of improved heat storage methods the coverage of any specific demand can be raised from the present 50% to 75%, regardless of daily or seasonal fluctuations in the demand. Further, for reasons of orientation, town planning etc., only 80% of the dwellings and buildings can actually be provided with solar heating.
3. The research and development work on photovoltaic cells will have resulted in conversion efficiencies of 25% and in such storage methods for electricity that any specific demand can be covered for 50%, regardless of daily or seasonal fluctuations in the demand.
4. Some photochemical conversion methods with an efficiency of 15% will have been developed and the produced photochemical fuels can be stored so easily that any specific demand can be met for 100%.
5. The long term potential of windenergy for the Netherlands amounts to 2500 MW and the real practical land use of wind turbines is virtually zero.
6. The utilization of bio-waste materials and other waste is well developed and supplies 5% of the present energy demand (15).

The general philosophy behind the assumptions on energy conservation is that any increase in energy use will have to be avoided and that all present energy waste will have to be converted into a decrease in energy use. This philosophy implies that any improvement in the material standard of living and any economic growth will have to be accompanied by higher efficiencies in energy use, longer lifetimes of capital goods, etc. Certainly the structure of industry will change considerably in the long run. However, these changes are so unpredictable that their influence on energy use has to be omitted. For similar reasons, any changes in the population of the Netherlands are not considered, because no substantial increase is expected for the future. Based on this philosophy, and on various recent publications on energy conservation, the following six assumptions appear to be justifiable:

1. By means of thermal insulation, air-tight construction, high performance appliances etc., the heat demand for the built environment and services can be reduced to 1/3 of its present value (15, 16).
2. Implementation of heat regeneration, coproduction of power and heat, utilization of waste heat, etc., will reduce the net industrial demand for low temperature heat (below 150°C) by 50% (15).
3. The industrial power plus high temperature heat demand will be equal to the present one, a modest increase of the industrial activity remaining possible because of a higher industrial energy efficiency (15).
4. The industrial demand for fuels for non-energy use (e.g. as a raw material for the manufacture of plastics) will remain constant.
5. The efficiency of central power stations will, sometime in the next century,

reach 50%, as compared to 40% at present. Moreover, half of the waste heat of the power stations will be utilized, preferably for district heating. Further, the end use of electricity will have increased by 25% as the higher efficiency of electrical equipment and appliances will to the greater part be compensated for by a large increase in their number (in particular for information purposes).

6. The fuel needs for transport will remain substantially constant because improvements in efficiency and organisation will be annihilated by an increase in the capacity of the transport system.

Finally, a very crucial assumption has to be made regarding the space that will be available for the accommodation of solar installations. Solar collectors for heating purposes, which can be mounted on roofs, need not be taken into account here as they do not really require separate land area. Also, the energy production from waste does not require much land, because of its high production density. So the problem reduces to the accommodation of the photovoltaic and the photochemical installations and the photothermal installations in the industry. No doubt an adequate energy supply is of fundamental importance for an industrialised society, and not less important than e.g., good transport facilities. On this ground, assume that a land area equal to the present land area of present roads can and will eventually be made available for the accommodation of these solar installations. This amounts to 750 km^2 , or 2.3% of the land surface of the Netherlands, excluding rivers and the larger lakes.

THE CONDITIONAL OR CRES MODEL FOR THE NETHERLANDS

The conditional or CRES model for the Netherlands resulting from the foregoing assumptions is summarised in Fig. 6. The first column in the table gives the fuel use for the various societal sectors in 1979 and the second column the corresponding primary energy supply after implementation of the conservation measures mentioned above, but completely based on fuel (fossil and/or nuclear). In the third column the energy supply is split into "fuel" and "renewable" parts. The corresponding land use is given in the last column. In the bottom part of the table the final results are given. In short, it appears that over the long term roughly half the Dutch energy supply may be derived from renewable energy sources, without an unduly large engagement of land area. As this is a surprisingly large fraction it may be useful to point out that this fraction still represents less than 1% of the solar radiation energy. It is also useful to repeat that the figures are of an illustrative character; e.g., "roughly half" is equivalent to "between one third and two thirds".

SECTOR	PRESENT FUEL USE (1979)	EFFICIENT FUEL USE (2050)	R.E.S. (TYPE) AND/OR FUEL (2050)	LAND USE ₂ (KM ²)
ELECTRICITY	15000	15000	2500 WIND 2500 PHVC 5000 FUEL	(100) 100
BUILT ENVIRONMENT + SERVICES	27000	9000	(1250) WSTE 5400 PHTL 2350 FUEL	(120)
INDUSTRY LOW TEMP. HEAT	6000	3000 (+3000)	1800 PHTL 1200 FUEL (3000) WSTE	40
INDUSTRY POWER + HIGH TEMP. HEAT	12000	12000	12000 FUEL	-
INDUSTRY NON-ENERGY	14000	14000	14000 FUEL	-
TRANSPORT	10000	10000	10000 FUEL	-
TOTAL	84000	63000	61750 ')	750
ACTUAL GROSS FUEL USE OF WHICH: ENERGY FROM (BIO)WASTE PHOTOCHEMICAL FUEL NET USE OF IMPORTED FUEL ") FUEL DISPLACED BY R.E.S. ")			44550 - 4200 -10000 30350 31400	↑ : : : 610

') REAL + DISPLACED FUEL

") FOSSIL, NUCLEAR OR PHOTOCHEMICAL

") INCLUDING (BIO) WASTE

Fig.6. Conservation and Renewable Energy Source Model for the Netherlands some-time in the next century. All energy flows in MW. The RES displace roughly half of the fossile and/or nuclear fuel. Numbers between brackets do not enter in additions. For premises see text.

It might be argued that the model reflects an undue confidence in the future of the still very hypothetical photochemical conversion, because about half the renewable energy is expected from that source. However, this objection cannot be sustained because photovoltaic electricity may also be used for the production of "renewable fuel" (e.g. hydrogen). The difference between the assumed photo-voltaic and the photochemical conversion efficiencies (25% and 15% respectively) can easily compensate for the losses associated with the additional conversion process. It deserves attention that the average production of the conventional power stations is reduced by a factor of 2.4 in the CRES model. The reduction in the installed capacity will have to be less, however, because of the inter-action with the renewable power supply and the resulting load fluctuations.

SOME ECONOMIC ASPECTS OF THE CONDITIONAL CRES MODEL

The potential of renewable energy sources according to the conditional CRES model might be designated as to their technical potential. It goes without saying that economical and political considerations will also strongly determine the real potential. Data permitting firm conclusions are lacking here, but a few preliminary viewpoints can be developed. Fortunately, all calculations on the costs of energy conservation can be skipped as energy conservation pays for itself at today's energy prices.

The lowest future price for solar domestic hot water installations mentioned in a recent report from the Energy Study Center (17) is Dfl. 400/m² collector area (V.A.T. excluded). With some optimism it may be argued that the effects of mass productions and technological progress might reduce this price to, say Dfl. 300/m² (accounting for inflation). Regarding photovoltaic installations, a price of about Dfl. 1500/m² is projected for 1985 and large additional improvements are expected for the years thereafter (3). Photovoltaic technology is still in its infancy so it is not impossible that a similar price of Dfl. 300/m² of cell area can be approached in the distant future. This estimate is slightly below the total installation price implicitly assumed in a recent study (18). As regards photochemical conversion, it can be argued that either its price will have to be comparable to that of photovoltaic cells plus the costs of electricity into a fuel, or it will not be utilized at all.

Consequently, the most optimistic estimate on the future investment for solar installations that can be made is Dfl. 300/m² of collecting area (which may e.g., be the mirror area in concentrating devices). This brings the investment for the complete 870 km² of collecting area, mentioned in Fig. 6, to about Dfl. 260 billion as a minimum. Note that the costs for a windenergy system are not included in this estimate. The fuel flow displaced by the solar systems corresponds to a power of 22.2 GW (2x 2500 MW for the wind energy has to be excluded). From a technical point of view, a number of nuclear breeder power stations might - in the long term - equally well provide for this power. With a load factor of 50% and a unit investment of Dfl. 5000/kWe installed, such a park would require an investment of Dfl. 220 billion, which is not much below the investment in the solar systems. Three points should be kept in mind, however:

- both lower and higher costs are quoted for nuclear breeder power stations;
- the "fuel" of the solar system is free and indigenous, contrary to the nuclear fuel; and
- the estimate for the solar systems is - as mentioned before - the most optimistic one that can be made. (Remark: low temperature waste heat can be gained from the nuclear power stations but, at least in principle, also from photovoltaic and photochemical conversion units).

An other interesting investment comparison in this context is a comparison with the capital value of the Slochteren natural gas fields. Assuming parity with oil (at US \$ 36/barrel) on an energy content basis, the present world market price of Slochteren natural gas is about Dfl. 0.37/m³. For the proved reserves of 1400 Gm³, this corresponds to a capital value of about Dfl. 500 billion, amply exceeding the investments estimated for the RES systems.

This result again suggests another comparison: For the turn of the century a domestic natural gas consumption of about 30 Gm³/year is being planned. This corresponds to an average energy flow of 30 GW, which is roughly the same order of magnitude as the energy flow from the RES systems. So directing the windfall profits of the Slochteren gasfields towards the building up of a RES supply system might, as it were, perpetuate this field for many years to come. Regarding this system as a national asset and consequently counting only the costs for keeping it up, i.e. approximately 2.5% depreciation (lifetime 40 years) and 1% maintenance, the price of the equivalent of 1 m³ of natural gas would be almost equal to the present world market value of our natural gas (and about 1/3 of the value from the viewpoint of economic growth (19)).

SOME ENERGY-POLITICAL ASPECTS OF THE CRES MODEL

However, such an approach would not be economically optimal, nor sound from an energy-political point of view. Inspection of Fig. 3, but also common sense, teaches that the intensity of solar radiation is appreciably higher in southern Europe than in the Netherlands. Correspondingly, the productivity of solar installations will be appreciably higher and the costs of photovoltaic electricity and photochemical fuels will be appreciably lower than in the Netherlands. In general fuels and, to a lesser extent, electricity can be transported over large distances at moderate costs. From a strictly economic point of view it is clear, therefore, that these forms of energy should preferably be imported from southern Europe, and should not be produced in the Netherlands. Taken to its extreme, this approach would leave only the non-conveyable forms of energy, heat at low and intermediate temperatures, together with windenergy and waste-biomass, as the real, economical potential of a RES. According to Fig. 6 this potential amounts to some 16 GW (displaced fuel), corresponding to about 25% of the future energy demand. The missing 75% would have to be imported in one or other form.

It is obviously an energy-political question whether such a high degree of energy dependence is acceptable. The most important considerations in this connection are:

- Which amount of energy is of such a vital importance, e.g. for food processing and transport, for medical care, for communication etc., that it has to be available from indigenous sources in all circumstances?
- To which degree will the European Community grow to such a real unity that the

exchange of energy between its members will be reliable, even in adverse conditions?

- To which extent are the members of the European Community really prepared to participate in the development of a common, integrated renewable energy supply system that can meet all sensible requirements of both environmental care and energy independence?

Only history will give the final answer to the last two questions, but the answer depends on the actions taken.

The first question requires careful further analysis, for the answer will largely determine the size of the independent energy supply system which will have to be created. As long as it is unknown whether this basic or emergency system will have to cover more than 25% of the normal future energy demand, it remains an open question which part of the 50% technical potential of the RES will actually have to be exploited.

REQUIRED GOVERNMENTAL AND INDUSTRIAL ACTIONS

Whatever the results of further and more detailed studies on the just mentioned issues may be, it is clear that, in the long term, RES are the only proved indigenous energy resource for the free countries of Europe. Taking also into account the environmental quality of RES, it is clear that the individual governments and the European Commission should consider this energy source much more seriously than they are doing now. For the Netherlands this means that plans should be developed for the gradual implementation of low and intermediate temperature solar heat, of windenergy and of waste-biomass conversion. Further fundamental research in the photochemical conversion and fundamental and applied research on the photovoltaic conversion should be promoted in co-operation with other European countries.

For industry, the actions in the context of the CRES model lie primarily with the manufacture and application of energy efficient equipment and processes. For renewable energy sources a small but rapidly expanding home market offers interesting opportunities in the fields of windenergy, biomass conversion and low and intermediate temperature solar heat. Further, but only in a European context, the development of photovoltaic conversion devices looks promising. Here specific applications for remote locations should be pursued first, as more widespread application will take another five to ten years. Finally, photochemical conversion is of only marginal significance for the industry at present, as many more years of laboratory work are required for the sorting out of the options.

In the meantime everybody should be aware of the instability and the revolutionary character of the world energy supply situation. Surprises will be normal for many years to come.

CONCLUSIONS

From the analyses presented in this paper, the following conclusions can be drawn:

1. Provided that energy efficiency is pursued to its sensible limits, the technical potential of renewable energy sources sometime in the next century amounts to roughly half the future energy demand in the Netherlands. The related costs are high but not prohibitive.
2. Provided that a real European co-operation can be established, restricting the domestic production of renewable energy to roughly one quarter of the demand offers an economically better solution. The said production should be mainly directed toward the utilization of windenergy and of waste-biomass, and the production of heat at low and intermediate temperatures.
3. Real participation of the Dutch government and industry in European efforts in the fields of photovoltaic and photochemical conversion is a necessary condition for the establishment of the required European co-operation. This equally applies to the government and industries of other northern European countries.
4. Renewable energy sources constitute the only proven indigenous energy source for the free countries of Europe by the middle of the next century.

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