THE IIASA SCENARIOS OF 1981 COMPARED WITH THE IEW RESULTS OF 1992

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Foreword

The Environmentally Compatible Energy Strategies (ECS) Project at IIASA focuses on the mitigation of energy-related sources of greenhouse gases and on the assessment of the impacts of and adaptation to global warming. An important part of this research constitutes scenario development and analysis. For example, two IIASA networks, the International Energy Workshop (IEW) and CHALLENGE, deal specifically with the comparative assessment of energy scenarios and projections. These activities build on a long tradition at IIASA of developing and analyzing long-term global energy scenarios.

More than 10 years ago, IIASA's Energy Systems Program published several scenarios of global energy demand and supply for the period 1975 to 2030. Two of them, the High and the Low Scenarios, received particular attention, both from the modeling community and from their critics. The author of this paper provides quantitative evaluations of how accurately the scenarios captured the actual development between the time of their formulation and today. Those parts of the scenarios that pertain to the future are compared with current long-term projections of global energy demand and supply. These projections are collected and evaluated within the IEW that is jointly organized by Stanford University and IIASA.

The main conclusion of the paper is that the Low Scenario has captured rather well the actual development. The scenario values for the years from 2000 to 2020 are in line with ranges of current projections. One exception is the anticipated high rate of growth of nuclear energy compared with its actual development and current expectations. From current perspectives, such high rates are clearly unrealistic.

One of the main methodological conclusions of this paper is that much of the controversy following the publication of the IIASA scenarios in 1981 was largely a consequence of an insufficient distinction between the normative and descriptive aspects of the scenarios, both on the part of the modelers and their critics. Normative scenarios describe a desirable, but not necessarily likely, future development path. Thus, they include explicit value judgements and preferences of the scenario developers. Conversely, descriptive scenarios attempt to describe likely future developments under a range of plausible assumptions concerning a continuation of current trends and energy policies. The good track record of the IIASA Low Scenario clearly illustrates that it is a prime example of the descriptive scenario category.

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The IIASA scenarios of 1981 compared with the IEW results of 1992

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Abstract: In 1981 the Energy Systems Program at the International Institute of Applied Systems Analysis (IIASA) published five scenarios of global energy demand and supply for the period 1975–2030. At least two of them, the high and low scenarios, are still quoted today. This paper analyses how accurately the IIASA scenarios of 1981 captured the actual development during the first 15 years of their time horizon. Those parts of the scenarios that refer to developments still in the future are also compared with current views of the long-term development of the global energy system as expressed in recent results collected by the International Energy Workshop (IEW). The comparisons show that the low scenario of 1981 came closest to actual developments up to 1990. With the exception of nuclear energy, its further projections fall well within the range of today's global energy scenarios.

Key words: evaluation of long-term energy projections, global energy scenarios, IIASA, International Energy Workshop.

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1 INTRODUCTION

More than ten years ago, the Energy Systems Program at the International Institute of Applied Systems Analysis (IIASA) published *Energy in a Finite World* [4], a detailed report of research results achieved in the 1970s. The most visible part of the report, the description of two globally comprehensive scenarios of energy demand and supply for the period 1980–2030, has often been criticised, and the reverberations of the two widely known articles by Keepin [5] and Wynne [11] in *Policy Sciences* are still found in more recent articles such as Dake [2], where they figure prominently as negative examples. Most of Keepin's and Wynne's criticism dealt with the way the scenarios had been derived and presented, culminating in the conclusion that they were merely input assumptions made by the modelling team and its leader which had hardly been processed, and that they were therefore biased.

In contrast to such process-oriented criticism of the IIASA scenarios, the time now seems right for a quantitative evaluation of how accurately they captured the actual development between the time of their formulation and today. At the same time, those parts of the scenarios that refer to developments still in the future will be compared with current views of the long-term development of the global energy system. As a reference, we use recently published projections of global primary energy demand and supply [6], collected by the International Energy Workshop (IEW), which cover the period between 1990 and 2020 in steps of ten years. For the comparison, the multitude of IEW poll responses for any individual item will be summarized by medians and precisely defined ranges.

2 THE INTERNATIONAL ENERGY WORKSHOP POLL

The International Energy Workshop (IEW) is a network of analysts concerned with international energy issues. Since 1981, the IEW has been organizing an on-going poll that surveys international projections of crude oil prices, economic growth, primary energy consumption and production, and energy trade. The poll results are published semi-annually, and all responses are reproduced with a publication date not

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International Energy Workshop Poll

Please do not make changes to the definitions indicated here. Leave out a number rather than making major changes to the items described here. Minor changes (such as "includes bunkers") can be formulated as footnotes. Ranges should be replaced by midpoints. Alternatively, more than one scenario may be submitted for a given region (on separate poll forms). Please TYPE your response!

Country/Region:__________

Organization/Project:__________

Reference (including date) of most recent report:__________

	1990	2000	2010	2020
1. International price of crude oil (e.g., Arabian Light) in [$90/bbl]				
2. Real GNP (or GDP) Units: Index numbers, constant purchasing power, 1990 = 100	100			
Primary energy, commercial, million tons of oil equivalent (mtoe)[1]				
3. Total consumption				
4. Total production				
5. Oil, consumption[2]				
6. Oil, production[2]				
7. Oil, exports – imports[2]				
8. Natural gas, consumption				
9. Natural gas, production				
10. Natural gas, exports – imports				
11. Coal, consumption[3]				
12. Coal, production[3]				
13. Coal, exports – imports[3]				
14. Hydroelectric and geothermal				
15. Nuclear energy				
16. Solar and other renewables				
Secondary energy, terawatthours (TWh)				
17. Total electricity generation				

[1] Useful approximations:

1 mtoe	≈	10^{13} kilocalories
0.65 mtoe	≈	1 million tons coal
0.83 mtoe	≈	1 billion cubic meters natural gas
23.5 mtoe	≈	1 quad BTU
22.5 mtoe	≈	1 EJ (10^{18} Joules)
50 mtoe/year	≈	1 million barrels daily

[2] Oil includes natural gas liquids, unconventional oils and synthetics based on tar sands and shale oil.

[3] Coal includes solid fuels such as lignite and peat. Includes coal consumed for manufacture of synthetic fuels.

Figure 1 *The International Energy Workshop Poll form.*

older than three years and summarizing the responses for major world regions in the form of histograms. Figure 1 shows the IEW poll form as it is currently used.

To give an idea of a typical IEW result and to lead into the discussion of the IIASA scenarios, Figure 2 shows the most recent histograms, one for each point in time, of projections of global primary energy consumption according to the poll report of January 1992. Each asterisk represents one response. In addition to the individual responses, Figure 2 shows a series of three intervals around the central cluster

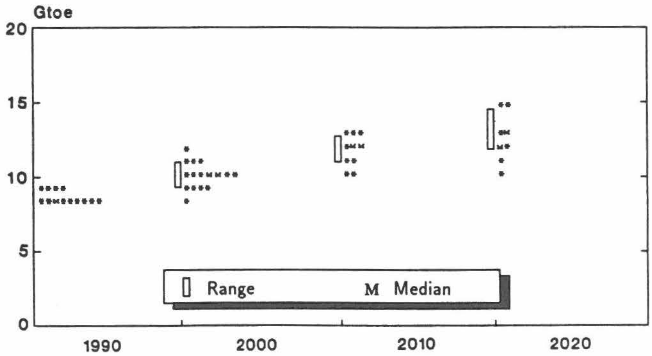

Figure 2 *Projections of global primary energy consumption and IEW poll ranges for January 1992 (1/1992).*

of responses for each year. Although these ranges could also be interpreted in probabilistic terms—because they have been derived using a common statistical method—it is sufficient for the arguments presented here to regard them as a formalized quantification of the variability of all poll responses to a given item. According to the method chosen, the intervals are two standard deviations wide and are centred on the mean of a log–normal probability density function. They cover some 68 per cent of the total probability according to the estimated probability distribution. In the following, these intervals will be referred to simply as *ranges*.

Another descriptor of a given set of poll responses for a particular item is the *median*, i.e. the response that has the same number of responses above and below itself. (In the case of an even number of responses, we take the arithmetic mean of the two middle responses.)

3 A BRIEF CHARACTERIZATION OF THE IIASA SCENARIOS

In addition to the detailed descriptions of the high and low scenarios, *Energy in a Finite World* (EFW) included three scenarios that had received much less attention during their preparation and dissemination. We will include here one of these three cases of sensitivity analysis, i.e. the 16 Terawatt (16TW) scenario. (For a long time, the IIASA scenarios were nicknamed by their global energy demand in the year 2030. It was only the 16TW scenario, in which this value did not change over time, which kept its name until publication. The other two cases analysed sensitivities with respect to nuclear power. A variant of the high scenario assumed higher growth rates for nuclear energy, and a variant of the low scenario assumed a moratorium on newly ordered nuclear reactors after 1979.)

Most of the input assumptions defining the shape of the EFW scenarios were formulated in the years 1976–79. Many events that influenced expectations about the future of the global energy system in the mid-1980s are therefore not reflected. Among these are the second oil price rise of 1979/80 and the Three Mile Island nuclear reactor accident—not to mention Chernobyl. The view of the future energy supply was determined by a perceived scarcity of energy resources, and the IIASA scenarios were the first to leave no gaps in a globally comprehensive picture of long-term energy demand and supply. This latter characterization is important because, at that time, the widespread pessimistic view of the global resource situation included serious doubts as to whether long-term economic growth could be sustained by an ever-increasing energy supply. Then, it seemed necessary to make a number of heroic assumptions to describe a consistent picture of demand and supply for fifty years into the future. Indeed, many of the assumptions leading to the two scenarios were considered extreme by insiders as well as by outsiders.

An important strategic design principle was that the IIASA scenarios were meant to be descriptive rather than normative. In other words, they were formulated to describe a range of plausible paths rather than limiting cases or particularly desirable developments. A formulation used to express this point was the designers' intention to capture the actual development between the high and the low scenario with a probability of 50 per cent. According to this rough rule, it was considered that one would be as likely to see the actual development of global energy demand be confined to the limits set by the two scenarios as to see it exceed them either on the low or the high side.

This expectation concerning the likelihood that the high and low scenarios may serve as the first example of originally held expectations that had to be modified soon after. From today's view of global energy demand developments, it would have been more realistic to take the 16 Terawatt scenario more seriously and to analyse it in a degree of detail comparable with the high scenario.

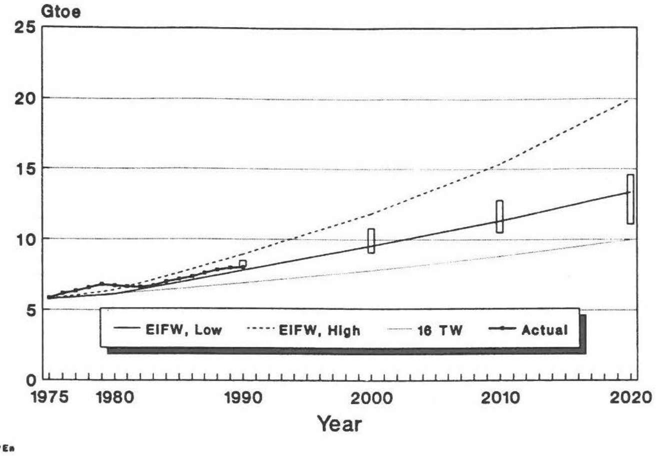

Figure 3 *Three IIASA scenarios: high, low, and 16 Terawatt.*

Table 1 *EFW results and IEW medians (Mtoe).*

Scenario	*Region*	*Year*			*EFW/IEW ratio*		
		2000	*2010*	*2020*	*2000*	*2010*	*2020*
EFW, high	TECs	2.60	3.25	4.13	1.16	1.39	1.45
	OECD	5.75	6.85	8.12	1.25	1.34	1.57
	ROW	3.50	5.27	7.68	1.10	1.27	1.63
EFW, low	TECs	2.25	2.75	3.03	1.01	1.17	1.06
	OECD	4.72	5.16	5.63	1.02	1.01	1.09
	ROW	2.60	3.42	4.70	0.82	0.83	1.00
EFW, 16TW	TECs	1.61	1.76	1.92	0.72	0.75	0.67
	OECD	3.48	3.49	3.49	0.75	0.68	0.68
	ROW	2.15	2.97	4.11	0.68	0.72	0.87
IEW	TECs	2.24	2.34	2.85			
	OECD	4.61	5.13	5.17			
	ROW	3.18	4.15	4.72			

4 PROJECTIONS AND THE ACTUAL DEVELOPMENT OF ENERGY DEMAND

We begin the evaluation of the IIASA scenarios with a comparison of global primary energy consumption. Figure 3 shows IIASA's high, low, and 16TW scenarios between 1975 and 2020, together with the actual development (according to [1]) to 1990. (The values of the 16TW scenario were derived for the year 2030 only. The curve shown in the figure and the numbers in Table 1 below are therefore the result of an interpolation between 1975 and 2030, shown until 2020.) For the years 1990, 2000, 2010, and 2020, Figure 3 also shows IEW ranges (as defined above) as narrow rectangles. This comparison shows that the high and the 16TW scenarios stay outside the mainstream of today's projections, but the low scenario moves well into the centre of the IEW range. The actual development between 1975 and 1980 shows that, at that time, the high scenario did not look high at all.

To find out how accurate the IIASA scenarios were in different parts of the world, we look at a disaggregation of the global results into three regions, i.e. transforming economies (TECs, the former Soviet Union and Eastern Europe), the OECD, and the rest of the world (ROW), including all developing countries, for the years 2000, 2010, and 2020. Table 1 shows that the biggest overshoot relative to IEW projections in the high and low scenarios—both in absolute and in relative terms—occurs in the industrialized part of the world. The same comparison with today's projections shows that in the 16TW scenario the primary energy consumption figures are low, reduced by about the same factor across the regions and across the time periods.

With this summary comparison we shall conclude the analysis of the EFW high and 16TW scenarios, and restrict the more detailed numerical evaluation to the low scenario.

5 COMPARISON OF PRIMARY ENERGY SOURCES

Figure 4 shows the projections of global oil consumption. Here, the IIASA low scenario reflects the 1973 oil price rise by projecting a depressed consumption between 1975 and 1980. After that, global oil demand rises to a kind of asymptote. In contrast, the actual development is shown to have been more influenced by the 1979/80 oil price peak than by the earlier price rise of 1973. Present IEW poll ranges do not show a clear trend because of the different sizes of the intervals. Looking at the years 1990–2010 only, the IEW shows a slight increase in global oil consumption.

In the IIASA scenario, the slow-down of global oil consumption growth after 2010 is explained by the substantial amount of coal-based synthetic fuels in this projection. This is illustrated by the comparison of the coal projections in Figure 5, in which coal consumption in the IIASA low scenario is the result of two substitutions, i.e. of massive

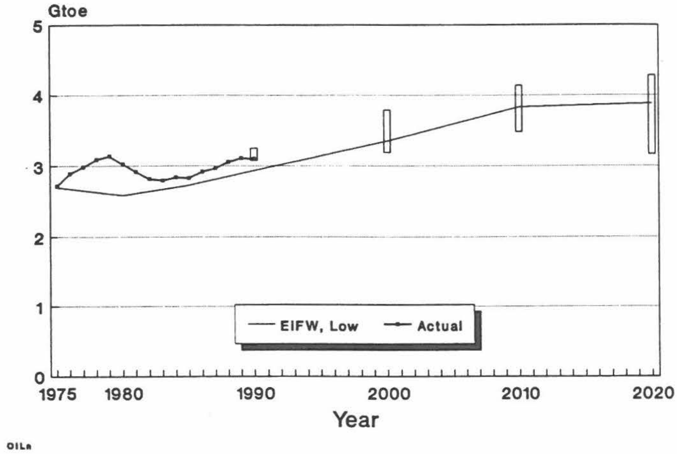

Figure 4 *Global oil consumption, IEW 1/92 and EFW low.*

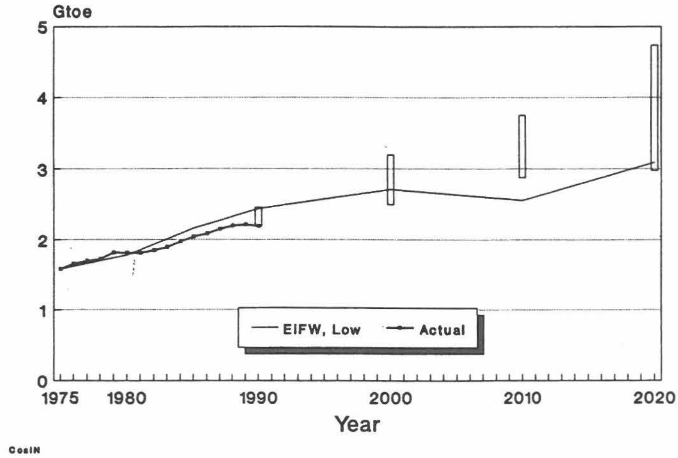

Figure 5 *Global coal consumption, IEW 1/92 and EFW low.*

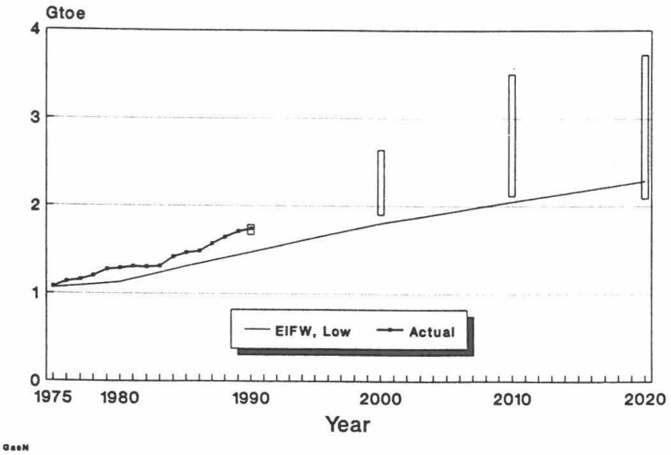

Figure 6 *Global consumption of natural gas, IEW 1/92 and EFW low.*

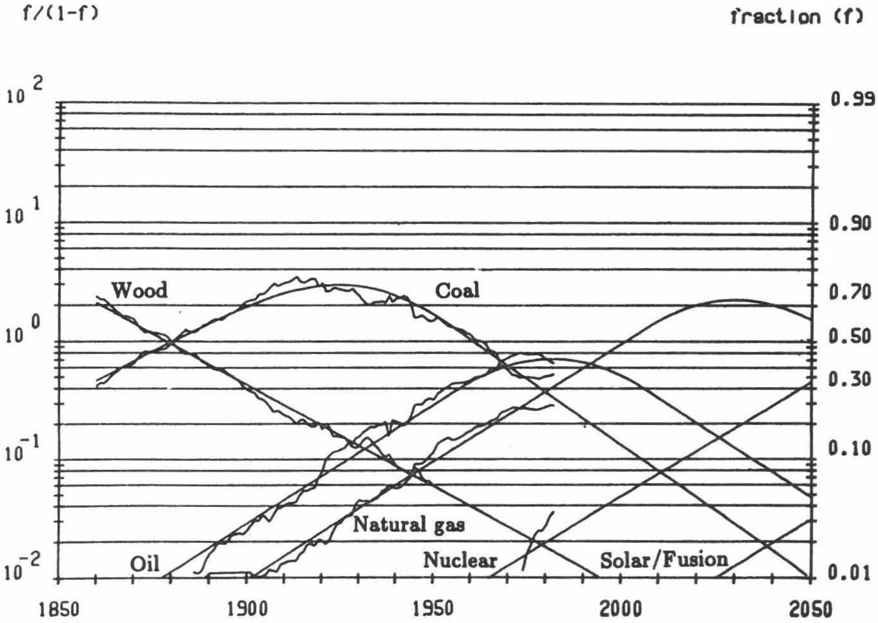

Figure 7 *Global primary energy development, logistic substitution model.*

replacement of coal-generated electricity by nuclear energy after the year 2000 and the equally dramatic increase of coal demands for liquefaction one decade later. Today's projections show a steadily increasing coal consumption through the year 2020 and significant disagreement among the IEW poll respondents, expressed by the increasing ranges of responses for the more distant years.

The IIASA projection for global natural gas consumption (see Figure 6) is rather low in comparison with the most recent IEW poll ranges. This is a surprising result because natural gas plays a much bigger role in other parts of EFW (see, for example, EFW, Chapter 8, and the results of the logistic substitution model below—see also Figure 7 below—which suggest that during its peak contribution, natural gas might

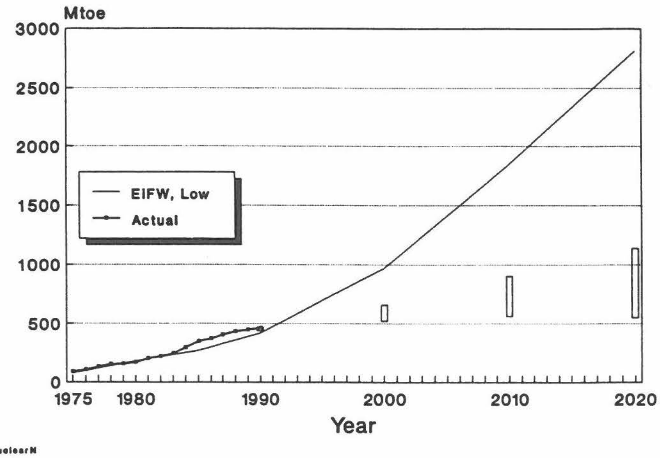

Figure 8 *Global consumption of nuclear energy, IEW 1/92 and EFW low.*

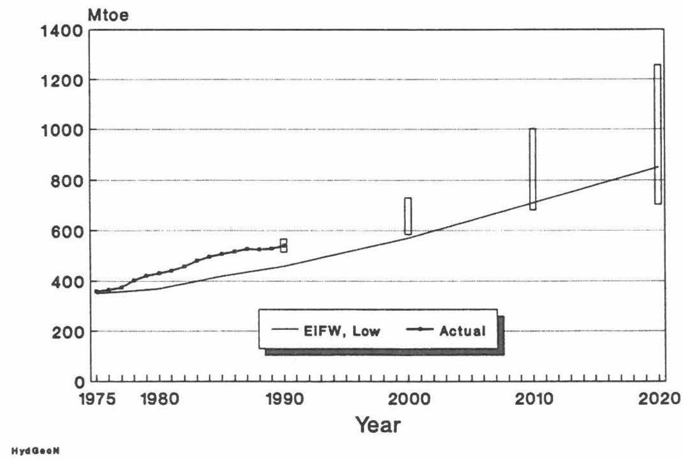

Figure 9 *Hydro and geothermal energy, IEW 1/92 and EFW low.*

supply more than 50 per cent of global primary energy demand). As in the case of coal, the IEW ranges reflect significant disagreement among the poll respondents.

The biggest miss of the low scenario is shown in Figure 8, where its projection of nuclear energy is compared with today's 'conventional wisdom'—presumably as reflected in the IEW poll ranges. By the year 2020, the low scenario deviates from the IEW median by at least a factor of three, although its record during the 1980s is between low and accurate. This means that the trends identified in the late 1970s and prevailing until 1990 had been too readily extrapolated beyond that date. Once again, the IIASA scenario failed to appreciate the warning sign given by the logistic substitution ('market penetration') model which suggested that the observed growth rates of nuclear energy in the late 1960s and early 1970s were in excess of what had been observed until that date (see Figure 7).

The comparison for hydro and geothermal energy (Figure 9) shows that EFW low underestimated the near-term potential (1980–90), but that it follows the mainstream of IEW responses between the years 2000 and 2020.

The picture for the IEW poll item 'solar and other renewables' (in Figure 10) tells a story of its own. It seems hardly possible to generate a trajectory that falls outside the

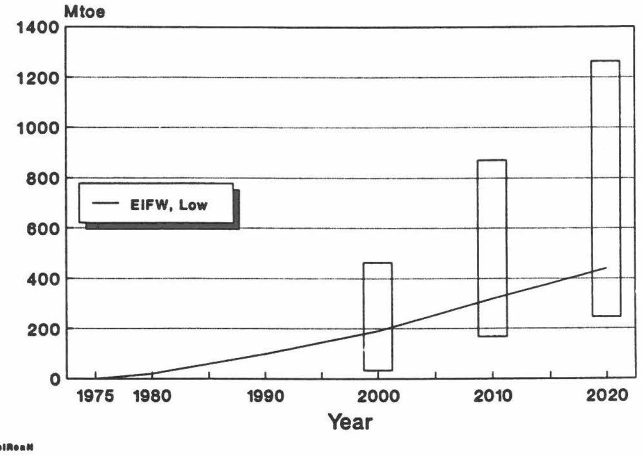

Figure 10 *Solar and Other Renewables, IEW 1/92 and EFW low.*

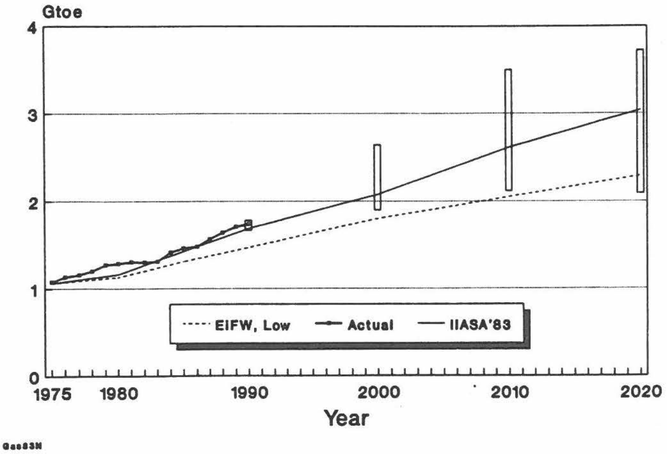

Figure 11 *Gas consumption, EFW low, IIASA '83, and IEW 1/92.*

IEW poll ranges. For the year 2000, for example, the ratio between its high and its low end is more than 13! This rather inconclusive pattern of projections for this item has been observed for some time (see, for example, Manne and Schrattenholzer [7]). It seems to indicate that there is no agreement within the forecasting community as to the definitions involved. This hypothesis is supported by the fact that the individual projections already diverge in the near-term. For the same reason, there seem to be no current statistics that could establish a reasonable reference trajectory. It is therefore omitted from this figure.

6 THE IIASA '83 SCENARIO

As has been described above, EFW reported on work that had mostly been done some years prior to the book's publication in early 1981. The events of the years around 1980 led to modified expectations in the early 1980s which resulted in the new IIASA '83 scenario [10]. IIASA '83 responded to the observations that the high scenario was an overestimation, and that a modified low scenario would be a reasonable best estimate in 1983. It eliminated major shortcomings of the original high and low scenarios, that is: (i) the high scenario

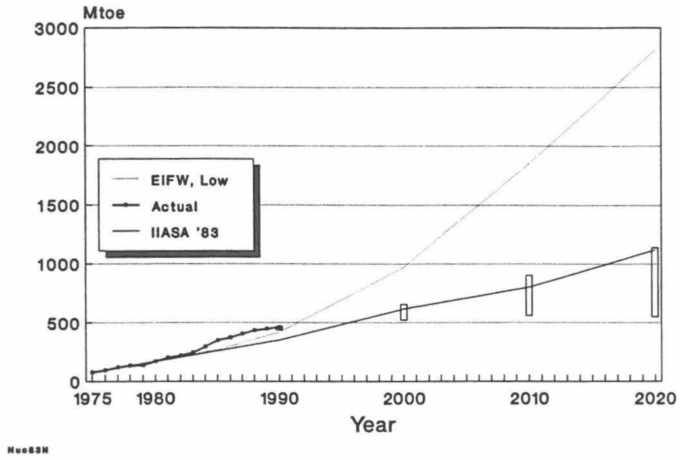

Figure 12 *Nuclear energy, EFW low, IIASA '83, and IEW 1/92.*

altogether; (ii) the irregular growth rates of the consumption curves for oil and coal in the low scenario; (iii) the underestimation of natural gas consumption; and (iv) the massive overestimation of the contribution of nuclear energy to the future energy supply. Figures 11 and 12 show typical results of the IIASA '83 scenario in comparison with the low scenario and the IEW ranges.

7 CONCLUDING REMARKS

The purpose of this article was to evaluate the quantitative results of IIASA scenarios that were published more than ten years ago. It turns out that only one of the two major scenarios, the EFW low scenario, warrants a closer look. The other two considered here, the high and the 16TW scenarios, are clearly outdated. Still, important lessons can be drawn from comparing all these scenarios with recent projections collected by the International Energy Workshop poll. It turns out that the low scenario's paths of global energy consumption are for most energy sources hardly distinguishable from recent projections as represented by ranges of IEW poll responses.

In conclusion, we want to look at the critics' own energy projections. This task is not so easy because most of the critics failed to present alternative scenarios of their own. A notable exception is Goldemberg *et al.* [3], who deserve credit for doing so in their publication *Energy for a Sustainable World.*

Table 2 *Global primary energy consumption: comparison of Goldemberg et al. and IEW poll medians.*

	1980	*1990*	*2020*
Goldemberg *et al.*	7.26		7.89
IEW poll 1/92		8.30	12.74

It is, of course, much too early to evaluate Goldemberg *et al.*'s projections from a decade's distance, but let us take a preview of what we can expect to find in 1998. Table 2 shows a comparison between their base case projections and IEW poll medians. The projection for the year 2020 has already been surpassed in 1990. (Goldemberg *et al.*'s base case values of global primary energy consumption are even lower than IIASA's 16TW scenario which, in fact, was exempted from the otherwise unsparing criticism of the high and low scenarios. They did not even mention it—at least not in connection with EFW.) Although a decrease in global primary energy consumption over the next couple of decades cannot be ruled out completely, the difference between current projections and Goldemberg *et al.* is ever increasing. In our view, this discrepancy demonstrates the difference between *descriptive* (as presumably represented by the IEW poll respondents) and *normative* scenarios as described in the latter publication. Their normative approach is certainly justified as a blueprint for a global energy system that, in comparison to business-as-usual projections, has many attractive features. However, plausibility is not among them, most probably by design.

On a general methodological level, it seems that the purpose of a scenario is the main key to its evaluation. Descriptive scenarios should be evaluated by the difference between their projections and the actual development, rather than by the assumed intentions of their authors. In contrast, normative scenarios should be judged relative to their self-imposed goal. Unless this goal explicitly includes a particular probability for their occurrence, they should not be expected to be realistic. Nevertheless, the deviations of their projections from the actual development can reasonably be discussed because they can tell us something about the values leading to the formulation of a normative scenario and the chances of their implementation in the real world.

Critical evaluations of projections made in the past can teach us important lessons for future initiatives in model and scenario building. We hope that this assessment of the scenarios presented in IIASA's *Energy in a Finite World* will encourage other forecasters to follow this example for the benefit of the whole energy modelling community.

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