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Perils of Long-Range Energy Forecasting: Reflections on Looking Far Ahead

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ABSTRACT

Critical examinations of long-range energy forecasts show a remarkable extent of individual and collective failure in predicting actual developments in five distinct areas examined in this article: major energy conversions, primary energy requirements, sectoral needs, exhaustion of energy resources, and energy substitutions. This experiences demonstrates that we should abandon detailed quantitative point forecasts in favor of the decision analysis or contingency planning under a range of alternative (exploratory as well as normative) scenarios. © 2000 Elsevier Science Inc.

Introduction

Long-range forecasts of energy matters became common only a generation ago, after the OPEC quintupled the price of crude oil in 1973–1974. They now cover an enormous spectrum ranging from fairly narrow exercises focusing on capacities and performances of individual exploration, production, and conversion techniques to ambitious, and highly disaggregated, demand and price models of national, regional, and global fuel and electricity futures. Some of these models are freely available from their authors, others (such as DRI/McGraw Hill World Energy Projections) require charter subscribers to pay tens of thousands of dollars annually.

During the past 30 years I have contributed to this *oeuvre* in various ways, beginning with a long-range forecast of technical developments concerning energy's impact on the global environment [1]. In the early 1970s I also began using MIT's DYNAMO in building models embracing energy, environment, population, and economy. One of those exercises, a long-term look at CO_2 emissions from fossil fuel combustion and their role in future global warming, was published in 1974, when few people were interested in such a topic [2].

The reception given to *The Limits to Growth* [3], the most celebrated forecast of its time, which used DYNAMO to model the entire world, made me very uneasy about

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long-range predictions. When taking the model apart, line by line, I was particularly astonished by the variables labeled *Nonrenewable Resources* and *Pollution.* Lumping together (to cite just a few of scores of possible examples) highly substitutable but relatively limited resources of liquid crude oil with unsubstitutable but immense deposits of sedimentary phosphate rocks, or short-lived atmospheric gases with long-lived radioactive wastes, struck me as extraordinarily meaningless.

Despite the fact that some writings identified major flaws of *The Limits to Growth* right after the book's publication [4, 5], too many people took seriously this grotesque portrayal of the world that pretended to capture the intricate interactions of population, economy, natural resources industrial production, and environmental pollution with less than 150 lines of simple equations using dubious assumptions to tie together sweeping categories of meaningless variables. I thought I could do better—but as my models were growing progressively more complex, I was getting more troubled by them.

Greater complexity that was required to make the forecasts more realistic also necessitated the introduction of longer chains of concatenated assumptions—and this necessity was defeating the very quest for greater realism. A few years later I was glad to see some of the same feelings concerning the limits of complex forecasting summarized in Alvin Weinberg's fine article on limits of energy modeling [6].

Although I have abstained from building any bulging models of long-range energy, environmental and socioeconomic interactions, I have continued to do some fairly straightforward forecasting of basic energy conversion techniques and of aggregate national and global fuel and electricity requirements. I have also tried to keep up with at least the most interesting new energy-related forecasts. As we now have a rather rich history of such long-range forecasts, including also plenty of less formal predictions predating the era of institutionalized clairvoyance, it is possible to derive a number of interesting lessons from the fascinating discipline of backcasting.

What strikes me most when looking back is the extent of individual and collective failure. Perhaps the most remarkable aspect of the lack of imagination underlying this failure—or, conversely, of exaggerated expectations, and of often surprisingly swiftly disproved quantitative predictions—is that so many erroneous forecasts have come from eminent innovators or from individuals (or, more recently, from institutions) considered to be the leading experts in their field. I will offer first, chronologically, just a few choice examples of failed predictions of some major developments regarding new energy conversion techniques; then I will look at forecasts of aggregate commercial energy consumption; at projections timing the exhaustion of fuel deposits; and, finally, at substitutions of energy resources.

Energy Conversions

Quoting more than just a couple of examples from the 19th and the first half of the 20th century is irresistible, as those predictions turned out to be so spectacularly wrong. In 1879, just 3 years before T. A. Edison began selling electricity for lighting, the Select Committee on Lighting by Electricity of the British House of Commons [7] heard an expert testimony that there is not "the slightest chance" that electricity could be "competing, in general way, with gas." Exactly a decade later Edison himself was making a big blunder: "My personal desire would be to prohibit entirely the use of alternating currents. . . . I can therefore see no justification for the introduction of a system which has no element of permanency and every element of danger to life and property" [8].

In his biography, Henry Ford reminisced that his employer objected to his experiments with the gas engine, believing that electric car was the coming thing, and that the Edison Company offered him the general superintendency but "only on the condition that I would give up my gas engine and devote myself to something really useful" [9]. In 1901, 3 years before the Wright brothers took off, Rear Admiral George W. Melville concluded that even if man should "succeed in building a machine small enough to fly and large enough to carry himself, then in attempting to build a still larger machine he will find himself limited by the strength of his materials in the same manner and for the same reasons that nature has" [10].

In 1904, Octave Chanute, Wrights's supporter and himself a designer of excellent gliders, called on first principles when he argued that airplanes will eventually be fast "but they are not to be thought of as commercial carriers . . . the sizes must remain small and the passengers few, because the weight will, for the same design, increase as the cube of the dimensions, while the supporting surface will only increase as the square" [11]. And, in 1936, Charles Lindbergh wrote to Harry Guggenheim that he "would much prefer to have Goddard interested in real scientific development" than in "achievements which are of less real value" [12].

Technological miscasting has continued to thrive after WWII. Certainly the most flagrant energy example is the uncritical faith in electricity generation through nuclear fission. This blindness was not common only during the 1950s when excuses could be made because of the early stage of the industry's development. And it seems almost unfair to single out an individual by an embarrassing quote (no shortage of those!) as so many physicists and engineers, including a number of Nobel Prize winners, foresaw a world shaped by ubiquitous and inexpensive nuclear energy. Nuclear fission was to produce not only all electricity but also to power cargo ships and passenger planes, its directed explosions were to uncover mineral riches, reverse river flows, and open new canals, and, installed in rockets, it was to ferry men to Mars. Nuclear energy was to open a future of abundance where "consumption, not production, will be a problem" [13].

And all of that just from classical fission, a mere prelude to breeder reactors and then to the endless supply of clean energy from nuclear fusion! But even experimental breeders have been scrapped, and nuclear fission, now supplying no more than about 7% of the world's commercial energy, is clearly moribund throughout the Western world where most of its capacity is located: neither any European country nor the USA and Canada have any plans to replace their existing aging facilities; instead, they are troubled by the prospect of decommissioning scores of reactors, and they have been unable to solve the problem of long-term disposal of radioactive waste.

As the nuclear mania faded during the 1970s, rising interest in renewable energies brought many similarly over-enthusiastic forecasts about the potential of new conversions. These nirvana techniques ranged from kelp plantations covering a large chunk of the Pacific to supply all of America's gaseous fuels [14], to wave-energy machines incessantly devouring the North Sea's swell and thus generating a surfeit of electricity for the UK [15]. Anaerobic fermentation of organic wastes, the idea of economies running on excrement, had a particular appeal to deep conservationists, and biogas was to be the fuel on which the world's most populous countries in Asia were to base their modernization. I devoted a whole book to deconstructing such feebly thought-out "soft energy" propositions [16], but I should not have bothered. They were so unrealistic that they were bound to meet the same fate as their extreme "hard energy" counterparts.

Primary Energy Requirements

Forecasting total primary energy consumption would seem to be a much easier task than glimpsing the fortunes of various energy conversion techniques. After all, the use of commercial energy is clearly tied to population growth and to the overall economic performance. Near-term population forecasts (up to 10 years) are fairly accurate, and GDPs, particularly those of mature economies, are advancing in a rather orderly fashion. Yet even when they appear to be right on, the exercises tying energy needs to population and economic growth do not really succeed much better than all those purely technical probes: two of my own forecasts illustrate perfectly this counterintuitive outcome.

In 1983, predictions of global primary commercial energy consumption submitted by the participants in the International Energy Workshop for the year 2000 ranged from 5330 million tonnes of oil equivalent (Mtoe) by Amory Lovins to 15240 Mtoe by the International Atomic Energy Agency; my forecast was 9500 Mtoe [17]. Using the actual consumption statistics for 1999 [18] and projecting just 1 year ahead (on the basis of average growth during the past 5 years, and by converting both hydro and nuclear electricity to Mtoe by using the average efficiency of fossil fuelled generation) brings the global consumption to about 9200 Mtoe by the year 2000, or 73% above Lovins's 1983 projection and 40% below the IAEA forecast.

My forecast will be off by a mere 2–3%—but I do not call your attention to it to congratulate myself for having done better than both the hard and the soft energy protagonists, but rather to tell you how wrong I was. Although I had nearly nailed the overall demand, I was much less successful on forecasting the makeup of the world's primary energy consumption. I underestimated both the use of natural gas and crude oil (by, respectively, 25 and 12%), and I overestimated the contributions of coal and renewable energies. If my breakdown would have been used for calculating the future emissions of CO_2, or emissions of SO_2 and NO_x, the gases responsible for nearly all anthropogenic acid deposition, the errors would have been considerable.

Also, my forecast of crude oil prices at the 1983 International Energy Workshop now looks quite ridiculous. I put the price of crude oil in the year 2000 30% above the 1980 level. Tenor of the time, the common bane of long-range forecasters, exercised its usual influence: in 1983 oil prices were just slightly off their historic peak they reached in 1980–1981 (spot prices of US$ 36–37 per barrel), and anticipation of further oil price increases was the norm. My forecast means that we should be paying (adjusted for inflation) about US$ 75 per barrel in the year 2000.

Only the most unlikely spectacle of Saudi and Iranian oil fields going up suddenly in smoke could save my forecast from being off by about a factor of three! The world where crude oil would wholesale for US$ 75 a barrel would be a very different place from the one where it costs about a third of that price! The only dubious consolation I can draw from this failure is that my 1983 oil price forecast was less ridiculous than that of the World Bank's chief economist (he had it 54% above the 1980 level).

In general, those institutional projections that erred on the high side of energy demand also erred on the high side of future energy prices, and hence, their demand forecasting error was even higher than is suggested by comparing them with actual energy requirements. And, despite the long historic record of falling energy intensities and changing economic structures, no institutional projections considered the impact of these changes. Today the very same methods—macroeconomic equilibrium models that fared so poorly over the short to medium term—are used by some of the same institutions to analyze climate change policies for 100 years into the future!

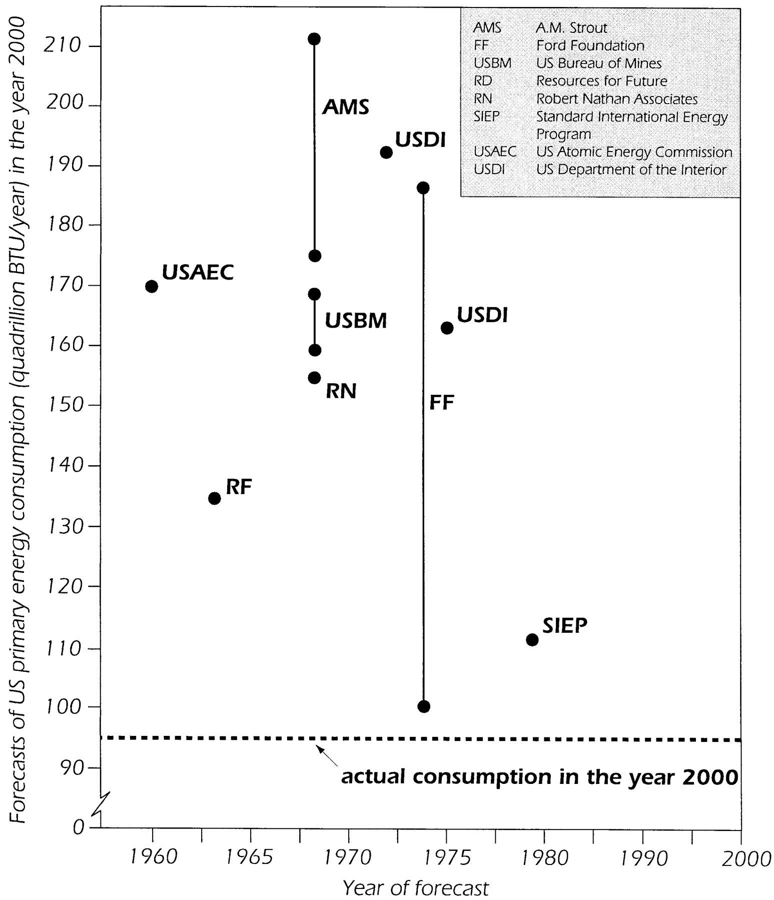

Fig. 1. Forecasts of the U.S. primary energy consumption in the year 2000.

But I have an even better example of an aggregate demand forecast whose numbers turned out very well—but where the overall setting and countless details have changed beyond anyone's expectations. Median forecasts of China's primary commercial energy consumption for the years 1985 an 1990, which I made in my first book on the country's energy written in 1975, turned out to have errors of, respectively, a mere 2 and 10% [19]. Yet, although I was certain that major changes will be inevitable, I could not have predicted the speed and the extent of China's post-1979 modernization with all of its complex implications for energy demand, economic expansion, and environmental degradation, which I traced 10 and 20 years later [20, 21]. During the 20 years after Mao's death in 1976, China's economy had grown about twice as fast as I anticipated—but its energy intensity fell by about half: I got an excellent result by being doubly wrong!

To see numerous examples of long-range projections (looking at least 20 years ahead) of national or global energy demand that have badly missed their targets requires nothing more than consulting just about every major institutional forecast done since the 1960s. Figure 1 plots the totals of some notable forecasts of the U.S. primary energy consumption in the year 2000 that were released between the years 1960 and 1979: most of them ended up at least 40–50% above the actual value (about 95 quadrillion Btu or the equivalent of 2.38 billion tonnes of crude oil).

Perhaps the most precious example of failed national long-range energy forecasting—remembered fondly, I am sure, by all those who have been around energy matters for some time—is the goal of U.S. energy independence charted by the Nixon administration for the 1980s [22]. Felix thought that the self-sufficiency can be realized by the year 1985, despite the fact that his forecast called for the consumption of some 3000 Mtoe in 1985 [23]. A reality check: in 1999 the USA imported more than a fifth of its total primary energy use, which was about 2400 Mtoe, and just over half of its demand for liquid fuels [24]!

Forecasting Sectoral Requirements

I will illustrate failures in this category by noting just the most spectacular example of totally missing a fundamental shift of a key trend: North American expectations for the growth of electricity generation during the last quarter of the 20th century. After 2 decades (1950–1970) of 7–10% annual growth (that is, doubling every 10 to 7 years), virtually every forecaster expected the identical, or even a bit faster, growth in decades ahead. Such expectations yielded incredible aggregate requirements. In 1970, in his opening speech at a meeting on environmental aspects of nuclear generation, Glenn Seaborg, at that time the Chairman of the U.S. Atomic Energy Commission, made the following forecast of the U.S. electricity needs [25]: "The projected growth of electrical generating capacity in the United States encompasses a range of estimates the median of which is 1600 million kilowatts by the year 2000. The upper limit of this range is currently about 2100 million kilowatts, which I am inclined to believe may be more realistic."

Actual U.S. generating capacity in the year 2000 is about 800 GW, less than 40% of Seaborg's "more realistic" estimate. A utility's experience is perfectly summarized by 10-year forecasts of load growth at the Southern California Edison Company: they declined from 9% in 1965 to 8% in 1970, 5% in 1975, 3% in 1980, and to just 2% by 1985 [26]. Sales of electricity in the U.S. grew by 50% during the 1970s, expanded by 30% during the 1980s—but rose just 11% during the first half of the 1990s [24].

Also, most of the new generating capacity during the last quarter of the 20th century has not been filled, in California or anywhere else in the Western world, either by multigigawatt nuclear stations sited offshore on artificial energy islands or by coal-fired turbogenerators with ratings surpassing 2 or 3 GW—but by fossil fuel-fired units of less than 300 MW, and by even smaller (less than 100 MW) gas turbines [27].

Projecting Exhaustion of Energy Resources

This is a venerable genre whose foundations were so thoroughly established more than a century ago by Jevons's book on England's bleak coal future [28]. As coal's world-wide importance receded, crude oil became the obvious target of producing running-out scenarios. These efforts now almost invariably assume the form of fitting the fixed total of recoverable oil (that is existing reserves and likely future discoveries) into a symmetrical exhaustion curve, a forecasting tool introduced by M. King Hubbert more than 4 decades ago [29]. Its use was greatly popularized by Hubbert's predictions of the permanent decline of U.S. oil extraction published during the 1960s [30].

Irrational panic caused by the OPEC's sudden quadrupling of crude oil prices in 1973–1974 produced a particularly rich crop of ridiculous forecasts. The Workshop on Alternative Energy Strategies—a major MIT-based international research program involving some 70 experts from business, government, and universities—concluded that "the supply of oil will fail to meet increasing demand before the year 2000" [31]. Oil

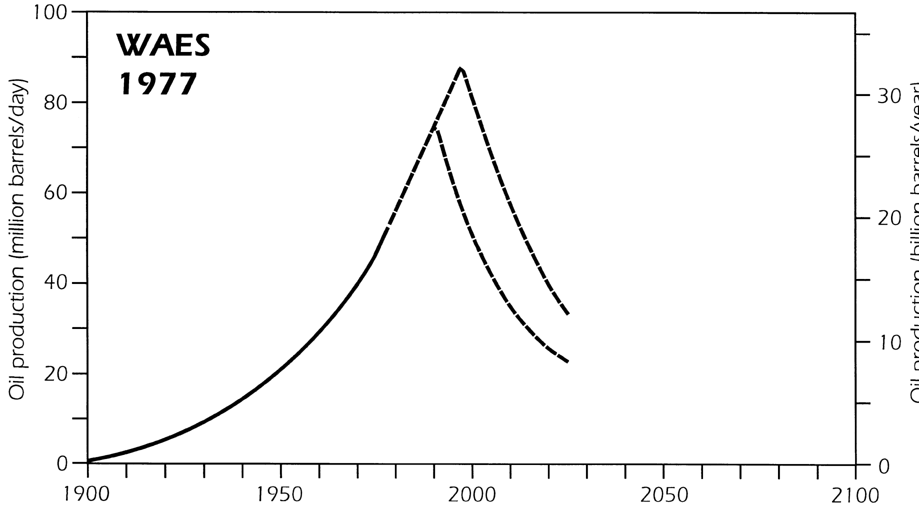

Fig. 2. Global oil exhaustion curves generated by the WAES in 1977.

exhaustion curves generated by the project showed the global output peaking as early as 1990—and no later than in the year 2004, with the most likely timing of the peak production put between 1994 and 1997 (Figure 2).

A year later, the U.S. Central Intelligence Agency offered an even more panicky projection issued at the height of Iranian revolution. The Agency concluded that "the world energy problem reflects the limited nature of world oil resources," and that, with consumption greatly exceeding supplies, the global "output must fall within a decade ahead" [32]. As a result, "the world can no longer count on increases in oil production to meet its energy needs" and it "does not have years in which to make a smooth transition to alternative energy sources." The last quoted sentence was truly astonishing, as it implied the necessity of doing something utterly impossible: converting the world's primary energy supply to a different source in a matter of months!

The latest contribution to the running-out saga is the series of studies published recently by Colin Campbell and Jean Laherrère [33–35]. They put the world's crude oil reserves at no more than 850 billion barrels, about 17% lower than the generally used *Oil & Gas Journal* summary; with no more than 150 billion barrels of oil to be discovered, we would have no more than 1000 billion barrels to produce in the future, only about 20% more than we have burned already. Campbell and Laherrère thus conclude that we have less than a decade of rising crude oil production followed by permanent decline of conventional oil output (Figure 3). Judging by the success of all of the past running-out time tables it is a safe bet that this one, too, will not come to pass [36].

Energy Substitutions

But there is one kind of energy forecasting that is supposed to be virtually error-free. Cesare Marchetti, IIASA's resident long-range energy forecaster, had studied histories of energy substitutions, and found that these transitions are remarkably orderly [37]. The process is very slow, with every new source taking about a century to penetrate half of the market share, and it is surprisingly regular: despite many possible perturbations, the penetration rates remain constant over long periods of time: "It is as though

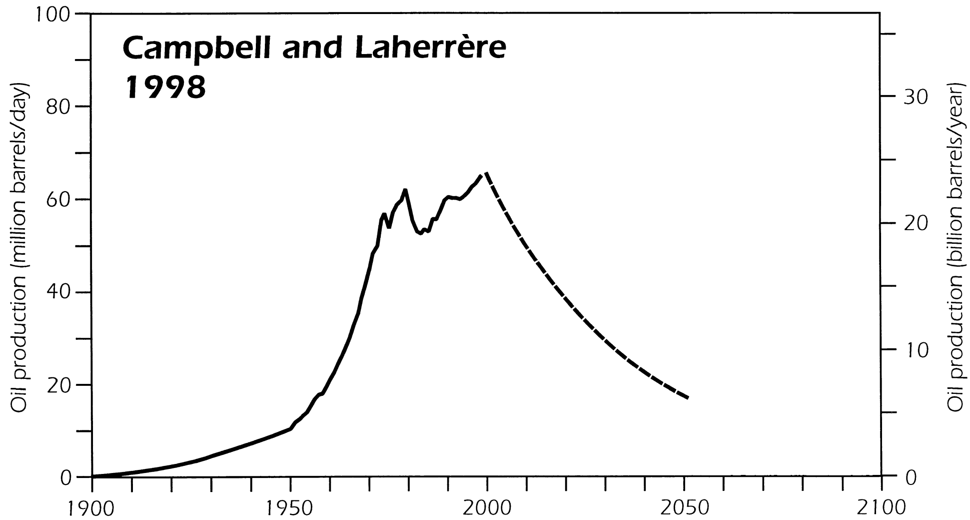

Fig. 3. Global exhaustion curve of 1750 billion barrels of liquid crude oil reserves according to Campbell and Laherrère.

the system had a schedule, a will, and a clock" [38]. As coal displaced wood and oil displaced coal, so will economic and technical imperatives ensure that natural gas, nuclear, and solar energies will displace oil: just use a revealing way to chart the past trends and watch the future unfold (Figure 4) because "all perturbations are reabsorbed elastically without influencing the trend" [38].

According to Marchetti, trying to change the course of these developments is futile: we are not decision makers, at best we are optimizers, and it is the system that is making the decisions. But Marchetti was wrong in concluding that the system's dynamics cannot be influenced. After 1973, many forces began reshaping the system on a massive scale, and the result on the global level has been a shift from a regime of energy substitution to one of largely stable energy shares with a minimal structural change. Only a decade after Marchetti made his predictions the actual share of oil in global energy consumption was well ahead of the predicted value (40 vs. 35%).

And Marchetti's model and reality appear generally unhinged in the year 2000: crude oil supplies about 37% of the world's primary energy needs, nearly 50% above Marchetti's prediction of 25%, while natural gas and coal each deliver about 25% of primary energy, a pattern very much unlike Marchetti's prediction of, respectively, 52 and 10% (Figure 5). Only the nuclear energy share is close to his forecast (7 vs. 6%), but biomass energies still provide about 6% of the world's primary energy, not less than 1% as predicted by Marchetti. Of course, Marchetti's model needs nuclear energy, and then other new sources of supply, sequentially kicking in: without them, the last entry in the substitution sequence (that is, natural gas in a world devoid of nuclear energy and renewable conversions) would have to supply eventually all of the world's energy needs!

But battered and contracting nuclear fission is not set to take over: it has been more than 20 years since any utility in the European Union or in North America ordered a nuclear reactor—and no large economy has any grandiose plans to boost its share of nuclear power in its total energy supply. Not surprisingly, the latest IIASA global energy

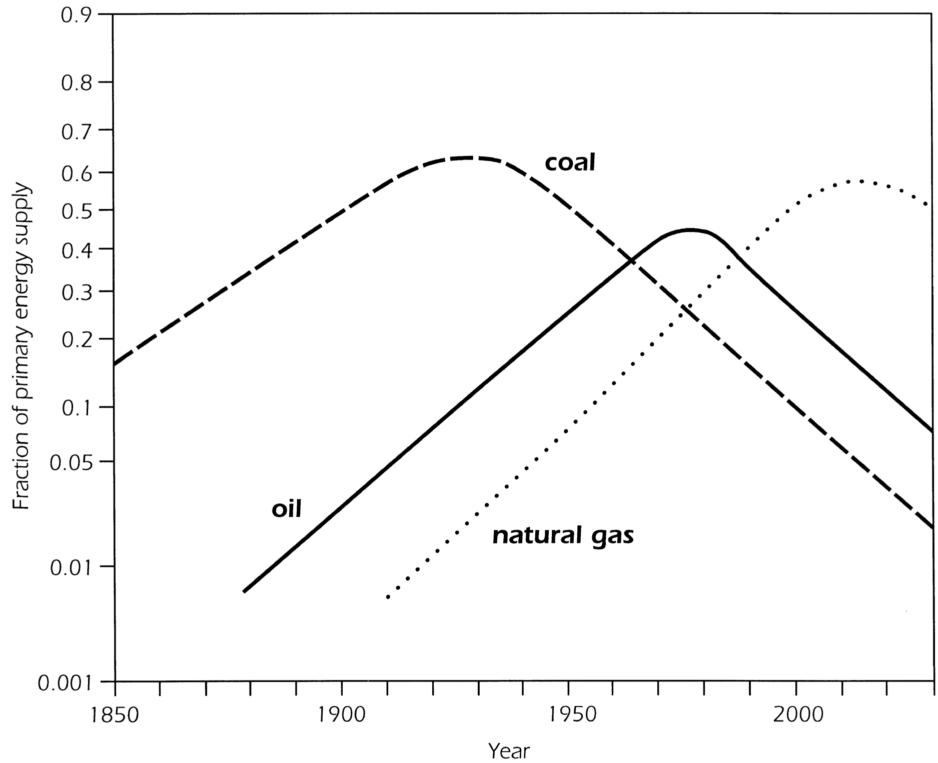

Fig. 4. Marchetti's energy substitutions working like a clock.

consumption forecast, prepared jointly with the World Energy Council, does not refer to any inevitable clockwork substitutions, and it does not offer any nuclear-rich scenarios [39].

Marchetti's forecasting failure has notable counterparts in many unfulfilled expectations on the extremes of energy spectrum. While the real world confounded his predictions pinned on a system with a supposedly immutable internal schedule, it also has failed to conform to unrealistic visions of excessive government-led tinkering promoted by advocates of both hard and soft energies. Massive world-wide resurgence of coal projected by the World Coal Study is an outstanding example in the first category [40]. And while coal and crude oil are hanging on well beyond their predicted shares, renewables are not moving in as fast as anticipated.

This point is best illustrated by comparing the actual performance of "soft energies" with their most touted forecast. In 1992, Amory Lovins looked back at his "soft path" prediction of aggregate energy consumption in the USA, which was published in 1976 [41], and concluded that 15 years later his scenario stood the test of time far better than the conventional wisdom [42]. True, his forecast is much closer to reality than all those simplistically exponential governmental predictions published during the 1970s. But it is a curious interpretation of reality when Lovins says that "the hard path hasn't happened and won't." We do not have giant nuclear islands—but neither do we have a new economy that is significantly dependent on renewable commercial energies, nor the one that is poised to swing sharply in that direction.

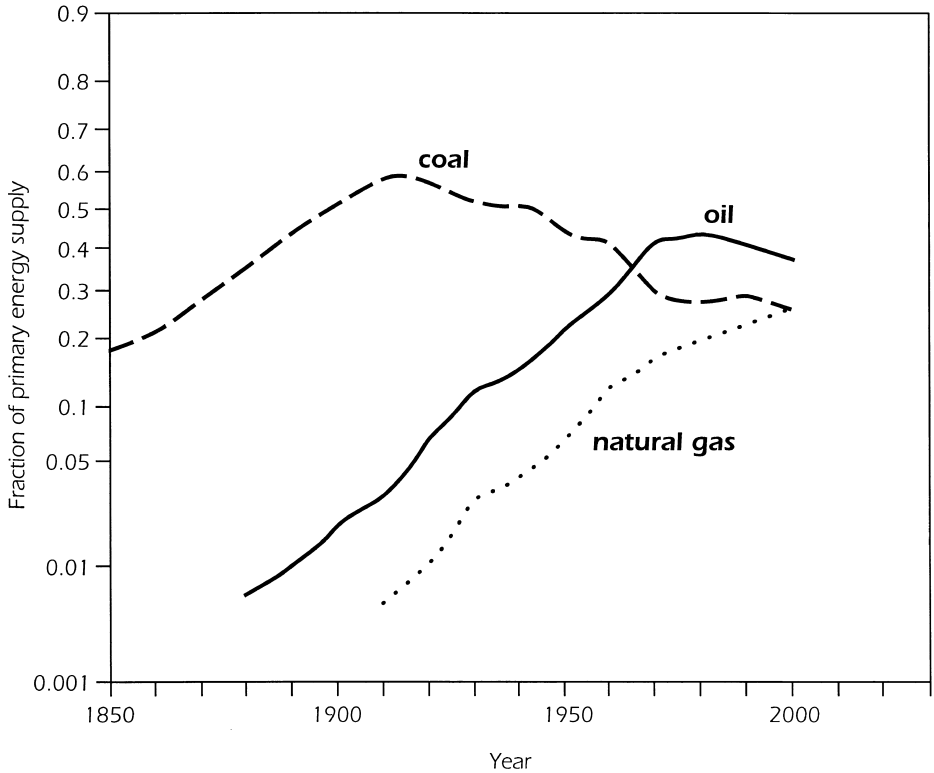

Fig. 5. Recent major departures from Marchetti's idealized system.

In 1976, Lovins [24] anticipated that the USA will derive about 30 quadrillion Btu (quads) of energy (about 750 Mtoe) from soft techniques by the year 2000—but the actual total for renewables, including all hydro, biomass and solar, is about 7 quads. After subtracting conventional large-scale hydro and geothermal generation (neither being a soft species, certainly), renewables contributed just over three quads, no more than about 10% of the share projected a generation ago by Lovins (Figure 6). Missing the target by 90% is hardly a noteworthy forecasting accomplishment. At least Lovins called for "just" around 30% of the USA total energy consumption to be delivered by renewables in the year 2000. In 1980, Sorensen [43] forecast an American energy future where 49% of the country's energy use by the year 2005 originated from renewables, with biogas supplying 5% of the total.

Lessons That Will Be Ignored

As with any accumulated experience, lessons arising from failures of long-range energy forecasting will be largely ignored. Having no illusions about the usefulness of my advise I will, nevertheless, offer the following conjoined axioms: no truly long-range forecast can be correct in all of its key aspects; most of these forecasts will be wrong in both quantitative and qualitative terms; some forecasts may get a few quantities approximately right, but they will miss the real qualities arising from subtly to profoundly altered wholes.

Simulations of highly dynamic natural systems have shown that models of growing complexity are moving slowly toward reasonable replications of reality: global climate

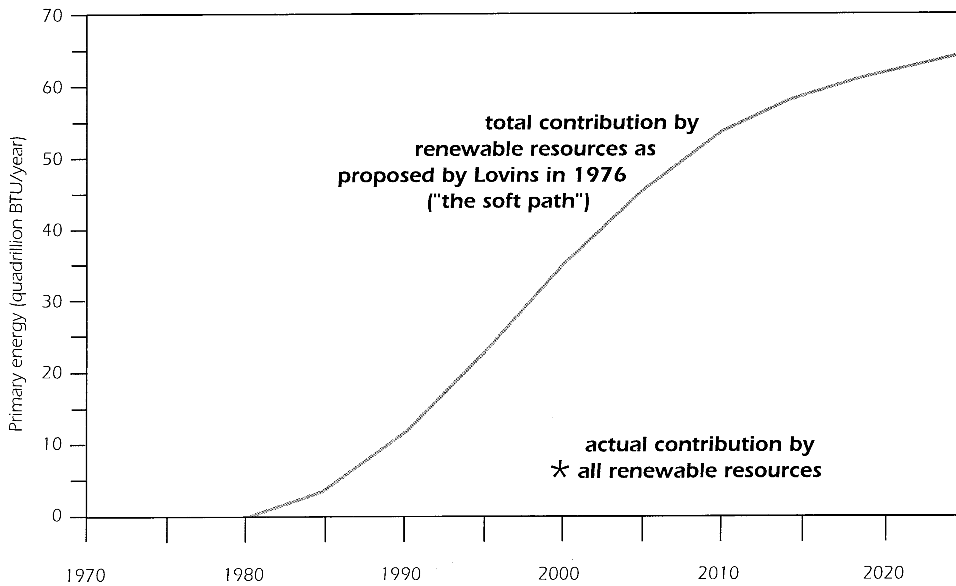

Fig. 6. "Soft energy" contributions to the U.S. primary energy supply forecast by Lovins in 1976 and the actual performance.

modeling is a fine example of this slow, but indisputable, trend [44]. In contrast, forecasts of interactions of social, economic, technical, and environmental developments are not going to improve by making models more complex. This is because so many critical variables determining eventual outcomes cannot be either anticipated or, when they get considered, their probabilities cannot be confidently placed within bounds narrow enough to generate a restricted fan of possible outcomes that might be used in confident decision making. Once the inherent uncertainties make the outcome fan too wide, there is little point in building more complex models: we might have obtained pretty much the same results with a small electronic calculator and the proverbial back of an envelope.

Asia's recent economic history offers excellent reminders of how much such unexpected, or badly appraised, shifts matter. In 1979, Ezra Vogel [45] envisaged *Japan as Number One*, and his predictions appeared to be strengthened 10 years later, as Japanese investors were buying up America, as the Nikkei index was closing on 40,000 (it stood at 38,586 in December 1989), and as the yen kept on soaring (from close to ¥ 250/US$ in the early 1980s to ¥ 144/US$ by the end of 1989). If the expectations prevalent between the late 1970s and the late 1980s would have turned out to be correct, North America and Europe would be by now destitute tributaries of the new Empire of the Rising Sun. As the Japanese miracle faded after the bubble economy burst in 1990 and stayed down (during the late 1990s the Nikkei index has been fluctuating mostly between 14,000 and 17,000!), admirers of rapid Asian economic growth (IMF and the World Bank included) shifted their adulation to the continent's smaller tigers: they were stunned when those economies tumbled so suddenly in 1997 [46].

Of course, both the protracted post-1989 Japanese economic stagnation and the recent Asian economic downturn have had enormous immediate, and important long-term, effects on the global demand for traded fossil fuels, and hence, on their world prices and on the volume of generated greenhouse gases. Forecasts of greenhouse gas emissions are particularly affected by socioeconomic discontinuities translated into changed energy demand. The two events that have affected global CO_2 emissions more than any technical change of the past generation have been the precipitous collapse of the Soviet empire and the rise of surprisingly more efficient China.

Since 1989, energy consumption in the successor states of the USSR and in the nations of the former Soviet empire fell by about a third, and as a result those countries released some 4 billion tonnes of CO_2 less during the 1990s than if they would have produced the gas at the 1988 emission level [47]. And unreformed China would have released close to 8 billion tons more of carbon between 1988 and 2000 than did the country's increasingly market economy with its still falling energy intensity [20]. Who among the forecasters of global CO_2 generation (they are mostly atmospheric physicists) would have even dreamt about including these shifts in global climate models they were building 20 years ago?

Long-range energy forecasters have missed every important shift of the past 2 generations. They paid hardly any attention to OPEC's unassuming rise (1963–1972); they were stunned as much by the quintupling (1973–1974) and then the additional quadrupling (1979–1980) of crude oil prices as they were by the cartel's sudden loss of influence (1985). They failed to anticipate first the drastic reduction of electricity demand throughout the Western world after 1970, and then the collapse of the oversold promise of nuclear generation. At the same time, many of them vastly overestimated the potential of new energy conversions—be they synthetic fuels, biomass, wind, geothermal and central solar power, or fuel cells, hydrogen, and electric cars—while greatly underestimating the cumulative contributions of mundane energy conservation (better wall insulation, double windows).

What to Do Instead

New embarrassments and new misses lie ahead. There will be no end to naive, and (not only) in retrospect incredibly short-sighted or outright ridiculous, predictions. Conversely, we will be repeatedly shocked by utterly unanticipated turns of events. Extreme futures are easy to outline—and, eventually, some of them they may come to pass [48]. What is immensely more difficult is to anticipate the more likely realities arising from a mix of well-understood and almost inevitable continua on one hand and of astounding discontinuities and surprises on the other. In this respect, a new century will make little difference to our ability of making point forecasts: we will spend more time and money on playing the future game—but our predictions will continue to be wrong.

But acknowledging these realities is not the same as advocating a complete abstention from looking far ahead. There is a fundamental difference between decisions that are good only if a particular prediction turns out to be correct—and the ones that are good for a range of alternative futures: scenarios, rather than point forecasts, are thus much more valuable, both from heuristic and from practical points of view. As the future is inherently unpredictable, it is the decision analysis or contingency planning under a range of alternative scenarios that should be pursued most diligently. Techniques comprising this approach range from narrative and normative scenarios to Monte Carlo simulations and to stochastic programming.

Normative scenarios, outlining what should happen rather than what is likely to happen, may be particularly useful providing, of course, that they always remain probing and critical, rather than being just advocacy tools promoted by true believers. And there is a considerable room for revealing differentiations within these scenarios as trends that appear robust despite all scenario variation can be identified and contrasted with trends that may be constructed by intervening actions. Examples in the first category include fundamental demographic shifts (near ZPG and aging populations in affluent countries), secular declines in energy intensity of national economies, or a pervasive trend toward higher energy quality (exemplified by rising shares of electricity in final energy consumption); actions relevant to the second category embrace approaches ranging from changed taxation and R&D support to increased investments and improved public education.

Also, we will be surprised even after adhering to these alternative modes of probing the future: even when some key features of actual developments will have been well encompassed by our scenarios, many particulars will combine to present new phenomena whose characteristics and dynamics will leave us wondering about long-term prospects.

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