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Energy forecasting: Predictions, reality and analysis of causes of error

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Abstract

Energy forecasting is an important task of immense value for predicting the future development and implementation of energy technologies. While a certain degree of uncertainty is to be expected in foreseeing future conditions, energy forecasts are typically quite inaccurate in their predictions. The possible causes of such inaccuracy are examined in this paper in the context of an energy forecast study conducted more than 30 years ago. This study, conducted using the Delphi technique, provided predictions for the development of nuclear energy production, nuclear reactor safety, fossil energy, energy transmission, environmental effects and the renewable energy in the years 1985 and 2000. A comparison with the current progress of the energy industry indicates that the predictions of the study were highly optimistic, and most of the predictions did not materialize nor are likely to be realized in the near future. An analysis of the probable causes of failure is presented in this paper. Such analysis can provide a better understanding of the forecasting process and will be valuable in designing a strategy for reducing the errors in energy forecasting.

Keywords: Energy forecast; Technological forecasting; Delphi study

1. Introduction

Technological forecasting is an attempt to project technological capabilities and predict the invention and spread of technological innovations in the future (Ascher, 1979). The forecast is, in essence, a reasonably definite statement about the characteristic functional capabilities of technologies in the future, based upon well-founded analysis of status and development of existing technology (Amara and Salanik, 1972). Technological forecasting allows one to make better decisions, gain competitive advantage and avoid surprises (Martino, 1983). Technological forecasting has been applied extensively in the estimation of evolution of energy resources, distribution and utilization (Bezdek and Wendling, 2002). This area is of critical concern, as the limitations of the fossil fuels resources that have driven the industrial revolution and consequent increase in societal wealth have become more apparent in recent years (Veziroglu and Barbir, 1992). Further, the harmful effects on the environment are assuming significance in addition to the questions regarding the sustainability of the current mode of energy consumption (Weisz, 2004). Energy forecasting is a difficult task and nearly all the forecasting studies conducted over the last few decades have invariably failed to predict the actual conditions with reasonable accuracy (Bezdek and Wendling, 2002). The objective of the present paper is to identify and analyze the causes of failures of energy forecasting studies. This analysis is conducted by considering the energy and environment predictions of a study conducted more than three decades ago (Smil, 1974) and comparing the predictions to the present conditions. The technique used by the study and its predictions are presented below, followed by the comparison with the present situation and an analysis of possible reasons for discrepancies. Such analysis will enable us to understand the shortcomings of such forecasts and will be of great significance in increasing the accuracy of future forecasts.

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2. Energy and environment trends: 1974 forecast

Technological forecasting is a complex task with considerable inherent uncertainty, therefore, forecasters employ several different methodologies to minimize uncertainties. The 1974 study applied the Delphi technique to develop the energy and environment forecasts. The Delphi technique is a participatory exercise in which recognized experts within a field are queried regarding the issue under consideration. The questioning is carefully planned and anonymous, eliminating psychological factors present in the direct personal interview methods. The process is iterative, providing a mechanism for feedback and reassessment of opinions, ultimately achieving a consensus among the participants regarding the issue. The Delphi groups typically outperform statistical and standard interacting (group discussion) groups (Rowe and Wright, 1999). The Delphi technique was developed at the Rand Corporation in the 1950s, with recent applications of the technique to renewable energy in India and the transformation of the oil industry in Lithuania being just two of the many situations where it has been recently applied (Iniyan and Sumathy, 2003; Pasukeviciute and Roe, 2001).

The Delphi group which studied energy and environmental issues in 1974 had a total of 40 participants, drawn from private industry, academia and government agencies. The specializations of the participants ranged from environmental protection and fossil energy to the nuclear energy industry, with the average professional experience of a participant being 21 years. Eighty-five percent of the participants held an advanced degree with almost half the participants holding a doctorate. More than half of the participants were professionals associated with energy (coal/oil/nuclear) industries, and academics comprised about 15% of the group. The group was international in its composition, with participants from Europe, Japan and the Americas. The group, with its mixture of industrial professionals, academicians and representatives of government agencies, appeared well qualified to conduct the energy

Table 1
Predictions of the 1974 study

Item	Status in 1985	Status in 2000
Nuclear energy generation	• First commercial liquid metal fast-breeder reactor in the US and Europe • High-temperature gas reactors • Maximum capacity 6000 MW, 10,000 MW plants under construction • Fusion energy research approaching controllability	• Large PWRs (15000 MW) • Nuclear power accounting for $>50\%$ in the US • Additional capacity in fast-breeder reactors • Full-scale demonstration of thermonuclear power plant
Nuclear reactor safety	• Nuclear power generation fail-safe • Emissions 1000 times lower than 1970	
Fossil energy	• Maximum capacity: 5000 MW, 6000–8000 MW plants under construction • Fuel cells supplying peaking power • Low-temperature gasification and liquefaction • Offshore rigs capable of drilling up to 2 km • Supertankers with 500,000 dead weight tons • Floating refineries • Large-scale shale oil recovery underway	• Coal plants reaching maximum capacity of 10,000 MW • Coal gasifiers and liquefiers • Coal, large-scale shale oil recovery facing severe environmental problems
Energy transmission	• Extra-high-voltage (1100–1400 kV) lines • Cryogenic underground superconducting cables	• Low-cost underground high-voltage systems • Progress in microwave and laser power transmission
Environmental considerations	• Water thermal pollution under control • Waste flue gas converted to marketable products • Price rise in energy acceptable	• Oil spills continuing ocean pollution
Renewables		• Hydroelectric power exploited to the limits of practical feasibility

forecasting. These participants examined various energy- and environment-related issues and developed scenarios for the future in three rounds. Forecasts for the years 1985 and 2000 by the Delphi group are briefly summarized in Table 1 (Smil, 1974).

The overall forecasts of the group can be termed as highly optimistic. The group anticipated a spectacular growth in nuclear power, predicting its share in electricity generation to be anywhere between 50% and 75% for individual nations. They predicted this growth not only through the increased capacity of traditional plants (boiling water reactor (BWR), pressurized water reactor (PWR)) but also via maturation of fast-breeder and high-temperature gas reactors. The study foresaw tremendous strides in the development fusion energy and thermonuclear power. Similar impressive growth was anticipated in power transmission technologies as also fossil energy utilization. Several technologies which appeared promising at the time of study (fuel cells, shale oil recovery, coal conversion) were forecast to be matured and implemented in practice in target years. The study was comprehensive and cognizant of the environmental problems including air pollution and oil spills. It also foresaw no technological or economic barriers to the conversion of waste flue gases. As discussed in the following section, the current status of the energy and environment presents a stark contrast to these predictions.

3. Energy and environment—current status

3.1. Nuclear energy and safety

The US has 103 operating nuclear power plants, based on either BWR or PWR technology (NEI, 2005). These reactors produce almost 20% of the total electricity generated in the country. The share of nuclear power in most nations ranges from 15–30% (falling short of the expected 50% share), except for France, where nuclear power accounts for more than three quarters of the total electricity generated (Fanchi, 2004). Most nuclear reactors have been built with highly reliable, automated, multiple redundant safety systems, designed to contain radiation and protect the population (NEI, 2005). The overall safety record of civilian nuclear power reactors has been exemplary with only two major accidents (Three Mile Island, USA; Chernobyl, Ukraine) in 11,000 cumulative reactor year operations in 32 countries (Uranium Information Center, 2003). Fast-breeder reactors, highly promising technologically, are yet to be commercialized (Simnad, 1998). Fusion energy is in the early developmental stages, with several nations pooling their resources for the development of The International Thermonuclear Experimental Reactor—ITER (Dean, 2003).

3.2. Fossil energy

Most large-scale power plants, operating with coal or natural gas, have a maximum operating capacity of ca. 1000 MW, far less than what was predicted by the study (Fanchi, 2004). A large number (2500) of stationary fuel cell systems have been installed around the world, mostly as small-scale installations (<5 MW) functioning as a backup or primary power source for residential/business systems (Fuel Cells, 2000, 2005). The world, and particularly the US, contains vast quantities of oil shale, which have looked promising from the energy supply point of view. However, currently, oil shale remains an insignificant and elusive energy source (Hepbasli, 2004). The low-temperature coal conversion processes (gasification/liquefaction) are in developmental stages, fairly close to commercialization (Miura, 2000; Trapp et al., 2004).

3.3. Energy transmission

The electrical power transmission and distribution network operates at 69–765 kV (Fanchi, 2004). Thus, the maximum voltage is significantly (30–50%) lower than that predicted by the study. Microwave and laser power transmission systems predicted by the study have not materialized. Underground power transmission is used on a limited basis, mainly in populated cities (Honjo et al., 2000).

3.4. Renewable energy and environmental considerations

Hydropower has nearly reached its potential in developed countries, where any increase in hydropower is essentially marginal in nature (Sen, 2004). The large-scale capacity additions are primarily in developing countries. At the same time, older hydroelectric plants are facing machinery obsolescence problems in countries such as Russia, where construction of new plants is also curtailed (Vasil'ev et al., 2000). Wind power is an established technology; however, the contribution by all forms of renewable energy remains negligible (Bezdek and Wendling, 2002; Sen, 2004). Significant progress is being made regarding the emissions of greenhouse gases and global warming through the obligations developed under the Kyoto Protocol (Dumanski, 2004). The protocol has, however, not been ratified by the US. Recycling carbon dioxide from the flue gas by utilizing it as a chemical feedstock is being attempted; however, the amount that can be utilized in this manner is relatively small—less than 1% of the emissions (Aresta et al., 2001; Creutz and Fujita, 2001; van Ree, 1995).

4. Analysis

It can be seen that substantial discrepancies exist between the forecasts and the actual conditions. The optimistic scenarios forecast for the growth of nuclear energy (including fusion energy), power transmission, fuel cell applications, renewable energy and reuse of waste flue gases have not materialized at the projected times, nor are they likely to materialize within the next two or three decades. The forecasts have been successful at predicting the actual conditions only in very limited fields related to fossil energy, for example, the super-tanker, oil spills or off-shore drilling. However, even in the fossil energy field, oil shale recovery or coal gasification/liquefaction technologies are nowhere near their projected potentials. The question arises as to the underlying causes of such discrepancies. The four possible causes which might explain the discrepancies are discussed below.

4.1. Use of improper techniques

The Delphi technique requires participation by experts—knowledgeable individuals—who are willing to enter into discussion. The complete anonymity of the Delphi technique can lead to a lack of accountability of opinions (McKenna, 1994). Further, achieving a consensus often means that extreme opinions are generally eliminated. The 1974 study does not seem to have suffered from the lack of participation of experts, based upon the composition of the study group and the qualifications of the participants A particular technique used for the study would be suspected to have played a role in the failure of the study to forecast accurately, provided that all the studies utilizing this technique resulted in inaccurate forecasts, while studies utilizing other techniques demonstrated excellent accuracy. However, the one feature shared by a large number of energy forecasting studies is their lack of success in predicting the future (Bezdek and Wendling, 2002). There does not seem to be any correlation between the technique used and accuracy of predictions for an energy forecasting study, implying that the use of Delphi technique played only a marginal role, if any, in the failure of the 1974 study.

4.2. Technological barriers

In certain cases, the prediction was based upon an optimistic estimate of advances in technology. For example, predicted milestones in power transmission were based in part upon the projected advances in superconducting materials. The field of superconductivity has seen significant progress since its discovery almost a century ago; however, the highest temperature for the superconducting materials remains fairly low, ca. 150 K (Benneman and Ketterson, 2003). Fast-breeder reactors were projected in 1970s to be the vast, non-polluting power sources of the next several millennia, yet a commercially viable system has yet to be demonstrated (McFarlane and Lineberry, 1999). Similarly, oil shale recovery, upgrading and processing technology has yet to reach maturation. (Bunger et al., 2004; Pettersson and Westerholm, 2001). It is of interest to note that fuel cells were invented in 1839, prior to the development of internal combustion engines. Yet, several technical issues need to be resolved before fuel cell systems find widespread application in automotive systems (Arita, 2002).

4.3. Socio-political considerations

The public perception and acceptance is critical for the development of technologies, including energy technologies. As mentioned above, nuclear reactors have had an exemplary safety record. However, the two major incidents concerning the nuclear reactor and energy safety (Three Mile Island and Chernobyl) substantially impeded the advancement of the nuclear energy. The Three Mile Island incident, in particular, was insignificant with respect to the radiation dosage to workers or the general public, but is of momentous significance in raising fears about, and opposition to, nuclear energy (Zebroski, 1998). Similarly, the concerns regarding waste management and non-proliferation may prove to be bigger hurdles than technological challenges in commercialization of fast-breeder reactors (McFarlane and Lineberry, 1999). New nuclear plants find it hard to win acceptance by the general public all over the world (Güldner, 2003). Forecasts based only on technological considerations, without accounting for these factors, would predict a highly optimistic scenario regarding the growth of technology, which may not materialize. Further, governmental support has a significant impact on technological innovation (OTA, 1978). Government-sponsored research and, more significantly, government regulations are highly influential in focusing or restricting technological innovations. For example, government actions have played significant roles in the development of environmental technologies (Taylor et al., 2003). On the other hand, lack of government support can very well lead to stifling of innovative activity in a field. Governments in representative political systems (democracies), in particular, have to be receptive to the public opinion and perception, and thus may not support the development of technologies that are fundamentally sound, possibly even needed for long-term sustainability due to public opposition. Nuclear energy seems to have suffered from these factors, not achieving the potential at levels forecast by the study.

4.4. Economic considerations

Economic factors may quite possibly be the single most important reason for the non-emergence of expected technologies. The availability of cheap and plentiful uranium resources played against the need to go to a technology (fast-breeder reactor) that requires higher capital investment cost (McFarlane and Lineberry, 1999). If this indeed is the case, then one can also argue that, since uranium resources are expected to be more than sufficient to satisfy the continuing and planned demands of the conventional nuclear plants in the 21st century (Scott, 2005b), commercialization of the fast-breeder reactor technology is at least that far away in future. Similarly, forecasts regarding the development of non-fossil energy technologies are invariably based on the premise that the world oil production is set to dwindle in near future as argued by various individuals (Campbell and Laherrere, 1998; Deffeyes, 2001). Conversely, if the world is not running out of oil (Scott, 2005a), then all the energy forecasts are bound to be in error as the primacy of the economic considerations takes over. In this case, *the only way to improve the accuracy of energy forecasts is by putting greater effort in predicting the oil-supply situation with greater certainty, particularly in view of the increasing global oil demand driven by the growth of developing Asian economies such as China and India*.

The abovementioned factors can effectively explain the shortcomings of the specific study examined in this paper. Other energy forecasting studies will also be subject to the constraints imposed by these same factors. Thus, these factors, individually and in combination with each other, may quite possibly explain the reasons for discrepancies between the energy forecasts and reality. Understanding these factors will enable us to develop more effective energy forecasting capabilities.

5. Conclusions

Economic impacts of energy utilization on the society and the concerns regarding the sustainability of current modes of energy supply and consumption are the motivating factors for engaging in the exercise of energy forecasting. Energy forecasts attempted in the past have invariably been found to have a low success rate in accurately predicting the future. Four possible underlying causes of the uncertainty displayed by energy forecasts identified in this paper are: possible use of improper techniques, technological barriers to the development of technologies, socio-political considerations and economic considerations. These four factors are further elucidated by comparing the future predictions of a 1974 forecast with the actual conditions. The economic considerations may be the single most dominant factor in determining the accuracy of energy forecasts. The limitations imposed by all the above causes must be understood in order to develop strategies for increasing the accuracies of future energy forecasts.

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