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A review of energy models

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Abstract

Energy is a vital input for social and economic development of any nation. With increasing agricultural and industrial activities in the country, the demand for energy is also increasing. Formulation of an energy model will help in the proper allocation of widely available renewable energy sources such as solar, wind, bioenergy and small hydropower in meeting the future energy demand in India. During the last decade several new concepts of energy planning and management such as decentralized planning, energy conservation through improved technologies, waste recycling, integrated energy planning, introduction of renewable energy sources and energy forecasting have emerged. In this paper an attempt has been made to understand and review the various emerging issues related to the energy modeling. The different types of models such as energy planning models, energy supply–demand models, forecasting models, renewable energy models, emission reduction models, optimization models have been reviewed and presented. Also, models based on neural network and fuzzy theory have been reviewed and discussed. The review paper on energy modeling will help the energy planners, researchers and policy makers widely.

Keywords: Energy models; Forecasting model; Optimization model; Fuzzy logic; Neural networks

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Contents

1. Introduction

In most of the developing countries, the energy problems to be addressed are countering the high dependence on traditional sources of energy which supply more than 90% of total energy used causing rapid deforestation, decreasing soil fertility, etc. Thus a large amount of information is required to describe their relationships, and several tools are necessary to analyze different issues and to achieve a variety of results that are needed for the planning process. Apart from the phenomenal growth in population, the marvels of modern technology have enhanced the aspirations of the people for an improved quality of life. One of the indices of improved quality of life is the per capita energy consumption, which has been rising steadily for the last few decades. The net result of this has been that the demand for energy has multiplied manifold and it can be no longer satisfied by the traditional inefficient energy technology using a few local resources only. Before the oil crunch of seventies, the planners and politicians of the Third world countries had envisioned energizing the rural areas on lines similar to developed countries. They had hoped that energy models could be developed for the efficient energy planning, forecasting and optimization of energy sources. The experience in India over the past decade has shown that decentralized energy technologies based on local resources can be viable alternatives to many commercial sources of energy in diverse energy end-uses. Models have become standard tools in energy planning. In recent years, considerable efforts have been made to formulate and implement energy planning strategies in developing countries. Appropriate methodologies for conducting energy surveys to estimate and project sectoral useful energy requirement are evolved. This article gives a brief overview of the various types of energy modeling.

2. Energy planning models

Researchers and scientists had tried developing integrated energy models linking both commercial and renewable energy sources. A brief review of these integrated energy system models has been presented here.

A simple model had been proposed by Peter (1977), which enables one to find conditions for the economic viability of solar thermal or solar photovoltaic energy conversion [1]. Marchetti (1977) had developed a synthetic model of primary energy substitution. The societal efficiency, literacy and mineral resources were used as variables in the model [2]. In the same year, Martin O. Stern (1977) had presented a quasi-equilibrium policy-impact model for the supply of depletable resources with applications to crude oil [3]. Borg (1981) had discussed a discriminating monopolist model of natural gas markets of the United States over the period 1960–1966 [4]. Subsequently, he had discussed the discriminating monopolist model of natural gas markets in the US [5]. Ambrosone et al. (1983) had developed a dynamic model for the thermal energy management of buildings [6].

Steven Fawkes (1987) had presented a model of the energy management process developed using a soft systems methodology. The model divides the energy management into four levels, namely, good housekeeping, retro-fit projects, plant replacement projects and new process design. From the model, a number of checklists for energy managers had been developed and presented [7]. The use of different energy-signature (ES) models for energy consumption predictions and building parameter estimations had been reviewed by Stig Hammarsten (1987) [8]. George Hsu et al. (1987) had presented the integrated energy planning model using a multi-objective programming technique linked with the traditional Leontief input–output model. Labour, GDP, resource availability, inter-industry interactions and sectoral capacity bounds were the variables considered in the model [9]. Sultan Hafeez Rahman (1988) had formulated an econometric energy–economy simulation model for energy policy studies for a wide range of developing countries. The variables used in the model were GDP and investment. Also, the model had been used for long-term energy demand forecasting for India [10]. Several important issues in the areas of energy policy and planning for the future relating to developing countries had been narrated by Natarajan (1990). The correlations between energy use and national income, and standard of life and quality of life had been examined. Also, he had presented the special role of electricity in end-use and the role of renewable energy sources in energy supply for a developing country like India [11]. Capros et al. (1990) had presented the main theoretical and empirical issues encountered in the construction of a short/medium-term energy–economy linked system of models, namely the Hermes–Midas system [12]. The use and limitations of economic models in the corporate environment had been described by Arnold and Anthony (1990). They have reviewed the alternative model types and their applications for business environment analysis, investment alternatives and strategic decisions [13]. A study on model credibility had been conducted by Yoichi Kaya (1990) in Japan. More than 10 economy wide models had been selected and GNP results were compared [14]. David B. Reister (1990) had discussed the various engineering-economic approaches for developing energy demand models [15]. The main theoretical and empirical issues encountered in the construction of a short/medium-term energy–economy linked system of models, namely the Hermes–Midas system had been presented by Capros et al. (1990) [16].

The evolution of input–output techniques and the associated linear and non-linear programming models had been introduced. The basic structures and mechanisms of multi-sectoral input–output planning models are then discussed including the objective function and various types of constraints. The standard PILOT macro-economic model and a multi-sectoral model of China had been presented. (Xia Shi and Yingzhong Lu, 1990) [17]. John P. Weyant (1990) discussed the overview of policy modeling, in which he explained how data analysis and modeling can be used in planning in the volatile environment in which the industry currently operates [18]. The integrated modeling theory had been discussed by Walter C. Labys and John P. Weyant (1990) [19]. NAPAP Integrated Model Set has been illustrated by Gale Boyd et al. (1990), which constitute a collection of engineering, emissions, forecasting and energy-market models [20]. Huq's model of integrated rural energy systems in revised form for a village in Bangladesh had been derived and the model forms the basis for the development of a computer model based on the system dynamics methodology of Forrester for policy planning (Alam et al., 1990) [21]. Paul J. Werbos (1990) had compared the econometric modeling with other forms of modeling used in energy modeling and engineering. He had also developed a model PURHAPS for the energy information administration (EIA) [22]. The theory of the process models with respect to the industry has been discussed by Walter C. Labys and Hiroshi Asano (1990) [23].

The use of dynamic programming in system expansion planning models had been discussed by Leslie A. Poch and Jenkins (1990). A brief overview of the dynamic programming methodology is presented along with an example of how dynamic programming was applied in a model developed for electric system expansion planning [24]. The introduction of multi-objective programming methods into a large-scale energy systems planning model had been discussed by Psarras et al. (1990). The author(s) reviewed several multi-objective techniques, ranging from simple methods to complex interactive algorithms providing best compromise solutions. An algorithm which implements a decentralized hierarchical decision process with multiple objectives had been reviewed and applied [25]. Walter C. Labys et al. (1990) had reviewed the various types of special programming models such as, elementary spatial programming, quadratic programming, mixed integer programming and linear complimentary programming models [26]. Mental and computer models are at the foundation of intelligent human decision, and they are intimately related. The relation between these models are outlined which identifies major approaches to model development and explores future evolution of model interactions (Oliver S. Yu, 1990) [27]. An analysis of the pay-off matrix technique, an approach to the solution of decision problems had been presented (Lev S. Belyaev, 1990). Special Wald, Laplace and Subjective probability estimations had been applied in the technique [28]. Robert Entriken and Gerd Infanger (1990) discussed the difficulties introduced by the stochastic parameters and reviews different approaches to handle them [29].

The author(s) (Thomas R. Bowe et al., 1990) had introduced the use of Markov models for engineering-economic planning. Markov models capture the uncertainty and dynamics in the engineering-economic decision environment. The author(s) describes how, when and why to use Markov models. The steps of model formulation, parameter estimation and solution had been described. The optimization decisions by stochastic programming are also presented [30]. Decision analysis in engineering-economic modeling had been discussed by Douglas M. Loagn (1990) with uncertain outcomes and difficult trade-offs, to evaluate the alternatives available to a decision maker and to rank them in light of his information and preferences [31]. Also, a multi-criteria evaluation method had been used to evaluate the alternatives for new energy-system development in Taiwan (Gwo-Hshiung Tzeng et al., 1992). The energy systems selected both conventional and renewable energy systems such as solar, wind and biomass as future energy options [32]. Energy modeling of a food industry, for which a cogeneration system is proposed in order to obtain electrical energy together with steam and hot water for process heat had been presented by Calderan et al. (1992) [33].

Bharati Joshi et al. (1992) had developed a simple linear decentralized energy planning model for a typical village in India for both the domestic and irrigation sectors to minimize the cost function for an energy-supply system consisting of a mix of energy sources and conversion devices [34]. A personal-computer based linear programming model of an integrated energy system for industrial estates (IESIE) had been developed as a prefeasibility tool (Brahmanand Mohanty and Haribandhu Panda, 1993) [35]. Mackay and Probert (1993) had discussed the future problems of the oil industry [36]. Nilsson and Soderstrom (1993) had framed a production planning model with optimal electricity demand with respect to industrial applications [37]. A model that simulates the performance and economics of a combined wind/hydro/diesel plant with pumped storage had been developed by Ashok Sinha (1993) [38]. Bala Malik et al. (1994) had described an integrated energy system planning approach for Wardha district in Maharashtra, a state in India for the year 2000 AD. Also, an optimal mix of new/conventional energy technologies using a computer based mixed integer linear programming model was presented [39]. The assumptions and important insights of the investment theories relating to energy technology had been reviewed by Blake E. Johnson (1994). The theories addressed include the capital asset pricing model, the arbitrage pricing theory and the theory of irreversible investment [40]. Zaheer-Uddin and Zheng (1994) had developed a model which had been used to simulate various energy management control (EMC) functions [41]. Andy S. Kydes et al. (1995) had discussed the recent directions in long-term energy modeling. The distinguishing features of long-term modeling such as technological change, shifts in energy supply and dynamic energy–economy interactions have been included in the study [42]. Ramanathan and Ganesh (1995) used an integrated goal programming-AHP model to evaluate seven energy sources usable for lighting in households against 12 objectives representing the energy–economy–environmental systems. Sensitivity analysis on these systems had also been performed [43]. The author(s) (Huang et al., 1995) had conducted a literature survey on decision analysis in energy and environmental modeling. The surveyed studies had been classified into two categories, namely, decision analysis technique used and by application area and found that the decision making under uncertainty is the most important application technique and energy planning and policy analysis is the most common application area [44]. Daily consumption pattern (DCP) models had been used for the analysis of rate effects (Mika Rasanen et al., 1995). The DCP was assumed to consist of the daily rhythm of consumption, the effects of outdoor temperature on consumption and random variations [45]. Victor et al. (1996) had analyzed the results of the reform to the Mexican energy sector from 1988 to 1994 [46]. Peter J. Spinney and Campbell Watkins G. (1996) had explained the use of Monte-Carlo simulation techniques for the electric utility integrated resource planning (IRP). Sensitivity analysis and decision analysis had also been presented [47]. Financial feasibility analysis of box type solar cookers had been discussed by Kumar et al. (1996) in India using cost functions and expressions for some financial performance indicators had been derived [48]. Able-Thomas (1996) had discussed the benefits and needs for renewable energy technology transfer to developing countries. Also, the author discussed the different models or channels of renewable energy technology transfer for successful dissemination in developing countries [49]. Models for energy conservation to be used in energy audits had been presented by Abdelhak Khemiri-Enit and Mohamed Annabi-Cenaffif (1996). The author(s) had demonstrated the usefulness of various models relating to the thermal energy (building heat and swimming pool heat), lighting and energy loss due to electrical transformers [50].

An energy planning model had been developed using multiple objective programming (MOP) technique for a small, medium and large farms in Punjab, a state in India. The model is having five objectives namely, minimization of energy input, maximization of gross returns, minimization of capital borrowing, minimization of labor hiring and minimization of risk for availability of energy inputs (Surendra Singh et al., 1996) [51]. The author(s) (Malik and Satsangi, 1997) had reviewed the energy planning problems in India at different levels. They had used a computer based mixed integer/linear programming data extrapolation techniques for energy systems planning [52]. A bottom–up simulation model had been formulated by Boonekamp (1997) to monitor the energy use of households, called SAVE households [53]. An integrated electric utility planning model, the resource policy screening model (RPSM) had been used to project acquisitions from independent power producers made by customers of a US power marketing authority (Franklin Neubauer et al., 1997) [54]. The mathematical model for the physical quality of life (PQL) as a function of electrical energy consumption had been reviewed by Alam et al. (1998). The equation formulated had been used to assess the physical quality of life as a guideline for national planning [55]. Gomes Martins et al. (1998) had presented a methodology for energy planning in urban historical centers, using the historical centre of Coimbra, an Old Portuguese city [56]. Akisawa et al. (1999) had introduced two types of energy system models for an energy efficient and environmentally friendly society.

Also, an assessment model has been developed to quantify the energy saving effect from the advanced energy cascade systems which consist of four major industry groups and 12 sub-groups in Japan [57]. Michael J. Scott et al. (1999) have added a stochastic simulation capability to the commonly used integrated assessment model MiniCAM 1.0 to analyze the sources of uncertainty and their relative importance and to help device strategies for depicting and coping with uncertainty [58]. An integrated long-term resource planning analysis for the supply- and demand-side effects of carbon tax in the Indonesian power sector had been performed by Ram M. Shrestha and Charles O.P. Marpaung (1999) [59]. GIS tools are used for renewable energy modeling by Bent Sorensen and Peter Meibom (1999). The model is being applied to various global energy scenarios and constitutes a quite common tool for energy system modeling, assessment and planning [60]. Harry Bruhns et al. (2000) have discussed a database for modeling energy use in the non-domestic building stock of England and Wales [61]. Bo Hektor (2000) has discussed the different planning models for bioenergy [62]. An integrated micro-economic, multi-level mixed integer linear programming (MILP) staircase model to estimate the aggregate supply of energy crops at the national level in France has been presented by Rozakis et al. (2001) [63]. Sun (2001) has indicated that it is illogical to use gross national products (GNP) as an economic variable in the economic output-energy model [64]. Rahul Pandey (2002) has developed a top–down and bottom–up energy policy models for addressing various policies and planning concerns in developed countries [65]. Jayram and Ashok (2003) had presented the integrated energy model for wind, PV and diesel power [66]. A dynamic top–down and bottom–up merging energy policy model has been formulated by Christopher W. Frei et al. (2003) [67]. The author(s) (Beccali et al.) presented the application of the multi-criteria decision-making methodology used to assess an action plan for the diffusion of renewable technologies at regional level (2003). This methodology helps the decision-maker to select the most suitable innovative technologies in the energy sector, according to preliminary fixed objectives [68]. Claus Huber et al. (2004) discussed the features and most important results of the computer model ElGreen, which is used to simulate various promotion strategies for different technologies in all EU countries [69].

3. Energy supply–demand models

The different types of energy supply models, energy demand models and energy supply–demand models had been reviewed in this literature in a detailed manner.

The nature and length of the impact that prices and economic activity have on the demand for motor gasoline and distillate fuel oil in the United States had been discussed. Also, a general approach had been implemented to aid any energy analyst in gaining insights into the modeling activity (Noel D. Uri and Saad A. Hassanein, 1985) [70]. Cliff Halliwell and Fatma Sherif (1985) had formulated a energy price and demand forecasting model to predict the energy price and demand of electric utilities [71]. An integrated supply and demand energy planning model for the state of Illinois had been described by Charles and Mark (1987) [72]. John D. Sterman et al. had formulated the energy supply model for the estimation of petroleum resources in the United States [73]. Kamal Rijal et al. (1990) had formulated a linear multiple regression energy demand forecasting model to project the energy requirements in rural Nepal [74]. Walter C. Labys (1990) discussed the econometric supply models. The econometric methods provide an approach for modeling supply processes where time delays, lags and capital formation are important.

Supply models of this type can be statistical or econometric, the later involving distribution lag [75]. A survey had been done by Walter C. Labys and Thomas Kuczmowski (1990) on the various methods employed in supply modeling and suggestions have been presented to improve the credibility and utility of the resulting models, especially those intended to support policy analysis [76]. Rong-Hwa Wu and Chia-You Chen (1990) had analyzed energy issues in the short-term for Taiwan using a static input–output (I/O) framework [77]. John Haraden (1991) developed a cost model for magma power generation. This cost model gives the potential cost of magma-generated power [78]. Masood A. Badri (1992) developed a Halvorsen-type mathematical model to analyze the demand for electricity in the residential, commercial and industrial sectors of United States. This model permits consistent estimation of total elasticites of demand for the above mentioned three sectors [79]. A two stage model for energy demand in Portuguese manufacturing sector had been framed by Antonio M. Borges and Alfredo M. Pereira (1992). In the first stage, a capital-labor-energy-materials framework had been used to analyze the substitutability between energy as a whole and other factors of production. In the second stage, the total energy demand had been decomposed into oil, coal and electricity demands. The two stages had been fully integrated since the energy composite used in the first stage and its price are obtained from the second stage energy sub-model. The role of price changes in energy-demand forecasting as well as in energy-policy had been clearly established by the model [80].

The residential sector accounts for most of the energy consumption in developing countries. A energy-supply–demand model with respect to developing countries relating to Nepal fuel wood-supply sustainability had been developed by Vishwa B. Amatya et al. (1993). The model is based on an end-use/process analysis approach, capable of simulating scenarios to address issues of increasing traditional energy-demand, sustainable supply capacity of the existing energy resources, potential for development of new and renewable energy resources and technology [81]. A linear optimized model of energy-supply and demand to predict and study long-term changes of the system to a village level with a population of 800 people in the North China Plain had been formulated (Fang Zhen, 1993) [82]. An econometric model had been used in a disaggregated approach to study the effects of energy demand for the manufacturing sector (1970–1987) respectively relating to UK energy market (Blakemore et al., 1994) [83]. Duangjai Intarapravich et al. (1996) had developed the Asia-Pacific energy supply and demand model to 2010 for high, low and base cases that take into account variations in economic performance, prices and fuel substitution in individual nations and in the region as a whole [84]. Norbert Wohlgemuth (1997) had presented the international energy agency's (IEA) approach of modeling world transport energy demand [85]. Michalik et al. (1997) had formulated the structural models to predict the energy demand in the residential sector [86]. Bala (1997) had presented projections of rural energy supply and demand and assess the contributions to global warming. The output of the dynamic system model had been used in the LEAP model and overall energy balances are compiled using a bottom–up approach [87].

A mathematical model has been developed for the electricity demand based on the concept of representative load curves (RLCs) by Balachandra and Vijay Chandru (1999) [88]. Sabine Messner and Leo Schrattenholzer (2000) obtained MESSAGE-MACRO by linking a macro-economic model with a detailed energy supply model. The author(s) had described an automated link of two independently running models [89]. A vector autoregressive models had been developed by Mudit kulshreshtha and Jyoti K. Parikh (2000) to predict the demand for coal in four main sectors in India using the annual time-series data from 1970 to 1995. The models have been estimated using co-integrating VAR framework [90]. Jan Bentzen and Tom Engsted (2001) had used the autoregressive distributed lag (ARDL) model approach to estimate a demand relationship for Danish residential energy consumption and the ARDL estimates have been compared to the estimates obtained using co-integration techniques and error-correction models (ECM'S) [91]. An attempt had been made by Purohit et al. (2002) to estimate the potential of using renewable energy technologies such as biogas plants, solar cookers and improved cook stoves for domestic cooking in India [92]. An econometric model had been formulated using regression method to determine the demand for commercial energy namely, coal, petroleum products and electricity in different sectors in Kerala, a state in India and the models had been refined by using Cochrane-Orcutt transformation algorithm to remove the effects auto-correlation (Parameswara Sharma et al., 2002) [93]. Bala and Md Fazlur Rahman Khan had developed a computer based system dynamics model of energy and environment for Bangladesh to project the energy supply and demand and assessing its contribution to global warming [94].

4. Forecasting models

Energy forecasting models have been formulated using different variables such as population, income, price, growth factors and technology. The models had been reviewed to determine the energy distribution patterns. The forecasting models have been categorized into two groups, namely commercial energy models and renewable energy models.

4.1. Commercial energy models

Noel D. Uri (1978) had developed a combined econometric model and time-series forecasting model based on Box–Jenkins approach to predict the monthly peak system load for a specific utility by taking account of changes in economic and weather related variables [95]. Noel D. Uri and Stephen P. Flanagan (1979) had formulated a time-series short-term forecasting model to predict the crude petroleum and natural gas production in the United States, using Box–Jenkins approach [96]. Noel D. Uri (1980) had discussed the model for estimating the undiscovered oil resources in the United States [97]. The regression equation had been used for forecasting the cost of energy conservation in the transportation sector for the period 1980–2000 (Hyder G. Lakhani, 1981) [98]. The regression equations had been used for forecasting the cost of energy conservation in the residential sector for the period 1980–2000 (Hyder G. Lakhani, 1982) [99]. A forecasting model to predict the minimum fuel requirements whilst minimizing operating costs in a multi-stage production inventory system had been formulated by Collier and Ornek, 1983 [100]. Badi and James (1983) had formulated a forecasting model to predict the gasoline consumption by considering the three separate determinants namely, utilization by auto, gasoline efficiency and the stock of cars on the road [101]. Deeble and Probert (1986) had formulated straight-line correlations to predict the annual energy consumption [102]. Bhattacharya et al. (1986) had discussed about energy consumption patterns with a stress on non-commercial energy sources for rural areas and the Indian energy scenario had also been highlighted [103]. Newborough and Probert (1987) had discussed the energy-consumption and health-care concerts relating to diet choices [104]. The logistic and energy substitution forecasting models had been used by Bodger and Tay (1987) to predict the electricity consumption in New Zealand using past consumption growth factor [105].

Sabine Messner and Manfred Strubegger (1987) had presented a framework to analyze the consumption of energy (FACE), by considering growth factor, economics and technology as variables [106]. John D. Sterman (1988) had described the ability of adaptive expectations and univariate trend extrapolations to explain the energy demand forecasting history [107]. Mahmoud Kaboudan (1989) had developed a non-linear dynamic econometric forecasting model to predict the electricity consumption in Zimbabwe through the year 2010 using 20 years of data [108] A description of the international petroleum exchange model (IPE) developed at Massachusetts institute of technology (MIT) had been presented (Nazli Choucri and Christopher Heye, 1990).

Also, they had presented a brief description of system dynamics [109]. Strategic demand forecasting models for electric utility industries had been developed by Ahmad Faruqui et al. (1990). More sophisticated econometric and end-use models forecasting techniques had been introduced to the utility industry [110]. Wolde-Ghiorgis (1991) had used the industrial energy utilization model to analyze the energy utilization patterns in three factories, namely, cement production, textile manufacturing and food processing industries in Ethiopia [111]. The GDP growth rate had been estimated for Mauritius by analogy with observed growth in more developed countries like Singapore and Hong Kong. The ratio of electricity to GDP is given as empirically determined elasticity coefficients (Harel and Baguant, 1991) [112]. The modeling of the diffusion of energy consuming durables had been studied using various growth curve models (Ang and Ng, 1992). The energy distribution patterns resulted from these models had been compared and taken for the study [113].

A new method had been presented for evaluating the normalized energy consumption in office buildings in Montreal using the information derived from utility bills (Radu Zmeureanu, 1992). The results derived from the new method had been compared with those obtained from the well-known PRISM method, using utility bills from 24 gas-heated buildings and 14 electrically cooled buildings [114]. Loren Lutzenhiser (1992) developed a cultural model of household energy consumption by considering the development of demand-side research, from an early interest in conservation behavior to a later focus on physical, economic, psychological and social models of energy consumption. The ecological foundations of the cultural model and its applications in energy research have been discussed along with some of the analytic consequences of this approach [115]. Stig-Inge Gustafsson (1993) had presented the mathematical modeling of district heating and electricity loads [116]. Hammond and Mackay (1993) had developed a forecasting model to project the oil and gas supply and demand to 2010 for UK [117]. The utilization of electricity within the domestic sector had been examined (Deering et al., 1993) [118].

An exponential forecasting model had been developed to predict the Jordan's energy consumption (Tamimi and Kodah, 1993). The model characterizes and quantifies Jordan's energy needs up to the year 2000 [119]. Heffington and Brasovan (1994) had formulated the mathematical model termed as growth curves for the prediction of US crude oil-production [120].

A forecasting regression model had been developed for the electrical energy consumption in Eastern Saudi Arabia (Ahmed Z. Al-Garni et al., 1994), as a function of weather data, global solar radiation and population. Five years of data had been used to formulate the energy consumption model. Stepping-regression technique was adopted for the variable selection. The problem of co-linearity between the regressors had been investigated by using standard statistical procedures and the model adequacy is determined from a residual analysis technique [121]. Mackay and Probert (1994) had presented a modified logit-function demand forecasting model for predicting national crude-oil and natural gas consumptions based on saturation curve extrapolations for the appropriate energy intensity [122]. Some methodological and application issues related to decomposing national industrial energy consumption into changes associated with aggregate industrial production level, production structure and sectoral energy intensity had been discussed by Ang B.W. (1995). He has presented a framework for decomposition method formulation by incorporating three different approaches [123]. Luis Giraldo and Barry Hyman (1995) had derived energy end-use models for pulp, paper and paperboard mills. The applicability of the modeling technique and framework to other industries had also been discussed [124]. A multi-logit model for fuel shifts in the domestic sector had been developed by Sudhakara Reddy (1995), using the energy-ladder concept to study the effects of different factors on the selection of an energy carrier for cooking or water heating. They have applied the model to explain energy-carrier choices in Bangalore [125]. Raghavendra D. Rao and Jyoti K. Parikh (1996) had analyzed the demand for petroleum products in India. A translog econometric model based on time series had been developed for forecasting. The demand forecasts till the year 2010 had been obtained for the various petroleum products using these models [126]. Tripathy (1997) had discussed the demand forecasting in a utility power system based on the projections for electrical energy consumption up to 2006–07, released by the central electricity authority (CEA), Government of India [127]. Gonzales Chavez et al. (1999) used univariate Box–Jenkins time-series analyses (ARIMA) models to formulate the forecasting model for the prediction of energy production and consumption in Asturias, Northern Spain [128]. Florides et al. (2000) used the TRNSYS computer program for the modeling and simulation of the energy flows of the modern houses of Cyprus followed by an energy consumption analysis [129].

The trend in current and near future energy consumption from a statistical perspective by considering two factors, namely, increasing population and economic development had been discussed by Shiro Kadoshin et al. (2000) [130]. Samer Saab et al. (2001) had investigated different univariate-modeling methodologies for the forecasting of monthly electric energy consumption in Lebanon. Three univariate models were used namely, autoregressive, autoregressive integrated moving average (ARIMA) and a noval configuration combining an AR (1) with a high pass filter [131]. Mackay and Probert (2001) have developed a bottom–up technique-forecasting model to predict the supplies and demands of fluid fossil fuels for United Kingdom. Also, a modified logit-function demand model was developed for use with the available historic consumption data [132]. An oil and gas supply model (OGSM) has been solved and the projections of oil and natural gas supply and demand to the year 2020 for Canada have been presented (Jai Persaud and Uma Kumar, 2001) [133]. Larry Chuen-ho Chow (2001) has discussed the sectoral energy consumption in Hong Kong for the period 1984–97 with special emphasis on the household sector [134]. Volkan S. Ediger and Huseyin Tatlldil (2002) used semistatistical technique to formulate the forecasting model to predict the primary energy demand in Turkey and analysis of cyclic patterns [135]. The heating degree–day method has been used by Sarak and Satman (2003) to determine the natural gas consumption by residential heating in Turkey [136]. The different scenarios namely, the base case with no mitigation options, replacement of kerosene and liquefied petroleum gas (LPG) by biogas stove, substitution of gasoline by ethanol in transport sector, replacement of coal by wood as fuel in industrial boilers, electricity generation with biomass energy technologies and an integrated scenario including all the options together in Vietnam have been discussed by using the Long Range Energy Alternative Planning (LEAP) model (Amit Kumar et al., 2003) [137]. The possible scenario of the development of the gas sector in Poland has been described. An adaptation of the Hubbert model has been implemented to the Polish situation based upon the Starzman modification to estimate the natural gas consumption in Poland (Jakub Siemek et al., 2003) [138]. Jesus Crespo Cuaresma et al. (2004) has studied the forecasting abilities of a battery of univariate models on hourly electricity spot prices using data from the Leipzig power exchange. The specifications studied include the autoregressive models, autoregressive moving average models and unobserved component models [139].

4.2. Renewable energy models

Solar, wind and biomass are accepted as dependable and widely available renewable energy sources. It is the need of the hour to formulate the forecasting and estimation models for renewable energy sources. The various types of renewable energy models have been reviewed in the following literature.

4.2.1. Solar energy models

Habbane et al. (1986) had developed a modified solar radiation model to determine solar irradiance from sunshine hours for a number of stations located in hot dry arid climates [140]. Five sunshine based correlations, namely, Benson et al., Gopinathan, Ogelman et al., Zabara and new quadratic correlation developed by Akinoslu and Ecevit (1990) had been compared for the estimation of global solar radiation. The overall results presented shows that the correlations of Benson et al. and Gopinathan fall in the second rank [141]. The actual data for the direct, diffuse and global radiations as measured by Eppley Precision Pyranometers had been analyzed. Also, the correlation between estimated and measured hourly and daily solar fluxes over Bahrain had been presented (Ragab and Som, 1991) [142]. Paul D. Maycock (1994) obtained the forecasting of international photovoltaic markets and developments to 2010. The author used two scenarios namely ‘Business as usual’ and ‘Accelerated’ for forecasting. Also, the status of all PV module producers had been summarized [143]. Gopinathan and Alfonso Soler (1995) had developed a diffuse radiation models to predict monthly average, daily diffuse radiation for a wide latitude range. Several years of measured data on global and diffuse radiation and sunshine duration for 40 widely spread locations in the latitude range 36°S to 60°N had been used to develop the model [144]. The oversizing method of estimation in PV systems and the theoretical calculations of the mismatch in PV systems had been discussed by Azmi Z. Taha (1995) [145]. A procedure had been formulated by Parishwad et al. (1997) to estimate the direct, diffuse and global hourly solar radiation on a horizontal surface for any location in India. An exponential curve, similar to the one used by ASHRAE, was fitted to the collected solar radiation data of six cities from different regions of India for the calculation of hourly solar radiation. The author(s) used three statistical indicators to compare the accuracy of the developed procedure [146]. A number of years of data relating the solar radiation on a horizontal surface, sunshine duration and wind speed in Sudan had been compiled, evaluated and presented by Abdeen Mustafa Omer (1997). The author used Angstrom formula to correlate relative global solar irradiance to the corresponding relative duration of bright sunshine. The regression coefficients obtained had been used to predict the global solar irradiance. Also, a radiation map of Sudan had been prepared from the estimated radiation values. The monthly average wind speed and average power had been determined for 70 stations of Sudan by analyzing the routine wind data of these stations. Also, a wind map of Sudan had been prepared [147]. Viorel Badescu (1999) had formulated the correlation to estimate the monthly mean daily global solar irradiation, with bright sunshine hour number or fractional total cloud amount as input for Romania [148]. Shafiqur Rehman (1999) had developed an empirical correlation for the estimation of global solar radiation in Saudi Arabia. Also, he had presented the comparison between the present correlation and other models developed under different geographical and varied meteorological conditions. The comparisons had been made using standard statistical tests, namely mean bias error (MBE), root mean square error (RMSE), and mean percentage error (MPE) and mean absolute bias error (MABE) tests [149].

Meyer and Van Dyk (2000) developed the energy model based on total daily irradiation and maximum ambient temperature. To predict the energy produced by photovoltaic modules under certain meteorological conditions, an energy model can be used. The regression analysis is used to formulate the model and the model is able to predict daily module energy based on the above two parameters only [150]. Batlles et al. (2000) had analyzed the results provided by different models in the estimation of hourly direct irradiance values. Several models proposed by Orgill and Hollands, Erbs et al., Reindl et al., Skarveit and Olseth, Maxwell and Louche et al. had been used for the analysis. Also, a parametric model proposed by Iqbal had been used to estimate the direct irradiance under cloudness sky conditions [151]. Zekai Sen and Elcin Tan (2001) have developed a simple parabolic model with three parameters to estimate the hourly, daily and monthly global or diffuse radiation for Northwestern part of Turkey [152]. Wong and Chow (2001) have reviewed the solar radiation models for predicting the average daily and hourly global radiation, beam radiation and diffuse radiation. Seven models using the Angstrom–Prescott equation to predict the average daily global radiation with hours of sunshine have been considered. Also, two parametric models have been reviewed and used to predict the hourly irradiance of Hong Kong [153]. Amauri P. Oliveira et al. (2002) have formulated a correlation model to estimate hourly, daily and monthly values of diffuse solar radiation on horizontal surfaces, applied to the city of Sao Paulo, Brazil [154]. Safi et al. (2002) used higher order statistics to predict the global solar radiation by means of two different procedures [155]. A Monte-Carlo backward ray tracing technique is used to calculate angular shading factors (ASF) for the determination of time varying diffuse irradiance (Tsangrassoulis et al., 2002) [156]. Jain (2002) developed stochastic models using Box and Jenkins technique for sunshine duration and solar irradiation measured at Sebele, Botswana. The data used consists of the monthly averages and the Julian-days averages of sunshine duration and solar irradiation sequences [157]. A study has been done on the measurement of luminance of day light and solar irradiance from a station in the Asian institute of technology (AIT) campus, which is situated in a tropical region. Also, mathematical models to predict global and horizontal daylight luminance and solar irradiance are presented (Surapong Chirarattananon et al., 2002) [158]. The conceptual model for marketing solar based technology to developing countries has been formulated by Raja Peter et al. (2002). The purpose of the study is to identify the factors that influence the adoption of solar based technology. The different variables are identified from the examination of the literature in the area of diffusion of technology [159]. Forecasting model to predict the demand on solar water heating systems and their energy saving potential in household sector during the period 2001–2005 in Jordan has been presented by Kablan (2003) [160]. A dynamic simulation code (TRNSYS) has been used by Cardinale et al. in 2003 to investigate a solar plant for hot water production. The author(s) using life cycle savings (LCS) method to evaluate the economic viability of such a plant by considering three conventional fuels namely gas-oil, LPG and electricity [161]. Jain et al. (2003) has presented the bivariate models that relate solar irradiation to sunshine duration, and solar irradiation to extreme temperatures for Sebele, Botswana [162].

4.2.2. Wind energy models

Wind has been proven as a reliable and cost effective energy source. Technological improvements over the last 5 years have placed wind energy in a stable position to compete with conventional power generation technologies. The various wind energy models have been presented in the subsequent paragraph.Barry N. Haack (1982) used a computer-operated simulation model, which incorporates wind speeds, residential electricity demands and parameters from the generator, inverter and storage components to determine the amount of energy from a wind-energy conversion system [163]. Panda et al. (1990) made a stochastic analysis of the wind energy potential at seven representative weather stations in India. A probability model for the wind data and potential has been developed. The author(s) used Box–Cox transformation to transform the data for all of the stations to a normal distribution [164].

Jamil et al. (1995) used Weibull probability distribution function to find out the wind energy density and other wind characteristics with the help of the statistical data of 50 days wind speed measurements at the materials and energy research centre (MERC)-solar site, Tehran in Iran [165]. The detailed description of the various types of equipments, instruments, site specifications and other technical needs for the wind assessment project in Saudi Arabia had been presented by Saleh H. Alawaji (1996) [166]. A cumulative

Semivarigram (CSV) model had been derived by Zekai Sen and Ahmet D. Sahin (1997) to assess the regional patterns of wind energy potential along the western Aegean Sea coastal part of Turkey. This innovative technique provides clues about the regional variations along any direction. The CSV technique yielded the radius of influence for wind velocity and Weibull distribution parameters. The dimensionless standard regional dependence (SRD) functions are obtained from the sample CSV, which has been used to make simple regional predictions for the wind energy or wind velocity distribution parameters [167].

Availability of wind energy and its characteristics at Kumta and Sirsi in Uttar Kannada district of Karnataka had been studied by Ramachandra et al. (1997), based on primary data collected at these sites for a period of 24 months. Wind regimes at Karwar (1952–1989), Honnavar (1939–1989) and Shirali (1974–1989) have also been analyzed based on data collected from India Meteorological Department (IMD) of respective meteorological observatories [168]. A comparison work on various forecasting techniques applied to mean hourly wind speed was done by Sfetsos (2000) using time series analysis, traditional linear (ARMA) models, feed forward and recurrent neural networks, Adaptive neuro-fuzzy interference systems (ANFIS) and neural logic networks [169]. The mean hourly wind speed data-forecasting model using time series analysis has been presented by Sfetses (2002) [170]. Cluster analysis technique is used by Gomez-Munoz and Porta-Gandara during 2002 to find the local wind patterns for modeling renewable energy systems, which strongly depends on wind loads [171]. The present state of wind energy utilization in Hungary has been discussed by Bartholy et al. (2003). The author presented the policy changes of the Hungarian government concerning the joining of the country to the European union planned in 2004 [172]. Youcef Ettoumi et al. (2003) used first-order Markov chain and Weibull distribution methods for statistical bivariate modeling of wind using the data wind speed and wind direction measurements collected every 3 h at the meteorological station of Essenia (Oran, a state in Algeria). Also, a detailed study has been made on the statistical features of the wind at Oran [173]. Also, the Weibull density function has been used by Weisser (2003) for the analysis of wind energy potential of Grenada (West Indies) based on historic recordings of mean hourly wind velocity [174]. Poggi et al. (2003) have discussed an autoregressive time series model for forecasting and simulating wind speed in Corsica [175].

4.2.3. Biomass and bioenergy models

The different types of biomass and bioenergy models have been reviewed in the following sections.

A mathematical model had been formulated to find the impact of biogas plants on energy use pattern of rural households in India (Rajeswaran et al., 1990) [176]. A generalized framework for economic analysis of biogas plants by capturing the effects of the biogas plant capacity in the benefits accruing from biogas utilization has been presented. (Tara Chandra Kandpal et al., 1991) [177]. A review of forecasting models for describing the behaviors of landfill-gas-producing sites had been presented by Gardner and Probert (1993) [178]. A comprehensive approach that considers fuel, fodder and fertilizer relationships had been used to analyze the rural energy system of Karnataka. A linear programming model (Painuly et al., 1995) that incorporates these relationships had been used to simulate and study the effects of various policy options on the rural energy system in 2000 A.D [179]. Tani E. Converse and David R. Betters (1995) used stepwise ordinary least-squares regression technique to develop equations to predict yields for short rotation black locust [180]. Kimmins (1997) had discussed the second and third generation hybrid simulation models FORECAST and FORCEE, which evaluate the sustainability of bioenergy plantations [181]. Alam et al. (1999) had formulated a quantitative dynamic simulation model as a system study for rural household–biomass fuel consumption in Bangladesh. The parameters, constraints and initial values in the model represent present conditions. The model had been simulated to project the status of the system over an extended period of time [182]. Yasuko Nishigami et al. (2000) had proposed a new synthesis method for the estimation of forest area near desserts [183]. A global land use and energy model (GLUE) had been developed to evaluate the bioenergy supply potentials, land use changes and CO2 emissions in the world. (Hiromi Yamamoto et al., 2000) [184]. Haripriya (2000) had discussed the estimation of biomass and the carbon contained in biomass of Indian forests for the year 1993, using species-wise volume inventories for all forest strata in various states [185]. The use of geographic information systems (GIS) for understanding the geographic context of bioenergy supplies and a regional-scale, GIS-based modeling system for estimating potential biomass supplies from energy crops had been discussed by Robert L. Graham et al. (2000) [186]. Factors that complicate bioenergy model building had been presented by Roos and Rakos (2000). The author(s) made some recommendations as to how the various aspects namely, the cost structure of energy production, information asymmetry, socioeconomic factors, household economics, strategic considerations and policy uncertainties could be considered in the modeling work to improve model accuracy [187]. Harje Baath et al. (2002) has developed a long-term forecasting model based on satellite image for the local assessment of forest fuels [188]. Specht and West (2003) have developed a mathematical model to estimate the biomass and sequestered carbon on farm forest plantations in Northern New South Wales, Australia [189].

5. Optimization models

Solar, wind and biomass are accepted as dependable and widely available renewable energy sources. Formulation of an allocation model will help in the proper allocation of these renewable energy sources in meeting the future energy demand in India. A review of different kinds of optimization models has been presented in the following sections. Gurfel (1979) had developed an optimization model for the fuel energy balance with higher accuracy [190]. De Musgrove (1984) had used the MARKAL, a linear programming model having total system discounted cost as the objective function and oil conversion and demand as constraints, to analyze minimum discounted cost configurations for the Australian energy system during the period 1980–2020 [191]. A deterministic linear programming model had been discussed by Ellis et al. (1985) for the development of acid rain abatement strategies in eastern North America. The maximization of the marginal cost based on environmental constraints was the objective of the model [192]. Das (1987) had developed a multi-objective linear programming based dynamic optimization model to analyze the renewable energy policy for Tamil Nadu, a state in India [193].

Satsangi and Sarma (1988) had discussed the possible options for meeting the energy needs of the economy for India for the year 2000–01. The minimization of the cost was the objective of the model, based on resource, capacity and upper/lower bound constraints [194]. Andy S. Kydes (1990) has discussed the general methodology for flow models and an overview of two Brookhaven energy system optimization model (BESOM) and Timed stepped energy system optimization model (TESOM). Both the models have been used to examine inter-fuel substitutions in the context of constraints on the availability of competing resources and technologies [195]. Pasternak et al. (1990) had formulated an optimization model for the economic evaluation of energy conservation projects with an emphasis on initiation time [196]. The mathematical programming energy–economy–environment (MPEEE) model had been developed by Suganthi L. and Jagadeesan T.R. (1992). The model maximizes the GNP/energy ratio based on environmental constraints, to meet the energy requirement for the year 2010–2011 for India [197]. An overview of energy planning research was presented on implementation of the LEAP model for Tanzania through the use of optimization models in combination with a forecasting model (Luhanga et al., 1993). Two models have been developed, in which the first model determines the optimum mix of energy resources at minimum cost. The second model seeks the optimum number of end-use biomass devices and hectares of land to be afforested to minimize the wood fuel deficit [198]. A linear optimization model and a multi-attribute value model had been introduced by Mustafa Tiris et al. (1994), to estimate the long-term energy, economy and environment interactions for Turkey [199]. Groscurth (1995) had developed a model, which describes regional and municipal energy systems in terms of data-flow networks. The model developed provides a highly flexible tool for dynamic and stochastic minimization of primary energy demand, emissions of pollutants and monetary cost. The conventional energy-supply techniques, rational use of energy, demand-side measures and utilization of renewable energy sources are included in the model [200]. A stochastic version of the dynamic linear programming model had been presented by Messner et al. (1996). The approach chosen explicitly incorporates the uncertainties in the model, endogenizing interactions between decision structure and uncertainties involved [201]. A cost minimization model for coal import strategy for Taiwan had been developed by Lai Jeng-Wen and Chen Chia-Yon (1996). The model was used to plan future coal import strategy, as well as to study the effect of cost changes by making the sensitivity test [202]. Lehtila and Pirila (1996) had formulated a bottom–up energy systems optimization model to support policy planning in Finland for the sustainable use of energy. The methodology of the Finnish EFOM model had been presented including the description of biomass use for energy, power and heat generation, emissions and the end-use of energy. Also, an important sub-model for the energy intensive pulp and paper industries was incorporated in the model [203].

A multi-level optimization (MLO) model had been developed by Sardar (1997) to study the various energy issues such as self-sufficiency, conservation and sustainability pertinent to Australia's situation. The Australian energy planning system optimization model (AEPSOM) is based on the MLO model [204]. Zhijun Xie and Michael Kuby (1997) had developed a strategic-level, network based investment-planning optimization model of China's coal and electricity delivery system [205]. MODEST, an energy system optimization model had been described by Dag Henning (1997). The model was applied to a typical local Swedish electricity and district-heating utility and to the national power system. MODEST uses linear programming to minimize the capital and operation costs of energy supply and demand-side management [206]. Raja et al. (1997) had presented an energy planning optimization model using linear programming technique for sustainable agriculture development in the Chellampatti block of Madurai district, Tamil Nadu, a state in India. The model had been developed based on the availability of various energy sources in the block and the requirements of various human and agricultural activities [207]. Kanniappan and Ramachandran (1998) had developed an optimization model using linear programming, in order to get maximum output of surplus biomass excluding the biomass assigned for fuel and fodder for animals, by suitably allocating the land area for the cultivation of different crops subject to meeting the food requirements for the population with regard to cereals, pulses, oilseeds, sugar and vegetables in Nilakkottai block of Dindigul district, Tamil Nadu, a state in India. Also, the model has taken into consideration the utilization of the available resources such as human labor, animal power and tractor power in the region mentioned [208]. The optimal renewable energy model (OREM) has been formulated to find the optimum level of utilization of renewable energy sources in India for the year 2020–21 (Iniyan S. and Jagadeesan T.R., 1998). The model aims at minimizing cost/efficiency ratio and finds the optimum allocation of different renewable energy sources for various end-uses. The constraints used in the model are social acceptance level, potential limit, demand and reliability. The author(s) also focused the study on the performance and reliability of wind energy systems and its effect on OREM model. By considering the above said factors, the OREM model is analyzed for wind energy system, solar energy system and biomass energy system [209]. Iniyan S. et al. (1998) has formulated an optimal renewable energy model (OREM) for the effective utilization of renewable sources of energy in India for the period 2020–21, with the objective function of minimizing cost/efficiency ratio and constraints—social acceptance, reliability, demand and potential. The allocation of renewable energy sources for various end uses such as lighting, cooking, pumping, heating, cooling and transportation has been accomplished using the OREM model for the year 2020–21 [210]. A modified econometric model that links energy consumption with the economy, technology and the environment has been validated through comparison with an econometric and time-series regression model. (Suganthi L. and Anand A. Samuel, 1999). The actual requirements of coal, oil and electricity obtained from the modified model has been used as input in the mathematical programming energy–economy–environment (MPEEE) model [211]. An optimal renewable energy mathematical (OREM) model has been developed to allocate the predicted renewable energy demand for different end-uses (Iniyan S. et al., 2000). A Delphi study has been conducted to find the level of social acceptance in the utilization of renewable energy sources for the year 2020–2021. A sensitivity analysis has also been done to validate the OREM model [212].

An optimization model has been developed to determine the optimum allocation of renewable energy in various end-uses in India for the period 2020–2021, taking into account commercial energy requirement (Suganthi L. and Williams, 2000). Sensitivity analysis has been performed on the model by changing the demand, potential, reliability, emission and employment factors [213]. Renewable energy sources are likely to play a significant role in meeting the future energy requirement of a developing country like

India. An optimal renewable energy model (OREM) that minimizes the cost/efficiency ratio and determines the optimum allocation of different renewable energy sources for various end-uses has been presented (Iniyan S. and Sumathy K., 2000). The potential of renewable energy sources, energy demand, reliability of renewable energy systems and their acceptance level have been used as constraints in the model [214]. A methodology of optimal wind-hydro solution estimation had been developed and subsequently applied to several typical Aegean Sea island cases, in order to define the most beneficial configuration of the proposed renewable station. The author(s) (Kaldellis and Kavadias, 2001) used real data, like long term wind speed measurements, demanded electrical load and operational characteristics of the system components [215]. Cormio et al. (2003) presented a bottom–up energy system optimization model using linear programming methodology based on the energy flow optimization model (EFOM) to support planning policies for promoting the use of renewable energy sources. The environmental constraints are also included in the model [216]. An optimization model for a geothermal energy source, based on the theoretical water well of different quality parameters has been presented by Drozdz (2003). The model maximizes the net power of the source [217]. The MIND (Method for analysis of INDustrial energy system) method with feedback loops has been developed for multi-period cost optimization of industrial energy systems, taking care of both energy and material flows. (Mei Gong, 2003) [218]. Ashok Kumar Sinha and Surekha Dudhani had presented a linear programming based methodology for allocating optimal share of renewable energy resources with varying technological and cost coefficients. The role of government and private agencies in promoting the growth of small hydro power had also been discussed [219].

6. Energy models based on neural networks

Intelligent solutions, based on artificial intelligence (AI) technologies to solve complicated practical problems in various sectors are becoming more and more nowadays. AI-based systems are being developed and deployed worldwide in myriad applications, mainly because of their symbolic reasoning, flexibility and explanation capabilities.

Fuzzy theory has been applied to the logistical optimization of the supply and demand sectors in order to assess the relative importance or degree of association between the supply and demand determinants (Sanders et al., 1993) [220]. A two layered feed forward artificial neural network forecasting model has been developed to relate the electric energy consumption in the Eastern Province of Saudi Arabia to the weather data, global radiation and population. Seven years of data have been used for model building and validation. The model adequacy has been established by a visual inspection technique and the chi-square test (Javeed Nizami and Ahmed G. Al-Garni, 1995) [221]. Michalik et al. (1997) used linguistic variables and fuzzy logic approach for the development of mathematical model to predict the energy demand in the residential sector [222]. Abductive network machine learning had been proposed by Abdel-Aal et al. (1997) as an alternative to the conventional multiple regression analysis method for modeling and forecasting monthly electric energy consumption of Eastern Saudi Arabia in domestic sector [223]. A neural network approach is formulated for the wind speed prediction and compares its performance with an autoregressive model (Mohamed A. Mohandes et al., 1998), after observing the statistical characteristics of mean monthly and daily wind speed in Jeddah, Saudi Arabia. The autocorrelation coefficients are computed and are found compatible with the real diurnal variation of mean wind speed. Also, the stochastic time series analysis is found to be suitable for the description of autoregressive model that involves a time lag of one month for the mean monthly prediction and 1 day for the mean daily wind speed prediction [224]. A fuzzy multi-objective linear programming approach to solve the energy resource allocation has been presented by Chedid et al. (1999). For this, nine energy resources, and six household end-uses have been considered. Also, the sensitivity analysis on the energy systems has been performed [225]. Soteris A. Kalogirou (2000) has used artificial neural network technique for the estimation of heating-loads of buildings and for the prediction of energy consumption of a passive solar building. Multiple hidden layer architecture has been used in the modeling [226]. Soteris A. Kalogirou and Milorad Bojic (2000) have developed a model based on artificial neural network for the prediction of energy consumption of a passive solar building. A multi-layer recurrent architecture using the standard back-propagation learning algorithm has been applied to develop the model [227]. Wavelet transform and neural network technique have been used to formulate the model for short-term electrical load forecasting (Yao et al., 2000) [228]. A fuzzy based multi-objective analysis has been made by Agrawal and Singh (2001), for the energy allocation for cooking in UP households in India. The economic, environmental and technical concerns are the main objectives included in the model [229]. Atsu S.S. Dorvio et al. (2002) used artificial neural network methods to estimate solar radiation by first estimating the clearness index, radial basis functions (RBF) and multi-layer perception (MLP) methods [230]. A neural network based energy consumption model has been developed for the Canadian residential sector (Merih Aydinalp et al., 2002) [231]. Che-Chiang Hsu and Chia-Yon Chen (2003) have collected empirical data to formulate an artificial neural network model to predict the regional peak load of Taiwan [232]. Metaxiotis et al. (2003) has given the overview of AI technologies as well as their current use in the field of short term electric load forecasting (STELF) [233].

7. Emission reduction models

Jae Edmonds and John Reilly (1983) had formulated a long-term global energy–economy model of CO2 release from the utilization of fossil fuels. They had projected that if the same trend continues; there will be tremendous amount of emission in the future [234]. David B. Reister (1984) had presented how a simple model could be implemented in conjunction with an elaborate model to develop CO2 emission scenarios [235]. Subsequently, they (John Reilly and Jae Edmonds, 1985) had presented three emission scenarios—which cover the future range. The impact of alternative energy evaluations other than commercial energy systems over the next 100 years had been analyzed by them [236]. The global atmospheric CO2 and the temperature variation that would result from various future CO2 emission scenarios had been determined using a coupled climate–carbon cycle model by Danny Harvey (1889) [237]. Danny Harvey (1990) had estimated the impact on atmospheric CO2 emission-reduction strategies, using the coupled climate–carbon cycle model [238]. Leif Gustavsson et al. (1992) used an end-use accounting model to identify the energy systems, which significantly reduce emissions of acidifying gases and CO2 from non-mobile sources for Western Scania, Sweden [239]. Kamiuto arrived a simple global carbon-cycle model for the forecasting of future atmospheric CO2 concentrations (1994) based on the previous theoretical model for a global carbon cycle considering CO2-fertilization effects of land biota [240]. Kamiuto (1994) developed a simple global carbon-cycle model with three main reservoirs, namely, the atmosphere, biosphere and the oceans. It includes a description of CO2-exchange processes between the reservoirs, disregarding the interior transfer processes with in the biosphere and the oceans. The model is utilized to reconstruct the time history of CO2-emission rates due to deforestation and changing land use during the past 200 years and to estimate the CO2-transfer rates between the reservoirs around 1980 [241]. A set of models for global carbon cycle, world population and atmospheric CO2 had been proposed by Kamo S. Demirchian and Karina K. Demirchian (1996) [242]. Ispersion modeling study of SO2 concentrations in Gebze, Turkey had been conducted by Tiris et al. (1996). They have predicted the winter average SO2 contributions to the air quality over Gebze by using the emissions, meteorological and topographical data that have been loaded on the USEPA-approved ISCLT Model [243]. Gert Tinggaard Svendsen (1998) had formulated a general CO2 regulation model for Denmark. This model may guide the future energy policies in other countries as well [244].

A regional engineering model for assessing space heating energies and related green house gas emissions for North Karelia, Finland has been presented. The objective of the modeling is to improve the quality and quantity of heating energy and emission data, especially for the benefit of local decision making (Snakin, 2000) [245]. Some of the basic requirements of useful greenhouse gas reduction model have been reviewed by Mark (2000) [246]. Kris R. Voorspools and William D. D'haeseleer (2000) have formulated an evaluation method for calculating the emission responsibility of specific electric applications. Also, a tool and a methodology have been developed to simulate and evaluate electric demand- and supply-side options [247]. A multi-objective programming approach integrated with a Leontief inter-industry model had been used to evaluate the impact of energy conservation policy on the cost of reducing CO2 emissions and undertaking industrial adjustment in Taiwan. An inter-temporal CO2 reduction model, consisting of two objective equations and 1340 constraint equations has been constructed to simulate alternative scenarios (George J.Y. Hsu and Feng-Ying Chou, 2000) [248]. Matthews (2001) has formulated a standard methodology for evaluating the energy and carbon budgets of biofuel production systems, with emphasis on wood fuel production from short rotation coppice [249]. A time-series analysis of energy related carbon emissions and their relationships with energy consumption and GNP in Korea have been studied by Ki-Hong Choi and Ang (2001) from 1961 to 1998 [250]. Ricardo Cunha da Costa (2001) has compared some Brazilian energy and CO2 emission scenarios in 2010 in order to verify how far model structures influence findings and decisions [251]. Marian Leimbach (2003) has analyzed the equity issues that frame decisions on emission rights allocation, based on the ICLIPS model [252].

8. Conclusion

The different energy models have been reviewed globally. The following important factors in the energy utilization such as gross income, gross output, profit, energy quantity, GNP/energy ratio, energy performance, energy production have been considered as the objective function of linear programming models. Also, it was identified that technology, efficiency, supply, demand, employment and resource availability were used as constraints in the model. It has been observed that the behavioral or econometric models and the macro-statistical single-entity models reflect the overall aggregate characteristics of energy supply and consumption and are oriented towards forecasting. It has been observed that the linear programming models of different types can be used profitably in all the time frames and the econometric models are best suited to the short- and medium-term forecasting. Also, it was noticed that the efficiency and cost factors, which were identified to be critical parameters in the objective function formulation. It has been observed that the energy–economy models helps in understanding the way in which energy–economy interactions work. In addition, they enable the planners to predict and plan the future. It has been concluded that the models serve to promote discussion and formulation of policies, which are appropriate to the situation. As far as utilization of renewable energy concerned, the prime factors like life span of the system, reliability, intermittent supply, site selection, investment and social acceptance have to be analyzed. It has also been suggested that the neural networks can be used in the energy forecasting and the fuzzy logic for energy allocation of the country.

References

[1] Landsberg PT. A simple model for solar energy economics in the UK. Energy 1977;2:149–59.
[2] Marchetti C. Primary energy substitution models: on the interaction between energy and society. Technol Forecast Social Change 1977;10:345–56.
[3] Stern MO. A policy-impact model for the supply of depletable resources with applications to crude oil. Energy 1977;2:257–72.
[4] Borg S. A discriminating monopolist model of natural gas markets over the period 1960–1966. Appl Energy 1981;9:153–8.
[5] Borg S. Further results on a discriminating monopolist model. Appl Energy 1983;13:317–22.
[6] Ambrosone G, Catalanotti S, Matarazzo M, Vicari L. A dynamic model for the thermal energy management of buildings. Appl Energy 1983;15:285–97.
[7] Fawkes S. Soft-systems model of energy management and checklists for energy managers. Appl Energy 1987;27:229–41.
[8] Hammarsten S. A critical appraisal of energy-signature models. Appl Energy 1987;26:97–110.
[9] Hsu GJY, Leung PS, Ching CTK. A multiobjective programming and interindustry model for energy-economic planning in Taiwan. Energy Syst Policy 1987;11:185–204.
[10] Rahman SH. Aggregate energy demand projections for India: an econometric approach. Pacific Asian J Energy 1988;2:32–46.
[11] Natarajan R. Some essential considerations in energy policy and planning for the future. Urja 1990;27/1: 39–50.
[12] Capros P, Karadeloglou P, Mentzas G, Samouilidis JE. Short and medium-term modelling and problems of models linkage. Energy 1990;15:301–24.
[13] Baker AB, Finizza AJ. Corporate point of view on modelling. Energy 1990;15:149–53.

[14] Kaya Y. Credibility of models. Energy 1990;15:163–70.
[15] Reister DB. The hybrid approach to demand modeling. Energy 1990;15:249–60.
[16] Capros P, Karadeloglou P, Mentzas G, Samouilidis JE. Short and medium-term modeling and problems of models linkage. Energy 1990;15:301–24.
[17] Shi X, Lu Y. Multisectoral planning models. Energy 1990;15:325–39.
[18] Weyant JP. Policy modeling: an overview. Energy 1990;15:203–6.
[19] Labys WC, Weyant JP. Integrated models. Energy 1990;15:341–4.
[20] Boyd G, Fox J, Hanson D. Set of models. Energy 1990;15:345–62.
[21] Alam MS, Huq AMZ, Bala BK. An integrated rural energy model for a village in Bangladesh. Energy 1990;15:131–9.
[22] Werbos PJ. Econometric techniques: theory versus practice. Energy 1990;15:213–36.
[23] Labys WC, Asano H. Process models. Energy 1990;15:237–48.
[24] Poch LA, Jenkins RT. Dynamic programming models. Energy 1990;15:573–81.
[25] Psarras J, Capros P, Samouilidis JE. Multiobjective programming. Energy 1990;15:583–605.
[26] Labys WC, Kuczmowski T, Infanger G. Special programming models. Energy 1990;15:607–17.
[27] Yu OS. Interface between mental and computer models. Energy 1990;15:621–9.
[28] Belyaev LS. Pay-off matrix technique. Energy 1990;15:631–43.
[29] Entriken R, Infanger G. Decomposition and importance sampling for stochastic linear models. Energy 1990;15:645–59.
[30] Bowe TR, Dapkus WD, Patton JB. Markov models. Energy 1990;15:661–76.
[31] Loagn DM. Decision analysis in engineering-economic modeling. Energy 1990;15:677–96.
[32] Tzeng G-H, Shiau T-A, Lin C-Y. Application of multicriteria decision making to the evaluation of new energy system development in Taiwan. Energy 1992;17:983–92.
[33] Calderan R, Spiga M, Vestrucci P. Energy modeling of a cogeneration system for a food industry. Energy 1992;17:609–16.
[34] Joshi B, Bhattiand TS, Bansal NK. Decentralized energy planning model for a typical village in India. Energy 1992;17:869–76.
[35] Mohanty B, Panda H. Integrated energy system for industrial complexes: part I: a linear programming approach. Appl Energy 1993;46:317–48.
[36] Mackay RM, Probert SD. Predicted supplies of oil: a controversy revisited. Appl Energy 1993;46:113–47.
[37] Nilsson K, Soderstrom M. Industrial applications of production planning with optimal electricity demand. Appl Energy 1993;46:181–92.
[38] Sinha A. Modelling the economics of combined wind/hydro/diesel power systems. Energy Convers Manage 1993;34:577–85.
[39] Malik B, Shashi BM, Satsangi PS, Tripathy SC, Balasubramanian R. Mathematical model for energy planning of rural India. Energy Res 1994;18:469–82.
[40] Johnson BE. Modelling energy technology choices which investment analysis tools are appropriate? Energy Policy 1994;22:877–83.
[41] Zaheer-Uddin M, Zheng GR. A VAV system model for simulation of energy management control functions: off normal operation and duty cycling. Energy Convers Manage 1994;35:917–31.
[42] Kydes AS, Shaw SH, McDonald DF. Beyond the horizon: recent directions in long-term energy modeling. Energy 1995;20:131–49.
[43] Ramanathan R, Ganesh LS. Energy alternatives for lighting in households: an evaluation using an integrated goal programming-AHP model. Energy 1995;20:63–72.
[44] Huang JP, Poh K, Ang BW. Decision analysis in energy and environmental modeling. Energy 1995;20: 843–55.
[45] Rasanen M, Ruusunen J, Hamalainen RP. Customer level analysis of dynamic pricing experiments using consumption-pattern models. Energy 1995;20:897–906.
[46] R.-P., Victor, Vargas R. Energy reform in Mexico: a new development model or modernization of statism? Energy Policy 1996;24:265–74.
[47] Spinney PJ, Campbell Watkins G. Monte carlo simulation techniques and electric utility resource decisions. Energy Policy 1996;24:155–63.

[48] Kumar S, Rubab S, Kandpal TC, Mullick SC. Financial feasibility analysis of Box-type solar cookers in India. Energy 1996;21:1257–64.
[49] Able-Thomas U. Models of renewable energy technology transfer to developing countries. Renew Energy 1996;9:1104–7.
[50] Khemiri-Enit A, Annabi-Cenaffif M. Models for energy conservation to be used in energy audits. Renew Energy 1996;9:1299–302.
[51] Singh S, Singh IP, Singh S, Pannu CJS. Energy planning of a Punjab village using multiple objectives compromise programming. Energy Convers Manage 1996;37:329–42.
[52] Malik SB, Satsangi PS. Data extrapolation techniques for energy systems planning. Energy Convers Manage 1997;38:1459–74.
[53] Boonekamp PGM. Monitoring the energy use of households using a simulation model. Energy Policy 1997;25:781–8.
[54] Neubauer F, Westman E, Ford A. Applying planning models to study new competition: analysis for the Bonneville Power Administration. Energy Policy 1997;25:273–80.
[55] Alam MS, Roychowdhury A, Islam KK, Huq AMZ. A revisited model for the physical quality of life (PQL) as a function of electrical energy consumption. Energy 1998;23:791–801.
[56] Gomes Martins A, Figueiredo R, Coelho D, de Sousa JL. Energy planning in urban historical centres: a methodological approach with a case-study. Energy Policy 1998;26:1153–65.
[57] Akisawa A, Kang YT, Shimazaki Y, Kashiwagi T. Environmentally friendly energy system models using material circulation and energy cascade—the optimization work. Energy 1999;24:561–78.
[58] Scott MJ, Sands RD, Edmonds J, Liebetrau AM, Engel DW. Uncertainty in integrated assessment models: modeling with MiniCAM 1.0. Energy Policy 1999;27:855–79.
[59] Shrestha RM, Marpaung COP. Supply- and demand-side effects of carbon tax in the Indonesian power sector: an integrated resource planning analysis. Energy Policy 1999;27:185–94.
[60] Sorensen B, Meibom P. GIS tools for renewable energy modeling. Renew Energy 1999;16:1262–7.
[61] Bruhns H, Steadman P, Herring H. A database for modeling energy use in the non-domestic building stock of England and Wales. Appl Energy 2000;66:277–97.
[62] Hektor B. Planning models for bioenergy: some general observations and comments. Biomass Bioenergy 2000;18:279–82.
[63] Rozakis S, Sourie J, Vanderpooten D. Integrated micro-economic modeling and multi-criteria methodology to support public decision-making: the case of liquid bio-fuels in France. Biomass Bioenergy 2001;20:385–98.
[64] Sun JW. Is GNP energy model logical? Energy Policy 2001;29:949–50.
[65] Pandey R. Energy policy modeling: agenda for developing countries. Energy Policy 2002;30:97–106.
[66] Jayram KSV, Ashok S. Model for optimal integrated energy system. Energy technologies for sustainable development. Uttar Pradesh, India: Prime Publishing House; 2003 p. 167–71.
[67] Frei CW, Haldi P-A, Sarlos G. Dynamic formulation of a top–down and bottom–up merging energy-policy model. Energy Policy 2003;31:1017–31.
[68] Beccali M, Cellura M, Mistretta M. Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. Renew Energy 2003;28: 2063–87.
[69] Huber C, Faber T, Haas R, Resch G. Organising a joint green European electricity market: the model ElGreen. Renew Energy 2004;29:197–210.
[70] Uri ND, Hassanein SA. Modelling the high frequency demand for energy. Appl Energy 1985;19:49–59.
[71] Halliwell C, Sherif F. The EMR energy demand and price modeling system. IMACS 1985;227–32.
[72] Macal CM, Bragen MJ. An integrated energy planning model for Illinois. Energy 1987;12:1239–50.
[73] Sterman JD, Richardson GP, Davidsen P. Modelling the estimation of petroleum resources in the United States. Technol Forecast Social Change 1988;33:219–49.
[74] Rijal K, Bansal NK, Grover PD. Rural household energy demand modeling. Energy Econ 1990;279–88.
[75] Labys WC. Econometric supply models. Energy 1990;15:545–7.
[76] Labys WC, Kuczmowski T. Remarks on supply optimization. Energy 1990;15:619–20.
[77] Wu R-H, Chen C-Y. On the application of input–output analysis of energy issues. Energy Econ 1990;Jan: 71–6.

[78] Haraden J. A cost model for magma power generation. Energy 1991;16:1191–8.
[79] Badri MA. Analysis of demand for electricity in the United States. Energy 1992;17:725–33.
[80] Borges AM, Pereira AM. Energy demand in Portuguese manufacturing: a two-stage model. Energy 1992; 17:61–77.
[81] Amatya VB, Chandrashekar M, Robinson JB. Residential sector energy-supply–demand analysis: a modeling approach for developing countries and fuelwood-supply sustainability in Nepal. Energy 1993;18: 341–54.
[82] Zhen F. A model of the energy-supply and demand system at the village level. Energy 1993;18:365–9.
[83] Blakemore FB, Davies C, Isaac JG. UK energy market: an analysis of energy demands. Part I. A disaggregated sectorial approach. Appl Energy 1994;261:277.
[84] Intarapravich D, Johnson CJ, Li B, Long S, Pezeshki S, Prawiraatmadja W, Tang FC, Wu K. Asia-Pacific energy supply and demand to 2010. Energy 1996;21:1017–39.
[85] Wohlgemuth N. World transport energy demand modeling: methodologies and elasticities. Energy Policy 1997;25:1109–19.
[86] Michalik G, Khan ME, Bonwick WJ, Mielczarski W. Structural modeling of energy demands in the residential sector: 1. Development of structural models. Energy 1997;22:937–47.
[87] Bala BK. Computer modeling of the rural energy system and of CO2 emissions for Bangladesh. Energy 1997;22:999–1003.
[88] Balachandra P, Chandru V. Modelling electricity demand with representative load curves. Energy 1999; 24:219–30.
[89] Messner S, Schrattenholzer L. MESSAGE-MACRO: linking an energy supply model with a macroeconomic module and solving it iteratively. Energy 2000;25:267–82.
[90] Kulshreshtha M, Parikh JK. Modelling demand for coal in India: vector autoregressive models with cointegrated variables. Energy 2000;25:149–68.
[91] Bentzen J, Engsted T. A revival of the autoregressive distributed lag model in estimating energy demand relationships. Energy 2001;26:45–55.
[92] Purohit P, Kumar A, Rana S, Kandpal TC. Using renewable energy technologies for domestic cooking in India: a methodology for potential estimation. Renew Energy 2002;26:235–46.
[93] Parameswara Sharma D, Chandramohanan Nair PS, Balasubramanian R. Demand for commercial energy in the state of Kerala, India: an econometric analysis with medium-range projections. Energy Policy 2002; 30:781–91.
[94] Bala BK, Khan MdFR. Modelling of energy and environment. Energy technologies foe sustainable development. Uttar Pradesh, India: Prime Publishing House; 2003 p. 571–76.
[95] Uri ND. Forecasting peak system load using a combined time series and econometric model. Appl Energy 1978;4:219–27.
[96] Uri ND, Flanagan SP. Short-term forecasting of crude petroleum and natural gas production. Appl Energy 1979;5:297–310.
[97] Uri ND. Models for estimating undiscovered oil resources. Appl Energy 1980;6:257–64.
[98] Lakhani HG. Forecasting the cost of energy conservation in the transportation sector. Appl Energy 1981;9: 139–51.
[99] Lakhani HG. Forecasting the cost of energy conservation in the residential sector: 1980–2000. Appl Energy 1982;10:215–31.
[100] Collier PI, Ornek A. A mathematical model for energy and in-process inventory assessment in a manufacturing system. Appl Energy 1983;13:265–80.
[101] Baltagi BH, Griffin JM. Gasoline demands in the OECD: an application of pooling and testing procedures. Eur Econ Rev 1983;22:117–37.
[102] Deeble VC, Probert SD. Straight-line correlations for annual energy-consumption predictions? Appl Energy 1986;25:23–39.
[103] Bhattacharya B, Sen D, Nanda SK. Management of rural energy systems: the need. Energy Manage 1986;115–21.
[104] Newborough M, Probert SD. Relating energy-consumption and health-care concerns to diet choices. Appl Energy 1987;27:169–201.

[105] Bodger PS, Tay HS. Logistic and energy substitution models for electricity forecasting: a comparison using New Zealand consumption data. Technol Forecast Social Change 1987;31:27–48.
[106] Messner S, Strubegger M. A framework to analyse the consumption of energy. Proceedings of the workshop of economics, modelling, planning and management of energy, Trieste, Italy 1987 p. 315–28.
[107] Sterman JD. Modelling the formation of expectations: the history of energy demand forecasts. Int J Forecast 1988;4:243–59.
[108] Kaboudan M. An econometric model for Zimbabwe's future electricity consumption. Energy 1989;1: 75–85.
[109] Choucri N, Heye C. Simulation models. Energy 1990;15:363–78.
[110] Faruqui A, Kuczmowski T, Lilienthal P. Demand forecasting methodologies: an overview for electric utilities. Energy 1990;15:285–96.
[111] Wolde-Ghiorgis W. Industrial energy utilization patterns in a developing country: a case study of selected industries in Ethiopia. Energy Convers Manage 1991;31:285–93.
[112] Harel P, Baguant J. A growth prediction for electrical energy consumption in Mauritius. Energy 1991;16707–11.
[113] Ang BW, Ng TT. The use of growth curves in energy studies. Energy 1992;17:25–36.
[114] Zmeureanu R. A new method for evaluating the normalized energy consumption in office buildings. Energy 1992;17:17235–46.
[115] Lutzenhiser L. A cultural model of household energy consumption. Energy 1992;17:47–60.
[116] Gustafsson S-I. Mathematical modeling of district-heating and electricity loads. Appl Energy 1993;46: 149–59.
[117] Hammond GP, Mackay RM. Projection of UK oil and gas supply and demand to 2010. Appl Energy 1993; 44:93–112.
[118] Deering S, Newborough M, Probert SD. Rescheduling electricity demands in domestic buildings. Appl Energy 1993;44:1–62.
[119] Tamimi A, Kodah Z. Modelling of energy consumption and projection in Jordan. Energy Convers Manage 1993;34:427–32.
[120] Heffington WM, Brasovan MW. Prediction of US crude oil-production using growth curves. Energy 1994; 19:813–5.
[121] Al-Garni AZ, Zubair SM, Nizami JS. A regression model for electric-energy consumption forecasting in Eastern Saudi Arabia. Energy 1994;1043–9.
[122] Mackay RM, Probert SD. Modified logit-function demand model for predicting natural crude-oil and natural-gas consumptions. Appl Energy 1994;49:75–90.
[123] Ang BW. Decomposition methodology in industrial energy demand analysis. Energy 1995;20:1081–95.
[124] Giraldo L, Hyman B. Energy end-use models for pulp, paper, and paperboard mills. Energy 1995;20: 1005–19.
[125] Sudhakara Reddy B. A multilogit model for fuel shifts in the domestic sector. Energy 1995;20:929–36.
[126] Rao RD, Parikh JK. Forecast and analysis of demand for petroleum products in India. Energy Policy 1996; 24:583–92.
[128] Tripathy SC. Demand forecasting in a power system. Energy Convers Manage 1997;38:1475–81.
[128] Gonzales Chavez S, Xiberta Bernat J, Llaneza Coalla H. Forecasting of energy production and consumption in Asturias (Northern Spain). Energy 1999;24:183–98.
[129] Florides GA, Kalogirou SA, Tassou SA, Wrobel LC. Modelling of the modern houses of Cyprus and energy consumption analysis. Energy 2000;25:915–37.
[130] Kadoshin S, Nishiyama T, Toshihide I. The trend in current and near future energy consumption from a statistical perspective. Appl Energy 2000;67:407–17.
[131] Saab S, Badr E, Nasr G. Univariate modeling and forecasting of energy consumption: the case of electricity in Lebanon. Energy 2001;26:1–14.
[132] Mackay RM, Probert SD. Forecasting the United Kingdom's supplies and demands for fluid fossil-fuels. Appl Energy 2001;69:161–89.
[133] Jai Persaud A, Kumar U. An eclectic approach in energy forecasting: a case of natural resources Canada's (NRCan's) oil and gas outlook. Energy Policy 2001;29:303–13.

[134] Chow LC-h. A study of sectoral energy consumption in Hong Kong (1984–97) with special emphasis on the household sector. Energy Policy 2001;29:1099–110.

[135] Ediger VS, Tatlldil H. Forecasting the primary energy demand in Turkey and analysis of cyclic patterns. Energy Convers Manage 2002;43:473–87.

[136] Sarak H, Satman A. The degree-day method to estimate the residential heating natural gas consumption in Turkey: a case study. Energy 2003;28:929–39.

[137] Kumar A, Bhattacharya SC, Pham HL. Greenhouse gas mitigation potential of biomass energy technologies in Vietnam using the long range energy alternative planning system model. Energy 2003;28: 627–54.

[138] Siemek J, Nagy S, Rychlicki S. Estimation of natural-gas consumption in Poland based on the logistic-curve interpretation. Appl Energy 2003;75:1–7.

[139] Cuaresma JC, Hlouskova J, Kossmeier S, Obersteiner M. Forecasting electricity spot-prices using linear univariate time-series models. Appl Energy 2004;77:87–106.

[140] Habbane AY, McVeigh JC, Cabawe SOI. Solar radiation model for hot dry arid climates. Appl Energy 1986;23:269–79.

[141] Akinoslu BG, Ecevit A. A further comparison and discussion of sunshine-based models to estimate global solar radiation. Energy 1990;15:865–72.

[142] Ragab FM, Som AK. Correlation between estimated and measured hourly and daily solar fluxes over Bahrain. Appl Energy 1991;40:83–99.

[143] Maycock PD. International photovoltaic markets, developments and trends forecast to 2010. Renew Energy 1994;5:154–61.

[144] Gopinathan KK, Soler A. Diffuse radiation models and monthly-average, daily, diffuse data for a wide latitude range. Energy 1995;20:657–67.

[145] Taha AZ. The oversizing method of estimation in PV systems. Renew Energy 1995;6:487–90.

[146] Parishwad GV, Bhardwaj RK, Nema VK. Estimation of hourly solar radiation for India. Renew Energy 1997;12:303–13.

[147] Omer AM. Compiliation and evaluation of solar and wind energy resources in Sudan. Renew Energy 1997; 12:39–69.

[148] Badescu V. Correlations to estimate monthly mean daily solar global irradiation: application to Romania. Energy 1999;24:883–93.

[149] Rehman S. Empirical model development and comparison with existingcorrelations. Appl Energy 1999; 64:369–78.

[150] Meyer EL, Van Dyk EE. Development of energy model based on total daily irradiation and maximum ambient temperature. Renew Energy 2000;21:37–47.

[151] Batlles FJ, Rubio MA, Tovar J, Olmo FJ, Alados-Arboledas L. Empirical modeling of hourly direct irradiance by means of hourly global irradiance. Energy 2000;25:675–88.

[152] Sen Z, Tan E. Simple models of solar radiation data for northwestern part of Turkey. Energy Convers Manage 2001;42:587–98.

[153] Wong LT, Chow WK. Solar radiation model. Appl Energy 2001;69:191–224.

[154] Oliveira AP, Escobedo JF, Machado AJ, Soaresa J. Correlation models of diffuse solar-radiation applied to the city of Sao Paulo, Brazil. Appl Energy 2002;71:59–73.

[155] Safi S, Zeroual A, Hassani M. Prediction of global daily solar radiation using higher order statistics. Renew Energy 2002;27:647–66.

[156] Tsangrassoulis A, Niachou K, Papakostantinou N, Pavlou C, Santamouris M. A numerical method to estimate time-varying values of diffuse irradiance on surfaces in complex geometrical environments. Renew Energy 2002;27:427–39.

[157] Jain PK, Lungu EM. Stochastic models for sunshine duration and solar irradiation. Renew Energy 2002;27: 197–209.

[158] Chirarattananon S, Chaiwiwatworakul P, Pattanasethanon S. Daylight availability and models for global and diffuse horizontal illuminance and irradiance for Bangkok. Renew Energy 2002;26:69–89.

[159] Peter R, Ramaseshan B, Nayar CV. Conceptual model for marketing solar based technology to developing countries. Renew Energy 2002;25:511–24.

[160] Kablan MM. Forecasting the demand on solar water heating systems and their energy savings potential during the period 2001–2005 in Jordan. Energy Convers Manage 2003;44:2027–36.
[161] Cardinale N, Piccininni F, Stefanizzi P. Economic optimization of low-flow solar domestic hot water plants. Renew Energy 2003;28:1899–914.
[162] Jain PK, Lungu EM, Prakash J. Bivariate models: relationships between solar irradiation and either sunshine duration or extremum temperatures. Renew Energy 2003;28:1121–223.
[163] Haack BN. Economic analysis of small wind-energy conversion systems. Appl Energy 1982;11:51–60.
[164] Panda RK, Sarkar TK, Bhattacharya AK. Stoschastic study of the wind-energy potential of India. Energy 1990;15:921–30.
[165] Jamil M, Parsa S, Majidi M. Wind power statistics and an evaluation of wind energy density. Renew Energy 1995;6:623–8.
[166] Alawaji SH. Wind energy resource assessment in Saudi Arabia—I. Network design and description. Renew Energy 1996;7:319–28.
[167] Sen Z, Sahin AD. Regional assessment of wind power in western Turkey by the cumulative semivariogram method. Renew Energy 1997;12:169–77.
[168] Ramachandra TV, Subramanian DK, Joshi NV. Wind energy potential assessment in Uttara Kannada district of Karnataka, India. Renew Energy 1997;10:585–611.
[169] Sfetsos A. A comparison of various forecasting techniques applied to mean hourly wind speed time series. Renew Energy 2000;21:23–35.
[170] Sfetses A. A novel approaches for the forecasting of mean hourly wind speed time series. Renew Energy 2002;27:163–74.
[171] Gomez-Munoz VM, Porta-Gandara MA. Local wind patterns for modeling renewable energy systems by means of cluster analysis techniques. Renew Energy 2002;25:171–82.
[172] Bartholy J, Radics K, Bohoczky F. Present state of wind energy utilization in Hungary: policy, wind climate, and modeling studies. Renew Sustain Energy Rev 2003;7:175–86.
[173] Youcef Ettoumi F, Sauvageot H, Adane AEH. Statistical bivariate modeling of wind using first-order Markov chain and Weibull distribution. Renew Energy 2003;28:1787–802.
[174] Weisser D. A wind energy analysis of Grenada: an estimation using the 'Weibull' density function. Renew Energy 2003;28:1803–12.
[175] Poggi P, Muselli M, Notton G, Cristofari C, Louche A. Forecasting and simulating wind speed in Corsica by using an autoregressive model. Energy Convers Manage 2003;44:3177–96.
[176] Rajeswaran R, Swaminathan KR, Kunhimohamed KT, Vadivel A. Impact of biogas plants on energy use pattern of rural households. URJA 1990;28:41–2.
[177] Kandpal TC, Joshi B, Sinha CS. Economics of family sized biogas plants in India. Energy Convers Manage 1991;32:101–13.
[178] Gardner N, Probert SD. Forecasting landfill-gas yields. Appl Energy 1993;44:131–63.
[179] Painuly JP, Rao H, Parikh J. A rural energy–agriculture interaction model applied to Karnataka state. Energy 1995;20:219–33.
[180] Converse TE, Betters DR. Biomass yield equations for short rotation black locust plantations in the central great plains. Biomass Bioenergy 1995;8:251–4.
[181] Kimmins JP. Predicting sustainability of forest bioenergy production in the face of changing paradigms. Biomass Bioenergy 1997;13:201–12.
[182] Alam MS, Islam KK, Huq AMZ. Simulation of rural household fuel consumption in Bangladesh. Energy 1999;24:743–52.
[183] Nishigami Y, Sanoand H, Kojima T. Estimation of forest area near desserts—production of global bio-methanol from solar energy. Appl Energy 2000;67:383–93.
[184] Yamamoto H, Yamaji K, Fujino J. Scenario analysis of bioenergy resources and CO2 emissions with a global land use and energy model. Appl Energy 2000;66:325–37.
[185] Haripriya GS. Estimates of biomass in Indian forests. Biomass Bioenergy 2000;19:245–58.
[186] Graham RL, English BC, Noon CE. A geographic information system-based modeling system for evaluating the cost of delivered energy crop feedstock. Biomass Bioenergy 2000;18:309–29.
[187] Roos A, Rakos C. The limits of modeling. Experiences with bioenergy in practice—Could models have predicted this outcome? Biomass Bioenergy 2000;18:331–40.

[188] Baath H, Gallerspang A, Hallsby G, Lundstrom A, Lofgren P, Nilsson M, Stahl G. Remote sensing, field survey, and long-term forecasting: an efficient combination for local assessments of forest fuels. Biomass Bioenergy 2002;22:145–57.

[189] Specht A, West PW. Estimation of biomass and sequestered carbon on farm forest plantations in northern New South Wales, Australia. Biomass Bioenergy 2003;25:363–79.

[190] Gurfel B. Model of the economic efficiency of the exploitation of oil shale in comparison with other mineral sources of energy. Appl Energy 1979;5:205–13.

[191] De Musgrove AR. A linear programming analysis of liquid-furl production and use options for Australia. Energy 1984;9:281–302.

[192] Ellis JH, McBean EA, Farquhar GJ. Deterministic linear programming model for acid rain abatement. J Environ Eng 1985;111:119–39.

[193] Das TK. Multiobjective linear programming approach to renewable energy policy analysis. Energy Manage 1987;55–121.

[194] Satsangi PS, Sarma EAS. Integrated energy planning model for India with particular reference to renewable energy prospects. Solar Energy Society of India, energy options for the 90's. New Delhi: Tata McGraw Hill; 1988 p. 596–620.

[195] Kydes AS. Flow models. Energy 1990;15:561–71.

[196] Pasternak H, Segal I, Engel H. Economic evaluation of energy conservation projects with an emphasis on initiation time. Energy Convers Manage 1990;30:381–5.

[197] Suganthi L, Jagadeesan TR. A modified model for prediction of India's future energy requirement. Int J Energy Environ 1992;3:371–86.

[198] Luhanga ML, Mwandosya MJ, Luteganya PR. Optimisation in computerized energy modeling for Tanzania. Energy 1993;18:1171–9.

[199] Tiris M, Atangunduz G, Dincer I. Energy, economy and environment modeling: applications for Turkey. Energy 1994;19:1005–9.

[200] Groscurth HM, Bruckner Th, Kummel R. Modelling of energy-services supply systems. Energy 1995;20: 941–58.

[201] Messner S, Golodnikov A, Gritsevskii A. A stochastic version of the dynamic linear programming model message III. Energy 1996;21:775–84.

[202] Jeng-Wen L, Chia-Yon C. A cost minimization model for coal import strategy. Energy Policy 1996;24: 1111–7.

[203] Lehtila A, Pirila P. Reducing energy related emissions: using an energy systems optimization model to support policy planning in Finland. Energy Policy 1996;24:805–19.

[204] Islam SMN. Sustainable economic developments in the Australian energy sector: findings of the Australian energy planning system optimisation model (AEPSOM). Renew Sustain Energy Rev 1997;1:229–38.

[205] Xie Z, Kuby M. Supply-side-demand side optimization and cost-environment tradeoffs for China's coal and electricity system. Energy Policy 1997;25:313–26.

[206] Henning D. MODEST—an energy system optimization model applicable to local utilities and countries. Energy 1997;22:1135–50.

[207] Raja R, Sooriamoorthi CE, Kanniappan P, Ramachandran T. Energy planning and optimisation model for rural development—a case of sustainable agriculture. Int J Energy Res 1997;21:527–48.

[208] Kanniappan P, Ramachandran T. Optimisation model for energy generation from agricultural residue. Int J Energy Res 1998;22:1121–32.

[209] Iniyan S, Jagadeesan TR. Effect of wind energy system performance on optimal renewable energy model—an analysis. Renew Sustain Energy Rev 1998;2:327–44.

[210] Iniyan S, Suganthi L, Jagadeesan TR. Renewable energy planning for India in 21st century. Renew Energy 1998;14:453–7.

[211] Suganthi L, Samuel AA. Optimal energy forecasting model for the economy environment match. Ambient Energy 1999;20:137–48.

[212] Iniyan S, Sumathy K, Suganthi L, Samuel AA. Sensitivity analysis of optimal renewable energy mathematical model on demand variations. Energy Convers Manage 2000;41:199–211.

[213] Suganthi L, Williams A. Renewable energy in India—a modeling study for 2020–2021. Energy Policy 2000;28:1095–109.

[214] Iniyan S, Sumathy K. An optimal renewable energy model for various end-uses. Energy 2000;25:563–75.
[215] Kaldellis JK, Kavadias KA. Optimal wind-hydro solution for Aegean Sea Island's electricity-demand fulfillment. Appl Energy 2001;70:333–54.
[216] Cormio C, Dicorato M, Minoia A, Trovato M. A regional energy planning methodology including renewable energy sources and environmental constraints. Renew Sustain Energy Rev 2003;7:99–130.
[217] Drozdz M. An optimization model of geothermal-energy conversion. Appl Energy 2003;74:75–84.
[218] Gong M. Optimization of industrial energy systems by incorporating feedback loops into the MIND method. Energy 2003;28:1655–69.
[219] Sinha AK, Dudhani S. A linear programming model of integrated renewable energy system for sustainable development. Energy technologies for sustainable development. Uttar Pradesh, India: Prime Publishing House; 2003 p. 193–200.
[220] Sanders I, Batty WJ, Hagino K. Supply of, and demand for, a resource: fuzzy logistical optimization technique. Appl Energy 1993;46:285–302.
[221] Javeed Nizami SSAK, Al-Garni AG. Forecasting electric energy consumption using neural networks. Energy Policy 1995;23:1097–104.
[222] Michalik G, Khan ME, Bonwick WJ, Mielczarski W. Structural modeling of energy demand in the residential sector: 2. The use of linguistic variables to include uncertainty of customer's behaviour. Energy 1997;22:949–58.
[223] Abdel-Aal RE, Al-Garni AZ, Al-Nassar YN. Modeling and forecasting monthly electric energy consumption in Eastern Saudi Arabia using abductive networks. Energy 1997;22:911–21.
[224] Mohandes MA, Rehman S, Halawani TO. A neural networks approach for wind speed prediction. Renew Energy 1998;13:345–54.
[225] Chedid R, Mezher T, Jarrouche C. A fuzzy programming approach to energy resource allocation. Int J Energy Res 1999;23:303–17.
[226] Kalogirou SA. Applications of artificial neural networks for energy systems. Appl Energy 2000;67:17–35.
[227] Kalogirou SA, Bojic M. Artificial neural networks for the prediction of the energy consumption of a passive solar building. Energy 2000;25:479–91.
[228] Yao SJ, Song YH, Zhang LZ, Cheng XY. Wavelet transform and neural networks for short-term electrical load forecasting. Energy Convers Manage 2000;41:1975–88.
[229] Agrawal RK, Singh SP. Energy allocations for cooking in UP households (India): a fuzzy multi-objective analysis. Energy Convers Manage 2001;42:2139–54.
[230] Dorvio ASS, Jervase JA, Al-Lawati A. Solar radiation estimation using artificial neural networks. Appl Energy 2002;74:307–19.
[231] Aydinalp M, Ismet Ugursal V, Fung AS. Modelling of the appliance, lighting and space-cooling energy consumptions in the residential sector using neural networks. Appl Energy 2002;71:87–110.
[232] Hsu C-C, Chen C-Y. Regional load forecasting in Taiwan—applications of artificial neural networks. Energy Convers Manage 2003;44:1941–9.
[233] Metaxiotis K, Kagiannas A, Ashounis D, Psarras J. Artificial intelligence in short term electric load forecasting: a state-of-the-art survey for the researcher. Energy Convers Manage 2003;44:1525–34.
[234] Edmonds J, Reilly J. A long-term global energy-economic model of carbon dioxide release from fossil use. Energy Econ 1983;74–88.
[235] Reister DB. The use of a simple model in conjunction with a detailed carbon dioxide emission model. Energy 1984;9:637–43.
[236] Reilly J, Edmonds J. Global energy and carbondi-oxide. IMACS 1985;245–50.
[237] Danny Harvey LD. Managing atmospheric CO2. Clim Change 1989;15:343–81.
[238] Danny Harvey LD. Managing atmospheric CO2: policy implications. Energy 1990;15:91–104.
[239] Gustavsson L, Johansson B, Bulow-Hube H. An environmentally benign energy future for Western Scania, Sweden. Energy 1992;17:809–22.
[240] Kamiuto K. Forecasts of future atmospheric CO2 concentrations for a simple global carbon-cycle model. Energy 1994;19:1099–101.
[241] Kamiuto K. A simple global carbon-cycle model. Energy 1994;19:825–9.
[242] Demirchian KS, Demirchian KK. A simple model of carbon cycle for upgrading global fossil fuels consumption and carbon emission forecasts validity. Energy Convers Manage 1996;37:1265–70.

[243] Tiris M, Ekinci E, Okutan H. Modelling of SO2 pollution changes with fuel shifting in Gebze, Turkey. Energy 1996;21:371–5.
[244] Svendsen GT. A general model for CO2 regulation: the case of Denmark. Energy Policy 1998;26:33–44.
[245] Snakin JPA. An engineering model for heating energy and emission assessment: the case of North Karelia, Finland. Appl Energy 2000;67:353–81.
[246] Diesendorf M. Energy scenarios in global economic models of greenhouse gas reduction. Int J Global Energy Issues 2000;13:70–85.
[247] Voorspools KR, D'haeseleer WD. An evaluation method for calculating the emission responsibility of specific electric applications. Energy Policy 2000;28:967–80.
[248] Hsu GJY, Chou F-Y. Integrated planning for mitigating CO2 missions in Taiwan: a multi-objective programming approach. Energy Policy 2000;28:519–23.
[249] Matthews RW. Modelling of energy and carbon budgets of wood fuel coppice systems. Biomass Bioenergy 2001;21:1–19.
[250] Choi K-H, Ang BW. A time-series analysis of energy-related carbon emissions in Korea. Energy Policy 2001;29:1155–61.
[251] da Costa RC. Do model structures affect findings? Two energy consumption and CO2 emission scenarios for Brazil in 2010 Energy Policy 2001;29:777–85.
[252] Leimbach M. Equity and carbon emissions trading: a model analysis. Energy Policy 2003;31:1033–44.