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A Stochastic Approach to Energy Policy and Management: A Case Study of the Pakistan Energy Crisis

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Abstract: The energy policy of a country dictates its ability to better manage and deal with an energy crisis. A sustainable energy policy deals with not only energy production but also with energy consumption. In the past, the government of Pakistan has lacked such an approach. This study aims to develop a policy-making framework to improve the energy management of Pakistan through a probabilistic approach. Stochastic analysis is performed in this study and the uncertainty in energy data is used to propose a holistic energy policy. Energy-utilization data from 17 different sources are used to compare the accuracy of energy-consumption data from 1989 to 2013. The analysis reveals that there exists an uncertainty in energy-consumption data and the major cause of this uncertainty is energy theft. The analysis shows that the industry has the highest uncertainty in its energy-data utilization, followed by the transport and the domestic sectors of Pakistan. Based on stochastic analysis, seven recommended energy-policy guidelines are presented to manage the energy crisis in the country. The analysis proposes that Pakistan needs to take measures to control energy theft.

Keywords: energy; policy; theft; uncertainty; loss; guidelines

1. Introduction

Pakistan, being the world's sixth largest populated country, has quite obvious energy demands [1]. An analysis of Pakistan's historical energy consumption and supply data, as represented in the literature [2], shows an increasing trend in both variables. Such trends are quite obvious as Pakistan's population has increased tremendously over time; its growth rate has been 3.1 percent per annum [3]. This increase in population positions Pakistan as an overpopulated country with respect to its energy resources being explored or used. To meet its energy demands, Pakistan is largely dependent on conventional energy sources such as coal, natural gas, and petroleum. To fulfil energy demands, 86% of the total energy in Pakistan is fulfilled through conventional energy sources [4]. Electricity in Pakistan is produced mainly through these energy sources. In 2010, nearly 94,653 GWh of electricity was produced in Pakistan. In the energy mix of the country, the contributions of thermal, hydel, and nuclear power are 62.5%, 33.6%, and 3.9%, respectively [5]. In thermal power, petroleum oil makes the highest contributions with 35.1%, while natural gas and coal make up 27.3% and 0.1%, respectively [5]. Pakistan, located at an excellent topological location and blessed with natural hydrological conditions, has huge potential for hydropower, which can add huge amounts of energy in Pakistan's energy portfolio. There is a potential for nearly 60,000 MW of energy that can be produced from hydropower in the country, most of which lie in Khyber Pakhtunkhwa, Azad Jammu and Kashmir, Punjab, and Gilgit-Baltistan [6]. The distribution of hydropower generation for each province is shown in Figure 1.

Figure 1. Pakistan's hydropower potential (Pakistan's map courtesy of OnTheWorldMap.com).

Hydropower resources are mainly located in the northern region of Pakistan. As shown in Figure 1, these resources can be divided into six regions, namely, Punjab, Khyber Pakhtunkhwa, Gilgit-Baltistan, Sindh, Azad Jammu and Kashmir, and Balochistan. In the Khyber Pakhtunkhwa region, there are nearly 142 hydropower project sites and these projects have a total hydropower potential of 24,736 MW. Out of this, projects producing 3849 MW of energy are in operation and projects producing 9482 MW and 2398 MW are in the implementation phase by the public and private sector, respectively. While feasibility studies of 77 MW projects have been completed and 8930 MW of hydropower projects are raw sites (sites identified but no technical feasibility conducted) in Khyber Pakhtunkhwa—all totaling to 24,736 MW. In Gilgit-Baltistan, there is total potential of 21,125 MW of hydropower energy, out of which 8542 MW of projects are raw sites while feasibility studies of 534 MW of hydropower projects have been completed. Both the public sector and private sector are implementing hydropower projects worth 11,876 MW and 40 MW in Gilgit-Baltistan, while operational projects are producing 133 MW of energy. The Punjab province of Pakistan has potential to produce 7291 MW of hydropower, out of which operational projects are producing 1699 MW of energy, while projects in pipelines can produce 720 MW and 1028 MW of hydropower through public- and private-sector investments, respectively. In Punjab, a feasibility study has been completed for projects worth 3606 MW of energy and raw-site projects have potential to produce 238 MW of hydropower energy in the province. Hydropower resources in Azad Jammu and Kashmir play an important role and have an energy potential of 6450 MW, in which operational projects are producing 1039 MW of hydropower, while the projects under the implementation phase would produce 1231 MW and 3364 MW of power through the public and private sectors, respectively. In Azad Jammu and Kashmir, there are 915 MW of hydropower projects with raw sites, while 1 MW project feasibility has been completed. There are no hydropower projects, either operational or implemented, in Sindh and Balochistan. In Sindh and Balochistan, a feasibility study has been completed for projects to produce 67 MW and 1 MW of hydropower, respectively. Sindh province has identified raw sites that can produce hydropower of 126 MW, but there has been no raw site identified in Balochistan [6].

Despite all these and various other potential energy resources, today Pakistan is facing a huge energy crisis. There are many factors which precipitated this severe energy crisis. These is a rapid increase in demand for energy in the manufacturing sector [7,8], the transportation sector, which includes transportation by road vehicles, rail, aviation, and shipping [7], industrial-sector growth [8], a slow uptake in adopting new renewable-energy technologies and ineffective energy policies [9], and the sluggishness in exploring more natural energy resources like coal, natural gas, and crude oil [10]. Moreover, hikes in energy prices and the poor development of energy-management policies have played a vital role in darkening the streets of Pakistan [11]. In the electricity sector alone, there is approximately a gap of 5000–8000 MW between the demand and production of electricity, which is increasing at a steady rate of 6%–8% on an annual basis [12]. Though such facts are either presented by Government of Pakistan [13] or by researchers, there exists an uncertainty within these data that has misled policy makers in the past.

Uncertainty in data is defined as the deviation of the data from their original values or the lack of true data [14]. Analytically speaking, due to the presence of uncertainty in data, a mathematical model may not be an accurate representation of the system, but only an approximate one. Uncertainty in data is related to the level of precision of the data. In probabilistic terms, it would be the probability of the correctness of the value of the data and these data characteristics need to be estimated and reported along with the data presented. There are two methods to quantify uncertainties in a system: deterministic and stochastic. In the deterministic method, all properties of a system are well-known and there is no randomness present in any system variable. The outcomes of deterministic mathematical models can be precisely determined. In these models, the same output will always be produced every time a given input is used. On the other hand, the stochastic method includes randomness in the model, which means that, with the assumptions of initial conditions (range of values), there are different outcomes or ranges of values. These assumptions and outcomes are represented in terms of probability distributions. One type of stochastic method is the Monte Carlo method. The Monte Carlo method repeatedly simulates the behavior of a physical system. The process is known as a Monte Carlo Simulation (MCS). The basic principle behind MCS is that of stochastic uncertainty propagation [15]. In an uncertainty analysis, a Monte Carlo Simulation produces outputs in terms of probability distributions while considering the randomly varying uncertainties in the inputs, which are based on defined probability distributions [16]. Uncertainty is determined by analyzing the distribution of the simulated outputs. This characteristic allows the accommodation of nonlinear relationships among different uncertainties, since summing various uncertainties does not result in the final uncertainty [17]. In MCS, the input quantities are assigned with known probability density functions (PDFs). Such assigned distributions are propagated through the model, which represents the mathematical relationship among input and output quantities, to develop a PDF of the output. The knowledge of PDFs for input parameters is the key to evaluate the behavior of unknown random outputs [18]. A PDF of a quantity is its probabilistic profile by which the quantity is observed in a random measurement process [19]. The stochastic model, which represents the inputs and outputs, is:

$$Y = f(X_1, X_2, X_3, \ldots X_N) \tag{1}$$

where Y is the output quantity, also known as "measurand", and $X_1, X_2, X_3 \ldots X_N$ are sets of N number of input quantities. The f in Equation (1) shows the measurement formula through which inputs are passed along to produce outputs. There are various types of PDFs that could be assigned to the input variables, the details of which are presented in the literature [20]. Since the objective is to perform the simulations many times to replicate the actual system, a computer-based MCS allows many simulations (10,000 trials or more). The use of random inputs turns the deterministic model into a stochastic one. Previously, many researchers have studied uncertainty in various aspects. An uncertainty present in data influences the quality of decision-making processes; therefore, such ambiguities cannot be ignored. Previously, there have been many studies performed on data uncertainties for a wide range of subjects. A study was conducted to accurately model the market operator based on transactive energy by considering uncertainty in network interaction and inputs [21]. In this study, the Taguchi orthogonal array test (TOAT) unit was used to generate uncertainty scenarios with occurrence probability. Researchers also modeled uncertainties in load and wind turbines using normal distributions and Weibull distributions, respectively. The study provided optimal control of energy-system resources and demand-side management [21].

In another study, a smart transactive energy framework was presented that studied energy-demand fluctuations management. The study developed demand-side management based on total profit considering the uncertainty [21]. Stochastic modeling has been a powerful tool in the past to study uncertainty in data. For example, stochastic modeling was utilized to study uncertainty in energy-management schemes by incorporating Conditional Value at Risk (CVaR) [22]. In another study, stochastic approach was used to study economic performance of renewable energy systems [23].

Uncertainty present in cost data accounts for the risk of exceeding estimated cost values [24]. The authors performed uncertainty analysis on the cost of producing biodiesel. Uncertainty in their data was due to process design simulations and cost data, which were adopted either from the literature or internet-based price data. Their results were helpful to identify key economic risk factors for biodiesel production plants.

Uncertainty present in a process design simulation may lead to underestimated design and subsequent underestimated plant economics [25]. The source of uncertainty data in the study was due to ambiguities in the thermodynamic model performing the process simulation. These uncertainties in the thermodynamic model caused design changes in the process equipment as well as a change in the process economics. The results were helpful to identify key elements of uncertainties in a process design simulation for a process industry.

Uncertainty present in a wind-energy production system can influence the economic viability of the system [17]. The study estimated uncertainties in annual energy production for a wind farm. The results helped to mitigate errors and increased the wind farm's reliability. Often, uncertainty is represented in terms of probability distribution, which indicates the likelihood of each possible outcome [26]. The current study performs uncertainty analysis on Pakistan's energy data and provides policy guidelines based on the outcomes. The advantage of the methodology proposed in this study lies in the fact that the model can be utilized to develop an energy-policy framework considering the vagueness in energy data of a country. Moreover, the methodology can help to identify core energy consumers that contribute in a substantial and least extent in energy-data uncertainty. The applications of the proposed methodology can be found in power systems, energy planning and development, and in the development of energy-policy guidelines.

As highlighted through the presented literature, stochastic modeling has been a powerful tool to study uncertainty. However, to the best of the authors' knowledge, there has been no study performed so far that could develop energy-policy guidelines based on stochastic analysis of Pakistan's energy data. This paper lists some key issues regarding energy-data management and the need for more reliable data for policy making in Pakistan. Inadequate energy-data management has been a known issue in many developing countries, as it is in Pakistan. This paper attempts to quantify the variation in consumption statistics of different end-use sectors across different data sources. This study contributes in the existing literature by proposing a methodological framework to study uncertainty in Pakistan's energy-consumption data and presenting energy-policy guidelines in the light of the results obtained.

Problem Statement

Energy-consumption data of Pakistan have been reported in various literatures and through various sources. Pakistan's Water and Power Development Authority (WAPDA) provides annual data on the generation, consumption, distribution, and transmission of power in the country [27]. WAPDA mostly deals with power data related to water and hydropower projects in the country. Energy-consumption data are also published by the Ministry of Finance, Government of Pakistan [13], under the Pakistan Economic Survey that is issued in each fiscal year by the respective Ministry [13].

The Hydrocarbon Development Institute of Pakistan (HDIP), working under Pakistan's Ministry of Petroleum and Natural Resources, also publishes energy data in Pakistan Energy Yearbooks on a yearly basis [28]. Electrical-energy data are also provided by the National Transmission and Despatch Company (NTDC) Pakistan. For electrical-energy projects and their data, NTDC co-ordinates with various distribution networks in the country. These networks collect energy data through their own sources. These networks include the Lahore Electric Supply Company (LESCO), Karachi Electric Supply Corporation Limited (KESC), Faisalabad Electric Supply Company (FESCO), Multan Electric Power Company (MEPCO), Islamabad Electric Supply Company Limited (IESCO), Gujranwala Electric Supply Company (GEPCO), Hyderabad Electric Supply Company Limited (HESCO), Quetta Electric Supply Corporation (QESCO), Peshawar Electric Supply Company (PESCO), and the Tribal Area Electric Supply Company (TESCO) [29]. Energy data published by these organizations can be accessed on the NTDC webpage [29]. The Ministry of Finance also publishes energy data and their associated costs and profits on an annual basis. Pakistan's energy data are also published by Global Economy [30], which develop their data through various surveys. The Unites States Energy Information Administration [31] publishes Pakistan's energy data in the International Energy Statistics database [31]. Having detailed studies of energy data in these many resources, it is revealed that none of the resources has reported the same energy data. For example, electricity consumption as reported by Global Economy in 2011 was 73.93 billion kilowatt-hours; however, for the same year, the Pakistan Energy Yearbook reported a value of 6,278,947 TOE. A unit equivalency shows that the value reported by the Pakistan Energy Yearbook was 73.02 billion kilowatt-hours, which is different than what was reported by Global Economy. This introduces uncertainty into the energy data and could be misleading to energy policy makers. Hence the objective of the current study is to perform uncertainty analysis on Pakistan's energy data and put forward energy-policy guidelines based on the findings of the analysis. The scope of this study includes performing uncertainty analysis on energy-consumption data only. This is based on the fact that, as opposed to energy supply, energy-consumption data have more chance of being reported vaguely, as highlighted in various research works [32,33]. The energy variables in this study are the consumers, which include industry, domestic, and commercial use, agriculture, transportation, and other government businesses. Energy-consumption data for each energy variable are reported separately, which indicates their non-interdependence. Uncertainty analysis here does not represent the uncertainties in energy-production processes, as has been reported by some researchers [25,32]. This research does not study their interdependencies. However, there are methodologies available to study such interdependencies [32]. To curb its energy crisis, Pakistan is also focusing on renewable energy sources; however, their environmental impact is yet to be examined [33].

2. Methodology

Stochastic analysis was performed on energy data produced from conventional energy sources, which included resources from fossil fuels (oil, gas, coal, LPG, and electricity). Since some other resources, such as sustainable energy options and nuclear energy, are relatively new in Pakistan, i.e., they have only been introduced in the last few decades, their data lack reliability and hence are ignored in calculating total energy consumption. For methodology demonstration purposes, analysis was performed on energy data for each fiscal year from 1989 to 2013. The methodology presented in [24] was extended to implement in this research. The methodological framework of this research is shown in Figure 2. Oracle® Crystal Ball software was used as a tool to perform a Monte Carlo Simulation on total energy-consumption data. The following steps were followed to perform energy-uncertainty analysis followed by energy-policy recommendations:

Step 1: Define the set of random inputs of the model generated in step 1 (X_i's, i = 6).

In this step, six energy variables (X_i), namely, domestic, commercial, industrial, agriculture, transport, and other government businesses, were assigned PDFs for each fiscal year from 1989 to 2013. Since this study deals with characterization and analysis of a large sample size of continuous variables, the probability trend of individual data quantities, also known as the PDF, was critical to define. The Central Limit theorem states that a large dataset that contains various distributions, poisson, triangle, or binomial (characterized by respective PDFs), tends to show a bell curve as sample scattering goes to infinity. PDFs were defined based on the historical nature of each individual dataset. The data for consumption by domestic, agriculture, transportation, and other government businesses were characterized by normal (Gaussian) distribution; as the time period and dataset were large enough, these variables converged to a normal distribution [34]. Normal distribution has the statistical parameters of standard deviation and mean. Mean was the value of data around which uncertainty was being measured. Commercial and industrial energy-consumption data were assigned a triangular and gamma distribution, respectively. Triangular distribution was chosen for commercial energy variables as three different true values of it were observed; hence, a triangular distribution could best describe it [35], while gamma distribution allowed to accommodate large uncertainties in energy-consumption data of the industry [36]. Table 1 shows the details for each energy variable and their characteristics used for 2012–2013 data.

Step 2: Generation of a parametric model.

To represent the system under study, a model consisting of total energy consumption and individual variables was developed. Total energy consumption is defined as the sum of energy consumed by various domestic, commercial, industrial, agricultural, transport, and other government businesses. Energy-consumption data reported for each variable are the total energy data for that variable. The measurement model, a mathematical relation defined between input and output data, provided the probabilistic profile of total energy consumption as an output.

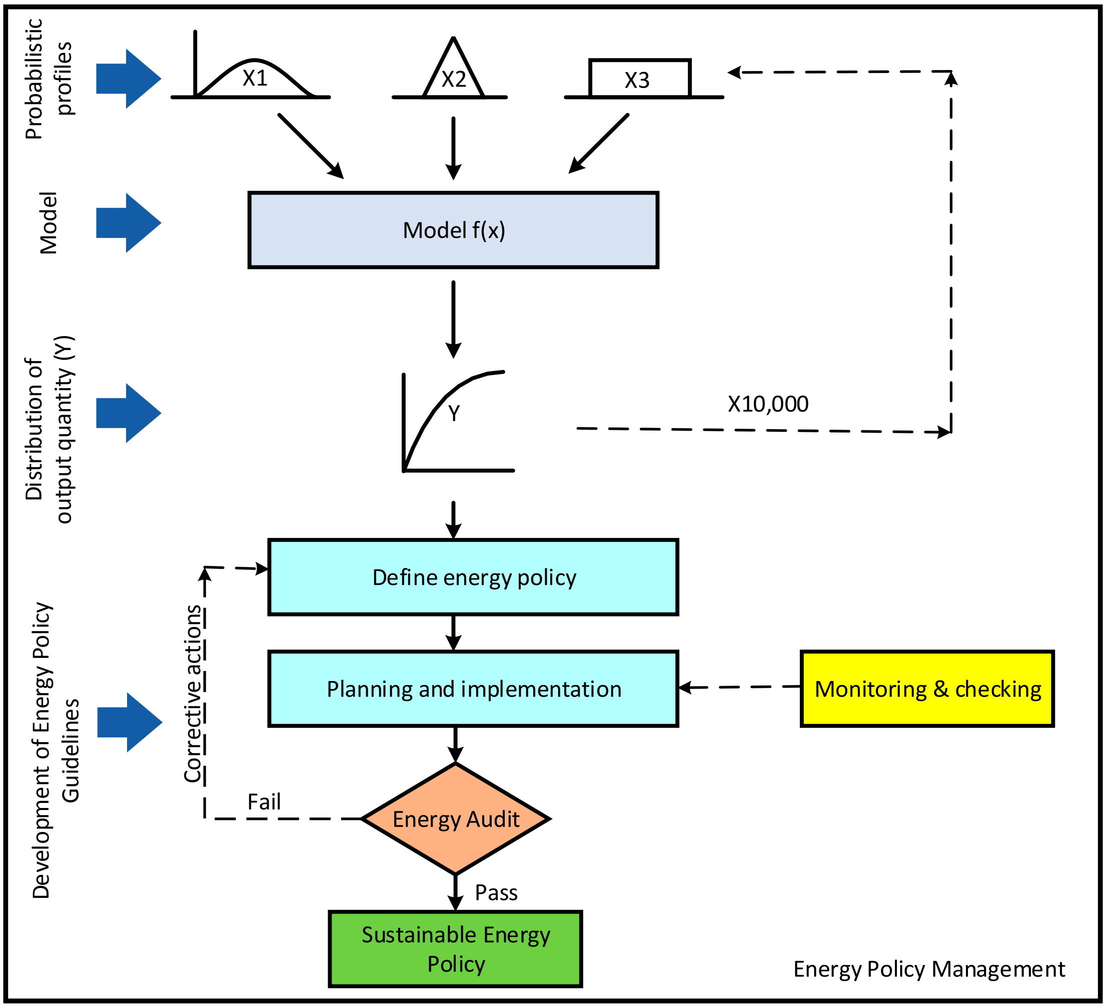


Figure 2. Methodology for development of energy policy guidelines.

Table 1. Energy variables and characteristics of their probability density functions (PDFs).

Energy Variable	Nature of the Variable	PDF *—f [18]	PDF Input Year 2012–13	Input Characteristics
Domestic	Normal Distribution	$\frac{1}{\sqrt{2\pi\sigma}} exp\{-\frac{1}{2\sigma^2}(x-u)^2\}$	x = 10.1190 MTOE	Mean = 10.12, SD = 1.01
Commercial	Triangular	$\begin{cases} 0\ for\ x < a \\ (2\|b-a)\ for\ x = c \\ 0\ for\ b > x \end{cases}$	x = c = 1.64 a = 1.48 b = 1.81	Maximum value = 1.81 Minimum value = 1.48
Industrial	Gamma distribution	$\frac{x^{k-1} e^{\frac{-x}{\theta}}}{\Gamma(k)\theta^k}$	X is location = 14.26	K is shape parameter = 2 θ is a scale parameter = 1.43
Agriculture	Normal distribution	$\frac{1}{\sqrt{2\pi\sigma}} exp\{-\frac{1}{2\sigma^2}(x-u)^2\}$	x = 0.66 MTOE	Mean = 0.66, SD = 0.07
Transport	Normal distribution	$\frac{1}{\sqrt{2\pi\sigma}} exp\{-\frac{1}{2\sigma^2}(x-u)^2\}$	x = 12.71 MTOE	Mean = 12.71, SD = 1.27
Other government businesses	Normal distribution	$\frac{1}{\sqrt{2\pi\sigma}} exp\{-\frac{1}{2\sigma^2}(x-u)^2\}$	x = 0.79 MTOE	Mean = 0.79, SD = 0.08

* PDFs adopted from [18].

Step 3: Repeat step 2 and 3 N number of times.

Steps 2 and 3 were performed for individual energy-consumption data from 1989 to 2013. In order to develop stability in the results, 10,000 iterations were performed. The simulation developed PDFs of total energy for each respective year. The PDF profile for each year was analyzed to study uncertainty in respective years.

Step 4: Energy-policy recommendations and energy management.

The resulting profiles of total energy consumption for each year were used to put forth future energy-policy recommendations. Once the proposed energy policy passed the planning and implementation phases, the proposed energy-policy guidelines were subjected to an energy audit.

3. Results and Discussion

To demonstrate the results of this work, the energy data for 2012–2013 are illustrated here. The results of the forecasted chart for 2012–2013 are shown in Figure 3. The energy data available in the literature for 2012–2013 revealed that total energy consumption of that year was 40.18 Mtoe. In Figure 3, it can be seen that the base case of 40.18 remains there but is just one "number" among many others. Rather than reporting a single number, analysis provides a profile instead with a full range of data. With 100% certainty, the value lies between 34.76 Mtoe and 58.6 Mtoe. As shown in Figure 4, for the total energy of 40.18 Mtoe, certainty is only 88.19%, which shows that there is an uncertainty of 11.81% present in the data of total energy consumption for the year 2012–2013. This shows that the energy-consumption data reported have ambiguities, reducing the confidence that energy-consumption data reflect true energy consumption. There are many possible sources of uncertainty in energy-consumption data. It may be due to errors in human data collection. For example, the same instrument used by more than one person may produce different measurements, or the energy-consumption measurement device may be inaccurate or imprecise. In the next section, various reasons are reported in detail. This uncertainty in energy data could impose the risk of having ineffective energy policy.

The statistical results of total energy consumption PDF are shown in Table 2.

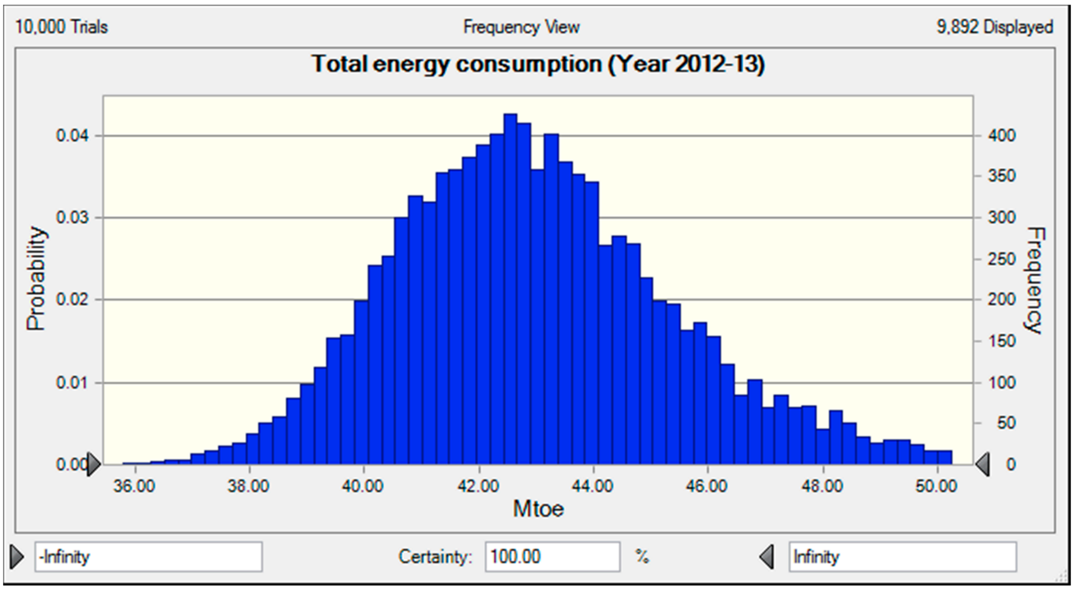


Figure 3. Frequency chart for total energy consumption year 2012–2013.

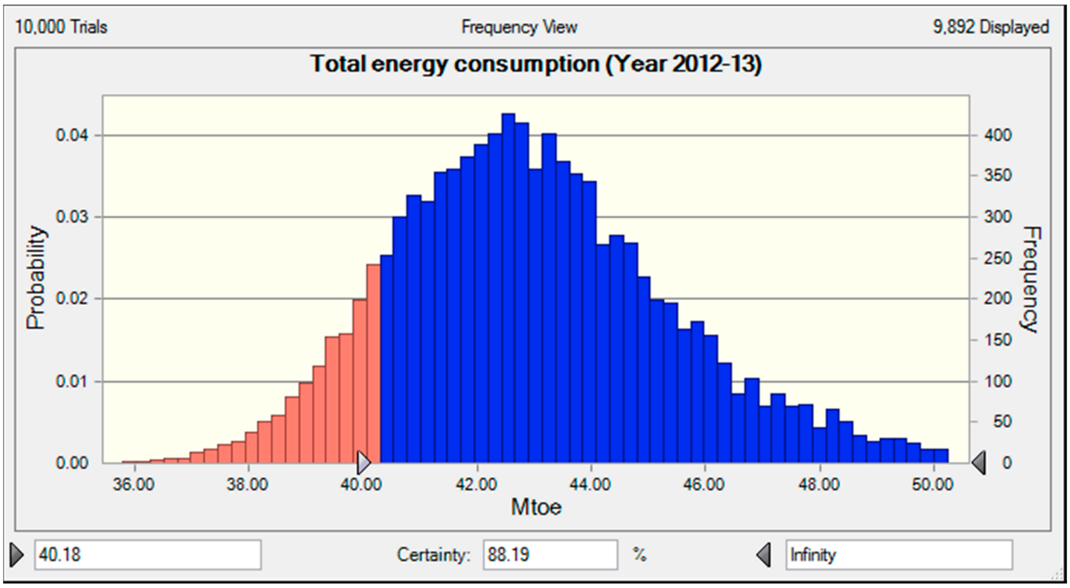


Figure 4. Certainty of 40.18 MTOE for energy consumption for 2012–2013.

Table 2. Statistical parameters of total energy consumption 2012–2013.

Statistical Parameter	Forecast Values
Trials	10,000
Base Case	40.18
Mean	43.01
Median	42.81
Mode	-
Standard Deviation	2.58
Variance	6.67
Skewness	0.569
Kurtosis	3.87
Coefficient of Variation	0.06
Minimum	34.76
Maximum	58.6
Mean Std. Error	0.03

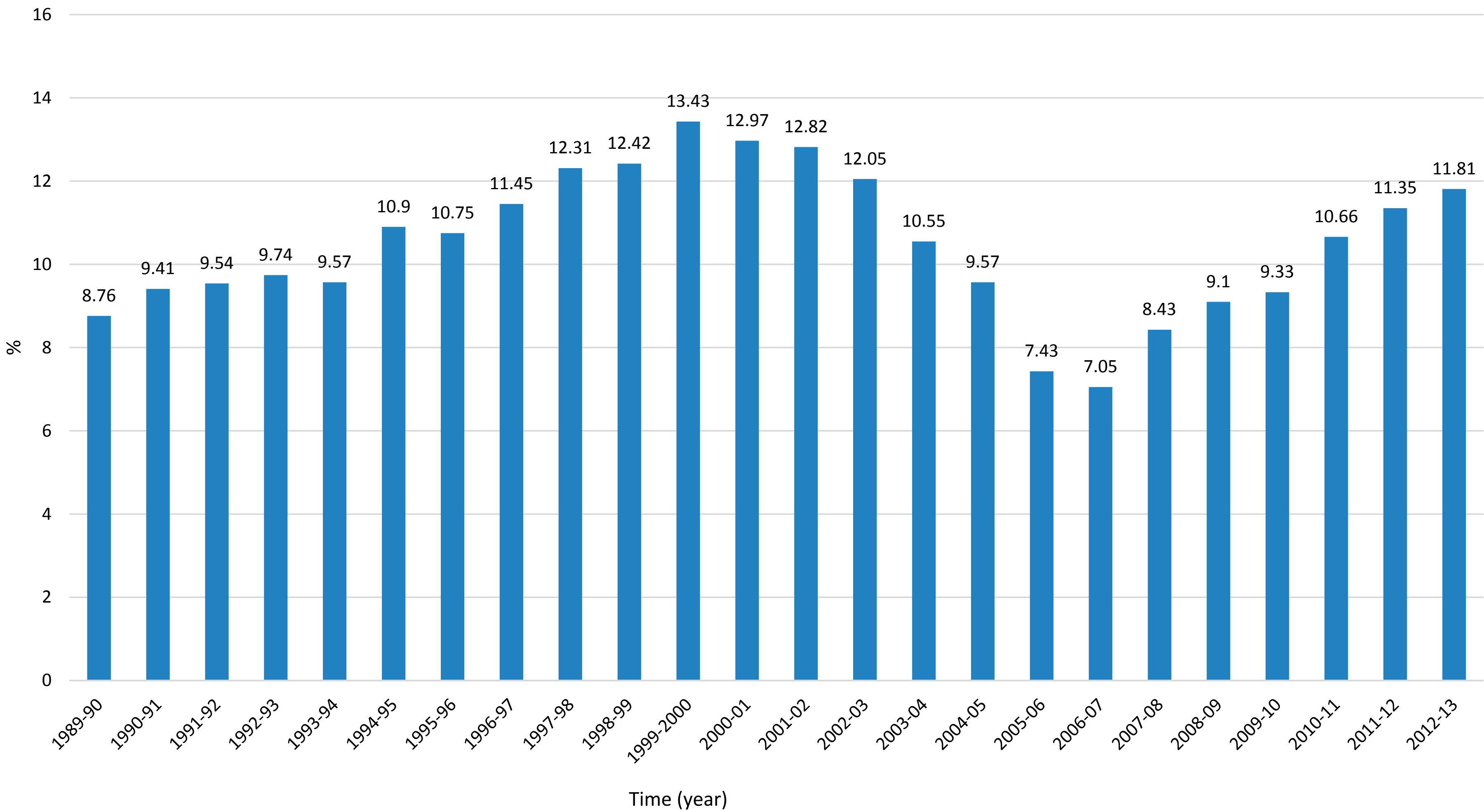
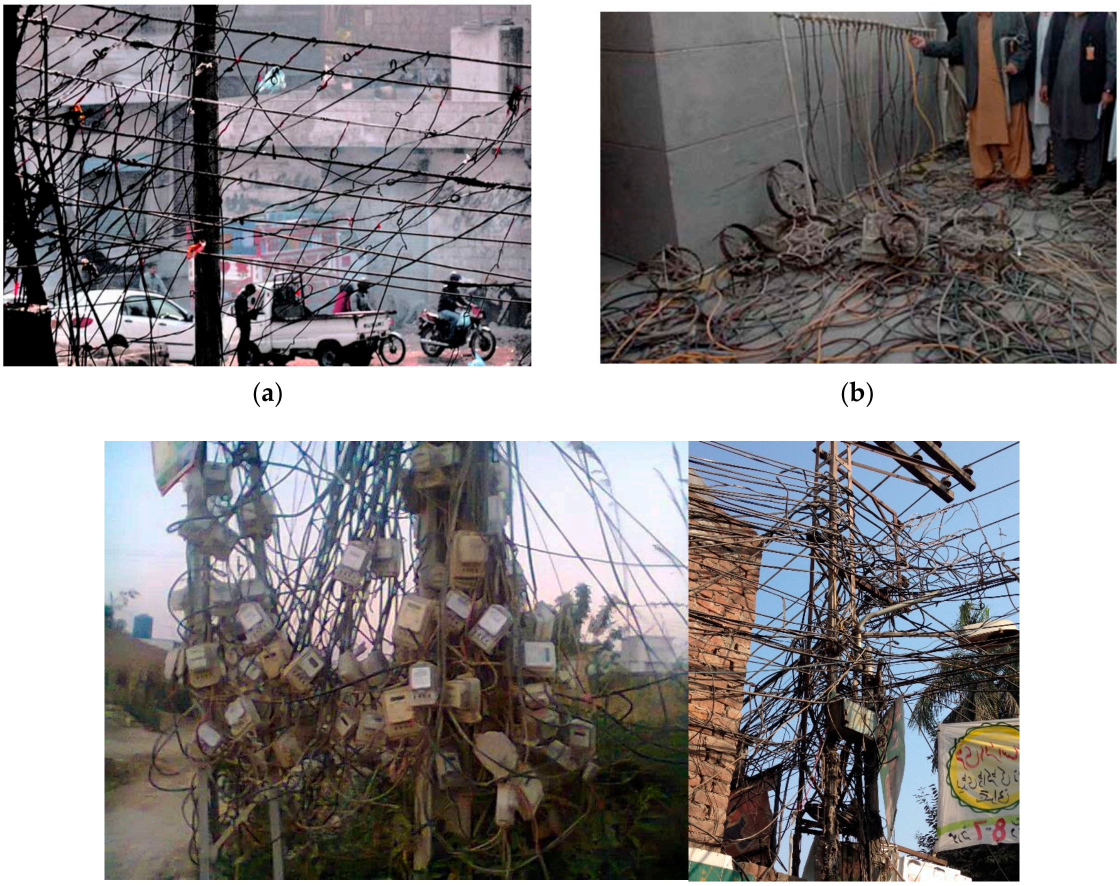


Figure 5. Yearly uncertainty in energy data.

The results show that, from 1989 to 2013, the highest uncertainty in energy-consumption data was in the fiscal year 1999–2000. This indicates that there has been the least confidence in energy-consumption data in the years 1999–2013 for the past 25 years' data. The next highest uncertainty is present in the fiscal year 2000–2001. The least uncertainty is present in the year 2006–2007, which shows the highest certainty in energy data with the least variability. The least variability in energy data around 2006–2007 shows either that the energy data in this year were cross-verified among different resources or that the loss of energy was controlled through governmental measurements. This means there seems to be consistency in energy-data measurement among GoP statistical measurement and international energy-reporting agencies. The results also show a steady increase in the level of uncertainty in energy data from 2007 to 2013. Since Pakistan is tackling ways to curb its energy crisis, it is crucial that such high energy-data uncertainty be reduced to better plan and execute energy projects in the country. A closer examination of Pakistan's energy policies shows that Pakistan started to face severe electricity shortage in 2006; then, it worsened with high energy demand. Energy demand is much higher in summers, when the ambient temperature in some parts of the country reaches 45 C and consumers turn on air-conditioning or cooling fans, which consume high amounts of energy. The results of the present study show an increase in uncertainty in energy data from 2005–2006 to 2012–2013. This could be linked to an increase in electricity demand and its shortage that started in 2006 and kept on increasing. Pakistan's energy policies are based on energy demand and, as the analysis shows that there was a high level of uncertainty in energy data, the effectiveness and correctness of Pakistan's energy policy is questionable. This justifies the need to develop an effective, comprehensive, practical, and long-term energy policy based on true forecasts of energy demand and supply in the country. Among many other factors, the forecasted energy is dependent on the historical use of energy. However, as this research shows, there was uncertainty present in historical energy-consumption data, so the forecasted energy values would have an associated uncertainty. This could potentially lead to mismanagement and poorly planned energy policy for Pakistan.

Pakistan can develop much more effective energy policy by considering the uncertainty in its energy data and by eliminating potential sources of uncertainties in energy-data collection. There are various ways to eliminate such uncertainties. Pakistan needs to eliminate energy theft in the country, both in the form of electricity theft and gas theft. Domestic, industrial, as well as commercial energy consumption are measured by energy meters. To measure the consumption of electricity and gas, electricity meters and gas meters are installed at the location of the respective energy consumers. A fuel dispenser measures the consumption of fuel oil utilized by the consumer. This device measures the oil consumed using a numerical display/electrical pulses. Though these energy meters are efficient in measuring energy consumption, due to energy theft, such devices are bypassed illegally by consumers and the government is unable to record accurate energy-consumption data. Such energy theft is quite common in Pakistan and is the root cause of uncertainty in energy data of the country. Energy theft could be due to fraud (meter tampering), unpaid bills, billing irregularities, or theft (illegal connections) [37]. This is because of a failure to plan and implement energy polices in the country [38]. In particular, electricity theft is a major issue in the country. Electricity is stolen by illegally connecting an electric wire to the main power source line, which bypasses the electric meter. The system is called the 'kunda' (hook) system in Pakistan [37]. Since consumers are bypassing their electric meter and still using electricity, consumption data collected either by the government or nongovernment institutions do not reflect true consumption. Hence, such consumer behavior introduces uncertainty into energy-consumption data. Electricity-consumption data also have uncertainty due to poor line networks. Some actual pictures are shown in Figure 6.

Planning and policy making of energy generation is based on the amount of energy consumed or needed. Since there is ambiguity in energy-consumption data, a true forecast of energy generation becomes vague. Hence, the application of methodology in this paper can help curb the uncertainty analysis in reporting energy-consumption data and by proposing energy policy-making based on such analysis.



(**a**) (**b**)

(**c**)

Figure 6. (**a**) Illegal electricity connections—the use of hook (kundas) on main electricity supply lines in Karachi, Pakistan, bypassing electric meters [39]; (**b**) Illegal gas connections in Lahore, Pakistan, bypassing gas meters [40]; (**c**) Conditions of electricity meters on electric poles (impossible to isolate energy consumption by consumer). Photo credit: unknown.

Sensitivity Analysis

Sensitivity analysis was performed using Oracle® Crystal Ball software as a tool. The inputs of sensitivity analysis were energy-consumption data from 1989 to 2013. Energy consumption variables studied were the consumption of energy in industry, transportation, domestic, agriculture, commercial, and other government businesses. Sensitivity analysis identified the energy variables that are contributing the most and least in introducing variability to the energy data. The results of sensitivity analysis for 2012–2013 are shown in Figure 7.

Analysis shows the contributions of variance towards total energy consumption for 2012–2013. The result shows that industrial energy-consumption data have the highest (54.6%) contribution towards variability in total energy data for the year 2012–2013. This indicates that the GoP should adopt a rigorous policy to measure energy-consumption data for the industrial sector of the country. The results show that there is high inconsistency in the energy data of the industrial sector, which shows potential energy theft by this sector. The second- and third-highest contributions are made by the transportation (28.3%) and domestic (15.7%) sectors, respectively. Analysis reveals that energy data for agriculture have the least contribution (0.1%) towards uncertainty in total energy data for 2012–2013, while commercial and other government sectors have significantly low contributions (0.7% and 0.6%, respectively). The results of the analysis extended to the remaining years are shown in Figure 8.

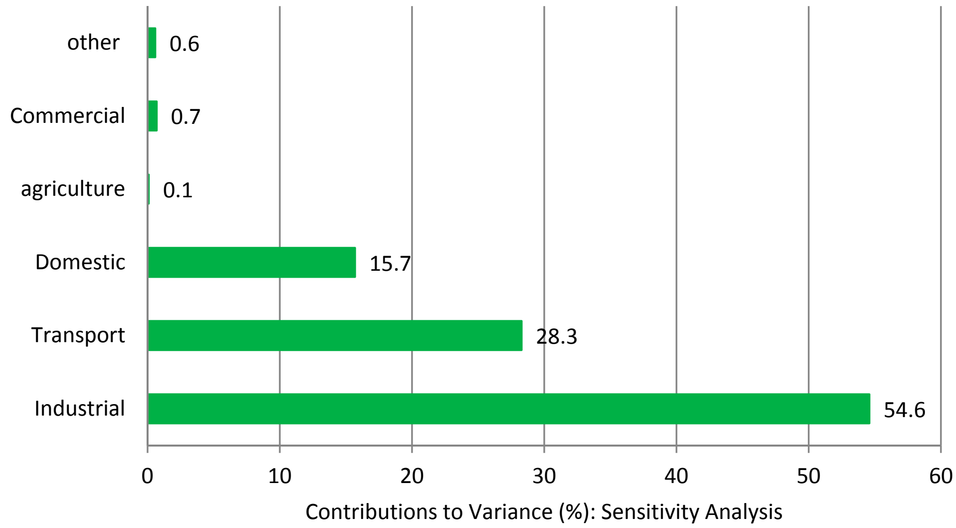


Figure 7. Sensitivity analysis of total energy consumption for year 2012–2013.

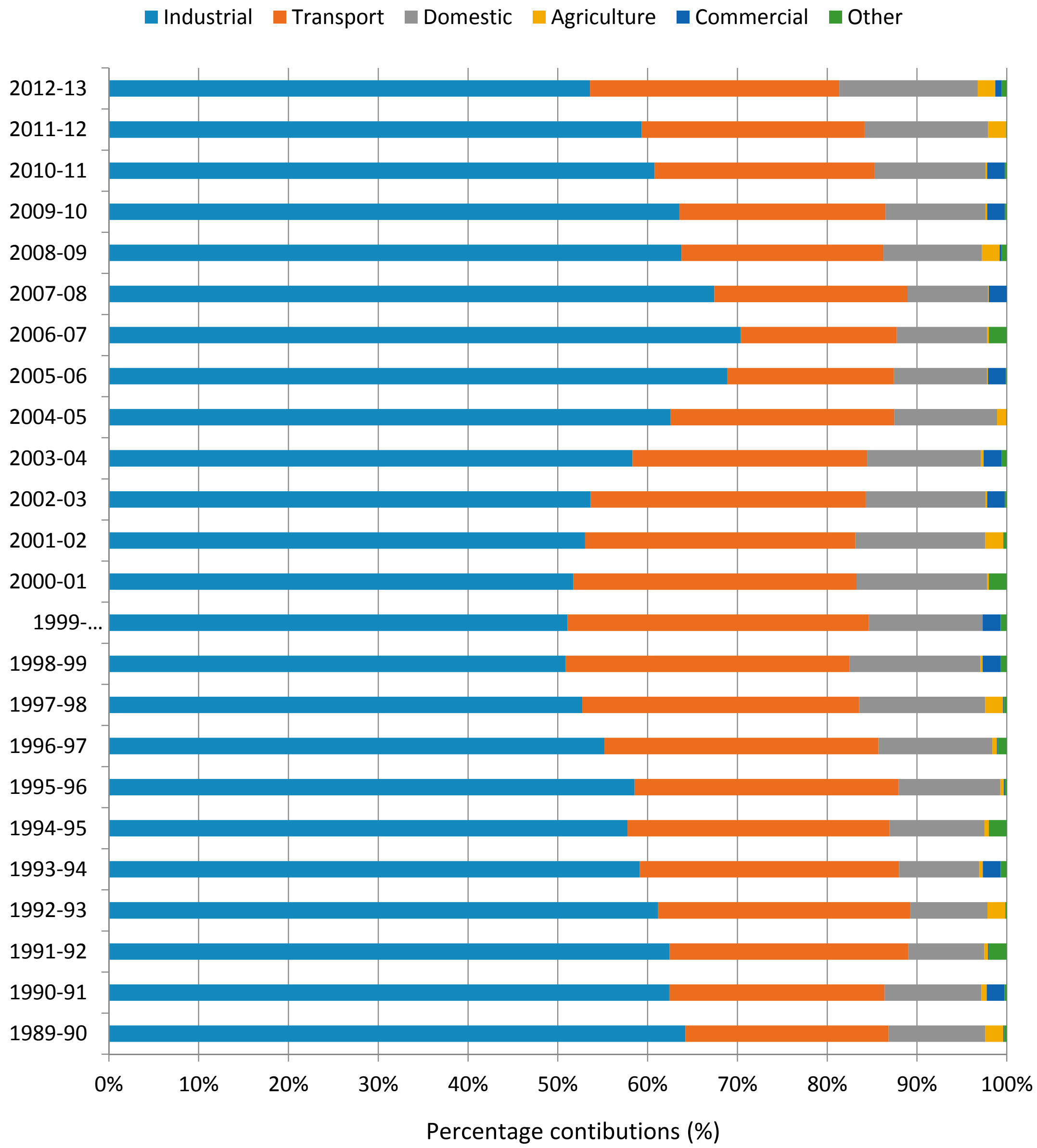


Figure 8. Percentage contributions in data uncertainty from 1989 to 2013.

The analysis shows that from 1989 to 2013, energy data of the industrial sector have been the highest source of uncertainty in this period. The second-highest variability in total energy data comes from the transport sector of the country and the domestic sector is the third-highest contributor towards uncertainty in energy data from 1989 to 2013.

Policy Guidelines

A critical review of Pakistan's past energy policies reveals that their focus has been varied and has never included complexities and uncertainties in its energy systems [41]. Moreover, after the birth of the country in 1947, the very first energy policy was formally announced after 47 years (1994). Since then, GoP started to focus formally on energy-policy formulation for the country. Various energy policies of Pakistan, along with their respective timelines, are shown in Figure 9. It is worth mentioning here that except for the National Power Policy 2013, none of these energy policies focused on electricity theft/loss—a root cause of uncertainty in energy-consumption data.

Pakistan should reshape its future energy policies based on uncertainty in its energy data. This means Pakistan should include vigorous guidelines to minimize and mitigate energy theft or loss. The planning and implementation of such rigorous monitoring policy would ensure robust energy-policy guidelines. It is also inferred that an energy audit should be performed to determine the viability and the variability of the developed energy policy under the umbrella of uncertain energy data. A successful energy audit would guarantee sustainable energy policy for the country. Based on the preceding analysis, the following are recommended guidelines to be included in the development of energy policy for Pakistan.

(1) Technical and nontechnical control of energy-line losses.

In an energy transmission and distribution system, energy-line losses occur due to conversion of energy or electricity into heat, which can never be recovered or utilized. Energy losses also occur due to the transformation of energy into electromagnetic energy, which is essentially wasted. Though such losses cannot be eliminated completely even in the most efficient energy system, they can be reduced to their minimal. As presented in this study, the Pakistan energy sector is facing huge energy-line losses and such losses need to be controlled. In light of the above analysis, this objective can be achieved by either considering nontechnical or technical solutions, or a combination of both. Nontechnical solutions may include legal and regulatory accountability of energy consumers in Pakistan, providing financial rewards for reporting energy theft, random checks on energy consumers belonging to different sections of society, and the enforcement of the law; this should include fair implementations of fines and imprisonment for stealing national energy resources. Technical solutions include advanced and sophisticated devices to monitor energy consumption, the details of which are presented in Section 4 of the policy guidelines presented in this paper. Rolling blackouts in Pakistan have not only paralyzed Pakistan industries but have also significantly influenced the GDP of the country.

(2) National- and regional-level energy audit system.

Considering the results of the uncertainty analysis, it is quite pertinent that Pakistan's industrial sector has the highest uncertainty associated with energy consumption. Based on this result, it is suggested that Pakistan energy-policy makers should include regional and local energy audit systems while developing energy polices for Pakistan's industries. There is a need to develop a new energy-audit department (or increase the effectiveness of existing audit departments) that can audit the energy consumption of Pakistan's industries. Currently, there are various energy-audit departments in the country; these are the National Productivity Organization [42]; the National Energy Efficiency and Conservation Authority [43], created due to the introduction of the National Energy Efficiency and Conservation Act 2016 by the National Assembly and the Senate of Pakistan [43]; and the National Cleaner Production Centre [44]. These government departments either do not effectively perform energy audits or do not have energy audits on a regular basis.

(3) Faulty energy meters.

As revealed through uncertainty analysis, faulty or sluggish energy-measurement meters introduce uncertainty in energy data. The energy policy of Pakistan should include the replacement or repair of sluggish and/or faulty energy-measurement meters. Such an addition to energy policy would facilitate the control of unmetered energy consumption that results in energy as well as financial loss. To reduce uncertainty in energy data, there is a need to test energy-consumption meters at regular intervals. The use of smart meters could help to achieve practical implementation of this proposed energy policy. Other than smart meters, the use of meter boxes and their proper sealing can also ensure no tampering is done. The impact of energy or power theft not only limits government revenue but also affects power availability and low voltage quality causing voltage dips, adding additional load to the energy system.

(4) Development of a single hub for collecting energy data.

As highlighted in the research problem statement, various government and/or nongovernment departments collect energy-consumption data. GoP should establish one department that can monitor and collect energy-consumption data. This department should be able to collect energy data from streets to big cities to the whole country. The usual system of collecting power-consumption data is by meter reader. As shown in Figure 6c, the poorly managed and unorganized conditions make it hard for a reader to note the correct data. Therefore, it is proposed that Pakistan should switch to prepayment meters that work only when the consumer adds credit to the meter. This not only eliminates the need to record power utilization by consumers but would also ensure no power theft. Other methods include the use of electronic tampering-detection meters, which automatically detect meter bypasses, meter tampering, and meter disconnection (as what takes place in Western countries). Another remedy is the use of antitheft cables and plastic meter encasements, which are meter seals made of hard plastic encasements.

(5) Vigilance programs for industrial, transport, and domestic sectors.

The uncertainty analysis showed that there are three major energy-consuming sectors with highest variations in their energy-data reporting. These are the industrial, transport, and domestic sectors. Pakistan energy policy should include an industrial, transport, and domestic vigilance program to reduce energy losses and uncertainties in energy data. Such measures should include separate feeders for industrial, transportation, and domestic use. This would introduce transparent accountability for these energy sectors. Considering agriculture consumers, there is a need for a one-consumer one-transformer policy. The agricultural sector of Pakistan should be made accountable for the use of poor quality equipment for water pumping in rural areas.

(6) Superconductive transmission.

All power plants, either based on natural gas, coal, or petroleum, work on the same principle. Fuel is burned to release heat, which is used to convert water into steam, and steam spins turbines that finally generate electricity. The long-distance transmission of generated electricity is performed through high-voltage lines. Losses in high-voltage-carrying lines could be due to the conversion of electricity into heat; subsequently, heat is lost to the environment. This loss could also be due to sagging of high-transmission power lines. Similar to other countries, power plants in Pakistan are remote, away from populated areas, and power losses due to line-sagging problems can be seen with electric-power transmission. Another study also confirms that Pakistan has higher transmission and distribution losses than countries in Europe, Africa, and the Middle East [45]. Hence, it is proposed that Pakistan energy policy should ensure that superconducting materials are used in transmission lines to control losses in electricity transmission and distribution.

(7) Detailed distribution system.

Considering the high level of energy data uncertainty, Pakistan needs to revise its energy-distribution system. The energy policy of Pakistan should include studying the existing energy-distributing system and developing guidelines for a new and improved distribution system. This improved system should be based on expected load development considering the energy-data uncertainties presented in this paper.

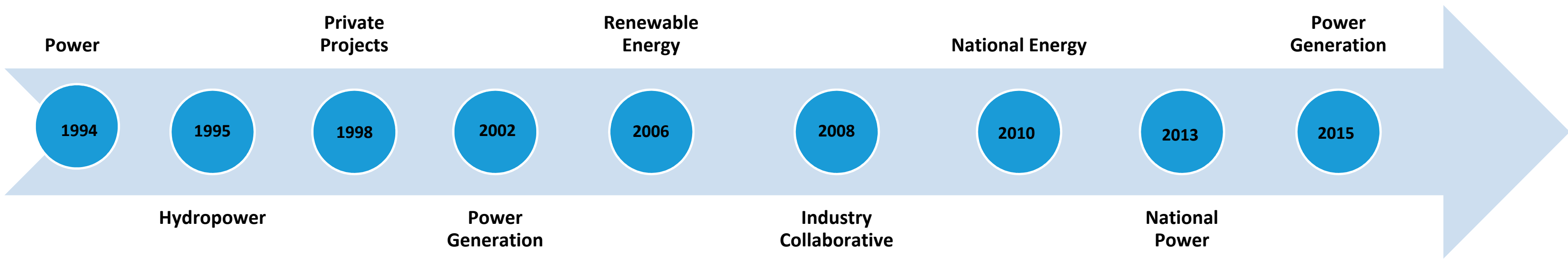


Figure 9. Timeline of Pakistan's energy policies showing various accomplishments.

In order to implement these policies, there is a need for good governance, implementation of laws pertaining to energy, transparency in the government and private energy sectors, competence, and engagement with the public over energy theft. It is pertinent to mention here that uncertainty in energy-consumption data is also a common issue even in many developed countries due to the complexity of consumption data itself and the variation in survey designs.

4. Conclusions and Policy Implications

Pakistan is facing a severe energy crisis, and with population growth, this energy crisis is becoming overwhelming. This calamity is not only darkening the streets of Pakistan but also affecting the economy of the country. Hence, there is a need to define new or re-evaluate the existing energy policy of Pakistan on a regular or annual basis. Effective energy management is only possible when all variabilities in energy data are considered. Energy policies of Pakistan are based on past energy data to predict future growth. In this study, a stochastic analysis was performed on Pakistan's historical energy-consumption data (1989–2013) using a Monte Carlo Simulation. Energy-consumption variables were assigned respective PDFs based on the historical nature of individual datasets. Total energy consumption was defined as the sum of energy consumed by commercial, domestic, agriculture, industrial, transportation, and other government business sectors. A simulation model was set up to find total energy consumption for the respective years. The simulation was performed for 10,000 iterations to develop probabilistic profiles of total consumption for each year. The developed profiles were analzsed and the energy-policy guidelines were presented in the light of the results obtained. The study reveals that there has been uncertainty in the past energy data of Pakistan. This not only leads Pakistan to underestimate its energy consumption, but also causes ambiguity in previously defined energy policies of the country. The current study performed stochastic modeling and found uncertainty in energy data for Pakistan from 1989 to 2013. None of Pakistan's energy policies has been effective due to the fact that these policies ignored the ambiguities in energy data. Except for the National Power Policy of 2013, none of the energy policies of Pakistan considered tackling energy theft in the country. Energy theft introduces uncertainties in energy-consumption-data recording. The findings of stochastic modeling are used to recommend energy-policy guidelines based on the uncertainty principle. The analysis concluded by providing seven new recommended guidelines that should be part of new energy policy of the country. All these guidelines involve tackling uncertainty in energy data and making consumers more accountable for their energy consumption. This study suggested implementing national- and regional-level energy-audit systems to achieve a sustainable energy policy for the country.

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