Energy Demand Forecasting

There are a large number of approaches for forecasting energy demand. Some of them are relatively simple, easy to use and less sophisticated approaches, while others employ more advanced methodologies. Some approaches are static in nature while others consider the dynamic adjustment process. Similarly, some approaches use a probabilistic framework while others are deterministic in nature

Forecasting Using Simple Indicators

Energy indicators can be used relatively easily to develop a quick understanding of changes in energy requirements in the future. Four such simple indicators commonly used for forecasting are: growth rates, elasticities (especially income elasticity), specific, or unit consumption and energy intensity. In addition, trend analysis that finds the growth trend by fitting a time trend line is also commonly used.

Forecasting using these indicators follows a two-step process:

(1) Using historical information of energy use, an understanding and appreciation of the indicator is developed;

(2) This then informs the possible future evolution of the indicator during the forecast period. The perception of changes in the indicator drives the future demand.

Procedure: Simple indicators for energy demand forecasting

1-Growth-rate based method

Let g be the growth rate in energy demand and *D*0 is the demand in year 0, and then demand in year *t*, *Dt* can be obtained by

$$\mathbf{Dt = D0(1 + g)^{t}}$$

2-Elasticity-based demand forecasting

Elasticity is generally defined as follows:

$$e_t = \frac{(\Delta EC_t / EC_t)}{(\Delta I_t / I_t)}$$

where

t is - a period given
EC is - energy consumption
I is - the driving variable of energy consumption such as GDP, value-added, price, income etc.
Δ is - the change in the variable.

Output or income elasticity is commonly used for energy demand forecasting. The elasticity of energy demand, particularly at the fuel level, is either estimated using historical information or obtained from a review of literature. Forecasts for economic growth can be found from international organisations such as the International Monetary Fund or government sources. The change in energy demand can be estimated from the elasticity of demand and the output growth forecasts.

3- Specific consumption method

Energy demand is given by the product of economic activity and unit consumption (or specific consumption) for the activity. This can be written as
$E = A \times U$
where
A - is level of activity (in physical terms)
U - is the energy requirement per unit of activity
These two factors are independently forecast and the product of the two gives the demand.

4-Ratio or intensity method

Energy intensity is defined as follows:

$EI = E/Q$
where
EI - energy intensity, E - energy demand & Q – output

This can be rearranged to forecast energy demand $E = EI \cdot Q$

Trend Analysis

The trend analysis extrapolates the past growth trends and is normally done by fitting some form of time trend to past behaviour. The analysis:

(a) Assumes that there will be little change in the growth pattern or in the determinants of demand such as incomes, prices, consumer tastes, etc.
(b) Finds the best trend line that fits the data. This is usually estimated by a least square fit of past consumption data or by some similar statistical methodology.
(c) The fitted trend is then used to forecast the future. Frequently, ad hoc adjustments are made to account for substantial changes in expected future demands due to specific reasons. Depending on the availability of data, the analysis can be

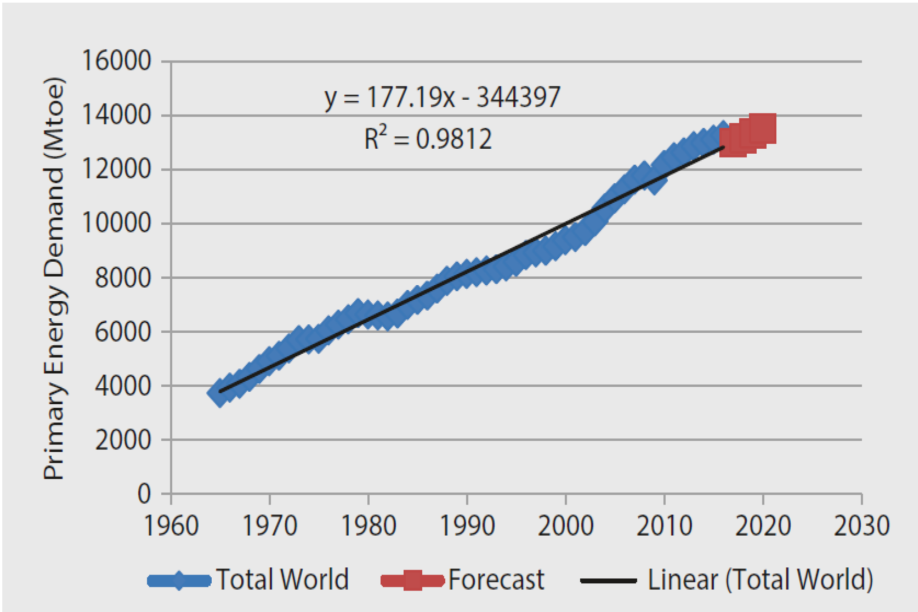
- Performed at the national level for a given energy source or they may be broken down by region, by consuming sector or by both.
- Used on its own or in combination with another method. For example, if energy demand is estimated using per capita consumption (i.e. unit consumption approach), the trend of population growth and per capita consumption can be estimated using trend analysis. The results can then be used in the unit consumption approach to get the final results.

For example

Years	Forecast (Mtoe)
2017	12,995.2
2018	13,172.4
2019	13,349.6
2020	13,526.8

The linear relationship is also shown in the figure.

$Y = 177.19X - 344397$, where X is Year.



Using the forecast year as X in the above relation, the forecast can be obtained. The fitted trend has achieved a good level of fit as is evident from the R2 information. The demand forecast for the period up to 2020 using this trend is given in table above.

Direct Surveys

Direct surveys are generally used to generate primary information essentially for the short term but surveys can also be used as a direct and reliable tool for demand analysis and forecasting. Surveys are widely used in the energy sector, particularly by national statistical offices or regulatory agencies. For example, Statistics Canada collects energy data through fuel specific surveys.

Advanced or Sophisticated Techniques

Sophisticated demand forecasting techniques rely on more advanced methodologies. A commonly used classification is the top-down and bottom-up models.

- Top-down models tend to focus on an aggregated level of analysis
- Bottom-up models identify the homogeneous activities or end-uses for which demand is forecast.
- Econometric models, grounded in the economic theories, come under the first category
- Engineering-economy models (or end-use models) that establish accounting coherence using detailed engineering representation of the energy system fall in the second category.
- Hybrid models are combining the features of these two traditions.

Other approaches are also used for energy demand forecasting.

The scenario approach is common in many traditions but scenarios as storylines are being developed independently as well.

Other techniques include

- Input–output models (which rely on forward and backward linkages in any economy to determine the demand for energy)
- System dynamics models
- Decomposition models
- Process models
- artificial neural networks

Scenario Approach

The scenario approach is widely used in demand energy forecasting.

The complex interactions of the energy sector with the rest of the economy and the multi-dimensional challenges that need to be addressed in the future (including climate change, sustainable development) imply that there could be different pathways of developing the energy sector in the future.

- A scenario is a story that describes a possible future.
- In simple terms, scenarios refer to a "set of illustrative pathways" that indicate how "the future may unfold"
- They indicate what could happen and not what will happen
- Evidently, they do not try to capture all possible eventualities but try to indicate how things could evolve.
- It is a particularly suitable approach in a changing and uncertain world.

Econometric Approach to Energy Demand Forecasting

The econometric tradition of demand forecasting extends the demand analysis. The relationship determined for the demand can be used for forecasting simply by changing the independent variables and determining their effect on the dependent variable.

The main step is to decide a systematic way of forecasting the independent variables.

A number of econometric forms (such as the reduced form and structural models) can be used for demand analysis

The forecasting follows the steps given below

- Forecast those using judgments, which could be based on a literature review or a survey of expert views or otherwise
- Use simple indicators (such as growth rates) to generate a set of data for the future
- The growth rates can be based on historical levels or expected levels as suggested by other agencies or experts
- Use a trend analysis of the independent variables to extrapolate the future values;
- Use a combination of above or any other plausible method.

One measure of accuracy of forecasting is given by the root mean square (RMS) error. This measures the deviation of the forecast from its actual value and can be written as

RMS forecast error

$$RMS\ Error = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(Y_t^s - Y_t^a)^2}$$

Where
Yst - forecast of Yt
Yat - actual value
T - Number of periods
The range of error here can be between zero and infinity. As this squares up the errors, larger errors influence the result more than the smaller errors.

End-Use Method of Forecasting

The basic idea behind the end-use approach of energy demand is to disaggregate the demand into homogeneous modules and sectors and to link the demand of each module to technical and economic indicators. The approach is called end-use approach.
Demand is estimated for different end-uses and the overall demand is estimated by adding up all end-use demands working backwards.
For instance, to estimate the demand for gasoline, the focus would be on the final use of gasoline (i.e. transport) in cars and motorcycles. The analysis would consider the number and types of cars, average unit energy consumption of each type, average traveling habit, etc. to arrive at an estimate of the demand.
The end-use analysis puts emphasis

- on the role of technology (e.g. fuel economy of vehicles, unit consumption of electrical appliances or of industrial processes)
- behaviour of consumers (mileage of vehicles)
- the economic environment (ratio value added/ physical output) in the demand analysis.

The end-use models normally have the following features:
(a) they contain a detailed representation of energy end-uses: being a disaggregated method of analysis, this approach breaks down the demand in small components and includes a technical picture of energy use at each level.
i. For example, the demand would be broken down into a number of sectors: industry, transport, residential and commercial.
ii. For each sector, further disaggregation would be made. For instance, in case of residential demand, a distinction between urban and rural consumption would be made. Within each zone, the demand for cooking, heating and lighting could be considered.
iii. For each type of use, different types of possible fuels would be allowed to be used.
(b) A few key driver variables would be used at each level: for example, per capita consumption could be used for the residential sector; value addition could be used for the industrial sector. These variables are forecast exogenously using scenarios or judgements.

(c) These models use a few policy variables, which could be changed to see the effect on the overall demand. Examples of such variables could include energy intensity, unit consumption, fuel mix, etc.
(d) The past data and information is used to establish a base or reference case. The data could be used to calibrate the model as well. The analysis is done in terms of a number of scenarios which are compared with the reference case. The results show how different policies could influence the future demand.
(e) The analysis is normally done providing snapshots of the future and does not provide a path to reach various ends.

Input–Output Model

The input–output table has long been used for economic analysis. It provides a consistent framework of analysis and can capture the contribution of related activities through inter-industry linkages in the economy. The following example will explain the basic approach easily.
Consider a small three sector economy with agriculture, industry and energy as the main activities. The interdependence of one sector on the other is indicated through purchases from other sectors). In this table, a column entry indicates the purchase of one sector from the others. For example, the agriculture sector uses $10 from agriculture, $10 worth of inputs from energy, and another $10 of inputs from industry to produce an output worth of $80. In the process, the agriculture adds a value of $50. Similarly, along the row, the uses of the output of a sector are indicated.

	Agriculture	Energy	Industry	Final demand	Total output
Agriculture	10	10	30	30	80
Energy	10	20	20	50	100
Industry	10	30	30	50	120
Value added	50	60	40	150	
Total output	80	100	120		

Thus the input–output method is able to capture the direct energy demand as well as indirect energy demand through inter-industry transactions. This feature makes this method an interesting analytical tool.

Artificial Neural Networks

An artificial Neural Network (ANN) is an information paradigm that is inspired by biological nervous systems. The system structure is composed of a large number of highly interconnected processing elements (neurons) working together to solve specific problems. These units are connected by communication channels referred to as “connections” which carry numeric data between nodes. Each unit operates only on its local data and on the inputs they receive via the connections.

Hybrid Approach

This approach relies on a combination of two or more method discussed above with the objective of exploring the future in a better way. These models have become very widespread now and it is really difficult to classify any particular model into a specific category. For example, econometric models now adopt disaggregated representation of the economy and have internalised the idea of detailed representation of the energy-economy activities. Similarly, engineering-economy models use econometric relationships at the disaggregated levels thereby taking advantages of the econometric estimation method. The end-use approach heavily relies on the scenario building approach to enrich itself.

MAED Model

The Model for Analysis of Energy Demand (MAED) evaluates future energy demand based on a set of consistent assumptions on medium to long term socioeconomic, technological and demographic developments in a country or a region.

Future energy needs are linked to the production and consumption of goods and services; technology and infrastructure innovation, lifestyle changes caused by increasing personal incomes; and mobility needs. Energy demand is computed for a host of end use activities in four main ‘demand sectors’: household, services, and industry and transport.

MAED provides a systematic framework for mapping trends and anticipating change in energy needs, particularly as these correspond to alternative scenarios for socioeconomic development.

Key questions addressed:

- How do social, economic, and technological factors affect future energy demand?

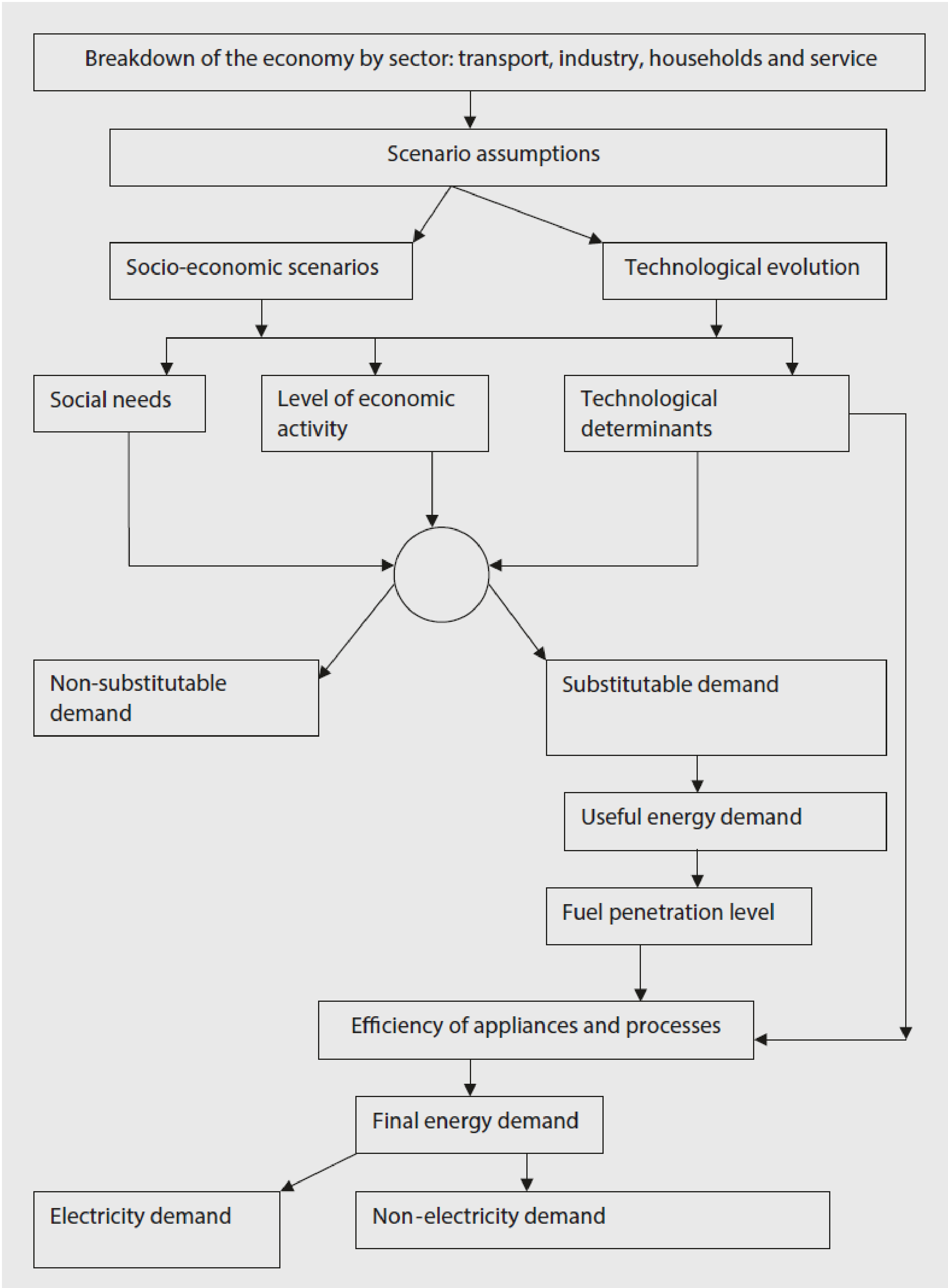
Sample data inputs:

- Energy sector data
- Scenario assumptions (socio-economic and technological)
- Substitutable energy uses
- Process efficiencies
- Hourly load characteristics

Sample quantitative outputs:

- Useful or final energy demand by sector/fuel
- Electricity demand
- Degree of electrification
- Hourly electric load
- Load duration curves

The energy demand is aggregated into four sectors: industry, transport, households and service. The industrial demand includes agriculture, mining, manufacturing and construction activities (or sub-sectors). The demand is essentially determined by relating the activity level of an economic activity to the energy intensity. However, the demand is determined separately for non-substitutable energy forms (electricity, motor fuels, etc.) and substitutable forms (thermal energies). The need for feedstock or other specific needs can also be considered. The demand is first determined at the disaggregated level and then added up using a consistent accounting framework to arrive at the overall final demand. The model focuses only on the final demand and does not cover the energy used in the energy conversion sector.



MAED Framework of analysis

LEAP Model

The Long-range Energy Alternatives Planning (LEAP) is a flexible modelling environment that allows building specific applications suited to particular problems at various geographical levels (cities, state, country, region or global).

The demand analysis, following the end-use approach, is carried out as follows

- The analysis is carried out at a disaggregated level, where the level of disaggregation can be decided by the users
- the disaggregated structure of energy consumption is organised as a “hierarchical tree”, where the total or overall activity is presented at the top level and the lowest level reflects the fuels and devices used. An example of such a tree will be: sectors, sub-sectors, end-uses and fuels/devices
- the socio-economic drivers of energy demand are identified. The distribution of these activities at the disaggregated level following the “hierarchical tree” is also developed.
- Generally, the product of activity and the energy intensity (i.e. demand per unit of the activity) determines the demand at the disaggregated level. However, the model allows alternative options:
- at the end-use level, useful energy can be considered to forecast the demand.
- Stock analysis allows the possibility of capturing the evolution of the stock of appliances/ devices or capital equipment and the device energy intensity.
- For the transport sector, the fuel efficiency of the vehicle stock and distance travelled can be used to determine the demand.