University of Genoa
Department of Mechanical and Energy Engineering

Energy Planning

Methodologies for Estimation of Energy Demand

Master Degree in Innovative Technologies in Energy Efficient Buildings
for Russian & Armenian Universities and Stakeholders

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MARUEEB

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Disclaimer

- Please consider that the present document is a presentation and it cannot be utilized without taking into account oral comments of the speaker
- The present document is a presentation and cannot be considered as a reference paper to study the subject contained in it
- Some of the topics reported in the following charts are treated in a simplified and not always rigorous way for the sake of the simplicity
- For an accurate discussion about the topics of the present document, you are warmly invited to consult the suggested bibliography.

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2. Energy demand forecasting
3. Analysis of the energy demand
4. Simple Forecasting Methodologies
5. Regression Analysis

Introduction to Forecasting

Predicting future using available data

Usually wrong!!!

Forecasting

Affects todays' decisions

A good forecast is more than a single number

- **Forecasting** is very **important** in **many sectors of activity**
- It is a **fundamental** step **in planning future activities**
- The **forecasting horizon largely varies** according to the final utilization of the projection

Formal vs informal forecasting

Formal

Main reasons to perform formal forecasting activities:

- Coping with complexity
- Coping with growth
- Coping with change
- Need for auditability and justification

Forecasting

Informal

- Forecasting is a very common activity
- Each person running a business has its own expectations about the future
- All the people who necessitate to take decisions which will influence the future performs forecasting

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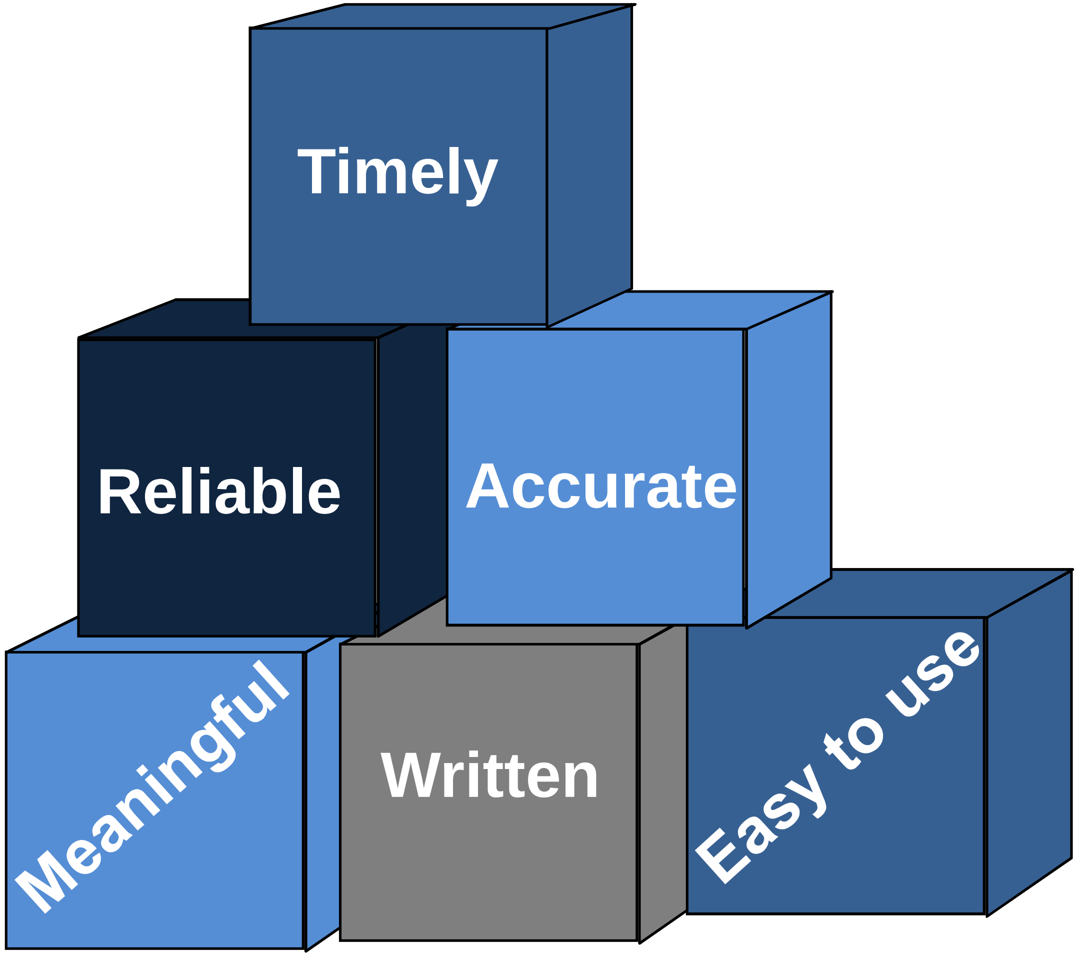
- Formal forecasting provides a framework for continuous and systematic improvement
- Informal forecasting is an activity naturally and instinctively performed by most of people running a business
- Large organizations need to develop accurate formal forecasting by using advanced methodologies

Characteristics of forecasting problems

Forecasting Problems

1. **Time Horizon**
   - Short term
   - Long term
2. **Data Patterns**
   - Seasonality
   - Trend
   - Cycles
   - Randomness
3. **Cost**
4. **Complexity**
5. **Accuracy**

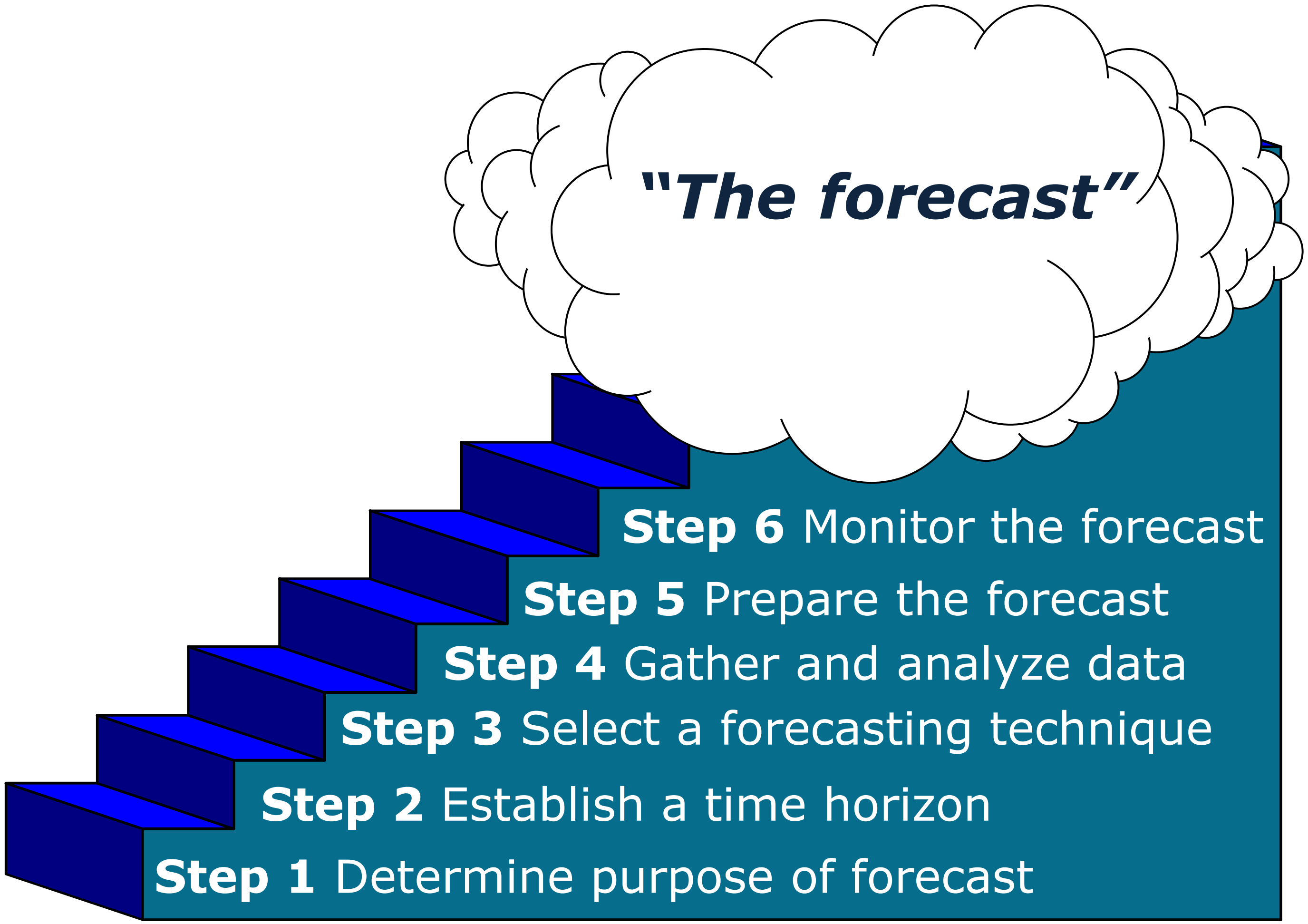
Elements of a good forecast 1/2



Elements of a good forecast 2/2

Timely	The forecast should be timely. Usually, a certain amount of time is needed to respond to the information contained in a forecast. For example, capacity cannot be expanded overnight, nor can inventory levels be changed immediately. Hence, the forecasting horizon must cover the time necessary to implement possible changes
Reliable	The forecast should be reliable; it should work consistently. A technique that sometimes provides a good forecast and sometimes a poor one will leave users with the uneasy feeling that they may get burned every time a new forecast is issued.
Accurate	The forecast should be accurate, and the degree of accuracy should be stated. This will enable users to plan for possible errors and will provide a basis for comparing alternative forecasts.
Meaningful	The forecast should be expressed in meaningful units. Financial planners need to know how many dollars will be needed, production planners need to know how many units will be needed, and schedulers need to know what machines and skills will be required. The choice of units depends on user needs.
Written	The forecast should be in writing. Although this will not guarantee that all concerned are using the same information, it will at least increase the likelihood of it. In addition, a written forecast will permit an objective basis for evaluating the forecast once actual results are in.
Easy to use	The forecasting technique should be simple to understand and use. Users often lack confidence in forecasts based on sophisticated techniques; they do not understand either the circumstances in which the techniques are appropriate or the limitations of the techniques. Not surprisingly, fairly simple forecasting techniques enjoy widespread popularity because users are more comfortable working with them.

Steps in the forecasting process



Types of forecasts

Types of Forecasts

1. **Judgmental** — Subjective analysis of subjective inputs

2. **Associative Models** — Analyzes historical data to reveal relationships between (easily or in advance) observable quantities and forecast quantities. Uses this relationship to make predictions.

3. **Times Series** — Objective analysis historical data assuming the future will be like the past

Judgmental forecasts

1. **Executives Opinion:** There are factors hard to quantify
2. **Sales Force Composite:** Retailer forecasts for the manufacturer
3. **Consumer Survey:** The guy at the mall who asks if you like cherry flavor in your shampoo
4. **Outside Opinion:** The guy at the mall who asks if you like cherry flavor in your shampoo
5. **Opinions of Managers and Staff:** Delphi method: A series of questionnaires developed sequentially

Associative forecasting

Associative Forecasting

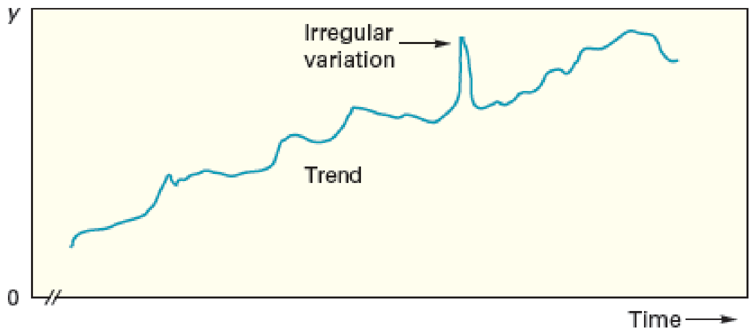
1. **Based on identification of related variables that can be used to predict values of the variable of interest** (e.g. Ice cream sales can be related to temperature)
2. **Find an association between the predictor and the predicted variable**
3. **Predictor variables: used to predict values of variable interest, sometimes called independent variables**
4. **Predicted variable: dependent variable**
5. **Regression: technique for fitting a line to a set of points. Linear regression is the most widely used form of regression**

Time series 1/2

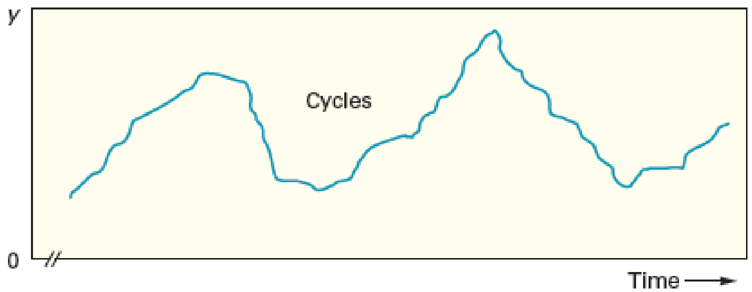
Time Series

1. **Time-ordered sequence of observations taken at regular intervals over a period of time**
2. **Future values of the series may be estimated from past values**
3. **Types of Variations in Time Series Data:**
   - ***Trend:*** *A long-term upward or downward movement in data*
   - ***Seasonality:*** *Short-term regular variations related to the calendar or time of day*
   - ***Cycles:*** *Wavelike variations lasting more than one year*
   - ***Irregular variations:*** *Caused by unusual circumstances, not reflective of typical behavior*
   - ***Random variations:*** *Residual variations after all other behaviors are accounted for*

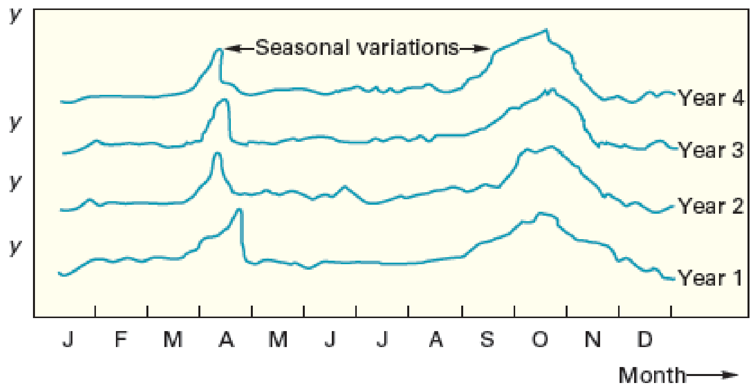
Time series 2/2



Trend with Random and Irregular Variations



Cyclical Variations



Seasonal Variations

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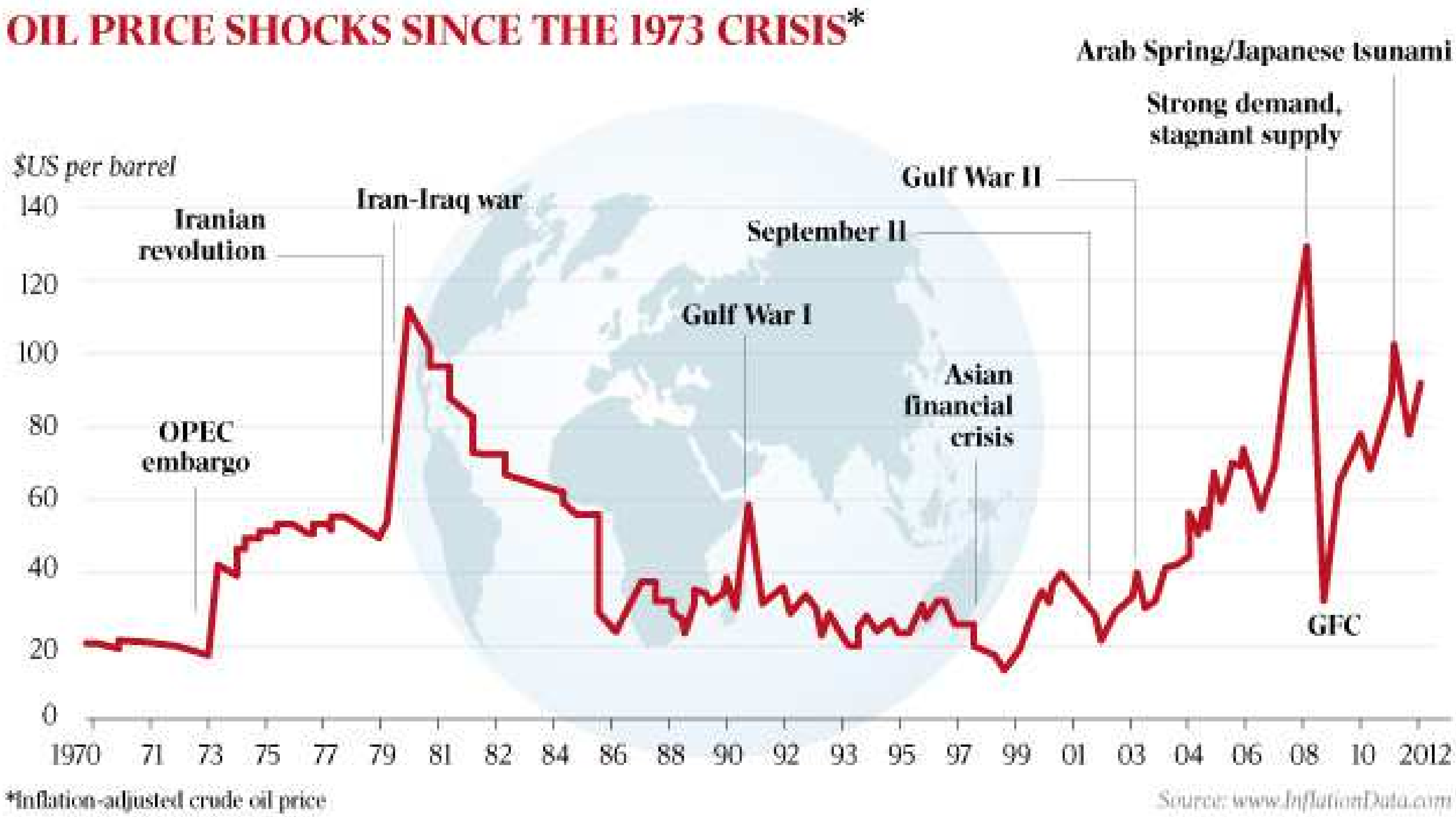
Energy Demand

Energy demand is a derived demand as energy is consumed through equipment. Energy is not consumed for the sake of consuming it, but for an ulterior purpose (e.g. for mobility, for producing goods and services, for obtaining a certain level of comfort, etc.).
Need is specific with respect to location, technology and user.

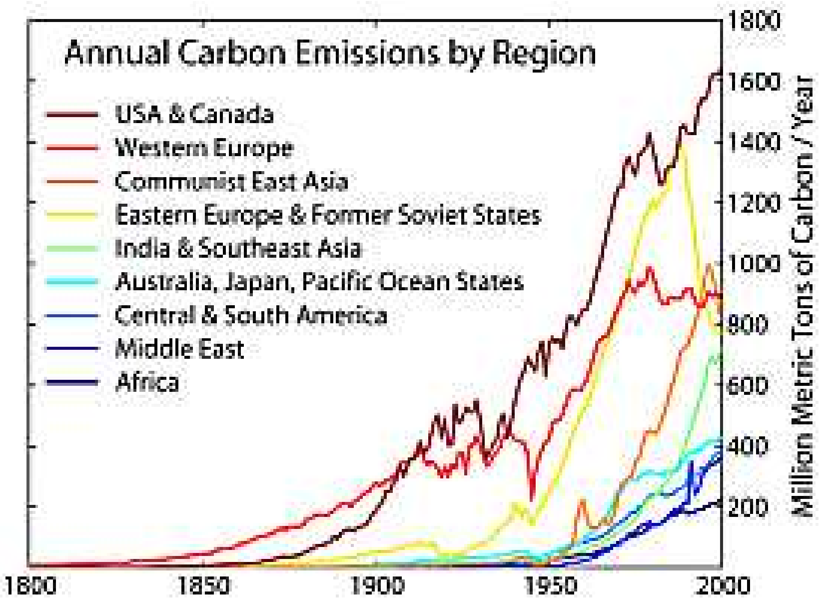
Demand vs. Consumption. Which is the difference?

- A distinction is sometimes made between energy demand and energy consumption
- Energy demand describes a relationship between price and quantity of energy. It exists before the purchasing is made. It is an *ex-ante* concept. Demand indicates what quantities will be purchased at a given price and how price changes will affect the quantities sought
- Consumption takes place once the decision is made to purchase and consume. It is an *ex-post* concept. It refers to the manifestation of satisfied demand and can be measured

Energy Demand Forecasting: Motivations 1/2



Energy Demand Forecasting: Motivations 2/2



- The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets
- Recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities."

Energy generation represents one of the most carbon intensive sectors, therefore an increase of its efficiency means less carbon emissions

Energy Demand Forecasting

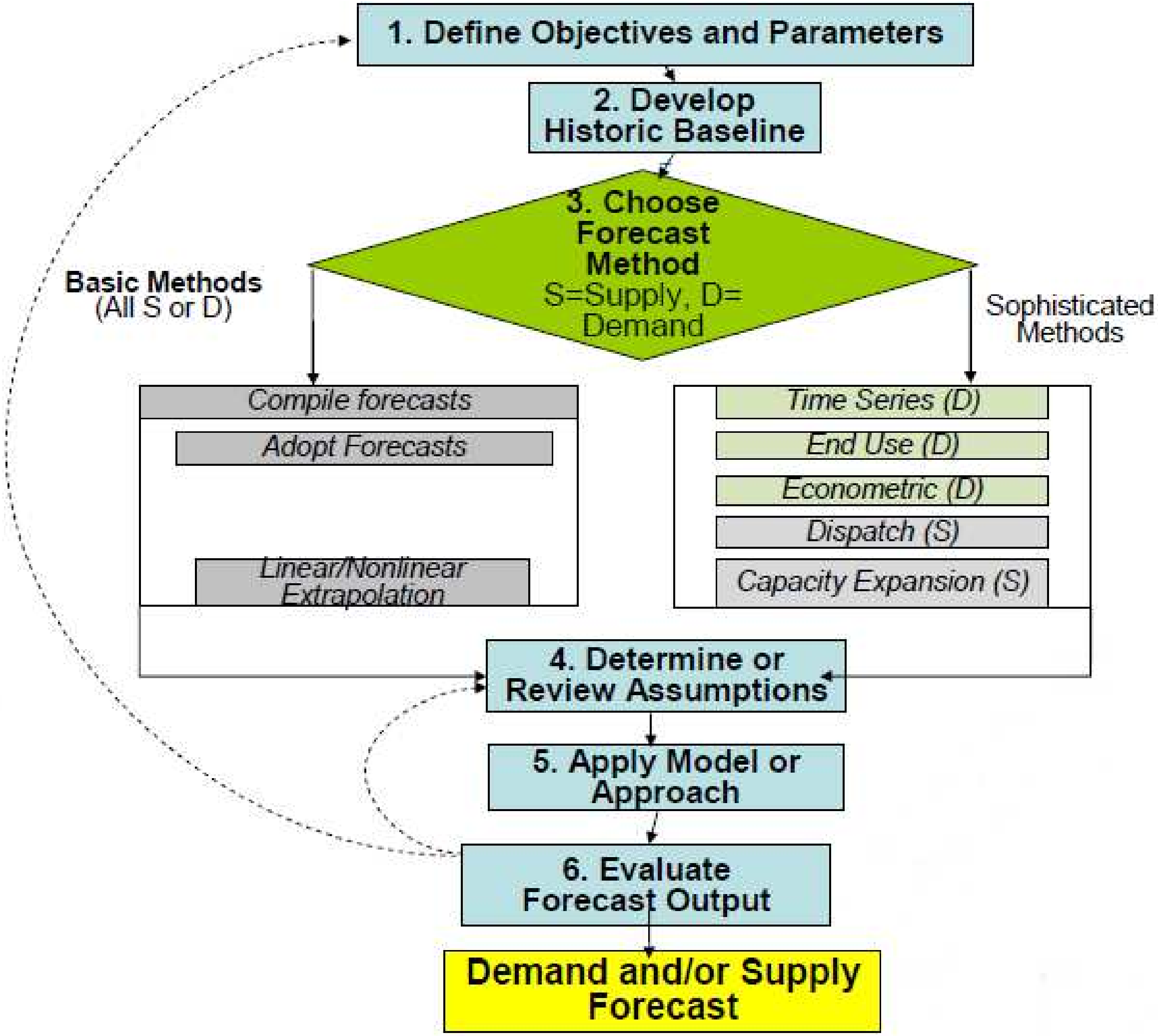
Energy Demand Forecasting

1. An energy forecast is a measurement and estimate of historic, current and projected patterns of energy supply and demand within a determined domain.

2. The baseline -or Business As Usual (BAU) - forecast illustrates what energy use will look like in the absence of additional policies beyond what is already planned.

3. It is a reference case against which to measure the energy impacts of policy initiatives or system shocks.

Steps to develop an energy forecast



Step 1: Define Forecast Objectives and Parameters

1. **Identify the use(s) and purpose(s) of the forecast** (e.g. to obtain a general energy profile or conduct a detailed analysis)

2. **Factors to consider:**

   - *short-term vs. long-term;*
   - *bottom-up vs. top-down;*
   - *level of rigor necessary;*
   - *availability of financial, labor and time resources to complete the forecast;*
   - *amount of energy data readily available.*

Step 2: Develop an Historic Baseline

1. **Historic baseline includes:**
   Energy consumption (demand) data by sector and fuel

   Energy generation (supply) data by fuel

2. **Data sources include:**
   Utilities

   Public utility commissions

   State energy offices

   Departments of transportation

   Transmission system operators

   International statistics

   Other

Step 3: Choose a Forecast Method

Basic vs. Sophisticated

1. **Basic Methods for Supply and demand Forecasts include:**
   - *Compilation of individual forecasts by others*
   - *Adoption of a complete forecast used by others*
   - *Linear and/or Nonlinear Extrapolation of Baseline*
2. **Sophisticated Methods for Demand include:**
   - *Time series models: Forecasts future events based on known past events and patterns*
   - *End use models: Develops load profiles for consumer types based on specific considerations*
   - *Econometric models: Complex and robust analysis which includes population, economics, energy relationships, structural changes*
3. **Sophisticated Methods for Supply include:**
   - *Electricity Dispatch Models: Determines how existing electricity system will meet projected demand*
   - *Capacity Expansion or Planning Models: Determines how energy system will change & capacity will be built in response to meet demand*

Step 4: Determine Assumptions and Review Data

1. Future projections of energy demand and supply depend on assumptions about population and economic variables
2. May already be embedded in others' forecasts and/or sophisticated models
3. Review data for gaps, inconsistencies, etc.

Steps 5&6: Apply and Evaluate

1. **Apply method or model**

2. **Evaluate Forecast Output**

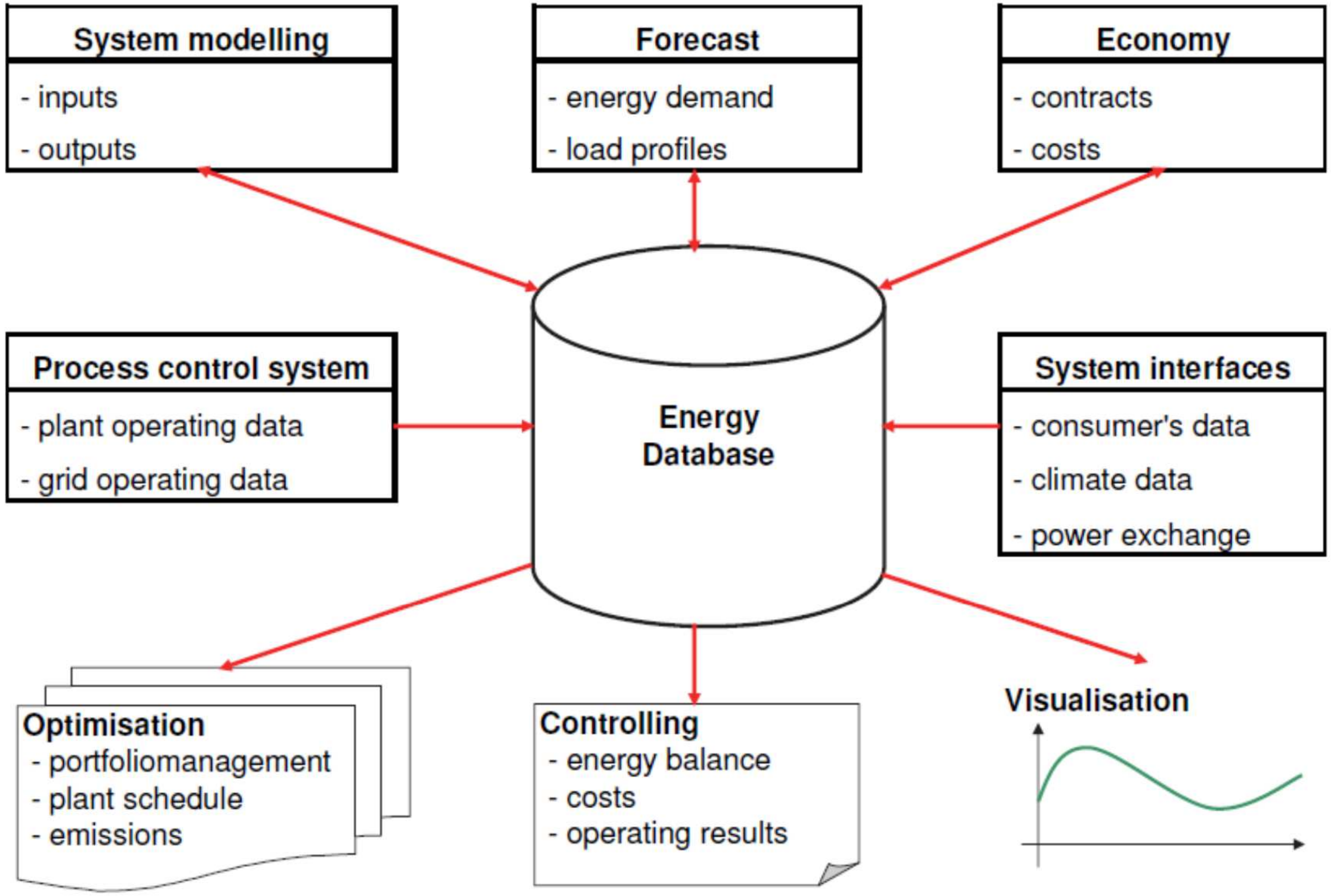
   Ensure that it makes sense and meets original objectives

   May need to revisit assumptions and rerun

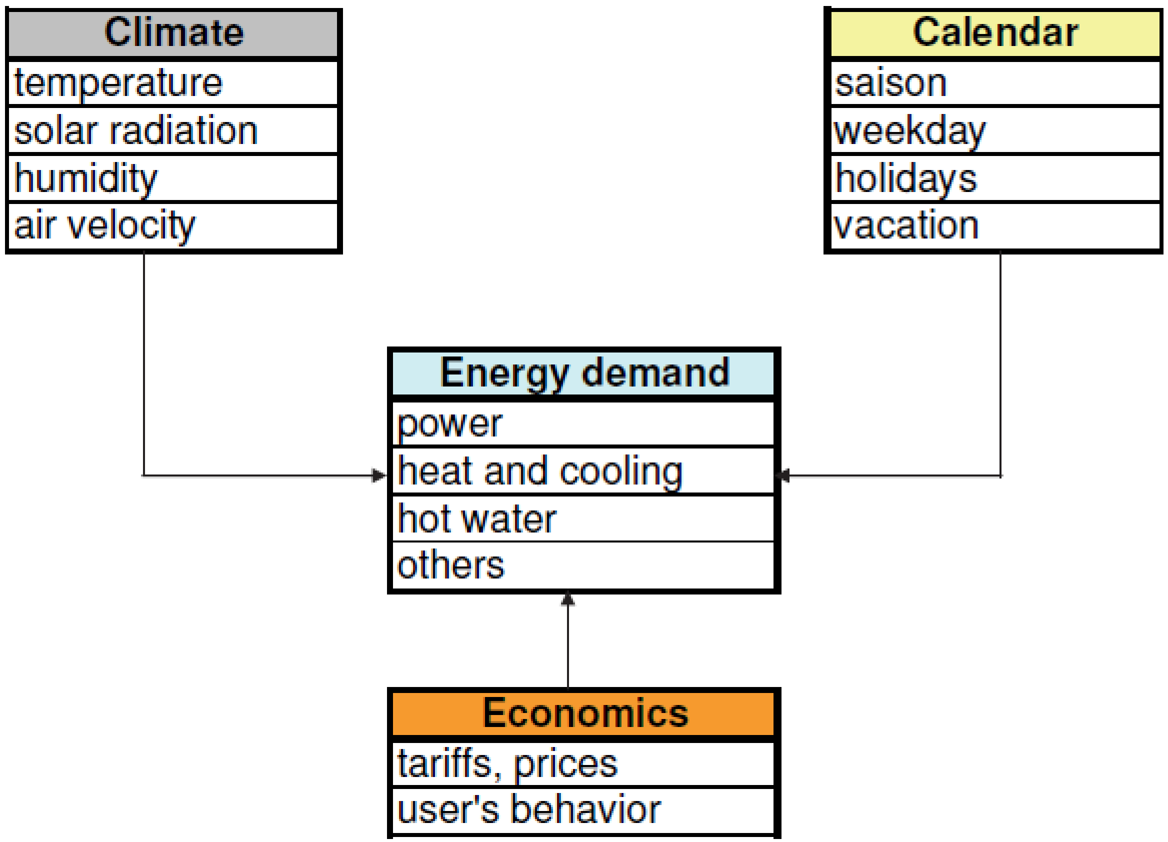
3. **Transparency is key**

   Forecasts, in particular, should very clearly state what is and is not included regarding assumptions about what will take place without any new initiatives.

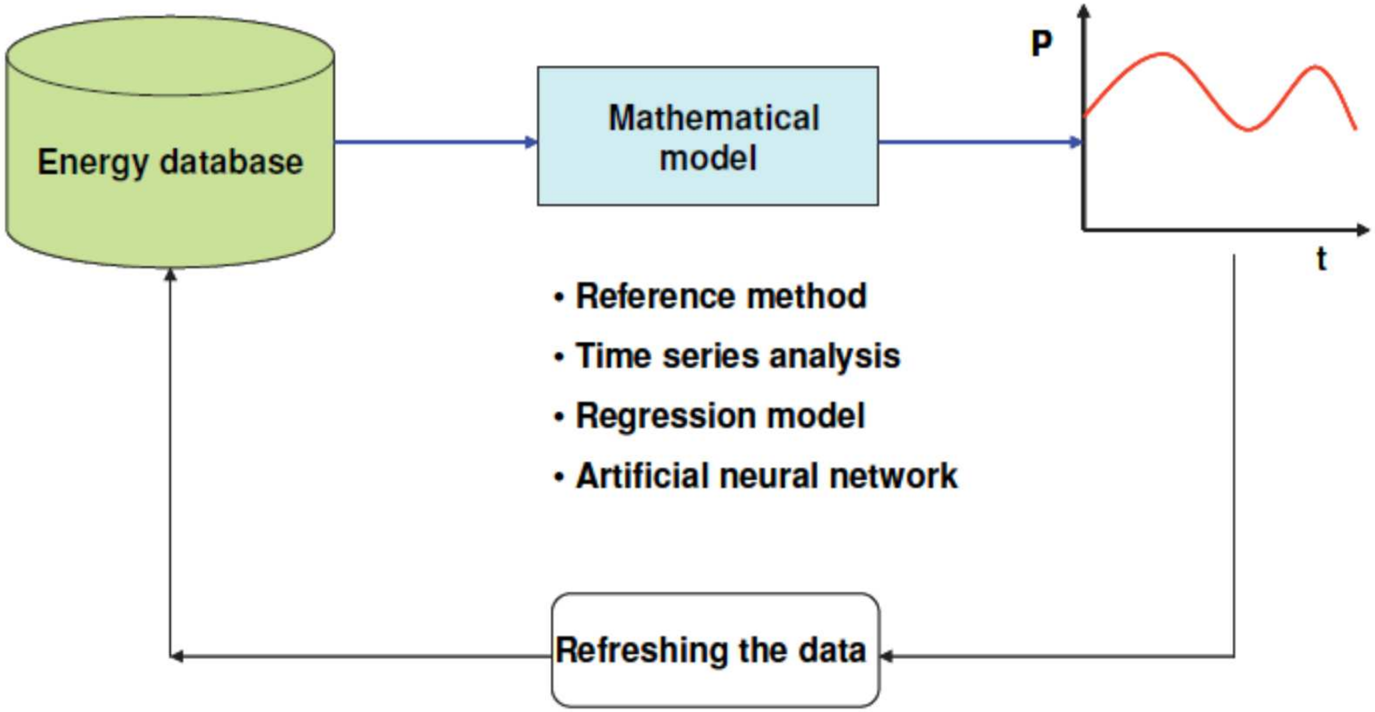
Energy system modelling



Schematic of energy demand forecasting



Process of energy demand forecasting



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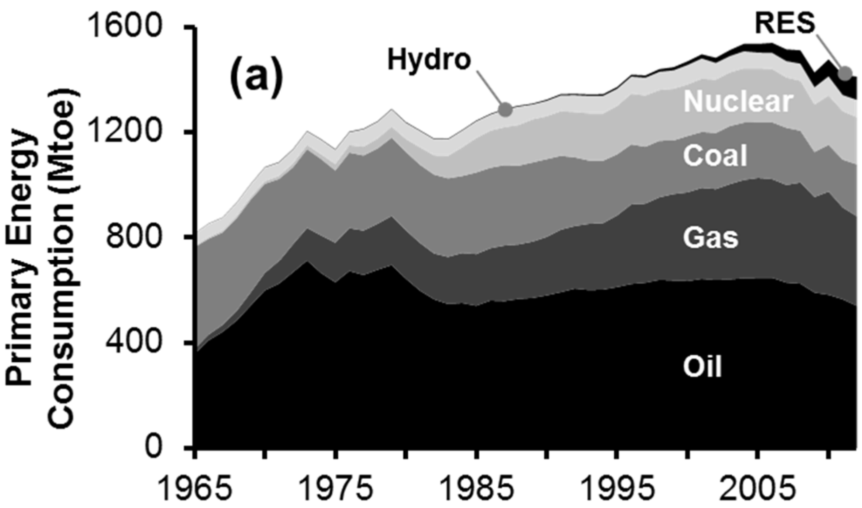
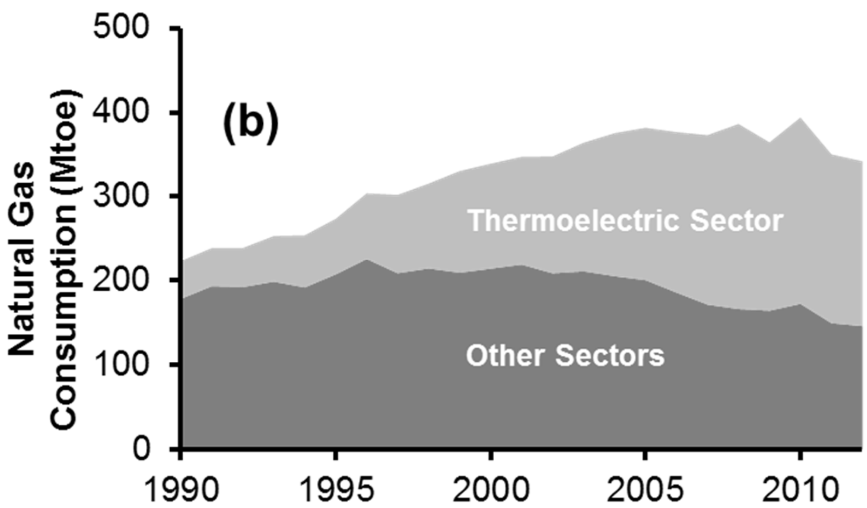
Descriptive Analysis





It is of fundamental importance to understand and interpret the past trend of energy demand, because it represents the basis for the future projections

Compound Annual Growth Rate

$$CAGR = \left(\frac{Q_x}{Q_y} \right)^{\frac{1}{x-y}} - 1$$

It gives the average increase or decrease of the consumption from year "y" up to year "x". It is a simple and very common indicator. It can be misleading because the years between x and y are completely neglected, therefore in periods of structural changes it provided incomplete information

Demand Elasticity

$$EC_I = \frac{\Delta EC_t / EC}{\Delta I_t / I_t}$$

Elasticity measures how much the demand would change if the determining variable changes by 1%. In any economic analysis three main variables are considered: GDP, price and average income

Energy Intensity

$$EI_t = \frac{EC_t}{I_t}$$

Energy intensity measures the energy requirement per unit of a driving economic variable. Energy intensity may refer to a particular source of energy or to various energy aggregates

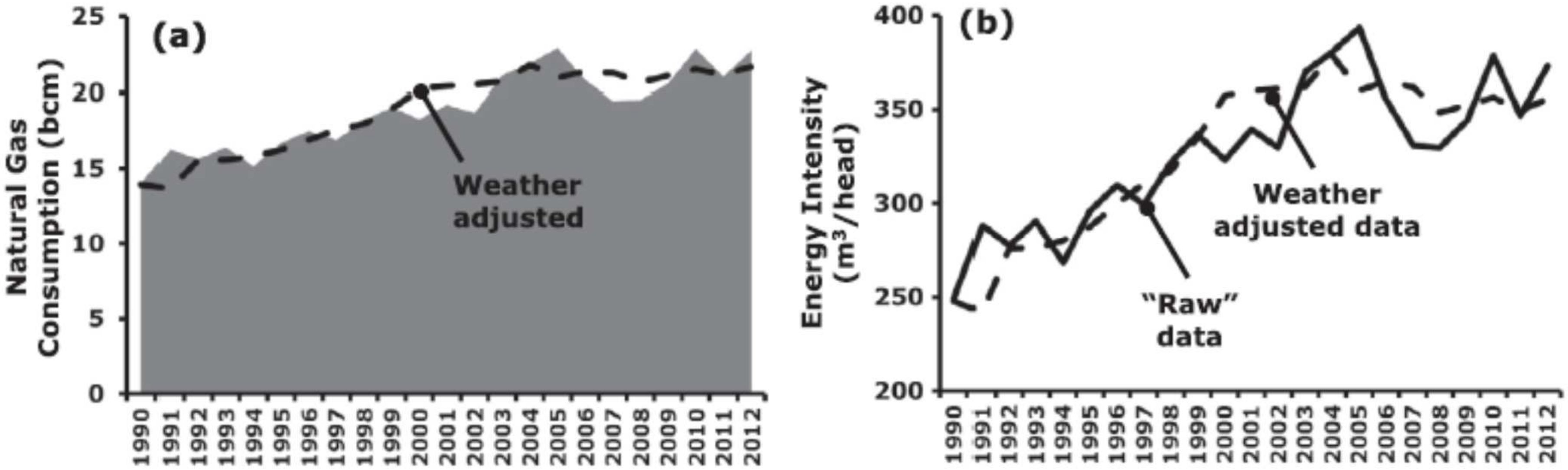
Energy Data "Weather Adjusting"

Some times energy consumption is strictly connected with weather conditions and this causes large fluctuations in the data. In order to "smooth" the data series a "weather adjusting" operation can be performed.

$$WAC_t = \frac{HDD_{avg}}{HDD_t}$$

For each year it is possible to determine a weather adjusting coefficient and by multiplying it by the energy consumption of that year it is possible to obtain weather adjusted data

Example of energy weather adjusted data



Weather adjusting operations are relevant when there is the necessity to evaluate the results of energy efficiency programs

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Very simple approaches

- **Stable time series data**
  - Forecast is the same as the last actual observation
  - $F(t) = A(t-1)$

- **Seasonal variations**
  - Forecast is the same as the last actual observation when we were in the same point in the cycle, where a cycle lasts n periods.
  - $F(t) = A(t-n)$

- **Data with trends**
  - There is constant trend, the change from (t-2) to (t-1) will be exactly as the change from (t-1) to (t)
  - $F(t) = A(t-1) + (A(t-1) - A(t-2))$

Very simple approaches

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Main discussion points

- **Check if the resulting accuracy is acceptable**

- **The higher the accuracy, often the higher the cost**

- **Do we really need our forecast that accurate? Is it worth the additional resources?**
  - **Why do you need forecasts for? How critical they are for operations?**

Random variations

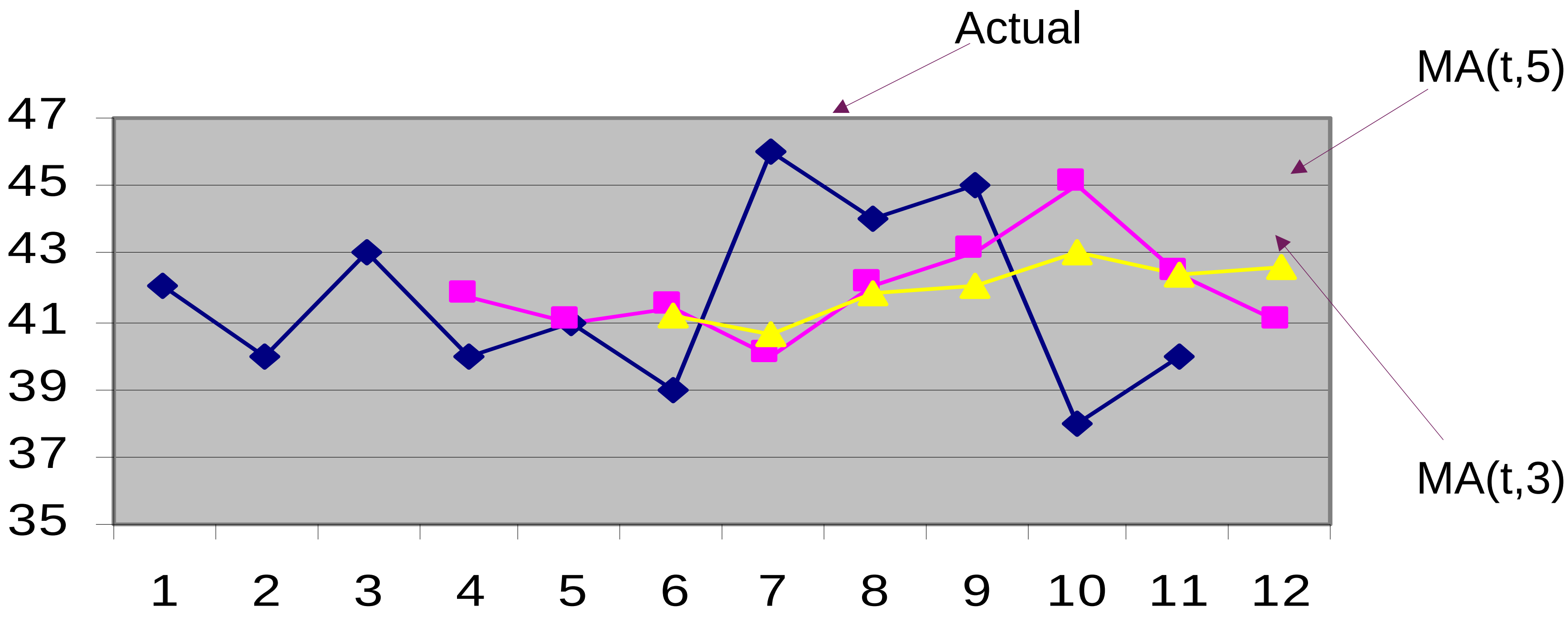
- Historical data contain random variations or noise
- Random variations are caused by relatively unimportant factors.
- What is random?
- The objective is to remove all randomness and have real variations.
- Minor variations are random and large ones are real.

Techniques for averaging

- Moving averages (MA)
  - Naïve methods just trace the actual data with a lag of one period, F(t)=A(t-1)
  - They don’t smooth
  - MA uses a number of the most recent actual data to smooth
- Weighted moving averages
- Exponential smoothing

Simple moving average

Averaging (over time) techniques are used to smooth variations in the data



$$F_t = MA_{t,n} = \frac{\sum_{i=t-n}^{t-1} A_i}{n},$$

$MA_{t,n}$: MA forecast made in period t - 1 using n actual observations

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Example: three period moving average

Month	Demand	
1	42	MA(6,3) = (43 + 40 + 41) / 3
2	40	= 41.33.
3	43	If A(6) = 39, then
4	40	MA(7,3) = (40 + 41 + 39) / 3
5	41	= 40.00
6	39	

Weighted moving average

Moving Average

- Advantage=Easy to compute and easy to understand
- Disadvantage=All values in the average are weighted equally

Weighted Moving Average

- Similar to moving average
- It assigns more weight to the most recent values in a time series
  - Idea: most recent observations must be better indicators of the future than older observations

Weighted moving average

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Weighted Moving Average

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Weighted moving average: calculations

Month	Demand
1	42
2	40
3	43
4	40
5	41
6	39

Compute a weighted average forecast using a weight of 0.4 for the most recent period, 0.3 for the next most recent, 0.2 for the next and 0.1 for the next.

Continuing with the data on the left

F(6) = .40(41)+.30(40)+.20(43)+.10(40)=41.0

If the actual demand for period 6 is 39,

F(7) = .40(39)+.30(41)+.20(40)+.10(43)=40.2

- The weighted average is more reflective of the most recent occurrences.

Exponential smoothing

Forecast error:=Actual – Forecast =A(t-1)-F(t-1)

$$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1})$$

Forecast today=Forecast yesterday+(alpha)*(Forecast error yesterday)

Each new forecast is equal to the previous forecast plus percentage of the previous error.

Today's forecast

- Depends on yesterday's (time-wise dependence, strong memory)
- But it has to be corrected by forecast error

Therefore, we should give more weight to the more recent time periods when forecasting.

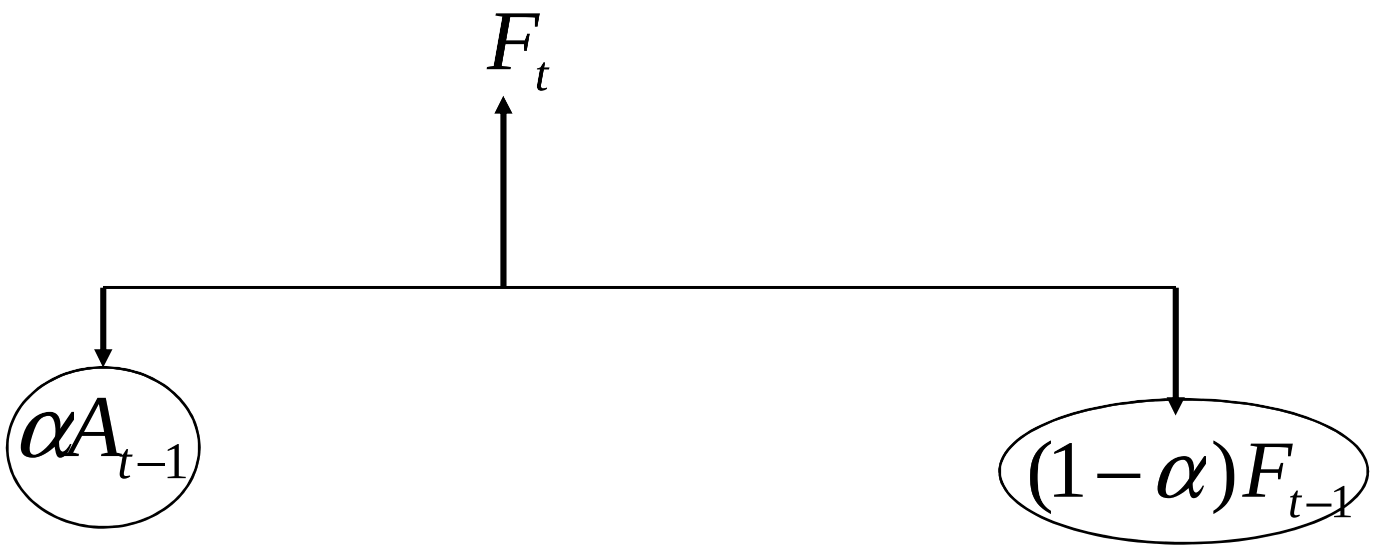
– Alpha = smoothing constant = percentage of the forecast error.

Exponential smoothing as a weighted average

$$F_t = \alpha A_{t-1} + (1-\alpha) F_{t-1}$$

Idea--The most recent observations might have the highest predictive value along with the most recent forecast errors.

Let us balance them:



Example of exponential smoothing

Period	Actual	Forecast wit	Error with	Forecast wit	Error with
1	42	Alpha=0.1	Alpha=0.1	Alpha=0.4	Alpha=0.4
2	40	42	-2.00	42	-2
3	43	41.8	1.20	41.2	1.8
4	40	41.92	-1.92	41.92	-1.92
5	41	41.73	-0.73	41.15	-0.15
6	39	41.66	-2.66	41.09	-2.09
7	46	41.39	4.61	40.25	5.75
8	44	41.85	2.15	42.55	1.45
9	45	42.07	2.93	43.13	1.87
10	38	42.36	-4.36	43.88	-5.88
11	40	41.92	-1.92	41.53	-1.53
12		41.73		40.92	

$$F_t = \alpha A_{t-1} + (1-\alpha) F_{t-1}$$

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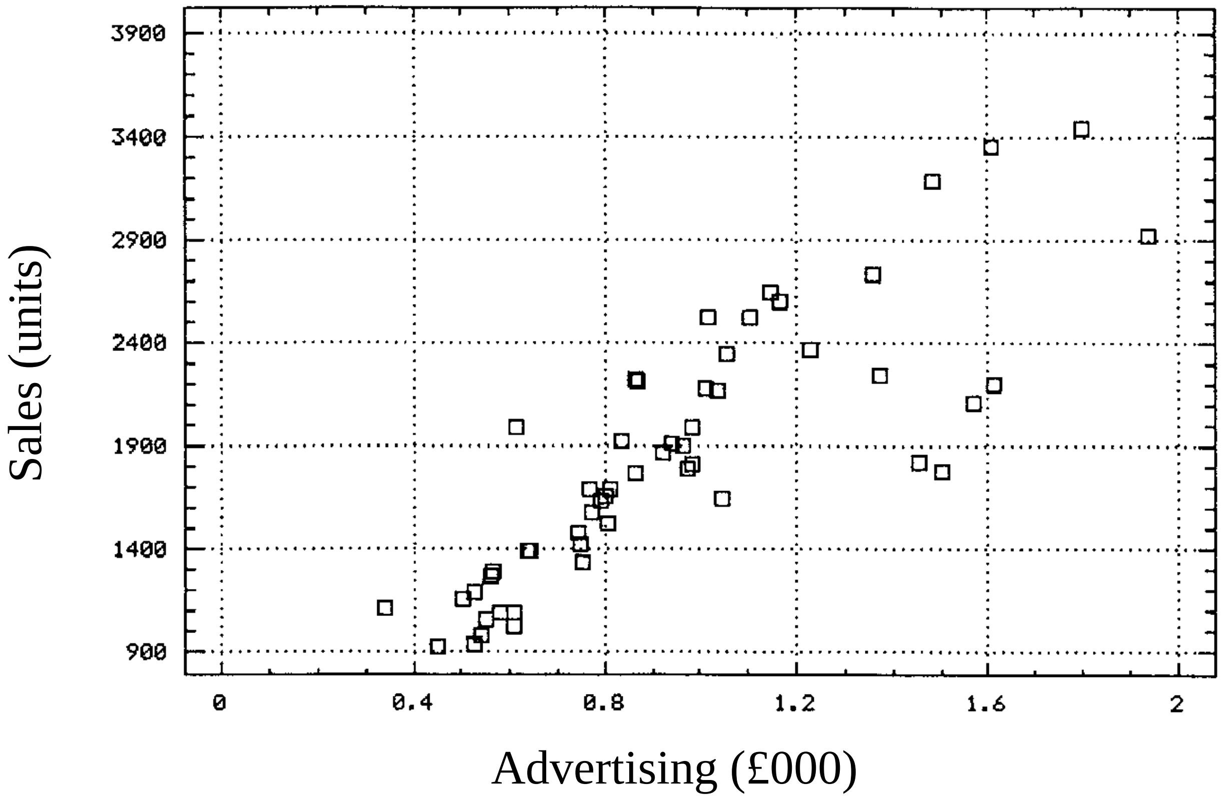
Regression overview

- Why understanding relationships is important
- Visual tools for analysing relationships
- Correlation
  - Interpretation
  - Pitfalls
- Regression
  - Building models
  - Interpreting and evaluating models
  - Assessing model validity
  - Data transformations
  - Use of dummy variables

Analysis of relationships



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Scatter Plots

- *What are they?*

  A graphical tool for examining the relationship between variables

- *What are they good for?*

  For determining
  - Whether variables are related
  - the direction of the relationship
  - the type of relationship
  - the strength of the relationship

Correlations

- *What is it?*

  A measure of the strength of linear relationships between variables

- *How to calculate?*

  a) Calculate standard deviations s_x, s_y

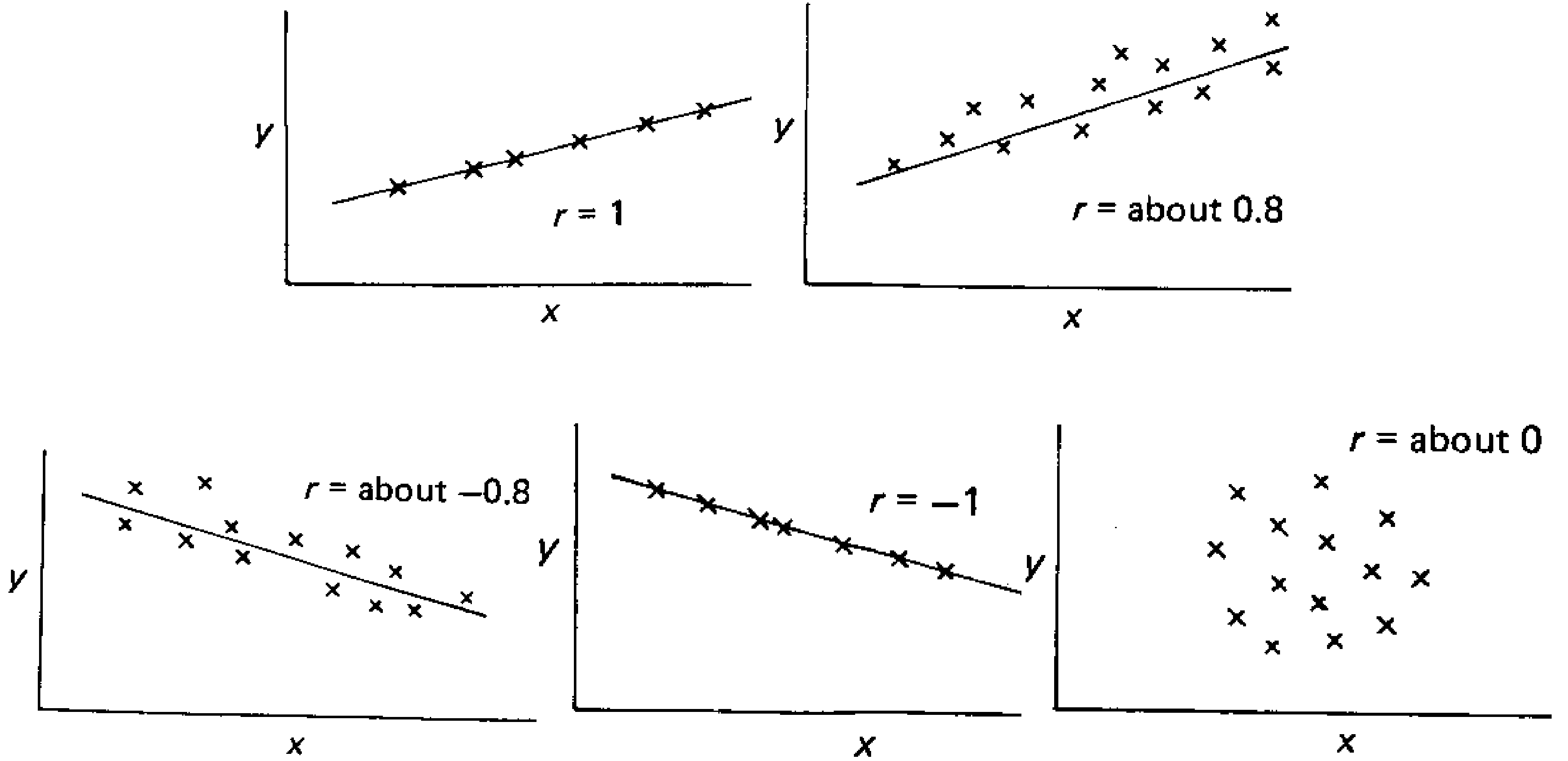
  b) Calculate the correlation using the formula

$$r_{xy} = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{(N-1)s_x s_y} \qquad s_x = \sqrt{\frac{1}{N-1}\left(x_i - \bar{x}\right)^2}$$

- Possible values

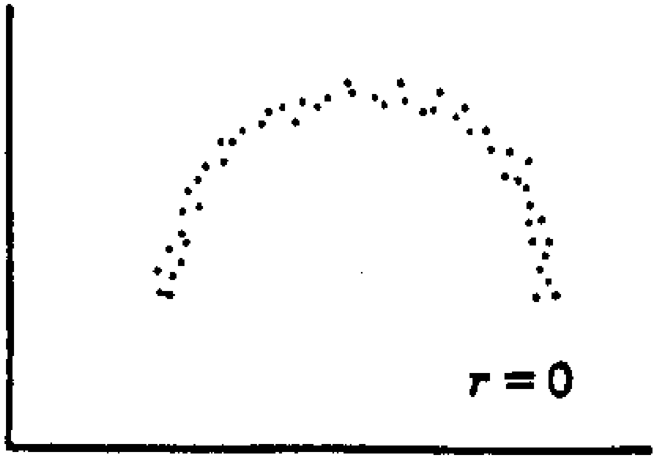
  From -1 to 1

Interpreting correlations



Correlation pitfalls

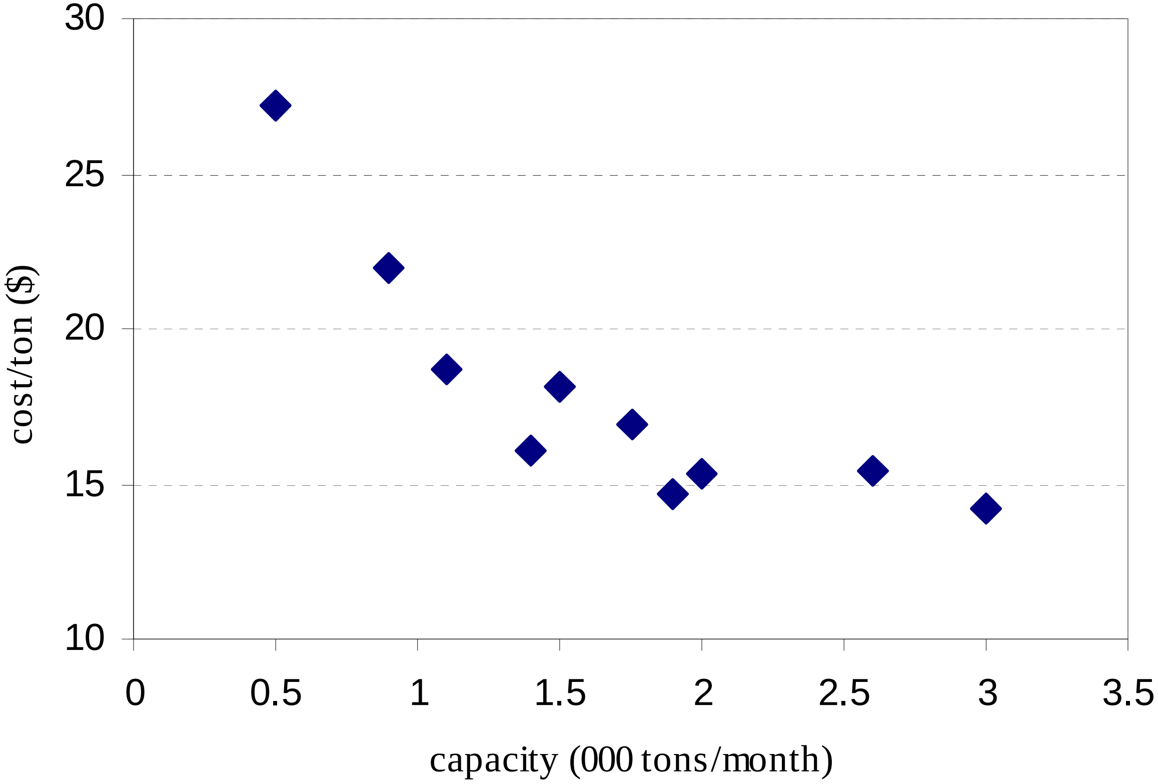
- Correlation measures only linear relationships



- Existence of a relationship does not imply causality

- Even if there exists a causal relationship, the direction may not be obvious

Visual inspection



Scatter plot of data to realize if a correlation among them may exist
Calculation of the correlation index

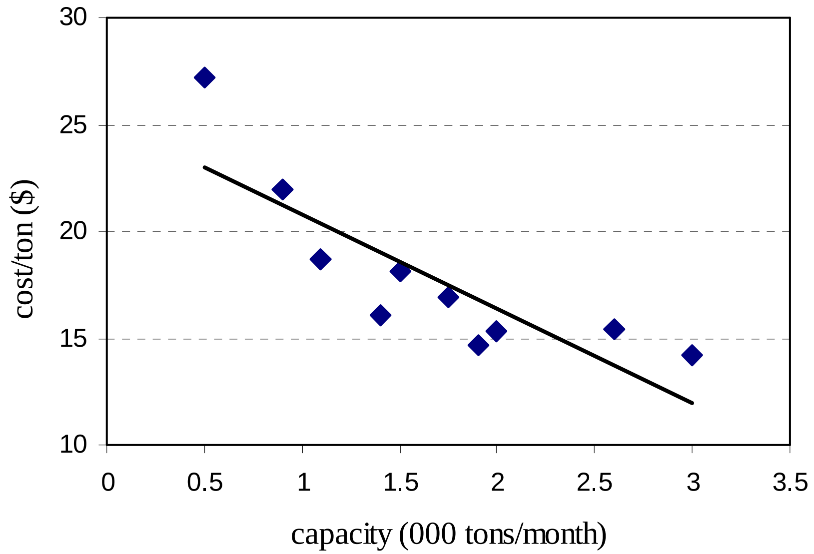
Simple linear regression

After analyzing the data a model of the following form can be determined:

$$Cost = a + b * Capacity$$

Simple regression estimates a linear equation which corresponds to straight line that passes through the data. Generally the OLS method is considered. It is based on the minimization of “least square” (i.e. the square of the distance between the approximating linear equation and original data)

Equation vs. real data



Regression model

$$Cost = 25.2 - 4.4\ Capacity$$

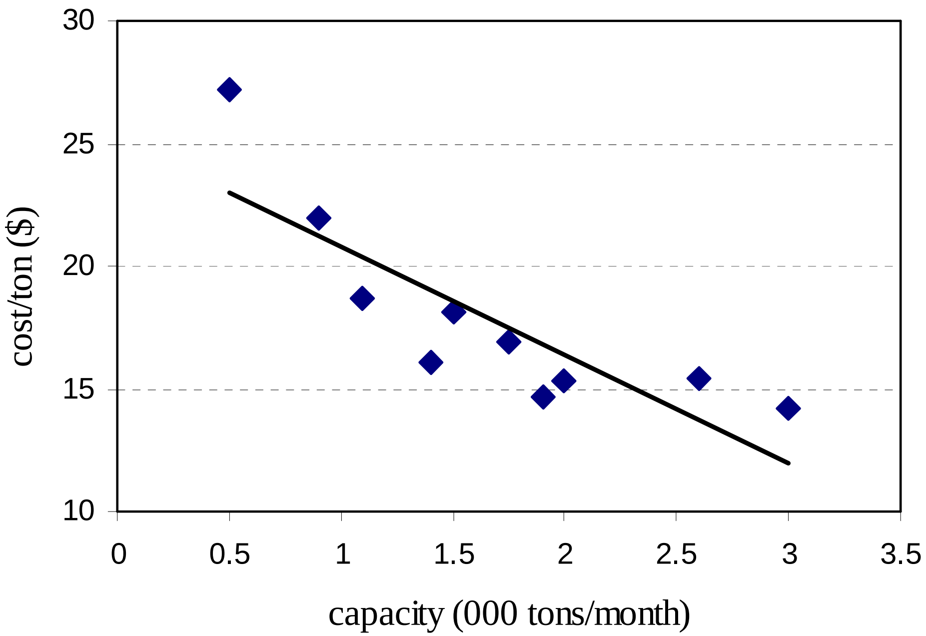
Dependent variable → *Cost*

Constant or intercept → *25.2*

Coefficient or slope → *4.4*

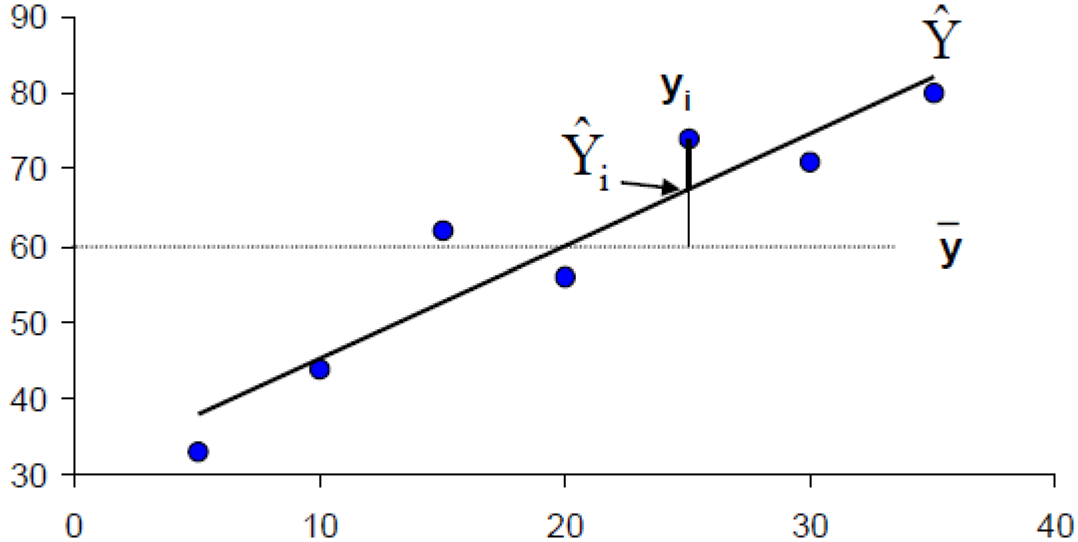
Independent or explanatory variable → *Capacity*

Residuals



- Residuals are the vertical distances of the points from the regression line
- In least squares regression
  - The sum of squared residuals is minimised
  - The mean of residuals is zero
  - residuals are assumed to be randomly distributed around the mean according to the normal distribution

R^2 indicator



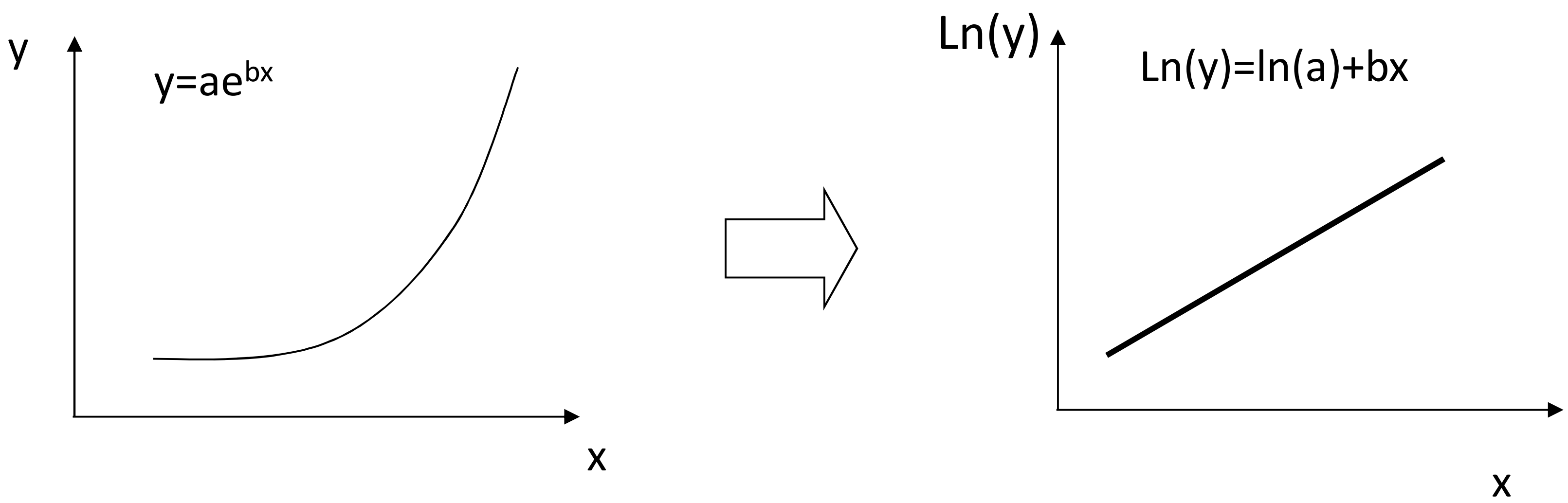
$$R^2 = \frac{\sum(\hat{y}_i - \bar{y})^2}{\sum(y_i - \bar{y})^2}$$

R2 has values between 0 and 1

R2 is an estimation of how well the regression approximates the real data.
It can be interpreted as the proportion of the variance of the dependent variable explained by the model

Transforming the data

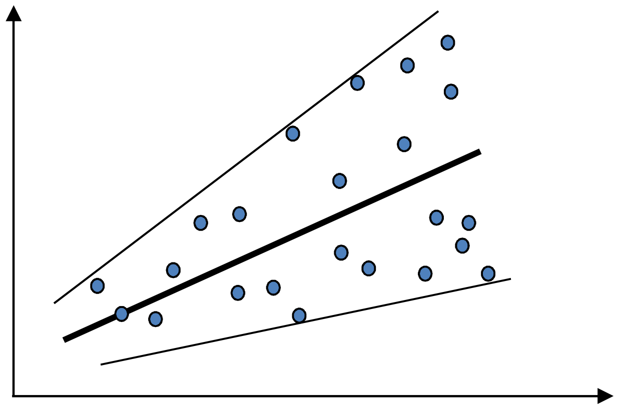
Linear regression can be applied only in the case of "linear correlation" among the data, but in some cases some suitable transformation can be done



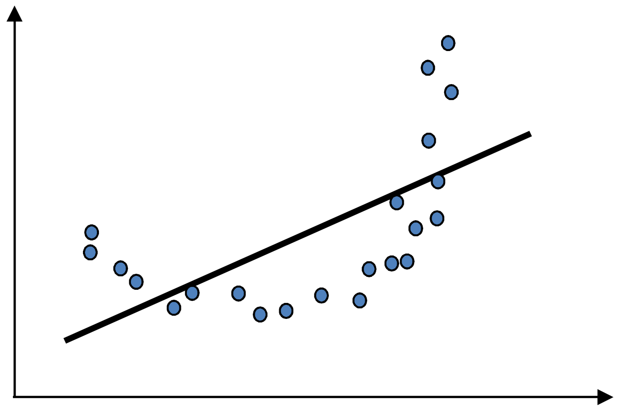
Checking residuals

Residuals should be random. Any systematic pattern indicates that our model is incomplete or not properly specified.

Heteroscedasticity



Autocorrelated residuals



Multicollinearity

Multicollinearity appears when explanatory variables are highly correlated.

Effects:

- Including Year adds little information, hence fit does not improve much
- Parameter estimates become unreliable

Remedial action:

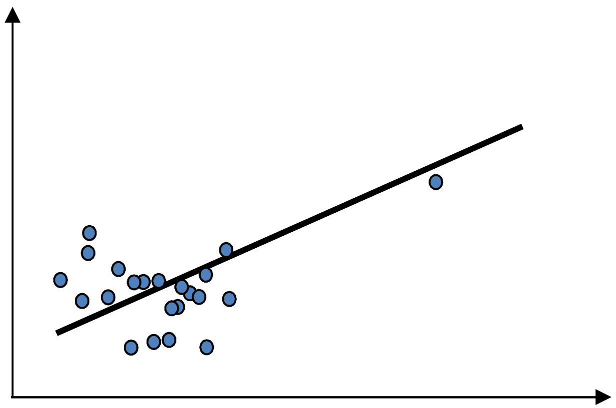
- Remove one of the correlated variables

Moral:

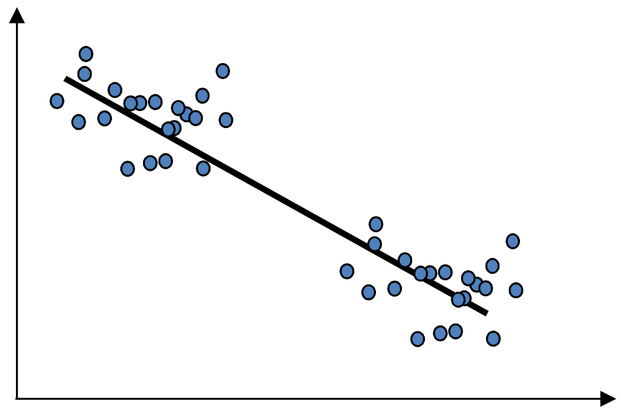
- Check for correlations between explanatory variables

Other inappropriate models

Influential observations and outliers



Clustering of data



Regression checklist

- Visually inspect the data (scatter plots)
- Calculate correlations
- Develop and fit sensible model(s)
- Assess and compare the model(s)
  - Significance of variables (t-values, p-values)
  - adjusted R^2
  - standard error (s)
  - residual plots
    - autocorrelation
    - heteroscedasticity
    - Normality
    - Outliers, influencial observations
  - Does the model make sense?
- If you are satisfied use the model for
  - developing business insights
  - forecasting

Scenario planning

"It is impossible to forecast the future and
it may be dangerous to do so"

Use of Scenario Planning

Develop a small number of internally consistent and credible views of how the world will look in the future, that present testing conditions for the business.

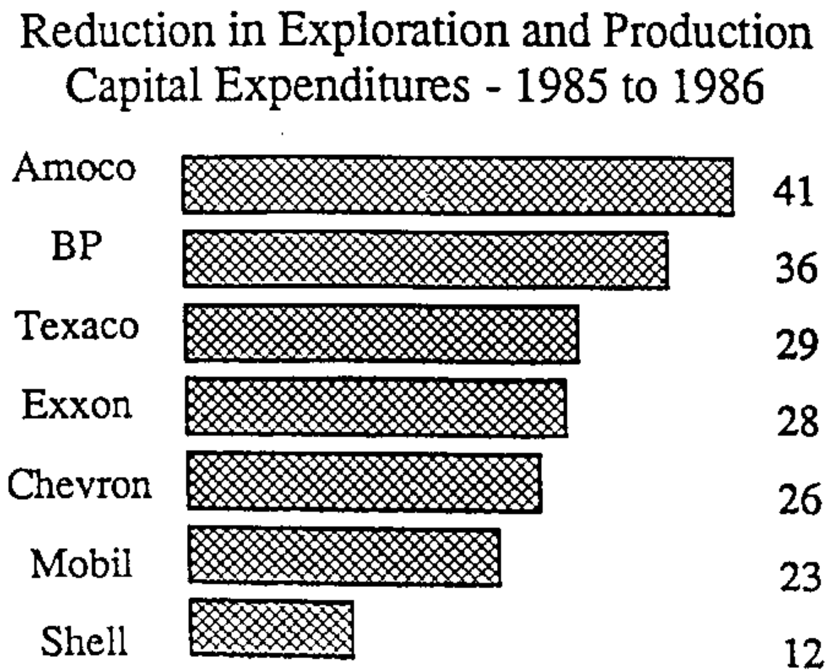
The future will of course be different from all of these views/scenarios, but if the company is prepared to cope with any of them, it will be able to cope with the real world.

The case of "Shell" 1/2

Scenario design	Oil shock scenario: Shell analyse the impact of a $15/bbl price on cash flows and investment plans	**Early 1985**
Strategic Plan	Re-evaluation of up-stream plans and cash-flow position of the operating companies	
Event	Oil price falls from $28/bbl to $10/bbl	**Early 1986**

The case of “Shell” 2/2

Result



Advantages of scenario planning

- Challenge preconceived ideas and single point forecasts
- Explore a wide range of uncertainties
- Encourage an active and creative attitude to the future
- Provide a background for specific project evaluation
- Provide a vehicle for communication between the different parts of the organisation

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University of Genoa

Department of Mechanical and Energy Engineering

Mathematical Model for Forecasting

Methodologies for Estimation of Energy Demand

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