ENERGY PLANNING : MODELLING AND DECISION SUPPORT

Chapter IV
Study case: Least cost planning of electricity generating system

-CONTENT-

4.5 How to choose the candidates for the expansion ?
- Type of fuels
- Size of the units
- Other considerations

4.6 How to determine the feasible plans ?
- Constraints of adequacy between the load and the supply
- Constraint on emission of CO_2 and pollutants

4.7 How to select the best plans ?
- Optimization
- Multiple criteria methods

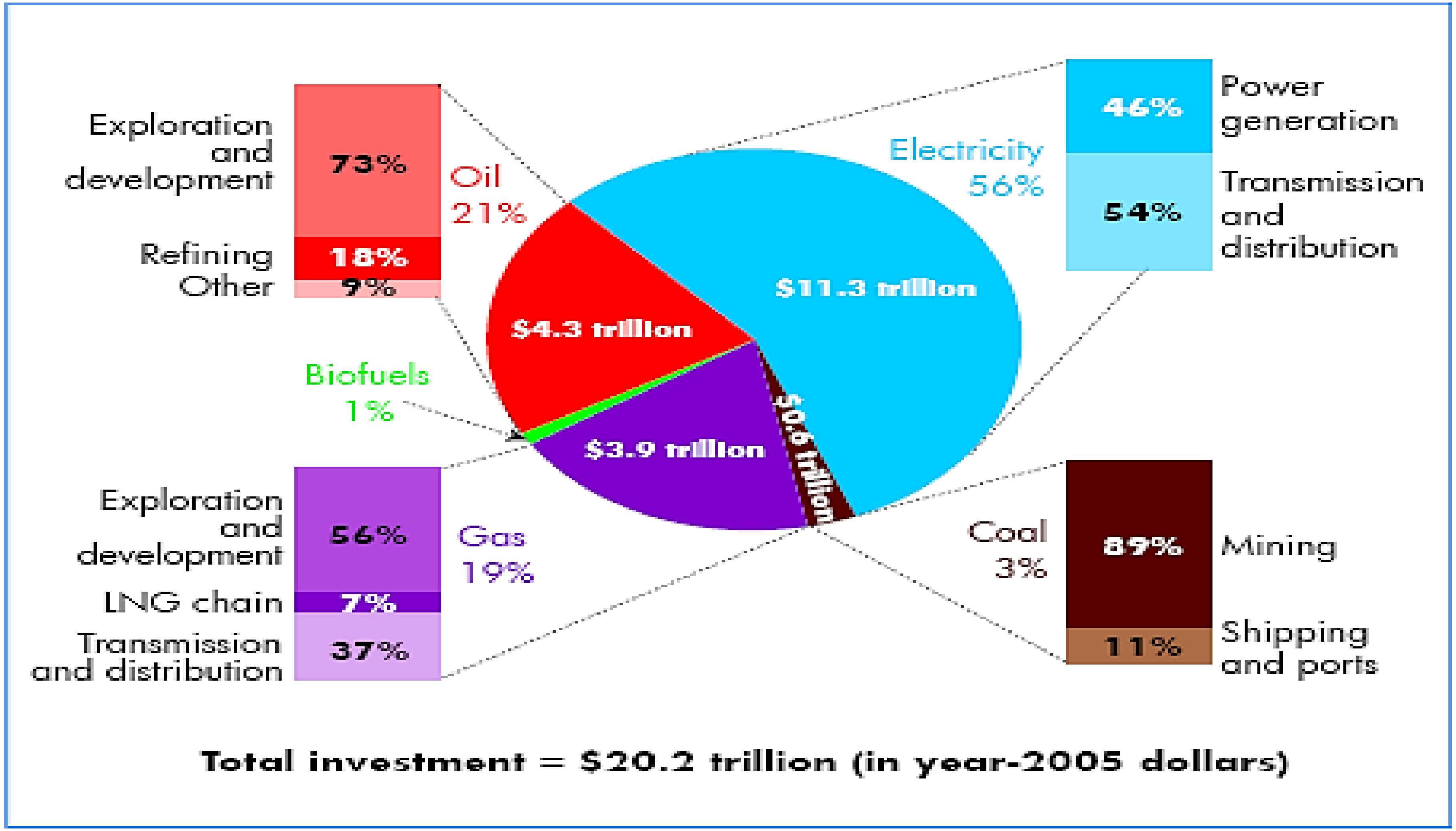
4.8 Planning with PlanElec-pro

4.9 Case study

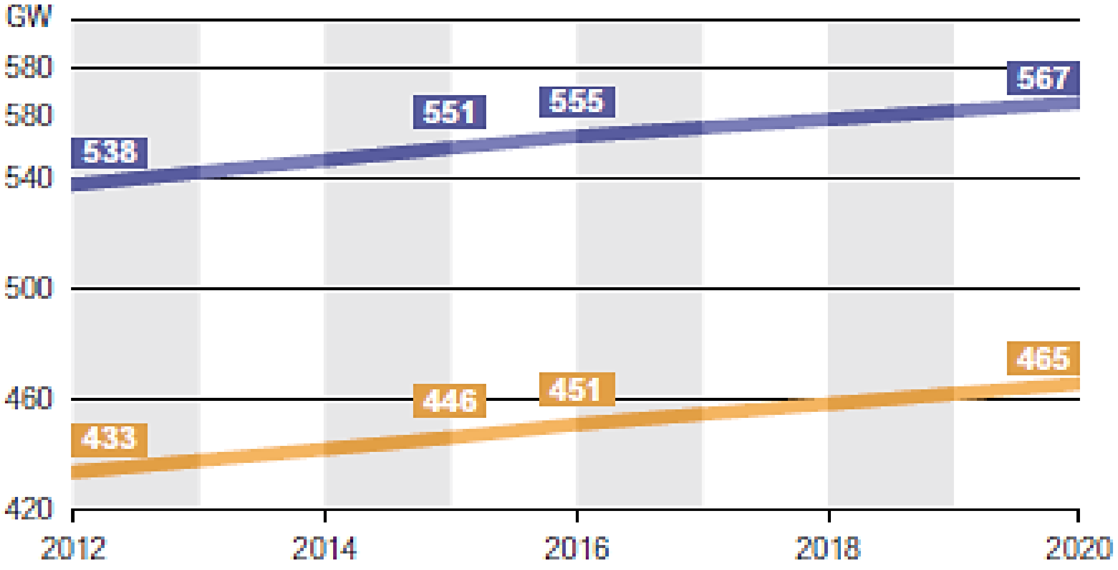
4.1 PLANNING OF THE ELECTRICAL GENERATING SYSTEMS: WHY?

Pros	Cons
• Development of Electr. Gener. Syst. is expensive • The life time of a gener. Plant is long : 15-80 years • Electr. Gener. Systems are one of the main responsible of emissions of pollutants and Green house Gases Monitor the development of the generating system in order to insure technical, economic and environmental efficiency	• The environment of the Electricity sector is changing from monopoly to a competitive market. No plan can be implemented due to market uncertainty • Many investors are involved in the development of the Electricity sector and the coordination of the investment is weak or does not exist at all Only market will give the good signal for optimal investment

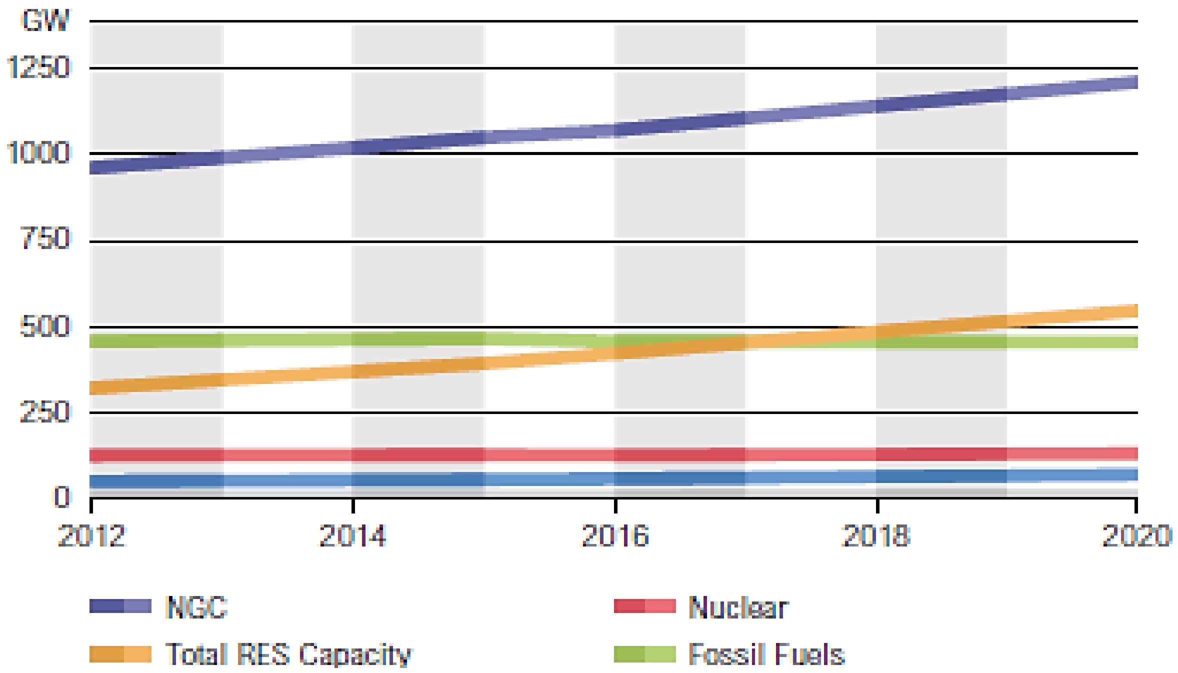
Cumulative Investment in Energy Infrastructure in the Reference Scenario by Fuel and Activity, 2005-2030 (in year-2005 dollars)



Indicative Planning of the Generating system in ENTO-E Countries (ENTO-E, 2012)



2012	2015	2016	2020
3,400 TWh	3,470 TWh	3,497 TWh	3,615 TWh



Between 2008 and 2020 the Electricity Demand will increase by 0.77% per year at ENTSO-E level according to the scenario EU 2020 (3 x 20%). The Net Generation Capacity of Renewable Power plant is asumed to cross and then overtake the one of fossil from 2017.

DISCUSSION ABOUT STRATEGIC PLANNING

Reference book: Henry Mintzberg. The fall and rise of the strategic planning. Free Press and Prentice International, 1994

In this book, H. Mintzberg addresses such issues such as:

1) What is the relationship between strategy and planning?
2) Is planning a future thinking?
3) What is the justification of planning?
4) What are the main hierarchies in strategic planning?
5) What are the main activities in planning?

Reference book: Henry Mintzberg. The fall and rise of the strategic planning. Free Press and Prentice International, 1994

According to H. Mintzberg:

- Planning is a formalized procedure to produce and articulate results in the form of integrated system of decision

- Strategy formation is the result of dialogue with stakeholders with feedback loops that seek to adapt a system to changes of its environments

Main lessons from Mintzberg’s book:

The formalized way planning that is undertaken should not induce the idea of the unicity of its results

Plan is not strategy

Strategic planning is an analysis

Strategic thinking is a process to seek for paths to achieve objectives; its results are in form of a consistent synthesis

Planning can be used as a tool in a strategy formation

Example of strategy: Swiss Energy Strategy 2050

After the Fukushima nuclear accident, the Swiss Federal Council has launched an «Energy Strategy 2050»

- The background of the strategy is to withdraw from nuclear electricity generation by 2034 while continuing to assure the security of electricity supply of the country
- Different consulting offices have fed strategic groups with results of planning results
- Incentives have been enacted by the federal Council and local governments towards the objectives

From strategy to Politics and Policy

- In 2011, the Swiss federal Council and the Parliament decided in favour of the Strategy 2050.
- How the political equilibrium of the Parliament changed after the Federal election of 2015?
- What was the consequence with regard to the Energy Strategy 2050?
- Explain the Politics framework of the enactment of the energy strategy 2050.
- How the final policy has been impacted by the political dimension?
- Is it positive or negative?

Questions

1) What could be in the present context of Energy in Europe the relevance of Energy planning? (Group 1)

2) What are the potential roles of modeling in Energy planning? Main issues with regard to modeling ? (Group 3)

3) Is simulation different from optimization? Please give few examples. How the results of simulations or optimizations should be interpreted with regard to decision making? What may mean «optimal energy strategy»? (Group 2)

4.2 LEAST COST PLANNING: MINIMIZING THE COSTS

Find the best expansion plan k of the Generating system that minimizes the objective function subject to a set of constraints

$$Min_k\ Obj = \sum_j \sum_t (1+a)^{-t}\left(Ik_{j,t} + Ok_{j,t} + CENSk_t - SALVk_{j,t}\right)$$

a: discount rate

$Ik_{j,t}$: Investment cost of plant j that enters in the system in year t in the plan k

$Ok_{j,t}$: Operating costs (fixed and variables) of the plant j that is in the system at time t

$CENSk_t$: Cost of the energy not served due to load shedding at time t

$SALVk_{j,t}$: Salvage value of the plant j that enters in the system at time t

CONSTRAINTS

$$G\,(k_t) \geq L_t \;\forall\, k, t$$
$$Q\,(k_t\,, L_t) \geq S_t \;\forall\, k, t$$

$G\,(k_{,t})$: Power generated by the system k at time t

L_t: System load at time t

$Q\,(k_t\,, L_t)$: Adequacy level between load and supply at time t for the system k

S_t: Required Adequacy at time t

Constraints on emissions (CO_2, SO_x, NO_x)

APPROACH

- Step 1: Forecasting of the Electrical Demand
- Step 2: Determine the fixed system
- Step 3: Choose the candidates for the expansion of the system and precise their characteristics
- Step 4: Define the feasable plans
- Step 5: Select the best plans

Questions

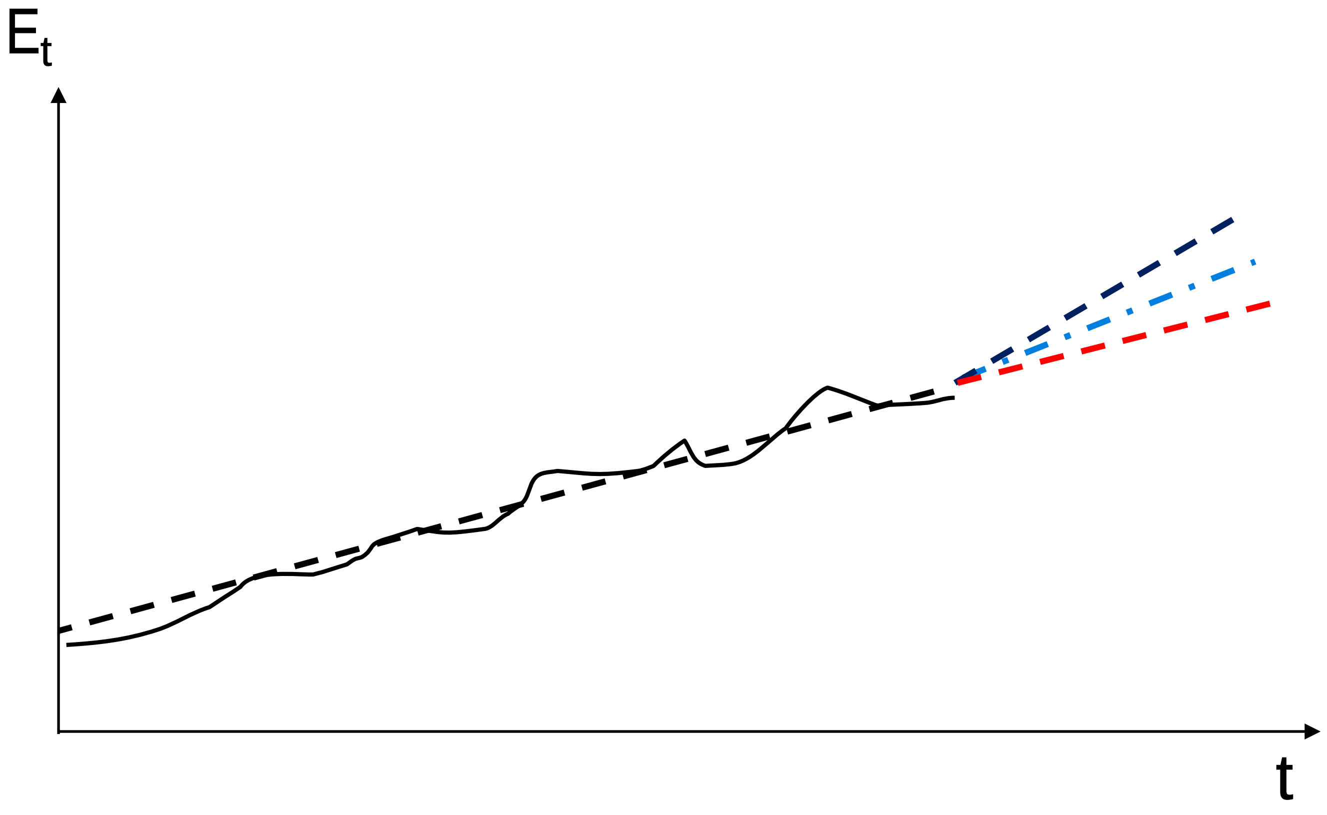
1) What are the main strengths of the least cost planning of the electrical generating System? (Group 3)

2) What are the main weaknesses of the least cost planning of the electrical generating System? (Group 2)

3) What are the main uncertainties that should be considered when least cost planning? How the results of least cost planning should be interpreted? (Goup 1)

4.3 HOW TO FORECAST THE ELECTRICITY DEMAND ?

FORECAST OF THE TREND



- Simple extrapolation methods: curve fitting
- Econometric methods: $E_t = f(x1_t, x2_t, \ldots, xn_t)$

  Identification, estimation, validation, forecasting
- End use simulation: bottom-up based on technology choice and uses

  Formulation, calibration, forecasting

Example: Final consumption of Electricity demand in Switzerland

Model 1

$$E(t-t_0) = E_0 * (1+a)^{(t-t_0)}$$

Exponential trend

Variable: t

Parameters: E_0 and a

Periods

	1980-2003	1980-84	1985-89	1990-94	1995-99	2000-03	1995-2003
E_0(GWh)	36'430,5	34'100,8	40'397,4	47'141,3	46'978,3	51'716,6	46'591,1
a (%/an)	1,79	2,88	2,41	0,06	1,55	1,60	1,90

FORECASTING OF TRENDS

Method of simple extrapolation

Example: Exponential regression

$$E(t-t_0) = E_0 * (1+a)^{(t-t_0)}$$

$$Ln(E(t-t_0)) = Ln(E_0) + (t-t_0) * Ln(1+a)$$

$$y(t-t_0) = b + m * (t-t_0)$$

$$\text{Linear Regr. (two parameters: b and m)}$$

FORECASTING OF TRENDS

Econometric methods

Example: Final consumption of electricity in Switzerland

Model 2

$$W(t-t_0) = E(t-t_0)/H(t-t_0)$$

$$Z(t-t_0) = Y(t-t_0)/H(t-t_0)$$

$$W(t-t_0) = c * Z(t-t_0)^a$$

$$H(t-t_0) = H_0 * (1+g)^{(t-t_0)}$$

$$Y(t-t_0) = Y_0 * (1+h)^{(t-t_0)}$$

$$E(t-t_0) = W(t-t_0) * H(t-t_0)$$

E: Electricity consumption
H: Population
W: Electricity consumption per capita and per year
W_0, H_0, Y_0, a, c, g, h: parameters of the model
a: elasticity of the electricity consumption per capita relative to the GDP per capita

FORECASTING OF TRENDS

Econometric methods

Example: Constant elasticity models

$$W(t-t_0) = c * Z(t-t_0)^a$$

$$Ln(W) = Ln(c) + a * Ln(Z)$$

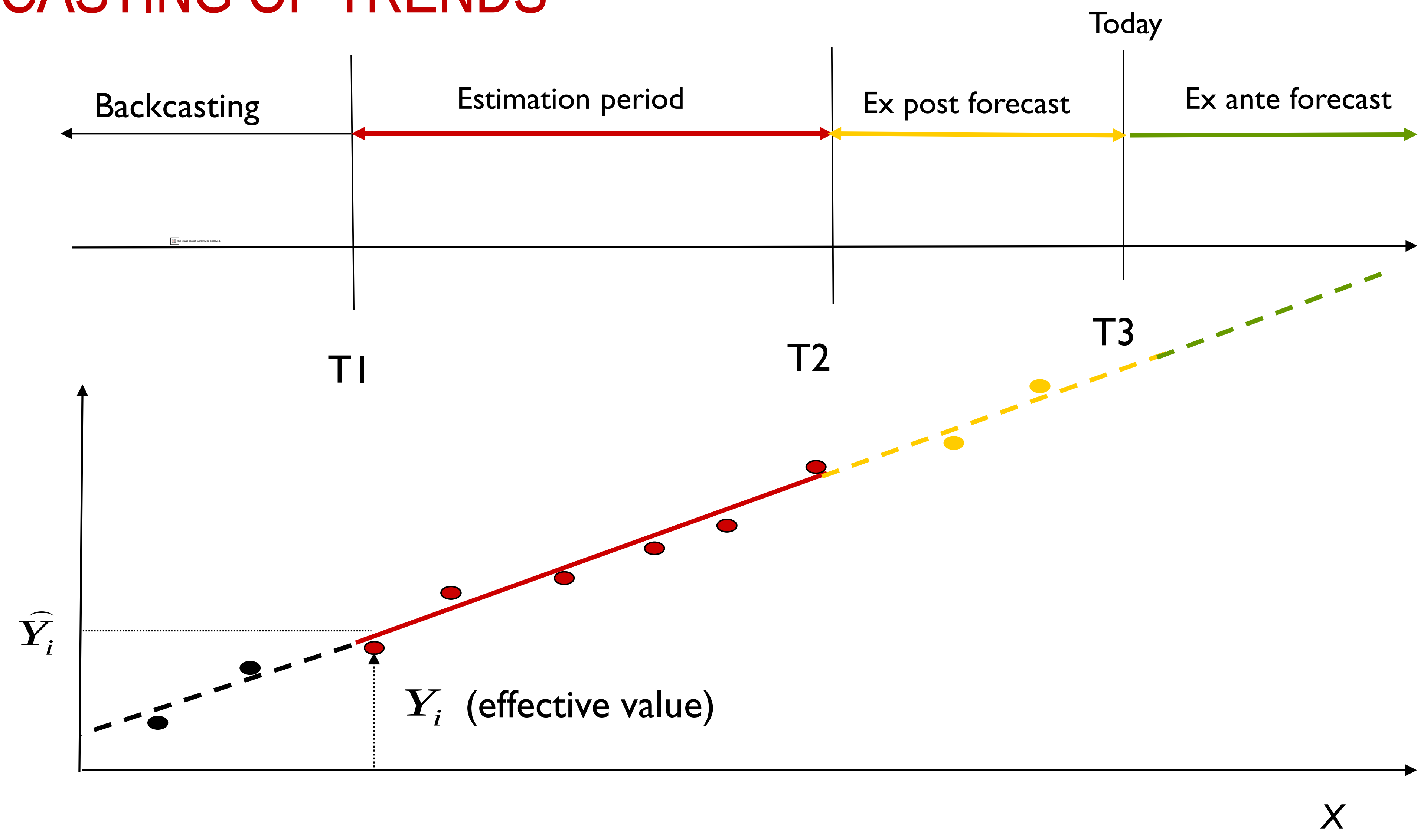
$$dW / W = a * dZ / Z$$

$$a = dW / W * (dZ / Z)^{-1}$$

a: elasticity of the electricity consumption per capita relative to the GDP per capita

Relative variation of the consumption per capita with respect to a unitary relative variation of the GDP per capita

FORECASTING OF TRENDS



VALIDATION

$$RMS\ SE = \sqrt{\frac{1}{T}\sum_{1}^{T}(E_t^s - E_t^a)^2}$$

RMS SE : Root mean square simulation error
T : Number of years in the estimation period
E_t^s :Forecasted Electricity consumption
E_t^a : Observed Electricity consumption

FORECASTING OF TRENDS

Econometric methods

Main Steps

- Problem formulation

  - Identification of the explanation variables

  - Identification of the relation between the explanation variables and the electricity consumption

- Formalisation

  Mathematical formalisation of the relation

- Estimation of the parameters (e.g. using Ordinary Mean-Square Method)

- Validation of the parameters (e.g. using student test and scientific knowledges)

- Validation of the quality of the model

- Estimation of the quality of forecasting with the model

FORECASTING OF TRENDS

Techno-economic models

Econometric models allow forecasting stable trends i.e. no structural change in the electrcitiy demand environment

→ Botton-up models are more suited to model structural changes

→ Technoeconomic models estabish direct relations between the electrcal appliances and electrcitiy consumption

→ The relations depend on the number of appliances, the average power per appliance and the average utilization time per year per appliance

FORECASTING OF TRENDS

Techno-economic models

Example of the residential sector

For a given appliance i, the electricity consumption is the following three factors: the number of households using that kind of appliance Mi, the average number of appliance per household that utilize the appliance Ni, the average electricity consumption per appliance per year vi.

Model 3

$$E_t = \sum_i M_{it} * N_{it} * v_{it}$$

FORECASTING OF TRENDS

Techno-economic models

Example of the residential sector

For a given appliance, let ri be the proportion of households using the appliance and Vi the average consumption of the appliance i per household then the following simplier formula:

$$E_t = M_t * \sum_i r_{it} * V_{it}$$

where:

$$V_{it} = N_{it} * v_{it}$$

FORECASTING OF TRENDS

Techno-economic models

Example of the residential sector

Finally the electricity consumption of households is the product of the average consumption of electricity per household c and the total number of households M:

$$\boxed{E_t = M_t * c_t}$$

where :

$$\boxed{c_t = \sum_i r_{it} * V_{it}}$$

FORECASTING OF TRENDS

Techno-economic models

Example of the residential sector: illustration

Year: 2010; Population: 6.5 Million; Average number of pers. per household:4; E= 6355 GWh

Device	Utilization rate	Anerage Cons. kWh/an	Consumption kWh/an
Fridge	1	450	450
Lighting	1	500	500
TV, Vidéo, Hi-Fi	1	250	250
Electrical cooker	0.95	450	427.5
Electrical humidifier	0.6	200	120
Dishwasher	1	400	400
Clotheswasher	0.8	300	240
Clothes dryer	0.75	350	262.5
Boiler	0.27	3000	810
Circulating pumps	0.75	400	300
Auxilliary electrical heating	0.755	200	151

FORECASTING OF TRENDS

Techno-economic model

Main Steps of the development and Illustration

Formulation of the problem:
Identification of the explanation variables

→

Formalisation:
Establish a computable model between the variable to be forecasted and the explanation variables

→

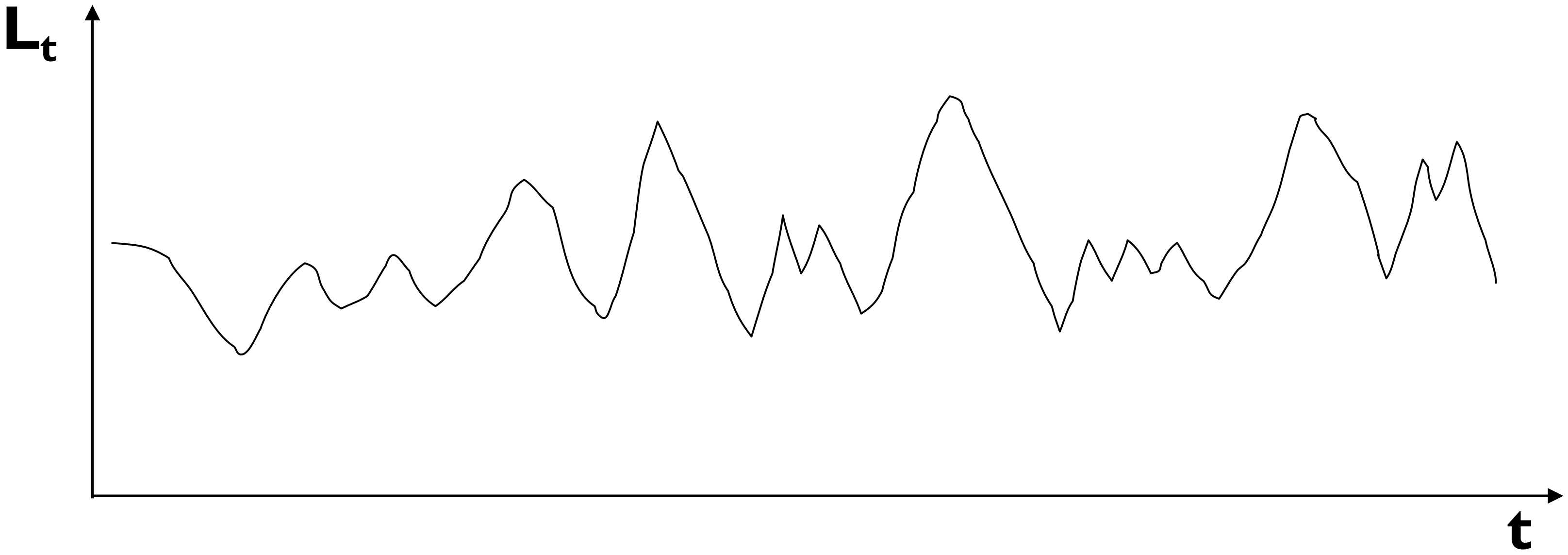
Calibration of the model for a given year

DISCUSSION ABOUT LONG TERM ELECTRICITY DEMAND FORECASTING

Questions

1) In which cases the simple extrapolation methods of forecast are more relevant?
2) In which cases the econometric models are more relevant?
3) What are the main advantages and drawbacks of techno-economic models?
4) How uncertainties can be taken into account in the different types of models?

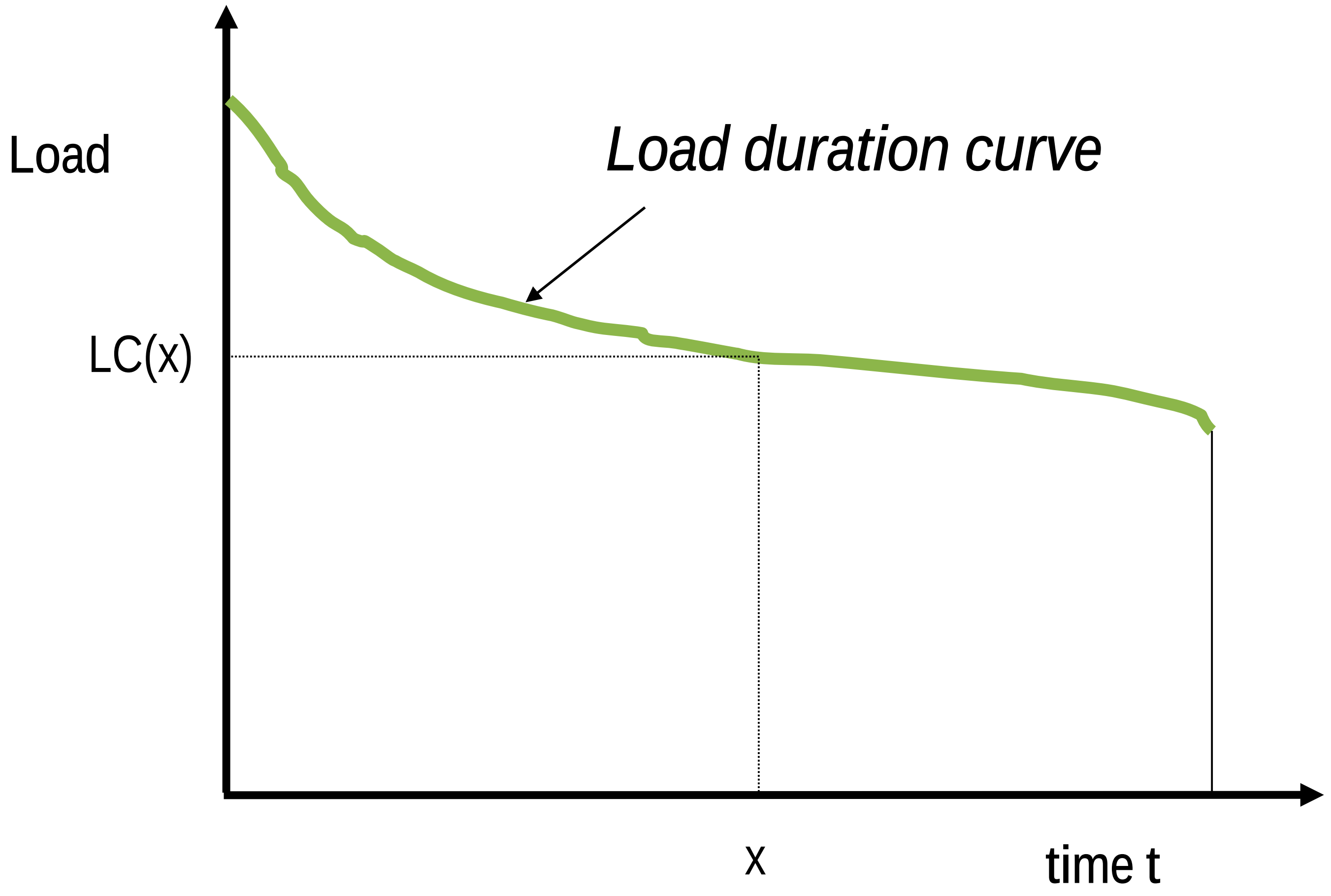
Forecast of the fluctuations



- Seasonal fluctuations
- Day-type profile
- Hour-type profile

Hourly load curve

Condense representation of the load curve



x: Number of hours the load is higher than LC(x)

4.4 HOW TO DETERMINE THE FIXED SYSTEM ?

$$[F_t] = [F_{t-1}] + [A_t] - [R_t]$$

$[F_t]$: vector of committed units up to year t

$[A_t]$: vector of committed addition of units in year t

$[R_t]$: vector of committed retirement of units in year t

$[F_t]_{\,t = 1..\,T}$: Fixed system

4.5 HOW TO DETERMINE THE CANDIDATES FOR THE EXPANSION?

$$[k_t] = [F_t] + [U_{k,m}]_{m=1..t}$$

$[k_t]$: vector containing the number of all generating units that a in the system in year t for a given plan k

$[F_t]$: fixed system in year t

$[U_{k,t}]$: vector of candidates added to the system in year t, according to the expansion plan k: $[U_{k,t}] \geq [0]$

CRITERIA FOR SELECTING THE CANDIDATES FOR THE EXPANSION

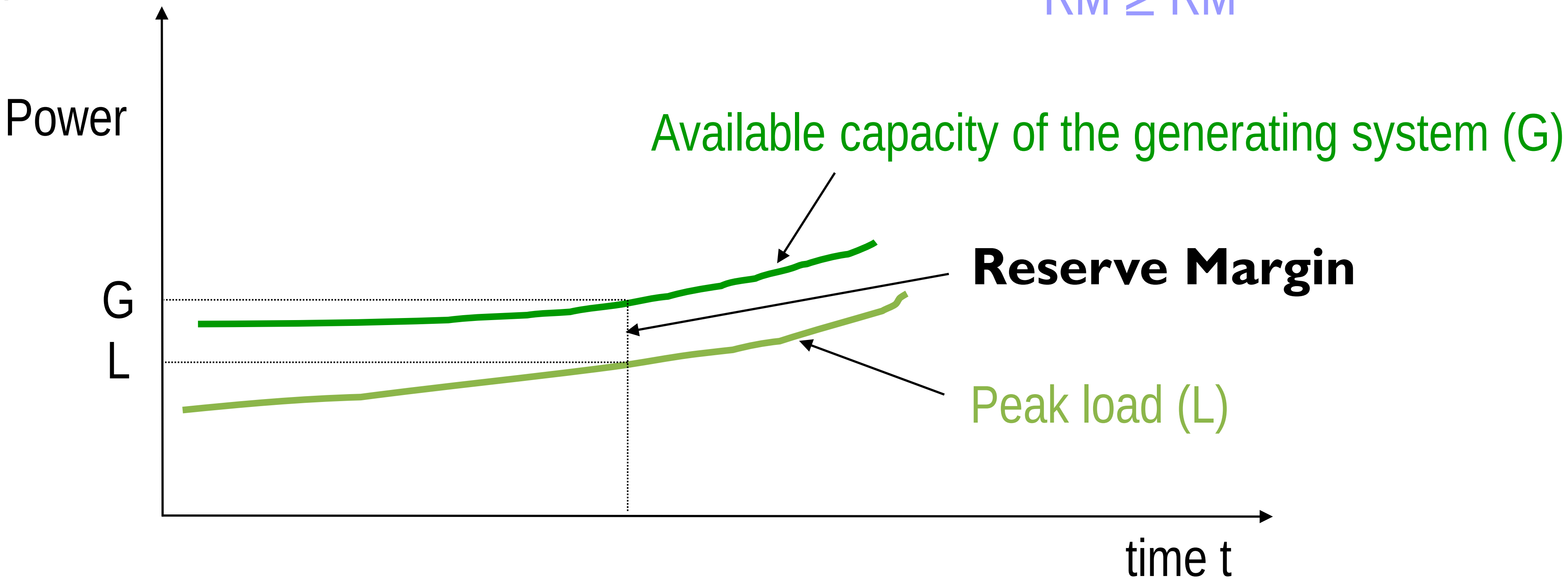
- Renewability, types of fuel and diversity
- Units'sizes in relation with the peak load of demand
- Balance between base load, intermediate load and peaking units
- Economic considerations
- Environmental aspects
- Strategic issues

4.6 HOW TO DETERMINE FEASIBLE CONFIGURATIONS ? ADEQUACY CRITERIA

Deterministic criteria

Reserve Margin (RM)

RM ≥ RM



$$\boxed{RM = (G-L) / L}$$

FEASABLE CONFIGURATIONS: ADEQUACY CRITERIA

Probabilistic criterion

The probability of deficit must be lower than a critical value:

$$Pr\ (L > (Ginst - Go)) \leq LOLP$$

Pr: Probalility

L : System load (demand) [MWe]

Ginst: System installed capacity [MWe]

Go: Capacity out of operating because of outage [MWe]

LOLP: Loss of the load probability

FEASABLE CONFIGURATIONS: DYNAMICS OF THE EVOLUTION

$$[k_t] = [k_{t-1}] + [U_{k,t}]$$

$$[U_{k,t}] \leq [U_{k,t}] \geq [U_{k,t}]$$

$$t = 1 .. T$$

FEASABLE CONFIGURATIONS: EMISSION OF PRODUCT J

$$Em\ i[k_t] \leq \overline{Em\ i}_t$$

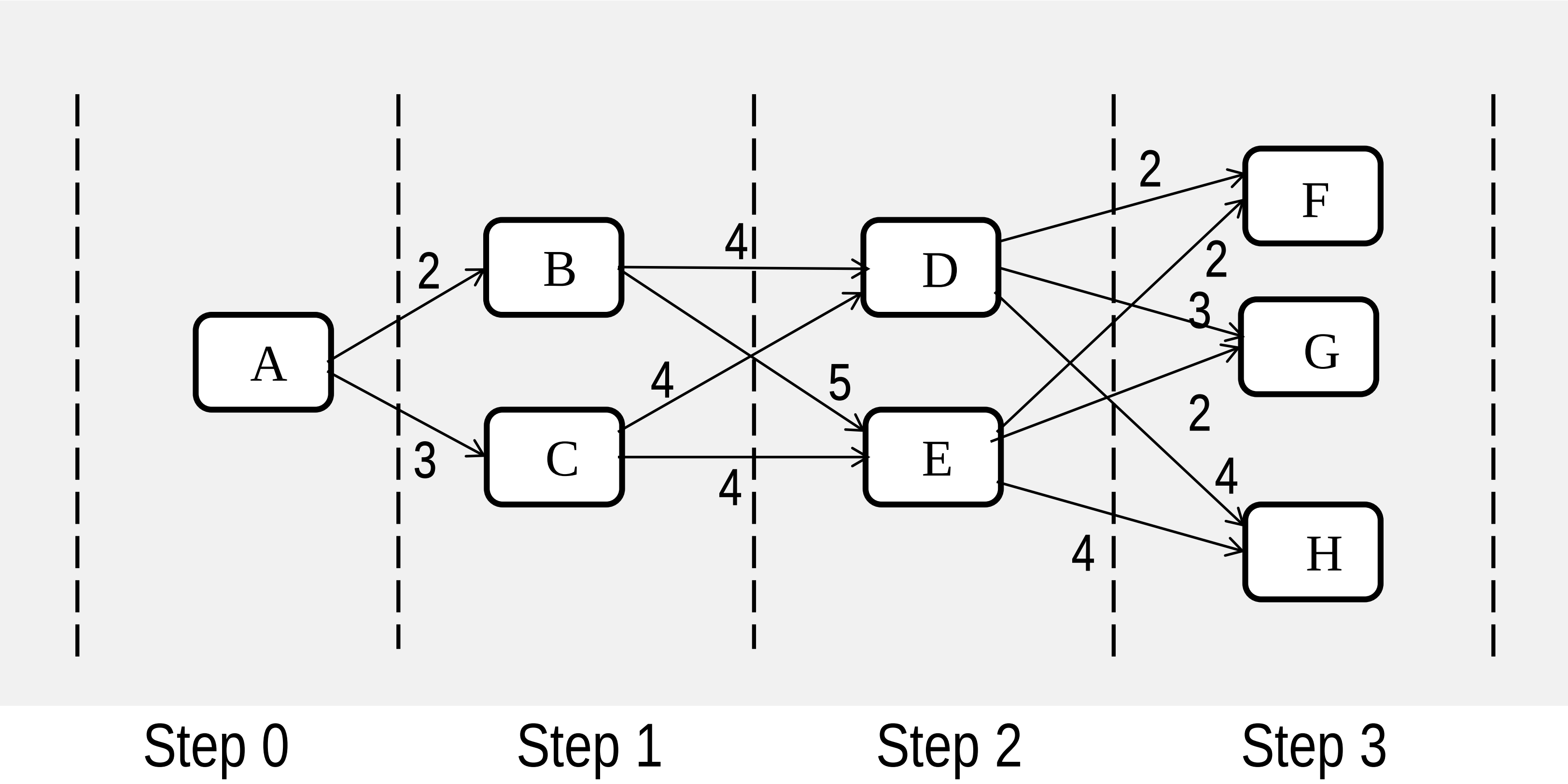
$$t = 1 \,..\, T$$

$Em\ i[k_t]$: emission of product i of the plan $[k_t]$

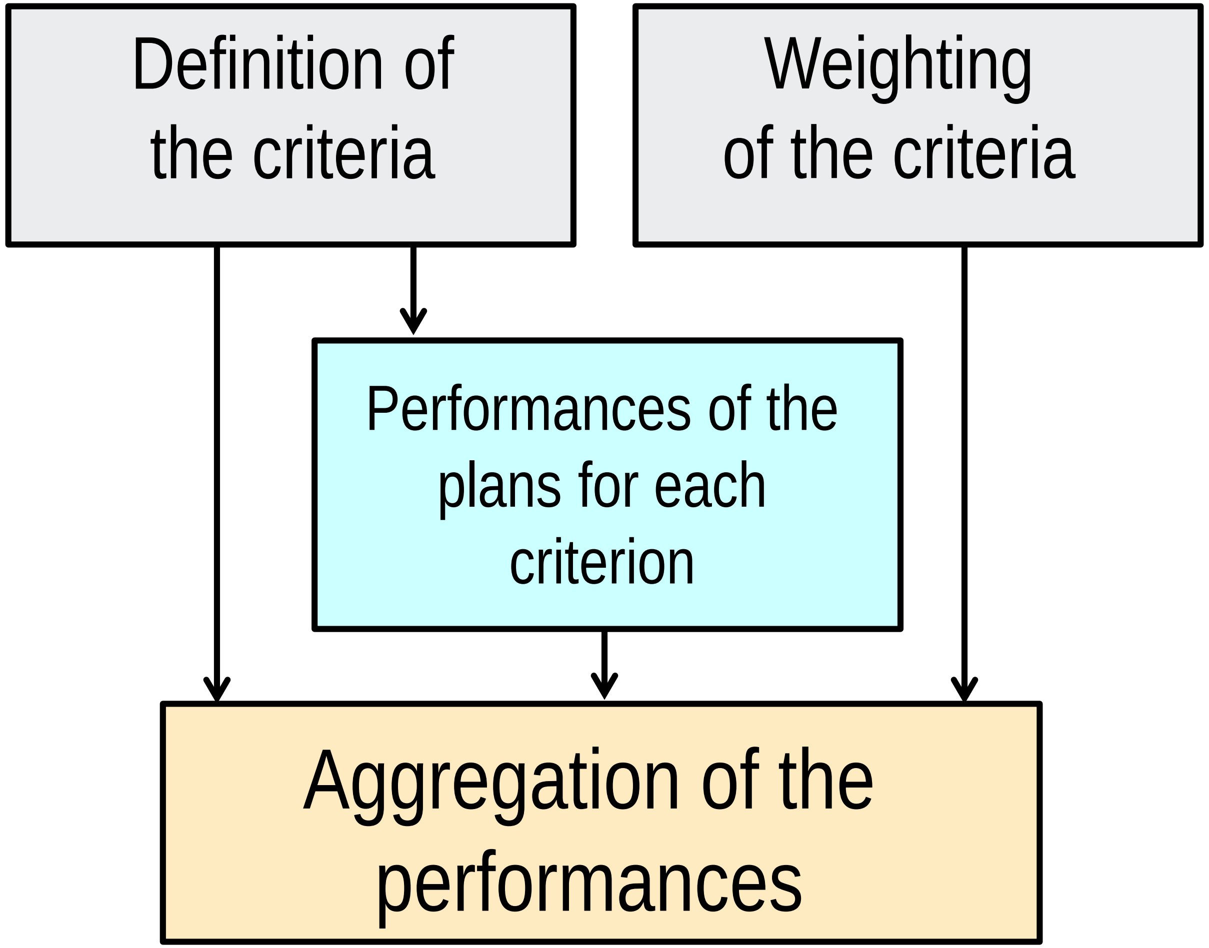
$\overline{Em\ i}_t$: maximum limit of product i emission in year t

4.7 HOW TO SELECT THE BEST PLANS?

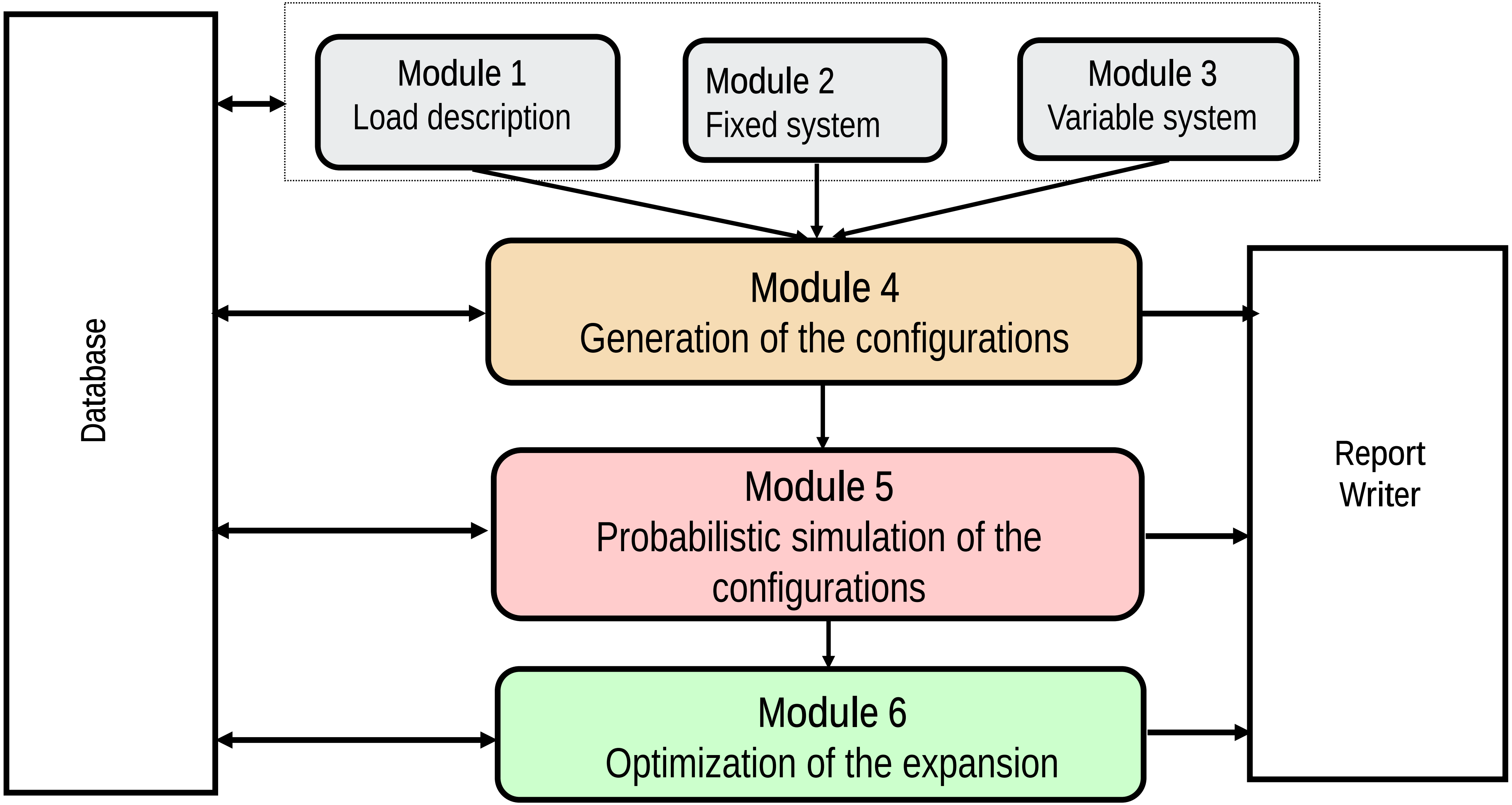
Optimization: e.g. dynamic programming (Bellman algorithm)



Multiple criteria methods



4.8 PLANNING WITH PLANELEC-PRO

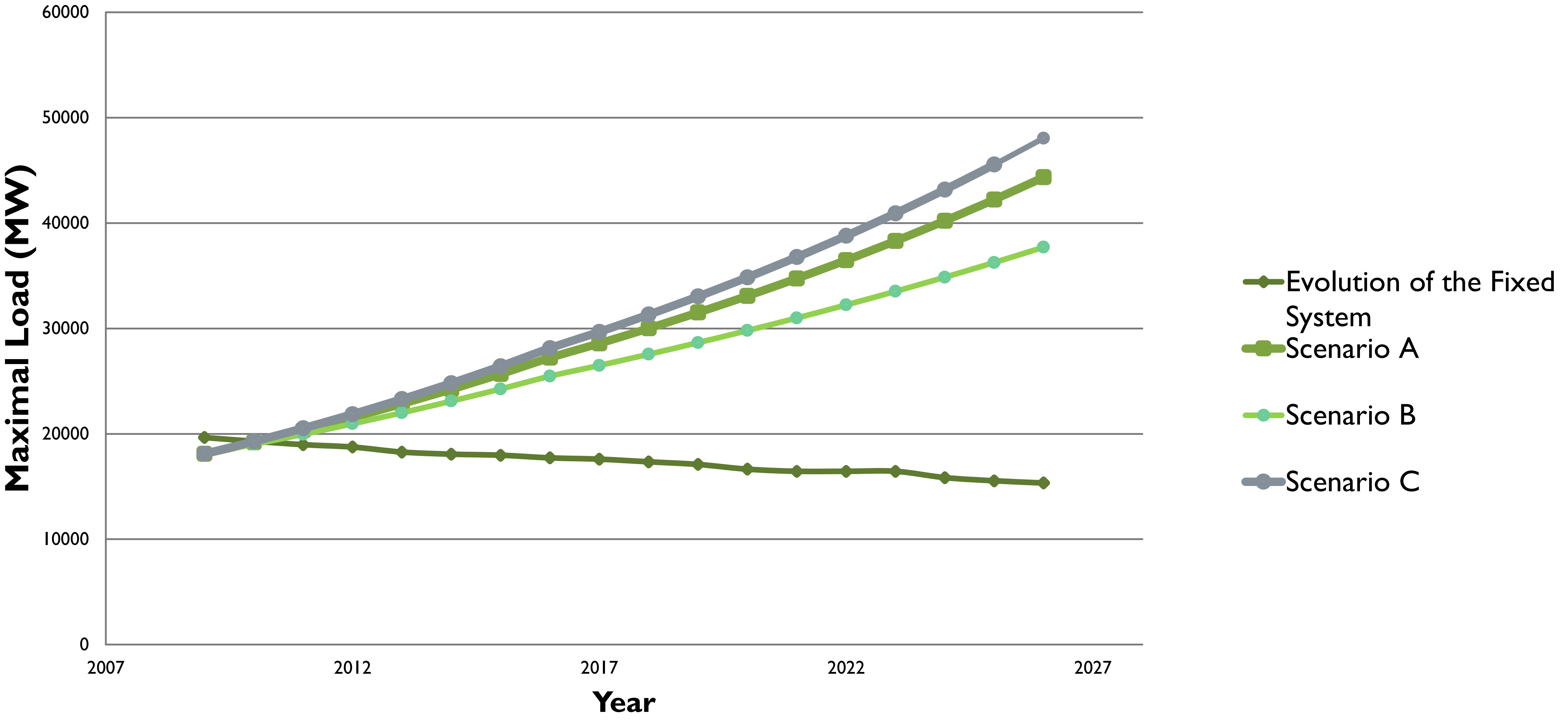


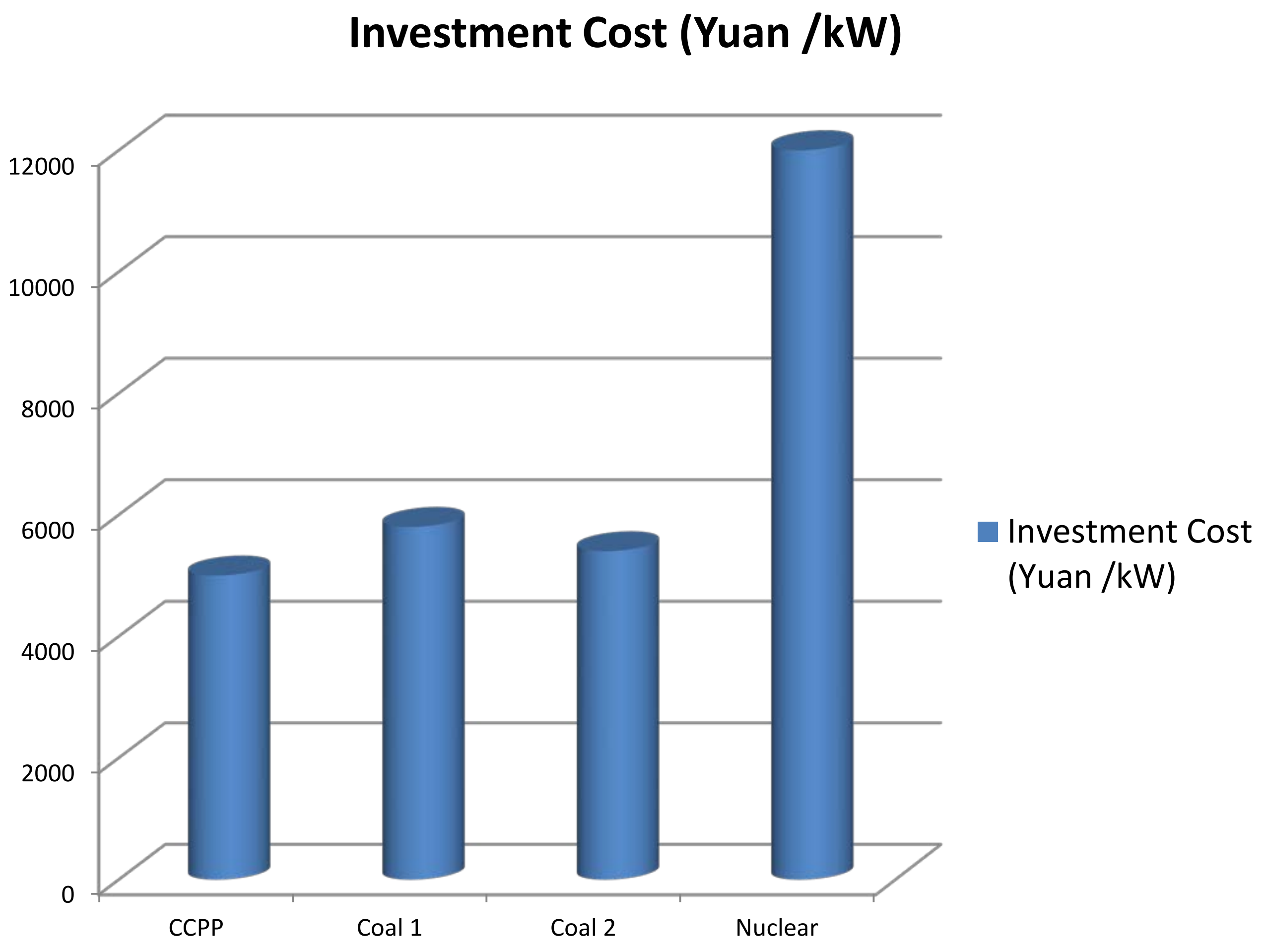
4.9 CASE STUDY: EXPANSION OF THE ELECTRICAL GENERATING SYSTEM IN SHANDONG PROVINCE (CHINA)

- What is the present situation of the electricity supply in Shandong Province?
- How will evolve the demand in long term ?
- From which year the supply can fail to meet the demand if no expansion is accomplished ?

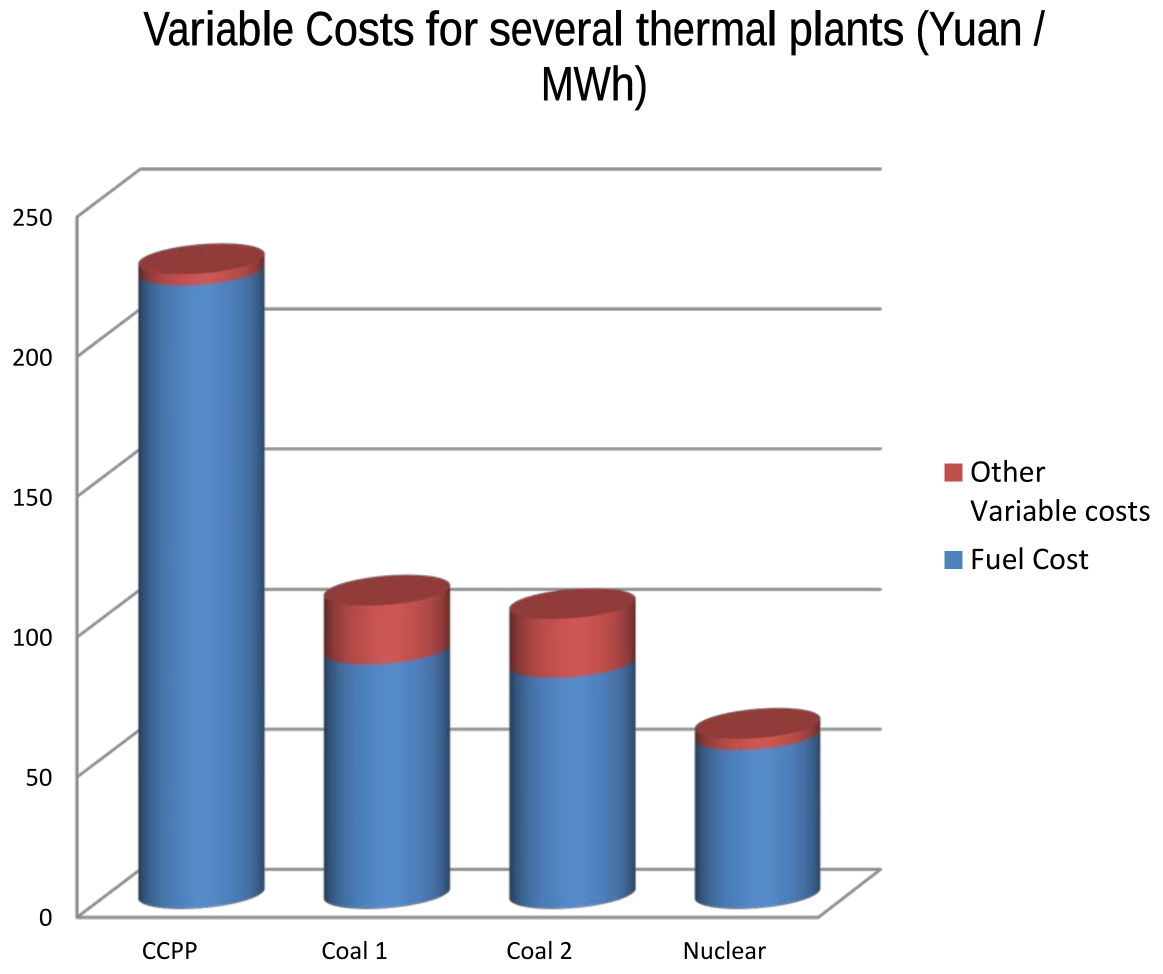
- What kind of candidates can be used for this expansion and why ?
- What are the environmental requirements for Power system and how the expansion can be constrained by these requirements ?
- What should be the quality of service in term of LOLP ?

Evolution of the load and supply capacity for different scenarios



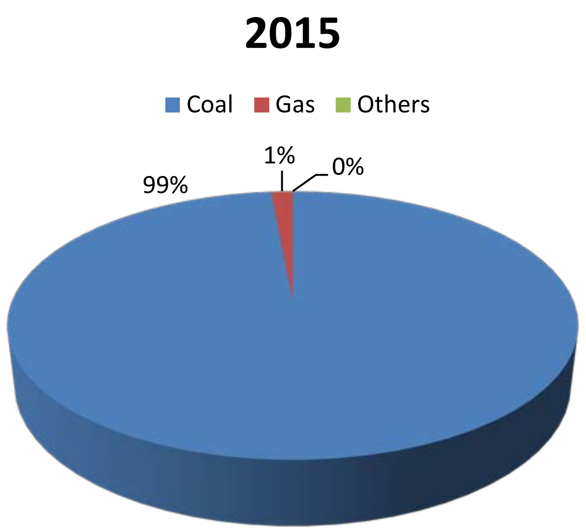


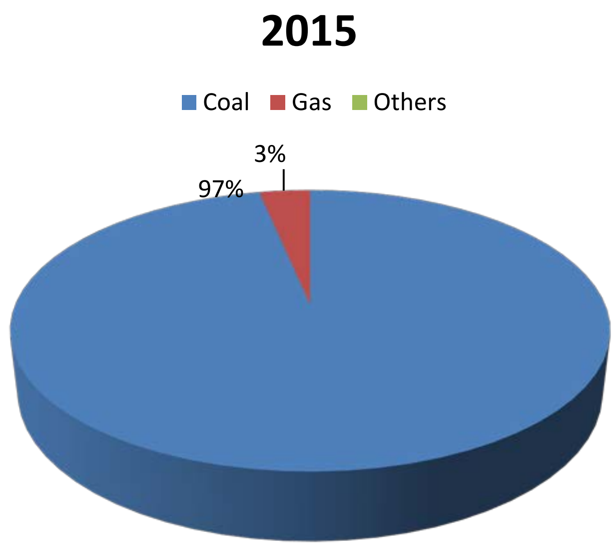
Investment Cost (Yuan /kW)
12000
10000
8000
6000
4000
2000
0
CCPP
Coal 1
Coal 2
Nuclear
Investment Cost (Yuan /kW)

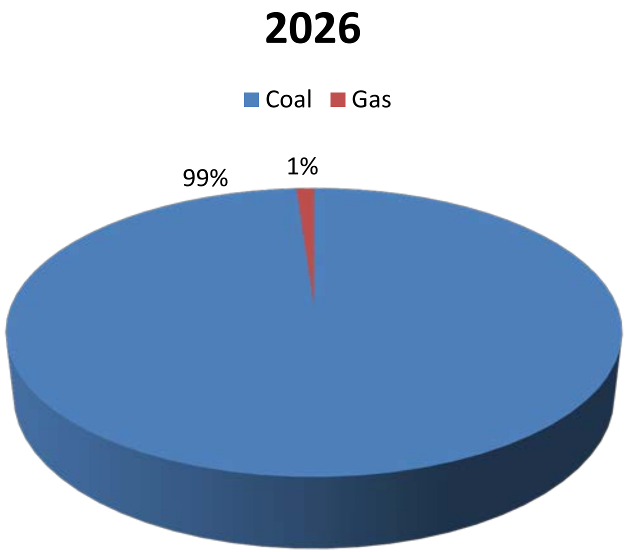


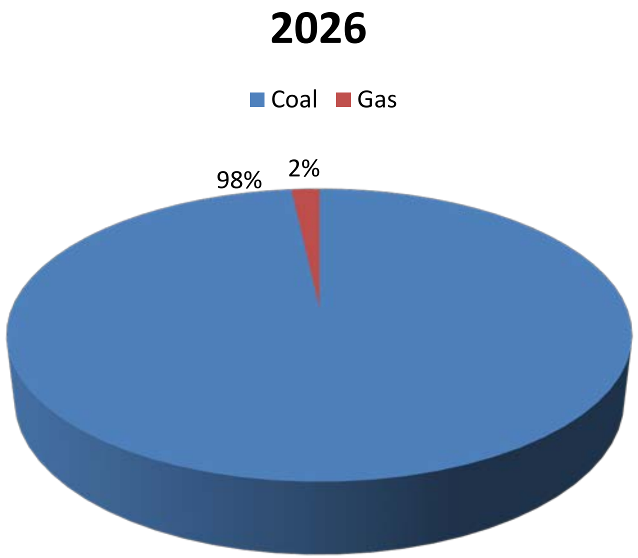
Variable Costs for several thermal plants (Yuan / MWh)
250
200
150
100
50
0
CCPP
Coal 1
Coal 2
Nuclear
Other Variable costs
Fuel Cost

– Coal vs. Natural gas –



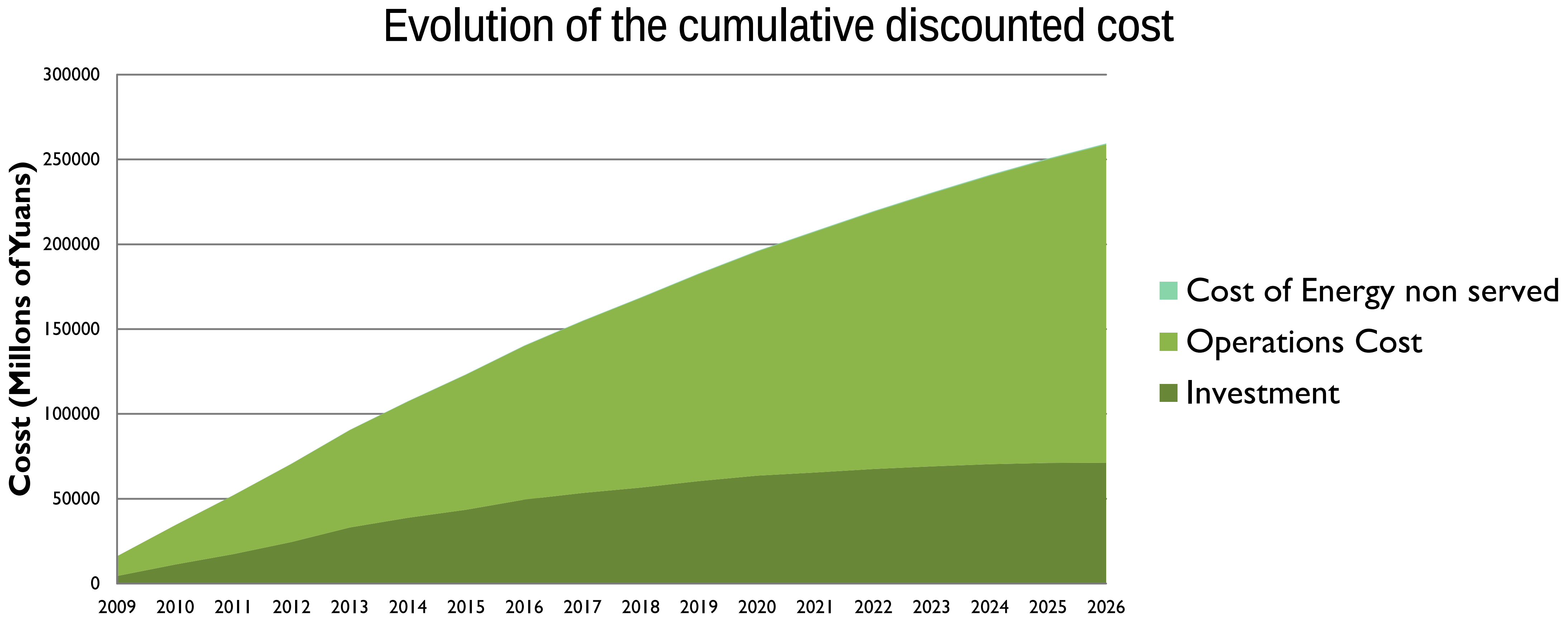






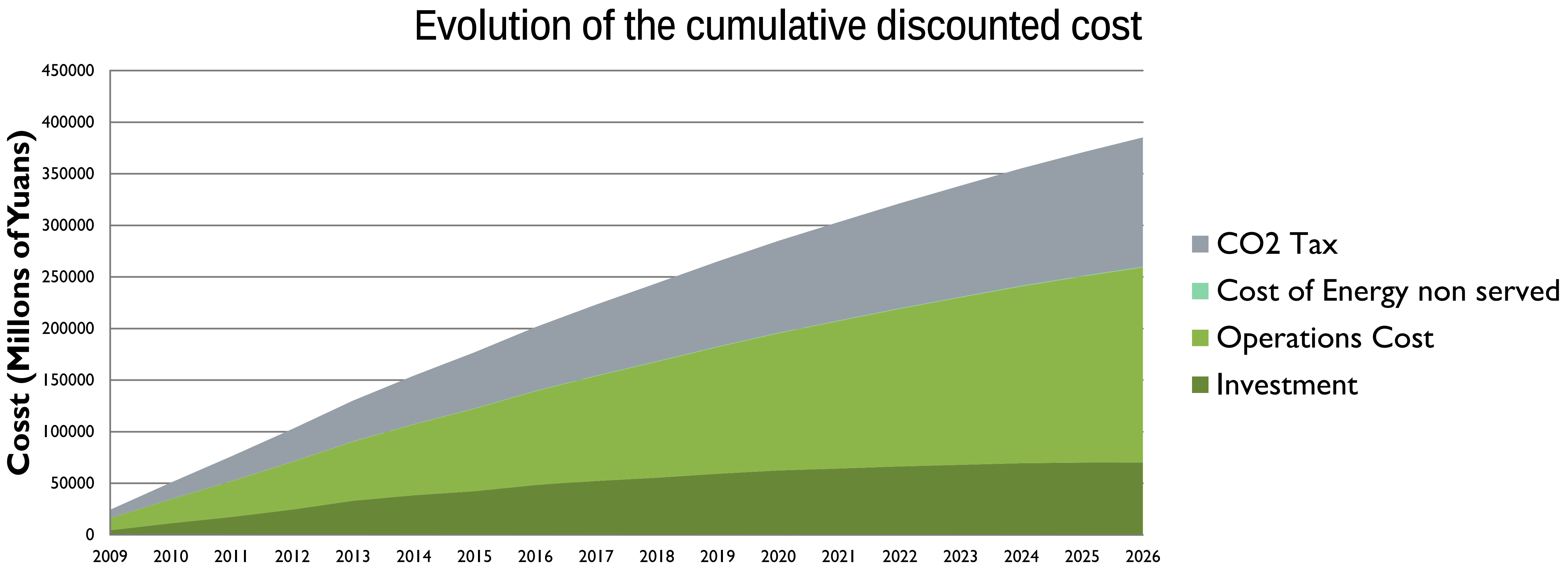
Cumulative Discounted costs

Without CO_2 tax



Cumulative Discounted costs

With CO_2 tax: 90 Yuan /tonne of CO_2



Articles Readings

1. Kagiannas et al. « Power generation planning: a survey from monopoly to competition ». Electrical Power & Energy Systems 26 (2004) 413-421
2. Alarcon-Rodriguez et al. «Multi-objective planning of distributed energy resources: A review of the state-of-the-art ». Renewable and Sustainable Energy Reviews 14 (2010) 1353-1366
3. Loken. « Use of multicriteria decision analysis methods for energy planning problem », Renewable and Sustainable Energy Reviews 14 (2005) 1584-1595