Generating multiple system configurations

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Energy system configuration

- A system configuration is defined by:
  - **Equipments**: conversion and storage with a given size S_u and an expected lifetime t_{S_u}
  - **Exchange flows** between equipments and with the embedding energy system/infrastructure for a collection of sequences of states defined by conditions p
    - $\dot{m}^+_{r,p}, \dot{E}^+_p, \dot{E}^-_p$ [kg/s, kW] : flows calculated in the system configuration during operating conditions p
    - d_p [s/lifetime] : probability of appearance of operating conditions p during the life time of the system

KPI : Key Performance Indicators of a system design

$$KPI^k = \sum_{p=1}^{n_p} \left(\sum_{r=1}^{n_r} \dot{m}^+_{r,p} v^{+,k}_{r,p} + \dot{E}^+_p v^{+,k}_{e,p} - \dot{E}^-_p v^{-,k}_{e,p} + \sum_{u=1}^{n_u} f_{u,p} v^k_{m,u} \right) d_p + \sum_{u=1}^{n_u} v^k_u (I_u(S_u)) \qquad \forall k \in \{KPI\}$$

$\dot{m}^+_{r,p}, \dot{E}^+_p, \dot{E}^-_p$ [kg/s, kW] : flows calculated in the system configuration during conditions p

d_p [s/lifetime] : probability of appearance of conditions p during the life time of the system

$I_u(S_u)$ [$ invested for the Size of u] : investment in the equipment of the system

For the same system configuration:

the values given to flows depends on the selected key performance indicator KPI^k

$v^{+,k}_{r,p}$ [KPI/kg]: value given to flows or investment to characterize the system configuration during conditions p

$v^{+,k}_{e,p}$ [KPI/kJ]: value given to Electricity to characterize the system configuration during conditions p

$v^k_{m,u}$ [KPI/use of u]: value of the maintenance cost of unit during the conditions p

v^k_u [KPI/$ invested] : value given to the investment of unit u over its lifetime (typically in $\frac{\$^{2020}}{year} \frac{1}{\$_{invested}}$)

Generating multiple configurations

- KPI can represent different performances
  - **Cost under given economic conditions**
    - expected energy prices for the next years of the life time of the investment
  - **Environmental impact with different indicators**
    - climate change, biodiversity, human health
  - **Social**: Job created, Risk, cost to the future generations,…
- **Sustainability** KPI should include the 3 pillars:
  - Economic, environmental and social
  - Include a long term perspective

- as there are more then 1 KPI, it is useful to generate more than 1 configuration
- KPI can be used as indicators or as contraints (e.g. planetary boundaries, Net-zero)

- Integer cut constraint on the equipment set $\{y_u\}$
  - assuming that we know already the configuration k
  - The problem k + 1 is defined by adding to the previous MILP problem the integer cut constraint

$$Problem^{k+1}:$$

$$Problem^{k}$$

$$\sum_{i=1}^{n_y}(2y_i^k - 1) * y_i \leq \sum_{i=1}^{n_y} y_i^k$$

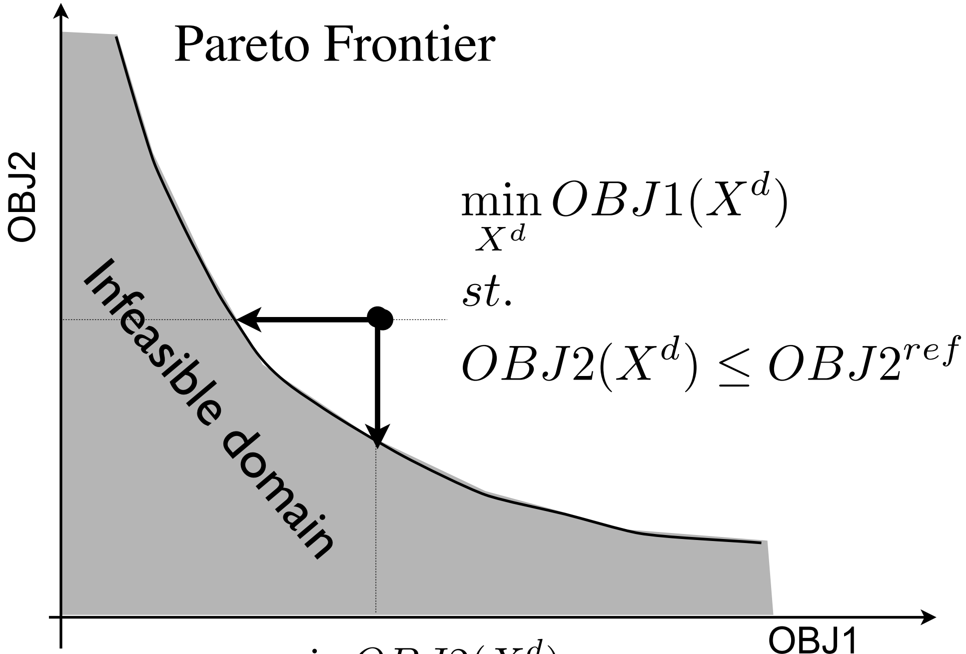
where y_i^k value of y_i in solution of problem k

Pareto Principle for conflicting goals

The cheapest for a given level of environmental impact

or

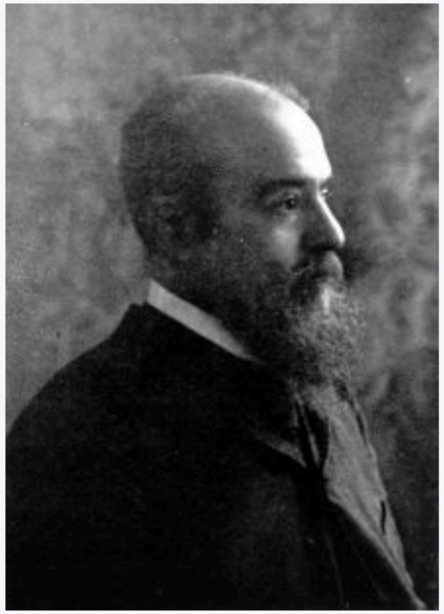
The lowest environmental impact for a given cost



$$\min_{X^d} OBJ1(X^d)$$
$$st.$$
$$OBJ2(X^d) \leq OBJ2^{ref}$$

$$\min_{X^d} OBJ2(X^d)$$
$$st.$$
$$OBJ1(X^d) \leq OBJ1^{ref}$$

Vilfredo Pareto



Born	15 July 1848 Paris, France
Died	19 August 1923 (aged 75) Céligny, Switzerland
Nationality	Italian
Institutions	University of Lausanne
Field	Microeconomics Socioeconomics

source : wikipedia

Muti-objective optimisation

- Single objective parametric optimisation
  - Weighting conflicting objectives

$$X_d(w) : min_{X_d}(1-w)\cdot OBJ_1(X_d) + w\cdot OBJ_2(X_d)$$
$$\forall w \in [0,1]$$

  - Vary parametrically the weight w from 0 to 1 by n steps:

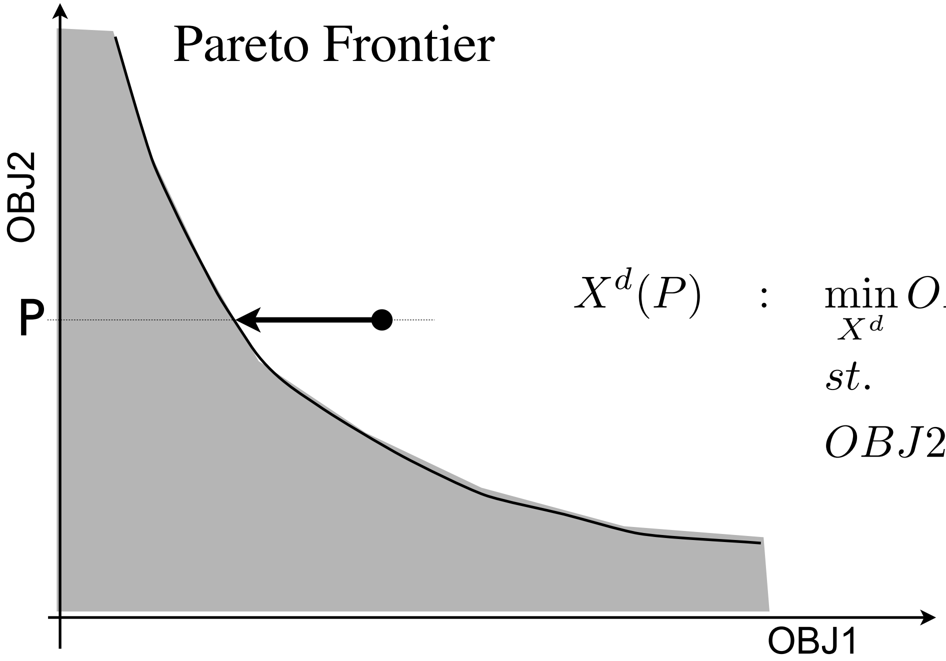
$$w^{k+1} = w^k + \delta_w \qquad \delta_w = \frac{1}{n}, k \in 1..n$$

  - Does not capture the position of the jumps (integer variables) in the MILP formulation
  - Note : if OBJ1 is a cost function

$$\frac{w}{1-w} \text{ is a tax on } OBJ_2(X_d)$$

Parametric programming

- Choose one of the conflicting KPI as the objective function (OBJ_1)
- The other (OBJ_2) is to be lower than a parameter P
- Vary P by n steps between $OBJ_2(x_D \,|\, \min_{x_D} OBJ_1) \,..\, OBJ_2(x_D \,|\, \min_{x_D} OBJ_2)$



$$
\begin{aligned}
X^d(P) \quad : \quad & \min_{X^d} OBJ1(X^d) \\
& st. \\
& OBJ2(X^d) \leq P
\end{aligned}
$$

Note : the Lagrange multiplier of inequality gives the slope of the Pareto curve

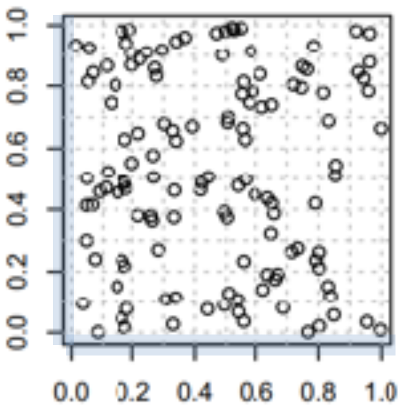
Multi-parametric optimisation

- Systematically vary multiple parameters by sampling

$$
\begin{aligned}
\min_{x} \quad & f_{TC}(x,\theta) & & \text{Objective : KPI 1} \\
\text{subject to} \quad & f_{FAR}(x,\theta) \leq \varepsilon_{n,FAR}, & \varepsilon_{FAR}^{min} \leq \varepsilon_{n,FAR} \leq \varepsilon_{FAR}^{max}, & \quad \text{KPI 2} \\
& f_{RES}(x,\theta) \leq \varepsilon_{n,RES}, & \varepsilon_{RES}^{min} \leq \varepsilon_{n,RES} \leq \varepsilon_{RES}^{max}, & \quad \text{KPI 3} \\
& g(x,\theta) \leq 0, & & \\
& h(x,\theta) = 0, & &
\end{aligned}
$$

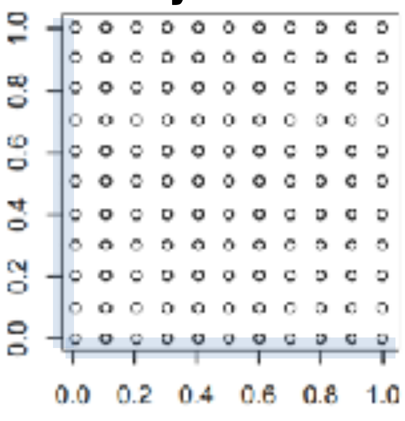
with $\epsilon_{en,FAR}$, $\epsilon_{en,RES}$ selected by a random sampling method

Random



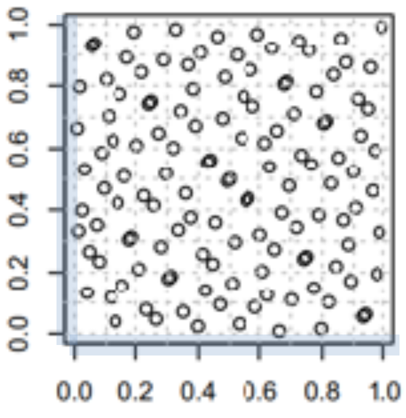
(Burhenne, 2011)

Systematic



(Gilbert, 1987)

Quasi-random



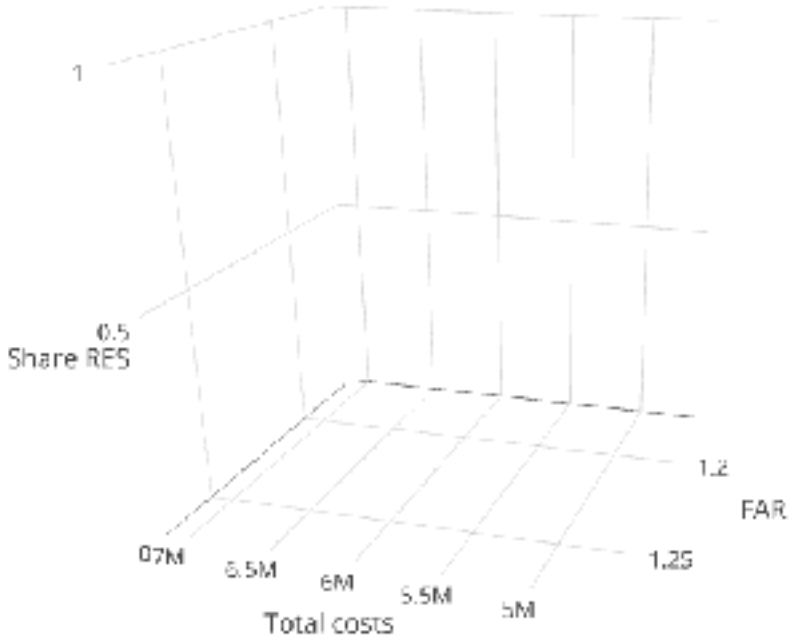
(Burhenne, 2011)

Latin hypercube

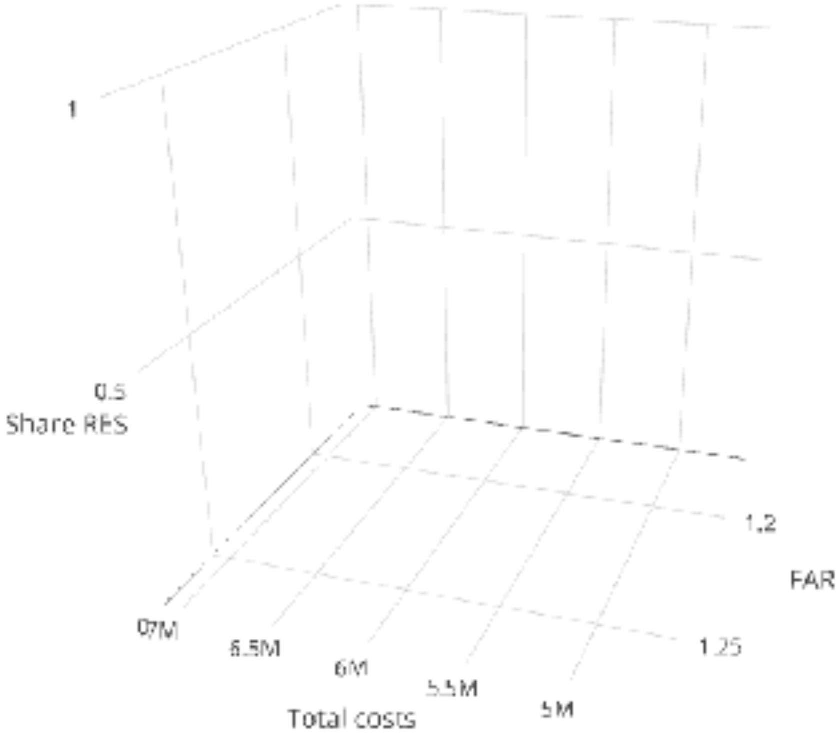
Sobol

Sobol sampling

Systematic



VS Sobol



Sobol sampling equations

$$
\begin{aligned}
\min_{x} \quad & f_l(x,\theta) \\
\text{subject to} \quad & f_j(x,\theta) \leq \varepsilon_{n,j}, && j = 1,\ldots,k, \quad j \neq l, \\
& \theta_t = \varepsilon_{n,t}, && t = 1,\ldots,u, \quad u \leq m, \\
& g(x,\theta) \leq 0, \\
& h(x,\theta) = 0,
\end{aligned}
$$

With the Sobol sampling approach, the user specifies a number of solutions N, and the corresponding parameters in E are computed as:

$$E_{N\times P} = (\varepsilon_{n,p}) = \begin{pmatrix} \varepsilon_{1,1} & \varepsilon_{1,2} & \cdots & \varepsilon_{1,P} \\ \varepsilon_{2,1} & \varepsilon_{2,2} & & \varepsilon_{2,P} \\ \vdots & & \ddots & \vdots \\ \varepsilon_{N,1} & \varepsilon_{N,2} & \cdots & \varepsilon_{N,P} \end{pmatrix}, \quad \varepsilon_p^{min} \leq \varepsilon_{n,p} \leq \varepsilon_p^{max}$$

$$\varepsilon_{n,p} = \varepsilon_p^{min} + s_{n,p} \cdot (\varepsilon_p^{max} - \varepsilon_p^{min}), \qquad n = 1,\ldots,N, \quad p = 1,\ldots,P, \tag{3.6}$$

where $s_{n,p}$ is an element in the matrix $S_{N\times P}$, whose rows contain the Sobol sequence of N coordinates in a P-dimensional unit hypercube. Various computer-based Sobol sequence generators have been

$$E_{5\times 3}^{sob} = S_{5\times 3} = \begin{pmatrix} 0.5 & 0.5 & 0.5 \\ 0.75 & 0.25 & 0.75 \\ 0.75 & 0.25 & 0.25 \\ 0.375 & 0.375 & 0.625 \\ 0.875 & 0.875 & 0.125 \end{pmatrix}$$

Parallel plots to compare configurations

Multiple KPI

Multiple configurations

(Gardiner et al, 1997)

(Wolf et al, 2009)

(Piemonti et al, 2017)