Hybridizing Multi-Objective Interactive Techniques

Some Applications to the Electricity Generation Industry

Francisco Ruiz

Department of Applied Economics (Mathematics), University of Málaga (Spain)

Outline

1. Motivation
   - Multiobjective Programming Methods
   - Interactive Techniques
   - How to choose an Interactive Method
2. Some Real Applications
   - Determination of Electricity Mix in Andalucía
   - Optimal Size of a Solar Thermal Plant
   - Optimization of Auxiliary Services
3. Conclusions

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Optimization vs. Decision (Romero, 1993)

Search and find

Find the cheapest bottle of wine.

- Search for the best solution
- Technological problem
- Everyone agrees about the optimal solution

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- Conflicting objectives
- Different DMs make different decisions
- Incorporate preferences

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Efficient Solutions

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Multiobjective Programming Problem

Definition

A Multiobjective Programming Problem (MOP) takes the following form:

$$(\text{MOP}) \begin{cases} \max & \mathbf{f}(\mathbf{x}) = (f_1(\mathbf{x}), f_2(\mathbf{x}), \ldots, f_p(\mathbf{x})) \\ \text{subject to} & \mathbf{x} \in X \end{cases}$$

Definition

- X is the decision space. $\mathbf{f}(X)$ is the objective space.
- A solution $\mathbf{x} \in X$ is said to be efficient if there does not exist any other feasible solution $\mathbf{y}$, such that $f_i(\mathbf{y}) \geq f_i(\mathbf{x})$ for all $i = 1, \ldots, p$, and $f_j(\mathbf{y}) > f_j(\mathbf{x})$ for some $j \in \{1, \ldots, p\}$
- If $\mathbf{x}$ is efficient, $\mathbf{f}(\mathbf{x})$ is said to be nondominated.
- All the efficient solutions of (MOP) form the efficient set E.

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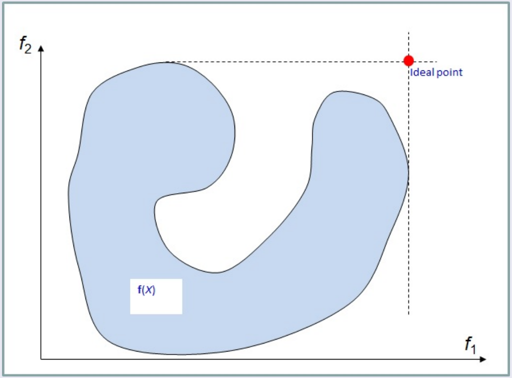
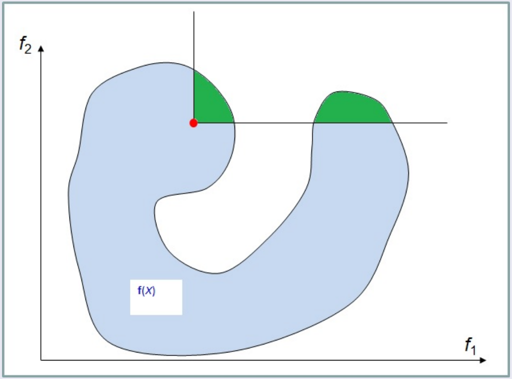
Graphical View of an Efficient Set

Feasible Set in Objective Space



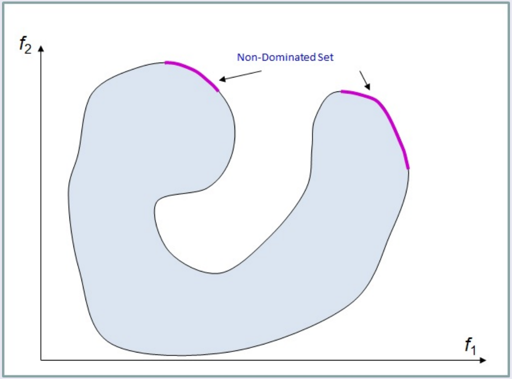
Graphical View of an Efficient Set

Dominated Solution



Graphical View of an Efficient Set

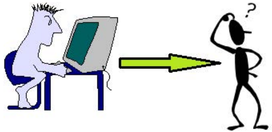
The Efficient Set



Multiobjective Programming Methods

A posteriori methods

- Weighting method
- ε-Constraint Method
- EMO Approaches



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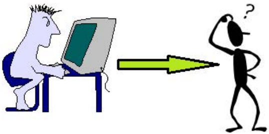
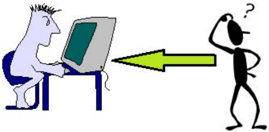


A priori methods

- Goal Programming
- Compromise Programming
- Reference Point Method



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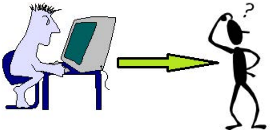

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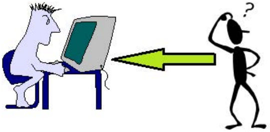
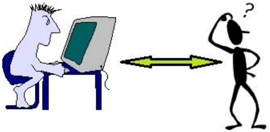


Interactive methods



What is an Interactive Method?

What is an Interactive Method?

It is a resolution method for Multiobjective problems, where the information exchange between the decision maker and the analyst is carried out in a continuous way during the resolution process. The method progressively incorporates the information given by the Decision Maker so as to lead him to his most preferred solution.
Interactive techniques are specially suitable for favoring learning processes for both the decision maker and the analyst.

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Basic Scheme of Interactive Methods

Steps of an Interactive Method

1. Generate an initial efficient solution
2. Present the current solution to the DM
3. Is the DM satisfied with the solution?
   - ✓ If "Yes", then end.
   - ✓ If "No", go to step 4
4. Ask the DM for preferential information
5. Generate a new efficient solution
6. Go to step 2

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What Type of Information may be Asked to the DM?

Types of Interactive Methods according to the information required

- Comparison Methods
  - ✓ Pair-wise comparisons
  - ✓ Several objective vectors
- Trade-off or local weights methods
  - ✓ The DM evaluates objective tradeoffs
  - ✓ The DM estimates subjective tradeoffs
- Level specification methods
  - ✓ Interactive Goal Programming methods
  - ✓ Reference Point based Methods
- Classification methods
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How do Interactive Methods Calculate New Solutions?

Types of Interactive Methods according to the optimization procedure

- Reduction of the feasible region
- Reduction of the weights space
- Feasible direction, line search
- Cutting planes (tradeoffs)
- Lagrange multipliers (constraint problems)
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Some Well Known Interactive Methods

Most representative methods for each information type

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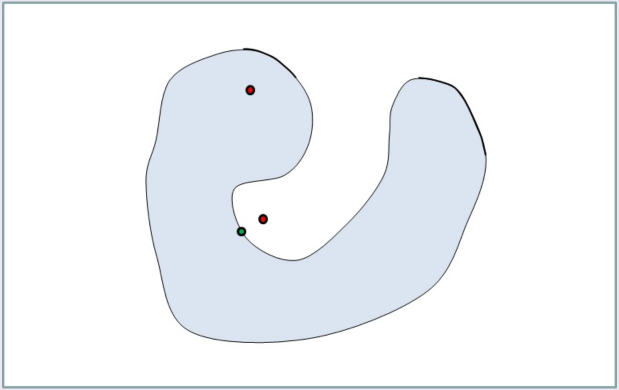
Graphical View of the Reference Point Scheme

Euclidean Distance is not appropriate



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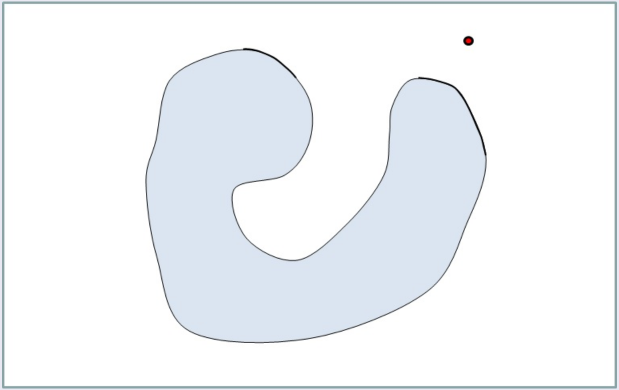
Reference Point



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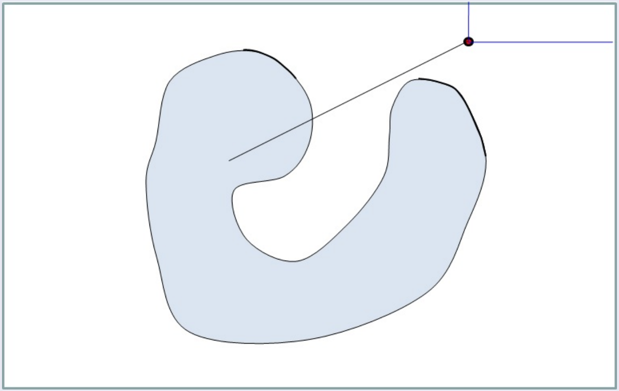
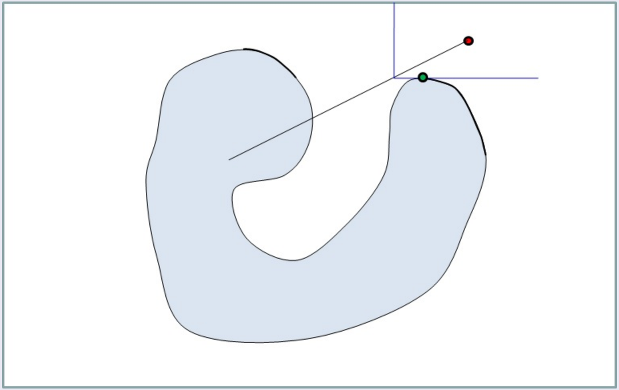
Non-Negative Orthant and Weights



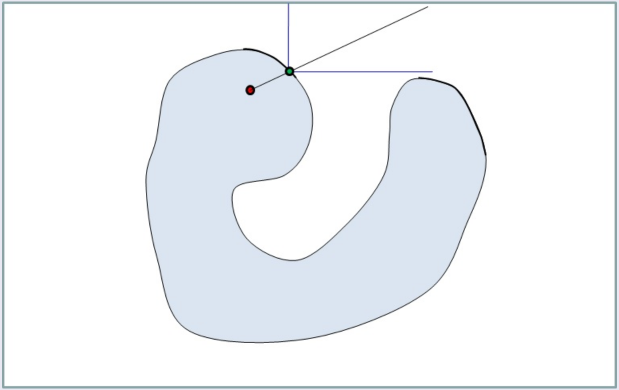
Graphical View of the Reference Point Scheme

Projection



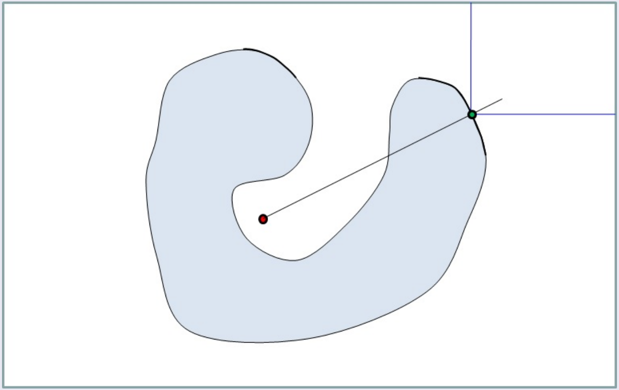
Graphical View of the Reference Point Scheme

Feasible Reference Point



Graphical View of the Reference Point Scheme

Non-Feasible Achievable Reference Point



What do we Have to Take into Account?

Technical Features of Interactive Algorithms

- Inner procedure. Computing times.
- Applicability (types of problems supported).
- Optimization techniques required.
- Stopping criterion
- Implementation.

What does the DM care about?

- Interaction style.
- Cognitive burden for the DM.
- Ease of use.
- Effectiveness in real decision processes

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What does the DM care about?

- Interaction style.
- Cognitive burden for the DM.
- Ease of use.
- Effectiveness in real decision processes

What do we Have to Take into Account?

Technical Features of Interactive Algorithms

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- Applicability (types of problems supported).
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Our Conclusion as Analysts

What do WE have to do?

- We have to choose a method:
  - ✓ For each problem
  - ✓ For each Decision Maker
- We need to offer a flexible framework:
- We will probably need to combine interaction styles.
  - ✓ Hybridize different interactive methods.
  - ✓ Application 1.
- We will probably need to combine solving techniques.
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- Determine the most preferred electrical mix to cover the demand of Andalucía, taking into account economic, environmental and vulnerability criteria.
- Evaluate the cost of moving towards a more sustainable mix.
- DM: Regional Ministry of Environment of Andalucía.

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Variables

- 8 electricity generation systems: Lignite, Carbon, Oil, Natural Gas, Nuclear, Photovoltaic, Eolic, Hydraulic.

  Y_j: Installed capacity (GW) for system j

- Demand: 108 time periods (t_k, hours), with a given hourly demand (d_k, GW).

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Elements of the Model (Cont.)

Constraints

- Diversification & security.
- Satisfaction of the demand.
- Electricity permanent availability.
- Technical constraints.

Objectives

- Cost
  - ✓ Fixed annualized costs.
  - ✓ Variable (fuel) costs.
- Vulnerability (Percentage of Imported Fuel).
- Environmental Objectives.
  - ✓ 12 Impact Categories.
  - ✓ Life Cycle Analysis.

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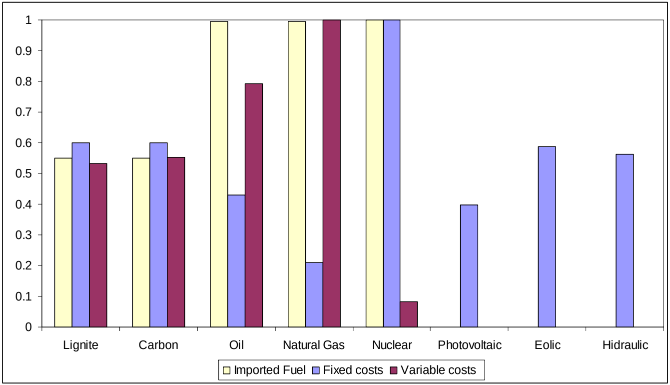
Cost and Vulnerability: Comparison of Alternatives



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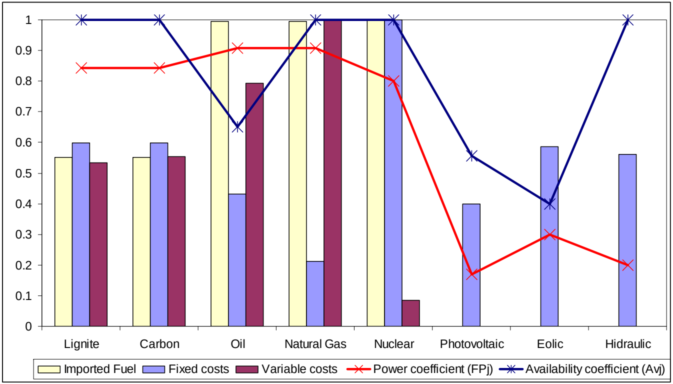

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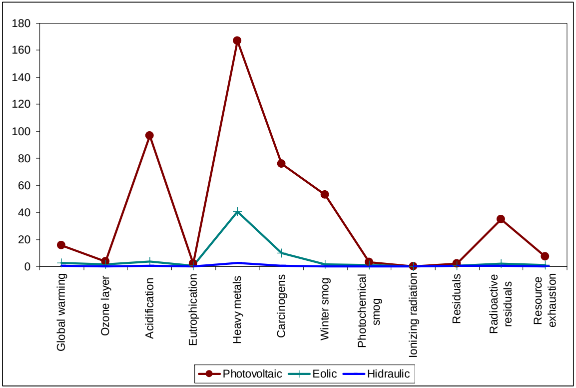

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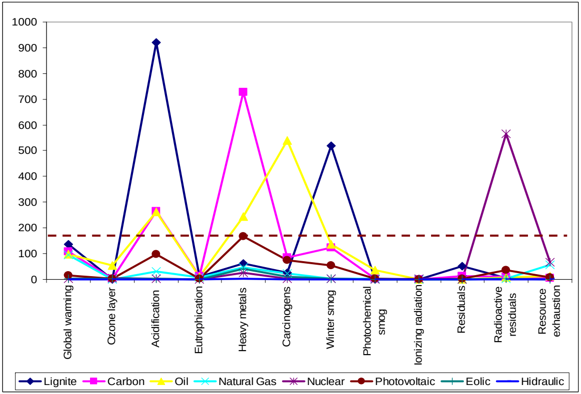

Model and Iterations

Features of the Linear Model

- 116 Variables.
- 1098 Constraints.
- 14 Objective Functions.

PROMOIN (Caballero, Luque, Molina, Ruiz, 2002). Iterations

- Initial Solution: minimum cost.
- Weighting of Objectives.
  - ✓ Cost – Vulnerability – Environmental
- Reference Points and Classification.
  - ✓ Improve Vulnerability
  - ✓ More balanced Environmental Impacts
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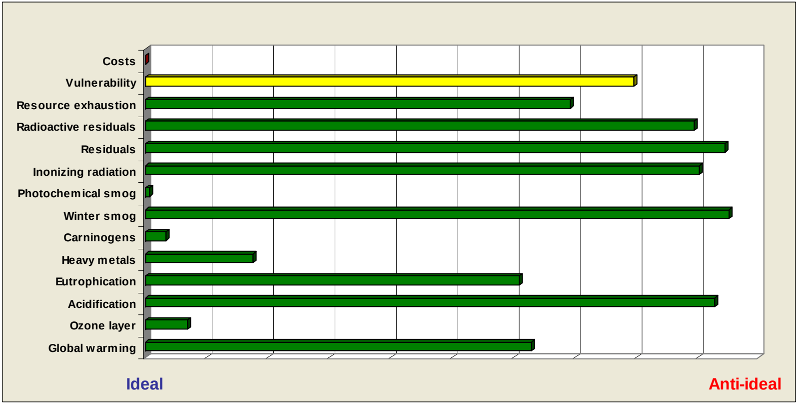
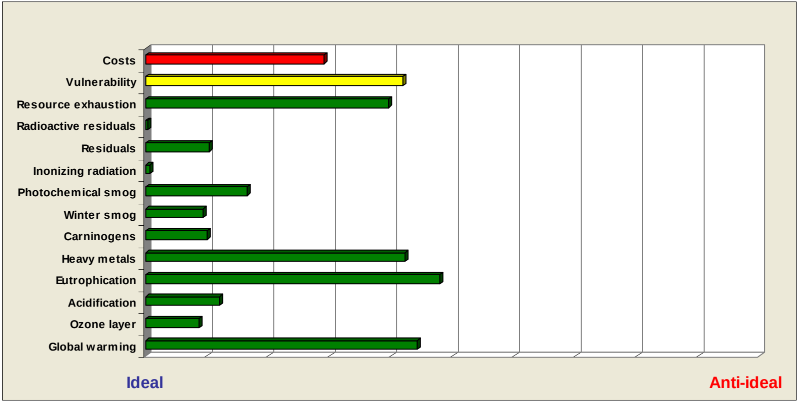
Results-Objectives

Minimum Cost



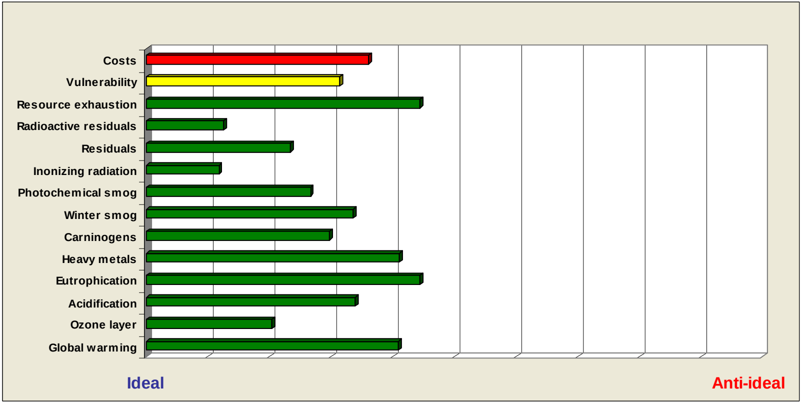
Results-Objectives

Weights



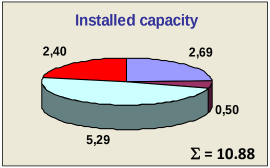
Results-Objectives

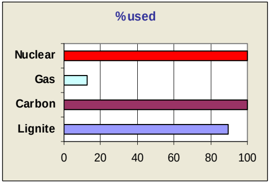
Reference Levels

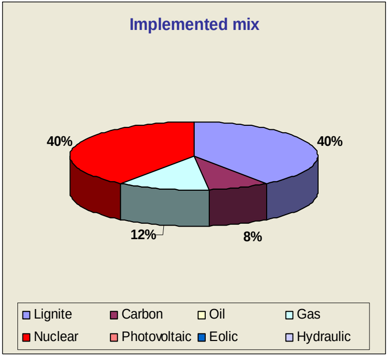


Results-Variables

Minimum Cost







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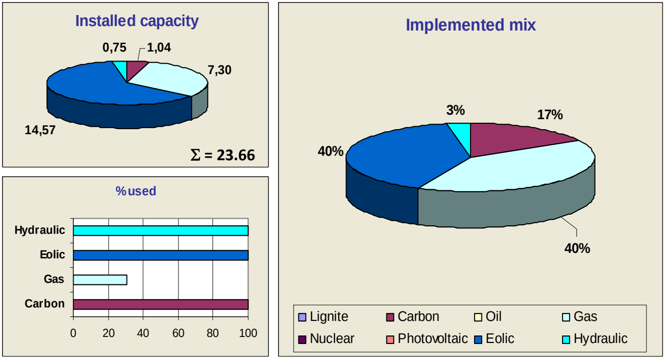

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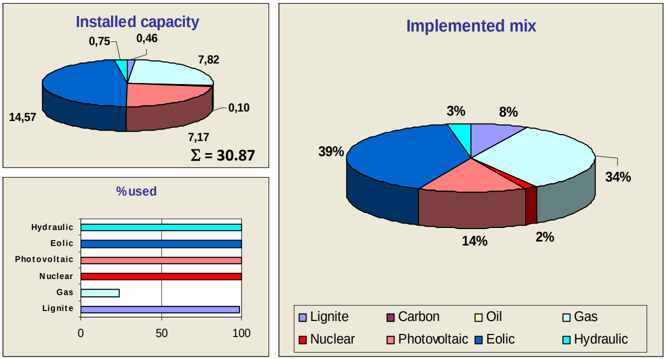
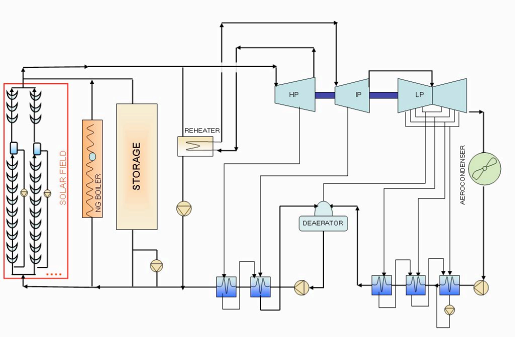


Purpose of the Study

Optimal Dimensions

- Solar Field
- Storage Tanks
- Auxiliary Boiler

Endesa Generación S.L.



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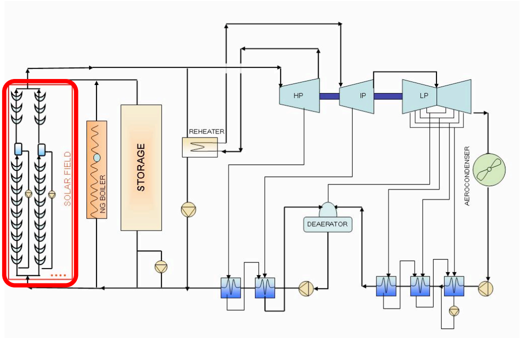

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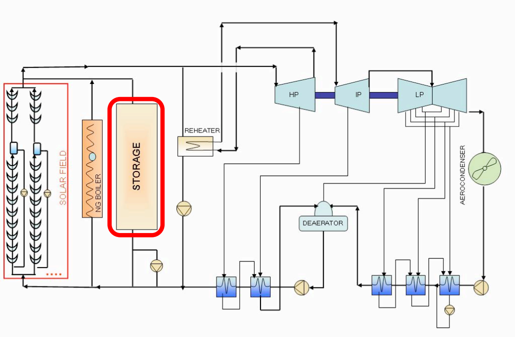

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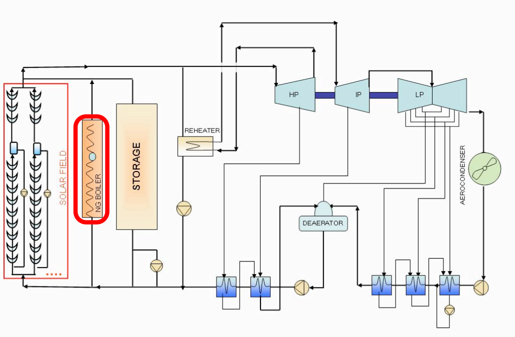

Elements of the Model

Variables

- A_C (m^2) Dimension of the Solar Field
  - ✓ File with expected direct solar radiation and temperature per hour (8760 hours) available. We determine the steam mass from the solar field at each hour.
  - ✓ $A_C \leq 750,000 m^2$
- E (KJ) Capacity of Storage Tanks
  - ✓ One tank maximum capacity: 8 hours.
  - ✓ One tank fixed cost: 15 million €.
- P_{AUX} (KW) Power of the Auxiliary Boiler
  - ✓ Legal limit: 15% hybridization.
- L $(\%)$ Load Fraction Limit
  - ✓ $L \leq 75\%$.

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Why is the Problem so Complex?

Operation Strategy

Every hour, the following decisions are made:

1. If steam mass from the solar field is enough to work at L or more, work only with solar field.
   - ✓ If steam mass produces more than $L = 100\%$, store remaining steam.
2. If steam mass is not enough for L, and there is enough energy stored, complement to work at L.
   - ✓ Ambient losses in the tanks are taken into account.
3. If steam mass and storage are not enough for L, test hybridization condition.
   - ✓ If it is possible to hybridize with the auxiliary boiler, work at L.
   - ✓ If not, store steam mass from the solar field and stop plant.
   - ✓ After a 8 or more hours stop, the electricity produced is devoted to re-starting the system.

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Black Box

- Operation strategy is simulated in a black box.
- We keep track of auxiliary variables.
  - ✓ E_i Energy stored after hour i.
  - ✓ $FUNC_i$ Load fraction of hour i.
  - ✓ $EAUX_i$ Energy generated by auxiliary system at hour i.
  - ✓ $PERC_i$ Accumulated hybridization after hour i.
- Hybridize with meta-heuristic techniques.

Yearly Profit

- Incomes.
  - ✓ 8760 hourly incomes.
  - ✓ Based on $FUNC_i$.
  - ✓ Taking stops into account.
  - ✓ Fixed selling price.
- Fixed costs.
  - ✓ Annualized installation costs.
  - ✓ Annual maintenance costs.
  - ✓ Insurance and contingency costs.
- Variable costs.
  - ✓ Fuel costs, based on $EAUX_i$.

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  - ✓ Insurance and contingency costs.
- Variable costs.
  - ✓ Fuel costs, based on $EAUX_i$.

Optimizing Yearly Profit

(Deb, Tewari, `http://www.iitk.ac.in/kangal/soft.htm`)

GA Solution

- Variables.
  - ✓ $A_C = 750,000$
  - ✓ $E = 15.68$ hours (2 tanks)
  - ✓ $P_{AUX} = 92,768$
  - ✓ $L = 75.00$
- Profit $29,201,020$ €
- Other Features
  - ✓ Investment: $406,769,471$ €
  - ✓ Internal rate of return: 13.32%
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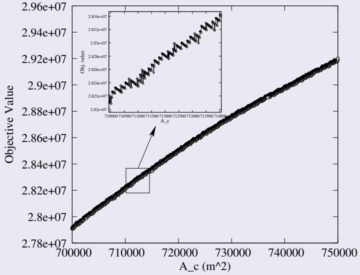

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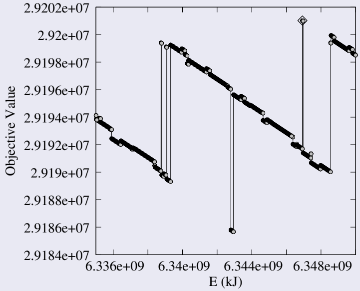

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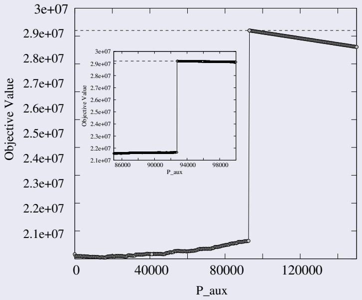

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The Multiobjective Model

Objectives

- Maximize Profit.
- Minimize Investment.
- Maximize IRR.
- Minimize Pollution.

Resolution Process

- Individual optima (GA).
- Efficient Front: NSGA-II (Deb et al, 2002).
- Reference Point based NSGA-II (Deb et al, 2006).
- Final Approach (GA).

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Individual Optima

What we learnt

- Optimal investment cost.
  - ✓ No activity.
  - ✓ The cost of the tanks is the highest component.
  - ✓ Lower values of L are better.
- Optimal IRR.
  - ✓ Maximum of 16.16%, with $E = 0$ and $L = 25$.
  - ✓ For non-zero values of E, maximum IRR is around 14.84%.
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  - ✓ Small A_C and small L.
  - ✓ Large enough E.
  - ✓ P_{AUX} is not used.

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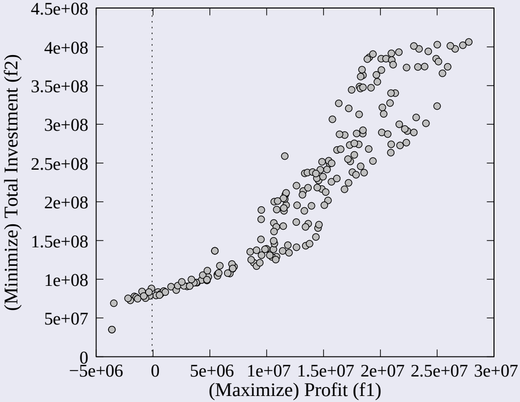
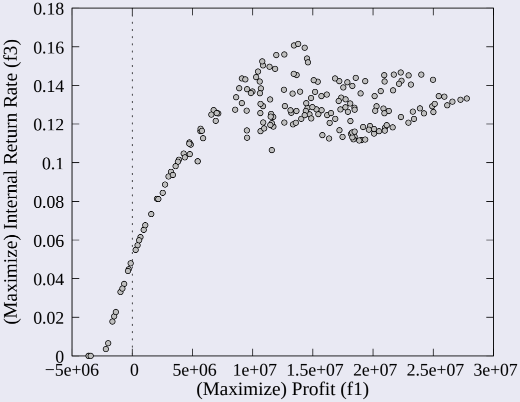
Efficient frontier - What we learnt

Profit vs. Investment Cost



Efficient frontier - What we learnt

Profit vs. IRR



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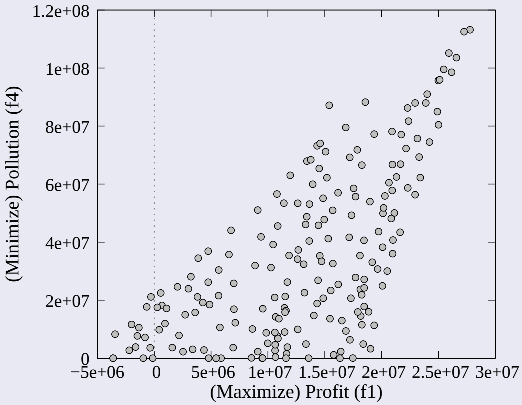
Profit vs. Pollution



Final Approach: Reference Point Based NSGA-II + GA

Initial Variables

- $A_C = 750,000$
- $E = 15.68$ hours (2 tanks)
- $P_{AUX} = 92,768$
- $L = 75.00$

Final Variables

- $A_C = 490,312$
- $E = 6,39$ hours (1 tank)
- $P_{AUX} = 90,261$
- $L = 63,52$

Decision Variables

Final Approach: Reference Point Based NSGA-II + GA

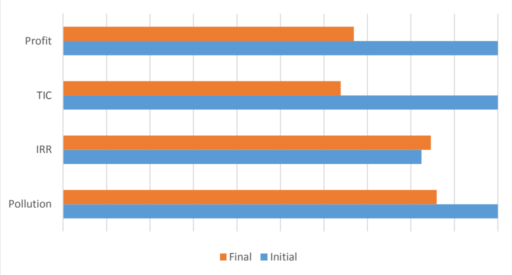
Initial Objectives

- Profit 29, 201, 020.
- TIC: 406, 769, 471.
- IRR: 13.32%.
- Pollution: 58, 125, 795.

Final Objectives

- Profit 18, 596, 015.
- TIC: 259, 779, 783.
- IRR: 13.67%.
- Pollution: 49, 956, 127.

Objective Functions



Purpose of the Study

Auxiliary Services of Power Plants

- Required for the plant operation:
  - ✓ Fuel, water or air supply.
  - ✓ Waste disposal.
- Examples: furnace draft fans, condensate and feed water pumps, circulating water pumps, cooling pumps and fans, coal mills,...
- Electricity consumption from the total electricity generation:
  - ✓ Fossil-fueled power plant: 6-15%.
  - ✓ Nuclear power plant: 4-6%.
- Reliable systems at full load ⇒ but poor efficiecy at partial loads.

Main Questions

- Is it possible to raise the efficiency of power plants through the improvement of the auxiliary services?
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Auxiliary Services Configuration

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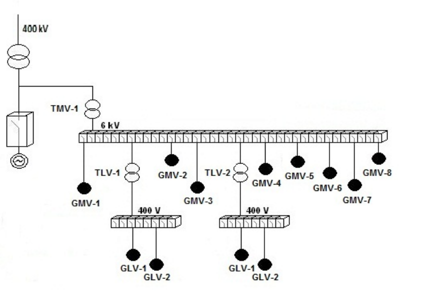

Improvement Strategies

1. Replacement of current motors.
2. Installation of Variable Speed Drives (VSD).
3. Reactive power compensation (Capacitors).

Objectives

1. Maximize the energy saving.
2. Minimize the investment.
3. Maximize the IRR.

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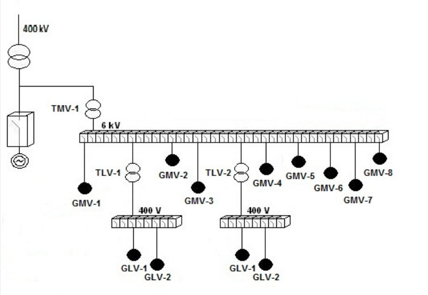

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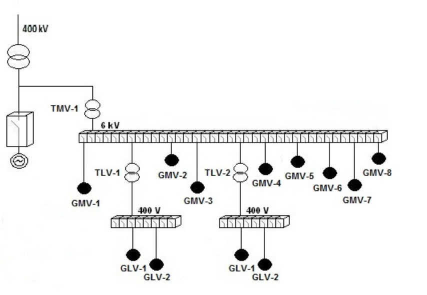

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Variables and Constraints

Decision Variables

- Strategy 1:
  - ✓ One binary variable per group of drives.
  - ✓ Set to 1 if the final motor is a high efficiency one.
- Strategy 2:
  - ✓ One binary variable per group of drives.
  - ✓ Set to 1 if the final motor has a VSD.
- Strategy 3:
  - ✓ One continuous variable per group of drives and per transformer.
  - ✓ Measures the amount of reactive power compensated for.

Constraints

- Strategies 1 & 2: The final situation is never worse than the initial situation.
- Strategy 3: The reactive power to be compensated for is never higher than the reactive power needed.

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Features of the Model

The Plant

- Thermal (coal) plant.
- 1,100 MW.
- Two units of pumps and fans.
- DM: Engineer of Endesa Generation.

Number of variables

- 22 binary.
- 13 continuous.

Again a Black Box!

- The whole network is interconnected.
- Each strategy modifies the powers needed by the drives, and the powers accumulated up to the transformers.
- Black box to simulate the system.
- Non-convex, discontinuous functions.
- Hybrid Interactive + EMO Techniques.

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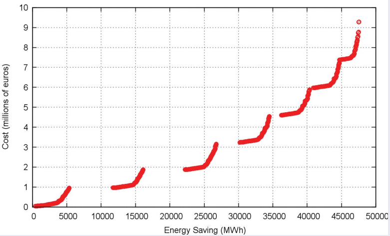
What we learnt

- Energy saving and investment are directly proportional.
- From an overall perspective, the IRR decreases as the energy saving increases.
- In general:
  - ✓ Higher energy savings ⇒ higher investments and lower IRR values.
  - ✓ Higher IRR values ⇒ lower investments and lower energy savings.

Energy Saving vs. Investment



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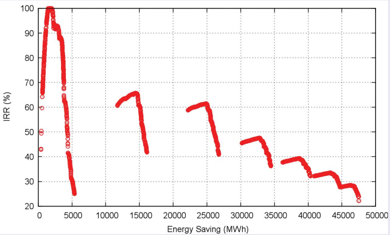

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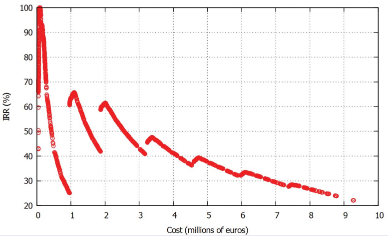
Investment vs. IRR



Phase 2: WASFGA (Ruiz, Saborido, Luque, 2015)

Solutions. Reference point: $\mathbf{q} = (30,000 \text{ MWh}, 4 \text{ million } €, 60\ \%)$.

- Solutions with higher IRR values, but less energy efficient.
- Solutions with higher energy savings, but lower IRR values.
- Final solution selected.

Sol.	Energy Saving (MWh)	Investment (million €)	IRR (%)
1	25,395.35	2.155	58.34
2	25,560.07	2.269	55.66
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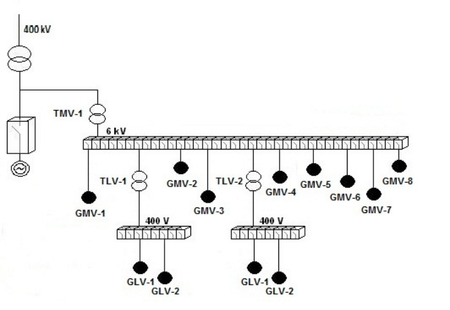
Analysis of the Results

Initial Situation



Analysis of the Results

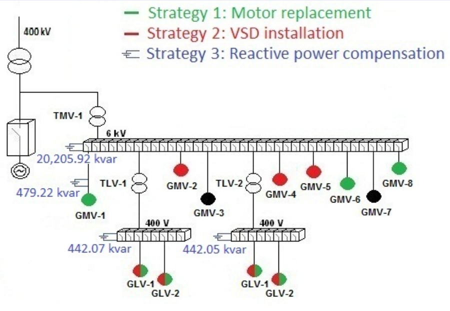
Objectives

- Energy saving: 34,091 MWh
- Investment: 3,992 million €
- IRR (10 years): 41.36 %

Improvements

- Replacement of motor: 5 groups
- Installation of VSDs: 5 groups
- Capacitors: 3 transformers and 1 group

Final Solution



What is Needed in Real Applications?

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  - ✓ Importance of intuition.
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OR as a Learning Process

We all Learn

- The modelling process itself is a rich learning phase for both the analyst and the DM.
- During the interactive phase, we learn:
  - ✓ About the structure of the feasible set.
  - ✓ About the tradeoffs among the objectives.
  - ✓ About the impact of the DM's preferences on the solutions obtained.
- It is only this learning process what makes the analyst and DM confident about the final solution obtained.

Thank you!