Decision Analysis Applications: Two water resources case studies

DEIO

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Agenda

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- Background
- Case 1: Kwanza river management
- Case 2: Fair water distribution in Kabylia
- Common lessons

Background

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Background

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- Two case studies in water resources management
- Africa (Angola, Algeria)
- Spanish Cooperation Agency (us, local uni, one or more local agents)
- Complex
- Policy making (public policy decision making)
- Decision Analysis
  - Stochastic Multiobjective Multiperiod
  - Multiobjective (Equity, Cost)

Case 1: Kwanza river management

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Background info. The Kwanza river

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- Divided in three parts: Upper Kwanza, Middle Kwanza, Lower Kwanza
- Length: 960 Km
- Basin area: 152,570 Km2
- Flow average: 825 m3/s

Background info. Angola

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- Estimated population: 17600000 inhabitants
- Human Development Index (2007):0.564, place 143 of 182
- Gross Domestic Product per capita (2008): US$ 4961
- **Population without access to improved water source (2006): 49%**
- **Population without access to energy (2005): 13,5 million of persons**
- **Electrification rate: 15% between 2000 and 2005**
- **Proportion of renewable energy supply: approximately 1% in 1990 and 1.5% in 2005**
- Number of hydrographic basins: 47, the most important is the Kwanza river.

Background info.

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Capanda

Cambambe

Problem formulation. Objectives

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- Maximize energy production
- Minimize water releases through both spillgates
- Minimize water deficit for irrigation
- Minimize water deficit for human consumption

Changed several times

Problem formulation. Uncertainties

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- Water inflow to Capanda
- Evaporated water in Capanda
- Similarly in Cambambe
- Water demand for irrigation in Luanda
- Water demand for human consumption in Luanda

Problem formulation. Constraints 1

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- Energy production constraints

For Capanda:

$$e_{Pt} = 9.0252 * h_P * U^1_{Pt}$$

Simlarly for Cambambe

Problem formulation. Constraints 2

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- Release constraints

Water through Capanda turbines smaller than the maximum

It. Through Capanda spillgates

It. Through Cambambe

Releases should respect navigability minima…

There is a maximum capacity for water treatment

Problem formulation. Constraints 3

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- Storage constraints

Storage at Capanda smaller than maximum

It. Cambambe

Continuity constraints

$S_{B(t+1)} = S_{Bt} + i_{Bt} - (U^1_{Bt} + U^2_{Bt}) - ev_{Bt}$

$i_{Bt} = U_{P(t-1)} + \beta_t * i_{Pt} - i_{P(t-1)}$

$S_{B(t+1)} = S_{Bt} + (U^1_{P(t-1)} + U^2_{P(t-1)}) + \beta_t * i_{Pt} - i_{P(t-1)} - (U^1_{Bt} + U^2_{Bt}) - ev_{Bt}$

Preference modelling.

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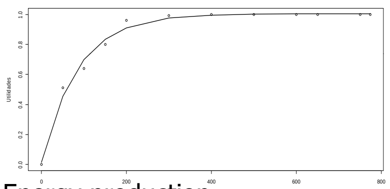

- Energy production

$g_1(e_t) = 1.005 - 0.991 * \exp(-0.012 * e_t)$

- $g^t(\text{dec, inc}) = 0{,}30 g_1(e_t) + 0{,}15 g_2(U^2_{Pt}) + 0{,}15\, g_3(U^2_{Bt}) + 0{,}17\, g_4(k_t) + 0{,}23 g_5(h_t)$

Uncertainty modelling. Inflows to Capanda

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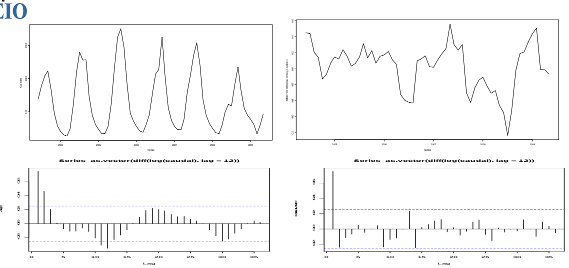

$y_t = -0.6637 * y_{t-13} + y_{t-12} + 0{,}6637 * y_{t-1} - 0{,}1683 * e_{t-13} - 0{,}5807 * e_{t-12} + 0{,}2899 * e_{t-1} + e_t$

Transform back!!

Uncertainty modelling. Inflows to Cambambe 1

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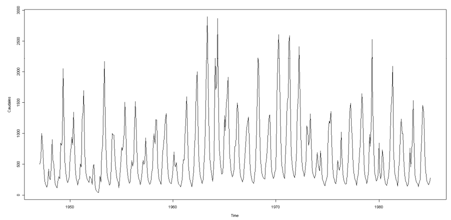

$y_t = 0{,}7907 * y_{t-1} + y_{t-12} - 0{,}7907 * y_{t-13} + e_t - 0{,}9971 * e_{t-12}$

Uncertainty modelling. Inflows to Cambambe 2

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Simulate to generate data for same years as Capanda

Regression model: i_{Bt} = alpha+beta *i_{Pt}

Uncertainty modelling. Water demand at Luanda 1

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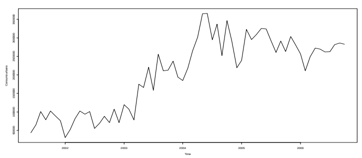
- Water demand for human consumption:



$y_t = y_{t-1} + e_t - 0{,}3892 * e_{t-1}$

Uncertainty modelling. Evaporation

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Visentini's approach. Relates evaporation with temperature.

For Capanda, the evaporation height estimated equation is:

$$\hat{e}vh_{Pt}=0{,}32T^2$$

Similarly, for Cambambe

Problem formulation 1

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The problem consists of maximising the following expected utility:

$$\Psi(U) = \int \ldots \int \Sigma[(0{,}55(1.027 - 1.012 * \exp(-0.0056 * e_t)) + 0.01(-0.045 + 1.098 * \exp(-0.475 * U^2_{Pt}))+0.01(-0.045 + 1.098 * \exp(-0.475 * U^2_{Bt}))+0.33(0.020 + 0.984*\exp(-0.083*k_t))+0.10(-0.007 +1.058 * \exp(-1.232 * h_t))]h(i,u)d\hat{i}_B\, d\hat{i}_p\, d\hat{u}_{urb}\, d\hat{u}_{irr}$$

Problem formulation 2

Subject to constraints

$0 \le U^1_{Bt} \le 725.76$

$0 \le U^2_{Bt} \le 27319.68$

$0 \le U^1_{Pt} \le 1036.8$

$0 \le U^2_{Pt} \le 21254.4$

$U^1_{Bt} + U^2_{Bt} - (U_{irrt} + U_{urbt}) \ge 285.12$

$U_{urbt} \le 8.29$

Problem formulation 3

$S_{B(t+1)} = S_{Bt} + (U^1_{P(t-1)} + U^2_{P(t-1)}) + \beta_t * i_{Pt} - i_{P(-1)} - (U^1_{Bt} + U^2_{Bt}) - ev_{Bt}$

$S_{P(t+1)} = S_{Pt} + i_{Pt} - (U^1_{Pt} + U^2_{Pt}) - ev_{Pt}$

$0 \le S_{Bt} \le 800$

$0 \le S_{Pt} \le 3450$

Problem solution. MC Approximation of objective function

- $1/N \, \Sigma[(g_t(U^1_{Bt}, U^2_{Bt}, U^1_{Pt}, U^2_{Pt}, U^j_{irrt}, U^j_{urbt}, i,d) + (g_{t+1}(U^1_{Bt+1}, U^2_{Bt+1}, U^1_{Pt+1}, U^2_{Pt+1}, U^j_{irr(t+1)}, U^j_{urb(t+1)}), i,d) + \ldots]$

Similarly for gradient

Problem solution. MC Approximation of objective function

- $1/N \, \Sigma[(g_t(U^1_{Bt}, U^2_{Bt}, U^1_{Pt}, U^2_{Pt}, U^j_{irrt}, U^j_{urbt}, i,d) + (g_{t+1}(U^1_{Bt+1}, U^2_{Bt+1}, U^1_{Pt+1}, U^2_{Pt+1}, U^j_{irr(t+1)}, U^j_{urb(t+1)}), i,d) + \ldots]$

Similarly for gradient

Problem solution. Number of stages vs Sample size (MATLAB on a standard Laptop)

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N / T	100	200	300	400	500
2	87.75	205.61	718.70	542.80	838.95
3	359.61	2030.80	4269.10	21871	7952.6
4	1073.3	9688.8	17748	5552.4	12382
5	4334.6	7187.5	15176	35756	65003
6	1504.4	1149	28218	110260	29911

Problem solution. Strategy adopted

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At a given time:
Forecast for next twelve months. (Inflows, Demands, 'Evaporations')
Optimise/plan for next twelve months. (Solve MEU)
Implement optimal alternative obtained this month.
Collect data for forecasting model.
Move to next time.

Variants:

- A different number of months
- Add a penalty term to mitigate miopicity

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Problem solution. An example of a run

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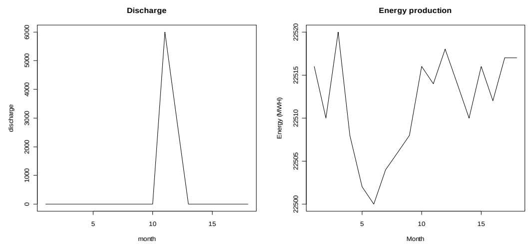
18 months planning. At each stage, 12 months. MC size 500.



Discussion

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- A complex decision making problem
  - Uncertainty
  - Multiple objectives
  - Multiperiod
  - Computational complexities
  - Partial lack of data
- Encouraging results
- Changing from BJ to DLMs
- A DSS based on this
- But still underutilised resources:
  - Capacity expansion
  - Impact within national energy mix
  - Increasing reliability of transmission

Case 2: Fair water distribution in Kabylia

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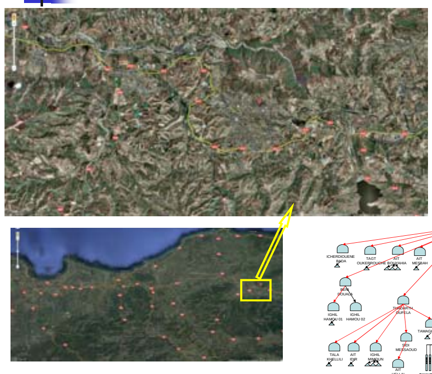
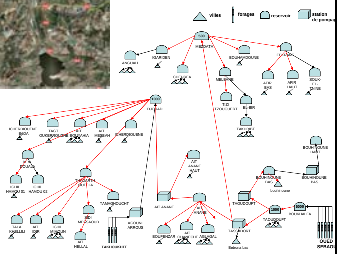
Background info





Background info

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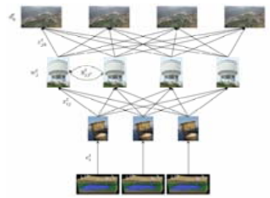
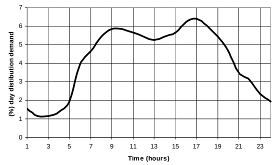
- Total area: 2957 km^2;
- 67 municipalities (1380 villages);
- Total population: 1,100,000;
- Population over 900 m: 110,000 (90 villages);
- Annual rainfall: 900 mm;
- Groundwater: 72%;
- In 2009: 6,500,559 m^3, up to 80% losses;

- 9 wells (Bouaid), pumping capacity: 1,040 $m^3 h^{-1}$;
- 5 wells (Takhoukht) pumping capacity: 140 $m^3 h^{-1}$;
- Taksebt reservoir, pumping capacity: 140 $m^3 h^{-1}$;
- 38 reservoirs (storage capacity: 28,000 m^3);
- 6 intermediate pumping stations 5,400 $m^3 h^{-1}$;





Description of the problem

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- Distribute water in a equitable & cost-efficient way.
- Difficulties to satisfy water demand adequately. Frequent water shortages create political unrest
- (Optimization of the pump operational schedules & strategic planning).
- Complex rules in energy fares (daytime & contractual issues).
- Pumping water uphill creates important engineering problems & high costs due to electricity consumption

Formulation of problem

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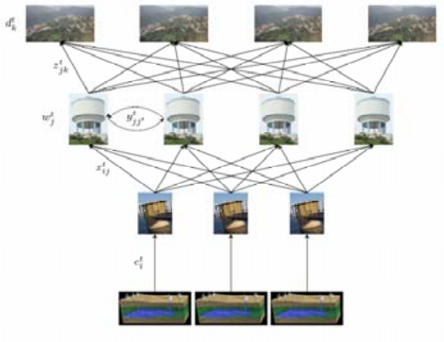

Solutions to the problem

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- **Egalitarian solution** (suggested by the water company), inflict same per capita water deficit L_k to all users & minimize L_k;
- **Smorodinsky-Kalai**, min-max L_k;
- **Utilitarian solution**, maximize sum of attained utilities (minimizing sum of $L_k \Rightarrow$ minimize average per capita water deficit);
- **Variance solution** (not an arbitration solution), minimize standard deviation of L_k;
- Minimize **inter** and **intravariability.**

Formulation of the problem

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- OBJ1: Minimize Cost (total electricity pumping consumption);
- OBJ2: Achieve equitable distribution.
- CONSTRAINTS:
  - Pumping capacity;
  - Storage capacity;
  - Water flow capacity;

Generation of Pareto frontiers

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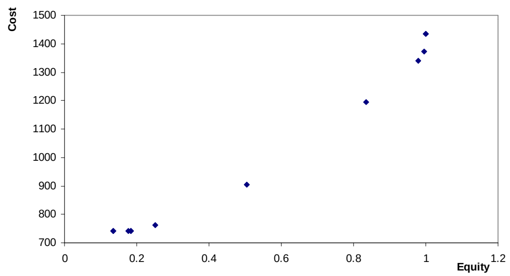

Case study

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- Two scenarios of distribution network losses (50% and 80% over-demand).
- Four infrastructure scenarios.

Scenario / Infrastructures	Base		50% Losses		80% Losses	
	Cost	Quality	Cost	Quality	Cost	Quality
Current	1,00	100%	1,27	99,8%	1,66	97,95
Optimal	0,88	100%	1,18	99,8%	1,62	98,1%
Takhoukhte	1,08	100%	1,68	98,7%	1,79	95,2%
Ait Anane-Djouad	1,11	96,6%	1,14	93,1%	1,25	89,3%

Case study

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- DSS under development
- Previously 'fixed' demand
- Demand data unavailable until this project
- DLM model per village. Hierarchical approach. Censored data
- Stochastic programming

Common lessons

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Common lessons

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- Multiple objectives
- Unclear objectives which evolved
- Uncertainty
  - Lack of data (simulate, extrapolate, censored)
- Planning over time
- Computational compromises with standard textbook DA
- No participation

- First quantitative approaches for our clients
- Encouraging results
- Unveil new realities
  - Angola (Capacity expansion, Transmission reliability)
  - Algeria (Thefts, Modify network, Reliability)