MATHEMATICAL PROGRAMMING APPROACHES FOR PROCUREMENT IN WATER IRRIGATION SYSTEMS

Manuel Díaz-Madroñero
Universitat Politècnica de València (UPV)
Research Centre on Production Management and Engineering (CIGIP)

ALSIA – Agrobios
Metaponto, 11th July 2019

AGENDA

1. Presentation
   i. Personal
   ii. UPV-CIGIP
   iii. Research lines
2. Mathematical programming and optimization approaches
3. Water resources management problems
4. Mathematical Programming Model for Procurement Selection in Water Irrigation Systems. A Case Study
5. Open questions

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PRESENTATION

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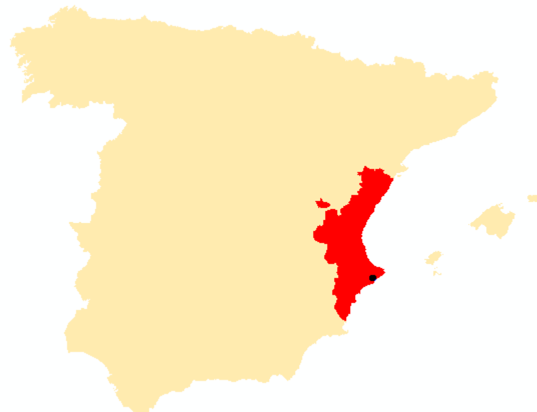
PRESENTATION

RISK-UNCERTAINTY-COLLABORATION AGRICULTURE PRODUCTION SYSTEMS



UNIVERSITAT POLITÈCNICA DE VALÈNCIA

CAMPUS D'ALCOI

PRESENTATION

Master's Degree in Organisational and Logistics Engineering

Information Systems
Quantitative Methods for Industrial Organization

Master's Degree in Business Administration

Technology And Operations Strategy

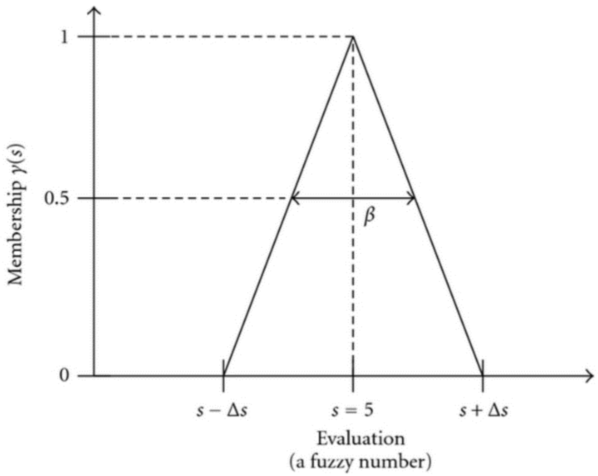
PRESENTATION

RISK-UNCERTAINTY-COLLABORATION AGRICULTURE PRODUCTION SYSTEMS

22 years
30 people
95 R+D projects
22 research lines
900 publications
125 contracts with companies

My research lines:

- Production and transport planning
- Approaches for planning under uncertain environments
- Multi-objective decision making
- Water resources and waste water plants management



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MATHEMATICAL PROGRAMMING

- Operations research employs the scientific method as a basis to deal with decision making problems by designing and solving mathematical models. One of the most studied and developed is linear programming, which seeks to optimisea linear objective function that is subject to some constraints which are also linear.

- Linear programming techniques are employed in a large number of problems:
  - Production planning
  - Financial planning
  - Human resources management
  - Transport problems and distribution
  - Forest planning
  - Scheduling flights
  - etc

MATHEMATICAL PROGRAMMING

- Linear programming is a mathematical process to determine the optimum allocation of scarce resources. The Simplex Method is a widely used solution algorithm for solving linear programmes.

- Any linear programming problem consists in an objective function and a set of constraints which must satisfy the following conditions:
  - The objective function must be linear.
  - The objective must represent the decision maker’s goal and must be the maximization or the minimization of a linear function
  - Constraints must also be linear.

MATHEMATICAL PROGRAMMING

- A linear programming model consists of the following components: decision variables, objective function and constraints. These three model components are linked by mathematical relations.
  - Decision variables are those factors among which the decision maker must choose and they are controllable variables. The aim of linear programming is to find the best values for these decision variables.
  - The objective function represents the relation between decision variables and uncontrollable variables which represent the limitations imposed by the environment (interest rates, prices of raw materials, market demand, etc.).
  - Constraints express the limitations imposed on management systems owing to the relations with the environment.

MATHEMATICAL PROGRAMMING

- Building a linear programming model consists in the following steps:
    1) Defining decision variables
    2) Defining the objective or goal in terms of the decision variables
    3) Defining all the system constraints
    4) Restricting all the variables so they are not negative.

- A linear programming model can be expressed canonically as:

$$\begin{array}{ll} \text{Maximise} & c^T x \\ \text{subject to} & Ax \leq b \\ \text{and} & x \geq 0 \end{array}$$

MATHEMATICAL PROGRAMMING APPROACHES

- Integer programming
- Quadratic programming
- Nonlinear programming
- Stochastic programming
- Robust programming
- Fuzzy mathematical programming
- Multi-objective optimization
- Heuristics and metaheuristics

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Why are the water and energy terms related?

The water has a high weight...

1 m^3 = 1000 kg = 1 ton

WATER RESOURCES MANAGEMENT PROBLEMS

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How many do kilogrammes comsume each family?

Electricity;	0 kg/year
Gas;	55 kg/year
Drinking water;	120000 kg/year
Irrigation water;	3500000 kg/year·ha

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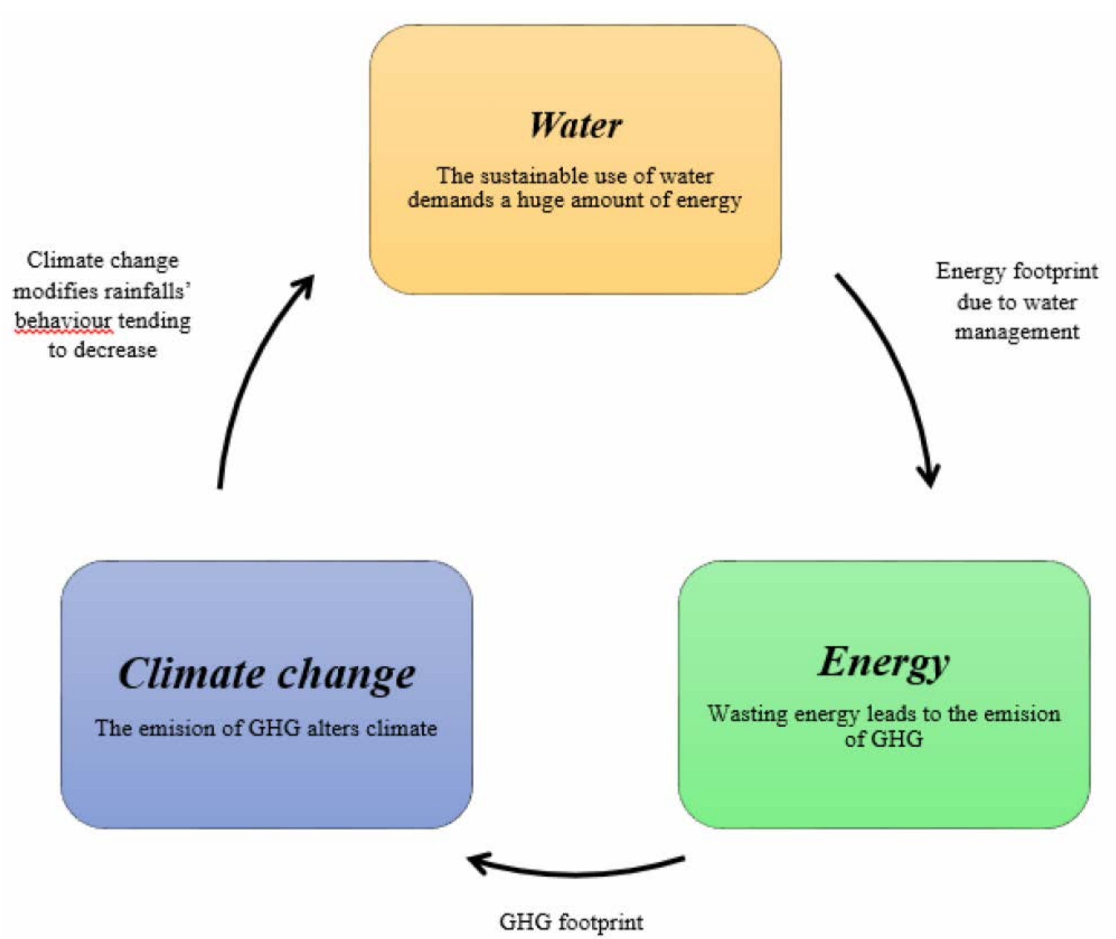
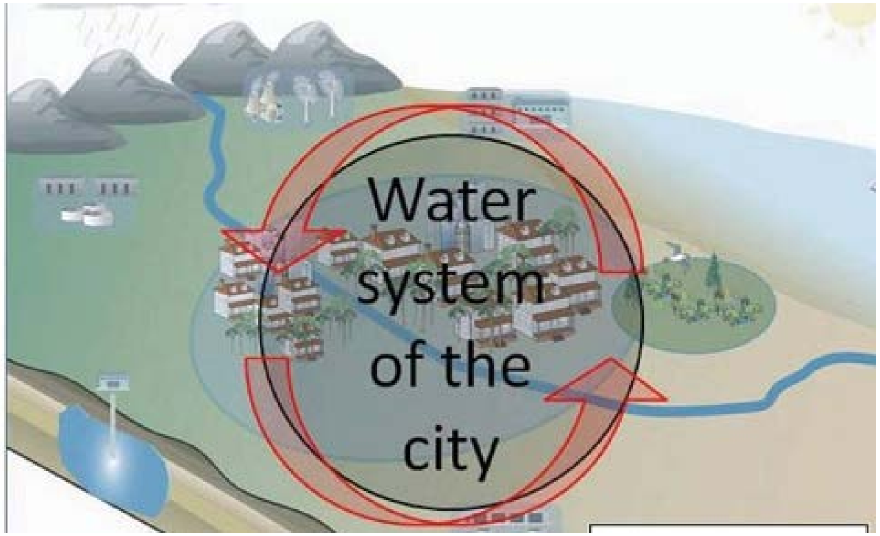
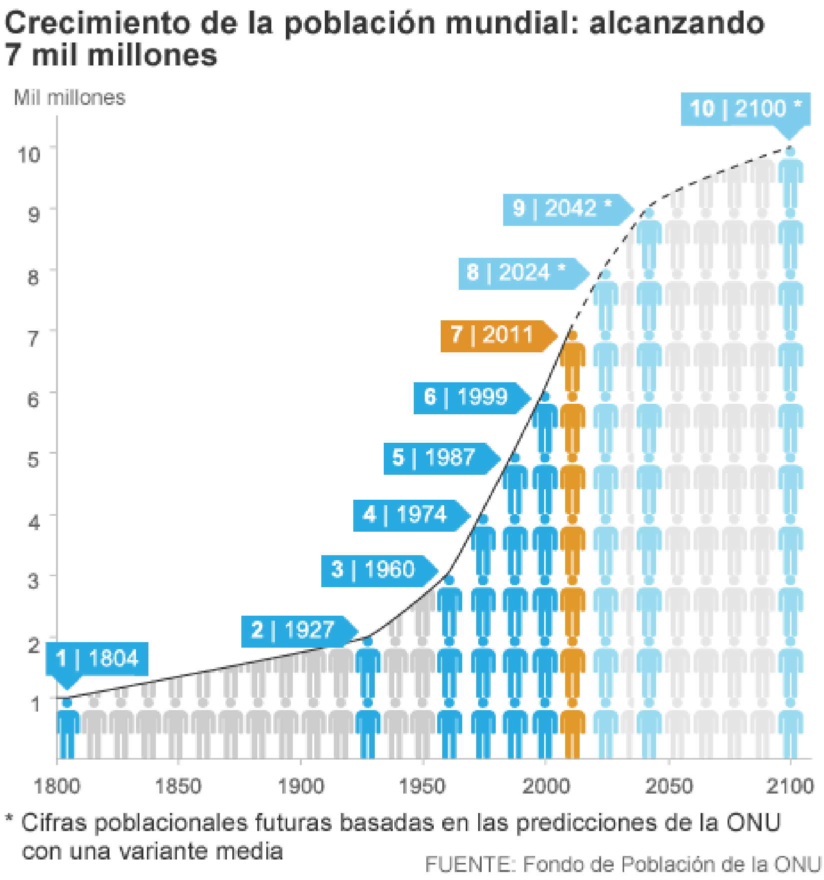


WATER RESOURCES MANAGEMENT PROBLEMS



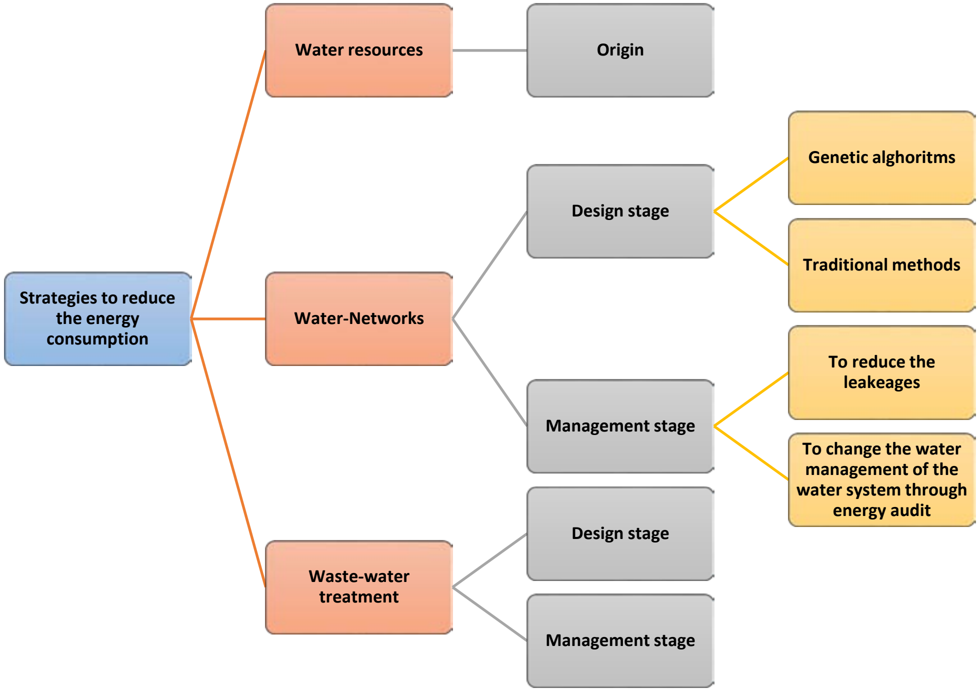


WATER RESOURCES MANAGEMENT PROBLEMS

What is the main objective currently?

The development of strategies to reduce the energy consumption along getting of water resource, distribution and recycle of the flows in the water cycle.

What could strategies be applied in the water systems?



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Research Article

Mathematical Programming Model for Procurement Selection in Water Irrigation Systems. A Case Study

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MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

- The development tools that are used to improve the water management takes on special relevance, particularly, when the area presents a high deficit of the water resource.
- Relevant in countries with increase of the population, the decrease of the water resources and the increase of the energy prices

SUSTAINABILITY

Profits of farmers

Efficient use of water resources

<u>Contribution:</u> To introduce an optimization tool for addressing the replenishment process in a local irrigation network with the aim to decide what volume is procured (source, quantity and timetable) as well as what volume is stored while minimizing the involved total costs

MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

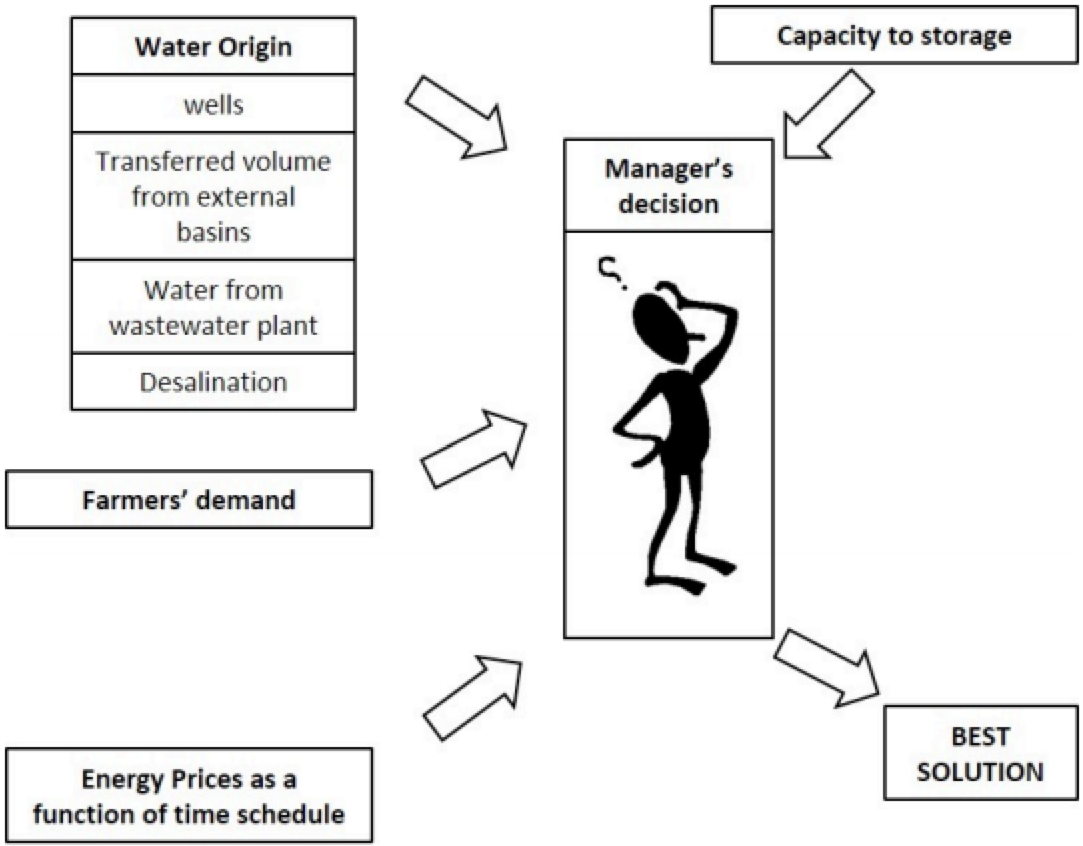


Fig. 1. Inputs to water manager's decision

Problem statement

- Given:
  - A set of water procurement sources
  - The possible procurement methods for each water source
  - The water demand over the planning horizon
  - The capacities for each source per period and method
  - Initial inventory level at the tank
  - Capacity of the tank for storing water and minimum safety stock
  - Inventory water holding cost and procurement fixed and variable costs from each source and method

Problem statement

- To determine:
  - The volume to procure from each source with each method per period
  - The water inventory level in the tank in each period
- The main goal to meet is:
  - To minimize total costs including procurement costs and inventory costs while meeting customers demand

MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

Indexes

$i \in I$	Procurement sources
$m \in M$	Procurement methods
$t \in T$	Time periods
$k \in K$	Months in the year

Sets

M_t^K	Set of time periods in month *k*

Parameters

d_t	Demand in period t (in m3)
CM_{it}	Maximum procurement level for source *i* in period *t* (in m^3)
CMT_i	Monthly maximum procurement level for source *i* (in m^3)
$CH_{i,m}$	Monthly available time for the procurement in source *i* with method *m*(in hours)
$IMIN_t$	Satefy stock level of stored water in period *t* (in m^3)
$IMAX_t$	Maximun level of stored water in period *t* (in m^3)
cpv_{imt}	Procurement variable cost for source *i* with method *m* in period *t* (in euros/m^3)
cpf_{imt}	Procurement fixed cost for source *i* with method *m* in period *t*(in euros/m^3)
ci_t	Storage cost in period (in euros/m^3)
cf_{im}	Procurement fixed cost for source *i* with method *m* over the planning horizon (in euros/m^3)

MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

Decision variables

I_t	Level of stored water in period t (in m^3)
Q_{imt}	Amount of procured water from source i with method m in period t (in m^3)
Y_{imt}	1 if any amount of water is procured from source i with method m in period t (in m^3), 0 otherwise
F_{im}	1 if any procurement from source i with method m is placed over the planning horizon, 0 otherwise

MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

RISK-UNCERTAINTY-COLLABORATION AGRICULTURE PRODUCTION SYSTEMS

Objective function

$$Min\ z = \sum_{t} ci_t \cdot I_t + \sum_{i}\sum_{m}\sum_{t} cpv_{imt} \cdot Q_{imt} + \sum_{i}\sum_{m}\sum_{t} cpf_{imt} \cdot Y_{imt} + \sum_{i}\sum_{m} cf_{im} \cdot F_{im} \quad (1)$$

Minimization of total costs

Subject to

$$I_t = I_{t-1} + \sum_{i}\sum_{m} Q_{imt} - d_t \quad \forall t \quad (2)$$

$$I_t \leq IMAX_t \quad \forall t \quad (3)$$

$$I_t \geq IMIN_t \quad \forall t \quad (4)$$

$$\sum_{m} Q_{imt} \leq CM_{it} \quad \forall i \forall t \quad (5)$$

$$\sum_{m} Y_{imt} \leq 1 \quad \forall i \forall t \quad (6)$$

$$Q_{imt} \leq CM_{it} \cdot Y_{imt} \quad \forall i \forall m \forall t \quad (7)$$

$$\sum_{m}\sum_{t \epsilon M_t^K} Q_{imt} \leq CM_{it} \quad \forall i \quad (8)$$

$$\sum_{t \epsilon M_t^K} Y_{imt} \leq CH_{im} \quad \forall i \forall m \quad (9)$$

$$I_t, Q_{imt} \epsilon \mathbb{R} \quad (10)$$

$$Y_{imt}, F_{im} \epsilon \{0,1\} \quad (11)$$

Constraint maximum, mininum (safety) and inventory balance → (2), (3), (4)

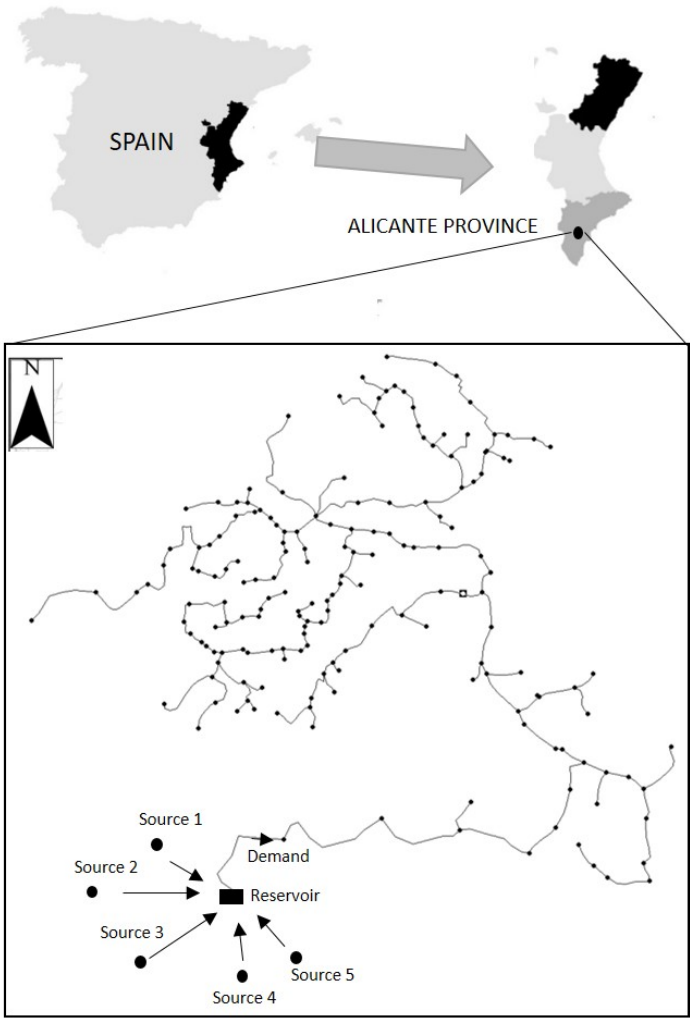
Constraint maximum capacity of source per hourly period → (5)

Constraint unique method per hourly period → (6)

Constraint maximum capacity of source per month → (8)

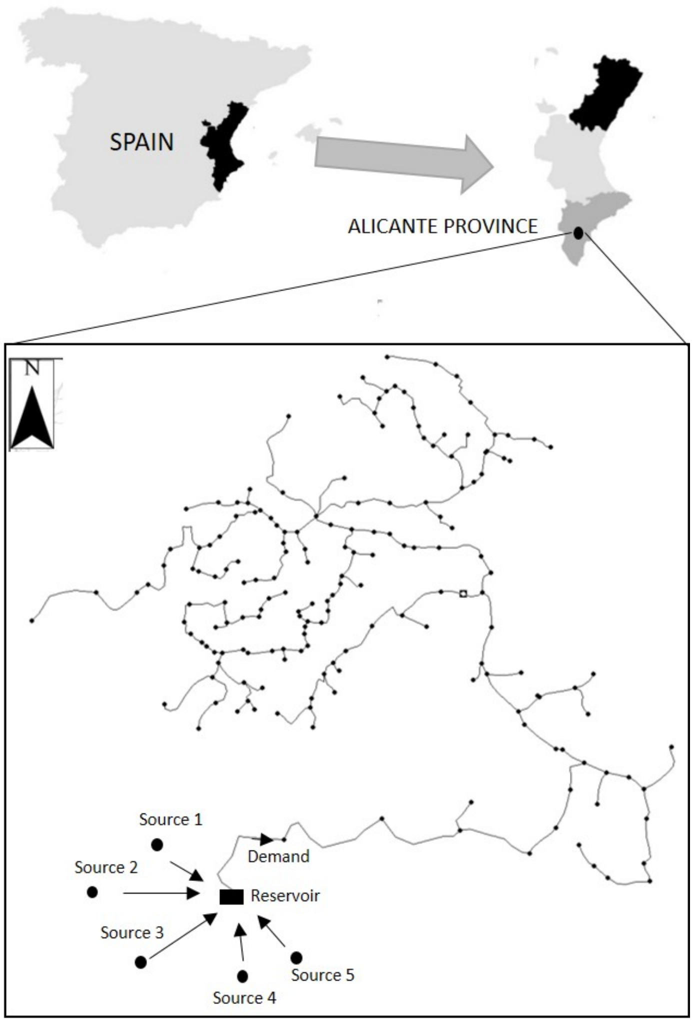
Constraint maximum capacity (in available hours) of source per month → (9)

MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

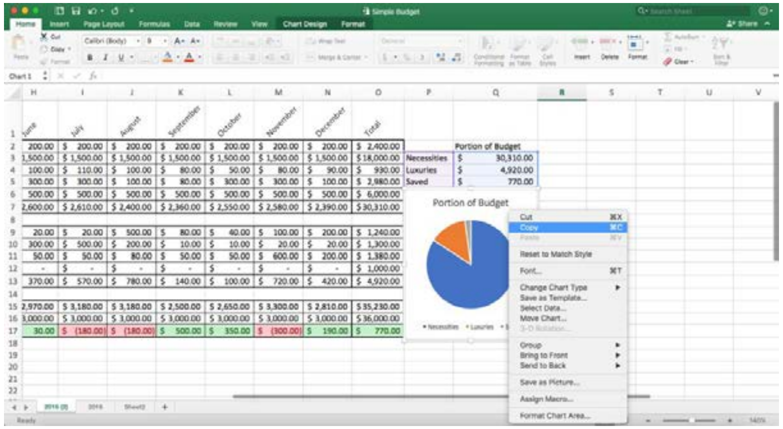


- Irrigation network that supplier 260 hectares
- Main crop is **vineyard** and some oil trees
- The topography varies between 590 m and 380 m above sea level
- The water is accumulated in a reservoir with a maximum capacity of **550000 m^3**, located at 610 m above sea level
- **5 possible sources** to get the water resource to meet the demand and **7 procurement methods** depending the time period and corresponding energy prices

MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS



- The manager and responsible of the procurement from the different sources used a **heuristic procedure** based on his experience and personal judgement supported by a spreadsheet.



SUBOPTIMAL RESULTS:
important errors that may involve substantial costs

MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

- The proposed model was implemented by using the modelling language MPL and the corresponding resolutions were carried out with Gurobi solver version 7.0.1 in a computer with a Inter Core i5 1.80 GHZ processor and 4 GB RAM memory.

MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

Table 2. Results obtained by the current procedure and the proposed model

	Current heuristic procedure (€)	Proposed model (€)
Total water management costs	128108.80	61181.31
Final inventory costs	52740.70	11203.75
Procurement variable costs	72168.09	46777.56
Procurement fixed costs	3200.00	3200.00

The proposed model reduces 52.2% the total water management costs when it is compared to the current heuristic procedure.

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OPEN QUESTIONS

Expansión

Los precios de la luz se disparan tras multiplicarse por tres la cotización del CO2

OPEN QUESTIONS

RISK-UNCERTAINTY-COLLABORATION AGRICULTURE PRODUCTION SYSTEMS

Público

PRECIO DE LA ELECTRICIDAD EN LA UNIÓN EUROPEA

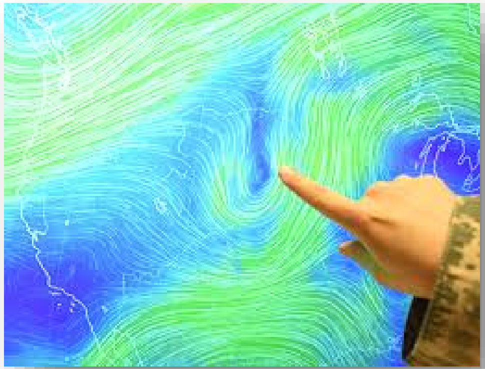
España, segundo país Unión Europea donde más creció el precio de la electricidad en 2018

El precio de la energía en 2018 pasó de una media de 21,8 euros por cada 100 kWh a 24,8 euros, un incremento del 13,8%. En cuanto a los precios del gas, España se situó como el cuarto país donde más cara fue esta forma de energía, con 8,8 euros por cada 100 kWh, un incremento del 1,2% frente a 2017 y solo por detrás de Suecia, Italia y Dinamarca.

To transform the proposed model with deterministic input data into a new model with uncertain data related to energy costs

OPEN QUESTIONS

- Profits generated by current crops?
- Changes in weather conditions?
- Anticipation of water purchases and financing through loans?



Questions? Suggestions?

Thank you very much

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