A COMBINED LINEAR OPTIMISATION METHODOLOGY FOR WATER RESOURCES ALLOCATION IN AN ALFEIOS RIVER SUBBASIN (GREECE) UNDER UNCERTAIN AND VAGUE SYSTEM CONDITIONS

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ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ, ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΣΠΑ 2007-2013
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

OVERVIEW

- Introduction in uncertainties in water resources management

- Brief description of applied methodology (Huang et al., 1992; Li et al., 2010)
- Characteristics of the studied Alfeios River Subbasin

- Formulation of the optimisation problem

- Uncertain variable identification
- Results & Conclusions

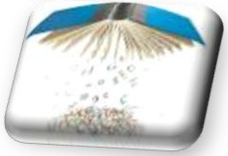
INTRODUCTION

- Uncertainties in water resources management in impact factors & system components :
  - Available water resources
  - Water Demand / supplies
  - Related cost / benefit coefficients
  - Sustainability requirements
  - Policy regulations

- In optimization problem: →
  - (A) Decision variables
  - (B) Objective function coefficients
  - (C) Constraints coefficients

- Types of uncertainty variables:
  - (A) Probability distribution
  - (B) Possibility distribution
  - (C) Interval (Upper & Lower Value)

DESCRIPTION OF METHODOLOGY



- **<u>Fuzzy-boundary interval - stochastic programming</u>** (Li et al., 2010):
  - Linear optimization problem
  - Uncertain variables: (a) favourable (X_{ij}^{+}) & (b) unfavourable (X_{ij}^{-})
  - **<u>Aim</u>**: Identification of optimal water allocation target with minimised risk of economic penalty from water shortage (water demand) & opportunity loss from spill water volumes
  - Two solution methods:
    1. "*Risk-Prone*" or "*Optimistic*" (best -case model)
    2. "*Risk-adverse*" or "Pessimistic" (worst -case model)

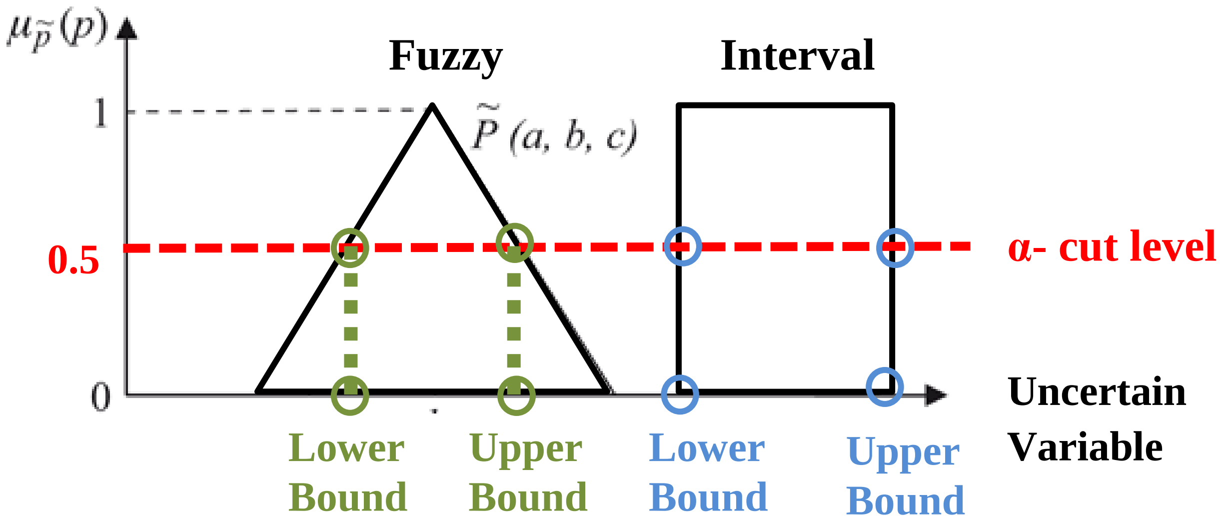
Different solution methods imply
different risk attitudes of decision makers
considering system uncertainties

DESCRIPTION OF METHODOLOGY

- Discretization of membership grade into α-cut levels (0, 1)

- Solving for each solution type and α-cut level:

  2^n deterministic submodels corresponding to all combinations of lower & upper bound value for n fuzzy / interval variables

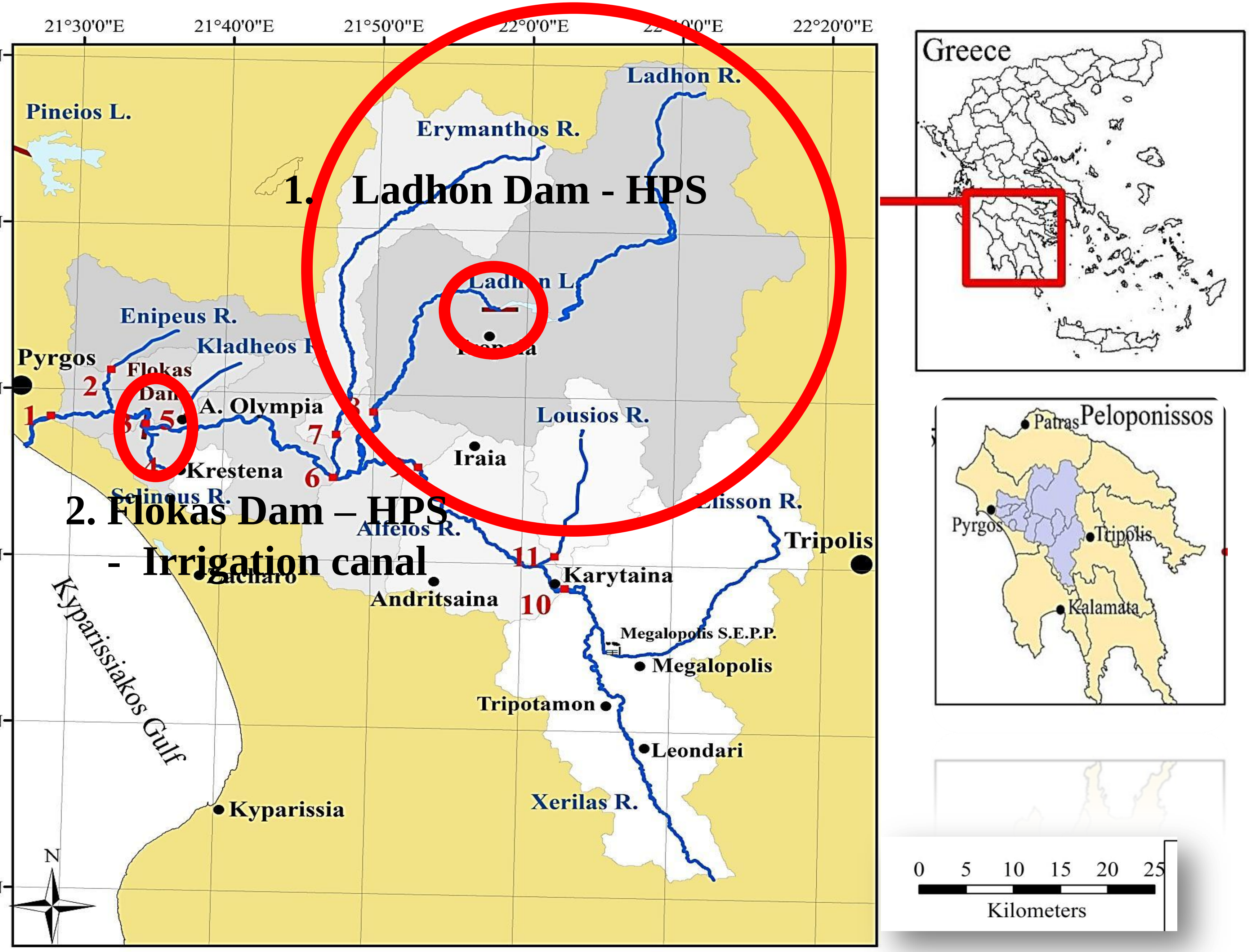


- For each solution type: $f^{\alpha}_{opt} = \{f_{min}^{\alpha}, f_{max}^{\alpha}\}$,

  where $f_{min}^{\alpha} = \min\{f_1, f_2, .., f_{2^n}\}$

  $f_{max}^{\alpha} = \max\{f_1, f_2, .., f_{2^n}\}$

EXAMINED ALFEIOS RIVER SUBBASIN



LADHON RESERVOIR & HYDROPOWER STATION

Ladhon Reservoir - Dam:

- Gross - usable storage: 57.6×10^6 - 46.2×10^6 m^3
- Main purposes: Irrigation & Hydropower production
- Monthly operational curve (target reservoir level)

Ladhon Hydropower Station:

- ~8 km downstream from Ladhon Dam
- Purpose: Satisfy peak energy demand
- Total max capacity: 70 MW
- Primary & Total Mean Annual Energy: 173 & 340 GWh

FLOKAS DAM – IRRIGATION

- **Flokas Dam:**
  - Diversion dam for irrigation purposes
  - 16 km from Kyparissiakos Gulf coastline
  - 97% of Alfeios catchment
  - **Small Hydroelectric Power Station** :

    Max power capacity : 6.6 MW

- **Flokas Irrigation canal:**
  - Present irrigated area : 50-60% Total irrigable area (12,250 ha)
  - Irrigation period : Mid April to Mid October
  - Crop pattern : Cotton, corn, alfalfa, watermelons, citrus
  - Surface and drip irrigation

OPTIMISATION PROBLEM

(A) Objective function:

Maximise Total Benefit :

Benefit(HPLadhon) - Penalty(SpillLadhon) +

Benefit(Irrigation+Extra) - Penalty(IrrigationShortage) +

Benefit(HPFlokas) - Penalty(SpillFlokas)

(B) Constraints: 1. Ladhon:

- ❑ Water Volume Mass Balance
- ❑ Min & Max pumping capacity
- ❑ Min & Max reservoir storage capacity
- ❑ Evaporation: linear F(average reservoir storage(t))

2. Flokas: (Degree of Ladhon Contribution to Flokas)

- ❑ Water Volume Mass Balance
- ❑ Min & Max pumping capacity
- ❑ Fish ladder flows & Min environmental flows

UNCERTAIN VARIABLES

VariableName	*Uncertainty Type*	*Variable Effect*
Unit Benefit HP Ladhon (€/MWh)	Fuzzy: LB (40, 50, 55), UB (60, 65, 75)	Favourable
Unit Benefit HP Flokas (€/MWh)	Interval: (80, 87.75)	-
Unit Benefit Irrigation Flokas (€/m^3)	Interval: LB (0.19, 0.2), UB (0.24, 0.26)	Favourable
Unit Penalty HP Ladhon (€/MWh)	Fuzzy: LB (90, 115), LB (0.19, 0.2)	Unfavourable
Unit Penalty HP Flokas (€/MWh)	Interval: (120, 130)	-
Unit Penalty Irrigation Flokas (€/m^3)	Fuzzy: UB (0.29, 0.31), LB (0.36, 0.39)	Unfavourable
Ladhon Contribution To Flokas (%)	Interval: (0.65, 0.71)	-

- For Hydropower Production Unit Benefit/ Penalty:
  - operators experience Flokas: Price for small HPS
  - Max observed energy sale price of Greek Energy Market
- For Irrigation Unit Benefit/ Penalty (Flokas):
  - Net agricultural income per crop + Irrigation water cost
  - Net agricultural income per crop + Groundwater pumping costs

RESULTS

❑ Optimisation using LINGO – M. Excel

❖ Available data: monthly inflows in Ladhon reservoir (2002-2012)

❖ Time step / period: Monthly / one year

❖ Selection of **a.** wet year (2003)

b. dry year (2007)

❖ Examined α-cut levels: 0 - 0.5 - 1

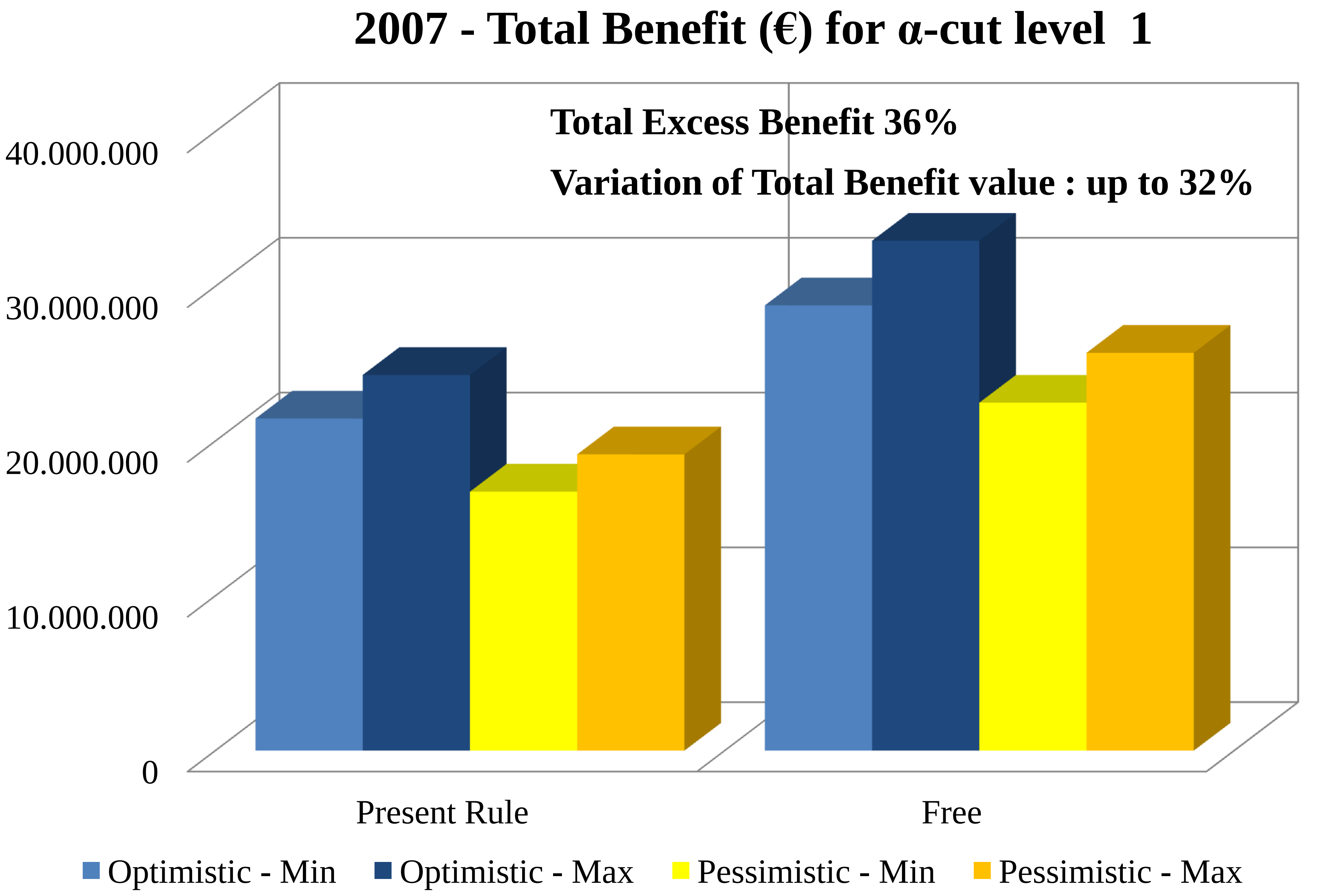
❖ Total number of deterministic submodels: 576

❑ Two alternative scenarios:

1. Present Water allocation: Min monthly reservoir water level (Ladhon)

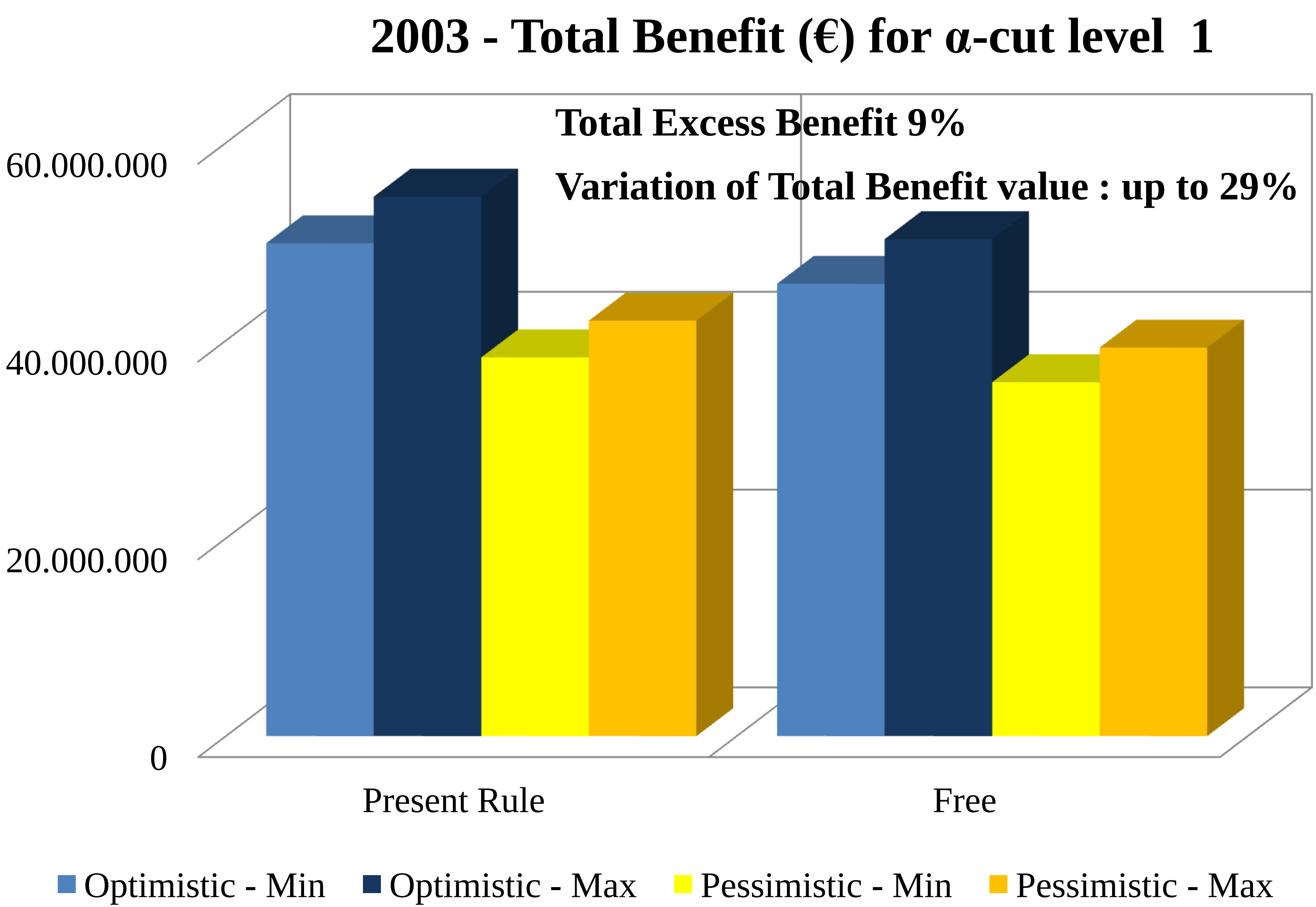
2 . Free: No operation rule (Ladhon reservoir)

RESULTS



2007 - Total Benefit (€) for α-cut level 1
Total Excess Benefit 36%
Variation of Total Benefit value : up to 32%
40.000.000
30.000.000
20.000.000
10.000.000
0
Present Rule
Free
Optimistic - Min
Optimistic - Max
Pessimistic - Min
Pessimistic - Max

RESULTS



2003 - Total Benefit (€) for α-cut level 1
Total Excess Benefit 9%
Variation of Total Benefit value : up to 29%
60.000.000
40.000.000
20.000.000
0
Present Rule
Free
Optimistic - Min
Optimistic - Max
Pessimistic - Min
Pessimistic - Max

CONCLUSIONS

- Flexible & efficient incorporation of uncertainties (intervals and fuzzy) in linear optimisation process through α-cut levels, providing a clear & comprehensive interpretation of uncertain variable values at each stage.
- Assessment & comparison of total benefit range of various water allocation pattern for a risk-prone and risk-adverse attitudes of decision makers

OUTLOOK

- Further analysis of uncertain variables: (social benefits and non consuming water uses i.e. tourism and recreation)
- Further investigation of appropriate adjustments incorporating stochastic water inflows into methodology

When you bend down and look at the waters of the Alfeios river near Olympia, their clarity is such that your face and soul are mirrored in them... The nature becomes here spirit. The clarity of waters becomes clarity of thought ...

Panayiotis Kanellopoulos (1902-1986)

Professor of Sociology, Prime Minister of Greece

Thank you for your attention!

ACKNOWLEDGEMENTS:

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

We would like to express our gratitude to:

1. Dimitrakopoulos D., Argyrakis I., Mavros I., Gatsis K., and Stathas I. from the Hellenic Public Power Corporation,
2. Panayotopoulos N., Rousakis I.from HPS Flokas,
3. Tzifas V., Altanis T. and Labadaris A.
4. Dr.-Ing Karellas S. from Laboratory of Steam Boilers and Thermal Plants School of Mechanical Engineering, National Technical University of Athens and Dipl.-Ing. Varela Gl., University of Stuttgart

for their support and for providing necessary data. This research is also supported by HYDROCRITES University Network. (http://www.hydrocrites.upatras.gr)

European Union
European Social Fund