Multi-Criteria Optimal Planning for Energy Policies in CLP

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Joint work with

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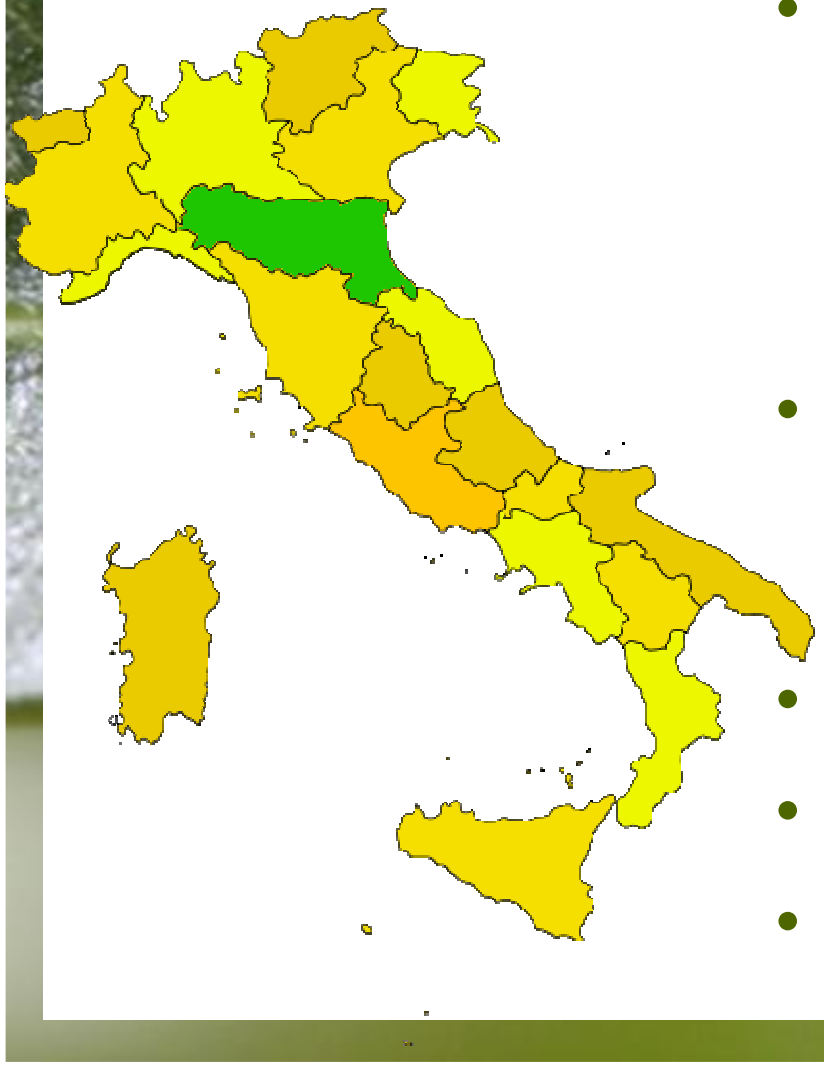
(R. Emilia-Romagna)

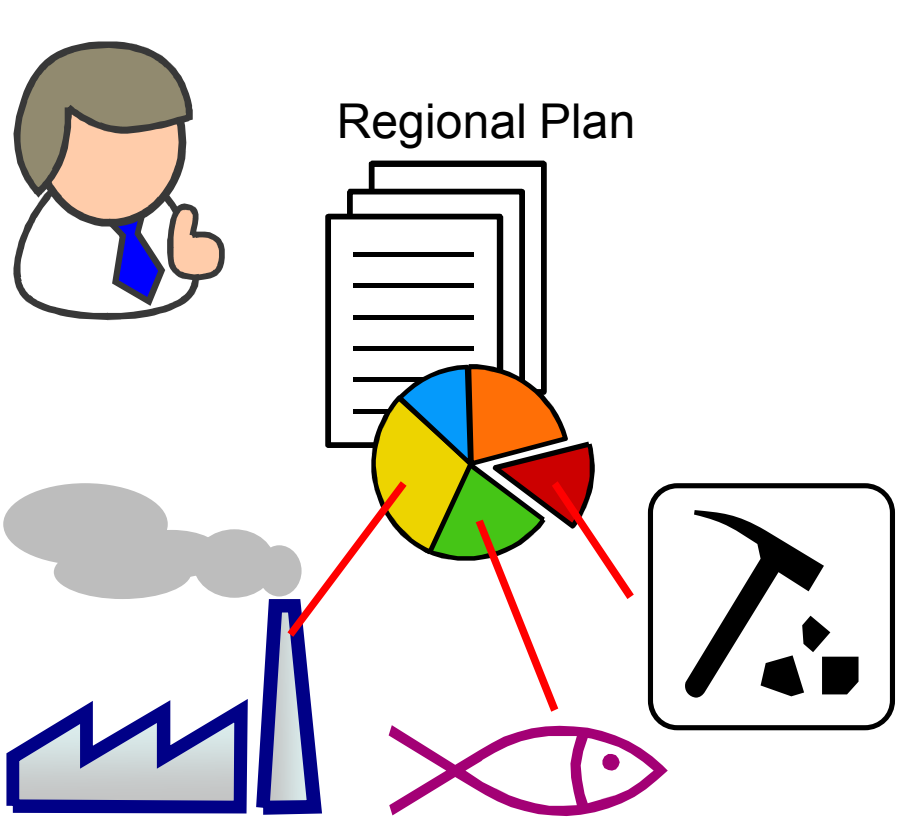
… and the other members of the ePolicy project

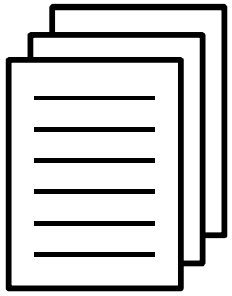
Outline



- Strategic Environmental Assessment
  - CLP(R), Probabilistic, Fuzzy
- Regional Energy Plan Emilia-Romagna, 1st prototype
- REP, Extensions
- GUI (demo) (?)
- Conclusions

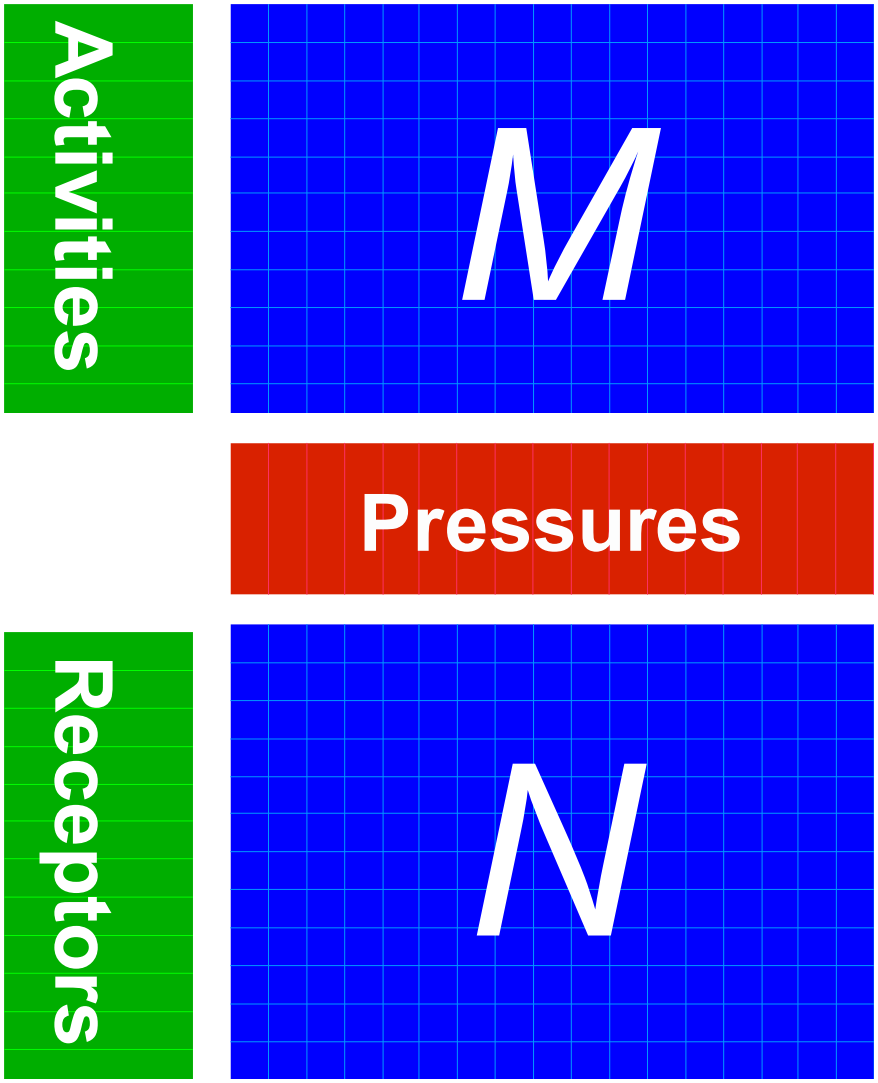
Strategic Environmental Assessment

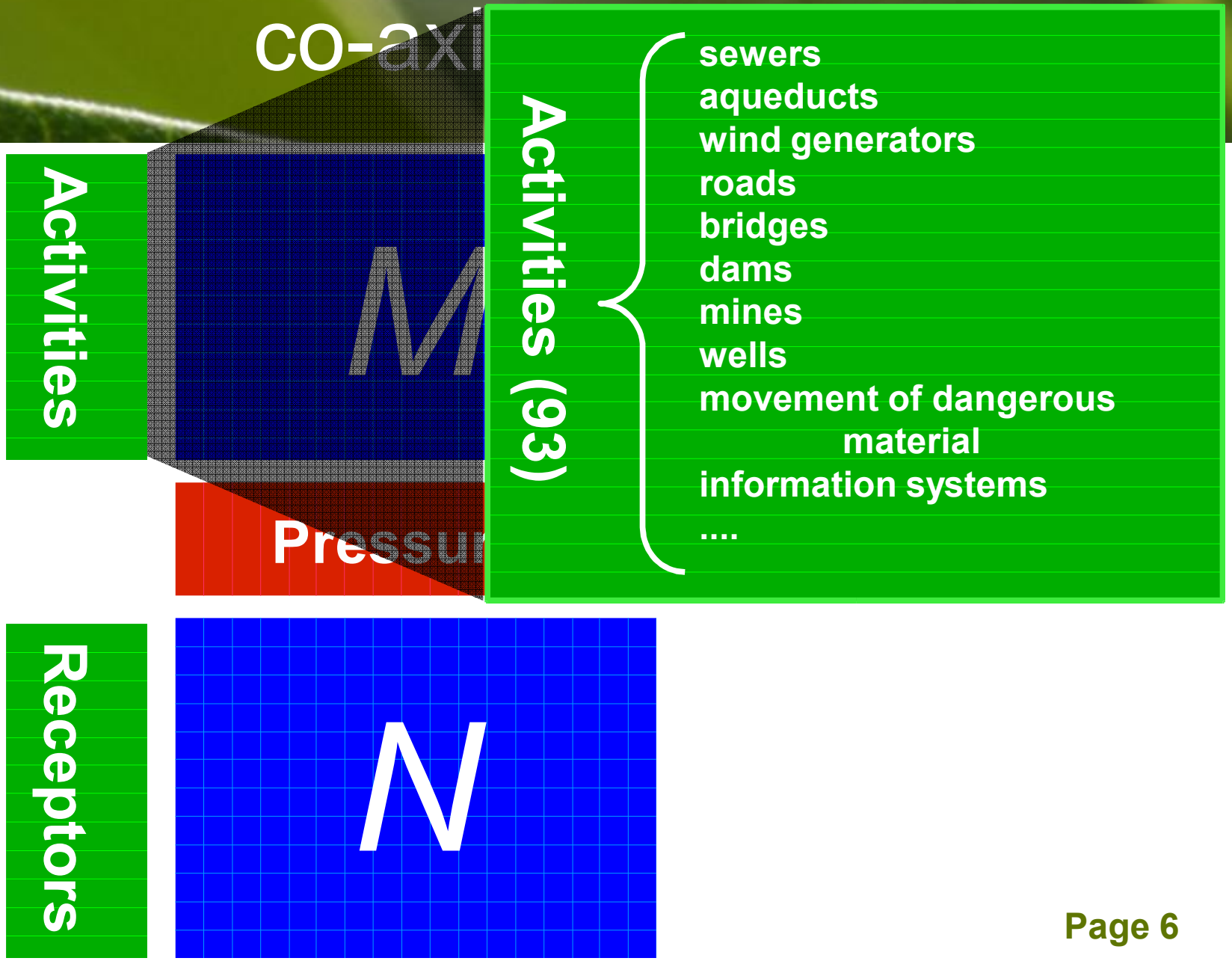




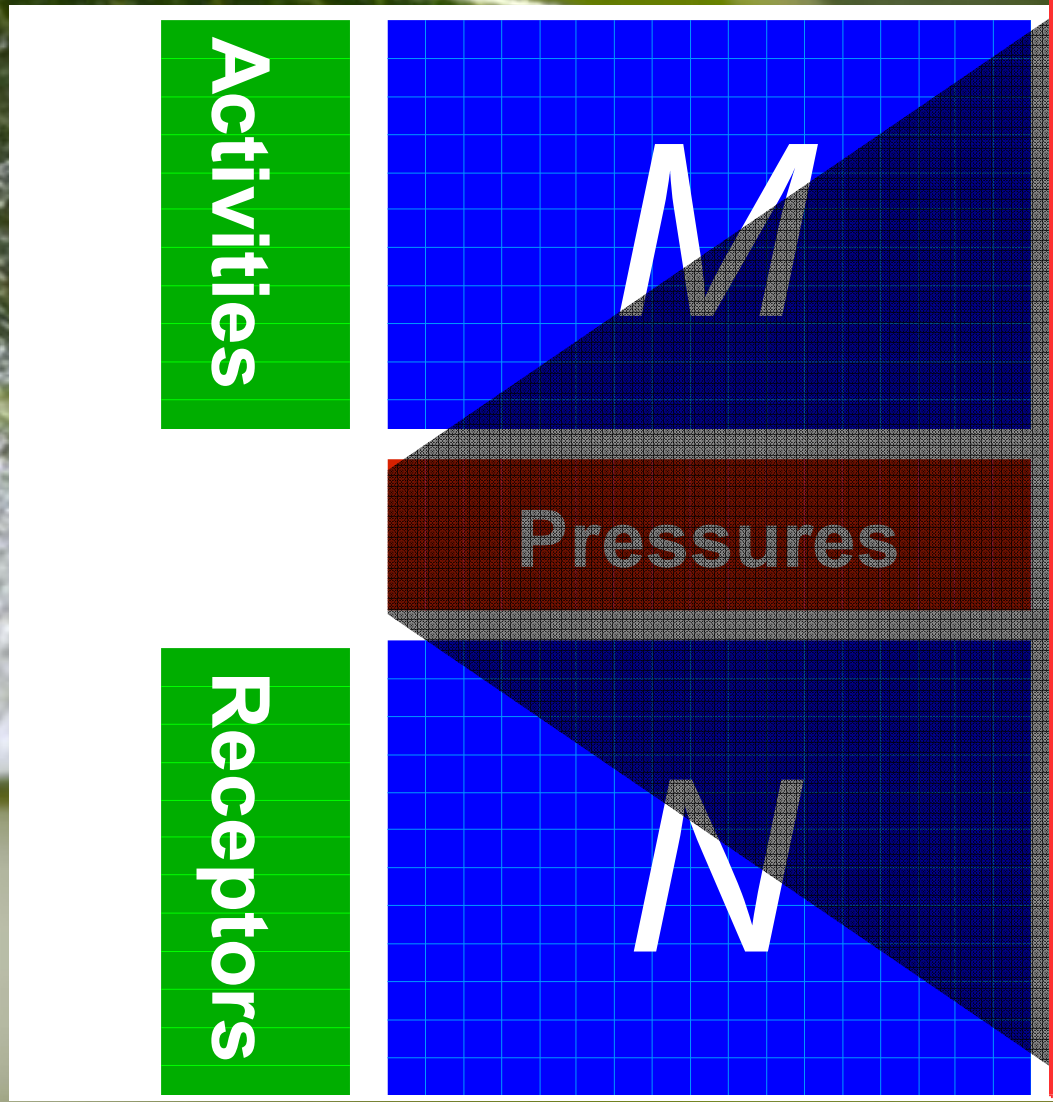
Strategic Environmental Assessment (SEA)

co-axial matrices




CO-axi
Activities
M
Pressur
Activities (93)
sewers
aqueducts
wind generators
roads
bridges
dams
mines
wells
movement of dangerous material
information systems
....
Receptors
N

co-axial matrices



Pressures

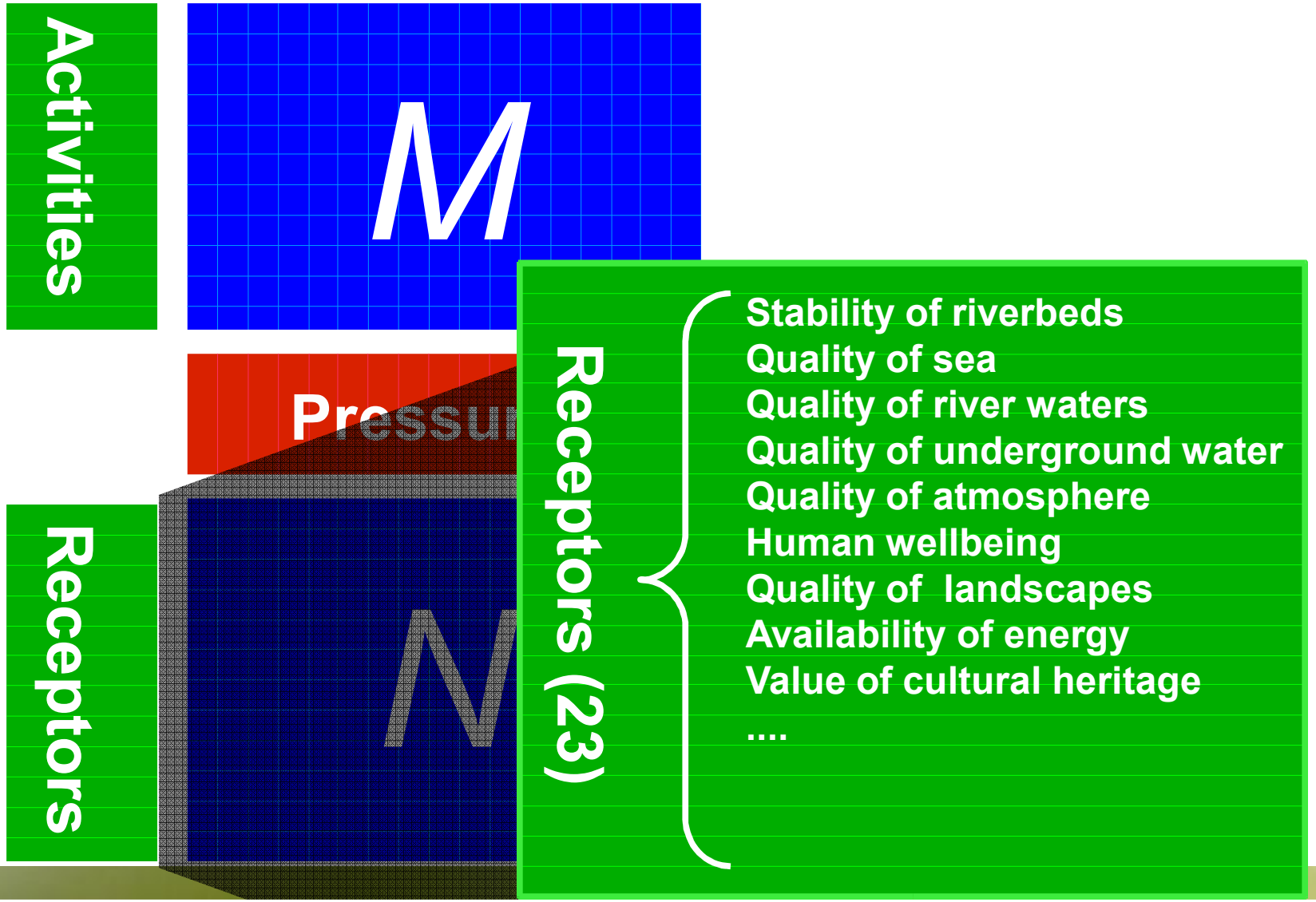
NEGATIVE: (29)

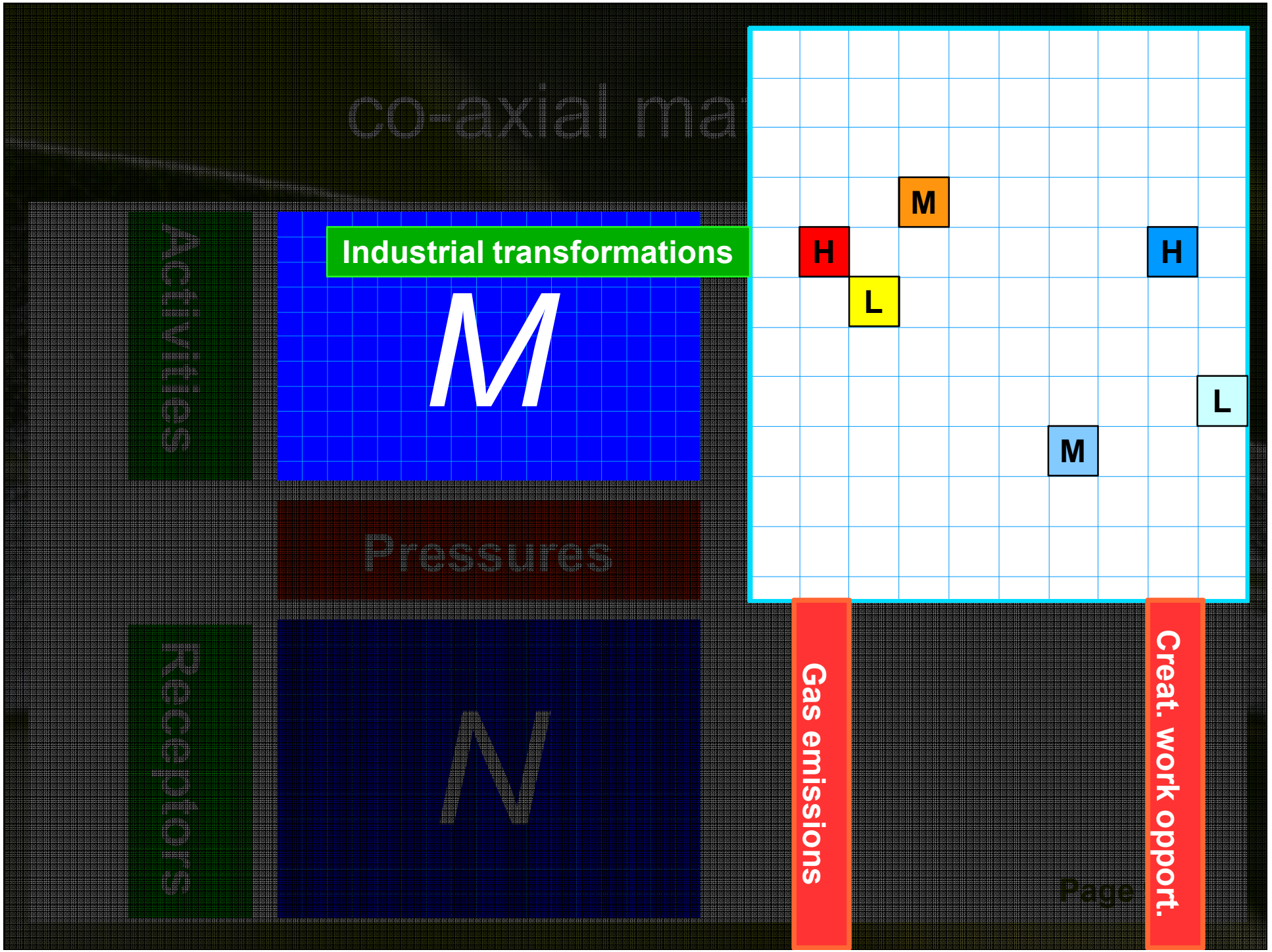
energy consumption
water consumption
modification of water flows
dispersion of dangerous material
production of waste
prod. smells
prod. noise
prod. electromagnetic fields
risk of accidents
...

POSITIVE: (19)

creation of work opportunities
reduction of pollution
creation of new ecosystems
savings of natural resources
...

co-axial matrices




co-axial ma
Activities
Industrial transformations
M
Pressures
N
Receptors
M
H
H
L
L
M
Gas emissions
Creat. work opport.
Page

[ICLP'10] CLP(R) model

- Qualitative values converted into numerical values, suggested by the expert
- Given a vector of activities, compute pressures as $\forall j, p_j = \sum m_j^i a_i$
- and receptors as $\forall j, r_j = \sum n_j^i p_i$
- Other linear constraints relating costs, primary/secondary activities, produced energy, diversification of sources, ...

H	0.75
M	0.5
L	0.25
L	-0.25
M	-0.5
H	-0.75

Logic Programs with Annotated Disjunctions

strong_sneezing(X):0.3 ; moderate_sneezing(X):0.5
:- flu(X).

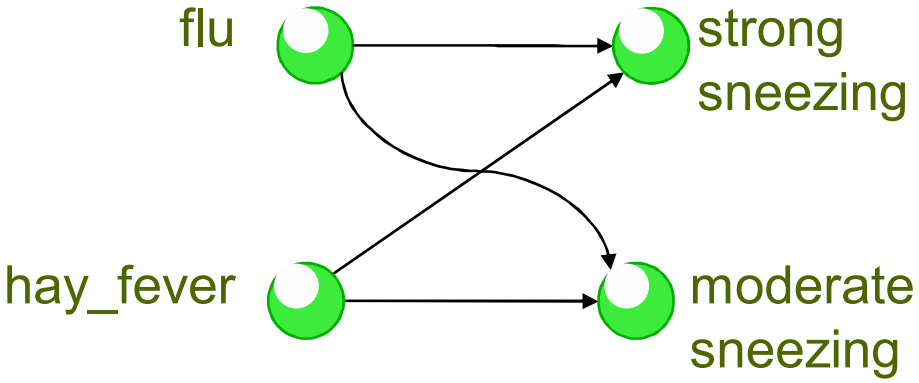
strong_sneezing(X):0.2 ; moderate_sneezing(X):0.6
:-hay_fever(X).

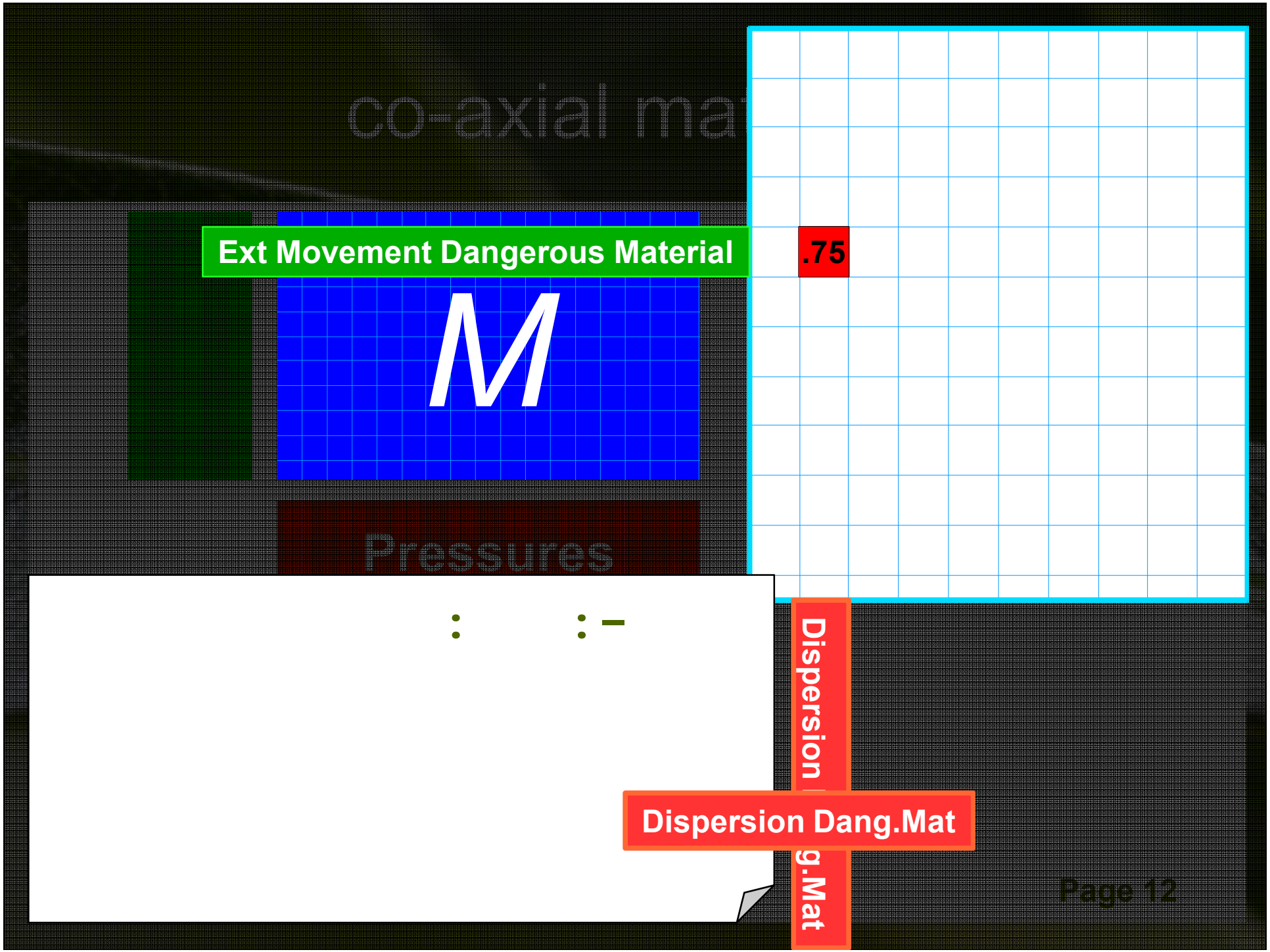
flu(david).

hay_fever(david).

- Can be converted

to a Bayesian network



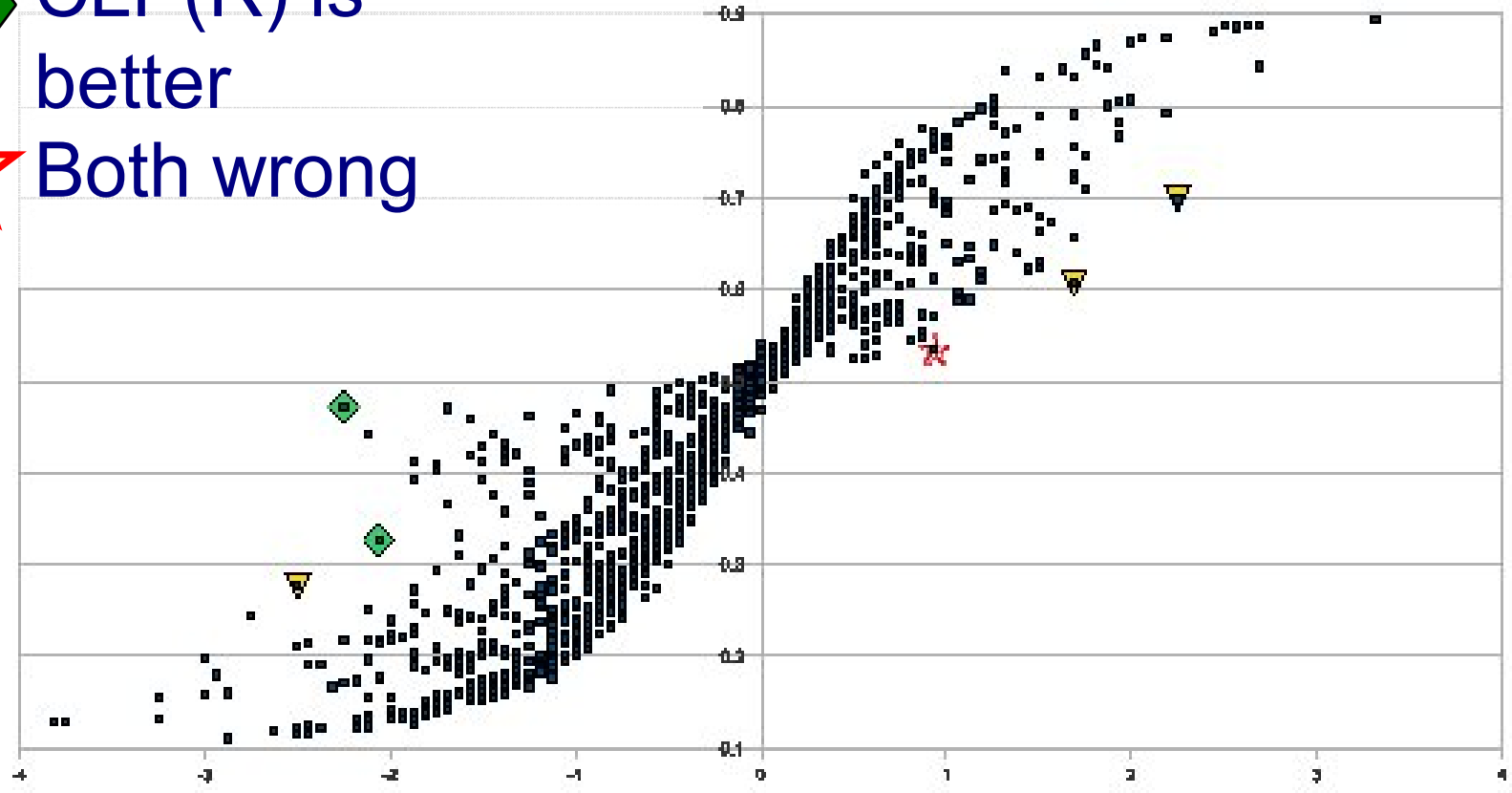

co-axial ma
Ext Movement Dangerous Material
M
.75
Pressures
Dispersion
Dispersion Dang.Mat
g.Mat

Comparison

? unable to say

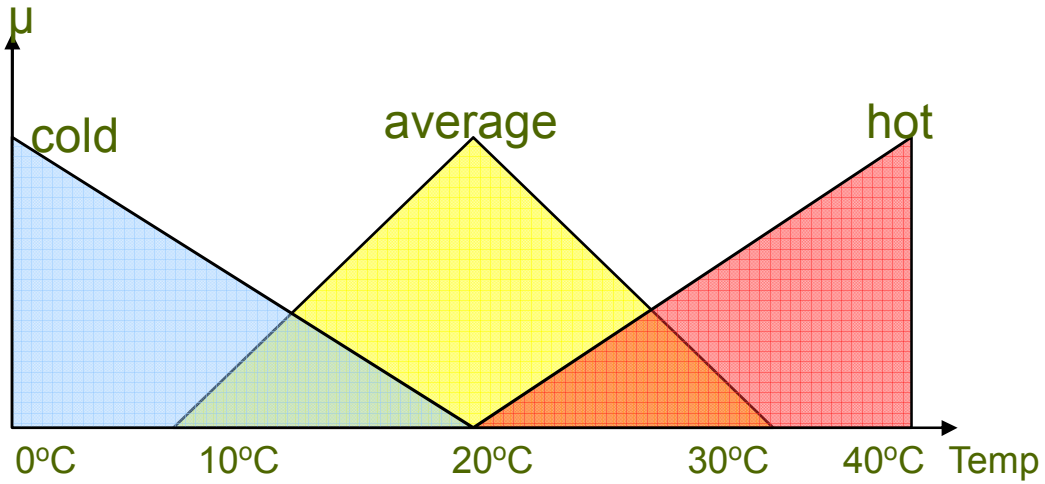
CLP(R) is better

Both wrong



Fuzzy linguistic variables

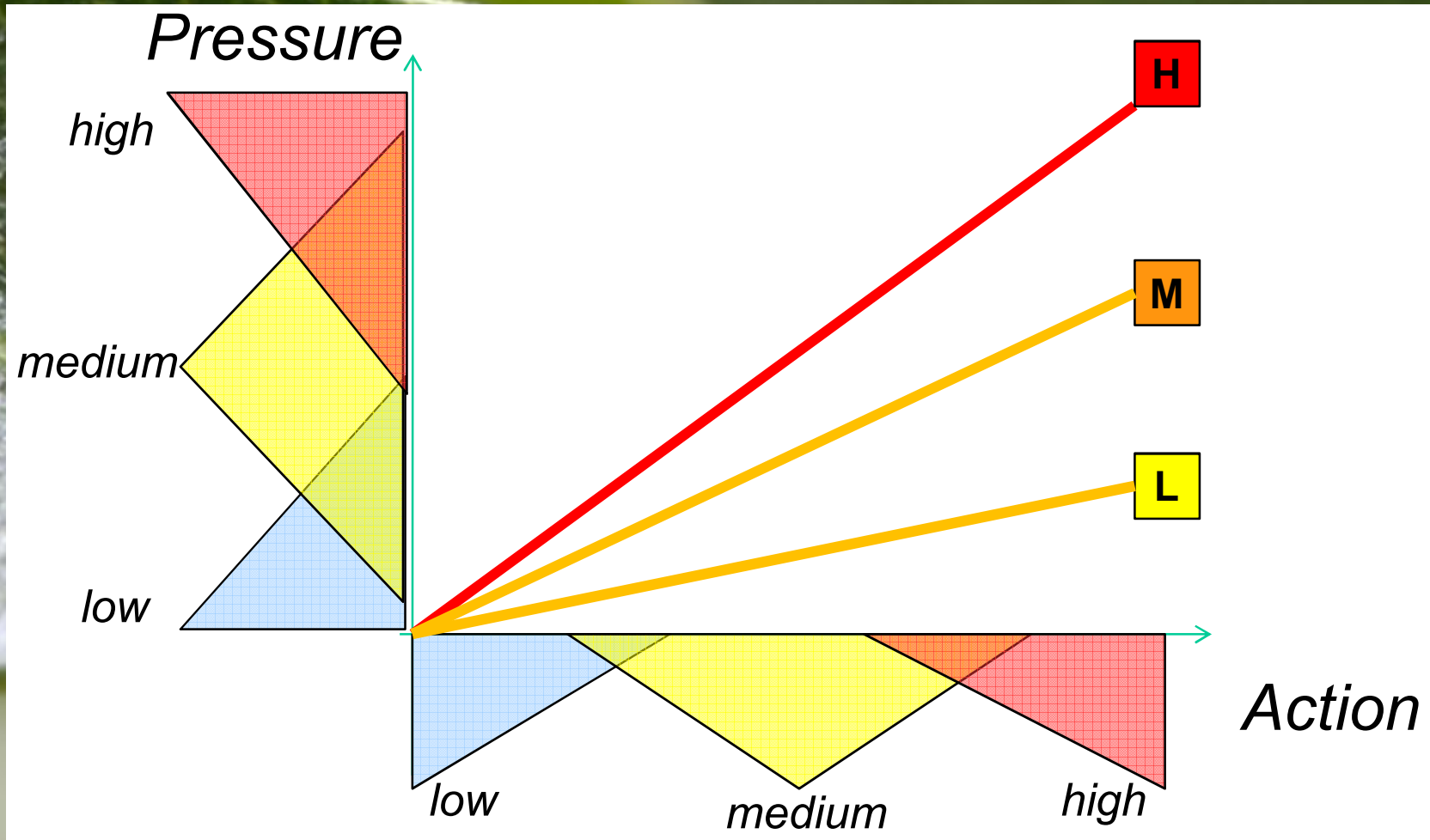
- Qualitative constructs for describing the value of a quantitative variable *X*



- Each ling. variable is associated to a linguistic domain
- Fuzzy values for the variable define a fuzzy partition of the domain of *X*
- Mamdani rules: fuzzy consequences from fuzzy premises

$$x \text{ is } A_j \Rightarrow_{\varepsilon} y \text{ is } B_k$$

Models III and IV




Regional Planning with CLP(R)
The Regional Energy Plan 2011-2013 of the Emilia-Romagna region

Regional Planning

- Activities are no longer fixed (i.e., constants), but they are decision variables

$$a_i$$

Activities have bounds

  - max availability of a resource in the Region
  - Policies: no more than some percentages

$$\forall i, \quad a_i \leq U_i$$

Costs

- Each activity has a Cost

$$c_i$$

- the total cost should not exceed a given budget

$$\sum_i c_i a_i \leq B$$

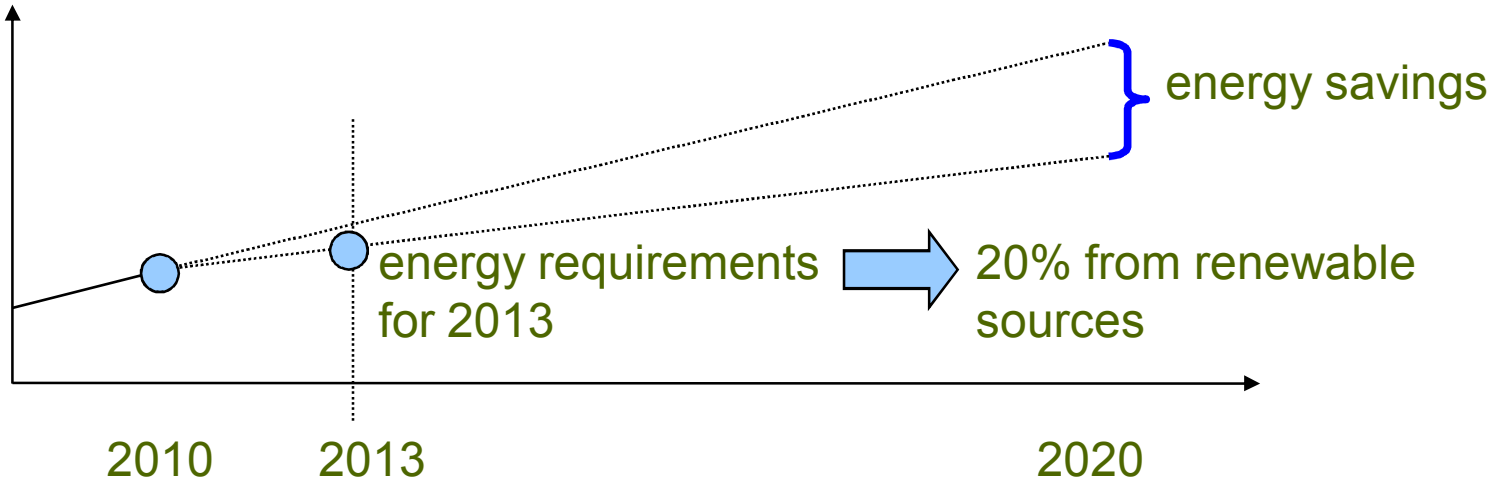
Outcomes

- The objective of a plan can be to improve some aspect, obtain a minimum goal
- Energy plan => objective: produce a minimum amount of energy o_{plan}

$$\sum_i o_i a_i \geq o_{plan}$$

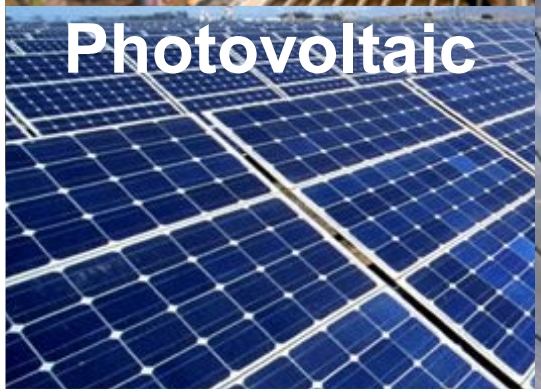
Regional Energy Plan 2011-13

- EU directive 20-20-20: objectives for 2020
  - 20% reduction CO_2 emissions
  - 20% energy comes from renewable sources
  - 20% of energy savings



Renewable energy requirement

- Total requirement for 2013: 177 kTOE (Tonnes of Oil Equivalent) of electrical energy from renewable sources



Unit outcomes

Source	Power (MW)	Energy (TOE)
Biomasses	1	0.602
Wind generators	1	0.12875
Hydroelectric	1	0.2235
Photovoltaic	1	0.10317
Thermodynamic solar	1	0.1

Primary/Secondary Activities

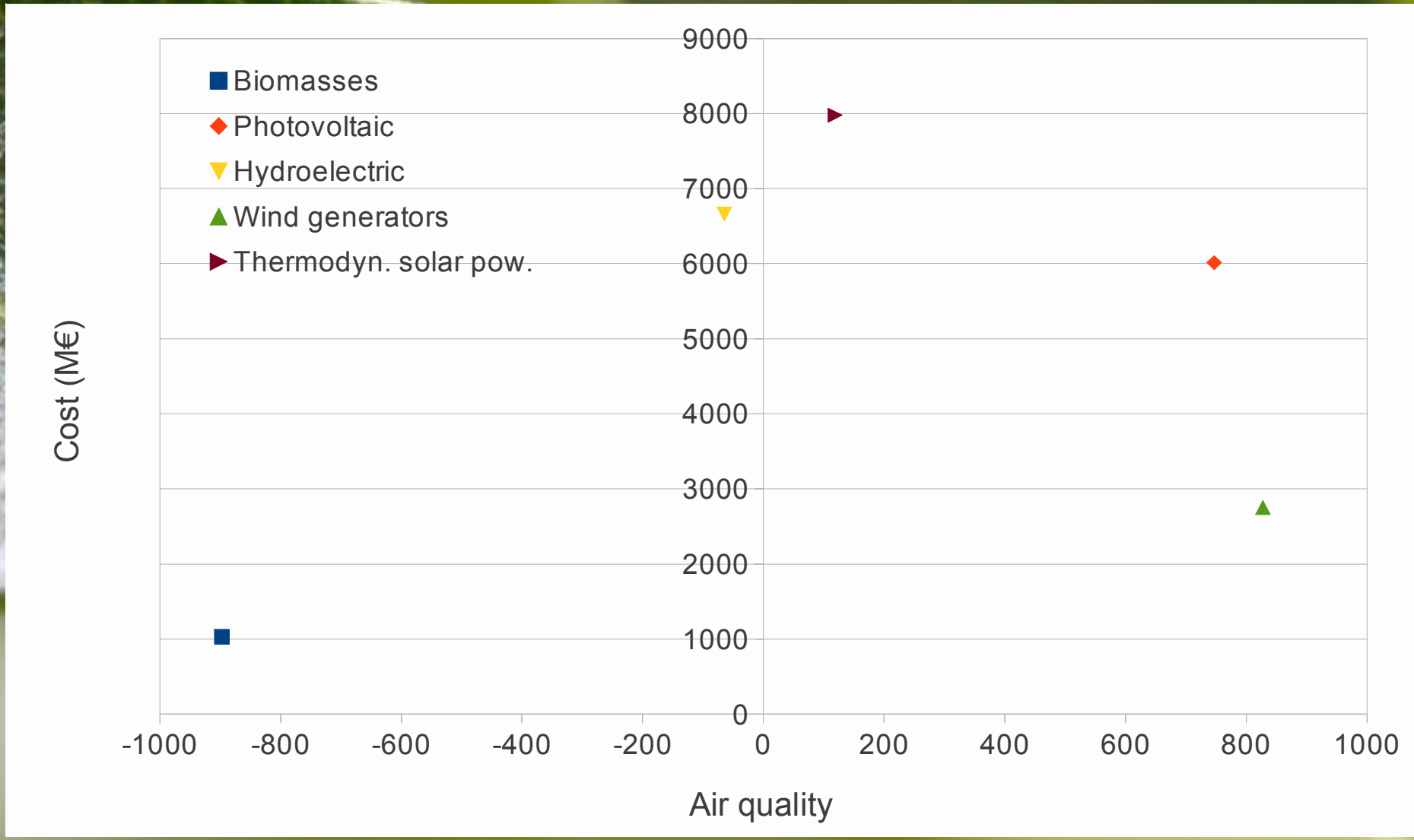
Primary/Secondary Activities

- Energy plan: primary activities are those producing energy
- In order to implement primary activities, other activities are necessary

$$\forall j \in A^S, \quad a_j = \sum_{i \in A^P} d_{ij} a_i$$

- secondary activities may also have impact on the environment!

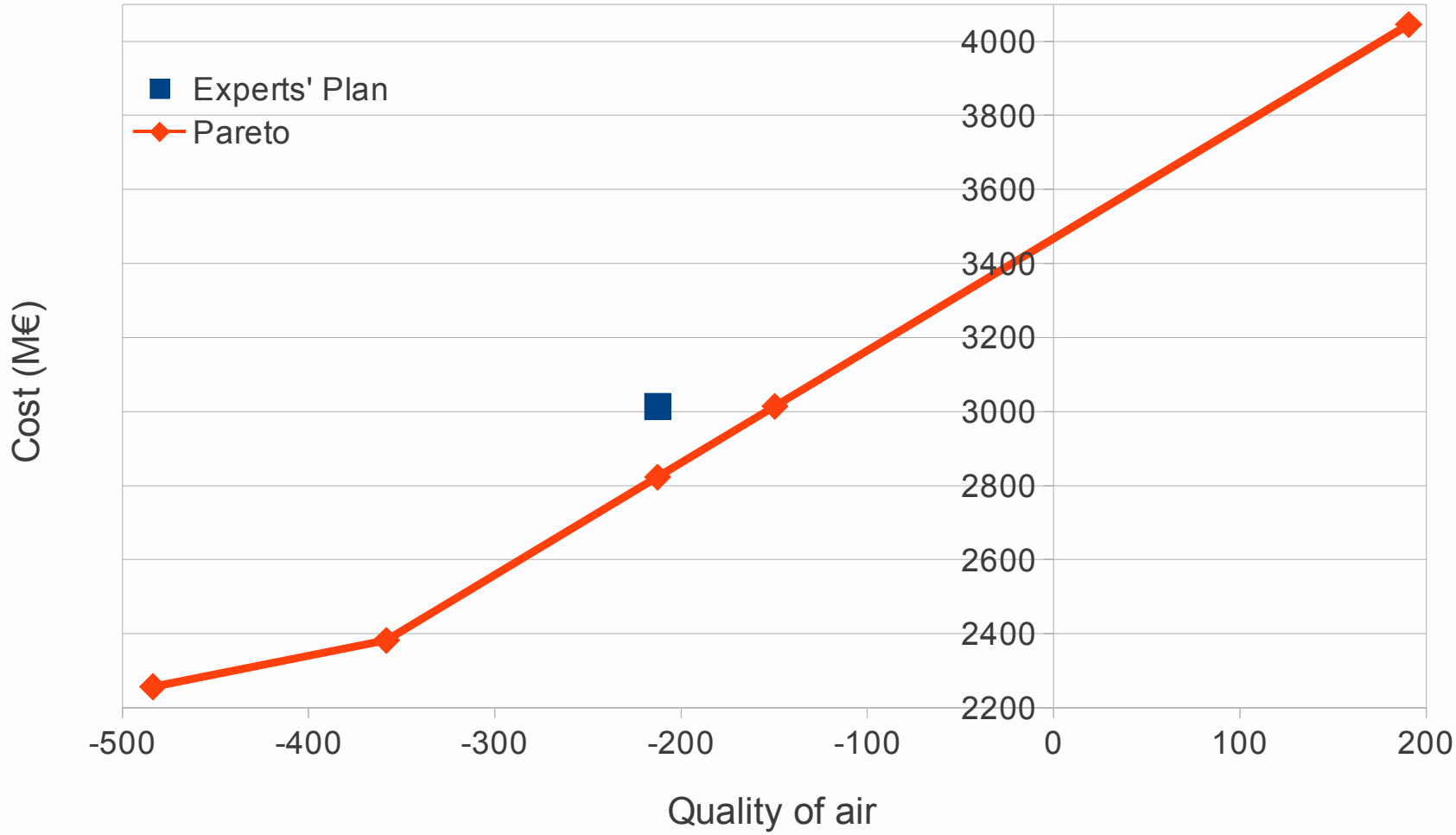
Results: single sources

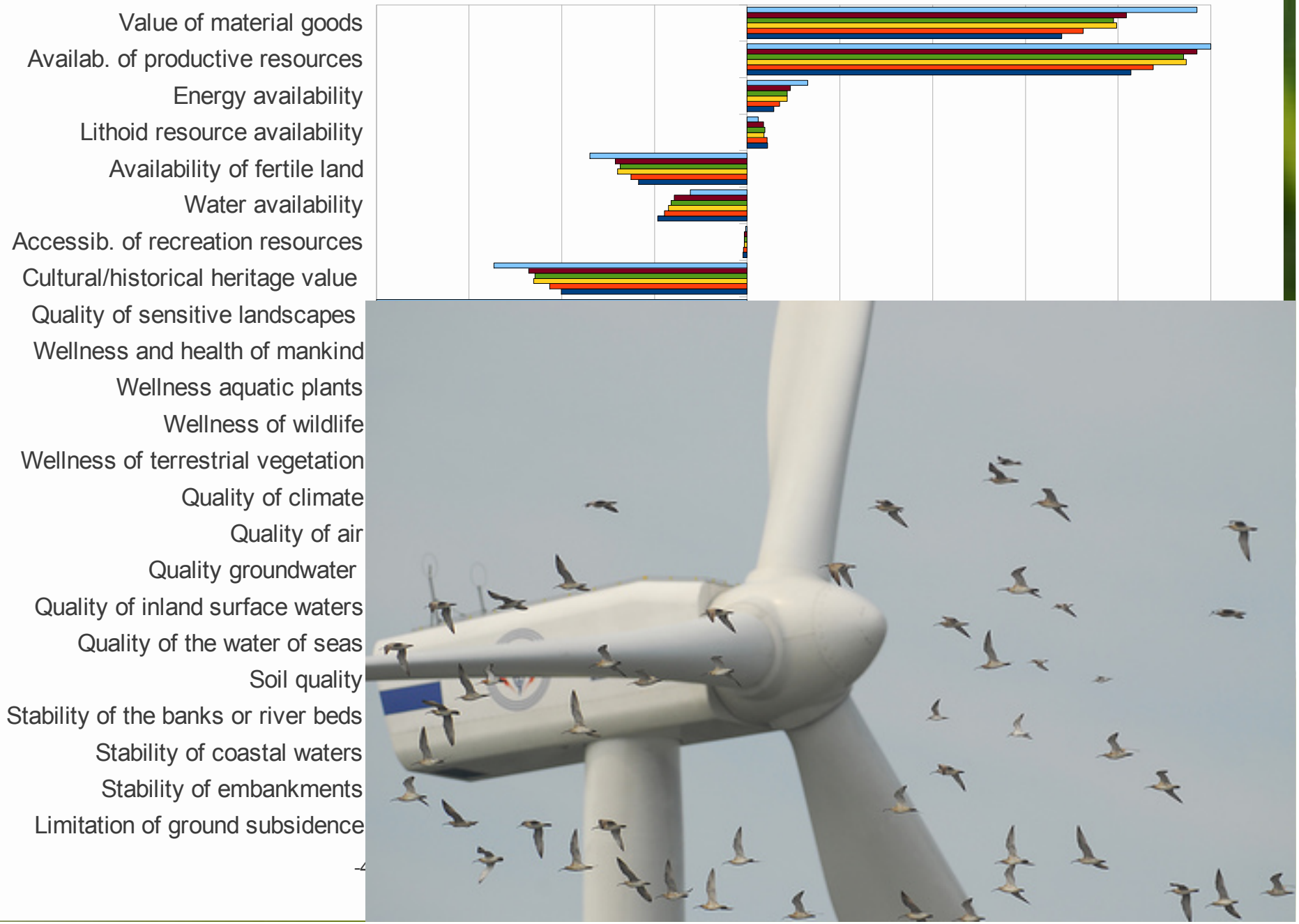


Expert's plan

Electrical Power Plants	Power 2010 (MW)	Power 2013 (MW)	Energy 2013 (kTOE)	Investments (M€)
Hydroelectric	300	310	69.3	84
Photovoltaic	230	850	87.7	2170
Thermodynamic solar	0	10	1.0	45
Wind generators	20	80	10.3	120
Biomasses	430	600	361.2	595
Total	**980**	**1850**	**529.5**	**3014**

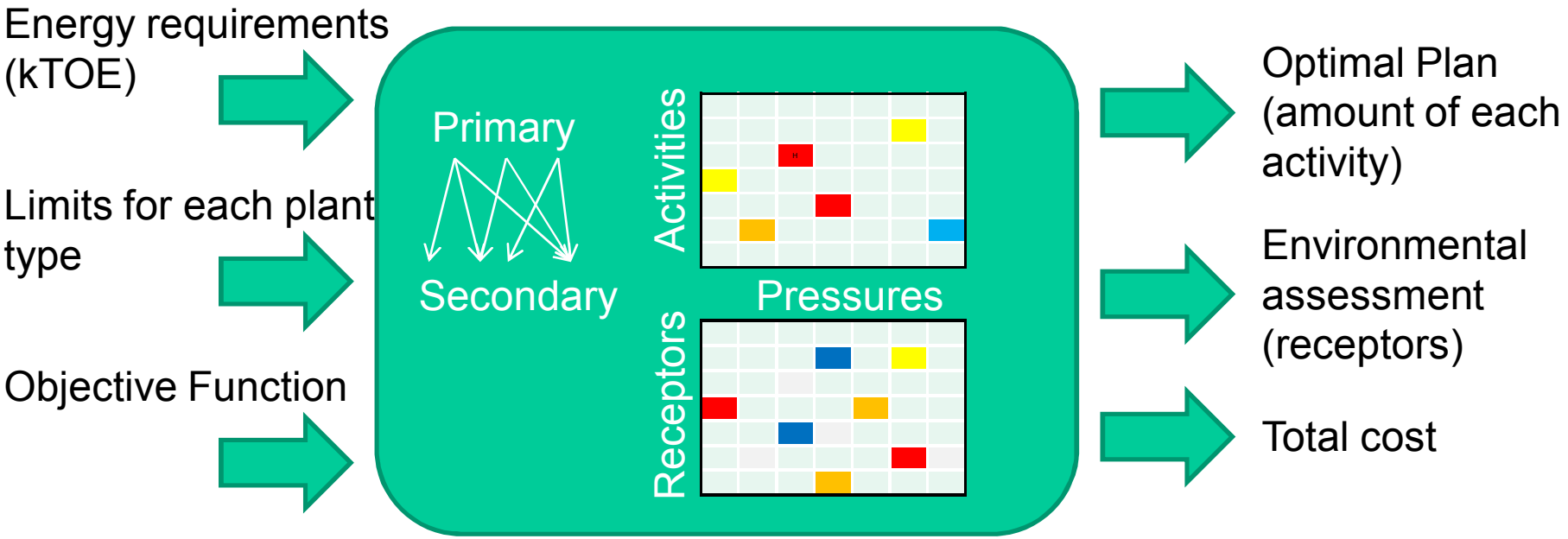
Pareto front




Value of material goods
Availab. of productive resources
Energy availability
Lithoid resource availability
Availability of fertile land
Water availability
Accessib. of recreation resources
Cultural/historical heritage value
Quality of sensitive landscapes
Wellness and health of mankind
Wellness aquatic plants
Wellness of wildlife
Wellness of terrestrial vegetation
Quality of climate
Quality of air
Quality groundwater
Quality of inland surface waters
Quality of the water of seas
Soil quality
Stability of the banks or river beds
Stability of coastal waters
Stability of embankments
Limitation of ground subsidence

Extended solution

DSS for Regional Energy Plans

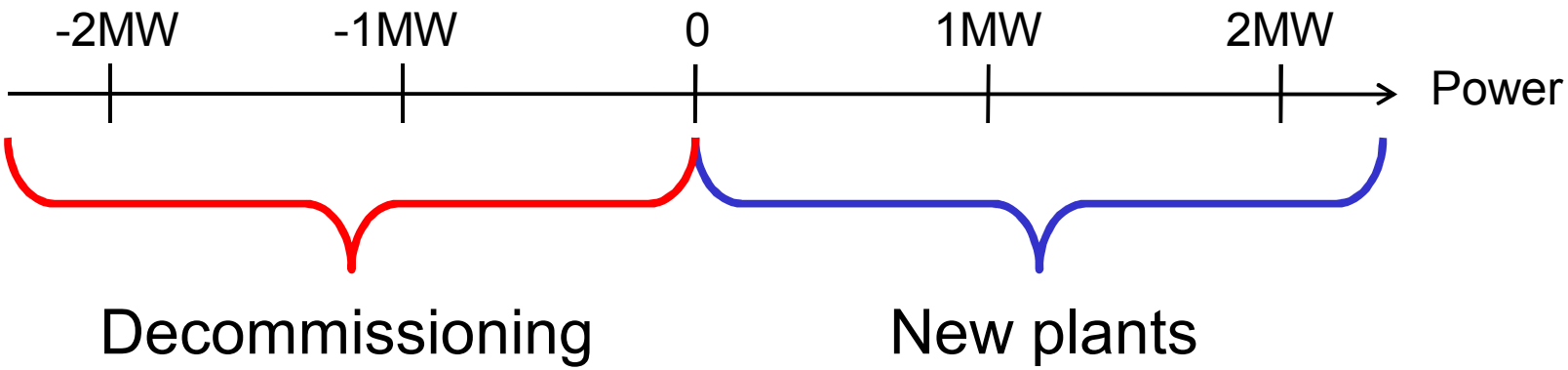


Decommissioning

- The Regional Energy Plan 2011-13 gave a strong impulse to Renewable sources
- Non-renewable sources are less used
- The next plan (2014-2020) will have to consider decommissioning of power plants

Decommissioning

- Domain of activities includes negative values

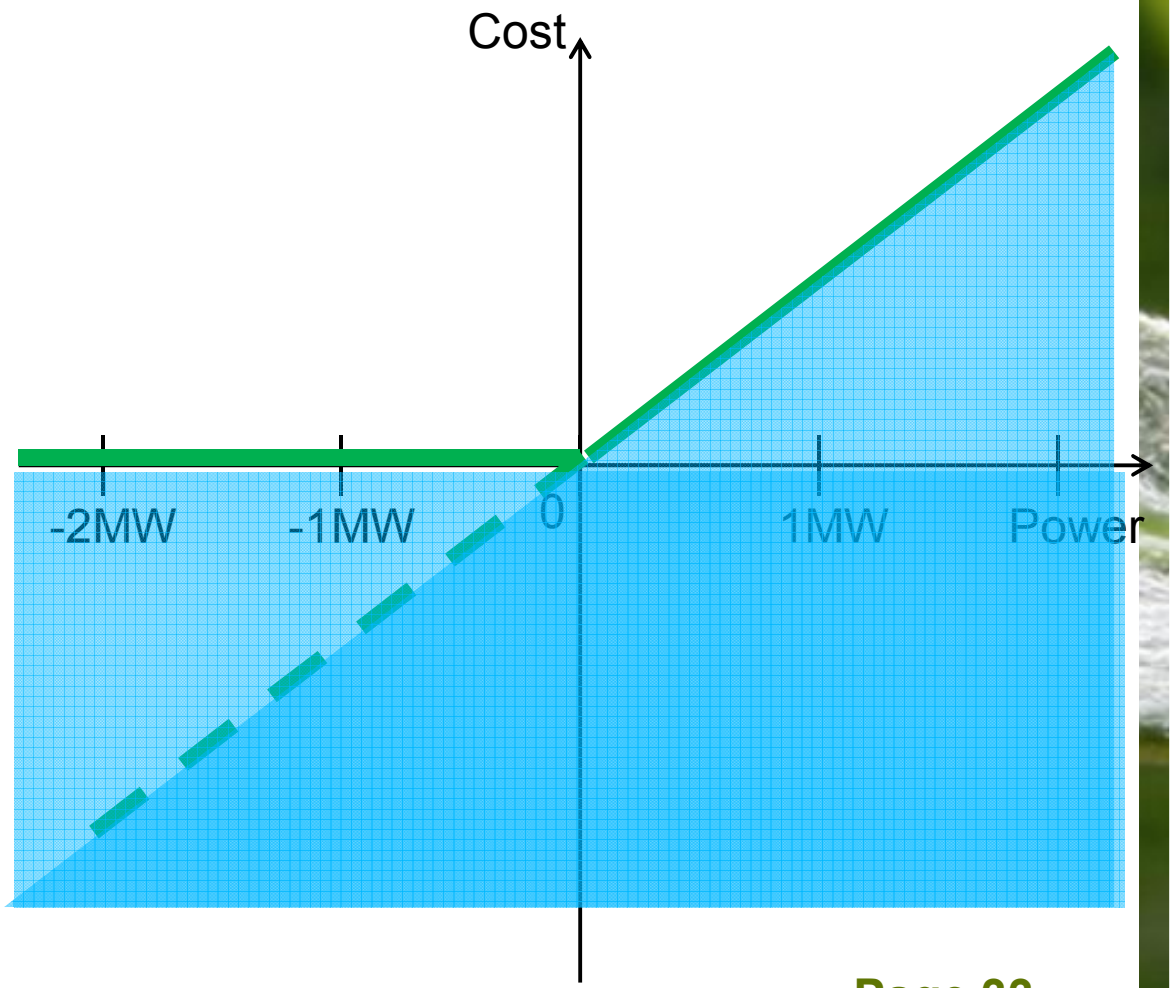


Non-linear relations

~~$Cost = kPower$~~

$Cost \geq 0$

$Cost \geq kPower$

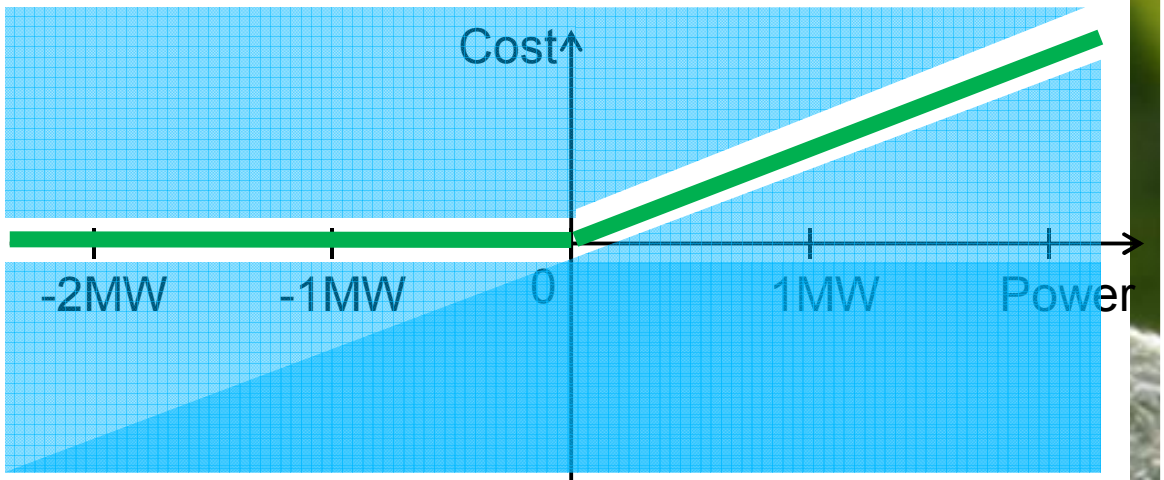


Non-linear relations

~~$Cost = kPower$~~

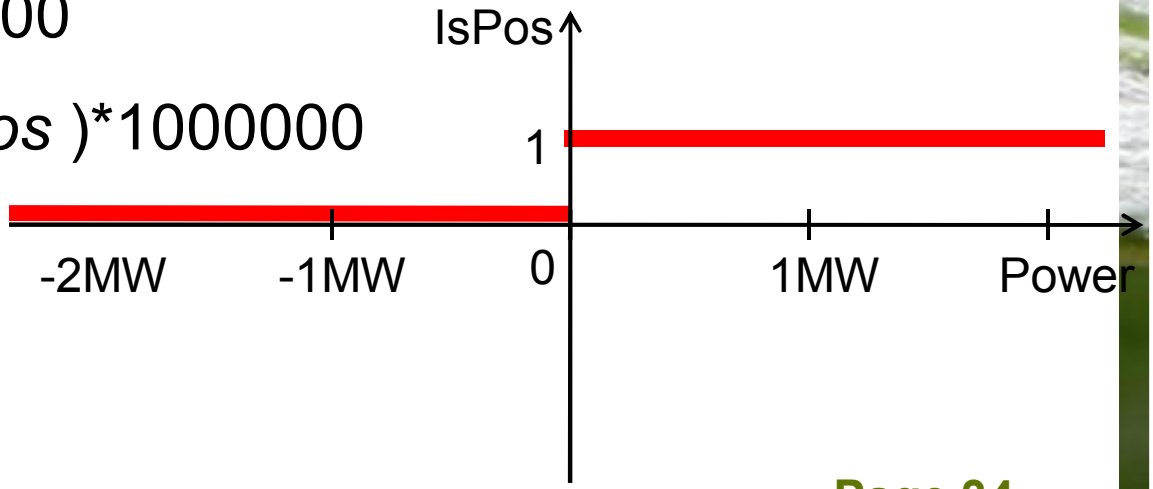
$Cost \geqslant 0$

$Cost \geqslant kPower$



$+ IsPos * 1000000$

$+ (1 - IsPos) * 1000000$



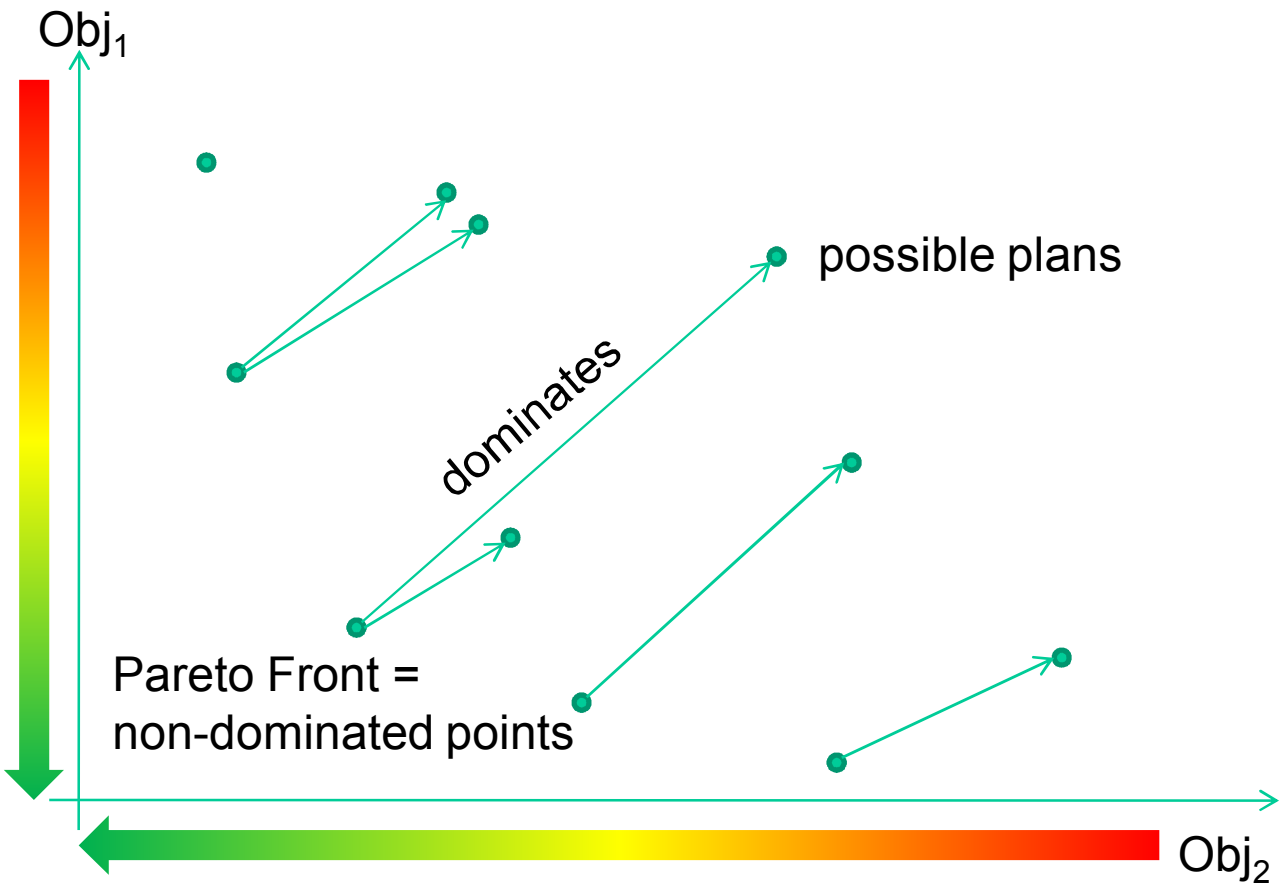
$0 \leq IsPos \leq 1$

$IsPos \in \mathbf{Z}$

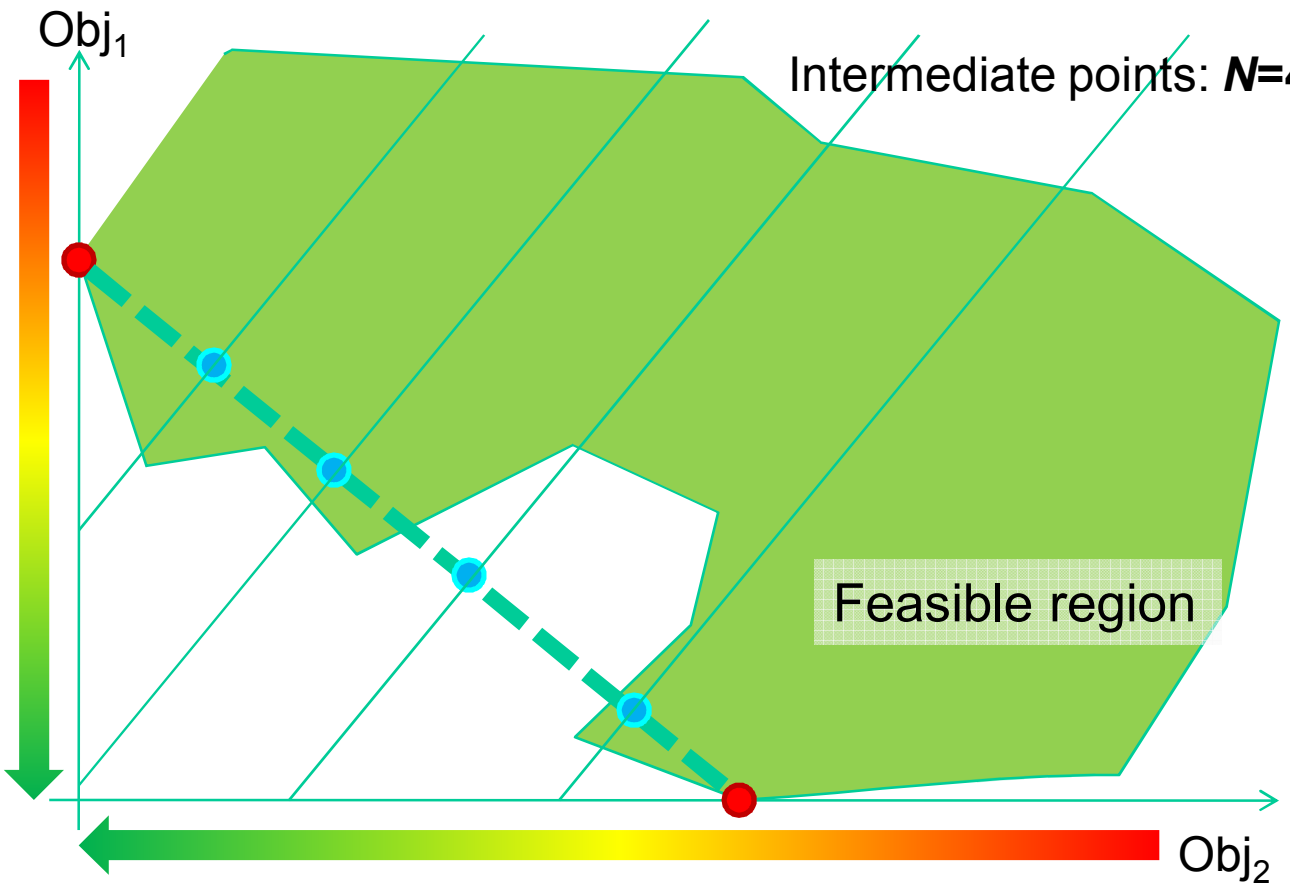
Pareto front

- In the first prototype, only one objective function is used
- In the second, two or more objectives can be given, and the Pareto front is returned

Pareto front



Pareto front: the Normalized Normal Constraint Method



A. Messac, A. Ismail-Yahaya, and C. A. Mattson. The normalized normal constraint method for generating the Pareto frontier. *Structural and Multidisciplinary Optimization*, 25(2):86–98, 2003.

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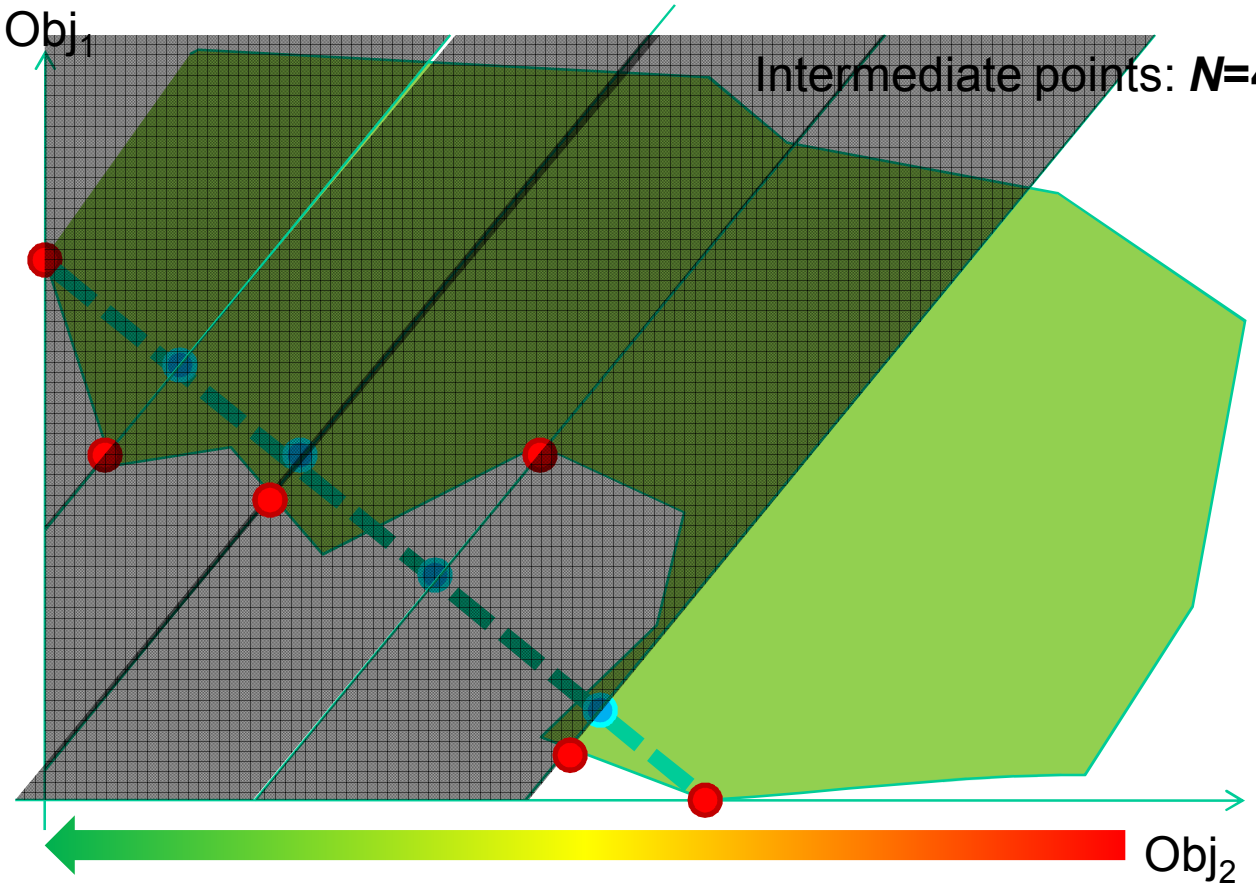

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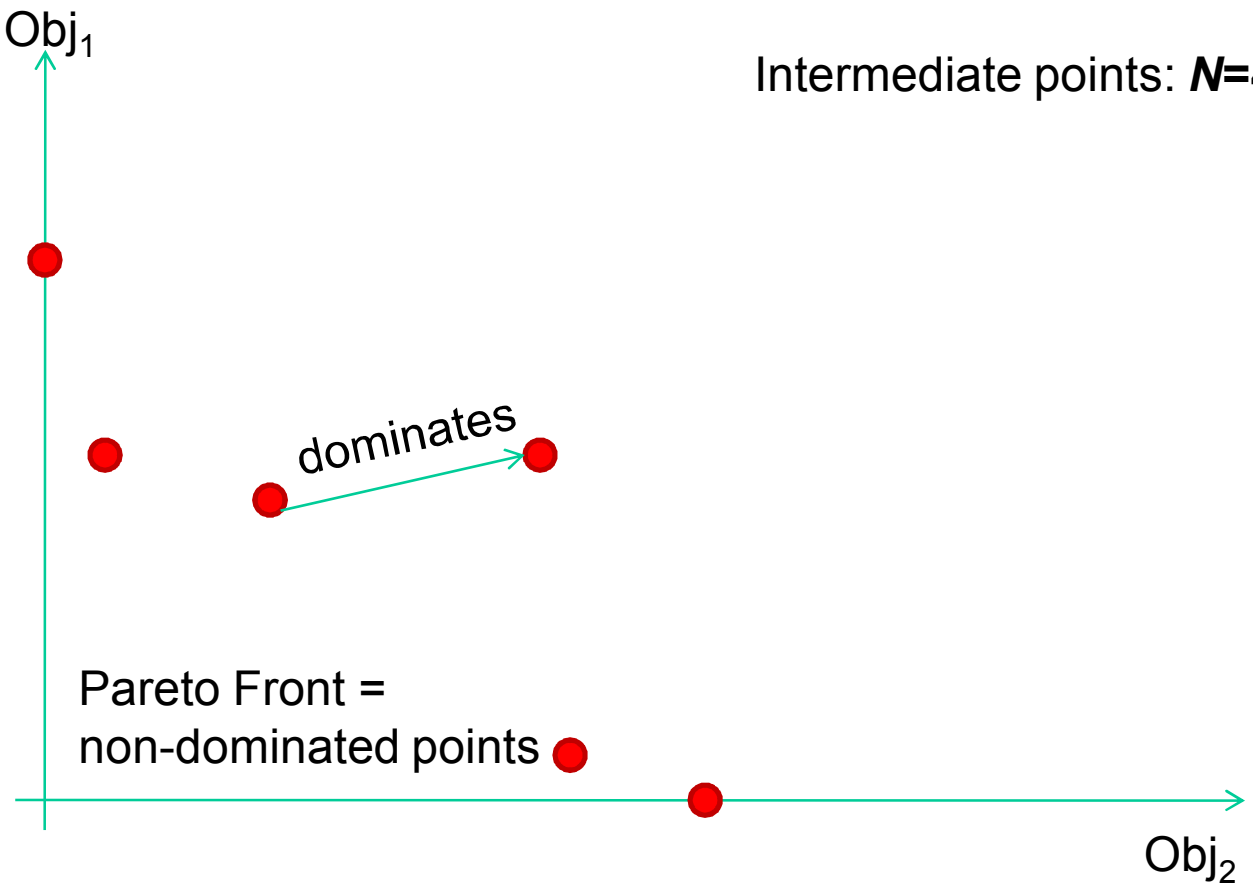
Pareto front: the Normalized Normal Constraint Method



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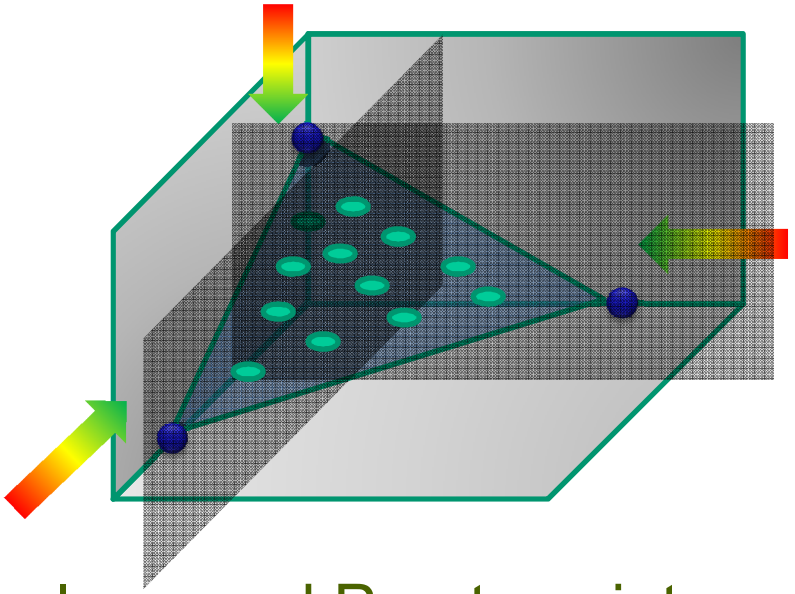
More than 2 objectives

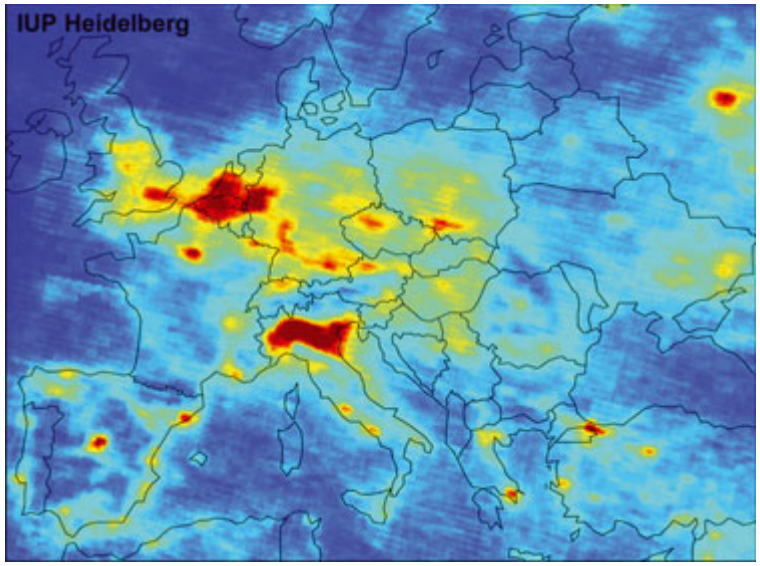
- The method works also with >= 3 objectives



- Features
  - Generates evenly spread Pareto points
  - Generates only Pareto points
  - Can be used for non-linear, non-convex optimization

Beyond qualitative values

- Extended the CLP model to include some quantitative values
- In Emilia-Romagna one of the most sensitive receptors is the air quality
- Focused on pollutants in the air



Nitrogen dioxide pollution in Europe measured by SCIAMACHY (ESA)

Data sources

ISPRA

Public power

	g/GJ							
	SOx	NOx	NMVOC	CH4	CO	CO2 (kg/Gj)	N2O	NH3
Steam coal	63,4692	60	1,5	1,5	12	91,65511	1,5	0,48
Lignite	382,411	60	1,5	1,5	12	99,106	1,5	0,86
Natural gas	0,217279	22,9661	2,5	1,5	20	56,76175	0,1	0
Gasoil	46,86409	35	1,5	1,5	12	73,274	0,6	0
Low sulphur fuel oil	73,16537	40	3	3	15	75,62739	0,6	0
High sulphur fuel oil	284,0207	40	3	3	15	75,62739	0,6	0
Other fuel oils	14,48527	40	3	3	15	94	2	0
Biomass	0	40	0	30	0	0	4	0

Public power

	mg/GJ									g/GJ	microg Teq/Gj	g/Gj		
	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	PM10	DIOX	PAH	PCB	HCB
Steam coal	8,378445	0,148291	10,60281	2,81753	0,852674	6,636025	4,634096	4,597023	9,818838	1,9271	0,003764	9,48E-07	0,000143	5,1E-07
Lignite	8,378445	0,148291	10,60281	2,81753	0,852674	6,636025	4,634096	4,597023	9,818838	8	0,00956	2,41E-06		
Natural gas	0,16	0,03	12,25	2,29	0,31	2,68	0,6	1,04	0	0,014	0	0		
Gasoil	0,774363	0,143401	4,760897	4,789577	0,774363	28,73746	2,523849	1,032484	3,484065	0,35	0,023432	0,000891		
Low sulphur fuel oil	0,774363	0,143401	4,760897	4,789577	0,774363	28,73746	2,523849	1,032484	3,484065	1,75	0,024388	0,000891	8,78E-05	
High sulphur fuel oil	0,774363	0,143401	4,760897	4,789577	0,774363	28,73746	2,523849	1,032484	3,484065	1,75	0,024388	0,000891	8,78E-05	
Other fuel oils	0,774363	0,143401	4,760897	4,789577	0,774363	28,73746	2,523849	1,032484	3,484065	1,75	0,024388	0,000891		
Biomass	0	0	0	0	0	0	0	0	0	3,5	0,00956	0,003658	5,74E-05	5,74E-06

ISPRA

- INPUT:
  - Power Plants: (8)
    - Steam coal, Lignite, Natural gas, Gasoil, Low sulphur fuel oil, High sulphur fuel oil, Other fuel oils, **Biomass**
- OUTPUT:
  - Pollutants: (22)
    - SOx, NOx, NMVOC, CH4, CO, CO2, N2O, NH3, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, PM10, DIOX, PAH, PCB, HCB
    - (including toxic emissions, heavy metals, greenhouse gases, particulate matter, dioxins, …)

- INPUT:
  - Boiler type & power (5)
    - Boiler with power <50MW, Boiler with power >50 < 300MW, Boiler w. power>300MW, Combustion engine, Gas Turbine
  - Fuel (28)
    - Petrol, biogas, carbon, coke, gas from industrial waste, gasoil, wood, solid urban waste, …
  - Other specifications (26)
    - boiler dry, boiler wet, controlled, grid furnace, …
- OUTPUT:
  - Pollutants (15)
    - SO2, NOx, NMVOC, CH4, CO, CO2, N2O, As, Cd, Cr, Cu, Hg, Ni, Pb,
      Se

Indicators

- If a plan emits 1kg of CO_2, is it better or worse than a plan emitting 1kg of Lead (Pb)?
- Indicators:
  - Human Toxicity
  - Greenhouse effect
  - Acidification

EUROPEAN COMMISSION

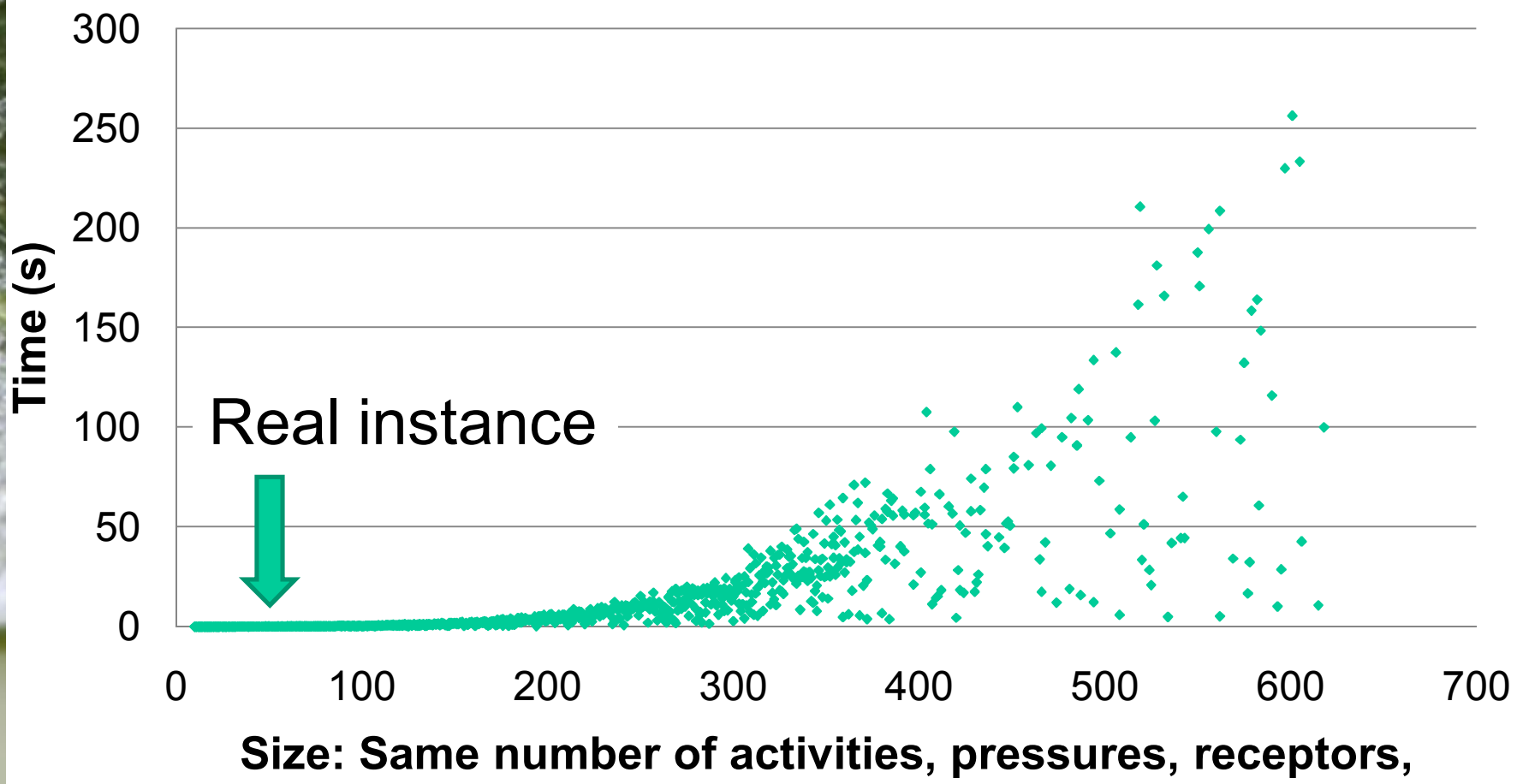
Integrated Pollution Prevention and Control

Reference Document on

Economics and Cross-Media Effects

July 2006

Efficiency, scalability



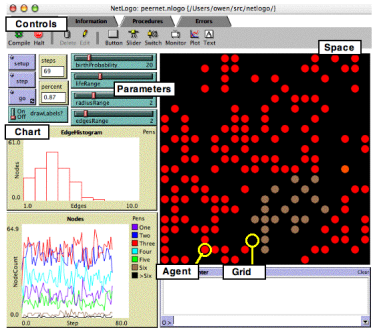
Costs and incentives

- Region cannot afford to build the plants
- Can incentivise private stakeholders
- What results can be expected?
- How do people *react* to different subsidy policies?

Simulation

simulator

Incentives,
regional policies,
taxes,
...



MW of installed power

- Agent-based economic and social simulation aids the policy maker to understand the individual perspective

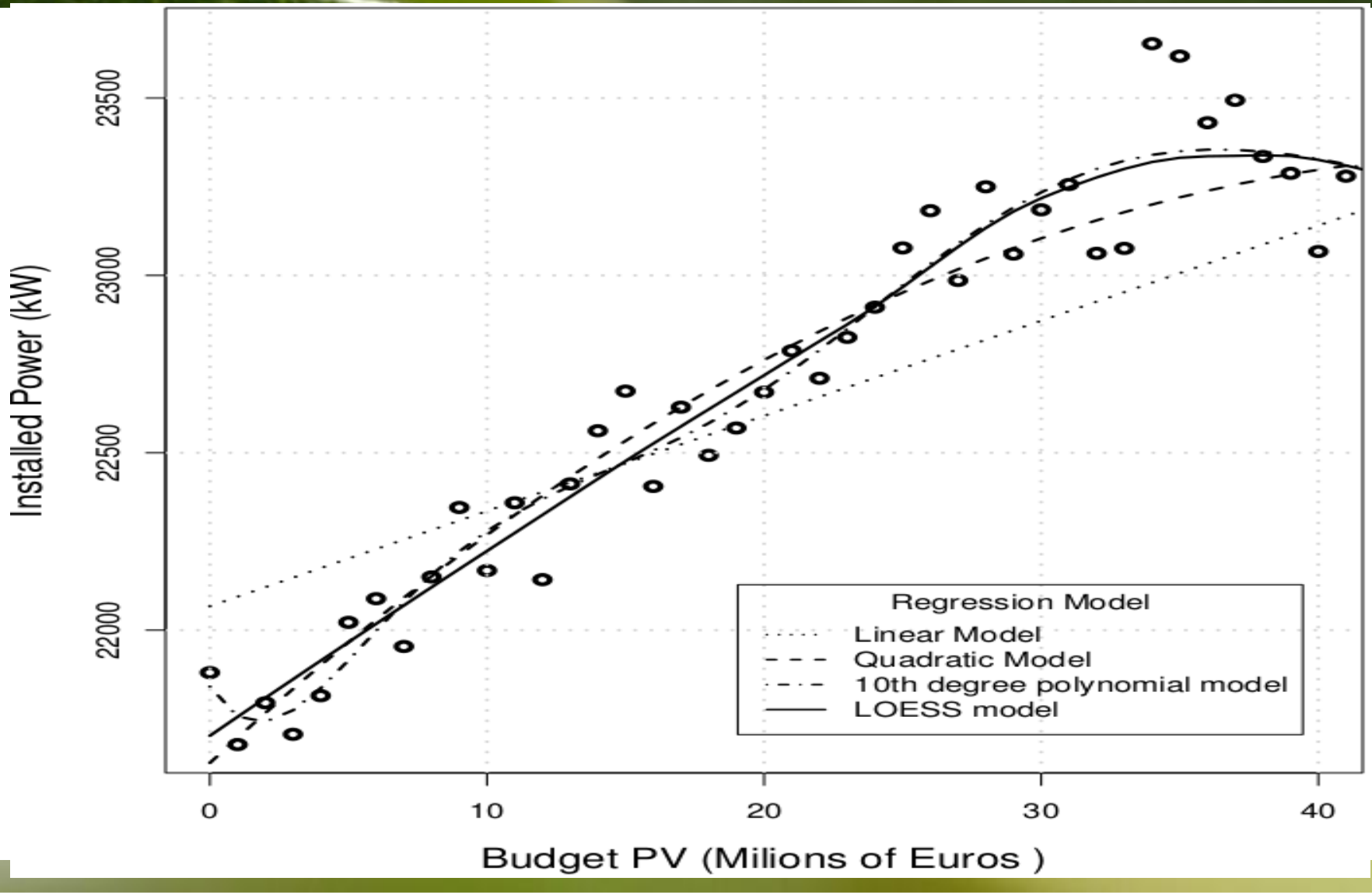
Emilia-Romagna Subsidies

- Production-based incentives
  - Feed-in tariffs
  - Feed-in Premium tariffs
  - Quota obligations
- Investment-based incentives
  - Loan-interest incentives
  - Loan-Guarantees
  - Fiscal incentives
  - Investment Grants
  - Tax exemptions
- Compulsion
- Green Power Marketing

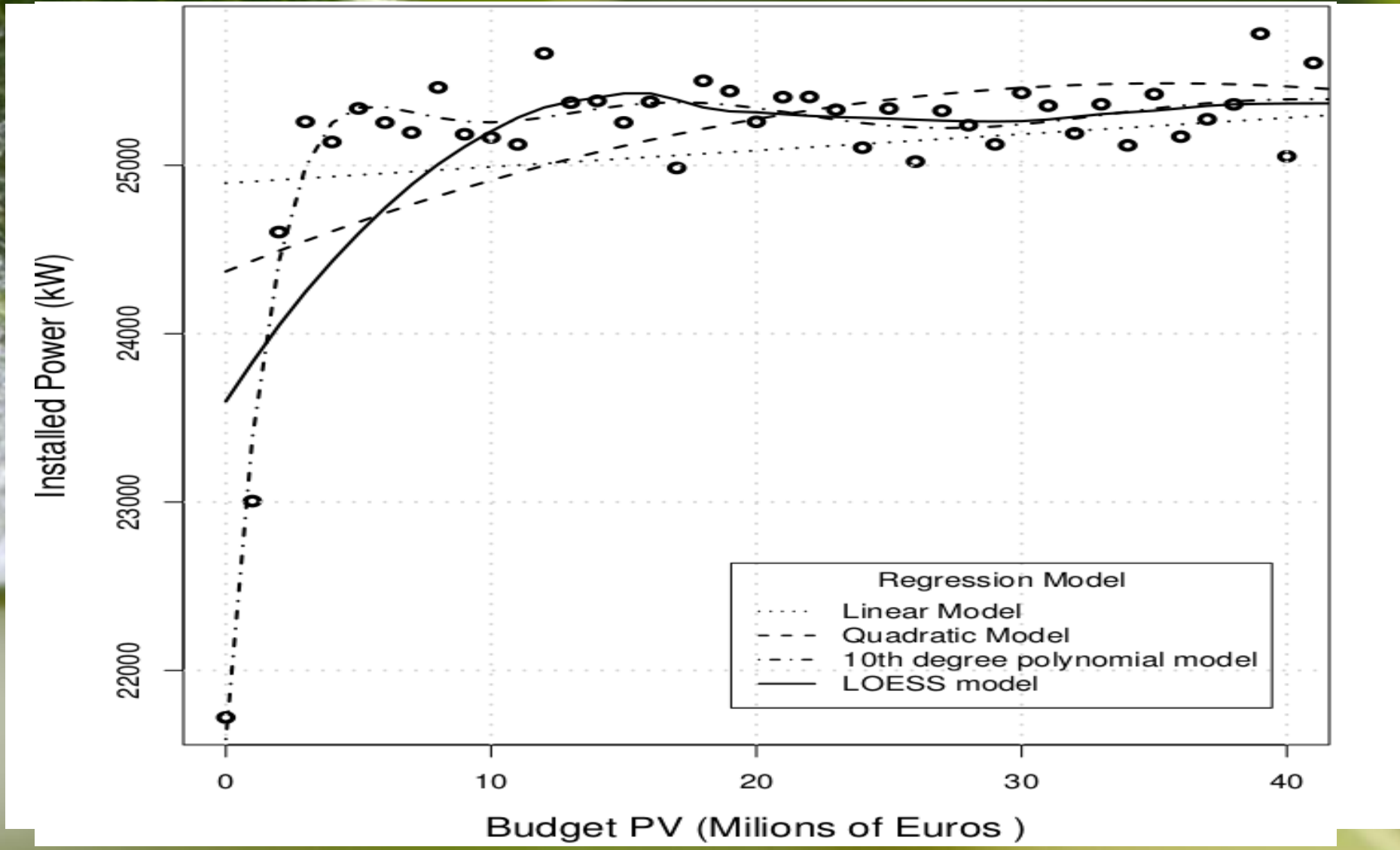
Italian Feed-In tariff

Regional Incentives in Emilia-Romagna on top of national incentives

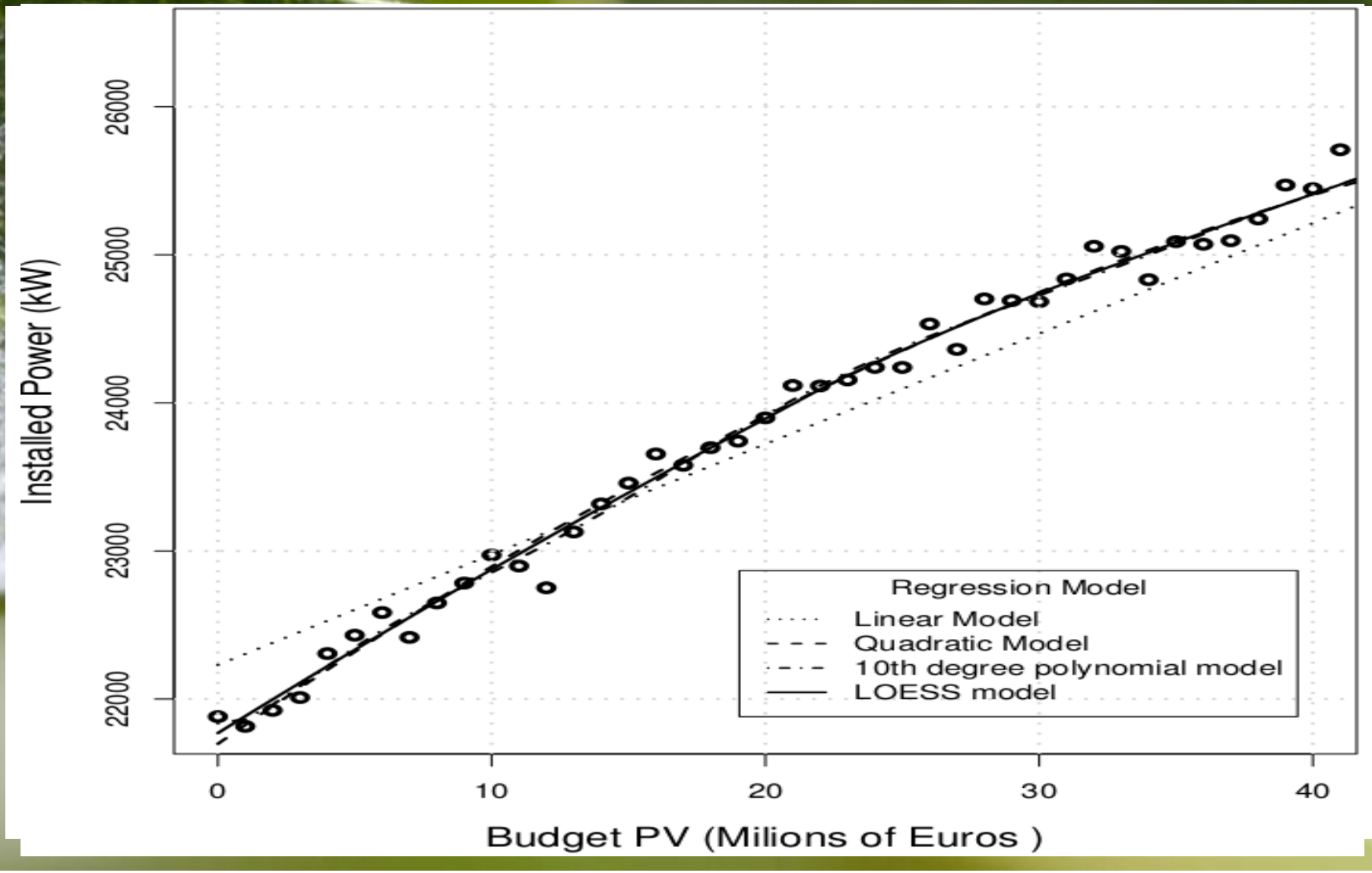
Relationships Learning
Investment Grant



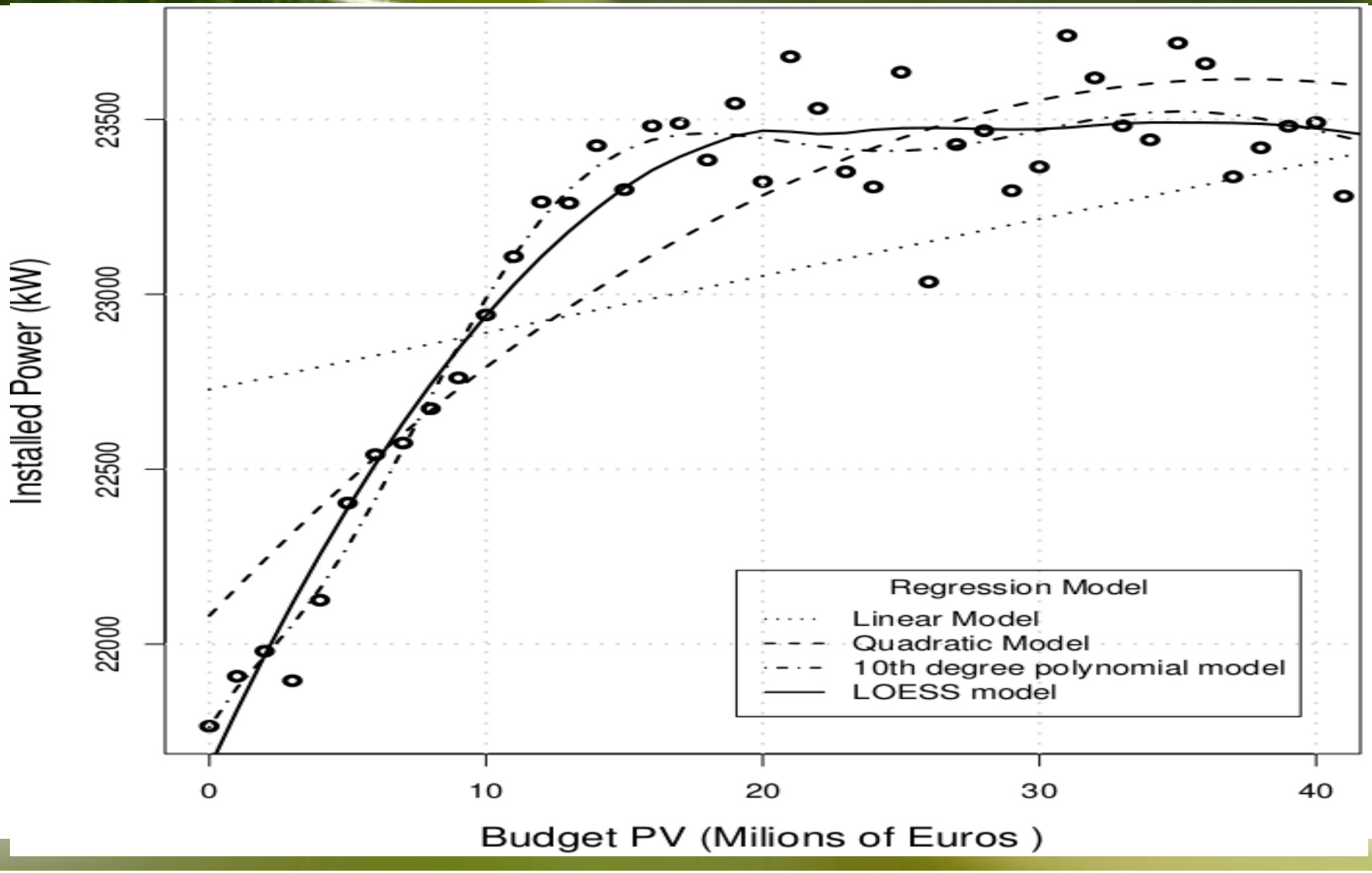
Relationships Learning
Interest Fund



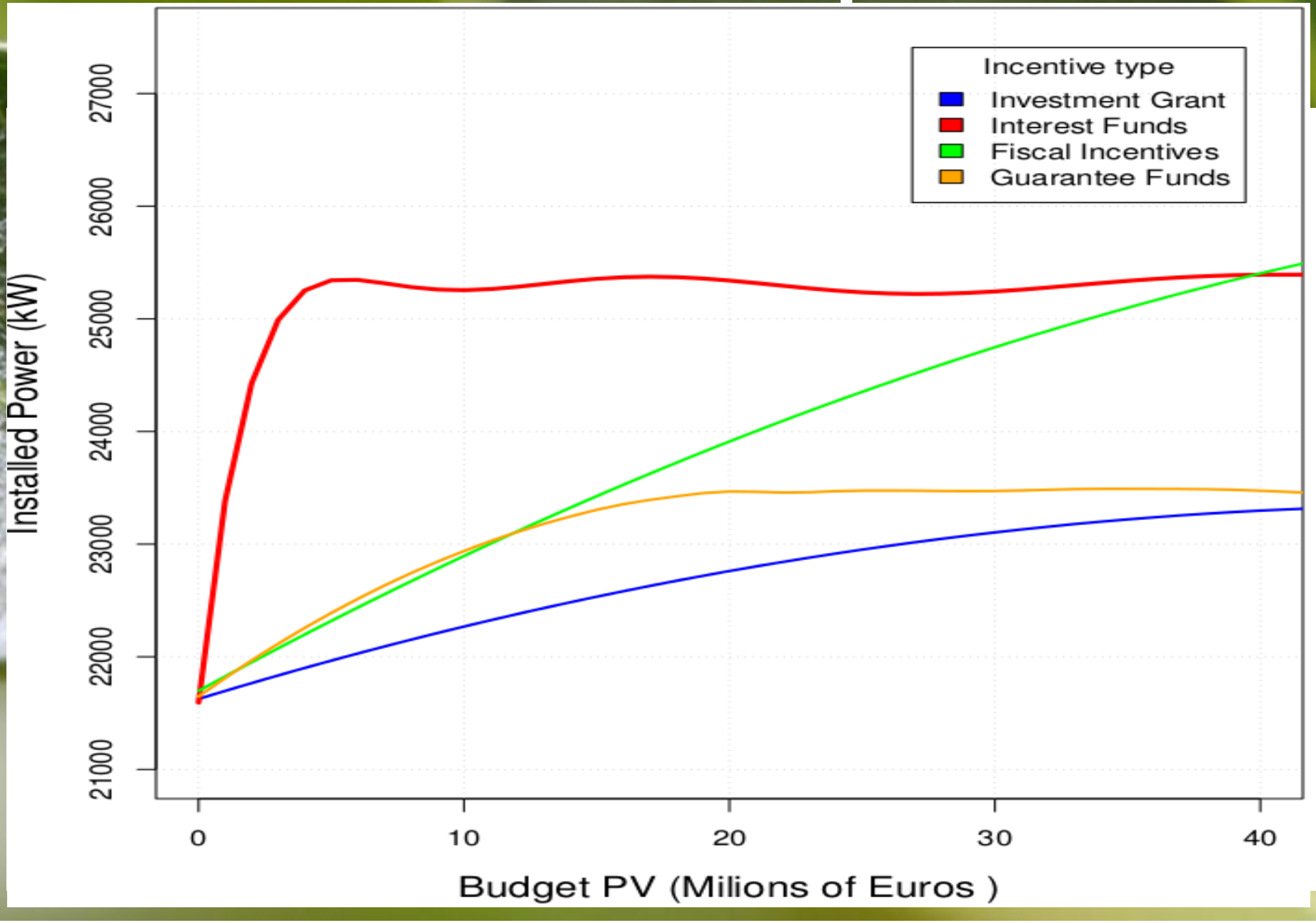
Relationships Learning
Fiscal Incentive



Relationships Learning
Guarantee Fund



Incentives Comparison



Demo

- Official user interface of the ePolicy project:

  http://epolicy.igd.fraunhofer.de/demo/

- Test user interface of the GlobalOptimizer:

  http://development.epolicy-project.eu/Pareto/

Conclusions

- Constraint based application for regional energy planning
  - Includes environmental assessment
- Practical Application, used in
  - Regional Energy Plan 2010-2013 of the Emilia-Romagna region
  - ROP ERDF 2014-20 Emilia-Romagna
  - Contacts with Regione Piemonte

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