Environmental Economics

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EPFL ENAC LEUrE

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MULTI-OBJECTIVE APPROACHES TO INVESTMENT CHOICE

Example:
finding the optimal mix of clean and dirty energy

- Energy can be produced in a clean and in a dirty manner
- Cost of quantity E_c of clean energy = $c_1E_c + c_2E_c^2$
- Cost of quantity E_d of dirty energy = $d_1E_d + d_2E_d^2$
- Emissions = eE_d
- Total energy need can be normalized to one
- Sufficient production condition: $E_c + E_d \geq 1$
- Dual objective: min $c_1E_c + c_2E_c^2 + d_1E_d + d_2E_d^2$ & min eE_d s.t. $E_c + E_d \geq 1$

Pareto frontier

min $c_1E_c + c_2E_c^2 + d_1E_d + d_2E_d^2$

min eE_d

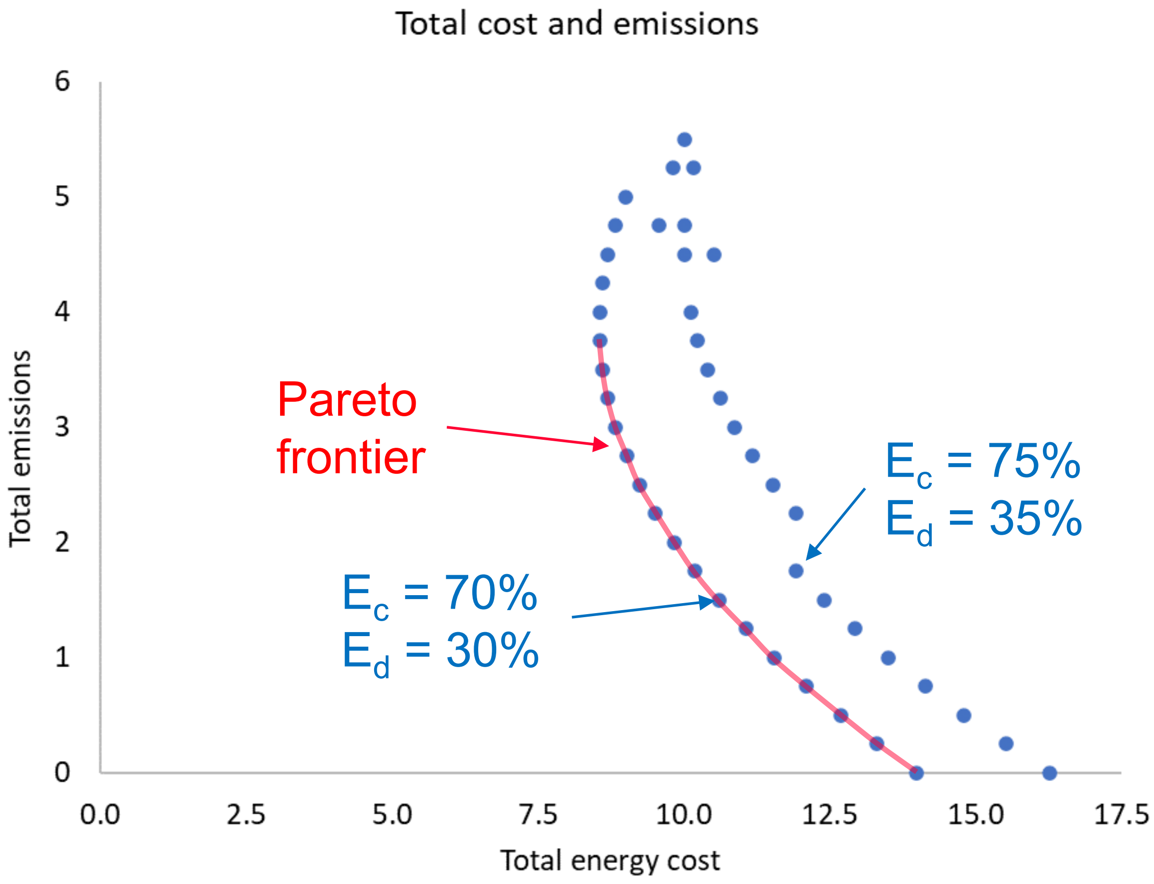
s.t. $E_c + E_d \geq 1$

For these parameter values, more clean energy raises costs but lowers emissions

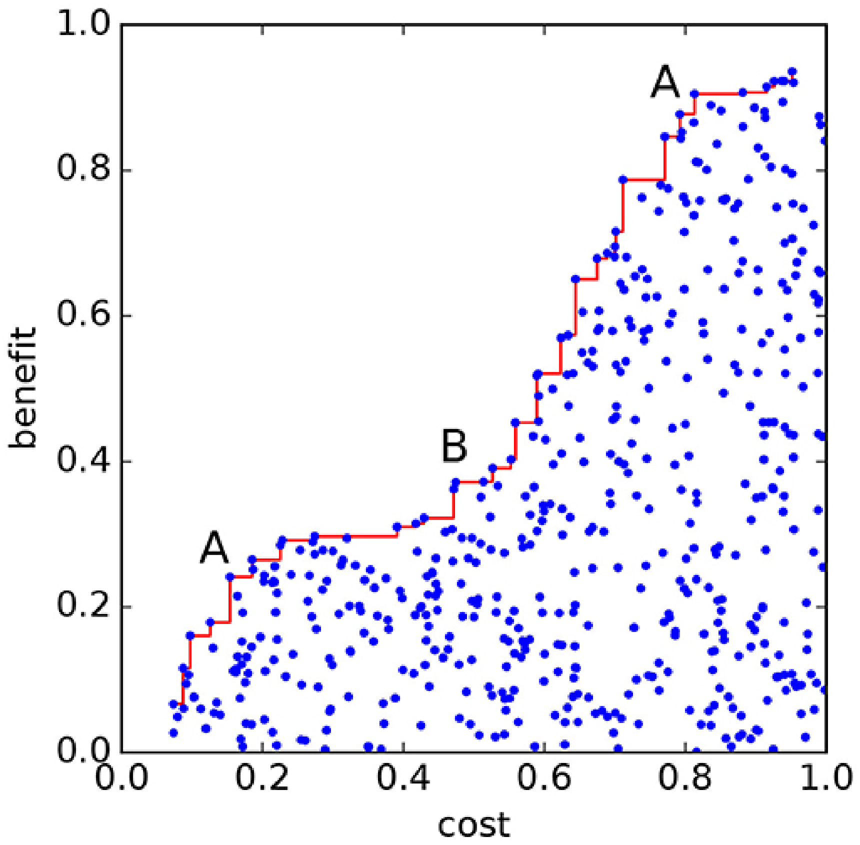
Higher cost for same emissions or higher emissions for same cost if $E_c + E_d > 1$

Frontier corresponds to energy mixes with $E_c + E_d = 1$

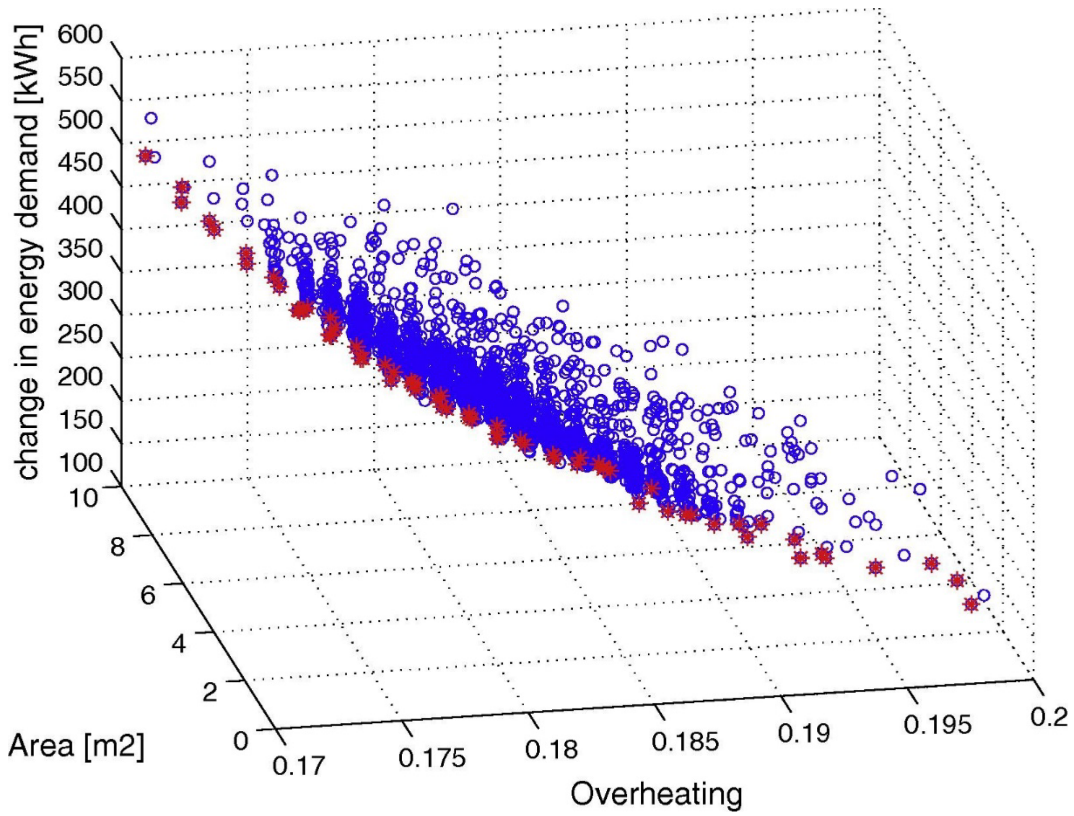
c_1	6
c_2	8
d_1	8
d_2	1
e	5



Pareto frontiers for multi-objective optimization



Fox Alan D., et al., "An Efficient Multi-Objective Optimization Method for Use in the Design of Marine Protected Area Networks", Frontiers in Marine Science 6, 2019, DOI=10.3389/fmars.2019.00017

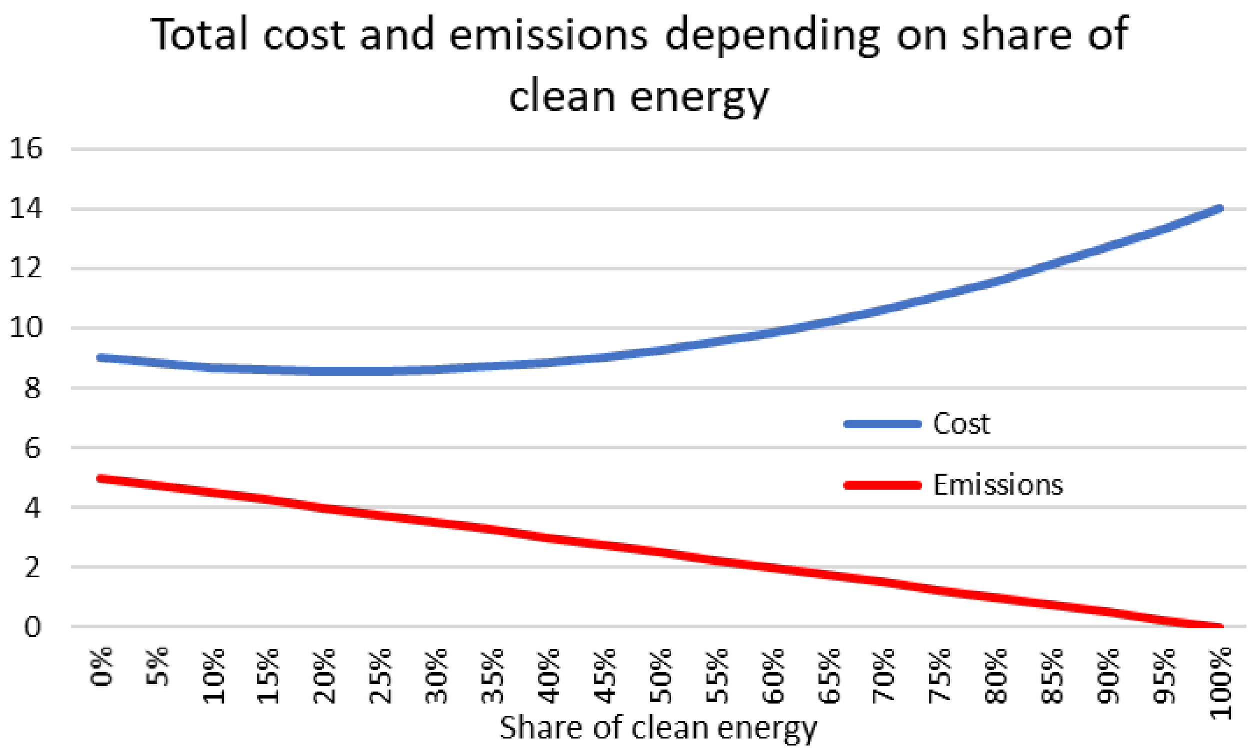


Marina Khoroshiltseva, Debora Slanzi, Irene Poli, "A Pareto-based multi-objective optimization algorithm to design energy-efficient shading devices", Applied Energy 184, 2016, pp. 1400-1410, doi=10.1016/j.apenergy.2016.05.015

See also: https://en.wikipedia.org/wiki/Multi-objective_optimization

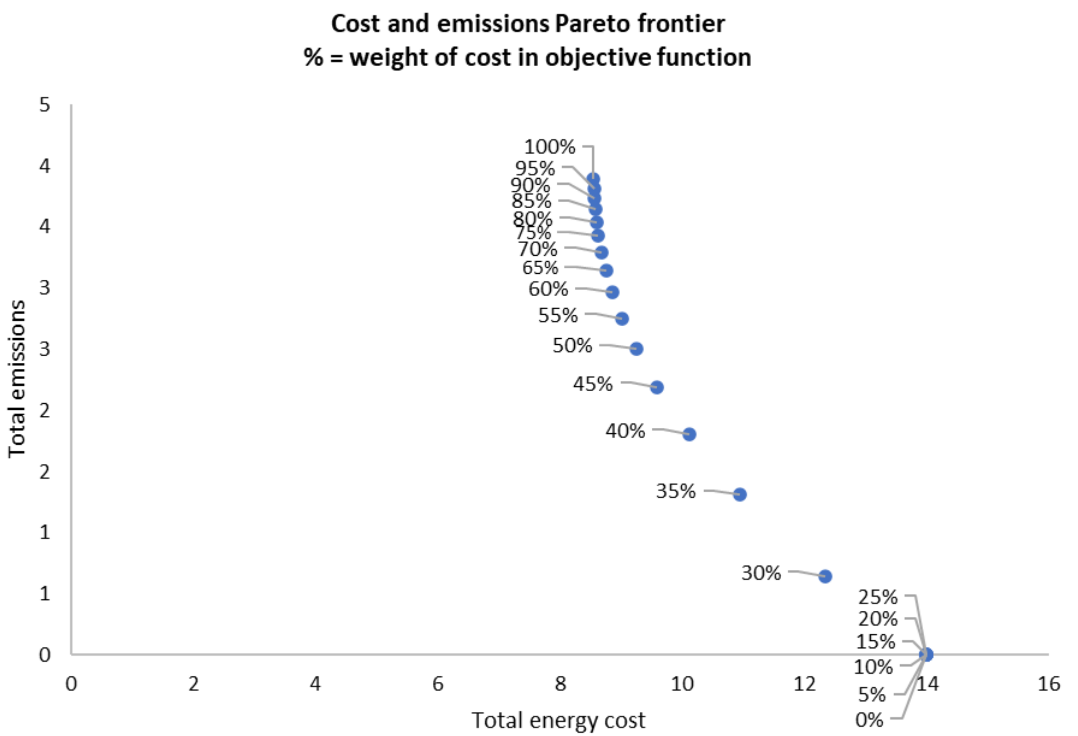
Optimal energy mix for cost minimization

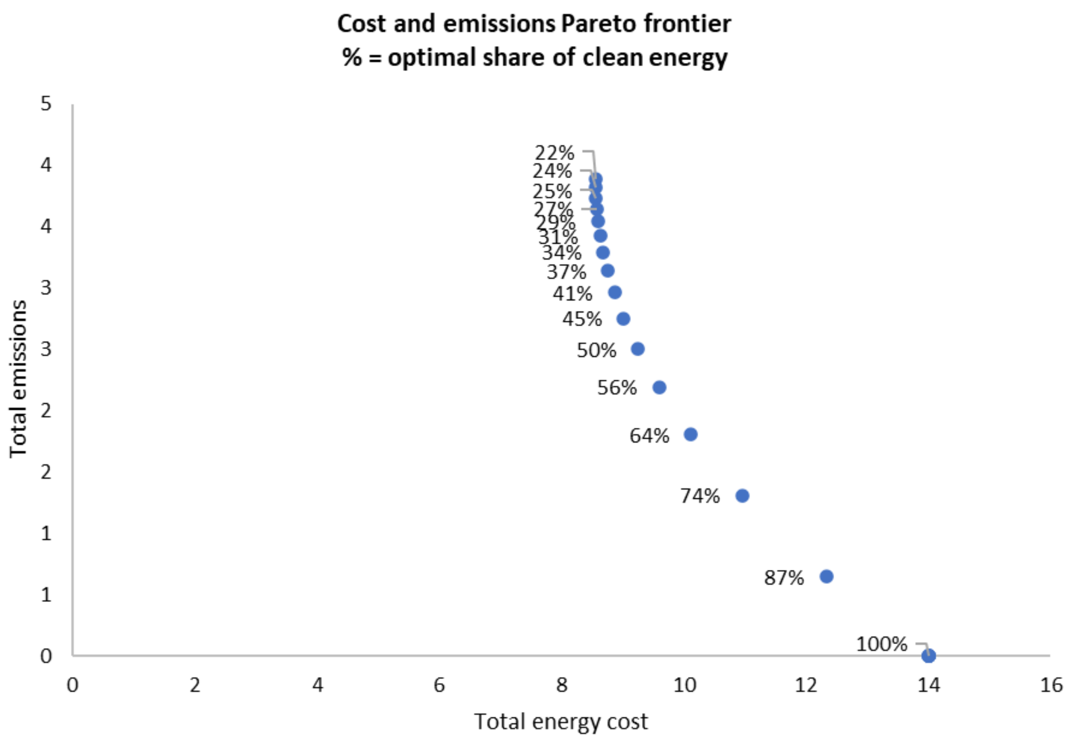
- Impose $E_c + E_d = 1$ and define x = share of clean energy
- Total cost of energy = $c_1 x + c_2 x^2 + d_1(1-x) + d_2(1-x)^2$
- This cost is minimized for $x^* = \frac{d_1+2d_2-c_1}{2(c_2+d_2)} = 22\%$
- This is the point furthest left on Pareto frontier
- Emissions could be lower with larger x…



Resolving the trade-off between objectives

- Assume that we attach a weight of ω to cost and 1−ω to emissions
- Objective function becomes:
  $\min \omega[c_1 x + c_2 x^2 + d_1(1-x) + d_2(1-x)^2] + (1-\omega)e(1-x)$
- This is minimized for $x^* = \frac{d_1+2d_2-c_1}{2(c_2+d_2)} + \frac{1-\omega}{\omega}\frac{e}{2(c_2+d_2)}$





MULTI-CRITERIA ANALYSIS

Terminology

- A multitude of terminologies: 'multi-criteria' or 'multiple-criteria', '… decision methods' or '… decision making' or '… decision analysis', with or without hyphens
- Most common: 'multi-criteria decision analysis' (**MCDA**) and 'multi-criteria decision-making' (MCDM)
- Fundamental building stones: a set of assessment criteria and a corresponding weighing scheme for these criteria

Formally

- A set of **alternatives** to be compared and ranked, with a view to helping choose the 'best' alternative: $A = \{A_i \mid i = 1, 2, ..., m\}$
- A set of **criteria** representing benefits or costs: $C = \{C_j \mid j = 1, 2, ..., n\}$
- A set of **weights**, one for each criterion: $W = \{w_j \mid j = 1, 2, ..., n\}$
- The weights are usually normalized: $\sum_{j=1}^{n} w_j = 1$
- MCDA amounts to filling a matrix with **scores**:

	Criterion C_1	Criterion C_2	…	Criterion C_n
	Weight w_1	Weight w_2	…	Weight w_n
Alternative A_1	s_{11}	s_{12}	…	s_{1n}
Alternative A_2	s_{21}	s_{22}	…	s_{2n}
…	…	…	…	…
Alternative A_m	s_{m1}	s_{m2}	…	s_{mn}

- Compute the score of each alternative: $S_i = \sum_{j=1}^{n} w_j \times s_{ij}$

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Challenges

- Criteria selection: only those that can be measured or also qualitative criteria? (→ fuzzy methods)
- Weighing choice: who sets the weights?
- Scoring: what formula?

Example for scoring problem

- Three competitors offered these prices in a procurement bid, for a client looking for the lowest price: A: 50, B: 55, C: 100
- Scoring options, on a scale of 1 (worst) to 5 (best):

	Rank based scoring	Distance-based scoring	Reference-based scoring	Proportional scoring
A	5	5	4.5	5
B	3	4.6	4.25	4.55
C	1	1	2	2.5
	Best gets max possible score, worst gets min possible score, the other ones are placed at equal distance in between	Best gets max possible score, worst gets min possible score, the other ones are scored according to their distance between best and worst: Score = 5-(P-Min)/(Max-Min)*(5-1)	Best possible price = 40, worst possible price = 120 Score = 5-(P-40)/(120-40)*(5-1)	Best gets max possible score, the other ones are scored proportionally to their ratio to the best: Score = 5 / (P/Min)

- Depending on the scoring method chosen, B and C have a better chance or not of catching up with A thanks to good scores on other criteria

The special problem of the price

- In many contexts, the price is by far the most important selection criterion, because the specifications guarantee the quality and time of delivery
- Nevertheless, the bid price could be just one criterion among the other ones, albeit with a high weight
- Alternatively, the MCDA score could be computed without the price, and then alternatives are compared based on 'quality' score and price (e.g.: quality score/price)
- If the 'price' is really a series of payments, the NPV, IRR, payback period could be used as an economic criterion

What weights?

- Regular weights imply that a bad score can be offset by a good score (cf. weak condition for sustainable development)
- Some criteria may be defined as absolutely required or essential: alternatives that do not satisfy these criteria should be eliminated → strict specifications and two-stage assessment
- The weighted arithmetic mean is not the only possibility: e.g. weighted product method $S_i = \prod_{j=1}^{n} s_{ij}^{w_j}$
- Some methods replace the single overall score by pairwise comparison of alternatives or by hierarchical ranking (lexicographic, one criterion after the other)
- Who decides on the weights? Client, stakeholder panel, experts, decision makers, inference from other decisions

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Example – choice of vehicle for garbage collection

Propulsion	Electrique_éco	Hydrogène_éco	GNC_6	Diesel_6
Prestataire	**Prest. 1**	**Prest. 2**	**Prest. 3**	**Prest. 4**
CO_2 / 5 ans	7 013	10 310	20 184	26 164
Points	**45**	**38**	**17**	**4**
	100%	147%	288%	373%

	Electrique_éco	Hydrogène_éco	GNC_6	Diesel_6
Unité	**Prest. 1**	**Prest. 2**	**Prest. 3**	**Prest. 2**
CHF/t	120	125	100	90
CHF / 5 ans	300 000	312 500	250 000	225 000
Points	**18**	**12**	**43**	**55**
	133%	139%	111%	100%

Critère	Points réalisables	**Prest. 1**	**Prest. 2**	**Prest. 3**	**Prest. 2**
Prix	55	18	12	43	55
Environnement	45	45	38	17	4
Total	**100**	**63**	**50**	**60**	**59**
Rang		*1*	*4*	*2*	*3*

- Emissions and costs are calculated for a town of 3,200 inhabitants producing 500 tons of household waste per year
- For the emissions, the maximum number of points is 45, given to the vehicle with the lowest emissions (no weighting, but splitting of 100 points)
- 0 points would be given for a vehicle that emits 4× more than minimum
- Parameters: max. points = 45, min. value = 7 013, range = 3× min. value = 21 039
- Points = (min. value + range – actual value)/range × max. points