Integral Indicator of Ecological Footprint for Croatian Power Plants

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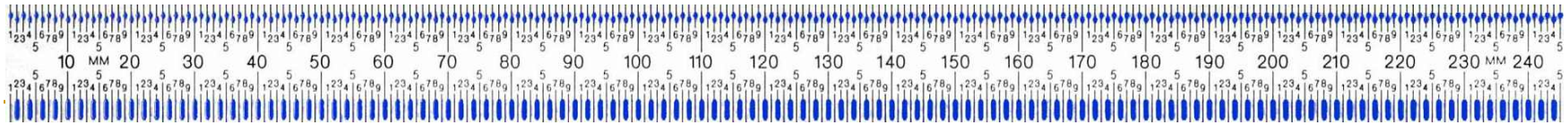
Definition

- The **integral indicator** is a **measure** of object's quality.
  - It is a scalar, corresponded to an object.
- The **integral indicator** is an **aggregation** of object's features that describe various components of the term "quality".
  - Expert estimation of object's quality could be an integral indicator, too.



Examples

Index name	**Objects**	**Features**	**Model**
TOEFL exams	Students	Tests	Sum of scores
Eurovision	Singers	Televotes, Jury votes	Linear (weighted sum)
S&P500, NASDAQ	Time-ticks	Shares (prices, volumes)	Non-linear
Bank ratings	Banks	Requirements	By an expert commission
Integral Indicator of Croatian Thermal PP's	**Thermal Power Plants**	**Waste measurements**	**Linear**

There is a set of objects

- Croatian Thermal Power Plants and Combined Heat and Power Plants

1. Plomin 1 TPP
2. Plomin 2 TPP
3. Rijeka TPP
4. Sisak TPP
5. TE-TO Zagreb CHP
6. EL-TO Zagreb CHP
7. TE-TO Osijek CHP
8. *Jetrovac TPP*

There is a set of features

- Outcomes and Waste measurements

1. Electricity (GWh)
2. Heat (TJ)
3. Available net capacity (MW)
4. SO_2 (t)
5. NO_X (t)
6. Particles (t)
7. CO_2 (kt)
8. Coal (kt)
9. Sulphur content in coal (%)
10. Liquid fuel (kt)
11. Sulphur content in liquid fuel (%)
12. Natural gas (10^6 m^3)

How to construct an index?

1. Assign a comparison criterion
   Ecological footprint of the Croatian Power Plants
2. Gather a set of comparable objects
   TPP and CHP (Jertovec TPP excluded)
3. Gather features of the objects
   Waste measurements
4. Make a data table: objects/features
   See 7 objects and 10 features in the table below
5. Select a model
   Linear model (with most informative coefficients)

Data table and feature optimums

N	Power Plant	**Electricity (GWh)**	**Heat (TJ)**	Available net capacity (MW)	SO_2 (t)	NO_X (t)	Particles (t)	CO_2 (kt)	Coal (kt)	Sulphur content in coal (%)	Liquid fuel (kt)	Sulphur content in liquid fuel (%)	Natural gas (10^6 m^3)
1	Plomin 1 TPP	**452**	**0**	98	1950	1378	140	454	198	0.54	0.43	0.2	0
2	Plomin 2 TPP	**1576**	**0**	192	581	1434	60	1458	637	0.54	0.37	0.2	0
3	Rijeka TPP	**825**	**0**	303	6392	1240	171	616	0	0	200	2.2	0
4	Sisak TPP	**741**	**0**	396	3592	1049	255	573	0	0	112	1.79	121
5	TE-TO Zagreb CHP	**1374**	**481**	337	2829	705	25	825	0	0	80	1.83	309
6	EL-TO Zagreb CHP	**333**	**332**	90	1259	900	19	355	0	0	39	2.1	126
7	TE-TO Osijek CHP	**114**	**115**	42	1062	320	35	160	0	0	37	1.1	24
				max	**min**	**min**	**min**	**min**	**min**	**min**	**min**	**min**	**min**

Each feature has its own optimal value (min, max)

Notations

$A=\{a_{ij}\}$ – $(n \times m)$ real matrix, **data set**,

q $=[q_1, \ldots, q_m]^T$ – vector of integral indicators,

w$=[w_1, \ldots, w_n]^T$ – vector of feature importance weights,

		w=			
		w_1	w_2	…	w_n
q=	q_1	a_{11}	a_{12}	…	a_{1n}
	q_2	a_{21}	a_{22}	…	a_{2n}
	…	…	…	…	
	q_m	a_{m1}	a_{m2}	…	a_{mn}

Data preparation – 1

Normalize data according to the Power Plan outcomes

$$a_{ij} \mapsto \frac{a_{ij}}{e_i + \frac{18}{5} h_i},$$

where e_i – Electricity (GWh) and

h_i – Heat (TJ) of i-th Power Plant.

Data preparation – 2

Convert data to the comparable scales,

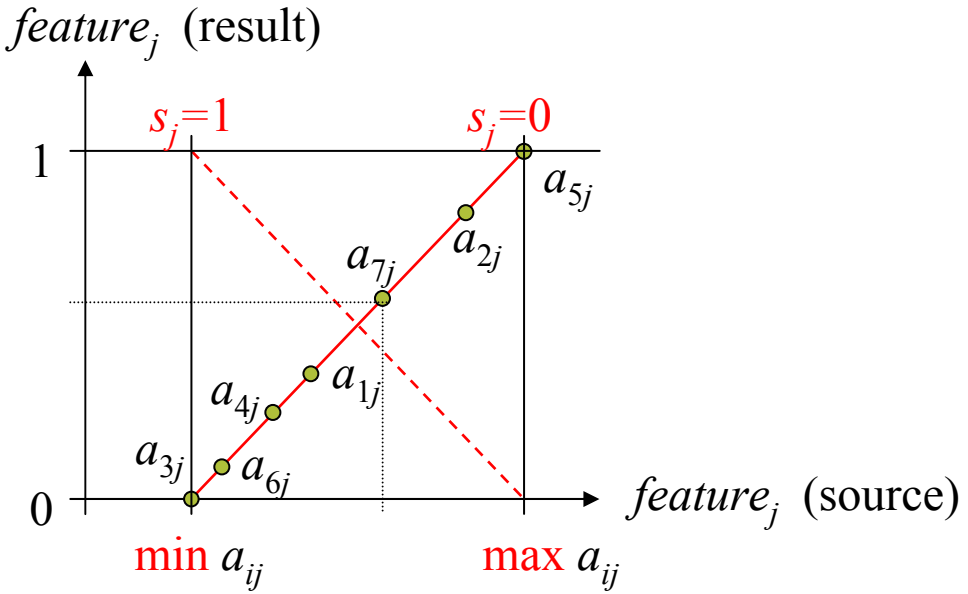
$$a_{ij} \mapsto (-1)^{s_j} \frac{a_{ij} - \min_i(a_{ij})}{\max_i(a_{ij}) - \min_i(a_{ij})} + s_j.$$

And put it to the principle "*the bigger the better*":

$s_j = 0$, if the desired value of j-th feature is **max**;

$s_j = 1$, if the desired value is **min**.

Data preparation, explanation



"*The bigger the better*" principle:
greater value of *i*-th object, given feature, involves greater value of the integral indicator for this object.

The algorithms

1. Pareto-Slicing
2. Metric Algorithms
3. Weighted Sum*
4. Principal Components Analysis
5. Expert-Statistical Technique*
6. Linear/Ordinal Specification*

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* Expert estimations required

Integral indicators and expert estimations

There are lot of ways to construct integral indicators. However, when algorithms are chosen and some results obtained, the following question arises:

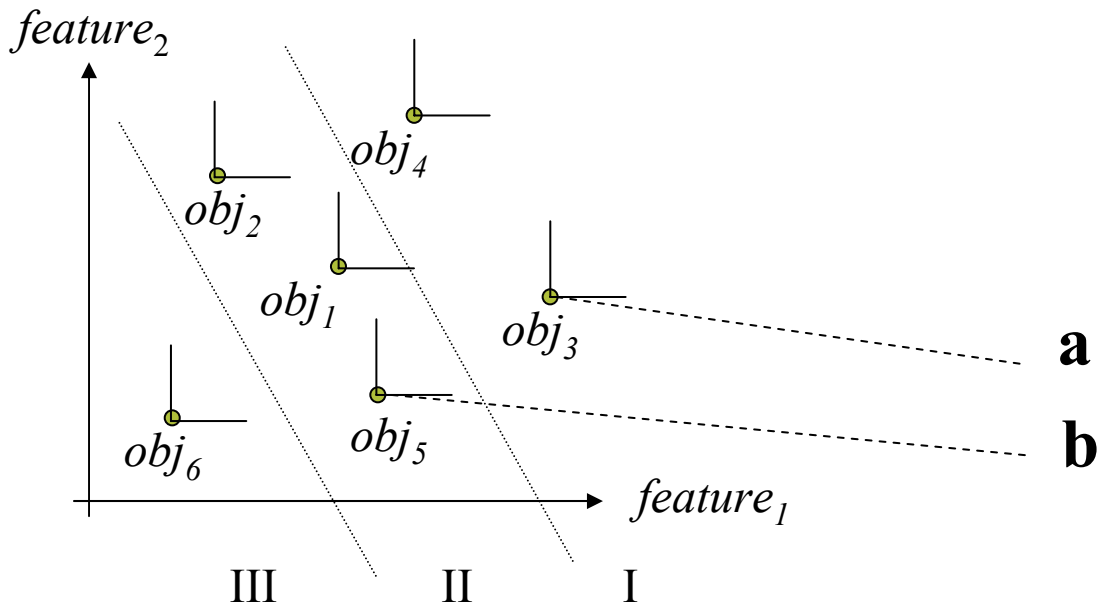
- **How to show adequacy of the calculated integral indicators?**

To answer the question analysts invite experts. The experts express their opinion and then the second question arises:

- **How to show that expert estimations are valid?**

The first method, Pareto slicing

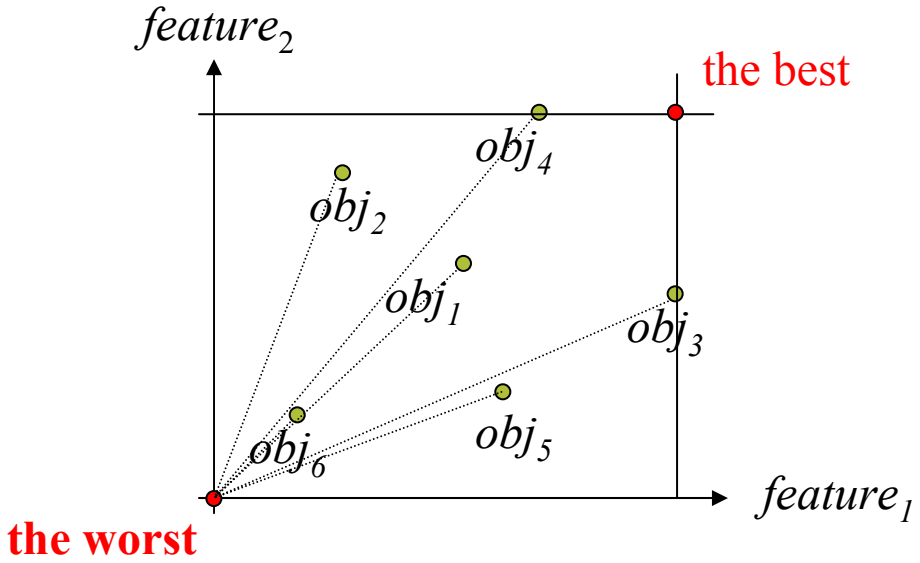
Find non-dominated objects at each slicing level.



The object **a** is non-dominated if there is no $\mathbf{b}_i$ such that $b_{ij} \geq a_i$ for all features j.

The second method, Metric algorithm

The worst (best) object is an object that contains the minimal (maximal) values of the features.



$$q_i = \sqrt[r]{\sum_{j=1}^{n} (a_{ij} - a_j^{worst})^r}$$

For $r = 1$, this algorithm coincides the weighted sum with equal weighs.

Supervised way-1,

the Weighted sum

$$\mathbf{q}_1 = A\ \mathbf{w}_{\text{expert}},$$

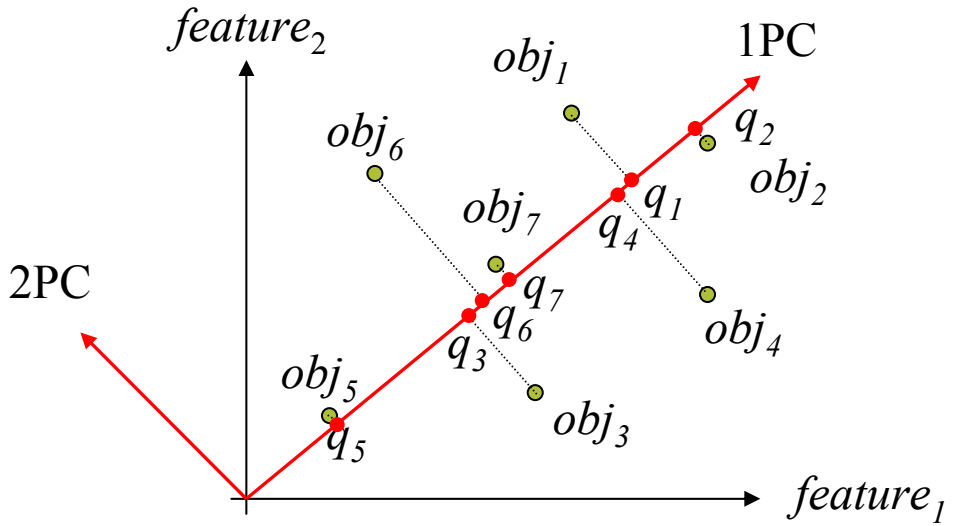
$$\begin{pmatrix} q_1 \\ \vdots \\ q_m \end{pmatrix} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \begin{pmatrix} w_1 \\ \vdots \\ w_n \end{pmatrix}.$$

Unsupervised way,

Principal Components Analysis

$Q=AW$, where W—rotation matrix of the principal components.

$\mathbf{q}_{PCA}=A\mathbf{w}_{1PC}$, where $\mathbf{w}_{1PC}$ is the 1st column vector of W in the decomposition $A = ULW^T$.



PCA gives minimal mean square error between objects and their projections.

Supervised way-2,

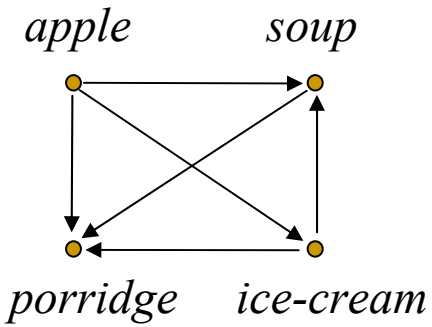
the Expert-Statistical Technique

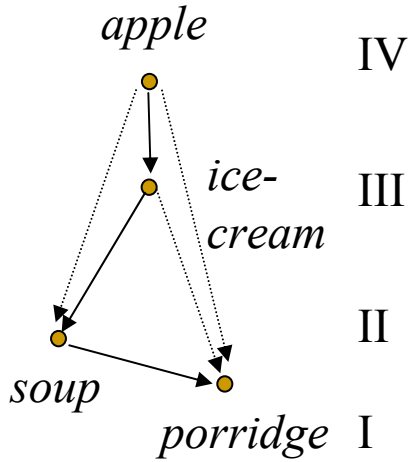
$$\mathbf{w}_1 = \arg\min \|\mathbf{q}_{expert} - A\,\mathbf{w}\|^2,$$

least squares, $\mathbf{w}_1 = (A^T A)^{-1} A^T \mathbf{q}_{expert}$.

Pair-wise comparison

	a	*s*	*p*	*i-c*
apple	●	+	+	+
soup		●	+	–
porridge			●	–
ice-cream				●





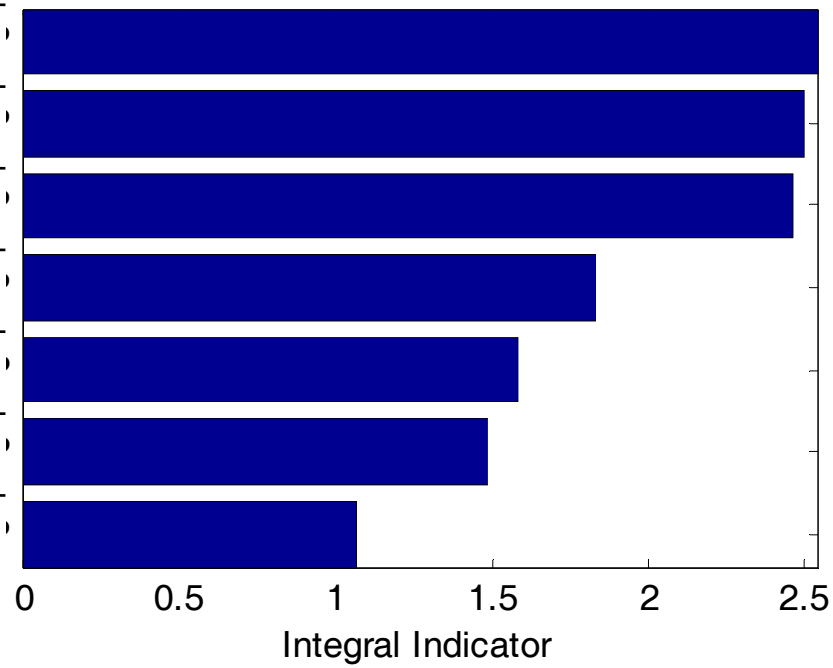
If an object in a row is better than the other one in a column then put "+", otherwise "-".

Make a graph, *row* + *column* means *row* ● → ● *column*.

Find the top and remove extra nodes.

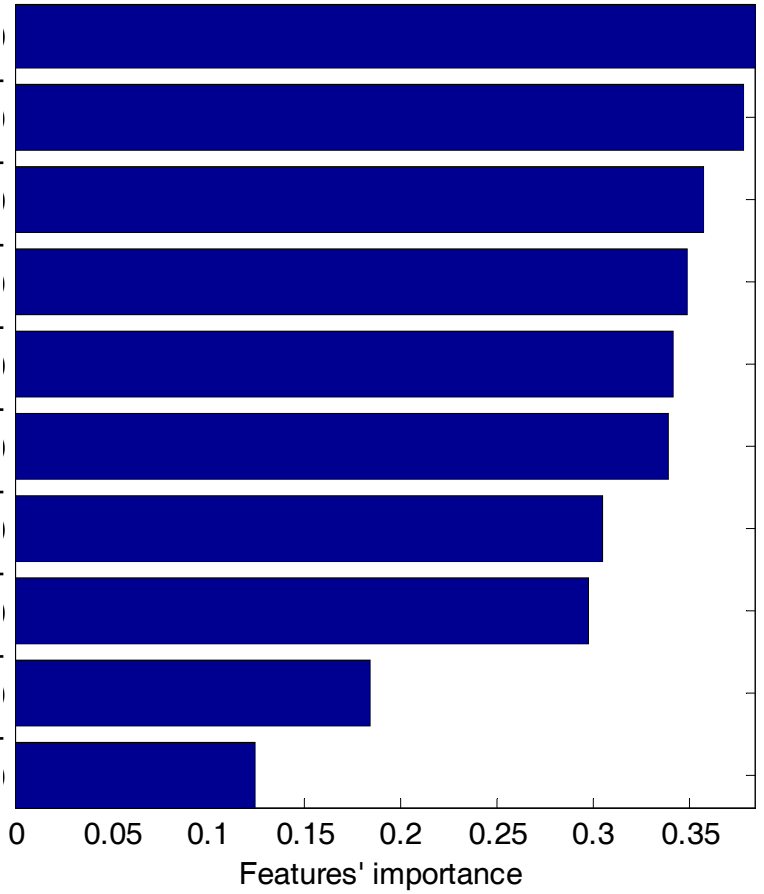
The Integral Indicator of Ecological Footprint for the Croatian Thermal Power Plants

Power Plant	Integral Indicator
TE-TO Zagreb CHP	2.53
EL-TO Zagreb CHP	2.49
TE-TO Osijek CHP	2.46
Plomin 2 TPP	1.83
Rijeka TPP	1.57
Sisak TPP	1.48
Plomin 1 TPP	1.07

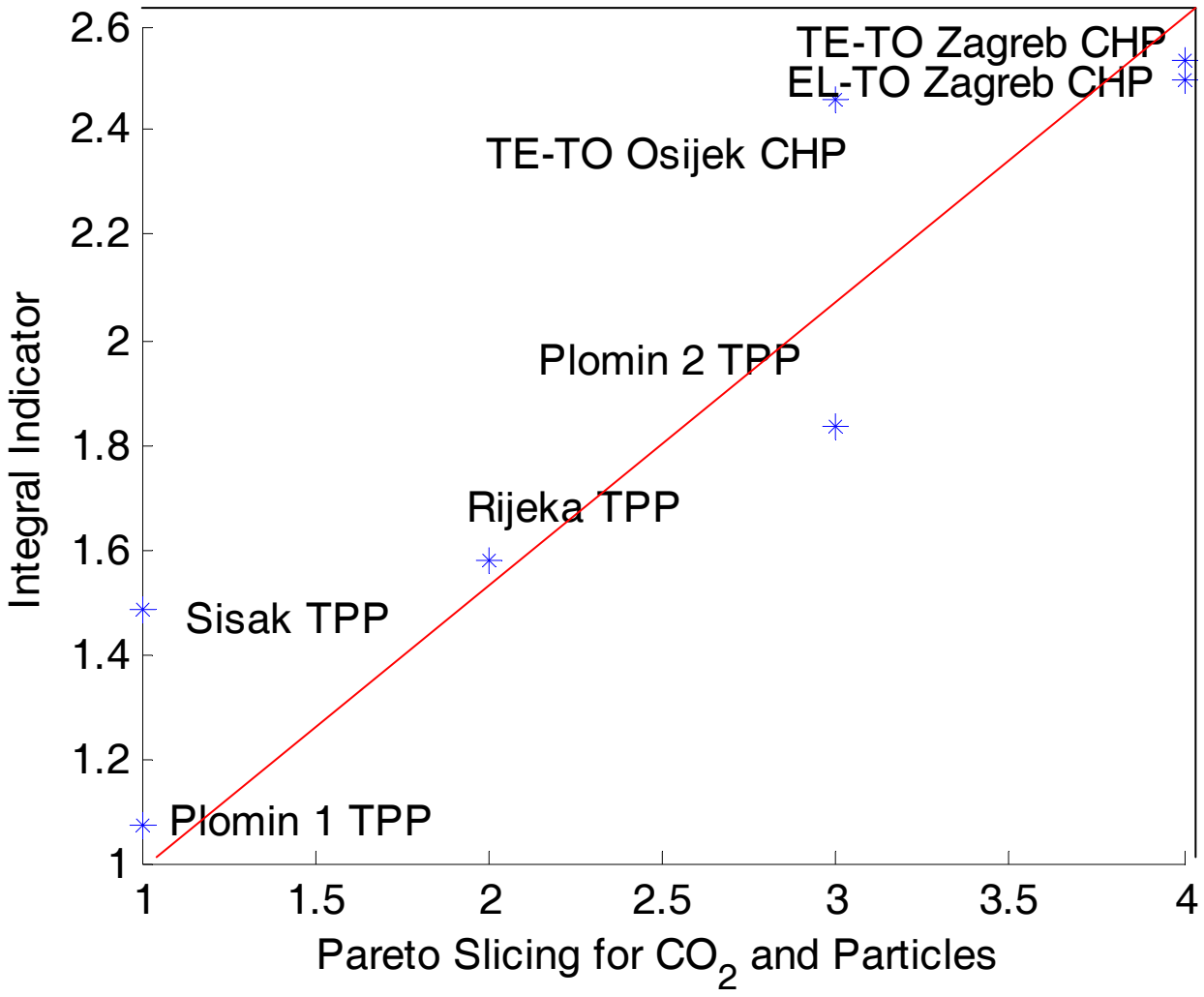


The Importance weights of the Features

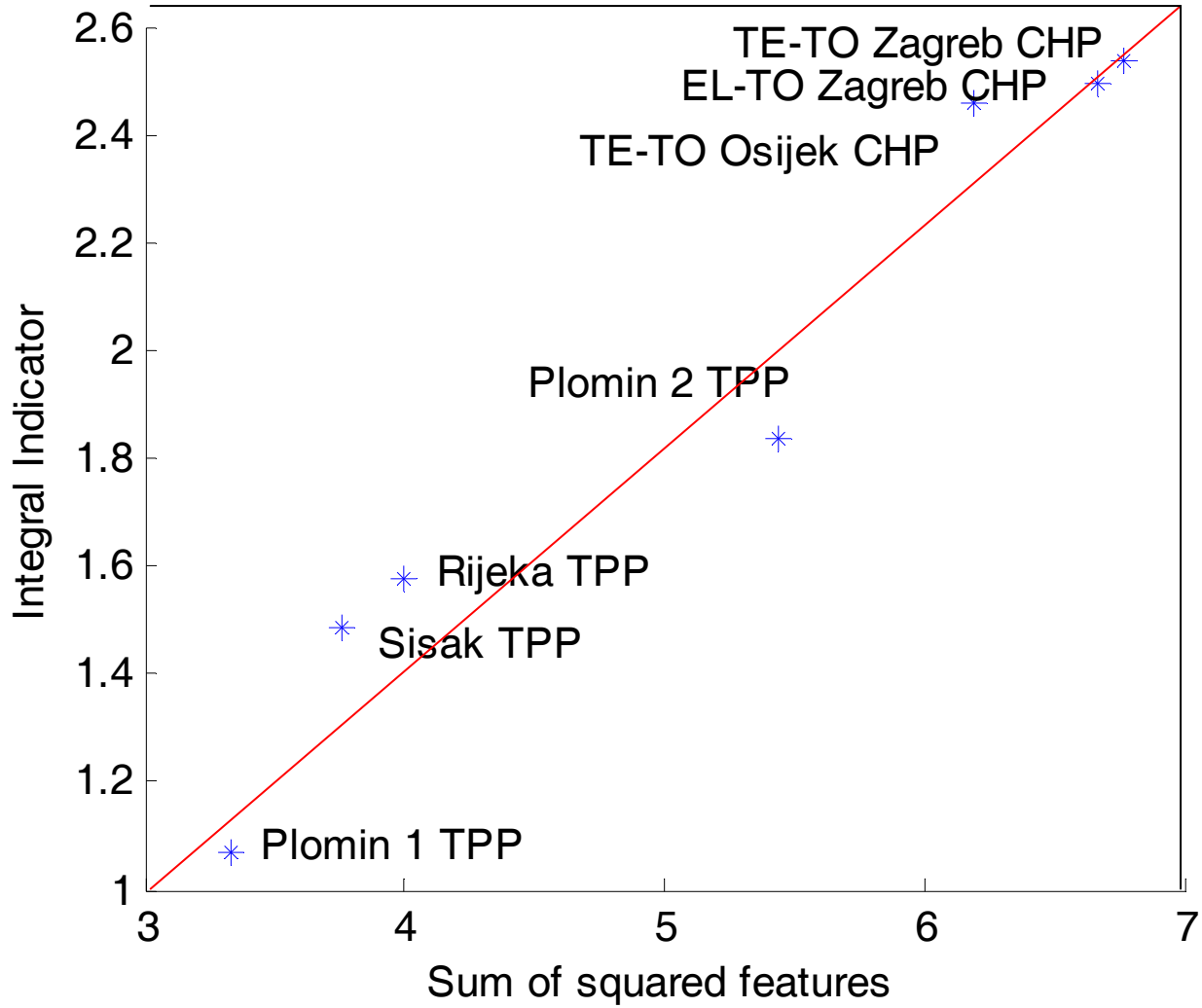
Feature	Weight
Coal (t)	0.38
Sulphur content in coal (%)	0.37
NO_x (t)	0.35
Liquid fuel (t)	0.34
SO_2 (t)	0.34
Particles (t)	0.33
Natural gas (10^3 m^3)	0.30
CO_2 (kt)	0.29
Sulphur content in l.fuel (%)	0.18
Available net capacity (MW)	0.12



The Integral Indicator versus Pareto Slicing



The Integral Indicator versus Metric Algorithm



Strong sides of the methodology

- The Integral Indicator is based on the open-source data
- The model of the Integral Indicator and the methodology of construction are published

→ Anybody can check the results

- The Integral Indicator could include expert estimations
- The methodology of the expert estimations specification is suggested

→ Experts are welcome to show opinions

The results

- The Integral Indicator of Ecological Footprint for the Croatian Power Plants includes
  - Thermal Power Plants
  - Combined Heat and Power Plants.

- Feature importance weights for the Waste measurements of the Power Plants
  - were obtained by Principal Component Analysis and
  - keep maximum information about measured data.