
Integral Indicator of Ecological Footprint for Croatian Power Plants

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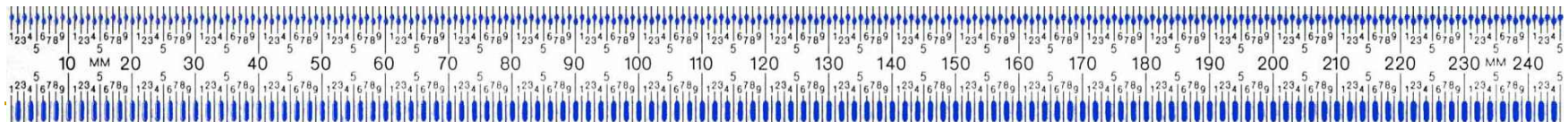
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Definition

- 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. SO₂ (t)
5. NO_x (t)
6. Particles (t)
7. CO₂ (kt)
8. Coal (kt)
9. Sulphur content in coal (%)
10. Liquid fuel (kt)
11. Sulphur content in liquid fuel (%)
12. Natural gas (10⁶ m³)



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**,

$\mathbf{q} = [q_1, \dots, q_m]^T$ – vector of **integral indicators**,

$\mathbf{w} = [w_1, \dots, w_n]^T$ – vector of **feature importance weights**,

		$\mathbf{w} =$			
		w_1	w_2	...	w_n
$\mathbf{q} =$	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,

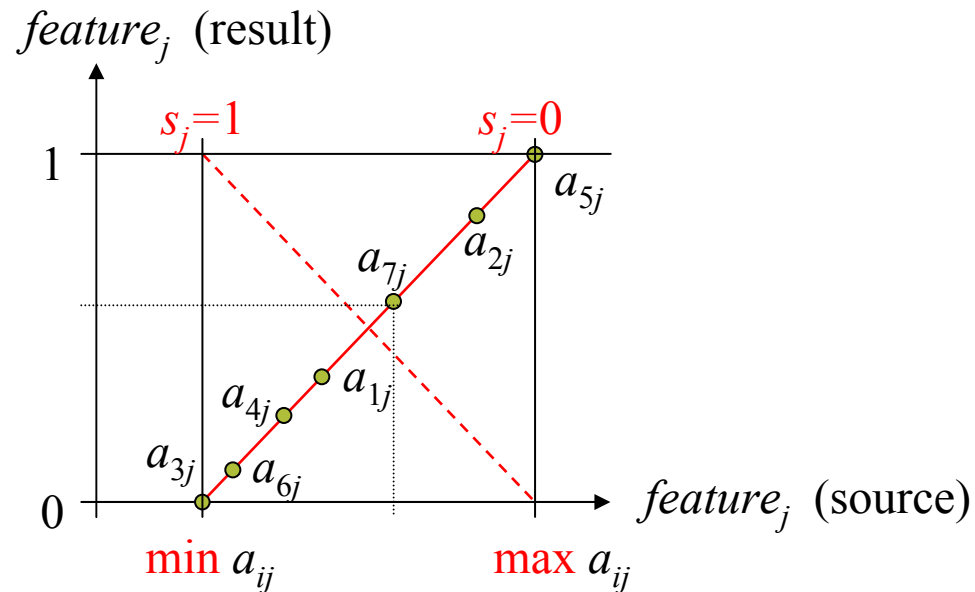
$$a_{ij} \mapsto (-1)^{s_j} \frac{a_{ij} - \min_i(a_{ij})}{\max_i(a_{ij}) - \min_i(a_{ij})} + s_j.$$

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*



* 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:

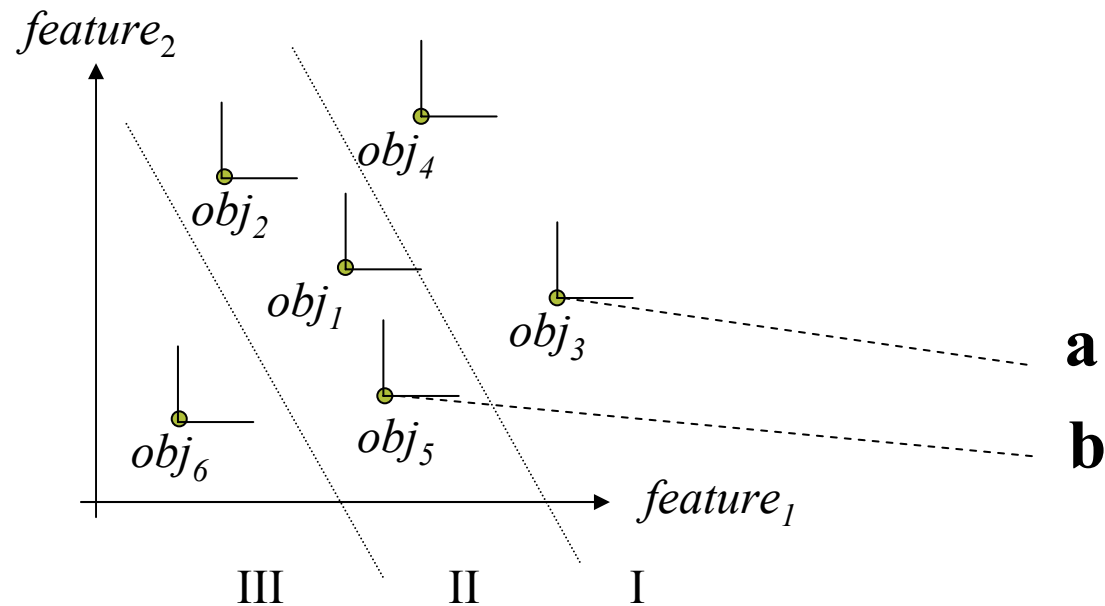
- **How to show adequacy of the calculated integral indicators?**

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

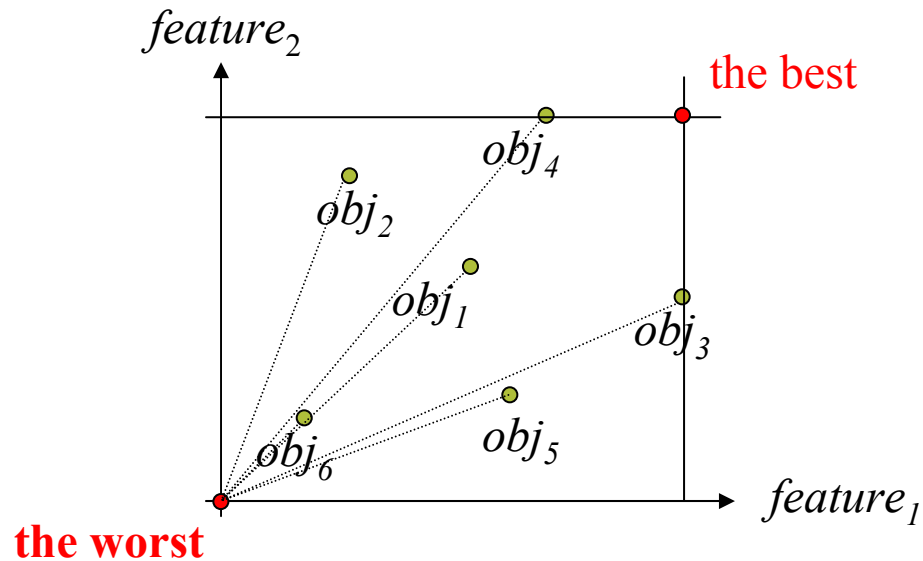
Find non-dominated objects at each slicing level.



The object **a** is non-dominated if there is no **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 weights.

Supervised way-1,

the Weighted sum

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

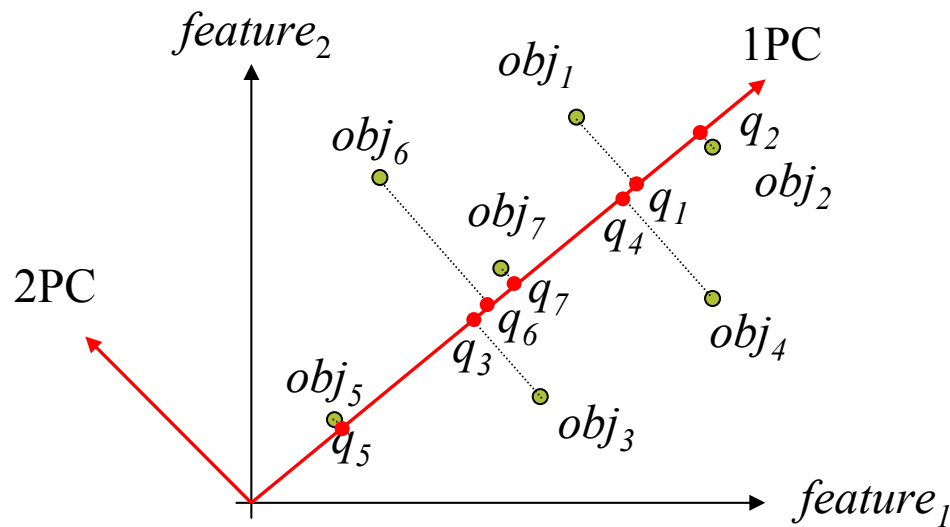
$$\begin{pmatrix} q_1 \\ \vdots \\ q_m \end{pmatrix} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \begin{pmatrix} w_1 \\ \vdots \\ w_n \end{pmatrix}.$$

Unsupervised way,

Principal Components Analysis

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

$\mathbf{q}_{\text{PCA}}=A\mathbf{w}_{1\text{PC}}$, where $\mathbf{w}_{1\text{PC}}$ 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

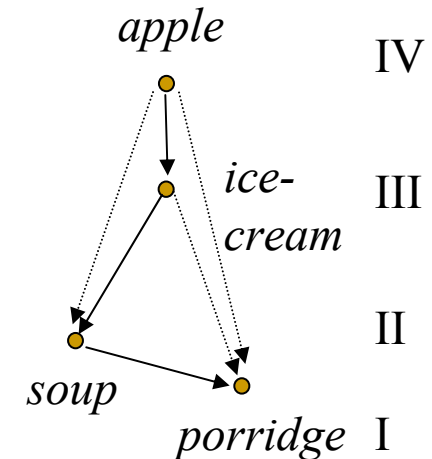
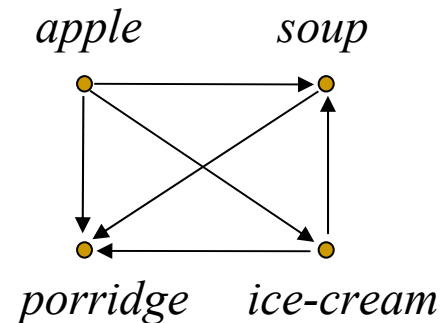
$$\mathbf{w}_1 = \arg \min \|\mathbf{q}_{\text{expert}} - A \mathbf{w}\|^2,$$

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

Check the expert! (toy problem)

Pair-wise comparison

	<i>a</i>	<i>s</i>	<i>p</i>	<i>i-c</i>
<i>apple</i>	●	+	+	+
<i>soup</i>		●	+	-
<i>porridge</i>			●	-
<i>ice-cream</i>				●

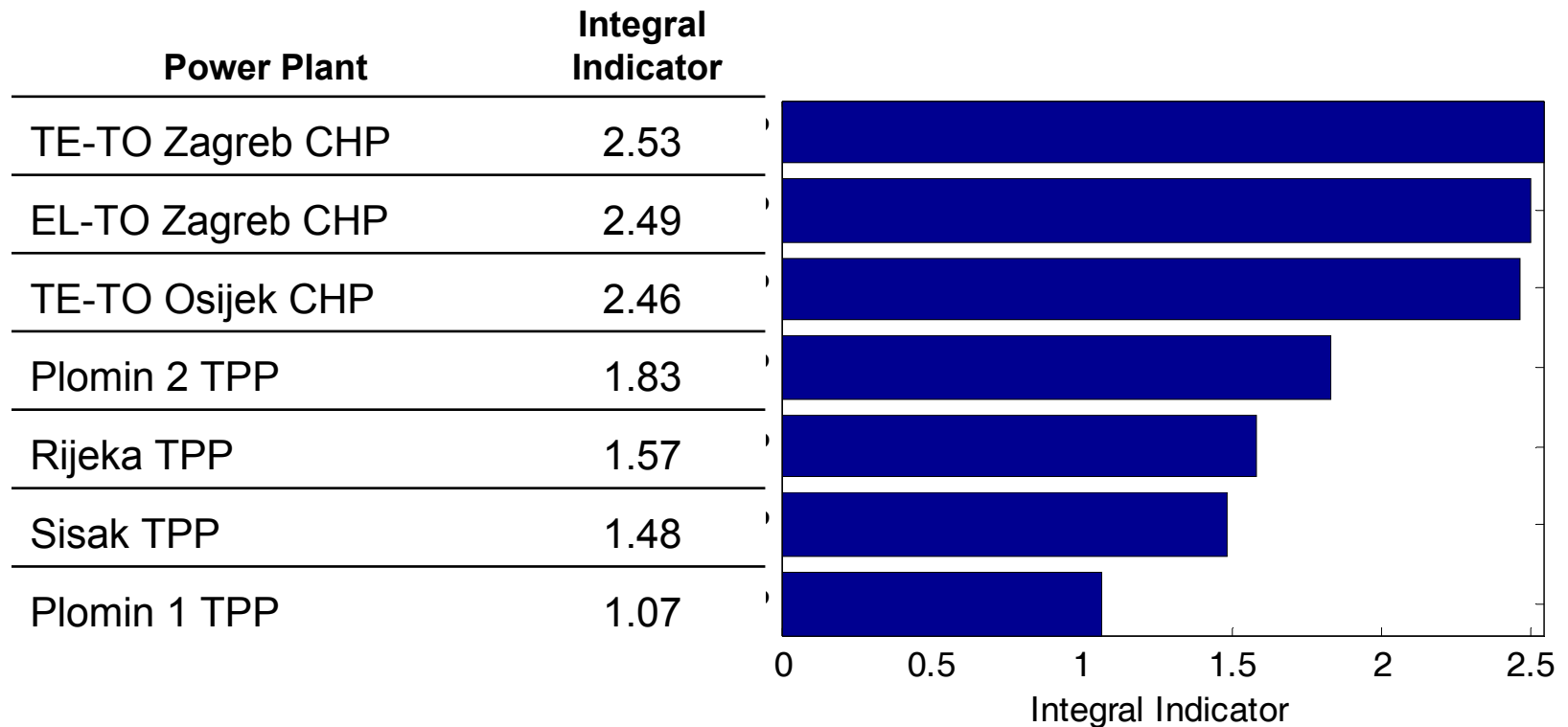


If an object in a row is better than the other one in a column then put “+”,
otherwise “-”.

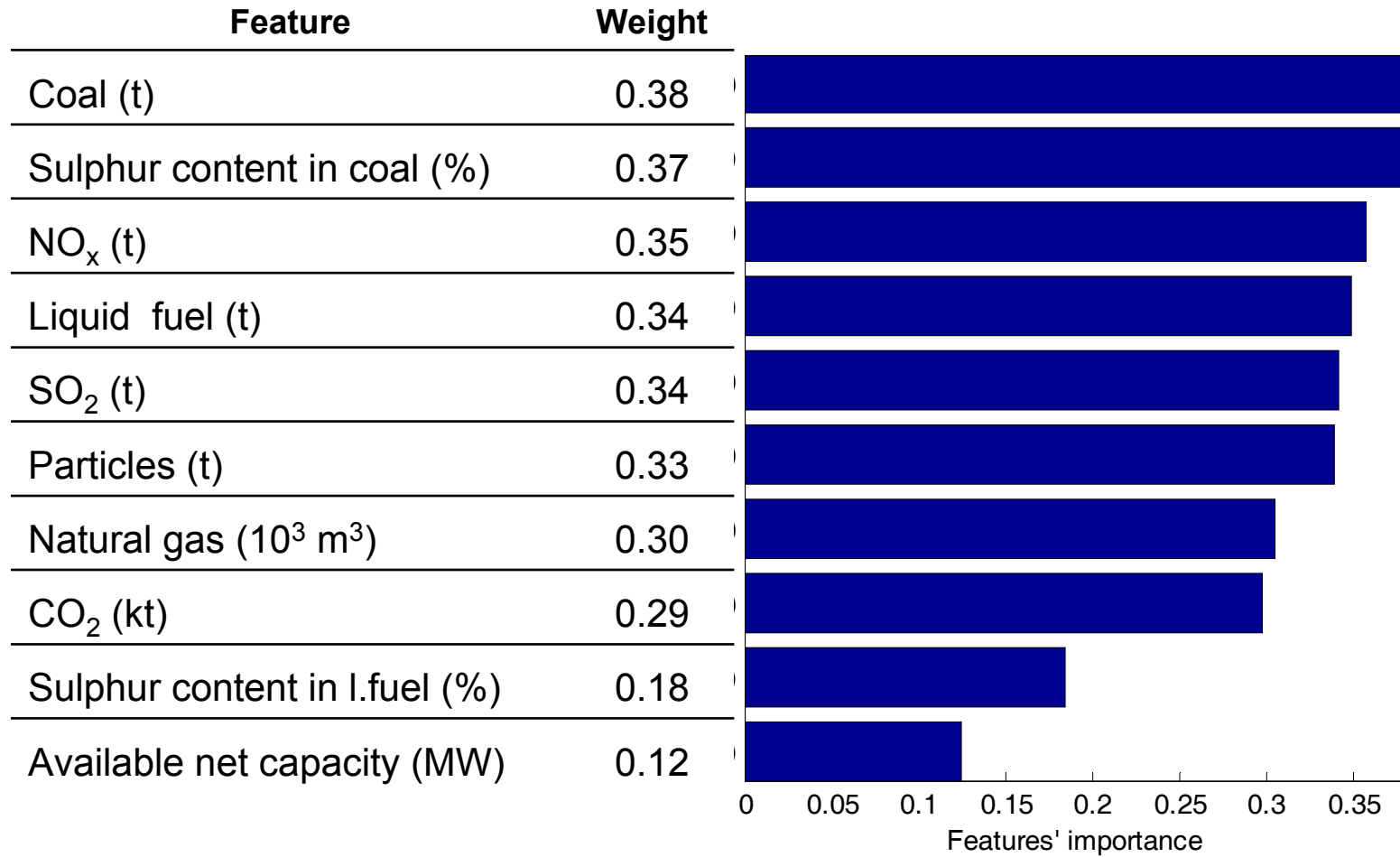
Make a graph, *row* + *column* means *row* ● → ● *column*.

Find the top and remove extra nodes.

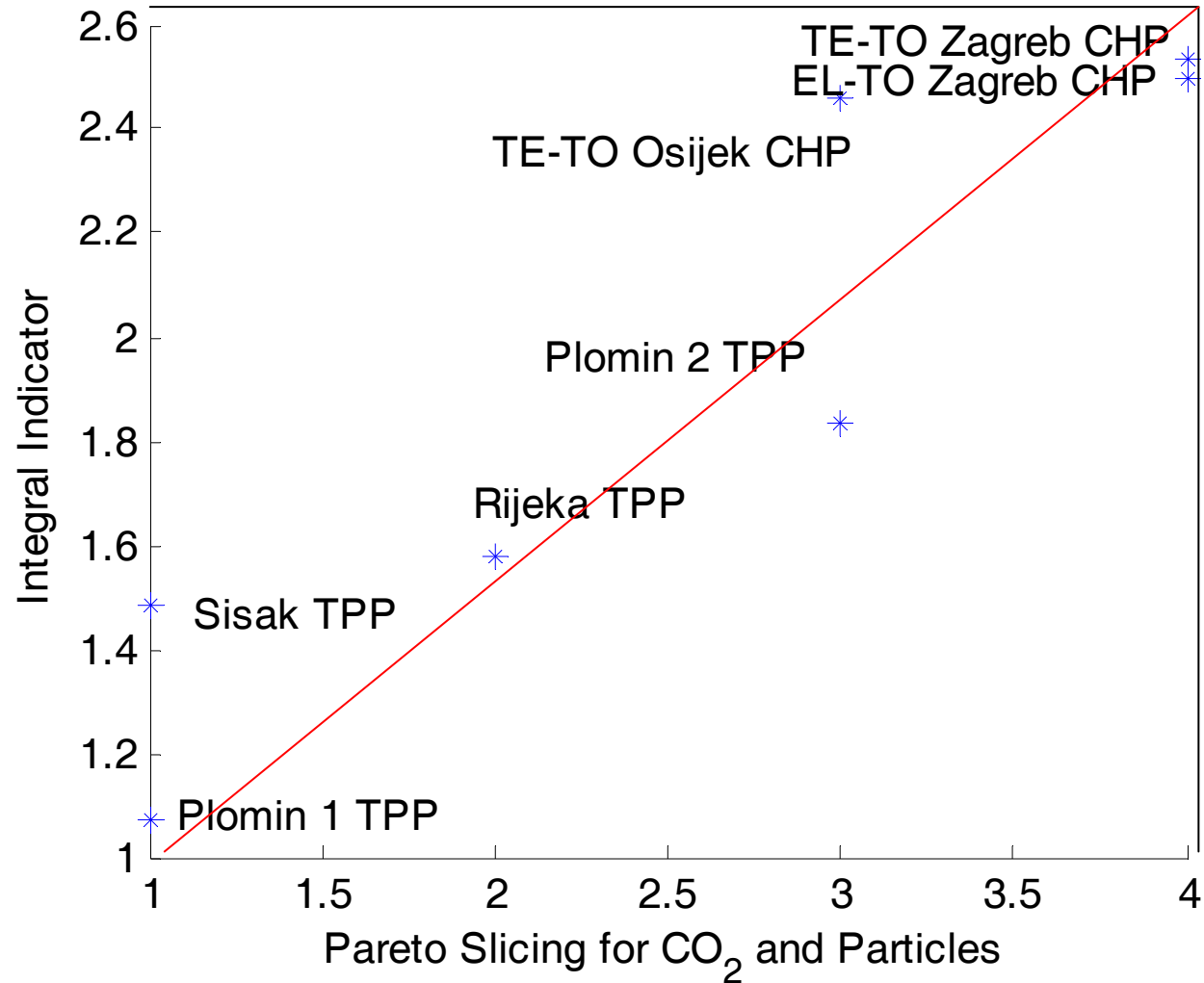
The Integral Indicator of Ecological Footprint for the Croatian Thermal Power Plants



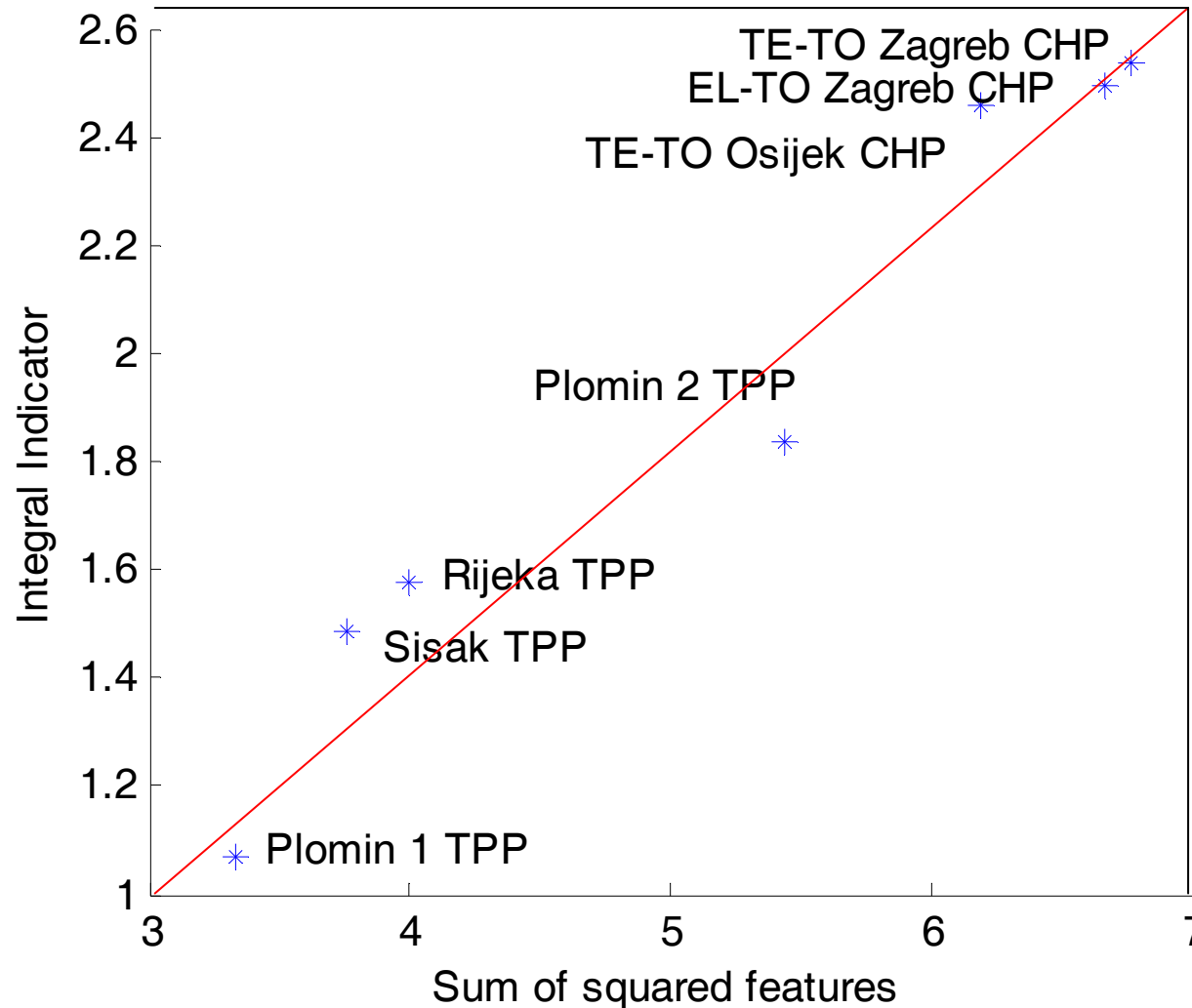
The Importance weights of the Features



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.

