GETTING THE MOST OUT OF OPERATIONAL DATA IN ENERGETICS

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Abstract.

Both energy and environment fields are of top priority in the current and strategic European Union policies. These sectors imply complex approaches and consistent investment in order to keep pace with depleting resources, converting to renewables and reduce the environmental footprint of anthropic activities. Operating power production facilities leads to huge amounts of installation data. The paper presents a possible alternative to large investments to improve the efficiencies of existing installations: namely the use of data-mining techniques for analysing existing operational data. Data-mining is emerging as a valuable concept based upon detailed analysis of operational records with advanced mathematical/statistical tools. Outcomes are, e.g.: evaluating the consistency of measurements, identifying new hardware needs, internal/external benchmarking, correlation of consumptions with power/ heat production, pointing out causes of high environmental impact, maintenance scheduling, stock optimization, analysing scenarios for future development and decision support for local managers, etc. The paper details the data-mining carried out at the TERMICA – Suceava power plant for the period 2007-2012. The analysis was carried out by a multidisciplinary, complex team (engineers of various specialities, environmentalists, economists, mathematicians, IT experts). Dta mining is much less expensive than rushing to investment in new equipment. Participation of Company's top management is fundamental, this being the driving force and motivation source for experts and operators. The approch presented is self learning.

Keywords: energy efficiency, data-mining, mathematical modelling, environmental footprint.

1. THE DATA-MINING APPROACH.

Data mining is the inquiring stage of the "Knowledge Discovery in Databases" process, a multidisciplinary area of computing science enabling the discovery of patterns and trends in large volumes of data. Statistical and stochastic modeling, expert system and artificial intelligence concepts, machine learning contribute to extract information from a existing measurements and convert it into a useful structure for further use. The data-mining process starts with the raw analysis and data pre-processing steps and, based on modeling and inference, it develops metrics for the processes, arranges informationion to support the management process and prepares the post-processing of discovered structures and future updating.
In the present paper, the data-mining analysis will evaluate the data at hand, pre-process for consistency and infer valuable information about the evolution of technological process at the TERMICA power plant, handed over to local managers for further use.

2. THE DATA-MINING PROJECT AT TERMICA POWER PLANT

The support of the TERMICA power plant top management, was at the start of the Data-Mining Project (DMP) presented here. A Data-Mining Team (DMT) was appointed and it included the technical director, the mechanics-energy chief engineer, the chief accounting officer, the heads of the quality and environmental compartments and two junior members that took care of the IT infrastructure and of uploading data in the Project databases. The team included also two experts from outside TERMICA, namely a software professor and an energy and environment consultant, both with experience in data-mining, mathematical and statistical modelling, having experience in EU BAT (best available techniques) documents related to power production and associated environmental impact. The DMT reported to the TERMICA top management on a daily basis so that the DMP could be carried on smoothly.
The TERMICA top managers and the DMT established the main objectives for the DMP:

- Choosing the technological, economic and environmental parameters to be analyzed;

- Identifying sources of data, evaluating their consistency and assessing needs for supplementary measuring and monitoring hardware, in order to increase the quality of data;
- Application of environmental accounting procedures (EMA, 2001; ISO 14051, 2011) for an objective analysis of environmental costs occurring at TERMICA;
- Correlation analysis
- Internal Benchmarking (when, how and why have been attained the best operational and environmental performances at TERMICA)
- External Benchmarking - reference to BAT (LCP, 2006)
- Regression analysis and trend identification;

As a working procedure, the top management and the DMT agreed that:

- the DMP should use software familiar to local experts (the Microsoft EXCEL was subsequently used);
- the DMP procedure and databases will be active, upgradable and at hand even after the Projects ends. Train TERMICA people with the use of the DMP procedures was an essential component of the DMP..

The data used in the DMP covered the period 2007-2012.
Databases with operational parameters of the installations (specific consumptions, power and heat produced and delivered, excess air to burners, wastewater and ash generated, together with their characteristic parameters, costs and other economic parameters, etc.) were set up and uploaded in an agreed format in the DMP computer databases.

Assessing the normal (Gaussian) distribution of data was carried out using

- histograms, descriptive statistics (including higher distribution moments like skewness and kurtosis for various data sets were inferred and they were found to be near zero in most cases – indicating a distribution near to normal);
- specific tests for normality, built up in EXCEL worksheet: Doornick-Hansen (χ^2), Jarque-Bera and Shapiro-Wilk tests (RUan, 2005). All calculate a *p*-value that is compared to and should be larger than the α-value chosen. All sets of parameter data passed the Jarque-Bera test and most of them the Doornick-Hansen (χ^2) test. Only a few passed the Shapiro-Wilk test.

It was assumed that the data are normally distributed and recommendations were made for installing higher quality monitoring devices to increase in future the consistency of acquired operational data.

3. ENVIRONMENTAL COST ACCOUNTING

In order to have a comprehensive image of the technology, economic and environment performance of TERMICA power plant, a detailed environmental cost accounting procedure was developed in order to associate costs to any material and energy flow in the power plant. Based upon UN (EMA, 2001) and ISO (ISO14051, 2011) documents environmental costs like those exemplified in Table 1 were derived.

Table 4. Examples of environmental costs evaluated at TERMICA.

Negative Flux Cost Index (2007=100)	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Share in total costs (%)	31.1	18.2	19.8	18.9	19.1	17.8
Internal power consumptions	100	105.6	165.1	114.7	129.0	119.0
Thermal Energy not delivered	100	133.5	183.1	135.7	133.3	131.4
Ash management costs	100	121.6	221.6	157.1	178.5	168.7
Carbon Dioxide associated costs	100	80.4	95.8	88.7	91.4	80.2
Cost of flue gases at 140^oC	100	109.2	145.3	102.8	102.4	101.6
Cost of water / wastewater	100	128.3	144.5	168.2	172.6	170.0

The term “negative flows” is used by ISO 14025 (“non-product outputs” in the UN methodology) to identify material / energy flows unintended, that can be reduced but, generally, cannot be avoided (losses, by-products, etc.). Table 1 shows the large share of environmental costs associated to power and heat production (up to 31.1% in 2007), stabilizing at around 18% in the last years.
The trend of these costs, in 201 is presented in Fig.1 indicating interesting conclusions for the TERMICA management. Examples:

- the larger share of negative costs is due to internal power consumptions and losses. Reducing these costs means investment in processing line, careful maintenance and monitoring of power consuming, transforming and transporting equipmen;
- the cost associated to flue gases can be reduced by lowering the gas exhaust temperature (currently 140^oC) but this may lead to water condensation and metal corrosion;
- costs associated to CO_2 has dropped once Romania has a market for this substance (CO_2 credits). TERMICA reduced its costs with CO_2 by trading CO_2 credits allowed to the company. It is a very favourable environmental issue and TERMICA managed to turn a waste (CO_2) into a source of income.

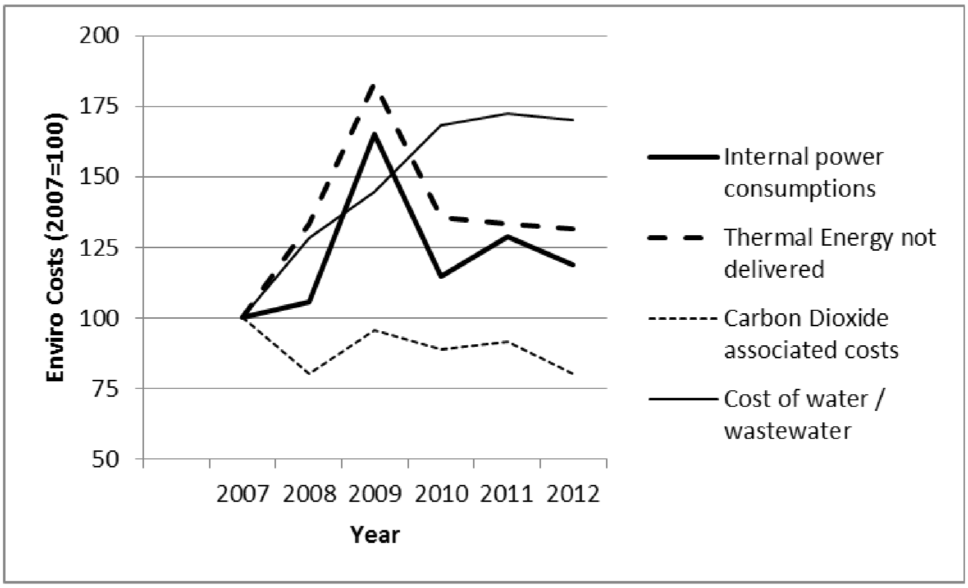

Fig. 12. Evolution of negative costs at TERMICA.

This preliminary analysis of the operational data recorded at TERMICA has already indicated the points where technical and managerial action is needed most, presenting objective costs, taken out of overheads.

3. CORRELATION ANALYSIS

Pearson correlation coefficients were derived and some of them are presented in Table 2. Some conclusions:
- the ash and flue gas to stack associated costs correlate best, as expected, as do water and wastewater management costs with the same flue gas costs.
- ash management cost does not correlate, as expected, with the amount of power / heat produced or with other consumptions (e.g., water), probably due to variations of ash content of different fuels used;

Reducing, e.g., the flue gas temperature, all other important costs correlating strongly with this parameter will also decrease, underlining again the need of a further detailed analysis of the opportunity of decreasing temperature at stack.

Table 5. Correlation coefficients derived from TERMICA database.

Parameter	Internal power consumption	Heat not delivered	Ash Manag.	CO_2 emitted	Flue gas costs	Water / wastewater
Internal power consumption	1.00					
Heat not delivered	0.70	1.00				
Ash Manag.	-0.11	-0.01	1.00			
CO_2 emitted	0.36	0.62	-0.76	1.00		
Flue gas costs	0.80	0.78	0.91	0.82	1.00	
Water/wastewater	0.58	0.45	-0.86	0.87	0.88	1.00

4. BENCHMARKING

Benchmarking compares performances of an industrial facility to similar installations operated elsewhere (external benchmarking) or to earlier performances in the same facility (internal benchmarking). The objectives of the benchmarking carried out by the DMP were:
- identify the best performances ever attained by the TERMICA installations in the period 2007-2012;
- evaluate how these performances have been attained and what can be done to reproduce and maintaining them.

Internal benchmarking shows to operators how well their installations can perform and asks them to maintain the conditions that enabled their own best performance. Improvements can be achieved by carefully operating existing equipment, good maintenance, etc. Practically no investment is needed.

Starting from their best ever performance, the installations should be aligned, by refurbishing and investing, to BAT reference level of performance (LCP, 2006; EE, 2009; ECMA, 2006). Table 3 illustrates the TERMICA vs BAT levels.

Table 6. Benchmarking data.

	BAT	2007	2008	2009	2010	2011	2012	%min/max
Fuel for power generation	1	1.21	1.16	1.24	1.24	1.20	1.18	93.5
Fuel for heat production	1	1.17	1.14	1.22	1.21	1.21	1.19	93.4
CO_2/MWh	1	1.78	1.62	1.84	1.79	1.8	1.77	88.0
Water m3/MWh	1	1.21	1.14	1.28	1.24	1.21	1.23	89.0
Internal power consumption	1	1.21	1.13	1.16	1.17	1.18	1.16	93.3

As shown by Table 3, all current performances at TERMICA are well off the level required by best available techniques at hand (external benchmarking). The situation generates extra costs and makes TERMICA less competitive on the energy market. It is obvious that investment should assure a fast trend towards levels attained by best power plants in the field.
Yet TERMICA could improve in a short term by maintaining the conditions that led to its highest efficiencies in the past (internal benchmarking). During 2008, the TERMICA performances were the highest for the period analysed. The last column of Table 3 shows the level of best to worst TERMICA under each parameter analysed. TERMICA could consume 6.5% less fuel per MWh or GigaCalorie generated, could reduce its water consumption by 11% and each internal energy consumptions by 6.7% by reproducing the operational conditions that led, in 2008, to its better level of efficiencies. This could be done by motivating operators, following exactly operational procedures, improve maintenance, etc.

5. TREND IDENTIFICATION

Data from the 2007-2012 period were used to identify current trends in TERMICA performances and evaluates the period of time until best available technology efficiencies are attained (Fig.2).
Fig. 2 indicates that continuing the current operational set-up and efforts to improve at the current pace (small investments in burning hardware, in water and ash management, etc.), TERMICA will reach the BAT level for water consumption in 2017, the BAT level for specific fuel consumption per 1 MWH in 2022 and the same consumption per 1 Gigacalorie in 2040! All these identified trends are correct (as they indicate a progress towards BAT level) but the period of attaining this BAT level is far too long. Internal power consumption is increasing instead of decreasing towards BAT value. This is a hot point that must be addressed with priority by managers and engineers.

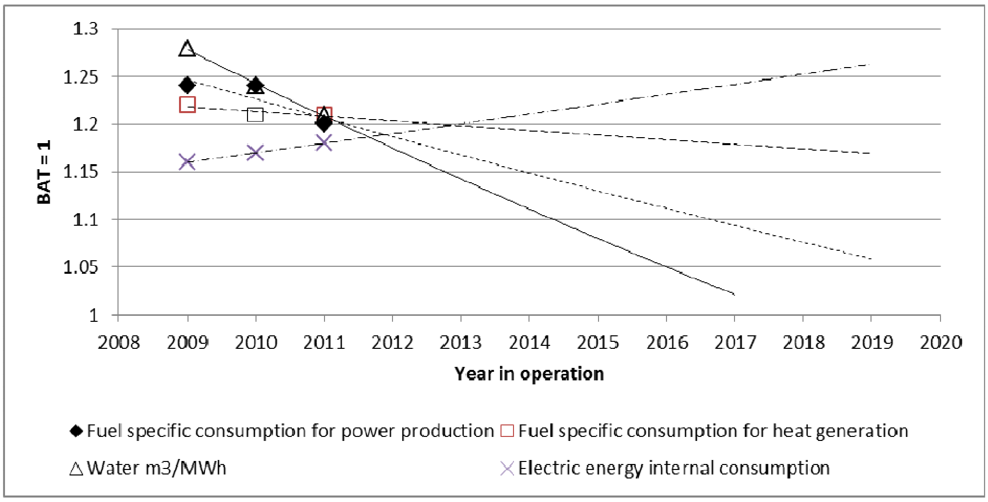

Fig. 13. Regression lines showing trends in TERMICA operational parameters (BAT level = 1).

6. CONCLUSIONS

With a dedicated team of engineers, economists, environmentalists, external consultants and having the full support of the top management at TERMICA power plant in Suceava (Romania), the DMP led to the following findings:

a. there is a good amount of relevant data at TERMICA that allow a sound data-mining analysis; further updating will enable the data-mining process to absorb extra information and produce updated conclusions;

b. procedures for testing the consistency of recorded data, evaluate their Gaussian distribution were implemented in EXCEL and recommendations for further improve the quality of data by investing in new monitoring equipment for data acquisition were made;

c. the DMT helped local specialists to derive objective estimates for their environmental costs, showing that these costs amount to 18-31% of total Company expenses, in the period of time analysed (2007-2012);

d. the structure of these costs showed that the hot points, where costs are the higher, are the internal consumption of electric power generated and the costs associated to flue gas. The environmental cost accounting procedure should remain in place as it ascertain best what the environmental foot print of TERMICA is and how it evaluates. Managers should reduce this footprint by acting where the environmental costs are the;

e. correlation analysis enabled the parameters that correlates best. Acting upon one of them will result in a corresponding improvement in all other correlated parameters;

f. The external benchmarking used BAT documents as reference. The Internal benchmarking indicated that 2008 was the best one in the recent history of the power plant. By reproducing the conditions valid in 2008, TERMICA could improve by 6-12% level of efficiency, without any investment;

g. regression analysis showed that almost all important operational parameters tend to approach the BAT levels, though the period in which those levels will be attained is considerable. This constitutes an objective assessment of the long-term performances at TERMICA and will help managers to decide where to act in the first place in order to improve.

The Project showed the importance of using every source of information and treating it using state-of-the-art methods in order to get the most out of such information. It should remain as a basic tool for local managers and specialists.

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