Plant utilities optimisation through environmental management system in ISO14001

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Abstract: The present work addresses the issue of defining a methodology able to select the best intervention(s) to reduce air pollution during the construction of an Environmental Management System (EMS) according to ISO14000 regulation. The objective is to achieve an EMS with the concurrent tasks of minimizing environmental impacts and maximizing overall performance in terms of energy saving, maintenance activities, and global management costs through the definition of three main parameters - time of the intervention, its complexity and economic convenience able to highlight the capability that a corrective measure can have to reduce the air pollution.
The approach has been validated analysing the plant utilities (electricity, compressed air, air conditioning, transports) of a firm producing smart cards. Within the application case a cogeneration system and a solar cell system have been compared through the methodology developed. As a result, we have obtained a solution able to reduce the environmental impact maximising energy saving.

Keywords: Environmental Management Systems, Energy, ISO 14000, Risk analysis, Maintenance

1. Introduction

For those firms whose business is distributed in a world-wide context the acquisition of the Environmental certification according to the ISO 14000 international standards has become fundamental (Long et., al. 2017; Corbett and Kirsch, 2001). As well known in an ISO 14001 environment the whole organisation and production processes are analysed and re-organised according to a set of rules and procedures included inside an Environmental Management System (EMS) (Menanno et.al 2020; D'Souza et., al., 2019; Koptseva, and Sitnikova, 2018). In order to implement an EMS we have to refer to existing legislative tools, and particularly to the EMAS rule and the ISO 14000 family of rules (ISO, 2001). These rules introduce a general approach to the environmental management, and define criterion able to evaluate objectively the environmental impacts, and then a planning procedure for corrective actions based on the evaluation of these impacts at all stages of the product life cycle. The definition of environmental impact assessment methods and the choice of remedial actions to reduce the impact is carried out by the specific system (Kassinis and Soteriou, 2003). In addition, during the implementation of an EMS a special attention is also reserved to plan the actions regarding to the reduction of pollution and energy optimisation.

Based on previous findings and considering the literature analyzed, we propose a specific approaches or methodologies that allow the evaluation of plant resources that allow, at the same time, both the reduction of pollution and energy saving. The paper is organized as follows. Section 2 describes the research approach used, while section 3 describes in detail a case study within a firm producing microchips for Smart cards. In section 4 the different alternatives proposed are analyzed while section 5 defines the assessment method and in section 6 the final score is evaluated. The conclusions are presented in section 7.

2. The research methodology

The methodology developed in this case study regards the definition of three main parameters: i) time of the intervention, ii) complexity and iii) economic convenience (Schmenner R. and Swink., 1998; Hill, 1989). These parameters may highlight the ability of a corrective measure to reduce air pollution and maximise at least one of these parameters. Figure 1 shows the research steps.

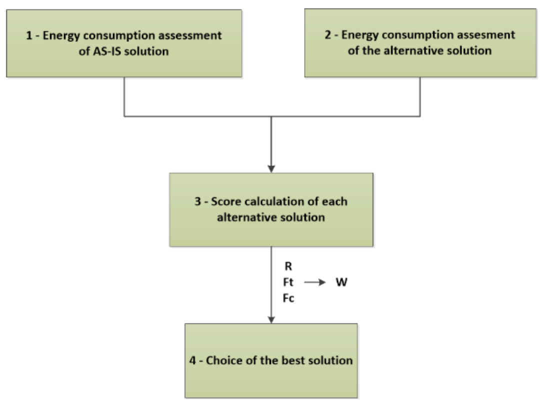

Figure 1: Research Methodology

In the first step (S1) the as-is solution has been chosen and analysed. In this step In this step an analysis is carried out

to evaluate the energy consumption.
In step (S2), two alternatives for energy production were proposed to reduce the environmental impact.
In S3, three different parameters were defined to assess the efficiency and effectiveness of a corrective action.
S4 introduced an analytical method for Environmental Impact Assessment in order to make the best choice among the proposed alternatives.

3. Energy consumption assessment of as-is solution

To verify the validity of the method we have applied it within a firm producing microchips for Smart cards (figure 2). The testbed line of the case study produces intelligent cards with a microchip for the new electronic passport (figure 3).

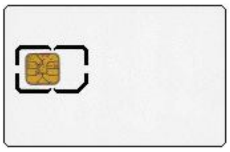

Figure 2: mobile phone card

Figure 3: Electronic passport card

Within this line there are two "clean rooms" (no dust or pollution inside) and two workstations for wafer cutting and chip insertion. The plant had some problem of energetic consumption due to the air conditioning system for the two clean rooms and refrigerating machines.

Actually, this plant utilizes methane boilers to produce thermal energy and electric refrigerating machines for summer air conditioning but has not got any cogeneration or energy recovery systems.

Figure 4 reports the electric power consumption during the four bands (table 1) of the main Italian Power Supplier (IPS).

Table 1: Timetable of IPS rates H_f

		Winter	**Summer**	**Total [h]**
F1	8,30-10,30 and 16,30-18,30 (mon-fri)	520		520
F2	6,30-8,30; 10,30-16,30 and 13,30-21,30 (mon-fri)	1430		1804.5
	8,30-12,30 (mon-fri) excluded August		374.5	
F3	6,30-8,30 and 12,00-21,30 (mon-fri) excluded August		1230.5	1230.5
F4	0,00-6,30 and 21,30-24,00 (mon-fri)	1170	963	5205
	Sat- sun Whole month of August	1248	1824	
Total [h]				**8760**

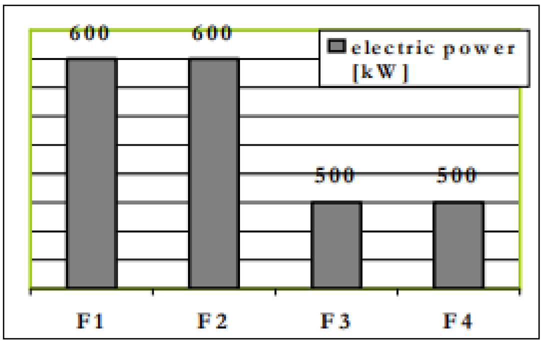

Figure 4: Electric power consumption

Using these values, we have appraised a total energetic consumption of 1.100 **TEP** (Equivalent Tons of Oil ≈ 11.000 kWh – eq. 1):

$$E = \frac{P_r * H_f}{\eta_{IPW}} =$$

$$\frac{(600*520)+(600*1804.5)+(500*1230.5)+(500*5205)}{0.374}$$

$$\cong 1100\, TEP \qquad (1)$$

where P_r is the electric power consumed during H_f, and η_{IPW} the *IPW* efficiency.

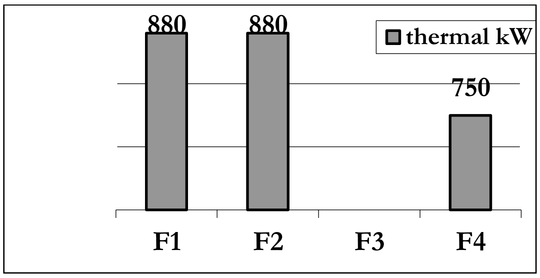

Figure 5: Thermal power consumption

Similarly, we have appraised a total consumption of methane (**V_m**) of 340 TEP[a] (eq. 2 and fig. 5).

$$V_m = \frac{1}{\eta_c * P_c} * (P_r * H_f) =$$

$$\frac{1}{0.9*9.59} * [(800*520) + (800*1430) + (750*2418)]$$

[a] 1 TEP ≈ 1.200 Nm^3 of methane

$$\cong 340\, TEP \quad (2)$$

where:

η_c is the boiler efficiency.

P_c is the calorific power of the methane.

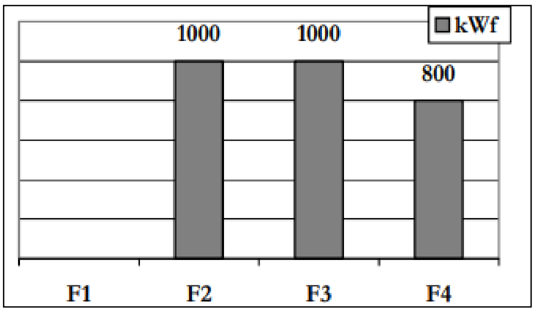

Figure 6: Frigorie consumption [kWf]

Finally, referring to the frigorie depicts in figure 6 we have obtained a total energetic consumption of 110 TEP (eq.3)

$$E = \frac{P_r * H_f}{COP_e} = \frac{(1000*374.5)+(1000*1230.5)+(800*2787))}{3}$$

$$\cong 110\, TEP \quad (3)$$

where COP_e is the efficiency of a refrigerating machine.

Hence, the total consumption of energy of **1550 TEP**. In order to reduce this amount of energy consumption we have compared – using the proposed methodology – a system producing electricity by a Combustion Chamber fed with methane (k=1) and a Solar Panels system (k=2).

4. Energy consumption assessment of the alternative solution

To reduce the environmental impact, two alternatives for energy production have been proposed:

1) Combustion Chamber
2) Solar panel

An estimate of the consumption of both solutions was carried out to evaluate the improvement compared to the as-is solution.

4.1 Alternative 1 – Combustion Chamber (k=1)

Using a system producing electricity by a combustion chamber fed with methane during winter season we are able to recover the high temperature working fluids and to use them as integration of the existing boilers, while in summer we can utilise them to "feed" an Absorption Heat Pump AHP in order to obtain the necessary frigorie power.

Referring to the total power requests of the plant we have sized this system choosing a combustion chamber able to produce 512 kW (P_F) of electric power with an efficiency (η_c) of 0.375; 342 kW (P_T) of thermal power and an AHP able to produce 410 kWf (eq. 4) with a Coefficient of Performance (COP_{ASS}) equal to 1, 2.

$$P_F = (P_T * COP_{ASS}) = 410 \text{ KW} \quad (4)$$

Then, we have calculated the volume of methane necessary to produce these power (eq 5)

$$V_m = \frac{1}{0.375*9.59} * (512 * 8760) \cong 1.000\, TEP \quad (5)$$

Since the plant needs 600 kW of electric power the absorption from *IPW* is given by equation 6:

$$E = \frac{[(600-512)*520+((600-512)*1804.5)]}{0.374}$$

$$\cong 50\, TEP \quad (6)$$

in the same way we have appraised a consumption of 180 TEP of methane for boilers (eq 7)

$$V_m =$$

$$= \frac{1}{0.9 * 9.59} * [(800 - 342) * 500 + (800 - 342) * 1430 +$$

$$+(750 - 342) * 2418] \cong 180\, TEP \quad (7)$$

In summer, using the warm refluis of the combustion chamber to "feed" the AHP, we have a methane consumption of 150 TEP, as stated by eq 8:

$$V_m = \frac{1}{\eta_c * P_c} * \left(\frac{(P_F)}{COP_{ASS}}\right) * H_f =$$

$$= \frac{1}{0.9 * 9.59} * [\left(\frac{1000 - 410}{1.2}\right) * 374.5 +$$

$$+ \left(\frac{1000 - 412}{1.2}\right) * 1230.5 + \left(\frac{800 - 412}{1.2}\right) * 2787$$

$$\cong 150\, TEP \quad (8)$$

Summarising, we have a total request of 1380 TEP and an energetic saving equal to 11%.

4.2 Alternative 2 – Solar Panels (k=2)

A different proposal is to install about 300 sqm of solar panels to produce thermal energy; particularly we have considered panels able to produce, as yearly average, 0.46 thermal kW/sqm obtaining 150 kW (eq. 9) and methane consumption, during the winter, of 270 TEP (eq. 10).

Summarising equations 1), 3) and 10) we have a total request of 1500 TEP and an energetic saving equal to 3 %.

$$P_t = 0{,}46 \times 300 \cong 150 kW \; (9)$$

$$V_m =$$

$$= \frac{1}{0.9 * 9.59} * [(800 - 150) * 520 + (800 - 150) * 1430 +$$

$$+(750 - 150) * 2418]$$

$$\cong 270\, TEP \qquad (10)$$

Table 2 report a comparison among the as-is solution and the alternative solutions.

Table 2: Energy saving with alternative solutions

	Energy consumption	Saving
As- Is solution	1550 TEP	
Alternative 1	1380 TEP	11%
Alternative 2	1500 TEP	3%

5. The assessment method

The efficiency and effectiveness of a corrective action has been pointed out by the definition of the following three parameters:

- **R** - The re-establishment of environmental conditions: this factor assigns higher values to interventions able to minimize the gravity of an environmental impact (Vastag, 2004);
- $\mathbf{F_t}$ - The factor of timeliness (Aleshin, 2001): the value of this factor is as greater as smaller is the intervention's time and as easier is its management;
- $\mathbf{F_c}$ - The factor of economic convenience (Dale et.al., 1998; Hill, 1989): this parameter aims to give evidence to measures involving smaller costs of installation and maintenance.

The proposed criterion is based on the main Risk Evaluation parameters (Aleshin, 2001) and on an application of Failure Mode and Effect Analysis – FMEA (Bartolini et.al., 2006) to the environmental problems, within ISO 14000 compliance.

The capability of each corrective measure to reduce the pollution in the shortest time, with the minimum expense and minimum maintenance operations (Brown et.al., 2008) is computed with the equations 11-13;

$$R_{i,k} = \left(G_{i,j} - G'_{i,j}\right) * (1 + \zeta_k\,) \qquad (11)$$

where:

i	is a process
j	is an environmental aspect
k	is one of the possible measures able to minimize j
$G_{i,j}$ and $G'_{i,,j}$	are the environmental damage on the environmental aspect *j* made by the process *i* respectively before and after the installation of a specific intervention
ζ_k	is equal to:

1 if we have to substitute periodically parts out of order;
0.333 if maintenance procedures require only cleaning or washing of elements;
0.666 when we periodically check-up the system

$$F_{t,k} = \frac{M_k}{T_k} \qquad (12)$$

Where:

T	is the necessary time to install the proposal intervention;
M	is the mean time between two periodical maintenance operations:
k	has the same meaning of eq. 11

$$F_{c,k} = \frac{CT_k}{n_k * C_m} \qquad (13)$$

Where:

Ct_k	is the first installation cost;
Cm_k	is the maintenance cost.
k	has the same meaning of eq. 11
n_k	is the number of maintenance cycles during the entire life of the measures k (V_{uk}). We have defined it as follows (eq 14):

$$F_k = \frac{Vu_k}{M_k} \qquad (14)$$

Using these three parameters we may choose, as better intervention, the one that maximises the weight of $W_{i,k}$ defined by eq. (15) (Aliperti et.al., 2003; Wilkinson et.al., 1996):

$$W_{i,k} = \sqrt{R_{i,k}^2 + F_{t,k}^2 + F_{c,k}^2} \qquad (15)$$

6. Score calculation

After that we have calculated G'; to do that we have introduced an analytic method for the Environmental Impact Assessment able to provide the measure of the pollution's level produced as a crisp number rather than as a subjective adjective (Aliperti et.al., 2003).

In general terms the measure of pollution produced by a singular processing is based on Risk Evaluation and the Gravity (G) of an Environmental Impact and can be considered as the product (Aliperti et.al., 2003), of these two factors (figure 7); tables 3, 4 and 4 bring the adopted criterion and their values.

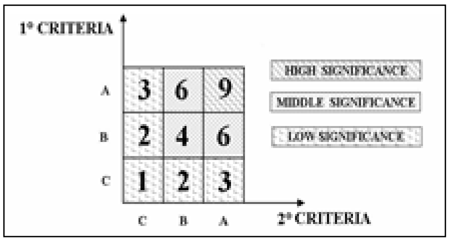

Figure 7 - Environmental Impact

Table 3: Criterion for the normal conditions of operation

1° CRITERION- (L) conformity of control parameter (P) with a fixed threshold (L). (L=1600TEP)		**2° CRITERION-(V)** Variation of control parameter in comparison with the previous year	
P>0,9L;	**A**	V>100%	A
0,7L<P<0,9L	B	90%<V<100%	B
P<0,7L.	C	V<90%	C

Table 4: Criterion for the abnormal conditions of operation

1° CRITERION-(F) Frequence of abnormal events.		**2° CRITERION-(C)** Persistence of the environmental damage produced.	
One a day;	**A**	Over 3 months;	A
One a month;	B	Over 1 week;	B
Over 6 months.	C	1 day.	C

Table 5: Criterion for the operation in emergency

1°CRITERION-(P) Probability of occurrence in emergence.		**2° CRITERION- Gravity (G) –** Irreversibility of environmental damage produced .	
One 3 months;	**A**	Irreversible event;	A
One a year;	B		B
Over 5 years.	C		C

Using the values reported in table 6 and 7 we have obtained an environmental impact (G') equal to two.

Table 6: 1° Criterion

1° Criterion- Resource characteristics	**VALUE**
Derived by the coal or oil - electric energy	A
Methane - cogeneration	**B**
Renewable and/or recovered energy	C

Table 7: 2° Criterion

2° Criterion - Specific consumptions in comparison with previous year	**VALUE**
More than 100%	A
Inclusive among 90% and 100%	B
Less than 90%	**C**

Considering the alternative 1, the Environmental impact takes the values $G'_{i,,j} = 2$.
In order to calculate $W_{9.1}$ we have used the following input data (table 8) obtaining an $F_t = 4$ (eq 12); an $F_c = 0.91$ (eq. 13) and an R= 9.1 (eq. 11)

Table 8: Input data

ζ	0.3
T	3 months
M	12 months
C_t	610.000 €
C_M	67.000 €
V_u	10 years

Regarding the alternative 2 and based on the values reported in table 9 and 10 we have obtained an environmental impact $G'_{i,,j} = 6$.

Table 9: 1° Criterion

1° Criterion- Resource characteristic	**VALUE**
Electric energy	**A**
Methane - cogeneration	B
Renewable and/or recovered energy	C

Table 10: 2° Criterion

2° Criterion - Specific consumptions in comparison with previous year	**VALUE**

More than 100%	A
Inclusive among 90% and 100%	**B**
Less than 90%	C

To calculate $W_{9.2}$ we have used the following input data (table 11) obtaining an F_t = 2 (eq. 12); an F_c = 7.5 (eq. 13) and an R= 4.8 (eq. 11).

Table 11: Input data

ζ	0.6
T	1 month
M	2 months
C_T	45.000 € [150 €/sqm]
C_M	100 €
V_u	10 years

Table 12 gives the score values considering the different alternatives.

Table 12: Scores of the alternative solutions

	Alternative 1	Alternative 2
$F_{t,k}$	4	2
$F_{c,k}$	0.91	7.5
$R_{i,k}$	9.1	4.8

At the end, using equation 2, we have obtained the weights W_1 (alternative 1) equal to 9.98 and W_2 equal to 9.12 as stated in eq. 16 and eq. 17, and indicating that the best alternative is the first.

$$\boldsymbol{W_{9.1} = \sqrt{(9.1^2 + 4^2 + 0.91^2)} = 9.98} \qquad (16)$$

$$\boldsymbol{W_{9.2} = \sqrt{(4.8^2 + 2^2 + 7.5^2)} = 9.12} \qquad (17)$$

Since the two values are very similar to each other, the index vector must be analysed to understand which parameter influences the final score value.
Particularly the first alternative introduces bigger values of R (so it is able to better restore the environmental conditions) and a smaller value of Fc, that indicates a less economic convenience with respect to the second one.

7. Conclusions

In this study we have proposed a methodology able to select the best intervention(s) allowing to reduce potential air pollution. The methodology proved to be easy to implement of an Environmental Management System according to the rules of Continuous Improvement proposed by the "Vision 2000" philosophy. At the same time our methodology allows to objectively identify the best solution and to to quantify the influence of the parameters F_c, R, F_t on the solution adopted.

The case study has been conducted within a firm producing smart cards, giving encouraging results in terms both of utilities optimisation and of minimization of environmental impacts.
Considering the two proposed alternatives, the assessment method allowed to establish that the use of the combustion chamber allows to have a saving of about 11% compared to the as - is state, while with solar panels it is 3%. This choice is also confirmed by eqs (16 and 17) in which the value of $W_{i,k}$ is higher for the first alternative.
A limitation of the proposed methodology is the analysis of the final score based on the evaluation of the parameters. Further work might investigate the allocation of weights for each parameter in order to obtain a score in which the most influential parameter has a greater weight in the business strategy.
Future studies could optimize the equations used to evaluate the risk and the gravity of an environmental impact, researching a procedure able to objectively define values relative to the operation conditions.

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