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9.4 Implementing energy efficiency in manufacturing – overcoming risk perception barriers and reducing cost impacts

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Abstract

The increased complexity of manufacturing has resulted in process chains and equipment which demand more energy and resource categories. Energy management standards are being adopted by industries in order to focus on improving this capability; however there is recognition that a more detailed approach is required. This paper proposes a novel application of risk methods to energy efficiency projects by investigating the application of two structured problem solving techniques to energy efficiency improvements within complex manufacturing chains. The techniques evaluated were the 6-sigma and analytical hierarchy (AHP) processes. Industrial investigations and results to date indicate the benefit of utilizing such approaches. The approaches enable a structured method to engage the worker in assessing risk and highlight the value of minimizing risk to core Overall Equipment Effectiveness (OEE) metrics in order to ensure energy optimization opportunities can be implemented.

Keywords

Energy Efficiency, risk, structured problem solving

1 INTRODUCTION

An anticipated increase in Industrial energy demand across Europe will result in potentially a 30% increase in energy consumption over the next 20 years [1]. This will pose further challenges to Europe's commitment of reducing energy consumption by 20% by the year 2020 [2]. Energy efficiency as a result is becoming a key topic within industrial environments as a response mechanism to this challenge. This is broadly being addressed by three different approaches within industry; engagement with management in terms of leadership, energy efficiency technology implementation and adherence to policies/regulations [3]. Historically facilities management and technical building services have championed energy efficiency improvements. Improving data availability and knowledge of manufacturing processes have been highlighted as challenges to the implementation of further sustainable practices [4]. The increased complexity of manufacturing equipment and process chains is resulting in increased demands for both energy and resource categories [5]. This is presenting a further challenge to energy efficiency improvements within industry due to the heavily compliant nature of these environments.

The adoption of energy management standards by industry, most notably the ISO50001 standard [6] is seen as an avenue to address this deficiency through the development of organization capability. Although this standard does place a heavy emphasis on monitoring and metering there is no formal risk consideration to the standard. The development of more detailed approaches is ongoing; ISO50004 through the ISO T/C242 and the SEAI [7, 8], is being pursued as well as improvements in energy awareness and consumption prediction models of production systems [9].

Risk assessment does form an integral part of decision making within many industries and disciplines. This is reflected through the design of machines or systems [10], identifying key factors in supply chain risk [11] and risk to project schedules [12]. Its primary role being to identify key factors that can impact core operating capabilities [13] to allow mitigation actions to be identified.

From a manufacturing perspective, engagement with appropriate experience within a workforce can support the identification of these factors. The application of lean techniques such as kaizen [14] and process mapping [15] utilise this experience. This suggests leveraging appropriate knowledge in a structured way to evaluate improvements has potential and has the additional benefit of identifying success criteria to support future risk mitigation [16] of core OEE metrics. Early work in applying this approach to energy efficiency within factories has been demonstrated [17]. This has the potential of delivering significant initial energy savings with minimal capital expenditure [18]. A formal path to assessing benefits, opportunities, costs and the risks associated with proposed solutions is the Analytical Hierarchy Process [19] where a problem is structured as a hierarchy through criteria and alternatives. Proposed alternatives can be evaluated in terms of defined and weighted criteria to ensure appropriate relevance to an overall problem statement [20]. The criteria defined; through the weighting process can ensure the appropriate dominance of customer needs [21]. This paper provides an overview of how workforce engagement, with appropriate consideration of risk factors can deliver energy efficiencies within compliant environments.

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2 INDUSTRIAL ENVIRONMENT

Energy consumption within industrial settings is a consequence of operations and manufacturing activity. As a result there is a direct relationship between waste within manufacturing process chains and energy inefficiencies, as shown in figure 1. This does however allow factories at an early stage in an energy improvement plan to improve energy efficiency through operational focus.

Waste Type	Energy Use
Overproduction	More energy consumed in operating equipment to make unnecessary products
Inventory	More energy used to heat, cool and light inventory storage and wharehousing space
Transportation and Motion	More energy used for transport
Defects	Energy consumed in making defective products
Over Processing	More energy consumed in operating equipment related to unnecessary processing
Waiting	Wasted energy from heating, cooling and lighting during production down time

Figure 1: Manufacturing and energy waste [13]

The complexity of manufacturing process chains and how they reside within their factory environments can create challenges. Specifically when considering unit or sub unit processes from both an energy and resource point of view. It can be seen from figure 2 that there are many inputs into a system which can require characterization initially. This is necessary to ensure appropriate performance information is understood for baseline performance referencing but also to ensure boundaries are well defined. For example, what resource category is included and which sub unit will be characterized for improvement. This discipline is critical to supporting the identification of risk factors and potential mitigation plans.

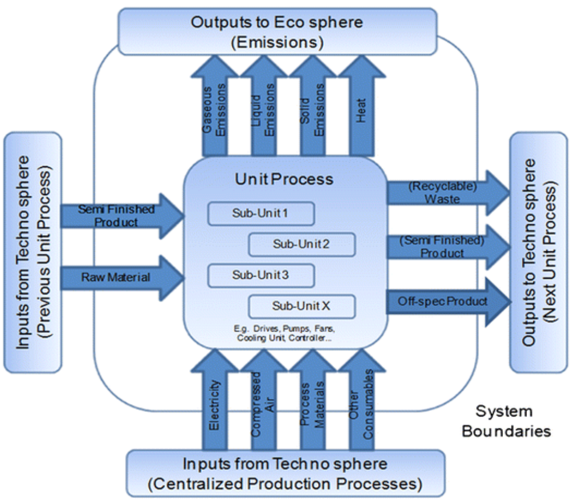

Figure 2: System boundaries and complexities [22]

3 RISK EVALUATION: FUNCTIONALITY

By engaging the appropriate workforce in brainstorming energy improvements on targeted production systems, their unique perspective on opportunity and their familiarization of process chains through preventative maintenance and good manufacturing practices can be leveraged. This level of experience in performing equipment based tasks ensures a thorough knowledge of what targeted equipment is functionally capable of. Manufacturing process equipment is historically optimized for functionality in terms of output and repeatability. As a result, optimised energy performance can be overlooked as a core requirement in production system set up. In terms of comprehending how capable targeted production equipment is of being optimised with respect to energy consumption, a number of considerations must be understood for example; safety, availability, quality and cost implications. By evaluating improvements in terms of tool ability or functionality, it allows an early opportunity for mitigation plans to be identified to allow energy optimizations, as shown in figure 3. This process will validate some opportunities as being feasible and potentially eliminate or delay some opportunities. Delays can be due to potential upgrades or improvements being required to support the energy improvement opportunity which may require capital funding.

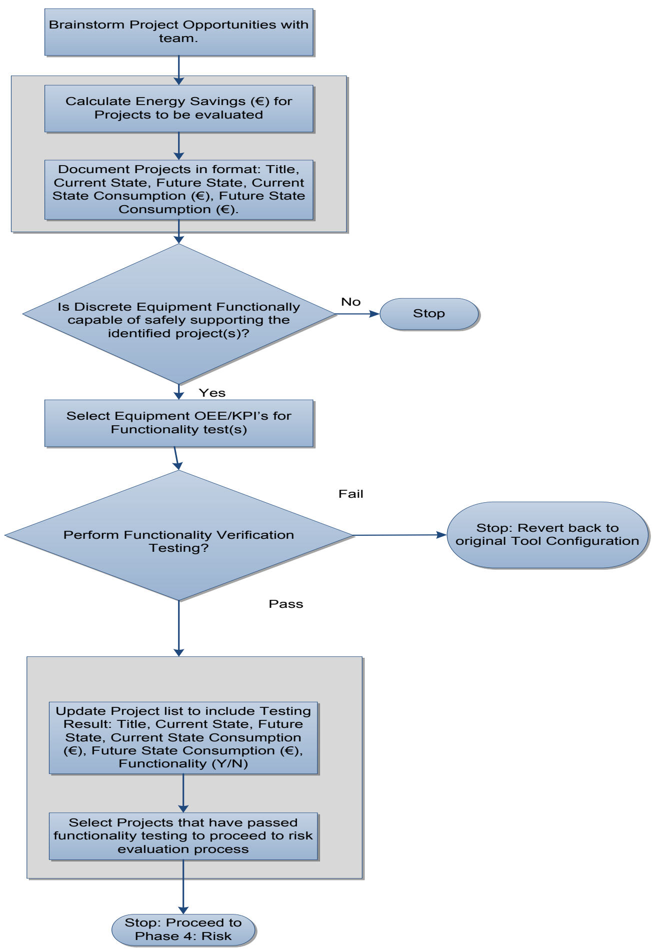

Figure 3: Top level approach to evaluating functionality

4 RISK EVALUATION: OEE

In terms of production systems, risk needs to be considered with respect to production impacts, in particular when one-of-a-kind production tools are present. To develop a deeper understanding of risk factors, functionally valid opportunities should be considered in terms of OEE and process chain performance. This can be achieved by targeting appropriate factory metrics (KPI's) which production equipment is managed to within a factory environment, for example availability or up time (A_1), quality or percentage of material within defined customer criteria (A_2) and cost of ownership of production equipment (A_3). Factory databases are used to collect this KPI information. A normalized or set of prioritization values B_1, B_2, B_3 can be generated, as shown in equation 1, which reflects how equipment performance is prioritised by resources on a shift level, daily or weekly basis. Within factory work cells or process chains, performance requirements are well understood but an understanding in terms of hierarchy can often be missing; this approach can facilitate this understanding and allow the appropriate KPI's to be targeted for more detailed further analysis.

$$\begin{array}{c} \\ \boldsymbol{A_1} \\ \boldsymbol{A_2} \\ \boldsymbol{A_3} \end{array} \begin{array}{c} \boldsymbol{A_1} \quad \boldsymbol{A_2} \quad \boldsymbol{A_3} \\ \begin{bmatrix} 1 & a_{12} & a_{13} \\ 1/a_{12} & 1 & a_{23} \\ 1/a_{13} & 1/a_{23} & 1 \end{bmatrix} \end{array} \begin{array}{c} \textbf{Priorities} \\ B_1 \\ =B_2 \\ B_3 \end{array} \quad (1)$$

As factory's are dynamic environments with multiple parameters or KPI's being managed, this subsequent testing provides the chance to ensure any potential gaps in the initial functionality testing that may only become apparent over time are noted. In order that no opportunities are rejected early this will allow potential improvement or mitigation steps to be actioned early to ensure no opportunities are rejected incorrectly. It also allows personnel from outside the production environment to understand what KPI's need to be evaluated in any projects that may impact production line performance. Figure 4 highlights a flow to evaluate how to identify effective KPI monitoring post functionality testing.

Within each of these performance metrics A_1, A_2 and A_3, how these metrics monitor performance, what reason they were put in place and their capability to support the management of a production line can also vary depending on the requirements at time of creation. As a result, it is necessary to formally understand what value the individual performance metrics deliver in terms of the manufacturing process chain, how and why they are used. This will ensure tailored monitoring can be defined to gain the maximum level of information when evaluating energy improvements. This can be achieved by reviewing each KPI in terms of the following capabilities; Likelihood (*L*), Detectability (*D*) and Severity (*S*). Where likelihood is defined in terms of the possibility of an energy change impacting a KPI, detectability is defined in terms of the ability of a KPI to detect a change and severity is defined as the negative impact of the change.

An importance value (*I*) can be assigned to each KPI in terms of L, D and S. For example the importance value (*I*) assigned by the workforce to the possibility of detecting a change (*L*) to the availability metric (A_1) is denoted as; I_{A1}^{L}

This will allow the workforce to weight the ability of the individual performance metrics to manage energy based change. Projects identified for example, Z_1 and Z_2 can be assigned by the workforce based on their experience, to the possibility a change in performance of a KPI (A_1, A_2, A_3) in terms of Likelihood (*I*), Detectability (*D*) and Severity (*S*). For example a Likelihood value (*L*) can be assigned by the workforce to the possibility of observing a change in the availability metric (A_1) if project Z_1 was implemented can be denoted as; L_{A1}^{Z1}

Likelihood (*l*) and Severity (*S*) are only considered for Availability (A_1) and Cost (A_3) as these metrics are extensively tracked within production environments which results in effective monitoring. Due to the high degree of variability that can occur in terms of Quality (A_2), detectability (*D*) should be considered.

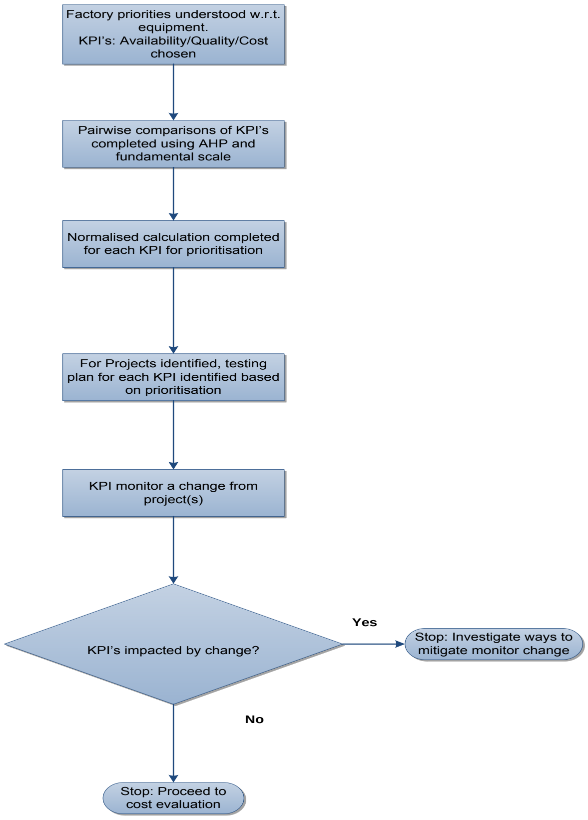

Figure 4 – Decision chart for OEE evaluation

The scoring values assigned reflect the workforces view on changes occurring to the KPI's in terms of Likelihood (*L*), Detectability (*D*) and Severity (*S*) as a result of energy projects, for example Z_1 and Z_2 being implemented. A capability score can then be calculated, as shown in equation 2 for project Z_1 which reflects a factory's ability to monitor and manage a change based on a company's priorities and capabilities.

$$Z_1 = \begin{bmatrix} B1\left((L_{A1}^{Z1} \times I_{A1}^{L}) + (S_{A1}^{Z1} \times I_{A1}^{S})\right) + \\ B2\left((L_{A2}^{Z1} \times I_{A2}^{L}) + (D_{A2}^{Z1} \times I_{A2}^{D}) + (S_{A2}^{Z1} \times I_{A2}^{S})\right) + \\ B3\left((L_{A3}^{Z1} \times I_{A3}^{L}) + (S_{A3}^{Z1} \times I_{A3}^{S})\right) \end{bmatrix} \quad (2)$$

6 CASE STUDY

An industrial boilerclave system, as shown in figure 5 was targeted to identify an optimized idle consumption state within a medical device manufacturing facility. The function of the system is to remove wax from a ceramic mold, with steam at operating temperatures between 160-180ºC. It is a process involving condensation, conduction and flow through a porous media. The main energy driver is electrical energy which is used through heating elements to create saturated steam. The process involves saturated steam (liquid & vapour), solid and liquid wax, wet and dry porous ceramic shells and air. The system is a one of a kind tool and as a result the production environment is sensitive to potential production impacts.

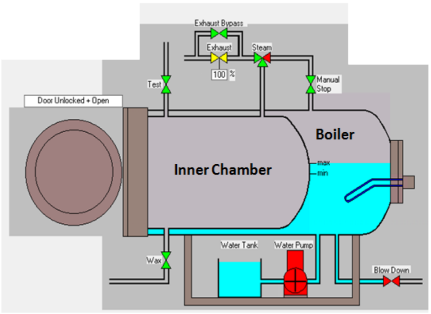

Figure 5 – Boilerclave system

From initial investigations in earlier work, 2 opportunities were identified as potential candidates for subsequent evaluation [23], as shown in table 1. Both settings met the initial concerns regarding functionality and were considered for evaluation in terms of OEE metrics.

Experiment	Pressure setting (psi)	Mean Power (kW)	Recovery Time
Reference	136	27	0
Exp #1 (Z_1)	100	14	6 mins
Exp #2 (Z_2)	80	7	12 mins 47 secs

Table 1 – Experimental summary

The KPI's; availability, quality and cost (A_1, A_2, A_3) were identified through a survey of the work cell as the critical parameters which the workforce focuses on with respect to the boiler cleave system. Table 2 reflects how the workforce prioritised these KPI's with respect to each other. This indicated experiment #1 (Z_1) being considered for further evaluation.

KPI	A_1	A_2	A_3	Priority
A_1	1	7	9	70%
A_2	0.14	1	5	25%
A_3	0.11	0.2	1	5%

Table 2 – Work cell priority

Table 2 reflects the significance of availability in the prioritization analysis indicating that 70% of area resource time focuses on maintaining availability performance. This resulted in a scoring matrix which reflected the workforces view on changes occurring to the KPI's, as shown in table 3. A simple scoring mechanism (1=bad, 10=good) was used to capture the workforces data based viewpoint.

KPI	Project	L	D	S
A_1	Z_1	8		8
	Z_2	3		3
A_2	Z_1	8	8	8
	Z_2	8	8	8
A_3	Z_1	9		9
	Z_2	9		9

Table 3 – Workforce input on ability on monitor energy projects

Using equation (2), each project was then scored, as shown in table 4. The value outlines the capability of the factory to monitor each project appropriately, rather than just a success rate.

Project	Capability
Z_1	8.1
Z_2	4.6

Table 4 – Project capability scores

This analysis improved confidence in identifying what upgrades would realize the energy savings estimated from the characterization completed. The relative difference within the scores highlights, based on the collective experience of the workforce used, gaps in a factory's capability to manage a change. In terms of projects identified, the relative difference in scoring is attributed to the impact on the availability KPI. This analysis improved confidence in identifying what upgrades would realise the energy savings estimated. The options selected were an upgrade to the human machine interact (1) and a modification to the systems PLC control (2) as shown in table 5. Both options were deemed suitable to factory management as a result of the process used with option 2 ultimately being selected on a cost basis as risk considerations were deemed to have been comprehended.

Option	Upgrade Considerations	Install Price (€)
1	HMI Upgrade	10,000
2	Switch Installation	5,000

Table 5 - Upgrades

A separate study was completed on all known equipment failure mechanisms to evaluate upgrades identified. A 6-sigma FMEA template approach was used which leveraged workforce and vendor experience to identify concerns, as shown in table 6. These involved analyzing historical failures to ensure all known failure mechanisms were comprehended prior to testing design. This allowed factory maintenance databases and vendor input to support the evaluation of each concern to ensure an accurate quantification.

Tool Subcomponent/Behavior Change	Concern	Evaluation	Risk Impact (1-10)	Probability of Impact (0-1.0)	Risk Measurement	Risk (H/M/L)
5X24 kW elements	Contactor Frequency Change	Lowered Pressure setting to 100psi to reduce the contactor frequency to the elements. Note: Elements are RTF.	1	0.1	0.1	L
5X24 kW elements	Ramp Frequency	Changing ramp frequency of current on the contactors/elements	1	0.3	0.3	L
100 psi setting	Issue with contactor	New change will have less contact between the contactor and element, will extend life of contactor as it is currently 'run to	3	0.1	0.3	L
Ramp frequency of contactors	Contactor operational profile changes	6 min recovery monitored during testing, no issues noted on tool during tests, no impact	2	0.1	0.2	L
Tool may not go from 100 to 136 psi when requested	This will be tested during tool upgrade by LBBC.	Upgrade designed to avoid this	2	0.1	0.2	L
Wax won't melt due to	Tool will only run at 136 psi	To be verified during LBBC	2	0.1	0.2	L
Door opens at 100psi	Misprocess	Door interlock requested for upgrade to ensure this does not	3	0.1	0.3	L
Door won't open at 136 psi	Normal risk	No different to current tool setting	1	0.1	0.1	L
Change does not work	If change does not work it will be reversed.	All exps completed to date prove the change will work. No impact to product as 136psi is maintained	3	0.1	0.3	L
PLC change causes machine to behave	To be fully tested with LBBC during upgrade.	To be verified during LBBC upgrade	2	0.1	0.2	L
New operational sequence for associates	GMP and ECC documents to be modified.	To be verified during LBBC upgrade	1	0.2	0.2	L
Safety implications with change	Change will not exceed 136psi as per current setting. . The tool will be operating at an average lower pressure with the change. No change to outer chamber - it will see 136 operational	Change has been manually tested multiple times	3	0.1	0.3	L

Figure 6 – FMEA Output

7 SUMMARY

The study outlined in this paper highlights the importance of considering risk factors to minimise subsequent cost impacts to ensure successful energy based project selection due to potential impacts on production environments. The approach outlined helps to address perceptions and concerns that arise within industrial environments due to project implementation. The potential impacts documented include both tool performance and production line performance. Workforce engagement in understanding both of these considerations was crucial. Using structured problem solving techniques ensured an effective capturing of workforce knowledge in terms of equipment functionality and OEE impacts. To support this understanding the 6-sigma FMEA structure proved effective at capturing workforce experience in identifying potential failure mechanisms which may impact project implementation. The analytical hierarchy proved effective at ensuring an accurate picture of work cell priorities were understood which allowed critical OEE metrics to be prioritised and monitored to ensure compliance. The structure outlined provided confidence to factory management that workforce experience identified appropriate solutions with minimal risk. The solutions outlined also displayed significant savings over a 5 year period, with Z_1 yielding €58,000 and Z_2 €88,000 savings over the period outlined. This highlighted the cost positive impact of energy based projects that can be achieved within manufacturing process chains.

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9 REFERENCES

[1] Report by the EU Director General for Energy, 2009. "EU Energy Trends for 2030".

[2] EU Director General for Energy, 2011. "Energy Efficiency Plan 2011". Accessed on 6 February 2013.

http://ec.europa.eu/energy/efficiency/eed/eed_en.htm

[3] Abdelaziz, E., Saidur, R., Mekhilef, S., 2011. "A review on energy saving strategies in industrial sector". Renewable and Sustainable Energy Reviews 15:150-168.

[4] Elmualim, A., Shockley, D., Ludlow, G., Shah, S., 2010. "Barriers and commitment of facilities management profession to the sustainability agenda" Building and environment 45:58-64.

[5] Gutowski, T., Murphy, C., Allen, D., Bauer, D., Bras, B., Piwonka, T., Sheng, P., Sutherland, J., Thurston, D., Wolff, E., 2005, Environmentally Benign Manufacturing: Observations from Japan, Europe and the United States, 13/1: 1-17.

[6] International Organisation for Standardisation, 2011, ISO50001, WWW.ISO.ORG.

[7] Report by the Sustainable Energy Authority of Ireland, 2010,ISO50004, http://www.seai.ie/Your_Business/Large_Energy_Users/LIEN/LIEN_Reports/LIEN_Annual_Report_2010.pdf

[8] International Organisation for Standardisation T/C 242, 2012, ISO50004.Accessed on 1 March 2013.

www.iso.org/iso/home/store/catalogue_tc/catalogue_tc_browse.htm?commid=558632

[9] Quilligan, F., Upton, C., "Visual decision support for energy aware manufacturing", *Proceedings of the 10th global conference on sustainable manufacturing (CIRP)*, pp453-458.

[10] Klein, J., Cork, R., 1998, "An approach to technical risk assessment", International journal of project management, 16/6: 345-351

[11] Li, X., Xie, Q., 2009, "A method of identifying supply chain risk factors", IEEE World congress on software engineering, pp369-373

[12] Project Management Institute, 2004, PMBOK Guide, pp249-257.

[13] Silvestri, A., Cagnoa, E., Trucco, P., 2009, "On the anatomy of operational risk", International conference on industrial engineering and engineering management, pp2174-2179

[14] United States Environmental Protection Agency, 2011, "Lean Manufacturing and the Environment". Accessed on 10 March 2013.

http://www.epa.gov/lean/environment/toolkits/environment/index.htm

[15] Sustainable Energy Authority of Ireland, 2009, "Alternative Methodologies". Accessed on 12 March 2013.

http://www.seai.ie/Your_Business/Energy_Agreements/Special_Working_Groups/AM_SWG_2008/AM_Project_Report.pdf

[16] Cagno, E., Worrel, E., Trianni, A., Pugliese, G., 2012, "Dealing with barriers to industrial energy efficiency: an innovative taxonomy". European council for an energy efficient economy, 759-707.

[17] Karnouskos, S., Colombo, W., Lastra, M., Popescu, C., 2009, "Towards the energy efficient factory", 7th IEEE International Conference on Industrial Informatics.

[18] Gonce, A., Somers, K., 2010, Climate Change Special Initiative Energy Efficiency: McKinsey & Company.

[19] Saaty, T., 1994, "How to make a decision: The analytical hierarchy process", INFORMS: Institute for operations research and the management sciences, 24/6: 19-43.

[20] Saaty, T., 2004, "Fundamentals of the analytical hierarchy process – multiple networks with benefits, costs, opportunities and risks", Journal of systems science and systems engineering, 13/3: 348-379.

[21] Saaty, T., 2004, "The analytical hierarchy and network processes", Journal of systems science and systems engineering, 13/1: 1-35.

[22] Kellens, K., Dewulf, W., Overcash, M., Hauschild, Duflou, J., 2012, "Methodology for systematic analysis and improvement of manufacturing unit process life cycle inventory (UPLCI) - CO2PE initiative", The international journal of life cycle assessment , 17/1: 69-78.

[23] Aughney, N., O'Donnell, G. E., 2012 "Lean Energy: A methodology to characterize and optimize energy and resource consumption within manufacturing process chains", *Proceedings of the 10th global conference on sustainable manufacturing (CIRP)*, pp718-723.