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# Economic and environmental evaluation via an integrated method based on LCA and MCDA

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### Abstract

The progress of business is moving fast and the key to maintain advantage and competitiveness is research and continuous improvement. Besides economic, environment is always more object of evaluation analysis. There are numerous ways to assess individually both economic and environmental aspects, but in order to guarantee a high quality of improvement, an integration of different methods and theories is required. Thus, this research provides an integration of two different approaches: The Life Cycle Assessment (LCA) and Multi Criteria Decision Analysis (MCDA). The first allows the analyst to understand the environmental issue. The second is useful in order to select the best solution for improvement. The main purpose of this study is to develop a systematic method, easy to use and giving useful results. In the present work existing methods are reviewed and integrated in a new approach proposed to support continuous improvement. A real case in an Italian bearing plant is presented.

*Keywords:* LCA, EPI, MCDA, Environmental, Economic, AHP

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## 1. Introduction

Resource depletion and pollution are environmental related issues that have emerged as a result of anthropological activities such as rapid industrialization and urbanization. These problems may occur locally or regionally, but have a global impact, e.g. emissions of greenhouse gases (Khan et al., 2004).

Thus, in the last decade, awareness of environmental problems has led to the development of strategies to promote an industrial production as ecological as possible, integrating environmental demands with product standards. Thus environmental requirements must become factors of innovation for a successful, and therefore ‘‘sustainable’’, product (Giudice *et al.*, 2004).

Since the ’60s and ’70s, tools and methods to analyse various aspects of environmental management have increased. They cover a wide range of areas but always more focus on efficiency and performance improvement in order not to lose competitiveness. Furthermore, methods to analyse both environmental and economic sustainability are lacking. Finding and validating the methodological approach has become urgent. Existing decision process such as Multi-Criteria Decision Analysis (MCDA) and Life Cycle Assessment (LCA), are frequently used with varying

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degrees of satisfaction reported (Sinclair, 2011). Most of the time economic and environmental development can be assessed and analysed in different ways, especially individually (Reza *et al.*, 2011).

Thus, an integrated and systematic approach is required to consent more efficient analysis and a lean improvement procedure.

The main purpose of this study is to develop a systematic method based on the MCDA-LCA approach. In the present work two methods are used to derive environmental evaluation and choose improving scenarios: the Life Cycle Assessment and the common MCDA technique called the Analytic Network Process (ANP). In literature there is several research regarding environmental evaluation, mostly using the MCDA approach, for example, to select the best material i.e. raw material impact of biomass production chains (Myllyviita, Holma, et all, 2012), or to evaluate packaging material (Huang, Ma, 2004; Battisti, Corrado, 2005).

The present work is different from others because it wants to provide a new framework useful to integrate information and avoid a bias towards either qualitative or quantitative approach. The paper is structured as follows: in section 2 literature review on the LCA and ANP is presented; in section 3 the methodological approach is defined; in section 4 a case study is analysed and finally in section 5 the conclusions are presented.

## 2. Literature Review on LCA and ANP

### *2.1. Life Cycle Assessment*

LCA is a systematic method useful to evaluate all environmental implications of products from raw material extraction to production, manufacturing, use and disposal (Curran, 1996). LCA has received much attention in the environmental field since 1990. It is a powerful and internationally accepted system analysis tool that studies the environmental aspect and potential impacts of a product or service system throughout its life cycle (raw material extraction, manufacturing, distribution, use, end of life and waste recycling) (Yu, 2009).

The Society of Environmental Toxicology and Chemistry (SETAC) defined LCA as a process to evaluate the environmental burdens associated with products, processes, or activities by identifying and quantifying energy and material used and waste released to the environment; to assess the impact of this energy, and material uses release to the environment; and to identify and evaluate opportunities to affect environment improvements (SETAC,1993). SETAC, ISO 14040 and CML (Center of Environmental Science of Leiden University) has provided best practices and guidelines for an LCA framework (see Figure 1). Though these organizations worked independently, general consensus on the LCA framework has been evolved that can be described by following four phases: *1) Goal and scope definition; 2) Life Cycle Inventory Analysis, LCI; 3) Life Cycle Impact Assessment, LCIA; 4) Life Cycle Interpretation*.

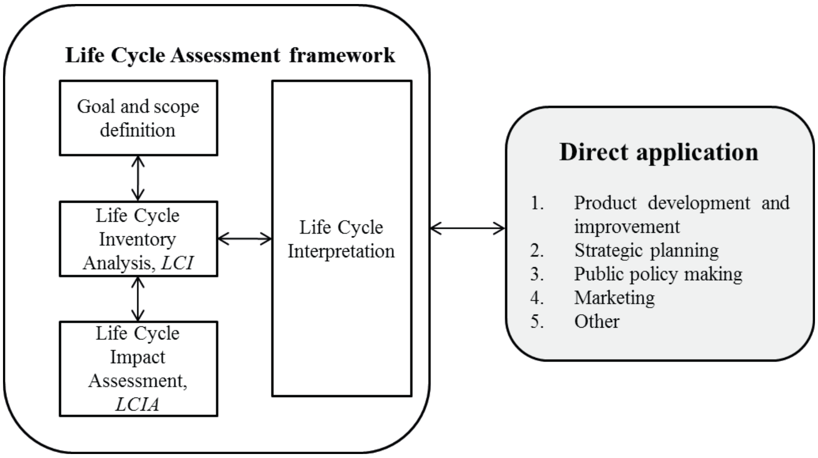

Fig. 1. LCA framework

Furthermore, the LCA is based on three different "*spheres"*(Hofstetter, Baumgartner et all, 2000. Thompson, Ellis et all, 1990):

- *Techno sphere*: the modelling of technical systems, such as production processes, transport processes etc.;
- *Ecosphere*: the modelling of environmental mechanisms ("what happens with an emission?"). Uncertainties are often one to three orders of magnitude, and often verification is difficult or impossible, for example, one cannot test-run climate change and repeat this several times to get good measurements;
- *Value sphere*: dealing with subjective choices. This includes weighing of impact categories.

Using the LCA approach it is possible to consider several environmental impact factors (Goedkoop, Effting et all, 2000): 1) *Human Health*: includes the number and duration of diseases, and life years lost due to premature death from environmental causes. The effects, respiratory effects and ionising (nuclear) radiation; 2) *Ecosystem Quality*: includes the effect on species diversity, especially for vascular plants and lower organisms. The effects included are: Eco toxicity, acidification, eutrophication and land-use; 3) *Resources*: include the surplus energy needed in future to extract lower quality mineral and fossil resources.

### *2.2. Analytic Network Process*

The Analytic Network Process (ANP) is a multi-criteria decision making tool which takes into account such a complex relationship among parameters (Neaupane, 2006). As said before, in the present work we have integrated LCA with ANP, that is the generalization of the Analytic Hierarchy Process, a well-known MCDA technique introduced by Saaty (Saaty, 1980).

AHP is conceptually easy to use; however, its strict hierarchical structure cannot handle the complexities of many real-world problems. AHP breaks down a decision-making problem into several levels in such a way to form a hierarchy with unidirectional hierarchical relationships between levels. The top level of the hierarchy is the main goal of the decision problem. The lower levels are the tangible and/or intangible criteria and subcriteria that contribute to the goal (De Felice and Petrillo, 2012 (a)). The bottom level is formed by the alternatives to evaluate in terms of the criteria.

As a solution, Saaty proposed the ANP model, a general form of AHP. ANP represents a decision-making problem as a network of criteria and alternatives (all called elements), grouped into clusters. All the elements in the network can be related in any possible way, i.e. a network can incorporate feedback and interdependence relationships within and between clusters. This provides a more accurate modelling of complex settings. A ANP is a more general form of the AHP. Both use a system of pairwise comparisons to measure the weights of the components of the structure, and finally rank the alternatives in the decision. One of the major advantages of the ANP is using pair-wise comparisons to determine weights and derive priority index in comparison to other weighting methods where weights are assigned arbitrarily.

The ANP can apply to convert subjective assessment of relative weights (importance, likelihood, or preference) to a set of priority ratio scale and overall scores.

Some of the recent publications involving ANP are found in strategic policy planning (Ulutas, 2005; Erdogmus et al., 2006), industrial management (Karsak et al., 2002; Partovi, 2006) economics and finances (Niemura and Saaty, 2004), forest management (Wolfslehner et al., 2004).

The literature review is poor in the field of LCA-ANP so the aim of the present work is to propose a systemic method useful to solve complex decision-making problems involving few alternatives with numerous criteria in the environmental field.

## 3. Methodological Approach

The aim of this study is to propose a methodological approach in order to support managers in suggesting and selecting the best solutions for economic and environment improvement. We adopted the LCA technique to evaluate the environmental impact. The analysis is based on the Eco-Indicator 99, a model that represents the total environmental load of a process or material (De Felice and Petrillo, 2012 (b)). In Figure 2 a methodological approach is shown. The approach is characterized by two phases. The first is PHASE 1 in which the economic and environmental assessment was performed using the LCA model. The second is PHASE 2 in which, through an AHP model, the technical feasibility assessment was defined in order to optimize energy consumption. Each phase is characterized by several steps.

### *3.1. PHASE 1 - Economic and environmental assessment.*

Here below are the steps characterizing Phase 1.

STEP 1 - LCA Analysis characterizing by 1) Inventory of all relevant emissions, resource extractions and land-use in all processes that form the life cycle product; 2) Model building; 3) Calculation of the damages these flows cause to Human Health, Ecosystem Quality and Resources. Weighting of these three damage categories (De Felice and Petrillo, 2012 (c)).

STEP 2 - Key Performance Indicators estimation. Starting from data collecting and LCA results, a set of EPIs and KEIs was defined.

STEP 3 - Optimization of energy consumption. In order to optimize the energy consumption different solutions were considered.

### *3.2. PHASE 2 - Technical feasibility assessment.*

In this phase the ANP Model was defined.

STEP 4 – Multi criteria Analysis. The purpose of this phase is to recommend any possible improvement in the system. The modelling process can be divided into different stages for the ease of understanding which are described as follows:

*Stage 1: Pairwise comparison and relative weight estimation.* Pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control criterion. Saaty suggested a scale of 1-9 when comparing two components. For example, number 9 represents extreme importance over another element. Number 8 represents between “very strong importance” and ‘‘extreme importance” over another element. Let $A_1$, $A_2,\dots,A_m$ denote the set of elements, while $a_{ij}$ represents a quantified judgment on a pair of $A_i$, $A_j$. Through the 9-value scale for pairwise comparisons, this yields an [m x m] matrix A as follows:

$$A = a_{ij} = \begin{array}{c|cccc|} & A_1 & A_2 & \dots & A_m \\ A_1 & 1 & a_{12} & \dots & a_{1m} \\ A_2 & 1/a_{12} & 1 & \dots & a_{2m} \\ \dots & \dots & \dots & \dots & \dots \\ A_m & 1/a_{1m} & 1/a_{2m} & \dots & 1 \end{array}$$

where $a_{ij} > 0$ (i, j = 1, 2,..,,m), $a_{ii} = 1$ (i = 1, 2,…,m), and $a_{ij} = 1/a_{ji}$ ( 1; 2;…,m).

A is a positive reciprocal matrix. The result of the comparison is the so-called dominance coefficient aij that represents the relative importance of the component in row (i) over the component in column (j), i.e., $a_{ij} = w_i/w_j$. The pairwise comparisons can be represented in the form of a matrix. The score of 1 represents equal importance of two components and 9 represents extreme importance of the component i over the component j. In matrix A, the problem becomes one of assigning to the m elements $A_1$, $A_2,\dots,A_m$ a set of numerical weights $w_1, w_2,\dots,w_m$ that reflects the recorded judgments. If A is a consistency matrix, the relations between weights $w_i$, $w_j$ and judgments $a_{ij}$ are simply given by $a_{ij} = w_i/w_j$ (for i,j = 1, 2, …, m). If matrix $w$ is a non-zero vector, there is a $\lambda_{max}$ of $Aw = \lambda_{max} w$, which is the largest eigenvalue of matrix A. If matrix A is perfectly consistent, then $\lambda_{max} w = m$. But given that $a_{ij}$ denotes the subjective judgment of decision-makers, who give comparison and appraisal, with the actual value ($wi/wj$) having a certain degree of variation. Therefore, $Ax = \lambda_{max}w$ cannot be set up. So the judgment matrix of the traditional AHP always needs to be revised for its consistency.

*Stage 2: Priority vector estimation.* After all pairwise comparison is completed, the priority weight vector ($w$) is computed as the unique solution of $Aw = \lambda_{max}w$, where $\lambda_{max}$ is the largest eigenvalue of matrix A.

*Stage 3: Consistency index estimation*. Saaty (1990) proposed utilizing the consistency index (CI) to verify the consistency of the comparison matrix. The CI of the derived weights could then be calculated by: $CI = (\lambda_{max}-n)/ n-1$. In general, if CI is less than 0.10, satisfaction of judgments may be derived.

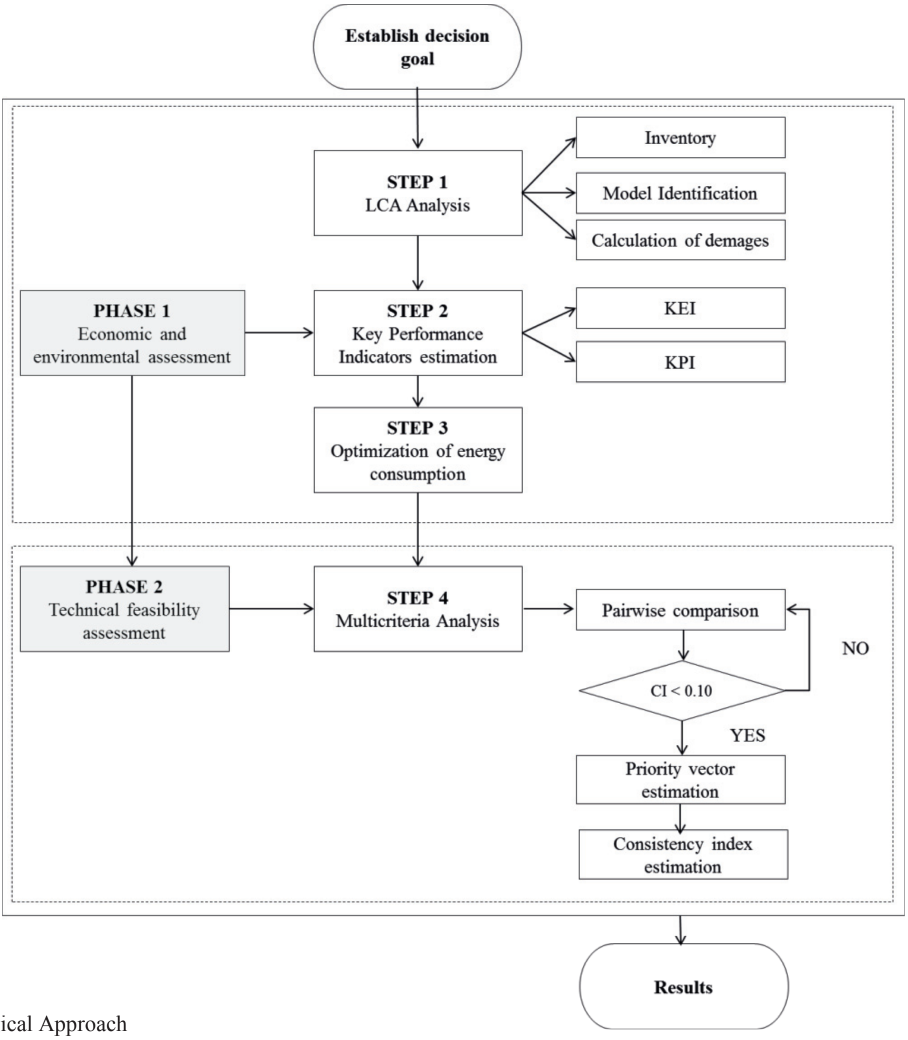

Fig. 2. Methodological Approach

## 4. Case study

In this paragraph a real case study concerning a bearing industry is presented. The LCA approach, that usually is from *cradle to grave* is, in this case, from *cradle to gate*.

### *4.1. PHASE 1 - Economic and environmental assessment.*

STEP 1 - LCA Analysis.

*Inventory*. One of the most important aspects in analysis is data collection.

Almost half of the electrical usage is required from the workshops and the other half is needed from the system that serves the plant (Compressor cluster = 23%; Production workshop 1 = 22%; Production workshop 2 = 33%;

Auxiliary system 22%). While the electrical usage for auxiliary system is: Heating = 2%; Sewage disposal = 11%; Colling tower 1 = 5%; Colling tower 2 – 9%; Oil pump division = 36%; Turning = 7%; Grinding = 6%; Workshop 1 – 8%; Workshop 2 - 5%; Washing process = 11%. Adding to the electrical usage, the data regarding raw material, waste, gas and manufacturing usage, that contribute to the product life cycle has been collected.

*Model identification*. After data analysis, in order to select the most relevant data, and referred all this information to the single product (unit of bearing in this case), the LCA model was defined.

The analysis was supported by SimaPro © software, that via Eco-Indicator 99 method, evaluates three kinds of environmental damages: Human health, Ecosystem Quality, Resources.

Table 1 illustrates an overview of the model built in SimaPro © software, regarding all the components of the bearing and the process needed to assemble it.

Table 1. Overview of the bearing manufacturing model

| **Nome** | | | |
|---|---|---|---|
| BEARING | | | |
| Materials/assemblies | Amount | Unit | Comment |
| Inner Ring | 1 | p | |
| Outer Ring | 1 | p | |
| Ball inner ring | 8,125 | p | |
| Retainer | 2 | p | |
| *SHIELD* | 2 | p | |
| Water demineralized ETH U | 0,0727 | kg | Water |
| Tapwater (from groundwater) | 0,009 | l | Tap water |
| *PROCESSES* | | | |
| Electricity, low voltage, at grid/IT U | 23,8944 | Wh | Production workshop 1 |
| Electricity, low voltage, at grid/IT U | 39,8036 | Wh | Compressor cluster |
| Electricity, low voltage, at grid/IT U | 1,9213 | Wh | Coolingtower 1 |
| Electricity, low voltage, at grid/IT U | 3,4584 | Wh | Coolingtower 2 |
| Electricity, low voltage, at grid/IT U | 13,8337 | Wh | Oilpumpdivision |
| Electricity, low voltage, at grid/IT U | 2,6899 | Wh | Turning |
| Electricity, low voltage, at grid/IT U | 2,3056 | Wh | Grinding |
| Electricity, low voltage, at grid/IT U | 3,0742 | Wh | TRANE workshop 1 |
| Electricity, low voltage, at grid/IT U | 1,9213 | Wh | TRANE workshop 2 |
| Electricity, low voltage, at grid/IT U | 0,7685 | Wh | Heating |
| Electricity, low voltage, at grid/IT U | 4,227 | Wh | Sewagedisposal |
| Electricity, low voltage, at grid/IT U | 4,227 | Wh | Washingprocess |
| Natural gas, burned in boiler modulating >100kW/RER U | 0,0418 | MJ | Methan (heating) |
| Ring and bearingwaste | 1,6165 | g | Waste |
| Packaging | 0,1928 | g | Waste |
| Wood packaging, pallet | 1,4504 | g | Waste |
| Junk (iron, steel) from old not working equipment | 0,1686 | g | Waste |
| Other junk steel cat.51 | 0,7836 | g | Waste |

Table 2 shows the model for the Inner Ring.

Table 2. Model of Inner Ring

| **Nome** | | | |
|---|---|---|---|
| Inner Ring | | | |
| Materials/assemblies | **Amount** | **Unit** | **Comment** |
| Steel low alloy ETH U | 11,139 | g | Steel 100 Cr6 |
| Processes | | | |
| Electricity, low voltage, at grid/IT U | 21,8184 | Wh | Workshop 2 |
| Electricity, low voltage, at grid/IT U | 11,95 | Wh | Workshop 1 |
| Natural gas, burned in industrial furnace >100kW/RER U | 0,02092 | MJ | Temper |
| Turning, steel, CNC, average/RER U | 0,9616 | g | Turning, grinding |

Similarly the data for each component of the bearing was obtained. Specifically, the model was made considering all the processes needed to assemble the bearing and, of course, all the processes needed to build and complete the components of the product. In the bearing manufacturing model (to build the bearing, or rather to assemble and complete the product) also the heating, tap water, industrial water etc., essential to the plant to permit an appropriate work environment was reported.

*Calculation of the damages.* Thanks to the Eco-indicator 99 model, we calculated the damages to Human Health, Ecosystem Quality and Resources. The output of the damage analysis, followed with normalisation and weighting, are information about: 1) *Damage to resources*, expressed as the surplus energy needed for future extractions of minerals and fossil fuels; 2) *Damage to ecosystems quality*, expressed as the loss of species in a certain area, during a certain time; 3) *Damage to human health*, expressed as the number of years of life lost and the number of years lived as disabled.

STEP 2: Key Performance Indicators building.

Two types of performance indicators were identified. One considered the environmental impact, and one the economic performance. Following are reported the EPIs (Environmental Performance Indicators): EPI 1: Primary energy (kJ/u); EPI 2: Green energy (kJ/u); EPI 3: Water consumption (dm3/u); EPI 4: CO2 emission (g/u); EPI 5: Local CO emission (g/u); EPI 6: PM10 emission [mg/u]; EPI 7: Local PM10 emission [mg/u].

All the indicators are referred on one unit of product. Regarding the economic aspect, a set of Key Economic Indicators were identified (KEIs) that take into account the impact of the improving investment: KEI 1: Economic benefits [c€/u]: that is, the saving, lose or stability for every unit; KEI 2: Δ primary energy/€ of investment [kJ/€]; KEI 3: Δ water consumption/€ of investment [dm3/€]; KEI 4: Δ CO2/€ of investment [g/€]; KEI 5: Maintenance costs [€/year]; KEI 6: Improvement costs [€]; KEI 7: Pay Back Period [n° of years].

STEP 3: Optimization of energy consumption.

Examining the results of the current evaluation, it is possible to progress with some scenarios of improvement. This decision was made because of the impossibility to change the technical and project features of the product.

In order to reduce the electric and thermo usage, we focused on the generation of energy from renewable sources, high efficient systems and integration of different kinds of systems, i.e. photovoltaic and CCHP. Five different projects were developed:

- *Photovoltaic system*, 500kWp. With reference to 26.000 m$^2$ of covered plant, it was calculated that at least 30% , about 7.800 m$^2$, could be used for the installation of photovoltaic panels. Consequently, the estimated power of the photovoltaic system is about 488 kW.
- *CCHP gas system, 650kW.* The factory has a high absorption of electricity and also of natural gas for heating during the winter period. It was estimated that the cost of natural gas used by heating boilers for 5 months of use is almost equivalent to the same source for the tempering process. With these findings it was reasonable to consider the propose of a tri-generation plant to produce thermal energy in the five winter months and cooling energy use in the four summer months and a contribution from electricity for the factory
- *Integration of photovoltaic system and CCHP gas system*. n this solution, the electrical energy input by network further decreases and it is replaced by the energy from photovoltaic and tri-generation plants.
- *CCHP biomass system, 500kW.* The use of a biomass tri-generation plant involves an improvement of global pollution. This also leads to possible job opportunities in a new biomass supply chain, as well as utility to the city in terms of disposal of the same.
- *Integration of photovoltaic system (proposed in point 1) and CCHP biomass system.* From an economic point of view, while having a high investment of installation with its related maintenance costs, this solution offers many benefits derived from encouraging the use of renewable energies

In Table 3 all the KPIs updated for every project proposed are reported.

Table 3. Updated KPIs for every improvement system proposed

| **Indicators** | **Unit** | **Current state** | **Photovoltaic system** | **CCHP gas system** | **Photovoltaic + CCHP gas system** | **CCHP biomass system** | **Photovoltaic + CCHP biomass system** |
|---|---|---|---|---|---|---|---|
| Main energy | kJ/u | 2201,7347 | 2189,8397 | 2126,1673 | 2114,2723 | 2226,0482 | 2200,2691 |
| Green energy | kJj/u | 0,0000 | 15,4651 | 0,0000 | 15,4651 | 13,4886 | 28,9536 |
| Water demand | $dm_3$/u | 985,2204 | 975,5920 | 946,7933 | 936,7899 | 973,0540 | 963,4183 |
| $CO_2$ emission | g/u | 204,9798 | 203,1173 | 199,3817 | 197,5191 | 201,7041 | 199,6398 |
| Local CO emission | g/u | 0,0007 | 0,0007 | 0,0050 | 0,0050 | 0,0014 | 0,0014 |
| $PM_{10}$ emission | mg/u | 55,6719 | 55,3938 | 54,5672 | 54,2891 | 56,0811 | 55,7926 |
| Local $PM_{10}$ emission | mg/u | 0,0696 | 0,0696 | 0,0820 | 0,0820 | 0,8382 | 0,8278 |
| Management gain | c€/u | 0,0000 | 0,1275 | 0,0457 | 0,1732 | 0,0504 | 0,1779 |
| Δ main energy/€ of investment | Kj/€ | 0,0000 | -1204,4939 | -24495,8265 | -25700,3204 | 9475,4844 | 8270,9905 |
| Δ Water demand/€ of investment | $dm^3$/€ | 0,0000 | -974,9757 | -12456,4699 | -13431,4456 | -4741,4776 | -5716,4533 |
| Δ $CO_2$/€ of investment | g/€ | 0,0000 | -188,6026 | -1814,6923 | -2003,2949 | 1295,4771 | 1106,8744 |
| Manteinance | €/year | 0 | 19744 | 8323 | 28067 | 11098 | 30841 |
| Cost of improvement | € | 0 | 1462500 | 456855 | 1919355 | 380000 | 1842500 |
| Pay Back Period | n° years | 0 | 6,0 | 5,3 | 5,8 | 4,0 | 5,5 |

### *4.2. PHASE 2 - Technical feasibility assessment*

STEP 4: Multicriteria Analysis

Thus, the model built is a network between four types of clusters, as shown in Figure 3: Alternatives; KEIs; KPIs; Social Aim.

The design of network requires experience and knowledge of the problem area. Definitively, in order to ensure the best representability we chose 2 experts representing the company; 2 experts representing the University (De Felice and Petrillo, 2012 (d)).

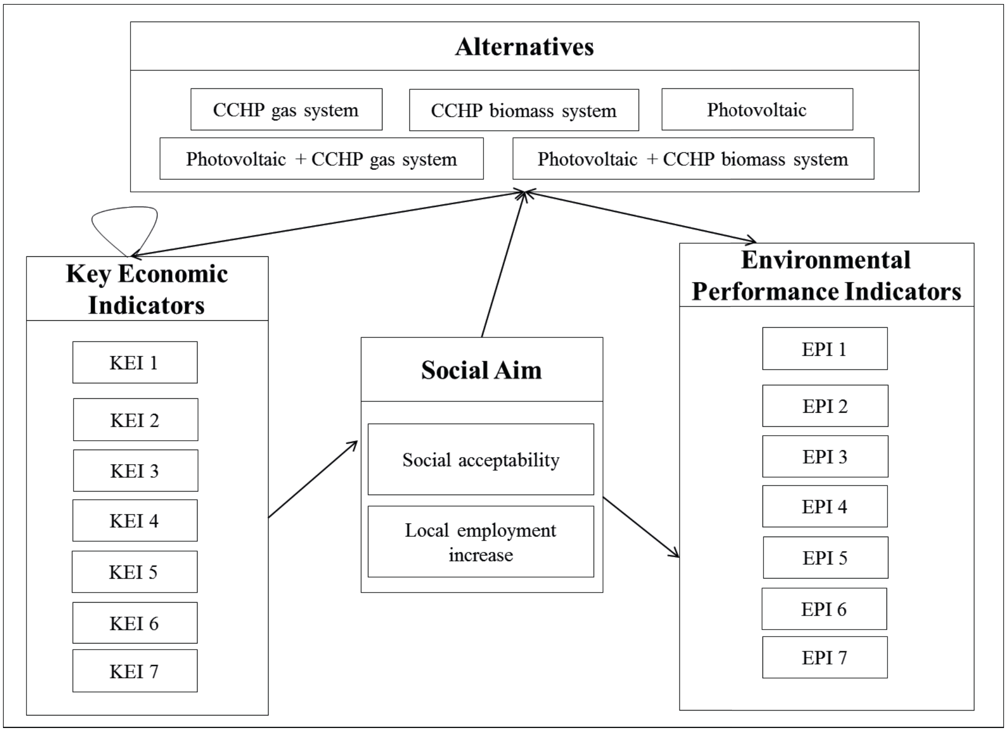

Fig. 3. ANP Model

*Pairwise comparison.* ANP uses pairwise comparison to allocate weights to the elements of each level, measuring their relative importance with Saaty's 1–9 scale, and finally calculates global weights.

*Consistency index estimation.* After running pairwise comparison for each element, the inconsistency index is calculated. Established that the inconsistency index of each comparison is ≤ 0.10, it can perform the synthesis, which indicates priority of intervention and then the best improvement action.

*Priority vector estimation*. In our case, the chosen improvement action is the integration of Photovoltaic and CCHP biomass system: CCHP biomass system (0.124); CCHP gas system (0.090); Photovoltaic (0.238); Photovoltaic + CCHP biomass system (0.386); Photovoltaic + CCHP gas system (0.160).
The integration of the Photovoltaic and CCHP biomass system can permit to cut gas usage down by 55% and $CO_2$ emissions by 2%. Moreover, there will be a contribution of renewable sources by 4% and a pay-back period of 5,5 years. Furthermore, the possibility of creating new job vacancies for the maintenance and biomass supply is possible.

## 5. Conclusion

The economic, energy and environmental topic is always more present in contemporary society. In particular, the environmental impact of a product is directly affected by the environmental properties of the materials used, as impacts corresponding to production and manufacturing phases, and recyclability. The LCA-ANP analysis is a systemic approach to evaluate environmental, economic, and socio-political impacts associated with construction processes and activities. The present paper proposes a new methodological approach that can aggregate the relative weights of different criteria and sub-criteria at different levels with the scoring of alternatives, to assess the sustainability impacts, over the life cycle of the production process of bearings. The developed model is flexible and it is possible to extend it in several scenarios. One of the major advantages of our methodology is:

- Break down a problem into elementary aspects;
- Collect basic input data for all criteria of LCA Analysis and ANP Model;
- Classification of the various environmental impacts;
- Aggregate weights and scores to establish the final ranking in order to define the optimum solution.

We believe that our new approach based on the LCA-ANP analysis helps decision makers to find sustainable alternatives among available options and promises a more sustainable product or process.

## References

Battisti R., Corrado A., "Evaluation of tecnical improvements of photovoltaic systems through life cycle assessment methodology." Energy 2005;30:952-67.

Curran M. A., "Environmental life-cycle assessment". New York, NY: McGraw-Hill, 1996.

De Felice, F. and Petrillo, A. (2012) (a). Green Policy in a Manufacturing System. The 2nd International Conference on Communications, Computing and Control Applications (CCCA'12) December 6-8, 2012 at Marseilles, France.

De Felice, F. and Petrillo, A. (b). Environmental indicators to evaluate sustainability performances in bearings industry. Proceedings of XVII Summer School "F. Turco", Venezia, 12-14 September, 2012. ISBN 9788890631917.

De Felice, F. and Petrillo, A. (2012) (c). Productivity analysis through simulation technique to optimize an automated assembly line. Proceedings of the IASTED International Conference, June 25 - 27, 2012 Napoli, Italy. Applied Simulation and Modelling (ASM 2012) DOI: 10.2316/P.2012.776-048 – pp 35-42.

De Felice, F. and Petrillo, A., (2012) (d). Hierarchical model to optimize performance in logistics policies: multi attribute analysis. The 8th International Strategic Management Conference. The 8th International Strategic Management Conference. June 21-23, 2012 Barcelona –Spain. Elsevier Procedia Social and Behavioral Sciences. Volume 58, 12 October 2012, Pages 1555–1564.

Erdogmus, S., Aras, H., Koc, E., 2006. Evaluation of alternative fuels for residential heating in Turkey using analytic network process (ANP) with group decision-making. Renewable and Sustainable Energy Reviews 10 (3), 269–279.

Giudice, F., La Rosa, G., Risitano, A., (2004). Materials selection in the Life-Cycle Design process: a method to integrate mechanical and environmental performances in optimal choice. Materials and Design 26 (2005) 9–20.

Goedkoop M., Effting S., Collingnon M., "The eco-indicator 99 – a damage oriented method for life cicle assessment". Manual for designers- 17-4-2000. 2ed. The Netherlands: PRé-Consultants B.V. Amersfoort; 2000.

Hofstetter P., Baumgartner T., Scholz W.R., "Modelling the Valuesphere and the Ecosphere: Integrating the Decision Makers' Perspectives into LCA". The MIIM LCA PhD Club, 2000.

Huang C., Ma C., H.W., Science of the Total Environment 324 (2004) 161-172.

Khan, F.I., Sadiq, R., Veitch , B., (2004). Life cycle iNdeX (LInX): a new indexing procedure for process and product design and decision-making. Journal of Cleaner Production 12 (2004) 59–76.

Karsak, E.E., Sozer, S., Alptekin, S.E., 2002. Product planning in quality function deployment using a combined analytic network process and goal programming approach. Computers and Industrial Engineering 44, 171–190.

Partovi, F.Y., 2006. An analytic model for locating facilities strategically. Omega 34 (1), 41–55.

Myllyviita T., Holma A., Antikainen R., Lahtine K., Leskinen P., "Journal of Cleaner Production 29-30 (2012) 238-245.

Neaupane, K.M. and Piantanakulchai M., (2006).Analytic network process model for landslide hazard zonation. Engineering Geology 85 (2006) 281–294.

Niemura, M.P., Saaty, T.L., 2004. An analytic network process model for financial-crisis forecasting. International Journal of Forecasting 20 (4), 573–587.

Reza, B., Sadiq, R., Hewage, K., (2011). Sustainability assessment of flooring systems in the city of Tehran: An AHP-based life cycle analysis. Construction and Building Materials, Volume 25, Issue 4, April 2011, Pages 2053–2066.

Saaty, T.L., 1980. The Analytic Hierarchy Process. Third ed. McGraw-Hill, New York.

Saaty, T. L. 1990. How to make a decision: The analytic hierarchy process. European Journal of Operations Research, 48, 9–26.SETAC. Guidelines for life-cycle assessment: a code of practice, 1st ed. Workshop at Sesimbra, Portugal; 1993.

Sinclair P. "Describing the elephant": A framework for supporting sustainable development Processes. Renewable and Sustainable Energy Reviews 15 (2011) 2990– 2998.

Thompson M., Ellis R., Wildavsky A., Cultural Theory, est view Print, Boulder, USA, 1990.

Yu SR, Tao J. E nergy efficiency assessment by life cycle simulation of cassava-based fuel ethanol for automotive use in Chinese Guangxi context. Energy 2009;34(1):22–31.

Ulutas, B.H., 2005. Determination of the appropriate energy policy formTurkey. Energy 30 (7), 1146–1161.

Wolfslehner, B., Vacik, H., Lexer, M.J., 2004. Application of the analytic network process in multi-criteria analysis of sustainable forest management. Forest Ecology and Management 207 (1–2), 157–170.