# An Integrated Approach for Sustainability (IAS): Life Cycle Assessment (LCA) as a supporting tool for Life Cycle Costing (LCC) and social issues.

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ABSTRACT: SPEAR is the acronym for the European research project Seismic Performance Assessment and Rehabilitation of existing buildings, and the SPEAR building is the three-storey replica of an existing non-seismic building, full-scale tested at the ELSA Laboratory.
In previous studies, a practical cost-benefits analysis was used to compare the performance of the specimen in the two different rehabilitated configurations: GFRP-retrofitted specimen and RC-jacketed structure.
This paper presents a method to assess the best solution between alternative interventions including sustainability issues in the economic evaluation. The main aim of this study, in fact, is to create an integrated approach as the key to make choices in terms of life cycle cost benefits analysis.
Normally, Life Cycle Assessment (LCA) is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment (from the cradle to grave).
In the present study LCA methodology is calibrated as a decision support tool for economic analysis. At this regard, the first step was the environmental impacts analysis derived from the production (pre-use phase), installation (use phase) and waste treatment (end of life phase) of the two retrofitting measures. SimaPro software (version 7.1.8) was used to implement LCA model and to carry out the assessment in terms of tons CO2 emissions.
It is clear that environmental results are not compatible with cost analysis (expressed in Euro) for the two configurations; therefore, to define a global result, CO2 emissions are converted in Euro unit, considering both the costs of the expected damages and the benefits derived from global climate change.

## 1 INTRODUCTION

The term sustainable development can be described as enhancing quality of life and thus allowing people to live in a healthy environment and improve *social*, *economic* and *environmental* conditions for present and future generations.

The emergence of the Life Cycle Assessment (LCA) in construction is, therefore, the effect of the growing awareness that environmental problems can no longer be addressed in individual compartments, but they require a comprehensive assessment and intervention.

Objective of LCA is to guide the choices of the project through a full assessment ("*from cradle to grave*") of the materials performance, construction techniques and service that, in general and not as a single component, enables reduced consumption of resources, reduced emissions and waste. The LCA is not only a means to environmental protection, it can become an important tool for strengthening the competitive dynamics and to reduce and control costs.

In such a context, the paper presents an *integrated approach* to make choices based on economic and environmental factors.

## 2 LIFE CYCLE ASSESSMENT

### 2.1 *Conceptual basis of Life Cycle Assessment (LCA)*

The Life Cycle Assessment (LCA) methodology used in this study follows the stages outlined by International Organization for Standards (ISO) 14040.

The four major stages of the LCA applied contain:

1.Goal and scope definition, including the analysis of system boundaries;
2.Life cycle inventory;
3.Life cycle impact analysis;
4.Life cycle interpretation and suggestions for improvement.

1.The *Goal and Scope Definition* phase describes the overall objectives, the boundaries of the system under study, the sources of data and the functional unit to which the achieved results refer.

2. The *Life Cycle Inventory (LCI)*, defined by ISO14041, consists of a detailed compilation of all the environmental inputs (material and energy) and outputs (air, water and solid emissions) at each stage of the life cycle.

3. The *Life Cycle Impact Assessment (LCIA)* phase aims at quantifying the relative importance of all environmental burdens obtained in the LCI by analysing the relative influence on the selected environmental effects. According to ISO14042, the general frame work of an LCIA method is composed of mandatory elements (*classification* and *characterisation*) that convert LCI results into an indicator for each impact category, and optional elements (*normalisation* and *weighting*) that lead to a unique indicator across impact categories using numerical factors based on value-choices.

4. According to the ISO14043 standard, in the *Life Cycle Interpretation* phase, results of the LCI and LCIA stages must be interpreted in order to compare alternative scenarios.

SimaPro v. 7.1.8 software application was used as supporting tool in order to implement the LCA model and carry out the assessment. In particular IPCC 2007 GWP 500a methods was used here to compare the results (Lavagna, 2008).

### 2.2 *Stage 1: Goal and Scope Definition*

The Life Cycle Assessment methodology has been used to obtain a comparative and comprehensive environmental picture relevant to two different retrofitting strategies (GFRP-wrapping and RC-jacketing) applied to the *realistic* SPEAR building, located in Campedei (BL) Italy (Figure 1). In particular, this study was carried out by evaluating $CO_2$ emissions in the atmosphere, crucial to global warming.


Figure 1. Location and render of the building under study

The *functional unit* is formed by all technological units by which the two retrofitting interventions are characterized.

Three distinct phases, pre-use, use and end-of-life, were included in the *system boundaries* (Figure 2).

The *Pre-Use phase* consists of the manufacturing, the transportation and production of retrofitting materials. The quantities were estimated from building drawings.

The *Use phase* encompasses all activities related to the site construction. In particular it includes the transportation from plant to installation site and the installation of GFRP wrapping and RC-jacketing.

As the last step, the *End-of-life phase* includes the transportation from site construction to waste treatment plant and all activities related to recycling, landfill and incineration examined in this specific case study.

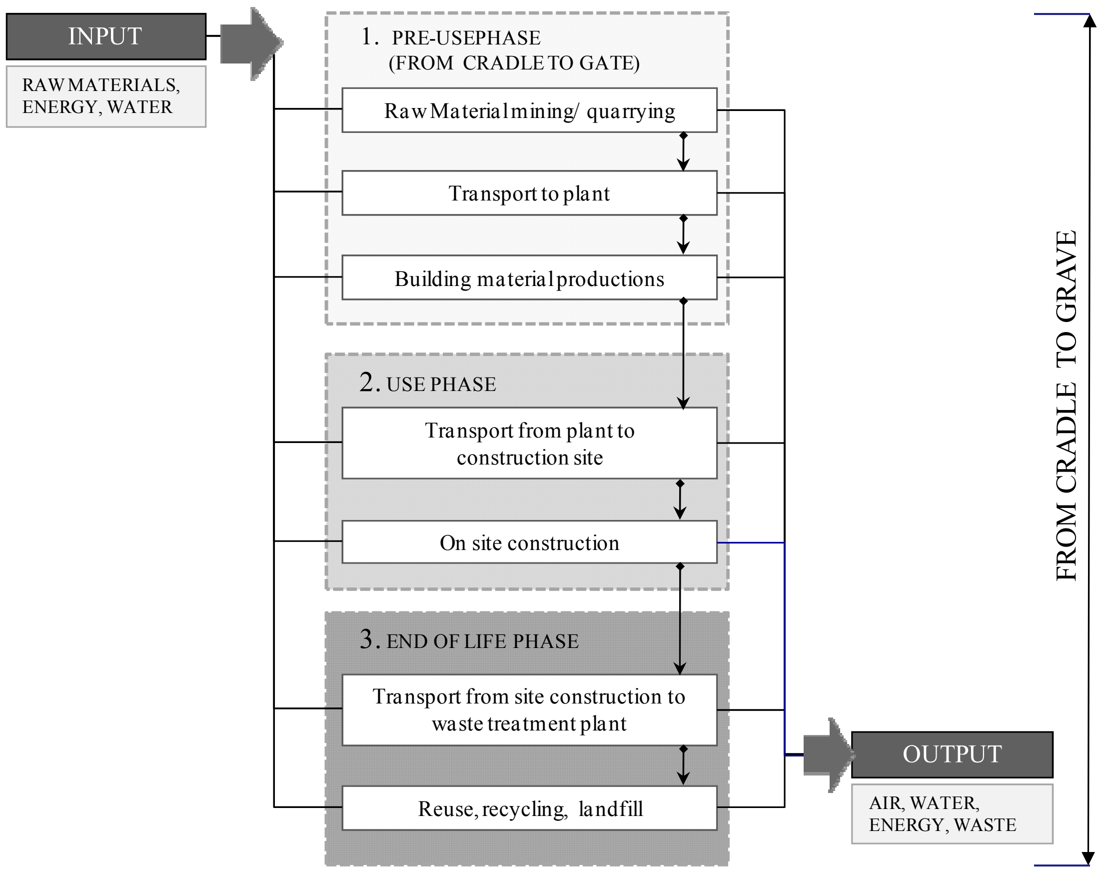


Figure 2. System boundaries

## 2.3 *Stage 2: Life Cycle Inventory (LCI)*

The input and output processes described into system boundaries must be quantified into the inventory. As a matter of fact, processes represent all activities, procedures and processes that lead to the implementation of each activity in the all stages of the life cycle, in terms of materials or energy. In this case the inventory data includes all the processes necessary to production, installation and waste treatment phases of GFRP wrapping and RC-jacketing.

Data for LCA were modeled from databases included in the SimaPro software package. In particular, the Idemat 2001 and ETH-ESU and Ecoinvent databases was the source for retrofitting materials, the BUWAL 250 database for transport operations, electricity and diesel use. Also inventory data for steel recycling were made available by Ecoinvent system processes used in SimaPro.

An example of inventory is described in Figure 3, in which network diagram shows the processes and materials to install GFRPs:

1. Sealing of the cracks;
2. Cleaning of the substrate;
3. Application of primer;
4. Application of the 1st epoxy resin layer;
5. Installation of the 1st GFRP ply;
6. Application of the 2nd epoxy resin layer;
7. Installation of the 2nd GFRP ply;
8. Application of the last epoxy resin layer.

The flow chart defines also the interaction and score (in Pt or in percentage) of each reported phases.

As far as production and transportation of concrete and cement are concerned, it was assumed that such products were manufactured in existing plants by local producers. Steel reinforcing bars were assumed to be produced according to the average processes that characterise the European steel industry.

About the transportation of retrofitting materials from production plant to construction site, distances to Campedei were calculated assuming that:

- GFRP wrapping and all material used for its installation were produced by MAPEI S.P.A. located in Milan, Italy;
- The materials to install RC-jacketing were produced by different plant; in particular concrete was transported from Vittorio Veneto (Treviso, Italy), steel reinforcing bars from Suzzara (Mantova, Italy).

Cracks checking

Seal the cracks

Application of epoxy resin layer

Installation of GFRP ply

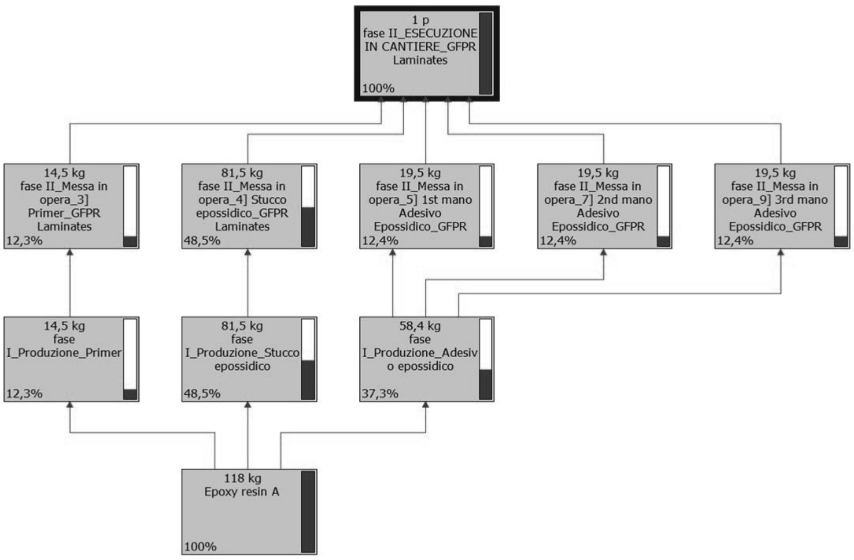


Figure 3. GFRP wrapping installation: example of SimaPro output in which the processes network are showed

For the waste scenario it was supposed that:

- the glass fiber and plastics were incinerated;
- the reinforced steel was recycled and the concrete was land filled.

Concerning the transportation, it was assumed that recycling station, land filing and incineration plant were situated in average at 200 km from the site; i.e. for each ton recycled, 200 km of transportation are accounted for. Track 16 B250 from database BUWAL 250 has been used in SimaPro.

## 2.4 *Stage 3: Life Cycle Impact Assessment (LCIA)*

Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment (SETAC, 1993). The *life-cycle* or *cradle-to-graves* impacts include the extraction of raw materials; the processing, manufacturing, fabrication of the product; the transportation or distribution of the product to the consumer; the use of the product by the consumer; the disposal or recovery of the product after its useful life.

In the present study, the analysis of environmental impacts, derived from the production (*pre-use phase*), installation (*use phase*) and waste treatment (*end of life phase*) of the two retrofitting measures, was carried out using *IPCC 2007 GWP 500* method, included in SimaPro v.7.1.8 software.

This method, developed by the Intergovernmental Panel on Climate Change (IPCC), was characterized by a system of equivalence factors to weigh the various substances as a function of their efficiency as greenhouse gases. In this way it is possible to calculate the so called Global Warming Potential" (GWP), considering the total effect given by the investigated substances in terms of $CO_2$ emissions. The conversion factors are calculated for three different time horizons: 20, 100 and 500 years.

For example, Table 1 includes conversion factors for 100 and 500 years; we can observe that when time horizon is higher the impact factor is lower, because it was assumed that they have a reaction in the atmosphere with the other components causing degradation and a lower effect.

In this case, environmental impacts are calculated for a climate change factor with a time-frame of 500 years.

Table 1. Characterization factors for greenhouse gases. GWP Potential

| Chemical compound | Formula | Conversion factor | |
|---|---|---|---|
| | | 100 years | 500 years |
| Fossil carbon dioxide | $CO_2$ | 1 | 1 |
| Carbon monoxide | CO | 2 | 2 |
| Nitrous Oxide | $N_2O$ | 320 | 180 |
| Methane | $CH_4$ | 25 | 8 |
| Non-methane volatile organic | NM-COV | 25 | 8 |

The results of LCA analysis, reported in

Figure 4, show that $CO_2$ emission produced by GFRP wrapping (1,35 tons $CO_2$) are higher than those formed by RC jacketing (0,817 tons $CO_2$): the incineration of glass fiber has an important environmental impact (97,8%).

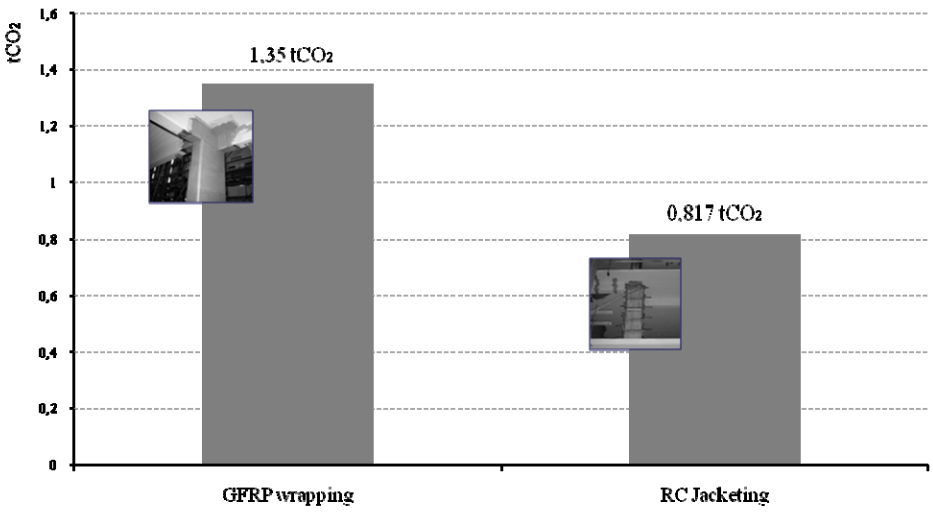


Figure 4. SimaPro output: results of impact assessment using the IPCC 2007 GWP 500a method

## 2.5 *Stage 4: Life Cycle Interpretation*

The interpretation of an LCA results is not simple: the conclusions and improvement suggestions are often subjective, and this makes it difficult to find and choose the best environmental solution among alternatives in comparison.

For this reason, the present study implements the LCA methodology as a decision support tool for the economic analysis, carried out in previous studies.

As a matter of fact, cost-benefit evaluation showed that none of the rehabilitation measures proved to be economically justifiable (Table 2). In terms of reduction of total expected losses, the GFRP-wrapped solution turned out to be by far the most effective, since the total expected loss was reduced to one fourth of the one of the original structure.

In terms of return of investment, it had to be noticed that none of the rehabilitation strategies had economic justification. However, it had to be recalled that neither possible casualties were accounted for in the analysis, nor the risk of loss of the contents was considered (Negro, Landolfo et al. 2008).

Table 2. Total expected losses and investments in 20 years for the two configurations

| | GFRP Wrapped | RC Jacketed |
|---|---|---|
| Total Loss (Euro) | 9,990 | 34,211 |
| Investment (Euro) | 107,500 | 39,500 |

It is clear that environmental results (Paragraph 2.4) are not compatible with cost analysis (expressed in Euro) for the two configurations; therefore, to define a global result, $CO_2$ emissions are converted in Euro unit, considering the costs of damages and benefits derived from global climate change, the social cost of carbon expressed in terms of future net benefits.

Concern over the impact of anthropogenic carbon emissions on global climate has increased in recent years. The development of environmental themes linked to $CO_2$ emissions took hold especially when the Kyoto Protocol came into force (16 February 2005) and the European Union Emission Trading System (EU ETS) had become operational.

The EU ETS is the largest multi-national, emissions trading scheme in the world, and is a major pillar of EU climate policy. Under the EU ETS, the governments of the EU Member States agree on national emission caps which have to be approved by the EU commission, allocate allowances to their industrial operators, track and validate the actual emissions in accordance against the relevant assigned amount, and require the allowances to be retired after the end of each year.

Like the Kyoto trading scheme, the EU scheme allows a regulated operator to use carbon credits in the form of Emission Reduction Units (ERU) to comply with its obligations. Thus one EU Allowance Unit of one ton of $CO_2$, or "EUA", was designed to be identical ("fungible") with the equivalent "Assigned Amount Unit" (AAU) of $CO_2$ defined under Kyoto. Of course, the Member State's plan can, and should, also take account of emission levels in other sectors not covered by the EU ETS, and address these within its own domestic policies. Unfortunately the approval process of National Allocation Plans (NAP) is long and tortuous.

In 2008, despite an explosion of transactions in June and a record share price at 32,25 Euro per ton of $CO_2$, the EU ETS showed signs of breathlessness after August. In particular, at the end of 2008 the EUA fell down to around 15 Euro, while in February 2009 the cost of a ton of $CO_2$ was about 9 Euro (Cretí 2009). Therefore, starting from LCA results ($CO_2$ emissions produced by GFRP wrapping and RC jacketing) and considering the cost of one ton $CO_2$, we can combine both values in terms of Euro (Table 3).

Table 3. Cost analysis in terms of $CO_2$ emissions

| Hypothesis of cost | Retrofitting strategies | CO2 | CO2 |
|---|---|---|---|
| | | ton | Euro |
| | GFRP wrapping | 1,350 | 12,15 |
| 1 ton $CO_2 \cong$ 9 Euro | RC jacketing | 0,817 | 7,35 |
| | Differences | 0,533 | 5,15 |

In this way, summing the *economic costs* and *ecological costs* (Table 4), it is possible to obtain a *global result* and to justify that the GFRP wrapping is the best rehabilitation strategy.

Table 4. Global result of life cycle cost benefit analysis

| | GFRP Wrapped | RC Jacketed |
|---|---|---|
| Investment (Euro) | 107,50 | 39,50 |
| $CO_2$ costs (Euro) | 12,50 | 7,35 |
| Total (Euro) | 120,00 | 46,85 |

## 3 CONCLUSIONS

A combined approach able to include both monetary terms (costs and associated expected losses) and environmental effects was presented in this paper.

This process was based on LCA methodology used as a decision support tool for cost benefits analysis and was tested in order to compare the two alternative structural solutions (GFRP-wrapping and RC-jacketing) in terms of $CO_2$ emissions impacts for SPEAR Building.

Starting from previous economic studies and considering the unitary cost of the ton of $CO_2$ emission, it was possible to identify the best solution between the two retrofitting alternatives by considering both economic and environmental aspects.

It can be concluded that an integrated design is a collaborative process for designing buildings which emphasizes the development of a holistic, multidisciplinary and sustainable design.

## 4 ACKNOWLEDGEMENTS

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