Analysing the impact of retrofitting and new construction through probabilistic life cycle assessment. A method applied to the environmental-economic payoff value of an intervention case in the Albanian building sector.

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Abstract. The EU building stock is relatively old with 40\% of it built before 1960. In Albania the building sector accounts for 26, 9\% of final energy consumption, offering high energy saving potentials due to the great number of old residential buildings. Intervention is not always possible and, in order to achieve significant environmental savings, the national action plans cannot rely only on the physical improvement of existing buildings. This paper proposes a probabilistic LCA and LCC evaluation model using MC simulation, for the prediction of intervention options in existing buildings. The potential environmental and economic impacts of three intervention options: standard, ambitious retrofitting and new construction during the whole life cycle of a building are analysed. A framework is defined, with the purpose of estimating the value of a building in a specific time during its life cycle. Comparing the generated values of potential environmental impacts and associating them with the changes on the buildings value enables the process of deciding upon the most desirable and/or agreed combination. The results of the SLED Study 2015 on Albanian building typology are used, while the new construction model is defined according to German EnEV2014 requirements. The GWP values from the LCA/LCC assessment of the intervention scenarios, done through the SBS tool of Fraunhofer IBP, are used to create a prediction model for future alternatives especially in early planning phase. Decision-making through this model can encourage a sustainability strategy for energy efficiency improvement in the building sector of Albania.

1. Introduction

In the EU building sector, the replacement rate of old buildings by new build is around 1\% a year, while the renovation rate goes up to 1-2\% per year. Considering that more than 90\% of the existing building stock in the EU was built before 1990, the renovation of old buildings holds major significance in employing energy efficiency strategies [1].

As the obligation to accomplish CO\textsubscript{2} emissions reduction by 2050 becomes more urgent, the responsibility of acting upon this goal cannot be directed only towards EU countries, rather it requires a joint pursuit in global scale. That is why non EU countries, as part of the Energy Community Treaty, have to be actively engaged and, as growing economies, their contribution on European energy efficiency improvement cannot be neglected. With regard to this, several studies have been carried out in non EU area in order to investigate current trends and encourage new politics and more
attention to environmental issues. Among them, in Balkan region, SLED Study (Support for Low-Emission Development in South Eastern Europe) reported for instance that the energy costs will be 47% lower in comparison to the costs of the BAU (business-as-usual) intervention scenario, if the ambitious retrofit is applied in 2030 [2].

Even if meaningful, the results provided by SLED study do not consider the environmental impact of the buildings during their whole life cycle, including renovations work because of building parts obsolescence, and neither do they consider the difference of the GWP values between different intervention scenarios. This is actually a methodological issue, which is largely debated within the sustainability assessment of products use phase and leads to new approaches which can derive more results and can be better related to external factors as well. Standard LCA and LCC methodologies, which are widely applied for the assessment of products environmental and economic sustainability, could represent the basis for a comparison study, but considering the complexity of the building sector and the different factors that are known to affect such decisions during a building’s lifespan [3], the necessity arises for a more complex processing of the environmental-economic results. For this purpose, some statistical instruments such as Monte Carlo Simulation have been recently introduced into “probabilistic approaches”, which can integrate parameters associated to specific economic and environmental boundaries and can provide results within the whole building’s lifespan in a more comprehensive form.

In this paper the environmental impact of different intervention scenarios for the building sector in a non-EU country is analyzed in order to generate relevant results for a non EU economic and environmental reality including a comparison between a static standard approach and a more dynamic probabilistic one.

2. LCA – LCC analyses for renovation measures: state of art
With the increasing attention to the existing building stock, new measures supported by new techniques and innovative materials lead to a richer terminology: classical terms, recovery and rehabilitation, have been recently accompanied by new words, such as retrofit and refurbishment. Such measures have overlying meanings, which very often leads to lack of clarity. In fact, while refurbishment process is a general improvement of the building by cleaning, decoration and re-equipping and includes energy efficient and sustainable activities, a retrofit measure is more specifically a provision of a component of feature not fitted during manufacture or addition of something that the building did not have when first constructed. The term derives in fact from the crisis of “retroactive” and “refit” (reassemble, repair). It conveys an addition of elements (surfaces, volumes, etc.) which were not provided during the object production, in order to extend its service life [4]. Among the variety of solutions, an aware choice has to be carried out in order to provide an indication about the pay-off time of the selected measure [5]. Nevertheless, the need for a change into more energy efficient systems has exposed the necessity of a more accurate investigation of such solutions in order to ensure a significant global enhancement of performance with awareness of the environmental impacts. In conclusion, the economic analysis cannot be anymore solely the instrument for decision-making, but it should be accompanied by an environmental assessment of the considered measures.

Life Cycle Assessment (LCA) is a standardized methodology which has been applied for decades in the building sector, especially as basis for the building certification labelling systems. LCA considers the entire life cycle of a product from raw material extraction and acquisition through energy and material production and manufacturing, to use phase and end-of-life treatment and final disposal. Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided. For such reasons, LCA results can be included in the decision process by considering natural science, framework and principles according to the international standards ISO 14040 and ISO 14044 [6].

The consideration of retrofitting and further measures on existing buildings can be seen as new challenge by LCA point of view. In fact, the selection of refurbishment technologies and the success
of a retrofit project cannot be indicated with complete certainty due to aspects and factors related to humans’ behavior and choices [7]. For these reasons, quite recently LCA investigations focused on uncertainties associated to this methodology. Such uncertainties are due to insufficient and incomplete information (e.g. lack of data on construction materials, geometry of the building, etc.), inaccuracies of models and available software unpredictability of future events (e.g. change of use, service life duration, unexpected seismic events, etc.) and, considering the wide building lifespan (50 years) can be relevant for the final evaluation. With the regard to the building carbon embodied emissions can be distinguished [8]:

- uncertainty about the current embodied carbon of construction materials, components and whole buildings;
- uncertainty about the future embodied carbon of construction materials and components, including technological innovation;
- uncertainty about future events in the service life of built assets, including length of component life, component replacement or substitution, changes of use, end of life;
- Uncertainty about system boundaries and methods of measurement.

With regard to handling uncertainties, many applications in literature are carried out with probabilistic approaches by using statistical instruments such as Monte Carlo Simulation (MCS). The basic idea of such approach is using randomness to solve problems that might be deterministic in principle and is the most useful when it is difficult or impossible to use other probabilistic approaches. In the field of LCA, MC Simulation performs risk analysis by building models of possible results by substituting a range of values – a probability distribution – for any factor that has inherent uncertainty [9].

3. Method

Taking into account that there are several possibilities of interventions able to render satisfying results with regards to energy efficiency and environmental improvement in the building sector, the involved actors face the existence of different decision strategies during a building's life cycle (50 years) [8]. The decision making process considers:

- the possibility of allowing the building to continue its life cycle in its existing state until it has reached its end of life
- the possibility of refurbishment/ retrofit and further local and global intervention during its life cycle, which can extend the nominal building service life as well
- the possibility of rebuilding, with demolition of existing building, in a given moment in time during the building's life cycle, in order to build a new

3.1. Economic issues in the final decisions

Decisions about existing building interventions are influenced by several factors associated to technical aspects, such as available technologies, material and engineering/ architects knowledge, as well as economical and financial limitations (i.e. -long payback periods, willingness of building owners to pay for retrofits with missing public financial instruments) [10]. On the other hand, the environmental evaluation of different intervention options, if accompanied by an economic analysis which facilitates the comparison among alternative refurbishment measures, can provide an indication of whether the alternatives are energy efficient and cost- effective.

As depicted here the economic factor is at the moment probably the most important one: especially for developing economies, such as non EU countries. For this reason, even if the main objective of this study is linked to the environmental assessment of retrofit/refurbishment measures, economical matters cannot be neglected in the decision making part of the methods.

3.2. Probabilistic LCA with MC Simulation: determined framework

In this paper a probabilistic LCA with application of MC Simulation has been carried out. For the assessment of the total GWP (kg CO₂-eq/ m² year) of an existing building subjected to renovation
works, the LCA analysis considers a cradle to grave system boundary (A1-A3, B4-B6, C+D phases). The study takes into account a 50 years period for the building’s life cycle, with 2018 as start of investigation.

The GWP values extracted from the environmental assessment of the building represent the data input. The reference building has been analyzed and probability values have been established by considering previous studies for each intervention alternative (existing, refurbishment, rebuild) [11]. The real age of the existing building type is assumed to be 40 years; hence, the start intervention probability on year 2018 is calculated to be 33.7%. Decision about an intervention option is fixed in a 5 year period, where a random value $R_v(x)$ impacts the behavior of the rest of the parameters. The first decision in the system regards only two possibilities: $0$ - no intervention, the building is assumed to continue the rest of its life cycle in its existing state; $1$- intervention, it is determined that the building is suitable for a change, but the specific intervention method is not yet defined. The generated random value is then compared with the given intervention probability functions. If the probability of intervention in a given moment in time ($t=x$) exceeds the random value ($R_v$), then an intervention occurs; otherwise the building will not be subjected to any renovation work (See 3.1).

$$R_v = \begin{cases} 
\geq P(I) & \text{No intervention Dec}=0 \\
< P(I) & \text{Renovation measure Dec} =1 
\end{cases} \quad (3.1)$$

Where: $P(I)$ – probability of intervention in a specific point in time

The next decision regards the type of intervention. The economic data are used as input values in this phase, where the decision for refurbishment ($\text{Intrv. 1}$) or rebuild ($\text{Intrv. 2}$) depends on the relation between the respective costs (3.2):

$$C_{t+p} = \begin{cases} 
\geq 75\% C(\text{Reb}) & \rightarrow \text{Rebuilding Dec} = \text{Intrv.2} \\
< 75\% C(\text{Reb}) & \rightarrow \text{Refurbishment Dec} = \text{Intrv.1} 
\end{cases} \quad (3.2)$$

Where: $C_{t+p}$ - total costs of refurbishment; $C(\text{Reb})$ – costs of rebuild

The total GWP after a study of 50 years is calculated by adding contribution due to production, use phase (due to total energy demand) and end-of-life of the building system. Since whatever intervention enhances the global energy performance of the buildings, the energy demand depends on the achieved quality of the building (3.3).

$$\text{GWP}_{\text{tot}} = \sum_{y=1}^{50} \text{GWP}_{\text{prod},y} + \text{GWP}_{\text{use},y} + \text{GWP}_{\text{EoL}} \quad (3.3)$$

With regards to the GWP due to retrofit and rebuilding interventions, as suggested by previous works [12], the environmental impacts are adapted through a decarbonisation rate. Such value expresses the potential development of technologies and processes in order to reach better environmental quality, as required by international agreements (i.e. Paris COP31) (3.4).

$$\text{GWP}_{\text{prod},y} = \text{GWP}_{\text{prod},y-1} \cdot (1-c_r) \quad (3.4)$$

Costs are analogously discounted by considering a price increase rate and a discount rate as defined below (3.5).

$$C_y = C_{y-1} \cdot \frac{(1-p_i)}{(1+d_i)} \quad (3.5)$$

The total time frame in which a series of decisions takes place: a 50 year period is considered for the building's life cycle. The sum of GWP values is calculated for the intervention strategy that takes place during the life cycle of the building. The distribution of most likely GWP values in the MC
simulation is measured by the standard deviation with larger values indicating higher probability of occurrence.

![Diagram of Time-based decision process](image)

**Figure 1.** Time-based decision process

4. Case study
The provided model analyses three intervention alternatives for the building stock. The evaluation model is applied in one building type taken as a case study from the Albanian building stock typology system, to show preliminary results, but it is considered relevant for the whole building sector.

This requires first of all a mapping of the Albanian existing building stock: a good overview has been provided by the CENSUS 2011 study, used to establish a building classification which consists of 20 building types based on use type, construction periods, size of buildings and number of floors. According to the INSTAT’11 statistical data, the greatest part of the building stock has been constructed during 1991-2000 with 21% of the whole building stock [13] and surveys carried out in 2009 about the comfort conditions on the Albanian households, ascertained that approx. 85% of them are in bad conditions [14]. Hence, the energy improvement of the building sector in Albania represents a necessity and at the same time a great challenge due to the high amount of required investments and the shortage of public funding. In addition to that, private investments are restricted by further economic obstacles, such as insufficiently funded EE (energy efficiency) units, depressed energy pricing and norm-based billing for heating, data incompliance, unreliable municipalities and homeowner associations, etc. [15].

Regarding climate characteristics and considering the Albanian zoning, 48% of the building stock belongs in Climate Zone B (hilly Mediterranean area) [14] [16]. The most common energy source was wood (57, 5%), followed by LPG (20, 8%) and electricity (15, 4%), while solar heating and other energy sources are irrelevant. Altogether, according to AKBN (The National Agency of Natural Resources) in 2008 electricity covered most of the energy demand (65%), followed by LPG (18%) and fuel wood (15%) [17].

In a second phase, retrofit solution have been investigated: based on the typology system for the Albanian building stock proposed on the SLED Study of the Regional Environmental Centre for Central and Eastern Europe (REC) in 2015, only the “ambitious retrofit” (improvement 2) option proposed is analyzed. The alternative of "standard retrofit" (improvement 1) in fact considers only changes in the envelope of the building but does not include energy use systems. The intervention case of "rebuild" assumes the substitution of an existing building type after demolishing it, with a new building that has same geometry, and energy standard compliant to EnEV2014 requirements.

As a case study the building type, B1 from the typology system is selected. This type is assumed to be the representative for the group of buildings that share same building function, material construction, building period and similar surface area. The B1 type represents detached houses built in the period 1961-1980.
The building’s construction characteristics are shown below (Table 1)

**Table 1.** Information applied for the life cycle assessment of the building

| Building type B1  | 1961-1980 | Type          | Features                                      | Figures       |
|-------------------|-----------|---------------|-----------------------------------------------|---------------|
| General information | Detached house | Exterior wall | Solid red brick                               | 208,4 m²     |
| Construction elements               | Roof/Ceiling | Roof with red tiles | 67,6 m²        |
|                                  | Floor slab   | Concrete floor | 67,6 m²        |
|                                  | Window       | Single glazed, wooden frame | 17,3 m², 4,92 W/m²K |
|                                  | Exterior door | Wooden door    | 7,2 m², 3,0 W/m²K                              |
| Energy supply system            | National net of electricity supply (Hydropower energy generation) |  |  |
|                                  | Multi-split AC | Pellet boiler |  |  |
| Energy demand                   |  |  | 275,32 kWh/m²a                                     |

**Envelope surface**

| User surface area | 368,0 m² |

| 135,12 m² |

GWP results are then calculated for the existing building model with the SBS Building Sustainability Tool in compliance with the LCA methodology for the ambitious retrofit (Refurbishment), as well as the “Rebuild” case [18]. Characteristics of the refurbishment measures and rebuild construction defined according to EnEV standards are shown in Table 2 and LCA/ LCC results of the life cycle and costs analysis for the three cases of intervention are reported in Table 3 [19]:

**Table 2** Differences in construction of two intervention options taken into analysis

| Construction | Refurbishment measures | Rebuild characteristics |
|--------------|------------------------|------------------------|
| Exterior wall | Red brick, Polyst. EPS 10cm, U-Value=0.29 W/(m²·K) | Limestone, EPS, Plaster, U-Value=0.24 W/(m²·K) |
### Roof/Ceiling
- Roof with red tiles, Polyst. EPS 12cm, U-Value=0.27 W/(m²·K)
- Plasterboard, Therm. insulation EPS, Wood constr., MDF-plates, Roof tiles, U-Value=0.176 W/(m²·K)
- Cement, Insulation EPS, PVC-P, reinforced concrete, mineral-wool, gips, U-Value=0.14 W/(m²·K)

### Floor slab
- Concrete floor, Polyst. EPS 5cm, U-Value=0.54 W/(m²·K)

### Window
- Triple thermal insulation glass, 90%
- Plastic frame, U-Value =0.65 W/(m²·K)

### Exterior door
- Plastic door, U-Value =0.75 W/(m²·K)

### Energy supply system
- Electricity (Hydropower)
- Pellet boiler 25% energy
- Low temperature gas system 10% energy
- Multisplit-clima unit 65% energy

### Energy demand
- 9.410,5 kWh/y. En. for electricity
- 27.785,9 kWh/y. heat energy demand
- 16.079,3 kWh/year

### Table 3 GWP and costs results. Life Cycle Assessment and Life Cycle Costing

| Building type | B1 | A1-A3 | B6 | C1-C4 | C3+D |
|---------------|----|-------|----|-------|------|
|               | (kg CO₂-<sub>eq.</sub>/m²) | €/m² | (kg CO₂-<sub>eq.</sub>/m²) | €/m² | (kg CO₂-<sub>eq.</sub>/m²) | €/m² |
| Existing state| -  | -     | 1737,85 | -     | 39,9  | 120,00 |
| Standard retrofit | 15,9 | 794,6 | - | 72,4 |
| Ambitious retrofit | 29,25 | 436,96 | 95,5 |
| Refurbishment | 175,00 | - | - |
| New building/ Rebuild | 242 | 257,38 | 35,25 | - | - |

For the economic analysis the information about investment costs on refurbishment are obtained from SLED Study, while for rebuild are obtained from the Albanian National Housing Authority [20]. According to OBC-Transeuropa, a trustworthy discount rate of 5.7% is applied to all the costs and price increase rate of 1, 5 % considered [21]. Discount rate does not consider any risk prices, in order to obtain a conservative estimation and price increase rate due to the Albanian inflation rate.

#### 4.1 Results
The Monte Carlo simulation is modelled in a first screening to identify the range of results generated through 200 runs. In the first instance maximal, minimal and average values are obtained. The GWP results are afterwards divided in 7 ranges and for each of them the probability of occurrence has been determined. The distribution of such probabilities shows that most of intervention scenarios for a 50 year time frame fall in the range of 1300-1600 kg CO₂-<sub>eq.</sub>/m² year.
5. Discussion and outlook

This paper proposes a probabilistic LCA approach for intervention cases in the Albanian building stock and illustrates the effectiveness through a building type case study undergoing three scenarios of intervention.

The results of this research show how different LCA approaches determine different final decisions. In fact, from the perspective of a static LCA, a rebuilding for the analyzed case study may be advantageous: the emissions during the use phase are in fact strongly reduced, thanks to the low yearly energy demand. On the contrary, the results of the probabilistic LCA, show that the refurbishment solution has been preferred the most: this is due to the included economic factors, which dictate strongly the final decision.

It is necessary to underline that refurbishment interventions alone are not advantageous in the long term: in fact, while they can improve the energy performance of the building, further issues, e.g. structural vulnerabilities, may not be solved. As shown in the case study of this paper, the building has almost exhausted its nominal service life and therefore a global integrated intervention may be required, rebuild included. On the other hand, the rebuild process requires a long time, high investments and the demolition of the previous construction produces huge quantities of waste destined to landfill [22]: in this sense, a rebuilding is not the optimal solution for both environmental and economic points of view. Hence, innovative technology options for eco-efficient buildings have been investigated: those can restart the service life of the building and improve the whole structural and energy performance. With awareness of the material choice, a good recycling rate can be guaranteed and total costs may be limited [23].

With regard to the LCA methodology, a static LCA approach would not reflect the likewise way of making a decision. On the other hand, this is possible by carrying out a probabilistic analysis: even if it represents a more complex procedure, it can handle the uncertainties due to variations or intervention during its operating phase. As further advantage of the probabilistic LCA with MC simulation, the methodology can be easily modified, depending on the economic and environmental conditions, and can take into account the remaining value of a newly constructed building after the 50 years of considered lifetime, which in this case is not included.
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