ATTI

XI Convegno della Rete Italiana LCA

Resource Efficiency e Sustainable Development Goals: il ruolo del Life Cycle Thinking

Siena
22 – 23 giugno 2017

a cura di Valentina Niccolucci, Arianna Dominici Loprieno, Simone Maranghi, Simona Scalbi

UNIVERSITÀ DI SIENA 1240

ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Rete Italiana LCA

Atti del XI Convegno della Rete Italiana LCA

Resource Efficiency e Sustainable Development Goals: il ruolo del Life Cycle Thinking

Siena, 22-23 giugno 2017

A cura di Valentina Niccolucci, Arianna Dominici Loprieno, Simone Maranghi, Simona Scalbi

Immagini del volume a cura di Paola Sposato

2017 ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e
lo sviluppo economico sostenibile

ISBN: 978-88-8286-352-4

Revisione editoriale: Giuliano Ghisu

Copertina: Cristina Lanari

SOMMARIO

Comitato Scientifico

Roberta Salomone
Università degli Studi di Messina, Dipartimento di Economia

Simona Scalbi
ENEA, Dipartimento Sostenibilità dei Sistemi Produttivi e Territoriali, Laboratorio Valorizzazione delle risorse nei sistemi produttivi e territoriali (SSPT-USER-RISE)

Antonio Scipioni
Università degli Studi di Padova, Dipartimento di Ingegneria Industriale, Centro Studi Qualità Ambiente (CESQA)

Alessandra Zamagni
Ecoinnovazione srl, spin-off ENEA, Padova

Choosing the LCA impact categories for the building sector

Andrea Invidiata[1*], Monica Lavagna[1], Enedir Ghisi[2]

[1]Politecnico di Milano

[2]Universidade Federal de Santa Catarina

Email[*]: *a.invidiata@gmail.com*

Abstract

In recent years, the Life Cycle Assessment (LCA) has become an important tool to evaluate the environmental impacts of the building sector. The analysis of buildings through LCA is complex and must take different factors into account. The selection of the impact categories is one of the issues related to LCA. Latest European standards have established the use of seven impact categories to analyse buildings through LCA. However, recent researches have been choosing the impact categories in an arbitrary manner. In general, studies on Life Cycle Energy Analysis (LCEA) take into account only the Energy Demand and, in some cases, the Global Warming Potential. In many cases, these two impact categories are not sufficient to describe the environmental impacts of the buildings in the life cycle. The correct choice of the impact category may be made based on three approaches, that are discussed in the last part of the paper.

1. Introduction

The building sector is considered one of the largest consumers of natural resources and energy. Buildings consume 30%-40% of primary energy and natural resources over their life-span (construction, operation, maintenance and demolition) and respond for 30% of the emission of greenhouse gases in the world (UNEP, 2007; IEA, 2011; IPCC, 2011). In Europe the building energy demand is about 40% of the global energy requirement (IEA, 2011).

In recent years, the research to improve the sustainability of buildings focused more on the reduction of energy consumption. International regulations of building energy performance have contributed to reduce the energy demand in buildings. According to the European Union guidelines (2010/31/EU), starting in 2021 new buildings must achieve the nearly zero-energy standards. However, the energy efficiency assessment is usually restricted to the operational phase of the building. According to Cabeza et al. (2014), upon arrival at the construction site, the materials that will compose the building have already consumed a lot of energy during the manufacturing, transportation and construction processes. Therefore, recent studies have addressed a more holistic approach, which covers from the production process of materials involved in the construction all the way to the demolition and recycling phases. In this context, two different approaches were developed to improve the quality of buildings and reduce the environmental impacts: the Life Cycle Assessment (LCA) and Life Cycle Energy Analysis (LCEA). The two methods, when applied to buildings, are tools for predicting how a facility will perform over its lifetime, which includes raw material extraction, manufacturing, construction, operation, maintenance, repairing, replacement and demolition. Whilst the LCA takes into account different environmental impacts, the LCEA focuses only on the energy demand in the life cycle of buildings (Anand and Amor, 2017). In recent years, the LCEA is increasingly being used to analyse the behaviour of the buildings in the life cycle. This is due to two main reasons: a more simple application related to LCA and to be a surplus compared to the normal analysis of the energy demand in the operational phase of buildings (Cabeza et al., 2014). Nevertheless, researchers (Pombo et al., 2016; Assefa and Ambler, 2017) have shown an increased interest in analysing buildings through LCAs. The use of LCA is complex and has to take into account different issues: definition of the scope, choice of data-base, number and choice of impact category and the interpretation of the results (Cabeza et al., 2014). The choice of the impact categories is one of the present issues when using the LCA methodology. The Life Cycle Energy Analysis method is a step forward compared to the simple operational energy analysis in buildings. Through the LCEA the energy demand of buildings is analysed over their life cycle. The main objective is to assess the energy demand of buildings during their different phases. Thormark (2006) emphasises the importance of analysing the energy performance of buildings using LCEA, while the embodied energy may represent up to 40% of the energy life-cycle. In Brazil, Paulsen and Sposto (2013) evaluated, through LCEA, a social housing unit located in Brasília with a lifespan of 50 years. The final result showed that the embodied energy represented 30% of the total energy consumed in the building. In Turkey, two residential buildings were evaluated considering the energy demand and dioxide carbon emissions in the life cycle (Atmaca and Atmaca, 2015).

Through the LCEA is analysed only one impact category in buildings and, in some cases, the associated carbon emissions. This paper inquire if the only two impact categories (energy demand and carbon emissions) used in the LCEA studies are sufficient to analyse the environmental impacts in buildings.
The main objective of this study is to provide a specified description of the history, the current situation and the future outlook regarding the use of LCA impact categories in the building sector. The research method used is a thorough literature review of mostly peer-reviewed papers and standard specifications of LCA of buildings.

2. Impact Categories

The impact categories represent environmental issues of concern to which Life Cycle Inventory (LCI) results may be assigned. The impact categories can be classified depending on their geographical scaling effect: global effects, regional effects, local effect, working environmental effects. Over 50 Life Cycle Impact Assessment (LCIA) models are currently available in Europe (EPLCA, 2010). They are specific techniques related to environmental impacts that comprise the scope of evaluations in that region and have been implemented within various of the most broadly applied LCIA models (Bueno et al., 2016), such as Ecoindicator 99, EDIP 97, EDIP 2003, (Dutch) Handbook on Life Cycle

Assessment (LCA) (CML2002), EPS 2000, Impact 2002, Swiss Ecoscarcity (Ecopoints 2006), TRACI, ReCiPe, MEEuP, LIME and EPD (EN15804, 2012). The main impact categories used in this models are: Global warming, Energy demand, Depletion of stratospheric ozone, Photo-oxidant formation, Acidification, Eutrophication, Ecotoxicity, Human toxicity, Occupational health and safety, Odour, Noise, Radiation, Waste, Resource consumption, Habitat alterations and impacts on biological diversity, Carcinogens, Land occupation, Ionizing radiation, Mineral Extraction and Smog.

Recently, two European standards have defined the impact categories to analyse products and buildings through the LCA (EN 15804, 2012; EN 15978, 2011). The seven impact categories are:
• Global Warming Potential (GWP, kg CO_2 eq);
• Ozone Layer Depletion Potential (ODP, kg CFC-11 eq);
• Acidification Potential (AP, kg SO_2 eq);
• Eutrophication Potential (EP, kg $(PO4)^{3-}$ eq);
• Photochemical Ozone Creation Potential (POCP, kg C_2H_4 eq);
• Abiotic Depletion Potential—non-fossil (ADP-non-fossil, kg Sb eq);
• Abiotic Depletion Potential—fossil (ADP-fossil, MJ net caloric value).

3. LCA and impact categories in the buildings sector

Life cycle assessment has been used in the building sector since 1990 (Ortiz et al., 2009; Anand and Amor, 2017). With the current push toward sustainable construction, LCA has gained importance as an objective method to evaluate the environmental impact of construction practices. In 2015 more than two hundred papers on LCA were published (Anand and Amor, 2017).

Table 1 shows some recent researches in the building sector based on LCA. The seven impact categories of the European standards (EN 15804, 2012; EN 15978, 2011), the energy demand and the characterization models of the different studies were analysed. Through three recent papers review (Anand and Amor, 2017; Vilches et al., 2017; Cabeza et al., 2014), studies after 2011 were selected. The main objective is to understand if recent studies used the European standard to analyse the buildings using the LCA method. The researchers analysed a different number of impact categories in their LCA study. The number of the impact categories carries a minimum of one to sixteen impact categories analysed (Guan et al., 2017; Buyle et al., 2015). In Belgium (Buyle et al., 2015), using LCA and LCEA, different design solutions were analysed to improve the environmental profile of new buildings. The authors used the seven impact categories of the EN 15978 (2011) plus other nine impact categories to investigate the best design solution for buildings. Also, Collinge et al. (2015) and Pombo et al. (2016) used the seven impact categories of the EN 15978 (2011). Stazi et al. (2012) studied 70 Italian residential buildings, of which five case studies were monitored and one case underwent an in-depth environmental evaluation. The authors used only the Global Warming Potential, Ozone Layer Depletion Potential and the Acidification Potential to analyse the building using the LCA method. Ardente et al. (2011)

studied the energy and environmental performance (with four impact categories) of a number of retrofit actions in six old non-residential public buildings situated in various European countries. Motuziene et al. (2016) analysed the life cycle of a single-family house in Lithuania considering three impact categories: Primary Energy Demand, Global Warming Potential and Ozone Layer Depletion. The goal of the study was to improve the energy efficiency of buildings, given the impact on the environment in the life cycle. Atmaca and Atmaca (2015) studied the life cycle of two different residential buildings in Turkey through two impact categories: the Primary Energy Demand and the Carbon Dioxide Emissions. Similarly, Takano et al. (2015) used the Global Warming Potential and the Primary Energy Demand to analyse a building in Germany.

Table 1. Impact categories used in the building sector.

Impact category EN 15804 EN 15978	Ardente et al. (2011)	Aktas and Milek (2012)	Stazi et al. (2012)	Collinge et al. (2013)	Collinge et al. (2015)	Mastrucci et al. (2015)	Buyle et al. (2015)	Atmaca and Atmaca (2015)	Takano et al. (2015)	Lewandowsk et al. (2015)	Motuziene et al. (2016)	Bueno et al. (2016)	Guan et al. (2016)	Pombo et al. (2016)	Ingraro et al. (2016)	Assefa and Ambler (2017)
GWP	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
ODP	x			x	x	x	x			x	x	x		x		x
AP	x	x	x	x	x	x	x			x		x		x		x
EP	x	x	x		x	x	x			x		x		x		
POCP	x			x	x	x	x					x		x		
ADP-nf					x	x	x			x				x		
ADP-f					x	x	x							x	x	x
Primary Energy	x							x	x		x		x			
Others		2		3	-	9	9	-	-	9	-	2	-	-	1	3
EICV Method	-	TRACI	Eco-indicator 99	TRACI	-	CML 2	ReCiPe	-	EPD (EN 15804)	Impact 2002+	-	EDIP 97/2003 CML 2001 Impact 2002+ ReCiPe	-	OVAM: MMG	Impact 2002+	-

Another important point analysed is the characterization model used in international researches. In some studies, the model of characterization is not specified. The TRACI, ReCIPe and the Impact 2002+ are the characterization model used more often (Collinge et al., 2012; Lewandowsk et al., 2015).

The environmental impact profile of life cycle assessments is often presented in different units difficult to grasp and compare. One way to make the interpretation of such scores easier is to normalise them: dividing such scores by a reference situation's score. According to ISO 14044 (ISO 2006), normalisation, in the context of Life Cycle Assessment, is an optional step of Life Cycle Impact Assessment which allows the practitioner to express results after the characterisation step using a common reference impact. This supports the comparison between alternatives using reference numerical scores. The normalisation factors express the total impact occurring in a reference region for a certain impact category (e.g. climate change, eutrophication, etc.) within a reference year. Most of the studies analysed do not use the normalisation method to evaluate and compare the final results. Assefa and Ambler (2017) analysed the potential life cycle environmental impacts of buildings in different scenarios on the two pathways: selective deconstruction and new construction. In all different scenarios, the Ozone Layer Depletion Potential resulted in the higher impact. Ingraro et al. (2016) analysed different solutions of external walls in buildings. The Global Warming Potential turned out to be the main impact category in the different walls analysed. Mastrucci et al. (2015), from their analysis of building stocks, reported that the consumption of Abiotic Resources was responsible for a higher environmental impact than other six impact categories.

4. Discussion

Choosing the impact categories is one of the main problems in the LCA method. The situation is no different for the studies about LCA in the building sector. In the literature analysed, it was noted that the impact categories used are different for quantity and typology. For a large number of LCA studies, the basis for choosing a particular impact category is not always clearly stated. The selection of indicators often depends on what is easily comprehensible by the stakeholders involved in comparison to what may be more relevant to the goal (Anand and Amor, 2017). In many cases, the studies were not based on the European standards and their seven impact categories (Collinge et al., 2012; Motuziene et al., 2016). In some researches, the impact categories choices are more than recommended by the two European standards (Buyle et al., 2015; Lewandowsk et al., 2016). Only in four studies the seven impact categories of the European standard were used (Collinge et al., 2015; Mastrucci et al., 2015; Buyle at al., 2016; Pombo et al., 2016). That is why recent studies have pointed out that the selection of the impact categories must be based on a method. Failing this can lead to neglect certain impact categories that may be essential (Reap et al., 2015; Anand and Amor, 2017).

In some cases, the selection of the impact categories is due to the LCA tools used for life cycle assessment of buildings. The availability of the impact category in LCA software depends on the impact assessment methodology available to the software. For instance, software such as GaBi and SimaPro provide a wide range of methodologies from energy assessment and water footprints to diverse impact category assessments. The methods can be customised based on the scope of the LCA. Some models may include limited methodologies (Assefa and Ambler, 2017).

The impact category more used was the Global Warming Potential followed by the Ozone Layer Depletion Potential and Acidification Potential. Similar to LCA in other fields, energy and emissions are the most popular metrics used in the building LCA publications. Energy Demand and Global Warming Potential may not be the most impact intensive indicators in all studies. In the literature analysed, through the normalisation method it was possible to verify that other impact categories have had the greatest impact in the environment (Assefa and Afler, 2017; Mastrucci et al., 2015). Also, in other international studies the normalisation used to compare the different impact categories in the building sector. In the USA, three different shading materials on buildings and their impacts to the environment were analysed in five climate zones (Babaizadeh et al., 2015). In this case, the Human health non-cancer resulted in the higher impact. In Australia, Sandanayake et al. (2016) analysed the environmental impact of the foundation construction in two case studies. The Global Warming Potential was the most prominent impact from all the perspectives considered. Unfortunately, only a few studies used the normalisation to compare the final results of different impact categories (Assefa and Ambler, 2017; Ingrato et al., 2016; Mastrucci et al., 2015). This aspect turns out to be a severe limitation and makes it more complex to understand which environmental impacts cause the greatest impact in the building sector.

Another way to select the correct impact category in a LCA is through a survey based on stakeholder perspectives. Souza et al. (2015) used this method to obtain the impact categories to analyse the development and implementation of a formal Brazilian Waste Electric and Electronic Equipment (WEEE). One of the most important aspects is the identification and involvement of all relevant stakeholders. The selection of impact categories depends on the purpose of the LCA, e.g. what kind of decision is going to be made based on LCA. Obviously, such selection also depends on the type of application of LCA. Basically, selection of impact categories is a matter between the commissioner and the practitioner. Although there is a method with specific guidelines on which impact categories should be included in the LCA of buildings at European level, it is not used.

5. Conclusion

The purpose of this research was to investigate the selection of the LCA impact categories in buildings. The goal was to verify if the only two impact categories used in the LCEA studies are enough. The literature review shows that there is neither an exact number of impact categories, nor which of impact categories, to analyse the environmental impacts of buildings and their materials. When the main objective of the study is to analyse the energy behaviour of buildings the LCEA method was used. In this case, only the energy demand was analysed and, in many cases, also the Global Warming Potential. This is a great step forward when compared to the energy regulation or the studies about energy efficiency to reduce the operational energy demand in buildings. This is not enough to analyse the environmental impact of the building sector. Some studies showed that the energy demand and the Global Warming Potential are not the categories with the greatest impact. The selection of other impact categories can assure a more comprehensive and accurate assessment. This choice may be made or by identifying the impact categories more used in the literature studies or by selecting the impact categories more significant after normalisation or by considering the impacts categories more relevant in the opinion of experts applying a survey.

Through one of these methods, one can get a LCA much more detailed and precise, and point out other significant environmental impacts in addition to the Global Warming Potential and the Energy Demand.

6. Bibliography

Anand, C, Amor, B, 2017. Recent developments, future challenges and new research directions in LCA of buildings: A critical review. Renew Sustain Energy Rev. 67, 408–416.

Ardente, F, Beccali, M, Cellura, M, Mistretta, M, 2011. Energy and environmental benefits in public buildings as a result of retrofit actions. Renewable Sustainable Energy Rev. 15, 460–470.

Assefa, G, Ambler, C, 2017. To demolish or not to demolish: Life cycle consideration of repurposing buildings. Sustainable Cities and Society. 28, 146-153.

Aktas, C, Bilec, M, 2012. Impact of lifetime on US residential building LCA results. Int J Life Cycle Assess. 17, 337–349.

Atmaca, A, Atmaca, N, 2015. Life cycle energy (LCEA) and carbon dioxide emissions ($LCCO_2A$) assessment of two residential buildings in Gaziantep, Turkey. Energy Build. 102, 10, 417-431.

Babaizadeh, H, Haghighi, N, Asadi, S, Broun, R, Riley, D, 2015. Life cycle assessment of exterior window shadings in residential buildings in different climate zones. Build. Environ. 90, 168-177.

Bueno, C, Hauschild, M, Rossignolo, J, Ometto, A, Mendes, N, 2016. Sensitivity analysis of the use of Life Cycle Impact Assessment methods: a case study on building materials. Journal of Cleaner Production. 112, 2208-2220.

Buyle, M, Audenaert, A, Braet, J, Debacker, W, 2015. Towards a more sustainable building stock: optimizing a flemish dwelling using a life cycle approach. Buildings. 5, 424–448.

Cabeza, LF, Rincón, L, Vilariño, V, Pérez, G, Castell, A, 2014. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renew Sustain Energy Rev. 29, 394–416.

Collinge, W, Thiel C, Campion, N, Al-Ghamdi, S, Woloschin, C, Soratana, K, et al. 2015. Integrating life cycle assessment with green building and product rating systems: north american. Perspect Procedia,118, 662–669.

Collinge, W, Landis, A, Jones, A, Schaefer, L, Bilec, M. 2012. Dynamic life cycle assessment: framework and application to an institutional building. Int J Life Cycle Assess. 18, 538–552.

EN15804, 2012. Sustainability of construction works – Environmental product declarations-Core rules for the product category of construction products. European Committee for Standardization.

EN15978, 2011. Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method. European Committee for Standardization.

EPLCA, 2010. European Platform on Life Cycle Assessment, List of Tools. Internet site developed by the European Commission, Direction Generale, Joint Research Centre, Institute for Environment and Sustainability.

Guan, J, Zhang, Z, Chu, C, 2016. Quantification of building embodied energy in China using an input–output-based hybrid LCA model. Energy Build. 110, 443– 452.

Ingraro, C, Scrucca, F, Tricase, C, Asdrubali, F, 2016. A comparative Life Cycle Assessment of external wall-compositions for cleaner construction solutions in buildings. Journal of Cleaner Production. 124, 283-298.

International Energy Agency IEA, 2011. Worldwide Trends in Energy Use and Efficiency. Authoring Institution: International Energy Agency (IEA). Available at: http://www.iea.org/publications/freepublications/publication/Indicators_2008.

Intergovernmental Panel on Global Change IPCC, 2011. Diana ürge-vorsatz, Climate Change Mitigation in the Buildings Sector: the Findings of the 4th Assessment Report of the IPCC.

ISO 14044:2006, 2006. Environmental management – Life cycle assessment – Requirements and guidelines.

Lewandowska, A, Noskowiak, A, 2015. Between full LCA and energy certification methodology- a comparison of six methodological variants of buildings environmental assessment. 9–22.

Mastrucci, A, Popovici, E, Marvuglia, A, Benetto, E, Leopold, U, 2015. GIS-based Life Cycle Assessment of urban building stocks retrofitting. 29th International Conference on Informatics for Environmental Protection, 47–56.

Motuziene, V, Rogoza, A, Lapinskiene, V, Vilutiene, T, 2016. Construction solutions for energy efficient single-family house based on its life cycle multi-criteria analysis: a case study. Journal of Cleaner Production. 112, 532-541.

Paulsen, J., Sposto, R., 2013. A life cycle energy analysis of social housing in Brazil: case study for the program “MY HOUSE MY LIFE”. Energy Build. 57, 95-102.

Pombo, O, Allacker, K, Rivela, B, Neila, J, 2016. Sustainability assessment of energy saving measures: A multi-criteria approach for residential buildings retrofitting - A case study of the Spanish housing stock. Energy Build. 116, 384-394.

Sandanayake, M, Zhang, G, Setunge, S, 2016. Environmental emissions at foundation construction stage of buildings e Two case studies. Build. Environ. 95, 189-198.

Souza, RG, Rosenhead, J, Salhofer, S, Valle, R, Lins, M. 2015. Definition of sustainability impact categories based on stakeholder perspectives. Journal of Cleaner Production. 105, 41-51.

Stazi, F, Vegliò, A, Di Perna, C, Munafò, P, 2012. Retrofitting using a dynamic envelope to ensure thermal comfort, energy savings and low environmental impact in Mediterranean climates. Energy Build. 54, 350–362.

Takano, A, Pal, S, Kuittinen, M, Alanne, K, Hughes, M, Winter, S, 2015. The effect of material selection on life cycle energy balance: A case study on a hypothetical building model in Finland. Build Environ. 89, 192–202.

Thormark, C, 2006. The effect of material choice on the total energy need and recycling potential of a building. Build. Environ. 41, 8, 1019-1026.

UNEP, 2007. Buildings and climate change: status, challenges & opportunities. Paris: United Nations Environment Programme; 2007.

Vilches, A, Garcia-Martinez, A, Sanchez-Montanes, B, 2017. Life cycle assessment (LCA) of building refurbishment: A literature review. Energy Build. 135, 286-301.