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Integrating climate change and energy mix scenarios in LCA of buildings and districts

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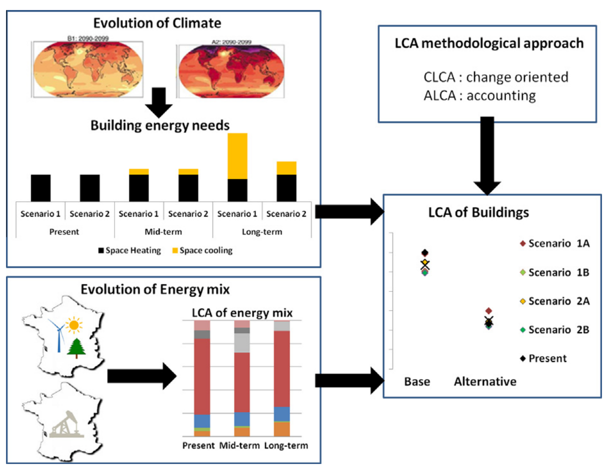
HIGHLIGHTS

- A method is suggested to integrate prospective parameters in LCA of buildings.
- Climate change and evolution of the energy system are accounted for.
- Environmental assessment is performed at an hourly time step.
- Both climate change and evolution of the energy mix influence results.
- The energy use in high performance building remains an important contributor of LCA.

GRAPHICAL ABSTRACT



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ABSTRACT

The objective of this study is to evaluate life cycle impacts of buildings, integrating climate change (RCP 4.5 and RCP 8.5 IPCC scenarios) and evolution of the energy mix on the long term (at 2050). Two methodological approaches were developed following the modelling principles of attributional and consequential life cycle assessment (LCA). The methodology is illustrated using a simple case study: a low-energy single family house located in France. Two design options were evaluated using life cycle assessment: the choice of a heating system and the integration of photovoltaic (PV) modules on the roof. Using an attributional approach and compared to a static LCA considering no prospective parameters, the carbon footprint of the house (total life cycle) varies from +21% to +43% for the electric heating alternative, −7% to +4% for the gas boiler alternative, −6% to +15% for the PV alternative depending on climate change intensity and evolution of the energy mix. Figures using the consequential approach have a larger magnitude of variation from −36% to −13% for the electric heating alternative, 0 to +16% for the gas boiler alternative and −14% to +1% for the PV alternative compared to a static LCA. Accounting for climate change and the evolution of the energy system has a large influence on LCA results.

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1. Introduction

1.1. LCA of buildings

Life cycle assessment (LCA) is a quantitative method evaluating the environmental impacts of products or services during their whole life cycle, from cradle to grave. The first application of LCA on buildings started in the late 1980s and focused only on energy [1]. Three decades later, life cycle assessment is increasingly used as a design aid for building projects, as shown in the reviews of Khasreen et al. and Cabeza et al. [2,3]. The methodology is now widely used for various objectives such as construction material improvement, building ecodesign, building certification as illustrated in the literature review of Ortiz et al. [4]. The scope is extending to the district scale [5,6].

As buildings are one of the main drivers of electricity consumption in OECD countries [7], dynamic interaction with the grid has been integrated in some studies [8]. Even though construction materials gain importance in contribution analyses due to the development of low-energy buildings, the energy consumption during the operation stage remains an important contributor [9]. The lifetime also has a large influence on the use stage contribution [10]. Buildings are expected to last and host people's activities for several decades, from 15 to 50 years for commercial buildings, and for 50–100 years for residential buildings [11]. During this large time frame, the climate is expected to change, as well as the energy mix (development of renewable energies, potential nuclear phase-out, etc.). These parameters have combined effects on the life cycle performance of buildings.

1.2. Urban development, building and climate change

Impacts of a changing climate on building thermal behaviour have been studied for more than a decade [12,13]. One of the favoured tool to produce future typical meteorological data is called 'morphing' and has been developed by Belcher et al. [14]. Some researchers also studied the effect of climate change on local heat island effect [15,16] in order to anticipate the rise of chiller energy consumption and the positive feedback into the heat island effect. Waddicor et al. [17] recently combined climate change and building ageing in the study of building energy performances, showing important effects of both parameters.

1.3. Linking LCA and prospective energy system analysis

The energy or electricity mix chosen in an LCA study usually has a great influence on the LCA results [18]. This is especially true for buildings, as shown for instance in [19,20]. However, since LCA approaches cover the whole lifespan of a building, the long-term transformation of the energy system and its related impacts constitute a challenge in terms of temporal modelling. This is particularly the case for electric systems where several competing technologies and climate policies can influence the future technical choices. As a result, the standard approach using fixed emission factors has strong limitations. It is usually based on one singular year which fails to represent average actual conditions and neglects seasonal, monthly, daily and hourly variations of electricity production. Such variations have been proven to be important in the case of buildings [8].

The objective of this study is to increase the robustness and realism in the environmental evaluation of buildings and district projects by integrating climate change and prospective scenarios of the energy system in LCA. Prospective assessments of energy and particularly electricity systems have been thoroughly studied. Numerous scenarios at various scales exist: from whole energy system [21] to sector-wide studies [21,22], to global [23,24], European [25–27] and national scales [28]. The novelty of the work proposed here is to integrate long-term energy scenarios in an LCA approach for buildings at a low temporal resolution (1 h time step) and taking into account various future climates.

One commonly used platform for long-term energy system analysis is the MARKAL/TIMES family of models. TIMES models enable a linear representation of the energy system through a disaggregated representation of the portfolio of energy processes and commodities, and then identify an optimal technology allocation path over successive periods. Using cost and conversion efficiency data, the total discounted cost of the system is then minimised. The bottom-up and technology-explicit approach of MARKAL-TIMES models is compatible with an LCA. Improvements of long-term emission factors that can be gained using TIMES models were proposed by Hawkes [29] for UK using a TIMES model with 15 annual time steps. In this paper, we extend this approach further by showing how a full LCA can integrate a detailed analysis of the dynamics of energy demand in a building, and inputs from long-term energy system prospects from a high temporal resolution TIMES model. In particular an original four-step methodology is suggested and illustrated on a simple case study. The case study is an individual house, expected to have a lifetime of 50 years, located in France and considered to be built in the present and demolished around 2065 (see Fig. 1). During this timeframe, the climate and the energy mix are going to evolve, potentially influencing the environmental assessment of (a) the house (attributional LCA) or (b) the decision to build this house (consequential LCA).

2. Methods and data

2.1. General framework for scenarios development

A simple framework was developed considering two alternative climate evolutions and two scenarios for the evolution of the main energy production in France. The contextualisation of the 4 resulting scenarios is described in Table 1.

2.1.1. Climate evolution

The Representative Concentration Pathways (RCP) scenarios from the IPCC 5th report are chosen to indicate climate change intensity [30]. Four scenarios have been developed, resulting respectively in a radiative forcing of 2.6 W·m^{-2}, 4.5 W·m^{-2}, 6 W·m^{-2} and 8.5 W·m^{-2} by 2100. Ouzeau et al. [31] downscaled them to France. The RCP 2.6 scenario was recently evaluated as

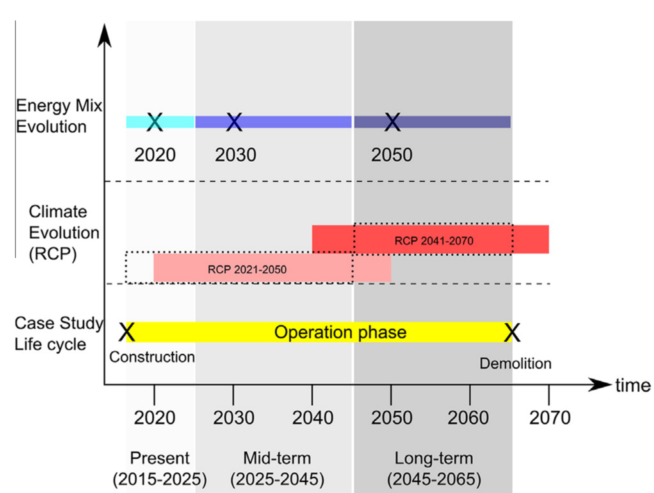

Fig. 1. Life cycle timeframe of the case study.