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Spatially and temporally explicit Life Cycle Assessment of building stock retrofitting actions at the urban scale

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Extended abstract: **Buildings are responsible for more than one third of global greenhouse gas emissions. Life Cycle Assessment (LCA) is a largely used methodology to account for building-related environmental impacts. However, its scalability to building stocks (district or city scale) for decision support in urban planning is still hampered by several operational challenges. Coupling LCA and Geographic Information Systems (GIS) is identified as an effective way to generate spatially differentiated inventories and calculated spatially differentiated impacts.**

This paper presents an approach for the LCA of housing stocks retrofitting based on GIS and explicitly considering both the spatial and temporal dimensions. The methodology includes the following steps: (i) Characterization of the urban housing stock building-by-building and development of retrofitting scenarios; (ii) Housing stock energy analysis running an automated model; (iii) Environmental assessment of housing retrofitting using LCA.

The methodology was tested on the housing stock of Esch-sur-Alzette (Luxembourg). The effect of different retrofitting scenarios for the reduction of global warming potential (GWP) was evaluated building-by-building and then aggregated at the city level. Results were displayed as maps for improved communication.

The study is innovative, being one of the first models able to perform a fully-fledged LCA at urban scale in a bottom up fashion and explicitly considering the spatial and temporal dimensions. The results are meant to help city planners to set priority strategies for carbon mitigation.

I. INTRODUCTION

Buildings contribute to more than 40% of the global energy use and one third of greenhouse gas emissions in Europe [1]. A number of studies focused on the assessment of the energy demand and energy savings potential of urban building stocks [2]-[3], to support energy efficiency and carbon mitigation actions planning. However, lacking a life cycle perspective could lead to an overestimation of environmental gains for refurbishment options [4] due to the omission of other life cycle stages (e.g. production of building materials).

Life Cycle Assessment (LCA) is broadly used to assess the environmental impacts of buildings [5]-[6]. Recently an upscale of the LCA of buildings at the urban scale was proposed [7]. Integration of Geographic Information Systems (GIS) with building stock modelling has been identified as effective in linking building statistics with the spatial location of different building types [4]. Nevertheless, operational developments are still needed for coupling LCA and GIS [8], such as software interoperability, data storage, processing and computation time reduction.

Few recent studies expanded the scope of LCA from single buildings to urban building stocks using a bottom-up approach. Despite the advancement brought by these studies, open issues remain regarding the spatial and temporal representation of the building stock.

This study aims at developing a spatially and temporally explicit LCA of building stock retrofitting at the urban scale. A building-by-building approach based on GIS was used to explicitly consider the variability of geometry, building envelope and technical systems characteristics of residential buildings across one entire city. Temporal aspects were taken into account both in the life-cycle inventory and impact assessment phase respectively by introducing rates of retrofitting for the existing housing stock and applying time-adjusted calculation for global warming potential (GWP).

II. MATERIALS AND METHODS

The methodology includes the following steps:

1. Characterization of the housing stock of one entire city and development of retrofitting scenarios;
2. Energy analysis of the housing stock running an automated building-by-building model;
3. Environmental assessment of housing retrofitting using LCA.

The methodology was tested for the housing stock of Esch-sur-Alzette (Luxembourg), including around 13 000 housing units.

The housing stock is characterized building-by-building by using GIS data, statistical data, information contained in regulations and standards. Input data and results are stored in a spatio-temporal database in PostgreSQL and its extension PostGIS for spatial data and can be further visualised as maps in GIS. Future retrofit scenarios are then developed considering the following measures: insulation of walls, roof and ground floor and windows replacement. In our study, the time horizon was fixed at 20 years (2015-2035). Retrofit scenarios were determined by combining different refurbishment rates and retrofit standard (Table 1).

TABLE 1: RETROFIT SCENARIOS.

Scenario ID	Retrofit rate (%)	Retrofit standard
1	0.5	Standard 1
2	0.5	Standard 2
3	0.5	Standard 3
4	1.0	Standard 1
5	1.0	Standard 2
6	1.0	Standard 3

Standard 1 is defined based on the current U-value limits contained in the national regulation [9]. *Standard 2* and *standard 3* express an improved level of performance

and were obtained by lowering the current U-value limits by respectively 10% and 20%.

The building stock energy model is based on the national regulation for the energy performance of buildings in Luxembourg [9]. The energy demand for space heating and domestic hot water is calculated on a monthly basis. Simplifications for existing buildings were applied in accordance with the national methodology regarding thermal bridges, shading calculation, efficiency of heating and domestic hot water systems. The model was implemented in a script in *R* connected to the building database to automate the calculation for buildings across the city for the current state and after the implementation of retrofitting measures.

The previous steps provide the life cycle foreground inventory for the LCA. Background inventory data from Ecoinvent 2.2 [10] were adapted to the context of Luxembourg, e.g. by modifying transportation distances and the generic electricity mix. The life cycle impact was assessed using the IPCC method for the evaluation of GWP and time-dependent characterization factors were applied based on the study of Kendall [11]. The environmental impact was calculated on a yearly time step for every scenario, taking into account the evolution of building retrofitting over the time. Results produced building-by-building were finally aggregated at the building stock level to provide global figures.

III. RESULTS

The difference in GWP per floor surface unit after retrofitting (standard 1) was estimated for different types of housing and periods of construction, taking into account the entire residual service life (Fig.1).

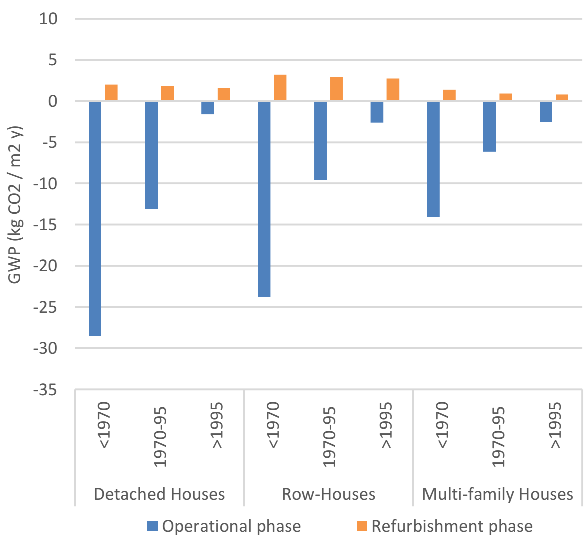

FIGURE 1: AVERAGE EFFECT OF RETROFITTING ON GWP INTENSITY PER TYPE OF HOUSING AND PERIOD OF CONSTRUCTION IN THE CURRENT PRACTICE SCENARIO.

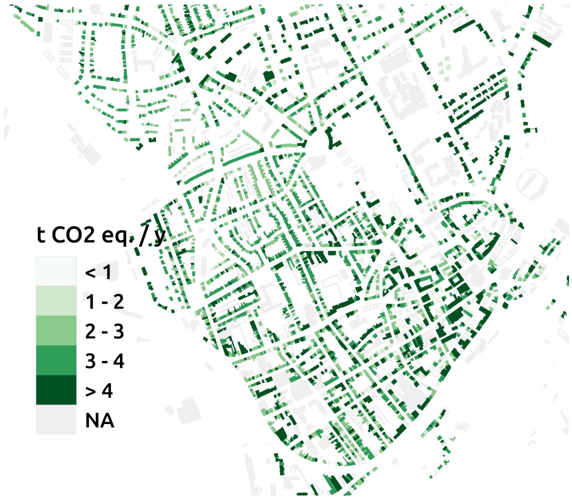

FIGURE 2: GWP REDUCTION POTENTIAL OF HOUSING IN ESCH-SUR-ALZETTE AFTER RETROFITTING (CURRENT PRACTICE SCENARIO).

The GWP reduction due to lower operational energy requirement is higher for older buildings (from 33% to 45% for buildings before 1970), as a result of building envelope insulation. Conversely, increase in GWP for refurbishment is slightly higher for older buildings, due to the higher amount of materials to be implemented. While benefits of retrofitting are evident for older buildings, burdens for the increased embodied energy nearly counterbalance the operational energy reduction for buildings after 1995. Results of GWP reduction were aggregated at the city scale and displayed as maps for decision support (Fig.2). The total estimated yearly reduction potential at the stock level is 18.3 kt CO2 eq. (31%).

Results of the time-dependent evaluation of retrofitting scenarios are reported in Fig.3. The GWP reduction for all scenarios at the 20 years-time horizon ranges 19–22%. Increasing the yearly retrofitting rate from 0.5% to 1.0% is particularly effective in reducing the GWP. In contrast, the difference given by the application of different retrofit standards is more limited.

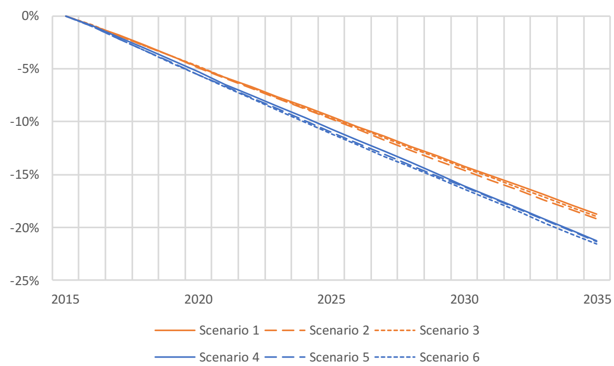

FIGURE 3: REDUCTION OF GWP DRIVEN BY DIFFERENT RETROFITTING SCENARIOS.

IV. CONCLUSIONS

We developed a spatially and temporally explicit LCA approach to assess the environmental impact reduction potential of urban building stocks retrofitting. The methodology was implemented and tested for an entire city in Luxembourg and provided promising results for the set up and development of building retrofitting scenarios.

Further developments will extend the evaluation to other cities in Luxembourg and other European countries. A web-based implementation of the models is available in the Smart City and Region Energy platform [12] to support decision in sustainable urban planning.

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