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Case study: ***Deep energy retrofit of the residential building stock***

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Introduction

In order to reach national and internal energy and climate policy objectives, and in particular to achieve the energy efficiency targets, energy use in the existing building stock needs to be reduced very significantly. To this end, deep energy retrofit is considered as viable and even essential strategy but at the same time the observed level of energy retrofitting is low and actual energy efficiency improvement in the existing residential building stock is clearly below expectations. Deep energy retrofit is hence challenging, calling for a thorough analysis of its advantages and trade-offs.

This summary of methodological development and of a case study by Streicher (2020) and Streicher et al. (2021) highlights a few retrofit pathways, using a dynamic stock model, a bottom-up energy model and an optimization model for different objective functions until 2060, under different climate scenarios. Next to a reference scenario (REF, representing a business-as-usual trajectory) the chosen objective functions are minimisation of final energy, primary energy (i.e. maximisation of energy efficiency) and GHG emissions as well as minimisation of costs (Net Present Value/NPV and/or investment costs).

The chosen approach is to implement a dynamic residential building stock model and geospatial climate change scenarios in combination with an optimization model. The pathway analysis considers the age of the building, thereby excluding deep energy retrofit for buildings with a remaining lifetime of less than 30 years and considering maintenance and (aesthetic) refurbishment costs for buildings which do not undergo deep energy retrofit. The implemented archetype approach distinguishes single-family versus multi-family houses (SFH, MFH), nine different age classes (construction periods, with their respective energy performance), three urban typologies (urban, rural and suburban) as well as the location with its specific climate (heating degree days), with Switzerland as geographical scope.

Three different economic assessment approaches have been developed and implemented by Streicher et al. (2020, 2021), which are defined as “Full” (FULL), “Improvement” (IMP) and “Depreciation” (DEP). The first approach, referred to with the label “Full” (FULL), is the most simple and most conservative, by starting

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from the premise that the full retrofit cost is paid by the owner and should therefore be compensated by the reduced energy cost. However, several scholars argue that this approach should not be applied to older buildings, since they anyway require a refurbishment in order to maintain adequate living conditions. In the second approach, hereafter referred to with the label "Improvement" (IMP), the costs not related to energy use (e.g. cost for painting the facade) are deducted from the full cost. As a consequence, only the cost related to the improvement of the thermal performance are taken into account. However, this approach implicitly assumes that the retrofit of the building elements occurs at the end of their economic lifetime and that it would have anyway been necessary to take action. Furthermore, this strategy does not consider inertia as a consequence of barriers and it might conflict with ambitious energy and climate policy targets, not allowing to wait until the end of the lifetime. The third approach, hereafter referred to with the label "Depreciation" (DEP), is used in order to take into account that old building elements can still have an economic value at the end of their economic lifetime (this intrinsic value explains, in part, why owners do not necessarily immediately refurbish or retrofit their building once it has reached the end of its lifetime) and in order to capture the higher cost of early replacement of building elements (the earlier the replacement, the more costly). All three approaches have their justification but we consider the DEP approach most adequate (for long-term scenario modelling) and most realistic.

Several other assumptions strongly influence the outcome, namely the considered default discount rate of 3%, a default salvage value of 20% (for building components), the CO_2 levy (currently 96 CHF/t CO_2 in CH) and the assumed time horizon of 30 years.

Findings

Despite the replacement of old by new buildings, energy demand and greenhouse gas (GHG) emissions in the reference scenario (REF) without deep energy retrofitting are likely to decrease by only about 25%, while incurring investments of 2–3 billion CHF/a. This reduction will not be sufficient to even get close to the Swiss targets of 60% energy demand reduction and net zero greenhouse gas emission target for 2050.

Among the retrofit pathways based on optimization the strategy that aims for lowest investment cost is found to result in too low retrofit activity and would subsequently lead to low energy and greenhouse gas savings. In contrast, a strategy that aims for maximum savings would lead to a very high saving potential up to 60% for final energy and 90% for GHG emissions, regardless whether greenhouse gas emissions, final energy or primary energy is targeted.

However, this high reduction potential comes with the drawback of very high full investment cost of up to 9 billion CHF/a, resulting in levelized cost of GHG abatement of around 182 CHF/t CO_2 (according to the DEP approach). If instead the cost-optimal retrofit pathway is chosen (based on the maximization of the net present value), only moderate trade-offs between required investment cost and greenhouse gas savings are to be expected. Such a pathway could reach GHG savings of 77% with specific cost in the range of -140 CHF/t CO_2 (according to the DEP approach; negative value to indicate profitability, i.e. win-win strategy). This indicates that there is a moderate trade-off for the cost-optimal pathway to the achievable savings in energy and environmental impacts.

Apart from providing overarching results the modelling framework allows to pinpoint which type of measure should be prioritized for which archetype at which point in time (see Figure A1 and Figure A2 in the appendix).

Discussion and Conclusions

GHG emissions reduction has been regarded as one of the primary objectives of energy and climate policy and the GHG-optimal pathway in the DEP approach can therefore serve as good indication of the technical potential of deep energy retrofitting, leading to a reduction of 89% in 2050 (the pattern is similar for final and primary energy savings). The cost-optimal pathway on the other hand leads to a smaller reduction of 70%, but fits well to intermediate scenarios in terms of energy savings and GHG emission reduction, while at the same time being economically attractive. This pathway can hence be interpreted as the cost-optimal saving potential of retrofitting the building stock.

The results indicate that early and deep energy retrofit is beneficial both from an environmental as well as cost-optimal perspective. This is a very important insight that highlights the need to increase the current retrofit rate as rapidly as possible in the Swiss residential stock and to encourage the implementation of high quality and high performance energy retrofit. Interestingly, these conclusions have been found to be independent of climate change scenarios. However, the choices of retrofit options for different building groups differ from each other, with the maximum greenhouse gas saving pathway addressing first older and shorter lasting buildings, whereas the most economical pathways focus mainly on long lasting buildings across all construction periods (see Figure A1 in the Appendix). The achievable level of implementation is subject to the maximum retrofit rate. However, the sensitivity analysis showed that an increase in the maximum retrofit rate would not substantially change the technical potential in the GHG-optimal pathway. This indicates that the assumed maximum retrofit rate of 2% per year would be sufficient to reach very high energy savings.

Exclusive profit orientation as represented by the FULL approach is leading to a very small number of economically viable retrofit options. In other words, deep energy retrofit is too expensive to allow saved energy costs cover the full investment (which, if viable, would be the most attractive business case). Systematic energy retrofitting following the natural refurbishment cycles (retrofit at end of the economic lifetime, thereby only considering the incremental costs compared to the reference), as implemented by the IMP approach, offers the most economically viable options. However, it might not be possible to overcome all related barriers of following always the refurbishment cycles and this IMP approach conflicts with ambitious energy and climate policy, which may make it necessary to consider the DEP approach. At the expense of reduced economic viability, the DEP approach allows to capture early energy retrofit strategies and the intrinsic asset value of buildings.

In spite of the gradually increasing share of new efficient buildings in the stock and despite a warmer climate in the future, non-existent or only partial retrofit activity would not allow to reduce the environmental impacts by more than 25% until 2060. Moreover, the results indicate that this pathway (REF) would not be economically beneficial. Only an early and deep energy retrofit pathway leads to cost-optimal energy and GHG savings in the next decade. At the same time deep energy retrofit implies high investment costs and long payback times, explaining why it is not a highly attractive business case. A retrofit pathway aiming for maximum reduction in environmental impacts would lead to a large trade-off concerning the required investment cost (compared to the least investment cost pathway) and a moderate trade-off for the economic viability compared to the cost-optimal pathway. These results hence indicate that the cost-optimal pathway is the best compromise between economic and environmental aspects, with moderate trade-offs in relation to the achievable reduction potential.

It should be noted that these analyses ignore external costs (e.g. avoided costs related to floods, storms and other climate-induced damage) which – if included – would lead to more favourable results. At the same time the various barriers

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related to the full exploitation of total potential are neither considered (lord-tenant problem, risk aversion, lacking access to capital etc.).

To conclude, while not representing a “low-hanging fruit”, deep energy and early retrofit can be cost-effective while saving very significant amounts of energy. Mobilizing this potential is not straightforward due to the high investment costs and the very long amortisation times. Consequently substantial policy support will be required in order to implement deep energy retrofit at large scale. If systematically put into practice, deep energy retrofit has a very important role to play in the energy system. This is a consequence not only of the direct effects we focussed on in this section but also due to indirect effects and co-benefits including, for example, the contribution to higher renewable energy shares, to larger self-sufficiency and to reduced reinforcement costs for electric grids (esp. of relevance for electrification using heat pumps).

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Appendix

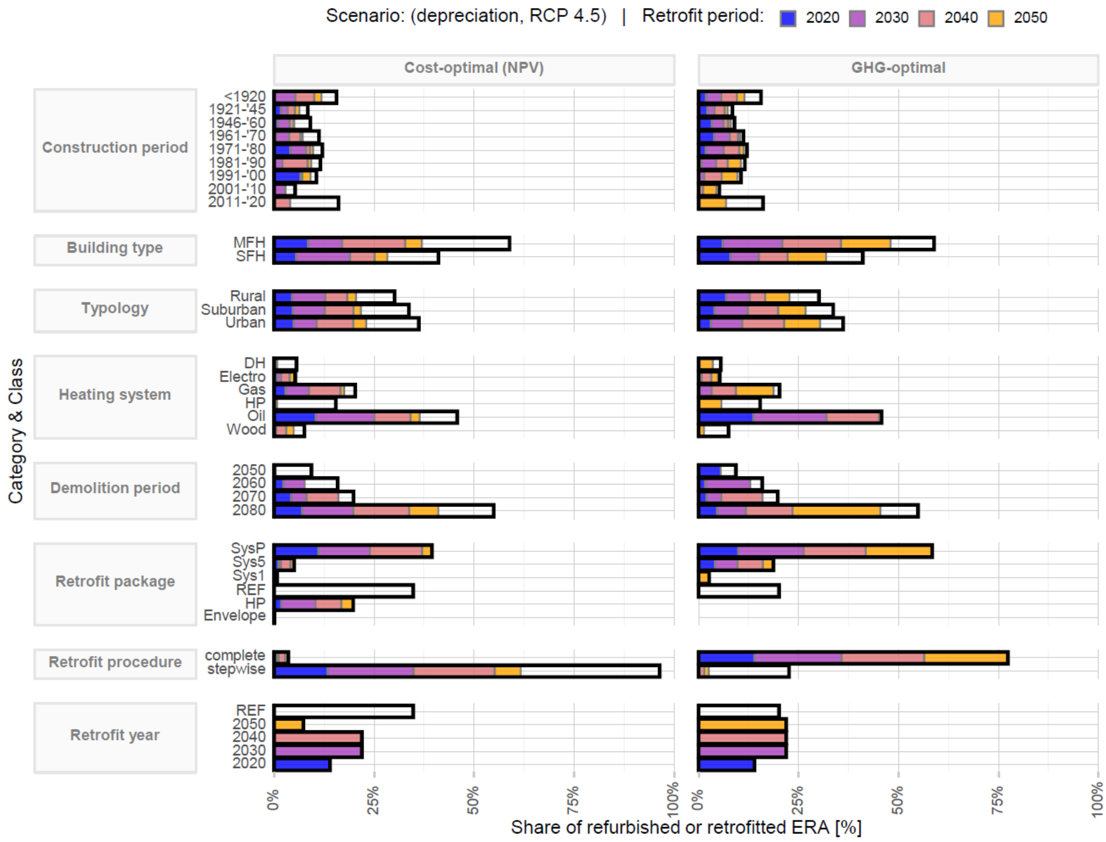

Fig. A1 (reproduced from Streicher et al., 2020, 2021) Choice of retrofit options among archetypes for the most economic (max. NPV) and the highest GHG saving retrofit pathway (pattern of results for final energy and primary energy is very similar to the results for GHG emissions presented here). The length of each horizontal bar represents the total amount of Energy Reference Area (ERA) either refurbished (white) or retrofitted (marked by a colour gradient for the retrofit periods). Results are shown for the DEP approach in the RCP 4.5 climate scenario.

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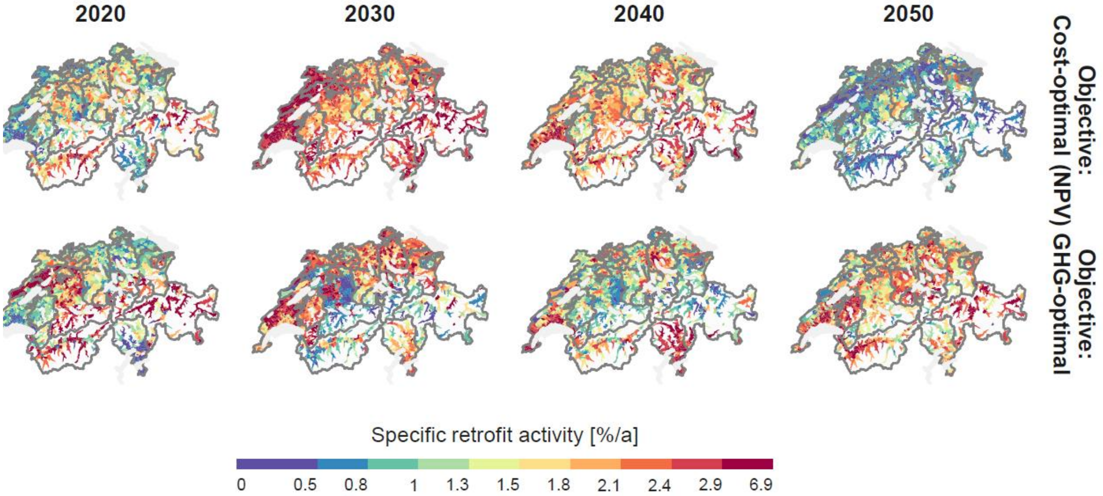

Fig. A2 (reproduced from Streicher et al., 2020, 2021) Geospatial distribution of the specific retrofit activity by commune for the highest GHG savings and the most economic pathway. Results are provided as the share of retrofit activity in relation to the total ERA per commune.