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How deep does the retrofitting have to be? A cost-benefit analysis of two different regional programmes

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ABSTRACT

The recent European energy proposals for the revision of the Energy Efficiency and the Energy Performance of Buildings Directives emphasize the importance of driving investments into the renovation of building stocks and stimulating retrofitting demand. Moreover, the ambitious targets on Green House Gas' abatement and energy consumption reduction require refurbishments to a high level of performance. This high level of performance subsequently represents high cost for households. Thus, with the necessity to lead to ambitious renovations, the question about the cost-effectiveness of the relevant level of performance has to be tackled. Unfortunately, the absence of reliable data often makes it difficult to answer this key question.

In this paper, we rely on two different regional energy efficiency programmes providing incentives for performing refurbishment with a great importance dedicated to thermal insulation and air tightness. Covering a sample of around 50 households per programme, data on energy consumption and the characteristics of individual dwellings were collected as well as on refurbishment costs.

Comparisons between the two programmes and within each programme provide information on the economic relevance of ambitious targets (in terms of energy and carbon). Both programmes pursue similar objectives but the cost associated were different. The first programme presents an average retrofit cost of 290 €/m² compared to an average cost of 415 €/m² for the second one, but both programmes present a large margin of uncertainty. On average the energy savings were 63 kWh/m² (final energy) for the less costly programme compared to 88 kWh/m² for the second programme.

Concerning the non-energy impacts, the households express satisfaction about comfort increase and green value of their refurbished real estate property. The findings underline the crucial importance of both financial incentives and extra benefits such as asset value to enhance the accessibility of deep retrofit potential.

Introduction

In France, the energy transition law for green growth has renewed the country's energy objectives, with the triple goal of reducing carbon emissions, final consumption and fossil fuels consumption. More specifically, with regard to buildings, France has set itself the aim of completing the energy renovation of 500,000 homes per year (Article 3), to have renovated all private residential buildings whose primary energy consumption is greater than 330 kWh of primary energy/(m²/year) by

2025 (Article 5), and to have a fully renovated building stock according to "low-consumption building" standards or similar by 2050 (Article 1) (JORF 2015).

Ambitious energy renovation is thus one of the central objectives of French energy policy. But unfortunately, the current renovation market in the diffuse sector (i.e. single-family homes (SFH)) is mainly characterised by inefficient or limited measures (in particular replacement of windows) and a relatively low average expenditure by household (€10,000 – translating a choice of step-by-step renovation). The average cost of the most efficient renovations (less of 10 % of the renovated dwellings) is €25,000, which is explained by a greater number of actions and better quality (ADEME 2016).

On the other hand, other study (Stolyarova 2016) has shown that households present a willingness to pay (WTP) for an additional 1% reduction in their energy bill that would be €330, indicating an attractiveness for the economic value of energy savings.

The high-performance retrofitting examined in this study is thus an important topic in terms of making it available to the mass market. The question of the absolute level of achievable performance thus arises, and the answer may depend on the aspects considered (financial profitability, environment, non-energy impacts [NEIs]). With this in mind, this study addresses and compares the results of two regional energy efficiency programmes that drive overall performance. First, we will present these two programmes, followed by the raw data (energy saving, cost of retrofit) and NEIs (comfort, quality, green value). Finally, we will consider the marginal cost of the difference in performance between the programmes in order to question the relevance of the absolute attainable level (i.e. the performance threshold).

Regional energy efficiency programmes

In this study, we analyse two regional energy efficiency programmes that provide retrofitting incentives, with a strong emphasis on thermal insulation and air tightness. These two programmes were carried out in the same region (East of France) but in different territories. One rural territory was used for the Low-Consumption Renovation ("Réno' Basse Consommation" - RBC) programme. This territory is poorer and less attractive than the more urbanized, more dynamic and richer territory chosen for the "I Renovate Low Consumption Buildings" ("Je Rénove Bâtiment Basse Consommation" - JRBBC) programme (Table 1).

Beyond the specific assistance for each program, households could also receive financial incentives from the state (interest-free loans or tax credits).

Table 1: characteristics of the territories of the RBC (Meuse and Haute-Marne) and JRBBC (Haut-Rhin and Bas-Rhin) regional programmes (source: INSEE, 2014).

	Meuse (55)	Haute-Marne (52)	Bas-Rhin (67)	Haut-Rhin (68)
Population (inhabitants/km²)	30.8	29.1	234	215.6
Change in population: average annual rate between 2009 and 2014 (%)	–0.3	–0.5	0.3	0.3
Main residences (%)	84.7	81.6	89.9	88.4
Households owning their main residence (%)	66.8	64.3	56.7	60.4
Taxed households with a personal tax income liability (%)	51.8	52.1	61.6	62.3
Median disposable income per consumption unit[1] (€)	19,342	18,887	21,647	21,963
Poverty rate (%)	14.9	15.8	12.4	12.7

[1] CU = 1st adults =1 ; 2nd adults = 0.5 ; child = 0.3…

JRBBC – "I Renovate Low Consumption Buildings"

The JRBBC programme was undertaken by the Alsace[2] region and the EDF group (EDF SA and Electricité de Strasbourg, a subsidiary of EDF) and started in 2010 for the departments of Haut-Rhin and Bas-Rhin. The aim was to renovate 500 single-family houses, with the goal of controlling household energy bills and reducing CO_2 emissions and energy consumption. The obligation to achieve a "low consumption" level was based on two main principles: give priority to improvements in the thermal envelope, and provide specific support for implementation in the form of project management (PM) for each operation (Mirtain-Roth, 2017). In effect, Nösperger and al. (Nösperger and al., 2011) underline the importance of one intermediary in order to ensure strong cooperation between different building trades.

Financial and technical support was provided by the Region and by EDF. More specifically, the programme included the following elements (Leroy and Mirtain-Roth, 2017; Leroy and Nussbaumer, 2017a):

- An on-site visit and recommendations for works, materials and implementations combined with a regulatory thermal study (Th C E-ex) (MTES, 2008).
- At least two to three measures relating to the thermal envelope. We observe in the the entire programme the following implemented measures:
    - Roof: 93% of the single-family houses participating in the programme underwent roof insulation work.
    - Walls: 93% (interior thermal insulation (ITI): 22 %; exterior thermal insulation (ETI): 78%).
    - Floors: 83%.
    - Glazing: 81%.
- Installation of a single-flow or double-flow Controlled Mechanical Ventilation (CMV) system.
- Change of heating system for 63% of homes (condensing boiler, water source heat pump) (Leroy *et al.* 2017).
- Performance of a leak test (with Q_4_psurf=0.8 $m^3/(m^2/h)$ for 84% of operations.
- Financial incentives from the Alsace region and EDF: 50 % of the cost of the PM capped at €3,000; up to €10,000 of assistance for insulation work (maximum of 70% of the work costs); financial support of € 1,500 for the air-tightness test.

To evaluate actual energy savings, a workable sample of 25 pre-renovation and 37 post-renovation operations were studied. Unfortunately, the homes belonging to both samples were very few (14 renovation projects). It should thus be noted that the different values obtained for the before/after sample contain discrepancies with results for the overall evaluation of the JRBBC programme thus the conclusion for the before/after sample should not be generalized for the whole JRBBC programme. Whenever possible, we will present these differences to indicate the presence or absence of sampling bias. All houses that were subject to work as part of the JRBBC programme were somewhat large (average between 150-160 m²). Those in the before/after sample, however, were slightly smaller (138 m² in average).

RBC - Low-Energy Renovation

The RBC programme took place in the departments of Meuse and Haute Marne starting in 2011 in the "Grand Est" region. The aim was to improve the attractiveness of the territory and to encourage businesses to achieve growth within the energy efficiency retrofit market. Programme participants

[2] Now "region Grand Est" (Alsace – Champagne Ardenne – Lorraine).

received technical and financial support from an EDF business manager, from thermal diagnosis of the home through to completion of the project, including:

- An overall thermal diagnosis of the property and identification of the renovation work to be undertaken.
- Qualified craftsmen and programme partners, sometimes in the form of clusters that allow local businesses to work together and deliver a high-quality offer.
- Cumulative financial assistance from EDF from €200 to €4,300, depending on the measures.
- Site handover with air-tightness test.
- Support from a business manager throughout the project.

For the evaluation study, a sample of 55 homes was investigated in 2015. These single-family houses were quite old (87% built before 1975) and large in size (125 m² in average whereas the national average is 112 m² (Arnault *et al.* 2015)). The majority of works carried out concerned the insulation of the building:

- Insulation of walls, attics, and possibly the floor.
- Installation of double- or triple-glazed windows.
- Installation of a single-flow or double-flow CMV (controlled mechanical ventilation) system.
- Change in the heating system for 45% of single-family houses, with the installation of either a heat pump (air-water mainly) or a condensing boiler or a biomass boiler.

To evaluate actual consumption, a workable sample of 31 pre-renovation and 46 post-renovation operations were studied. Unfortunately, again, only a few homes belong to both samples (31 renovation projects).

Methodology

Surveys of a sample of participants were carried out for both programmes. The standard questionnaire used for RBC has featured in previous studies (Raynaud *et al.* 2012, Raynaud *et al.* 2016), and will hence not be described here.

The calculation of the energy savings obtained for each participant is based on the difference in final energy consumption (all energies, all uses) between the years preceding and those following the renovation (ex-post evaluation). We studied the energy consumption for all uses; i.e. energy consumption reported by households via their bills. Actual energy consumptions were corrected for climate (heating degree days (HDD)) to return them to a normal climate level, assuming a linear dependence on HDD (Suerkemper *et al.* 2012).

We eventually calculate the levelized cost of conserve energy (LCCE) relying on the consideration of energy savings and non energy impacts. The method is explain in a following section.

Results

In this section, we will first present the work carried out for the before/after samples associated with each programme. Next, we will study the costs of these works, as well as their energy impacts (gross energy savings) and NEIs. Finally, we will compare the results of the two programmes using a marginal approach by which to quantify the cost associated with the difference in their respective performance.

To avoid added uncertainty, however, a marginal approach was not used for the individual analysis of each programme. Indeed, considering only price and marginal savings requires a point of reference (i.e., the minimum performance of a measure accompanied by its minimum price) that we were not able to fully estimate in this instance. For example, the point of reference could be either the minimum performance required by the thermal regulation[3] (TR) in the existing building (JORF 2017) or else the lack of retrofit (initial state). However, we were not able to estimate the impact in terms of marginal price due to the significant dispersion of market prices that was unrelated to performance, as observed elsewhere (Osso *et al.* 2018). To count marginal energy savings - quantities that we could calculate - but with gross prices would be inconsistent. The point of reference here is therefore the absence of measures. Given that we will compare the outputs of both programmes to estimate a marginal performance, this is of little importance.

Completed work

While the two programmes pursued similar objectives, such as the significant reduction in consumption and CO_2 by working mainly on the building shell, the means by which this was achieved were somewhat different. The following differences were observed between the works implemented in our before/after samples for the two programmes (Table 2, Table 3):

- ETI works were carried out systematically but in smaller numbers for JRBBC, with higher insulation levels (differential of +17% in thermal resistance).
- Less roof insulation for JRBBC, but with more expensive external roof insulation (sarking) measures.
- Slightly more efficient glazing for JRBBC.

Table 2: Measures implemented during the renovation and thermal performance (average value) associated with samples before/after the JRBBC and RBC programmes

Programme	Roof/ high-floor		Wall (ITI, ETI)		Floor		Glazing (double, triple)		CMV	Space heating system
	% works	R (m²K/W)	% works	R (m²K/W)	% works	R (m²K/W)	% works	Uw (W/m²K)	% works	% works
JRBBC	78	7.28	57	4.45	57	3.13	71	1.25	93	57
RBC	91	7.15	93	3.8	63	3.41	74	1.39	91	45

Table 3: Details of measures implemented during the associated thermal renovation and performance for samples before/after the JRBBC and RBC programmes

Programme	Roof			Window (double-glazing)		Window (triple-glazing)		Single-flow CMV	Double-flow CMV
	External roof insulation	Renovated attics	Uninhabitable attics	% works	U_w (W/m²K)	% works	U_w (W/m²K)	% works	% works
JRBBC	46	18	36	93	1.28	7	1.0	85	15
RBC	0	18	82	88	1.4	12	1.1	84	16

[3] Which only applies in case of retrofit.

Energy savings

We observed average actual final energy consumptions of 216 kWh/(m²/year) before retrofit and 127 kWh/(m²/year) after works for the JRBBC sample: a reduction of 41% (gain of 89 kWh of final energy/(m²/year)).

For all the JRBBC sites surveyed (25 pre- and 37 post-renovation), average energy savings were in the order of 83 kWh/m². These values, which are similar to the previous, suggest that our small sample (14 renovation projects) made up of homes whose before and after consumptions are both known does not suffer from any bias.

We observed average actual final energy consumptions of 218 kWh/(m²/year) before measures and 155 kWh/(m²/year) after measures for the RBC sample: a reduction of 29% (gain of 63 kWh of final energy/(m²/year)).

For all the RBC sites surveyed (31 pre- and 46 post-renovation), energy savings were in the order of 72 KWh/m² (33%). This value, similar to the previous one, again suggests that our small sample is made up of homes whose before and after consumptions are both known and does not suffer from any bias.

Investment

The investments presented in this section are the gross prices excluding value added tax of the renovation, with no deductions of financial aid, corresponding to the work supplied and installed (materials, equipment and labour).

For the RBC programme, the average price of renovation for our before/after sample was €33,000, with a minimum of €6,000 and a maximum of €74,000. The majority of the renovation works cost between €25,000 and €50,000. The average renovation price was thus €290/m² (median: €270/m²).

For our JRBBC before/after sample, the average price was €56,000, with a minimum of €17,000 and a maximum of €91,000. The average surface area price was thus €415/m² (median: €400/m²). For the entire JRBBC programme, the average cost of the renovation work was €68,000 (median: €60,000) with a minimum of €13,000 and surpassing €100,000 in 14% of cases. This corresponds to an average cost of €465/m² (median: €411/m²) (Leroy, Nussbaumer 2017b). Observed costs for the before/after sub-sample were thus in the same order of magnitude as those observed for the programme as a whole.

For both programmes, there was a high dispersion in the total cost of renovations. However, the average price per square meter was higher for JRBBC. This difference can be explained in part by a larger portion of ETI being used in JRBBC than in RBC, where ITI was mostly used (see Table 3). It should also be noted that the JRBBC programme included roof insulation by sarking, which is significantly more expensive than simple interior attic insulation (see Table 3).

Also, some existing costs for the JRBBC programme were not present in RBC. In the before/after JRBBC sample, for example, the average total cost of the project management (PM) and the thermal study was €6,000. In the case of RBC, support was provided by EDF and not billed to the client. If we subtract these additional costs (i.e. PM and the thermal study), the average price for JRBBC becomes €50,000 (€370/m²) to compare with the RBC program. However, this additional cost helps to reach a better efficiency (see below).

Finally, the price difference between the two programmes can also be explained, in part, by effects linked to the difference in income of the participating households (see Table 1). An initial "purchasing power effect" shows that costs are higher when households are richer; however, this effect is very weak (Osso *et al.* 2018). A second effect concerns the quality or brand of products that are more accessible for wealthy households, which have no direct link to their energy efficiency but come at a higher cost. Unfortunately, we have no information on this topic.

Non-energy impacts (NEIs)

For both programmes, the household's motivation was mainly to "save energy" and "improve comfort". Other motivations may also be apparent, such as enhancements to property, aesthetics, energy performance or environmental issues.

Overall, for both JRBBC and RBC, over 90% of households were satisfied with the work carried out. Nevertheless, both programmes experienced quality problems. However, these were resolved thanks notably to on-site monitoring. Thus, the cost of PM should be included in the RBC economic balance.

In JRBBC, winter thermal comfort was the criterion that saw the greatest improvement: 79% of the respondents declared that they felt an average or poor level of comfort before the renovation work began. Upon completion, only 5% made the same statement. In the same way, no occupants declared an excellent level of comfort before the renovation works began, compared with 40% upon completion. Temperatures were measured mainly between 18° C and 21° C (Leroy 2017).

For the RBC programme, temperatures were reported by households rather than measured. Overall, the comfort temperature increased slightly in the living rooms (+0.4° C) and more significantly in the other rooms (+1.5° C). We also observed a reduction in extreme values upon completion of the renovation works, with temperatures converging around 19-21° C.

Note that for the Grand Est region, where both programmes were located, the impact of energy performance rating on house prices (i.e. the green value) is relatively high, with a difference of 19% between classes F or G compared to class C (DINAMIC 2017). For the JRBBC programme, where thermal studies were systematically conducted, an average gain of four classes (F ➔ B) (Leroy 2017) was observed. For RBC, 47% of households reported an increase in actual estate values (without quantification) as a significant impact of their renovation work.

If the average impact of the energy performance rating is estimated at the regional level (i.e. no detailed data at a more scaled-down level), house prices differed according to the departments in which the programmes took place (Actualitix 2012): €942/m² for Haute-Marne and €946/m² for Meuse versus €1,840/m² for Haut-Rhin and €1,910/m² for Bas-Rhin. The absolute financial impact on property values was therefore greater for JRBBC than for RBC. On the basis of only 14% (the difference between band F or G and band D), the green value would represent 45% of the renovation costs for RBC and 60% for JRBBC.

Comparison of the two programmes: the marginal cost of performance

Although the initial average surface-area energy consumption of our before/after samples for the two programmes was equivalent (216 vs. 218 kWh/(m²/year)), the observed energy savings were different (89 kWh net of final energy/(m²/year) for JRBBC and 63 kWh net of final energy/(m²/year) for RBC). These differences raise two questions:

- What is the source of these additional gains for JRBBC?
- What is the marginal cost of additional energy savings?

The source of the additional gains for the JRBBC programme could be:

- The slightly higher thermal performance of the measures taken in JRBBC than in RBC, particularly for the walls (thermal resistance and ETI) and windows.
- A possible higher quality of work in JRBBC via the more "technical" monitoring provided by the PM compared to that of the EDF business manager in RBC.

Due to significant price dispersion and energy savings, it is not statistically valid to link the increase in energy savings with that of investments. We should hence remain cautious about any conclusions.

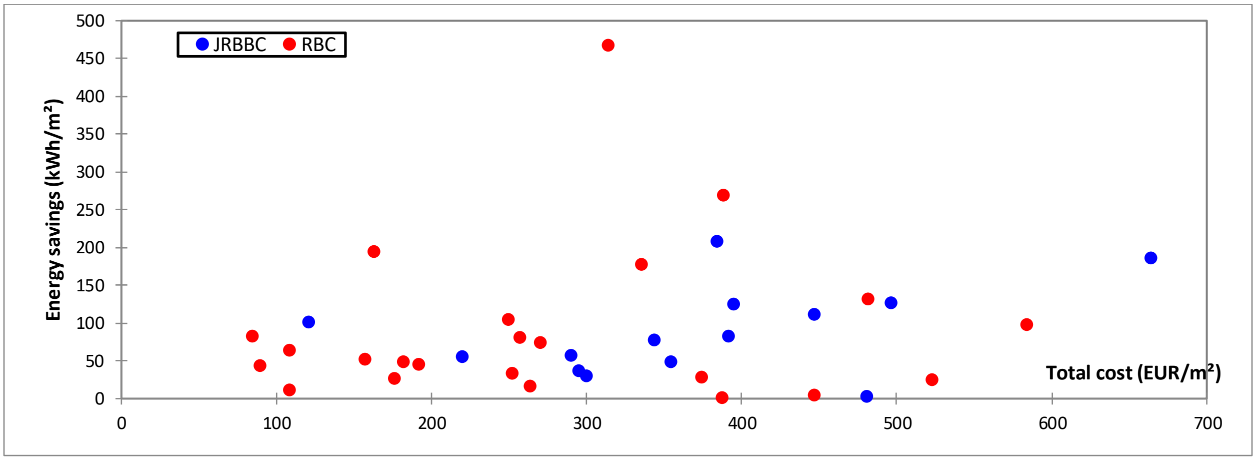

Figure 1: gain (kWh/m²) as a function of price (€/m²).

We can thus calculate the levelized cost of conserved energy (LCCE) (Krey *et al.*, 2014) for the two programmes studied here:

$$LCCE = \frac{CRF * \Delta I - \Delta GVL - WTP_c}{\Delta E} \qquad \text{eq. 1}$$

Where: *CRF*: capital recovery factor = $a(1+a)^n/((1+a)^n-1)$ with *a*=discount rate and *n*=number of years, *I*: investment, *E*: energy savings, *GVL*: depreciated and annualized green value, WTP_c: willingness to pay for comfort ((Nösperger et al. 2017), it depends on the energy prices and on their evolution, we consider a general energy prices escalation rate of 2%).

and estimate the marginal LCCE based on the differences in price and energy savings for the two programmes. As a first step, without taking into account the term associated with the green value, and ignoring the cost of the PM for JRBBC, the marginal LCCE[4] is then €0.154/kWh - a value lower than the average gross costs of energy savings GCES (GCES =*CRF***I*/*E*) in both programmes of between €0.20-0.22/kWh. If we include the price[5] of the PM in the investment costs for both programmes, the marginal cost increases slightly (€0.164/kWh) but remains under the average gross energy savings costs.

However, if we integrate the depreciated and annualized minimum green value (GVL, with GV =14 %) (Osso *et al.* 2016):

$$\text{GVL} = \Delta V_{F/G \to D} * \left[1 - \frac{\sum_{i=1}^{n}\left(\frac{1}{(1+a)^i}\right)}{n}\right] * \frac{1}{\sum_{i=1}^{n}\left(\frac{1}{(1+a)^i}\right)} \qquad \text{eq. 2}$$

With $\Delta V_{F/G \to D}$: the difference in the sale price associated with the transition from energy performance band F or G to energy performance band D.

[4] Calculation based on the differences in price and energy savings between the RBC and JRBBC programmes.
[5] In as much as no data concerning PM cost for the RBC programmes (business manager) we used the JRBBC PM cost adjusted to the income level of the region.

as a deduction from investments in the LCCE calculation (eq. 1), this gives us a marginal LCCE of €0.096/kWh. The integration of the green value therefore significantly reduces the LCCE (albeit the impact of green value is greatly diminished by its depreciation and discounting) to a level below the average gross energy savings costs in the two programmes. These results can be understood as the desire to invest with a view to increasing energy savings and reaching a better energy performance band, resulting in a home with a greater green value. From the perspective of households, however, the green value can be considered more as an "option value" on the future and hypothetical sale of their property[6] than a tangible financial gain.

Finally, the impact of the WTP for comfort further reduces the LCCE either slightly or more significantly depending on the assumptions retained (i.e. low or high WTP_c as observed in (Nösperger et al. 2017).

Table 4: GCES and LCCE estimate (€/kWh) between programmes, with the assumption of a lifetime (*n*) of 30 years and a discount rate (*a*) of 2.5 % including or not the JRBBC PM cost. High WTP_C = €/m²0.18, low WTP_c = €/m²1.44 (assessed from Nösperger *et al.* 2017).

programme	w/o JRBBC PM			w/ JRBBC PM			w/ JRBBC PM & green value	w/ JRBBC PM, green value & high WTP_c	w/ JRBBC PM, green value & low WTP_c
	€/m²	kWh/m²	€/kWh	€/m²	kWh/m²	€/kWh	€/kWh	€/kWh	€/kWh
RBC - GCES	290	63	0.220	329	63	0.249	0.222	0.191	0.218
JRBBC - GCES	370	89	0.201	415	89	0.225	0.186	0.164	0.183
LCCE	80	26	0.154	125	26	0.164	0.096	0.019	0.087

Conclusion & policy implications

This study compared two ambitious and similar regional energy efficiency programmes located in the same region but in different territories. Both programmes emphasized the reduction of energy needs via the quasi-systematic treatment of the walls of the building and improvements to ventilation (installation of a CMV and permeability test).

The energy savings obtained were consistent with higher average prices for more savings (-29% and -41% energy savings for a price of €290/m² and €415/m² for RBC and JRBBC, respectively).

Beyond a slightly better performance for JRBBC, these differences in energy savings can be explained by the different techniques employed (ITI vs. ETI) and closer technical support (dedicated PM).

The LCCE was slightly higher for JRBBC due to the cost of the PM. When we integrate the green value, however, this figure is lower than that of RBC. This seems to indicate that while the PM allows for additional energy savings via higher quality implementation, their presence increases the average price of kWh avoided. However, the financial value of the PM is retained when the green value is taken into account. Comprehensive financial assistance for on-site support - and not only for equipment - could be an interesting approach, in particular to improve the acceptability of this additional service, which rarely features in the current renovation market.

[6] The approach used in the tertiary sector whereby the green value is considered as a risk premium on the cash flow of the invested capital is more difficult to apply for owner-occupier households, unless one considers an imputed rent (fictitious rent).

The marginal gain of energy savings is highly sensitive to assumptions (integrated PM or not). It is thus difficult to draw a conclusion as to the economic relevance of the additional gains in energy savings without taking other parameters into account (NEIs).

Taking the green value, which is different in absolute value according to the territories, into account in the LCCE, even if this reduces the cost of kWh saved, further reduces the marginal cost of the additional savings. However albeit this is largely minimized in its strict economic calculation and does not necessarily reflect the feelings about property value that households seem to allocate it at the time of the renovations being carried out. A different approach could improve clients' attitudes to this green value.

Unfortunately, due to the somewhat limited data in our ex-post evaluation studies, it remains difficult to draw definitive conclusions. However, this paves the way for future reflection.

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Disclaimer

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