Regional efficiency programme valuating energy and multiple benefits: a balance between bill and comfort and far beyond

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Abstract

In the residential sector it is often observed that savings linked to energy efficiency actions are smaller than estimated *inter alia* especially due to the rebound effect. Thus, according to the sole energy viewpoint, outcomes of actions can seem low or even negative whereas in taking into account Multiple Benefits (MBs) the conclusion tends to be more positive. Nevertheless, these conclusions are more complex to obtain.

To include the MBs in the analysis, we use the functional economy model that focuses on the performance of a response to a functional need instead of the material production. This theory has other specific key features: the incorporation of external factors in meeting functional needs and a deep interaction with local economic development. Thereby, in such a framework, some of the MBs can be taken into account *via* an estimation of the monetized value of:

- Impact on household's welfare:
  - Set-temperature increase (willingness to pay for comfort).
  - Green value (building market value linked to energy labelling).
  - Health impacts.
- Economic development:
  - Disposable income fed back into economy (propensity to consume).
  - Added value created from the local installers.
  - Value creation for utilities (loss margin, Energy Efficiency Obligation if existing).
- Social welfare:
  - GHG mitigation (carbon price) and other externalities.
  - Social expenditure decrease.

To investigate this large field of study, we rely on a French regional energy efficiency programme providing incentive for a wood stove in case of an existing electric space heating system. 45 households were surveyed regarding their energy consumption and their characteristics. Likewise, the survey highlights household behaviours concerning both space heating before and after refurbishment (*e.g.* declared set-temperature). A three years billing is used to calculate the energy savings.

Beyond the electricity savings, we give a monetary value of the MBs considered on a progressively extended assessment scope, starting from a household perspective towards a societal perspective: adding step by step the value of MBs, we explicit the increase of energy efficiency value even if the figures include large uncertainties. We show the interest of such an approach by ranking the MBs and showing that the green value could be the largest MB of the studied programme.

List of variables

α_x: reimbursement rate of the medical expenses (in %)
γ_{elec}^{losses}: ratio of electricity losses (in %)
$\Delta V_{E\to D}$: variation of estate value due to energy label (in €)
ΔEA : income reduction of the electricity supplier (in €)
ω_{prod}^{i}: ratio of seasonal production by power plant types (in %)

a: discount rate (in %)
A_i: room area (in m²)
B_{hh}: household budget (in €)
CARBV: avoided carbon emission value (shadow price, in €)
CC: carbon content of electricity (in gCO_2/kWh)
COMFV: willingness to pay for more comfort (in €)
CV_{ex}: carbon value of externalities' study (in €/tCO_2)
C_x: energy consumption (*0* before retrofit, *1* after retrofit, in kWh)
ECOV: benefit to the national economy (propensity to consume, in €)
ES: energy savings (in kWh)
EX_i: externalities (in €/kWh)
EXTV: externalities value (in €)
GDP: gross domestic product (in €)
GHG: green house gas (in tCO_2)
GOP: gross operating profit (in €)
GREENV: green value (estate, in €)
HDD: Heating Degree Day (HDD^{norm} : normal climate, in °C.days)
HI_PART: financial health impact for the participant (in €)
HI_SOC: financial health impact for social accounts (in €)
INV: household's retrofit investment (in €)
I_x: income (*0*= before retrofit, *1* after retrofit, in €)
m: ratio of import expenses
ME_x: medical expenditures (in €)
MSh: electricity supplier market share (in %)
n: lifetime (in years)
ND: number of heating days (in days)
NPVES: Net Present Value of the retrofit according to ES (in €)
P: energy price (electricity, in €/kWh)
p: public subsidies
$P_{program}$: programme cost (in €/MWh_{cumac})
$P_{CO_2}^{ETS}$: ETS carbon price (in €/tCO_2)
PRODV: avoided electricity production value (in €)
$P_{EEO}^{obligation}$: Energy efficiency obligation price (white certificate in €/MWh_{cumac})
s: gross saving ratio
TO: turnover (in €)
T_x: indoor temperature (0= before retrofit, 1 after retrofit, in °C)
U_x: utility level (0= before retrofit, 1 after retrofit)
VAC: value added chain (in €)
WTP_{CO_2} : social willingness to pay for carbon emission abatement (in €/tCO_2)

Introduction

Although existing buildings represent an important source of potential energy savings in Europe, their renovation engenders many problems to exploiting this potential, particularly in the residential sector. Thus, it is not always economically cost effective for the investor to make energy saving investments based only on reducing the energy bill. Moreover, the home occupant mentions other benefits of this investment apart from reducing the bill, such as comfort or property value.
One way of broadening the cost effective range of these investments is to take account of other benefits (multiple benefits[1]) associated with these energy efficiency improvement action and to broaden the

1 Also called no energy benefits (NEBs), no energy impacts (NEIs) or co-benefits.

scope of the analysis (IEA, 2014). Obviously, the benefits to be taken into account depend on the scope of the considered stakeholders, varying from the beneficiary of the action alone, to a society approach as a whole (Cluett & Amann, 2015).
However, these « other » impacts have not been systematically evaluated, partly due to a critical lack of data and the absence of mature methodologies to measure their scope and their scale. Consequently, the extent to which energy efficiency could contribute to economic and social development is not well understood and is usually considered only qualitatively in national policy, and possibly not at all when making decisions (IEA, 2014).
However in practice, there are several standard tests defined in (CPUC, 2001; National Action Plan for Energy Efficiency, 2008), to attempt to evaluate the costs and benefits of an energy efficiency programme with different analysis scopes:

- *The Societal Cost Test* (SCT) compares the cost of the programme and some benefits for all members of society.
- *The Utility Cost Test* (UCT) compares costs and some benefits of the programme for the energy system.
- *The Rate Impact Measure Test* (RIM) only compares costs and benefits that affect the income of energy producers (such as loss of income due to lower energy sales), including the benefits and costs of the energy system.
- *The Participant Cost Test* (PT) compares costs of the programme and some benefits for customers who participate in the programme.

Our study considers all these four scopes: customer (PT), the energy producer administrating the programme (RIM), the electricity system (UCT) and the societal aspect (SCT), incrementally.
As mentioned above, the SCT test covers firstly all costs of the programme (including costs of participants and third party contributions but excluding taxes) and secondly the resulting benefits for the electricity producer, participating customers and also non-participating customers and society as a whole (*welfare*) (IEA, 2014). Some costs and benefits are included depending on which tests are used, but the financial value of multiple benefits is not usually evaluated.

Table 1. Summary of multiple benefits considered for the different tests considered incrementally. PT: Participant Cost Test; SCT: Societal Cost Test; UCT: Utility Cost Test; RIM; Rate Impact Measure Test. *direct benefit of the energy efficiency action.

Benefit	Indicator	Scope	Beneficiary	Variable
Energy savings*	NPV for the total investment	PT	Participant	NPVES
Improved comfort	Indoor temperature	PT	Participant	COMFV
Green value	EPC energy class	PT	Participant	GREENV
Reduction in medical expenses	Number of medical visits and remainder to be paid	PT	Participant	HI_PART
	Number of medical visits and reimbursement rate	SCT	Public accounts	HI_SOC
Created added value	Added value per installed system	SCT	Economy	VAC
Income reinvested into the economy	Propensity to consume	SCT	Economy	ECOV
Externalities	Avoided carbon emissions	SCT	Environment	CARBV
	Avoided electricity	SCT	Environment	EXTV
Sale of electricity	Loss of margin	RIM	Marketer	ΔEA
Programme cost	Programme cost	RIM	Marketer	
Electricity network	Avoided electricity losses	UCT	TSO, DSO	ELV
Avoided production means	Loss of margin	RIM	Producer	PRODV
Electricity not produced	ETS Carbon price	RIM	Producer	

We use the concept of service economy[2] that focuses on the performance of a response to a functional

2 "A service economy offer is a product offering, service or product-service, included in a service-based dynamic and made

need rather than performance of a product, in an attempt to include multiple benefits in an economic analysis. This theory performs other specific key functions: including external factors to satisfy functional needs and close interaction with local economic development. Furthermore, creating value is distinct from producing material goods (Guennec and Nösperger, 2009; Nösperger et al., 2015; Du Tertre, 2011). In the studied programme, the energy supplier propose "*offers investment purchase of capital equipment for the reduction of energy consumption… the performance rendering services now depends on reducing energy consumption, not to increase it*." (Vaileanu-Paun et al., 2012).
We have to keep in mind that in this paper we hold the values included in the various tests to be gradual to avoid large double counting (Table 1). However, in the framework of the functional economy a double counting could arise. This is the underlying question of the "service economy" compared to "evaluation" but is out of scope of this paper. In this paper, the only case of potential double counting is the freed additional participant's income (NPVES) which could be also accounted in the SCT test according to additional economic activity (ECOV). Thus, a saving can be counted several times if it is beneficial to several participants. This key question will be discussed in the results section (Table 4).
The direct rebound effect (Grenning et al, 2000; Sorrel et al, 2009) can be also considered as a benefit for society in the sense that it corresponds to an improvement in the well-being of occupants, a reduction in the number of sick people related to damp and cold, or to higher productivity, etc. For example, according to (Copenhagen Economics, 2012), the financial value of improved health due to energy renovation is of the same order of magnitude as the energy savings.
Thus, in this context, some multiple benefits can be included by estimating their financial value. These benefits could partly resolve the question of economically viability of retrofit actions (Galvin, 2014).
In the remainder of this paper, we will present firstly the studied energy saving programme and then the methodologies, concepts and assumptions used to evaluate the different multiple benefits and finally the results that can be used to classify the different benefits and beneficiaries in relation to each other.

Energy efficiency programme and participant survey

The French State, the Brittany Region, RTE[3], ADEME and ANAH made a commitment in December 2010 to implement an energy saving plan for the Brittany region (NW France) aimed at securing the electrical future of the region (EDF, 2015). In particular, EDF has set up the ENBRIN programme to achieve the following objectives:

- Accelerate and increase demand management over electricity consumption,
- Develop centralised and decentralised renewable energies,
- Optimise existing electricity production,
- Contribute to reducing greenhouse gas emissions.

The ENBRIN programme was applicable for home renovation actions such as insulation, the installation of a biomass heating system[4] (stove or wood insert), the replacement of existing electric direct heating by a heat pump. This programme entitles households to subsidised loans through Domofinance (subsidiary of EDF). Moreover, white certificates due to an energy efficiency obligation (EEO) are issued for completed renovation actions, for EDF (ATEE, 2014).
A quantitative telephone enquiry was made[5] between July and November 2014 with 141 owner-occupier customers[6] who had participated in the ENBRIN programme, and who lived in one of the

by a group of interested-parties on the basis of the cooperative management of a shared indivisible resulting positive externalities associated with the implementation of this offer in the long term." (Zacklad, 2007).
3 RTE: French Transmission System Operator, ADEME: French energy agency, ANAH: national housing agency.
4 To insure quality of installed products, a wood stove must comply to a minimal efficiency of 0.7 and to a CO concentration below 0.3% (ATEE, 2014).
5 Performed by the ETEICOS company (www.eteicos.fr.)
6 These customers were questioned at random among the panel of participants in the program without attempting any particular representativeness.

following four *Départements* (districts) in the Brittany region: Côtes d'Armor, Finistère, Ile et Vilaine and Morbihan.
Throughout the remainder of this study, we will focus only on action related to the installation of a wood stove in a detached house initially heated with electricity (52% of respondents) or electricity and wood (22.9%). The typology of participating households included in the enquiry is as follows:

- an approximately equal distribution between under 45 years of age (27.5%), persons between 45 and 60 years (34.1%) and over 60 years (38.5%).
- A recently built detached house constructed after 1990 (45.4%) and between 1982-1989 (15.6%), with an average inhabitable area of 129 m².

The respondents found that the leading criterion for initiating renovation work was an attempt to improve comfort (45%), of which 18.5 % declared discomfort problems. The second motivation (41%) was to reduce the energy bill.
The questionnaire used for this study is similar to questionnaires used for previous studies (Raynaud et al. 2012; Raynaud et al., 2015) and therefore it is not described in this document. This questionnaire was used to collect general information about the home and persons living in it and on its energy characteristics, the nature of the renovation work and energy bills for the last 3 years.
After deletion of cases with additional energy efficiency action(s) realized outside the programme during the 3 years period of energy bills and cases with aberrant values, 45 cases are usable for our study. Amongst them, 76% initially heated with electricity and 24% with electricity and wood as additional heating energy. Otherwise, all used only electricity for the other end-uses.

Evaluation methods

This section describes all methods used to evaluate identified multiple benefits. Many assumptions had to be made based on data derived from other studies. We attempted to use a minimised value of multiple benefits whenever there was an important uncertainty. It will be noted that this type of evaluation uses large quantities of data and is based on many assumptions that could be debatable. Our aim in this paper is to clearly identify multiple micro and macro benefits (Russell, 2015) and to estimate them (*i.e.* define an order of magnitude) based on a relatively simple methodology that does not require the use of complex models like those used in other studies, particularly for economic impacts (Russell et al., 2015; Bell et al., 2015). Our final objective is to demonstrate that the main savings may be where they are not initially sought.

Energy savings and NPV calculation

The calculation of energy savings made for each participant in the programme is based on the difference in electricity consumption between years before renovation (C_0) and after renovation (C_1). We study energy consumptions for all uses, *i.e.* electricity consumptions, as reported by households. Energy consumptions, for its space heating share assumed represent 70% (national average share for individual housing), were normalised in proportion to Heating Degree Day (HDD) for a normal climate (HDD^{norm}), so as to estimate energy savings (ES) related to actions rather than simple consumption changes (Suerkemper et al., 2012):

$$ES = \left(C_0 * \left(0.7 * \frac{HDD^{norm}}{HDD^{o}} + 0.3\right)\right) - \left(C_1 * (0.7 * \frac{HDD^{norm}}{HDD^{1}} + 0.3\right) \qquad \text{eq. 1}$$

The methodology has already been described in another paper (Raynaud et al., 2015) and the interested reader should refer to this paper. The Net Present Value (NPV) calculation is made using a discount rate (a) equal to 4%[7] and an equipment life (n) of 12 years (ATEE, 2014) for a constant electricity

7 Discount rate is chosen according to the French EEO scheme. However, implicit discount rate were assessed for retrofitting action in France around 6 % for household living in house (Stolyarova, 2016) and the standard EN 16627, about

price (P) equal to €152/MWh inc. VAT (SOeS; 2015) and a household investment[8] (INV) such that:

$$NPVES = -INV + \sum_{i=1}^{n} \frac{ES_i * P_i}{(1+a)^i} \qquad \text{eq. 2}$$

Comfort and rebound effect

It can be considered that some potential energy savings in an initially uncomfortable house are assigned to achieving decent comfort. The household can thus set aside some of these potential savings to improving thermal comfort. In this case, it is thus considered that part of the rebound effect is simply to catch up.

Financially, this assignment of potential energy savings to comfort means that the household is willing to pay for more comfort (COMFV). The initial utility level of the household used for the neoclassical formalism is U_0(income=I_0, temperature=T_0). The income I_0 being net of energy spending. Energy saving action should modify it to $U_1(I_0+ES_p, T_0)$, ES_p being potential energy savings (in €) where $U_1>U_0$. Actually the $U_1(I_0+ES_r, T_1)$ state is observed.

Formally, we then have $U_1(I_0+ES_r, T_1) = U_1(I_0+ES_p-(ES_p-ES_r),T_1)=U_1(I_0+ES_p, T_0)$, where $T_1 > T_0$, ES_r is the real energy savings and (ES_p-ES_r) is the share of potential savings assigned to comfort. It is clear that (ES_p-ES_r) is a willingness to pay (WTP) in the financial sense of the term.

The « desirable » and « acceptable » comfort level has to be defined. Standard EN 15251 (AFNOR, 2007) recommends a temperature of between 18 and 21 °C for homes.

When the initial temperature (T_0) is less than 19 °C (reference temperature) and an increase in the indoor temperature is observed ($T_1 - T_0 > 0$), we will allow for a financial value of comfort catch up until to 19 C. If we assume that HDD(T)=ND*(T-T_{ext}) where ND is the number of heating days per year and that this does not change dramatically[9] (ND = constant) before and after the retrofitting despite the temperature increase, we can express HDD(T) as a function of normal HDD (T=19°C) such that:

$$HDD(T) = ND * \left[\frac{HDD\ (19)}{ND} - (19 - T)\right] \qquad \text{eq. 3}$$

The space heating share of the observed total final consumption ($C_{1,sh}^{T_1}$, assumed represent 70% of the total consumption) is then calibrated to its potential value at the initial temperature ($C_{1,sh}^{T_0}$) using the following formula:

$$C_{1,sh}^{T_0} = C_{1,sh}^{T_1} * \frac{HDD(T_0)}{HDD(T_1)} \qquad \text{eq. 4}$$

If $T_1 \leq 19$°C, the part of the potential final consumption assigned to catching up to a decent level of comfort is calculated as the difference between the observed final consumption $C_{1,sh}^{T_1}$ and the potential final consumption $C_{1,sh}^{T_0}$:

$$C_{1,sh}^{T_1} - C_{1,sh}^{T_0} = C_{1,sh}^{T_1} * \left[1 - \frac{HDD(T_0)}{HDD(T_1)}\right] \qquad \text{eq. 5}$$

If $T_1 > 19$°C, the part of the potential final consumption assigned to catching up to a decent level of comfort is limited to 19°C:

building's economic evaluation, specifies a discount rate of 3% (AFNOR, 2015).

8 Household investment includes total equipment cost (inc. 5.5% VAT) and tax credit (15% of equipment cost).

9 For example, for the towns of Lorient and Rennes in Brittany in 2012, the average temperature was always less than 14 °C except for the month of September (14.8 °C) for Lorient and the months of May (14.2 °C) and September (15.1 °C) for the town of Rennes (Brittany Weather Service; 2015). It is considered that the error made on the duration of the heating season is second order.

$$C_{1,sh}^{19} - C_{1,sh}^{T_0} = C_{1,sh}^{T_1} * \left[\frac{HDD(19) - HDD(T_0)}{HDD(T_1)}\right] \quad \text{eq. 6}$$

By replacing the HDD values by their formulation (eq. 1), we obtain the WTP by assigning a financial value to this energy saving at the price of energy (P) and prorate to the areas of the rooms considered (A_i) relative to the inhabitable area (A_T). In its more general formulation, this annual evaluation is accumulated over the life (*n*) and is discounted (*a*) at 4 %:

$$COMFV\,(€) = \sum_{room}^{living,other}\left[\, C_{1,sh}^{T_1} * \frac{\min(T_1;19) - T_0}{\left[T_1 - 19 + \left(\frac{HDD(19)}{ND}\right)\right]} * \frac{A_{room}}{A_T}\right] * P * \sum_{i=1}^{n}\left(\frac{1}{(1+a)^i}\right) \quad \text{eq. 7}$$

As no precise data are available, the area of the living room is assumed to be 27% of the inhabitable area[10] of the home (see Table 2 for temperature variation).

Green value

The green value (Fuerst and McAllister, 2011; Dwaikat and Ali, 2016) is especially based on the increase in the market value (selling or rental price) (Cerqual, 2011). This increase in value (GREENV) may be considered by an investor as a WTP for a more energy efficient home. There are several available methods of estimating the value of real estate property. Most current studies use a comparison with the sale value to evaluate the impact of the energy performance alone, taken in isolation as a characteristic of the real estate property, on the value of this property. This approach is based on a logic of hedonic prices method, (Goodman, 1978, Pearce et al., 2006) and assumes an « all other things being equal » comparison. We decided to use this approach based on the most recent study available in France (Dinamics, 2015) that evaluates differences in selling prices ($\Delta V_{EC_i \to ECj}$) of homes depending on their energy class (EC) and the region.

Therefore the energy class change for the studied action, namely the installation of a wood stove, has to be calculated (DPE, 2006). A simulation of a building with an installation of a wood stove in Department 29 shows a change from class E (245 $kWh_{pe}/(m^2.y)$) to class D (228 $kWh_{pe}/(m^2.y)$[11]). For Brittany, this class change corresponds to an average difference in the value ($\Delta V_{E \to D}$) of +9% (between class E and D) with a confidence interval of between +11% and +7% (Dinamics, 2015). The average price per home in Brittany is of €1,632/m² (between €1,224 and €2,449) for a detached house (MeilleursAgents, 2015).

We are using an evaluation method that depreciates during its life (*n*=12 years) because although the gain is immediate, its value reduces in the future with the global improvement of all homes that will reduce this effect, even if a depreciation is always avoided. The calculation is made as follows using a discount rate (*a*) equal to 4%:

$$GREENV\,(€) = \Delta V_{E \to D} - \left[\frac{\Delta V_{E \to D}}{n} * \frac{1}{(1+a)} + \cdots + \frac{\Delta V_{E \to D}}{n} * \frac{1}{(1+a)^n}\right] = \Delta V_{E \to D} * \left[1 - \frac{\sum_{i=1}^{n}\left(\frac{1}{(1+a)^i}\right)}{n}\right] \quad \text{eq. 8}$$

Health impacts

The link between a healthy environment and health is known and the list of potential advantages for health and well-being related to the improvement in the energy efficiency is enormous. Nevertheless the manner in which these advantages can be assessed and the method of generating sufficiently robust results to help guide energy efficiency policies is still a subject for debate at the present time (Atanasiu et al., 2014; IEA, 2014). According to medical studies (RAPPEL, 2010), there

10 Based on a 27 m² living room for an inhabitable area of 100 m². The survey provides disaggregated data on set temperature by room types (living room vs. other room).

11 The gain in energy class is due to the primary energy coefficient of 2.58 for electricity and 1 for wood (DPE, 2006).

is a significant influence on health if the indoor temperature is below 16°C.
All that we estimate here are direct impacts on occupants' health, impacts of the quality of outdoor air (mortality, ill health) related to energy production are included directly in the calculation of externalities (see below).
The financial value of the impact on health (HI) from two viewpoints - the participant in the programme (HI_PART) and social accounts (HI_SOC). For social accounts, we assume that improved comfort in the case of initial thermal discomfort (T_0<16 °C) reduces medical expenses reimbursed by the Health Service (*Securité Sociale*). Each visit to a doctor has a cost (ME_{doctor}) equal to an average of €23, part of which (α_1) is reimbursed to the household (AMELI, 2015). The reimbursement rate (α_2) for prescribed medicine following a visit to the doctor varies depending on the medicine, and is equal to 65% (LEEM, 2015) and the average expenditure on medicine ($ME_{drugstore}$) is €74 (IRDES, 2015):

$$if\ T_0^{living} < 16\ °C\ ;\ HI\_SOC(€) = x * \left[(\alpha_1 * ME_{doctor}) + (\alpha_2 * ME_{drugstore})\right] * \sum_{i=1}^{n}\left(\frac{1}{(1+a)^i}\right) \quad \text{eq. 9}$$

with x: the number of avoided visits to the doctor, $\alpha_1 = \alpha_2 = 0.65$

When no data are available, the value of x is arbitrary defined at the minimum observable effect[12] (x=1). The household pays the additional amount not reimbursed by the Health Service:

$$if\ T_0^{living} < 16\ °C\ ;\ HI\_PART(€) = x * \left[\left((1-\alpha_1) * ME_{doctor}\right) + \left((1-\alpha_2) * ME_{drugstore}\right)\right] * \sum_{i=1}^{n}\left(\frac{1}{(1+a)^i}\right) \quad \text{eq. 10}$$

Economic impacts

Participant's income reinvested into the economy. When the programme participant makes financial savings on his energy bill (NPVES) and medical expenses (HI_PART), he frees up additional income that can be spent elsewhere (*i.e.* the propensity to consume (Mankiw, 2010) that can be considered as an evaluation of the indirect rebound effect (Herring & Roy, 2007)). Nevertheless, a portion that is saved should be deducted from the income thus freed. The gross savings ratio (s) (*i.e.* ratio between household savings and available gross income) is of the order of 15% in France (INSEE, 2015). Nevertheless, some of the expenses will lead to imports (*m=14%*) (Senate, 2009) that will have to be deducted from the benefit (ECOV) to the national economy.

$$ECOV\ (€) = [(1-s) * NPVES(>0) * (1-\mathrm{m})] + HI\_PART \quad \text{eq. 9}$$

This additional economic activity *de facto* increases energy consumptions at the social level that should be included in the form of externalities but they have been neglected herein. This invested income itself generates additional income that could also be reinvested into the economy and so on (budget multiplier factor (Charles et al., 2015)) but these factoring effects are not considered in this study. Nevertheless, the order of magnitude of the budget multiplier factor is 3, which illustrates the importance of other « loops » for reinjection of income into the economy. These two effects should be taken as a loopback term in a more general evaluation.

Creation of value. Many studies have attempted to demonstrate job creations as a result of an energy efficiency programme. However verification of these job creations is complex and many methodologies are used. We can start by separating direct jobs and indirect jobs, and indirect jobs can be separated into jobs related to the activity of the action adopted and jobs induced by spending the financial savings achieved in the economy (Bell et al., 2015). Thus, 70% of the global building production is due to services, commercial activities and the supply of raw materials and equipment (Saheb et al., 2015).
Since it seems to be difficult to estimate created jobs directly, we prefer to consider the economic

12 Example of around 0.5 fewer visit to doctor and 0.25 fewer visits to a pharmacist were quoted after energy efficiency improvement in low indoor temperature housing (Mzavanadze et al., 2015).

evaluation[13] directly as an added value indirectly including the different types of created jobs. We thus evaluate direct jobs (and indirect jobs) related to installation (and manufacturing) of a wood stove. To achieve this, we need to estimate the value added chain (VAC) for each installed stove starting from investments[14] (INV) of households in work and subtracting the imports ratio[15] (m_{ws}=0.157) related to the manufacturing of wood stoves. Sums invested in creation of value in the total economy should be subtracted from this value, starting from the ratio of household budgets (B_{hh}) to the gross domestic product (GDP) corrected by received public subsidies (*p*) and the imports ratio (*m*):

$$\text{VAC}\ (€) = INV * \left[(1 - m_{ws}) - \frac{B_{hh}}{GDP} * (1-p) * (1-m)\right] \quad \text{eq. 11}$$

Avoided environmental externalities

All energy consumptions include externalities[16] that need to be taken into account in the evaluation of multiple benefits. We will include impacts on health (mortality, ill health), climate change and also the impact on harvests, construction materials, ecosystems, etc. (European Commission, 2003). It should be noted that CO_2 is included in these externalities and therefore has to be taken out of the calculation if it is to be shown explicitly (CV_{ex} = €20/tCO_2) (European Commission, 1999). The value of externalities (EXTV) depends on the average externality ($EX_{average}$) expressed in €/kWh, and on the carbon content (CC in gCO_2/kWh) of avoided electricity (ES):

$$EXTV\ (€) = ES * [EX_{average} - (CC * CV_{ex})] \quad \text{eq. 12}$$

Since externalities (EX_i) are expressed as a function of power plant types, the production mix equivalent to electricity consumed by electric space heating has to be recalculated. Electricity consumed for space heating is estimated as being fully seasonalised (ADEME, 2012), externalities have to be calculated prorate to seasonalised production (ω^i_{prod}) for each production system[17] *i* (RTE, 2015) and their different externalities (EX_i) (European Commission, 2003):

$$EX_{average}(€/kWh) = \sum_i^5 \left(\frac{\omega^i_{prod}}{\sum_i^5 \omega^i_{prod}} * EX_i\right) \quad \text{eq. 13}$$

Therefore the average externality per kWh electric related to space heating is globally estimated at €0.011/kWh (ranging from €0.066/kWh to €0.003/kWh according to power plant).

Avoided carbon dioxide. We evaluated avoided carbon (CARBV) at its shadow value: based on official reference (Quinet 2008, Quinet 2013), the carbon value used in our analysis is €42/t in 2013. Given the discount factor used in public investment assessments, an escalation rate of 5.86 % is applied to this value up to 2030, this rate being lowered down to 4.5 % after 2030 (Quinet 2013). In this case, the net current value[18] of a saving of 1 tCO_2 over the 2013-2050 period would be €1,480 (by applying the recommendations of Quinet, 2009, Quinet 2013). This carbon value is close to the societal

13 Obviously, this approach is very simple and do not rely on a macro-economic modelling but the objective is to easily assess the magnitude of the effect.

14 Total investment (excl. VAT) as this programme implies an additional heating system (wood stove) that was not mainly pre-existing (more than 75% of studied cases without it initially).

15 For the year 2012: $m_{ws} = \frac{importation\ (154\ M€)}{national\ market\ (560\ M€) + installation\ (114\ M€) + wholesale\ market\ (305\ M€)}$ (ADEME, 2014).

16 Externalities are positive if their effects represent benefits for others, and negative if their effects represent costs for others. Production and consumption can generate external costs and benefits. The total social cost or benefit is obtained by adding externalities to the individual cost/benefit (ISO, 2008).

17 Nuclear, hydro, gas, coal and oil power plants (*i*: from 1 to 5).

18 €34 ^{2013} per tonne in 2008, namely €37 ^{2013} in 2010, increasing at 4.5% per year, discounted at 4.5%.

willingness to pay (WTP_{CO_2}) to resist climate change that is finally internalized and that is not comparable to the ETS price (see $P_{CO_2}^{ETS}$ below):

$$CARBV\ (€) = ES * CC * WTP_{CO_2} \quad \text{eq. 14}$$

Impacts on the electricity system

An energy efficiency programme can provide benefits for the entire electricity system (equilibrium between supply and demand, management of the load curve peak, optimisation of the production fleet, reduction or delay in investments in production or grid means, reduction in the volatility of wholesale prices, fewer unpaid bills and related administration costs) (IEA, 2014; Russell et al., 2015). Moreover, these benefits for the energy producer can be transformed into direct benefits for all final customers (reduction in retail prices, increased robustness of the electricity system). The various benefits for the electricity system have been described in detail in many North American studies over the last 3 decades (Baatz, 2015).

Electricity supplier. Implementation of an energy efficiency programme leads to the reduction in demand followed by a reduction in direct income for the electricity supplier (ΔEA). We can then calculate the margin lost by the supplier as being the result of the ratio between the gross operating profit (GOP) and his turnover (TO) in proportion to the value of the drop in consumption ($ES * P_{elec}^{retail}$) and his market share (MSh).

Furthermore, there is a cost for the supplier in implementing the energy efficiency programme ($P_{programme}$) (*e.g.* labour, subsidies) that is estimated as being equal to the price of the energy saving certificate for the action performed. On the other hand, the supplier thus satisfies part of his obligation ($P_{EEO}^{obligation}$) to provide a certificate that can either be evaluated at market price or at the cost of the penalty (€20/MWhcumac) (Suerkemper et al., 2011) based on savings that can be evaluated in the system (ES_{EEO}):

$$\Delta EA\ (€) = \left(-ES * P_{elec}^{retail} * \frac{GOP}{TO} * MSh\right) * \sum_{i=1}^{n} \left(\frac{1}{(1+a)^i}\right) + ES_{EEO} * \left(P_{EEO}^{obligation} \pm P_{programme}\right) \quad \text{eq. 15}$$

In 2012, the gross operating profit of EDF in France was equal to Bn€10.7 for sales of Bn€41.6 (EDF, 2013). In 2012, the weighted average price of the white certificate was €4.32/MWh_{cumac} (Locasystem international, 2015) with fixed savings (ES_{EEO}) rewarded by the EEO system[19] as 48 MWh_{cumac} for each installed wood stove (ATEE, 2014).

Distribution and transmission. Energy losses related to transmission (TSO)-distribution (DSO) depend mainly on the weather, the length of the transmission and distribution network, and network infrastructures. The reduction in losses (ELV) related to the reduction in consumption, usually expressed as an average percentage of consumption, is considered as a benefit for the programme (Baatz, 2015).

Losses (γ_{elec}^{losses}) represent about 2.5% for the TSO and 3.5% for the DSO for electricity that passes through the grid (CRE, 2010). Therefore we can assume avoided losses of the order of 6%. These losses can be evaluated financially at the 2012 wholesale price ($P_{elec}^{wholesale}$ = €50/MWh (CRE, 2012)):

$$ELV(€) = -ES * \frac{\gamma_{elec}^{losses}}{(1-\gamma_{elec}^{losses})} * P_{elec}^{wholesale} * \sum_{i=1}^{n} \left(\frac{1}{(1+a)^i}\right) \quad \text{eq. 16}$$

Due to the separation of activities between the transmission, distribution and production-marketing services within the EDF group (National Assembly, 2015), the benefit of the reduction in losses cannot

19 kWh_{cumac} means kWh cumulated over the lifetime of the action implemented and discounted at a rate of 4%. The "kWh_{cumac}" is the accounting unit of the French EEO scheme, corresponding to the energy saved annually accumulated and discounted over a period of conventional life determined for each action entitling certificate.

be assigned to the promoter[20] of the efficiency programme, but have to be counted as part of the UCT test (benefits for all customers of the electricity system) in calculating the routing tariff (TURPE[21]).

Production. The evaluation of avoided production (PRODV) depends on the energy context (increasing or reducing electricity consumption). The current context in France is towards lower electricity consumption (-0.6 %/y between 2010 and 2014) (RTE, 2015) therefore there is no need to invest in additional production capacity. Energy savings in this context are a loss for the producer because he cannot directly make use of a gain on avoided investments in production means. On the other hand, he has a direct gain through avoided production under the EU Emission Trading Scheme (ETS) (European Commission, 2015) that is evaluated at the market price of carbon ($P_{CO_2}^{ETS}$) namely €7/tCO_2 (CRE, 2015):

$$PRODV\,(€) = ES * \left(-P_{elec}^{wholesale} * \frac{EGOP}{TO} + CC * P_{CO_2}^{ETS}\right) * \sum_{i=1}^{n}\left(\frac{1}{(1+a)^i}\right) \qquad \text{eq.17}$$

These avoided production costs should be counted for the producer-marketer (*i.e.* EDF programme promoter).

Results

Participant

The most important direct gains for the programme participant are related to:

- comfort with a median gain of 2 °C in the living room when present (Table 2) ;
- and energy savings with a median gain of 24 kWh/m² namely 24% of the initial consumption (Figure 1) ;
- for indirect gains, the average calculated green value is €3,490/household.

Despite energy savings, the discounted NPV of 4% (excluding MBs) for the investment is negative (NPVES = -€1,270/hh on average) for an electricity price of €0.152/kWh and a median investment of €5,000 combined with a subsidy in the form of a tax credit[22]. The gain in comfort (eq. 7), is evaluated at €110/year and almost entirely compensates the negative NPV with a discounted comfort evaluation (COMFV) of about €1,100 over the lifetime of the equipment.

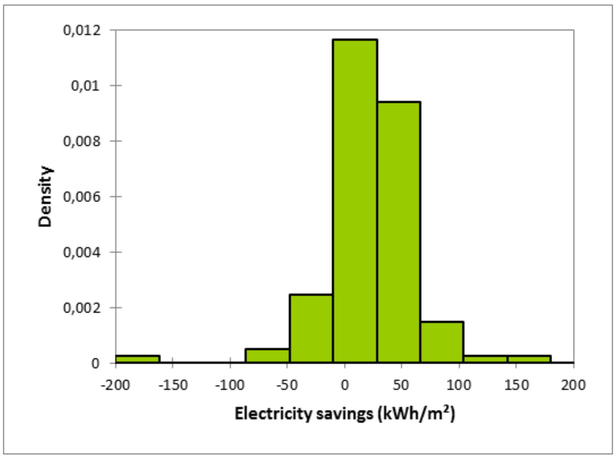

Figure 1. Distribution of observed energy savings (45 households)

20 Programme led by EDF SA: marketer and producer.
21 Costs related to compensation for energy losses on the electricity grid (CRE, 2015).
22 15% of the equipment amount with a labour content of 15%.

Table 2. Temperature in living rooms with presence before and after installation of the wood stove

(°C)	Living room		Other room	
	T_0 before the action	T_1 after the action	T_0 before the action	T_1 after the action
Minimum	14	17	14	15
Maximum	27	28	23	25
1st Quartile	18	20	17	18
Median	19	21	18	19
3rd Quartile	20	22	19	20
Mean	19	21	18	19

It is useful to compare the motivations and impacts of retrofit as estimated by participants. The main incentive for this type of work was comfort, as is confirmed by the main impact of the work done (Table 3). Only 6.5% of households mention added value of the home as the motivation, but this figure is doubled (13.4%) for impacts although the added value of the home is the biggest financial benefit estimated in this study.

Table 3. Main incentives (multiple answers possible) and impact of action according to households

(%)	Incentive to do retrofitting	Impact of the retrofit
Improved ambient comfort	45.5	35.8
Energy bill too high	41.0	-
Attractive financial offer	28.5	-
Better energy performances	20.0	26.0
Problem with discomfort in the home	18.5	-
Usage comfort	13.5	11.4
Improved aesthetics	12.0	10.5
Added value of the home	6.5	13.4
Other	32.5	2.8

Health impact

Considering an evaluation of at least the impact on the health of occupants participating in the programme (*i.e.* x=1), the gain for social accounts (HI_SOC) is €191/household and the discounted gain for households (HI_PART) is €103 over the lifetime of the equipment.

Economy

The different cost or benefit elements are then expressed in €/household (€/hh). Savings made on the energy bill and reinvested into the economy (ECOV) are evaluated at €1149/household over the period. Furthermore, the added value created for each installed system is approximately €2100/household on average.

Environmental externalities

Avoided negative environmental externalities (EXTV) related to electricity not produced (ignoring carbon) are evaluated at €24/household. The value of avoided carbon (CARBV) equal to €649/household should be added to this value.

Electricity system

There are three types of gains for the electricity system per implemented efficiency action/household:

1. For the programme and energy supplier, a cost per household equal to €434/hh for reduced

electricity sales and the cost of the programme[23].

2. For the transmission and distribution network, a saving of €61/household for avoided losses.
3. For the producer, a loss (PRODV) of €12/household.

The result globally for the entire electricity system is a cost of €380/household.

Comparison of multiple benefits

If the investment appears to be not cost effective for the participant considering final aspects only (NPVES<0), the total of the different benefits and costs is positive (PT Test = €3,100), particularly due to the green value that is predominant over all the household's other multiple benefits (Figure 2). The total gain for the supplier-energy producer responsible for the programme is negative[24] (RIM test = -€445/hh), even for the entire electrical system (UCT+RIM tests = -€380/hh).
Concerning externalities (including climate change), the gain is of the order of €670/hh and the impact on the economy is a global gain of €3,100/hh.

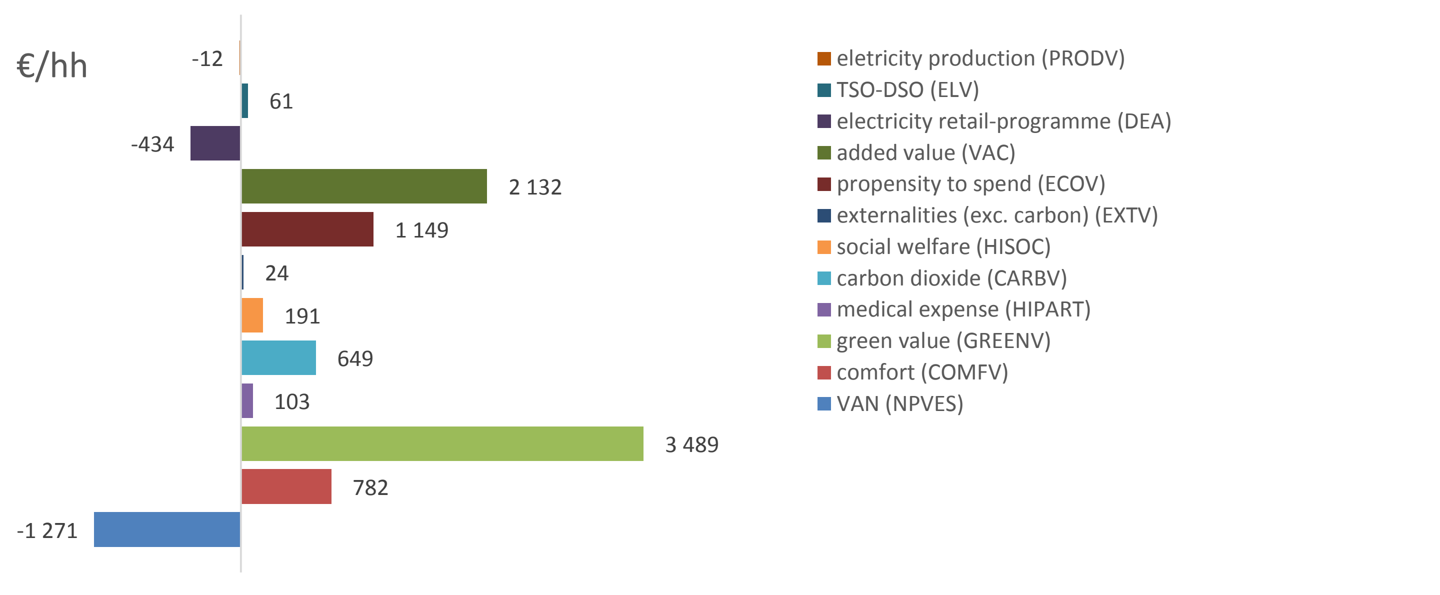

Figure 2. All multiple benefits evaluated per household

Thus, gains are principally for the participant and for society (Table 4) and costs are for the electrical system as a whole.
This programme has a Benefit-Cost Ratio[25] (BCR) equal to 2.01 for all multiple benefits, to be compared with a BCR equal to 1.49 for the participant alone and only 0.79 if the green value is excluded. If the BCR were calculated on economic cost effectiveness for the participant alone (NPVES), the result would be 0.61 on average. It has to be borne in mind that these average values conceal a large distribution of multiple benefits that are different for different participants (Figure 3).

23 An avoided cost of €300/hh could also be considered, allowing for a penalty fine avoided for lack of EEOs.
24 If the cost of the avoided EEO penalty equal to €20/MWh$_{cumac}$ is included, the gain for the energy supplier becomes positive (RIM = €00/hh). This change in cost effectiveness depending on the value adopted for the EEO certificate is similar to that obtained in other studies (Suerkemper et al., 2011).
25 For an investment of €5,000/hh and multiple benefits of €6900/hh and bill savings of €3000/hh.

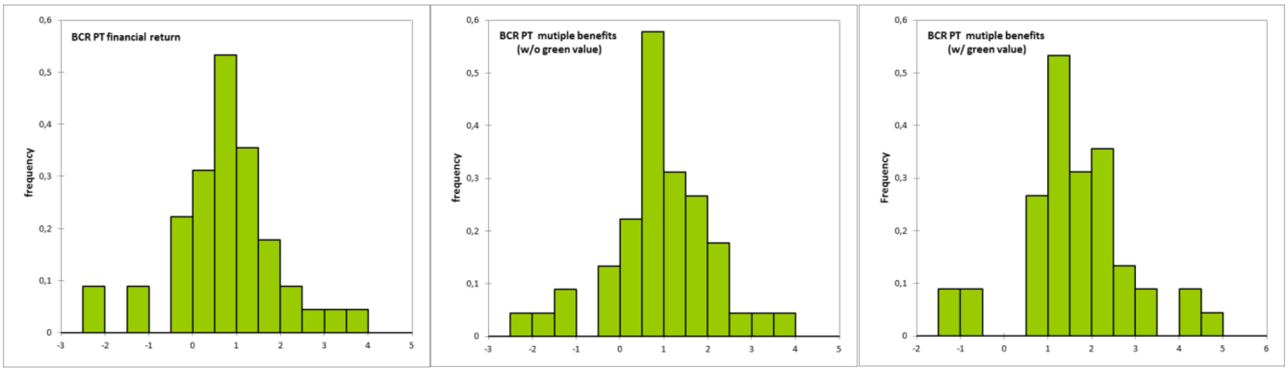

Figure 3. BCR for participants depending on selected benefits

We must bear in mind that we are only evaluating orders of magnitude and that the uncertainty is large for some variables. Nevertheless, in some cases the difference between benefits are large enough so that they are not very debatable.

Table 4. Incremental benefit depending on the studied scope (PT, SCT, RIM, UCT) per household. Double counting column provide figure to deduct to avoid double counting.

Evaluation test	€/hh	double counting (€/hh)	comment
PT	3103		
RIM	-445		
UCT	61		
SCT	4145	-1149	ECOV counted in NPVES
Total		5715	

The economic evaluation of the programme on a larger scale (including PT, RIM, UCT and SCT) clearly shows that the created value (in this case estimated at around €5700/hh) is incomparable with the results obtained on smaller scales (from -€445 to €3,400/household). Moreover, if taking into account that the household's income freed by the energy efficiency investment is reinvested into the economy the created value is then increased by +17 %.

Conclusion

This study emphasised the importance of the scope of the analysis in the evaluation of the economic interest of an energy efficiency programme. In fact, a larger scale evaluation including the electricity system, households and society impacts makes it possible to take account of and evaluate all multiple benefits of energy efficiency, well beyond energy savings alone.
One result of this evaluation is that gains are principally for the participant and for society and costs are for the electrical system as a whole.
For the participant, the most important benefit is the additional green value of his real estate related to the work involved. The evaluation of increased comfort is however significant and partially compensates the lack of financial cost effectiveness (60% of actions). This is the most important impact mentioned by households after the work has been done.
When the scope of the analysis is broadened (society scale), the second position in terms of gains is occupied by direct and indirect economic benefits.
Moreover, for the moment, the direct gains through avoided electric production under the EU Emission Trading Scheme (ETS) are valorized at a too low carbon price to have a global benefit for the electricity system.
However, making such an evaluation is only one step. Economic models should be set up that

genuinely determine the financial evaluation of these effects and transfers between the different participants. Each player in the private sector should define his company's economic model within this framework (Du Tertre, 2011):

- a way for creation and appropriation of value (production of usage value, productivity gains, externalities, cost effectiveness),
- a way of mobilising human resources,
- a mercantile relationship and inter-company relationships method (method of issuing contracts firstly with suppliers and secondly with customers);
- and a company financing way.

The theoretical model for the service economy, focusing on results and performance in several registers while fully integrating the region in value creation, will provide useful input for the design of economic models to make them consistent with a complete evaluation of the multiple benefits mentioned above. To go further, it would be very interesting to do a methodological comparison between the "service economy" method and the more usual "evaluation" method.

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