The residential refurbishment market far away from economic rationality: application of marginal abatement cost to the French white certificate

Jean-René Brunetière, Xiaofeng Xu, Dominique Osso, Marie-Hélène Laurent

The residential refurbishment market far away from economic rationality: application of marginal abatement cost to the French white certificate

Jean-René Brunetière
Chaire Economie du climat – IR5
Palais Brongniart
28, Place de la bourse
75002 Paris
France

Xiaofen Xu
Chaire Economie du climat – IR5
Palais Brongniart
28, Place de la bourse
75002 Paris
France

Dominique Osso
EDF R&D
Centre des Renardières
Avenue des Renardières
77818 Moret-sur-Loing
France

Marie-Hélène Laurent
EDF R&D
Centre des Renardières
Avenue des Renardières
77818 Moret-sur-Loing
France

Keywords
abatement, white certificates, building refurbishment, costs

Abstract
The initial idea of the French White Certificate (WC) scheme, which entered into force in 2006, was to rely on a tradable WC on the basis of market development leading to save energy at the lowest cost. However, the WC market lacks of liquidity and the majority of the trading is done over-the-counter[1]. Thus the question of the energy savings cost arise, especially to better understand where are the "low hanging fruits" and the highest ones.

Given the dominance of the residential building sector in the scheme (about 80 % of total WC have been issued in this area since the beginning of the program), we confine our study to the energy refurbishment market for residential buildings in this paper.

An economic model, based on standardized operations' monotonic functions of abatement costs (on the same model as Marginal Abatement Cost curve), is designed to estimate the distribution of energy saving costs (Euro per saved kWh). At the opposite of what is usually available in the literature, the costs are described using log-normal distributions, and not mean values, to take into account the scattering of retrofitting prices for the same operation. So we can take in account for each type of action the mean and marginal costs of refurbishment. This more realistic approach gives results that are significantly different from using mean values.

Two approaches are developed: following an economic rationality or simulating the current market (i.e. the refurbishment actions occurring in 2012) to compare the investment undertaken by the household and what should have been done according to a pure economic viewpoint. Moreover, the economic ranking of retrofitting actions could be done as well as the coverage level of the overall market.

Our results help us to quantify the gap between a pure economic analysis and the reality of the retrofitting market by comparing the cost of WC in both cases. Part of the gap is linked to the structure of this market mixing constrained[2] and self-willed actions as well as non-energy benefits (in terms of comfort, safety, aesthetics, etc.).

Such analysis gives us clues to understand the WC scheme evolution within the retrofit market from energy cost/benefit rationality to the customer's multidimensional perspective (i.e. including non-energy benefits and constraints).

Introduction
The EU Directive 2012/27/EU on energy efficiency (EED) (European Commission, 2012) requires in its Article 7 to implement an energy saving obligation scheme (Bertoldi and Rezessy, 2008) on energy suppliers and/or energy distributors. According to this Article 7, the target shall be at least equivalent to achieving 1.5 % additional savings each year from 2014 to 2020, averaged over the volume of energy sold between 2010 and 2012. To achieve this goal, France has decided to rely mainly (about 90 %) on his existing White Certificate (WC) scheme (MEDDE, 2013).

1. Over-the-counter: Trading done directly between two parties, without any supervision of the exchange.

2. By law or by a material necessity: failure, obsolescence …

Table 1. Overview of the French WC scheme from 2006 to 2017 (source: DGEC, 2015).

	Time frame	Obligation per period	WC delivered per period
1st period	01/06/2006–30/06/2009	54 TWh_{cumac}	65.2 TWh_{cumac}
Transitory period	01/07/2009–31/12/2010	No obligation	99.1 TWh_{cumac}
2nd period	01/01/2011–31/12/2013	345 TWh_{cumac} including 255 TWh_{cumac} for historically obliged parties of the 1st period and 90 TWh_{cumac} for fuel wholesalers	317.4 TWh_{cumac}
2nd period extension	01/01/2014–31/12/2014	115 TWh_{cumac}	153.2 TWh_{cumac}
3rd period	01/01/2015–31/12/2017	700 TWh_{cumac}	–

The French WC scheme which requires energy suppliers to generate energy savings to their customers was implemented in July 2006 and has already experienced two periods with the obligations reached each time (Table 1). The third period, from January 2015 to December 2017, will present a target of 700 TWh_{cumac} (DGEC, 2014). This goal of 233 TWh_{cumac} per year for the third period was set in line with the EED target of the Article 7. This annual target is about the double of the second period.

Concerning cost issues, available papers generally study the financial efficiency of WC schemes (Langniss and Praetorius, 2006; Transue and Felder, 2010; Perrels, 2008; Giraudet and Quirion, 2008) putting light amongst others on transaction cost or cost recovery as well as societal costs (Mundaca, 2007; Lees 2008). According to Giraudet et al. (2012) a WC scheme generates a social benefit but with discrepancy in cost–effectiveness following countries. Moreover, the WC scheme appears to provide good information about energy savings, but less about costs.

However, the uncertainties concerning cost (or savings) are not taken into account in these studies. In this perspective, an economic model based on standardized operations' monotonic functions of abatement costs (McKitrick, 1999; Brechet and Jouvet, 2008) is designed to estimate the impact of the evolution as well as to predict an economically optimal structure of the residential renovation market that is to be aimed for in the third period. As about 80 % of total WC have been issued in this sector, we will confine our study to the retrofitting market of housing.

The French WC scheme

We will only sum up the basics of the French WC scheme as it was already described in numerous papers (Baudry and Osso, 2011; Bertholdi et al.; 2010, Broc et al., 2011). French WC are delivered through 3 possibilities:

- Standardized Operations (SO) based on a portfolio of 304 standardized energy efficiency (EE) measures rewarded by deemed savings covering each sector of activities – residential, tertiary, industry, farming and transportation (see ATEE, 2014, for details).
- Specific actions corresponding to more complex or non-standardized measures.
- Direct funding for programs related to fuel poverty, public awareness, training programs or innovation.

The SO represent 94.8 % of the WC delivered since the beginning of the scheme and about 90 % of which are concerning the building sector – 80 % for residential and 10 % for tertiary (DGEC, 2014).

SO are rewarded by fixed energy savings amount (kWh_{cumac}) per unit of work depending on different segments (Table 2), (ATEE, 2013). These *ex-ante* deemed savings for standardized actions were revised in 2014 by ATEE[3] and ADEME (DGEC, 2014) to comply on one hand with the EED requirements of the Annex V and on the other hand to update the reference data, especially on energy consumption, lifetime and market efficiency, as some calculation had not been revised since the beginning of the scheme in 2006. The "golden rules" of the Annex V is that only the energy savings above the minimum efficiency performance of the current regulation (Ecodesign regulations as for example, European Commission, 2013, and Building regulation, MECSL, 2007) should be rewarded (see Osso et al. 2015 for details).

Refurbishment measures and case studied

We have selected eleven (Table 2[4, 5]) SO in residential buildings (coded[6] BAR-), four of which related to the building envelope (coded -EN) and seven relate to thermal equipment (coded -TH). All of these eleven operations represent 60 % of the national WC delivered in 2012. We must keep in mind that from the beginning of the scheme in 2006 until today the structure of the residential WC portfolio remained more or less identical

3. ATEE, *Association Technique Energie Environnement* [Technical Association of Professional], ADEME *Agence de l'Environnement et de la Maîtrise de l'Énergie* [French Energy and Environment Agency].

4. The values used are coming from the ATEE expert groups in charge of reviewing SO deemed savings in which one author was involved. These averaged theoretical values could be somewhat different from the observed values in the real conditions of use, due for instance to defects in the implementation and to the "rebound effect" or to the dwelling characteristics far from the average figure. The definitive values were published on the 24th december 2014.

5. WC coding: see Table 3 in the appendix for more details about these types of SO.

6. The standardized operations are coded with 3 letters refering to the concerned sector (BAR for residential, BAT for tertiary, IND for industry …), 2 letters for the type of action (TH for thermal equipment, EN for building shell, EQ for appliances …) and a numeral to distinguish each measure.

Table 2. Energy savings (in kWh_{cumac}) from WC sheets for the WC measures studied.

Building shell standardized operations						
		2nd period (2011–2014)		3rd period* (2015–2017)		Additional disaggregation
WC coding	Unit of work	Electric heating	Fuel boiler	Electric heating	Fuel boiler	
BAR-EN-01	kWh_{cumac}/m^2 of insulation	1,092	1,729	1,343	2,122	Virgin loft/occupied attic
BAR-EN-02	kWh_{cumac}/m^2 of insulation	1,779	2,810	2,190	3,466	Internal or external wall insulation
BAR-EN-03	kWh_{cumac}/m^2 of insulation	2,190	3,466	na	na	
BAR-EN-04	kWh_{cumac}/m^2 of glazing	1,525	2,451	1,989	3,154	
Space heating system and domestic hot water standardized operations						
WC coding	Unit of work	SFH	MFH	SFH	MFH	Additional disaggregation
BAR-TH-01	kWh_{cumac}/m^2 of solar collector	2909	–	4,489		
BAR-TH-04	kWh_{cumac}	149,611	57,795	101,125	46,221	Gas or oil boiler
BAR-TH-06	kWh_{cumac}	130,037	60,337	77,566	37,429	Gas or oil boiler
BAR-TH-07	kWh_{cumac}/dwelling	–	98,636		67,373	Gas or oil boiler
BAR-TH-12	kWh_{cumac}	53,131	–	10,221	–	
BAR-TH-29	kWh_{cumac}	119,648	42,205	90,092	29,326	
BAR-TH-48	kWh_{cumac}	17,200	12,000	22,288	17,718	

** It must be noticed that the energy savings quantifications for the 3rd period were not officially published at the time of this work, and therefore, definitive values could be slightly different but this will not change the concluding remarks of this paper.*

(i.e. the same top-ten OS,[7] DGEC, 2014) even if we observed an increase of the insulation measures (especially roof insulation, BAR-EN-01).

Due to the simplification of administrative processes, the WC standardised measures does not distinguish certain elementary measures. This leads to difficulties in calculating the unit cost of each elementary measure and requires desegregating of each standardized action into sub-segments (Table 2). For example, in the residential sector, the insulation on the inside or the outside wall is not distinguished by the WC measure simply named "Wall Insulation" (BAR-EN-02) irrespective of the technology implemented. But in fact, the two measures differ on the price of retrofit: internal insulation is cheaper than the external one. In the same manner, the measure "roof insulation" (BAR-EN-01) doesn't differentiate the virgin loft from occupied attic for which the roof surface insulated and the type of retrofit will be different.

In addition, segments of the residential buildings stock by type of initial space heating energy (electricity or fuels) and type of housing (Single Family House [SFH] or Multi-Family House [MFH]) were described. These segmentations already exist in the WC deemed savings quantification.

As the price of retrofit is expressed in €/dwelling, while energy saving in the WC scheme are expressed in kWh_{cumac} per unit of work (e.g. m² of insulated surface or equipment installed …) we are obliged to rely on reference dwellings as an intermediary step to be able to link the variables by calculating the cost per kWh_{cumac}. Typologies of dwelling are those used in a study by the French Union of Electricity (UFE, 2012). See Table 4 in appendix for details.

Cost of retrofitting measure

The investment cost paid by the household per unit of saved energy – called Unit Cost (UC) and expressed in €/kWh_{cumac} – will be based on:

- The deemed savings from the SO worksheet (ATEE, 2014), which allow us to quantify the energy savings express in kWh_{cumac} according to the different segments considered.[8]
- Each individual investment transaction giving rise to WC is the subject of an administrative file, containing the nature of the operation (SO), its volume (kWh_{cumac}) and the cost of the work (investment in Euro). The data used in this paper are drawn from the analysis of these files in two different studies for assessing the cost of action from market survey (UFE, 2012, Osso et al., 2014).

7. For example, the continuous first WC action (individual condensing boiler, BAR-TH-06) represented 17.6 % of the total WCs in December 2010 and 15.3 % in July 2014.

8. In this paper, we consider the actual energy savings may be validly estimated by the WC values. Of course, this hypothesis deserves confirmation through retrospective measures among households, who may find a place in further work.

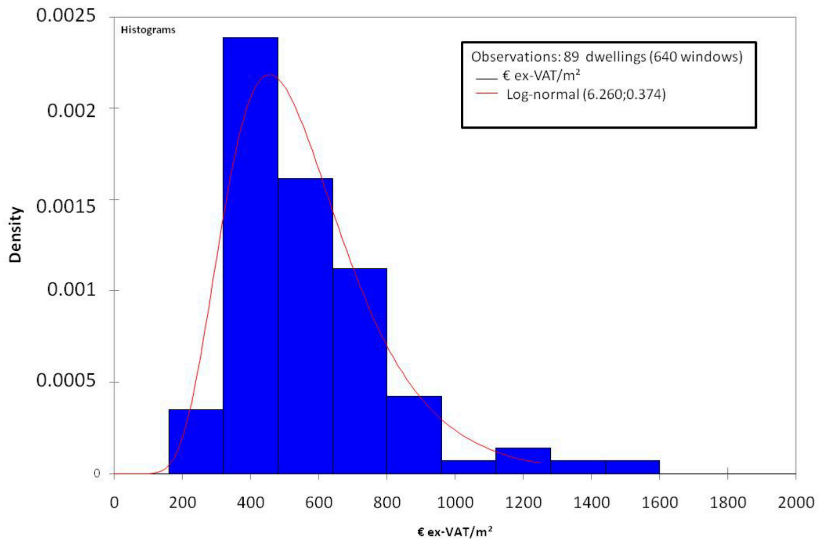


Figure 1. Density function of investment cost (in Euro ex-VAT/m²) concerning double glazing (MFH and SFH, all energies). Source: EDF-R&D.

RETROFITTING MARKET COSTS

In this paper we considered, for each SO studied, the total investment cost of the household including principal and secondary costs as well as labour and hidden costs (Laurent et al., 2009). The financial incentives (e.g. tax credit) have not been taken into account in the cost calculations. The actual costs incurred by households are coming from two different studies:

- The UFE report (French Union of Electricity Suppliers) (UFE, 2012) which gives the average price of customer investment cost by retrofit measure (cost in € incl. VAT[9]),
- New empirical data collected as initial part of this study based on an invoice survey conducted by EDF-R&D (Osso et al., 2014). This dataset, based on up to 200 invoices per SO, was used to provide the distribution functions of investment cost characterized by median, mean, mode and variance (cost in Euro excl. VAT), (Osso et al., 2014). These figures were in line with the aforementioned study (UFE, 2012).

The analysis of works quotations shows us that the investment cost of SO paid by the households present a significant heterogeneity for a given technology and a given performance level (see Figure 1 as example). The observed prices of refurbishment show that in the first approximation it can be modelled by a lognormal function as previously analysed (Laurent et al., 2011). Thus, the statistical distribution of the market price c (in Euro/unit of work) is modelled by with a cumulative distribution function $\varphi(c)$ (Wikipedia, 2014):

$$\varphi(c) = \frac{1}{2} + \frac{1}{2} erf\,[\frac{ln(c) - \mu}{\sigma\sqrt{2}}] \qquad (1)$$

where μ is the location parameter and σ the scale parameter.

An example of the probability density function of the investment cost for the four SO_i related to double glazing is shown in Figure 1.

9. The value added tax (VAT) for the refurbishment of a residential building is 7 %.

COST OF SAVED ENERGY

With all the data presented above, it is possible to estimate the Unitary Cost (UC) in Euro/kWh_{cumac} as the ratio of investment cost to the volume of deemed savings (Table 3). If we consider only the average unitary cost, most of the various operations of insulation, except for "double glazing" are more profitable than measures concerning the space heating or hot water systems. Nevertheless, we can note that condensing boilers, air-to-air-heat pump or wood stove presents comparable UC with insulation measures (Figure 2).

Looking at these results, and considering that the SO investment costs have remained relatively steady over a 10 year timeframe (Osso, 2013), especially compared to the uncertainty, one can question the idea of a "merit order" in the household investment where the retrofitting market start with the most profitable EE measure for decisions as their potential is out, to move progressively towards less profitable. At the same time coexist operations whose performance is 0.85 c€/kWh_{cumac} to 60.16 c€/kWh_{cumac} while the majority of studied actions remains below 10 c€/kWh_{cumac}. We must notice that the gap is by a factor of 70 between the extremes.

Gazeau et al. (2014) have also estimated the cost of WCs for household with a range of values between 2 and 24 c€/kWh_{cumac} depending on the SO in question, which are in the same order as in our study. As an example, their cost evaluation for double glazing is 24 c€/kWh_{cumac} for a SFH with fuel space heating which is the same as in our study. However, in our study we also have calculated value for three other double glazing options, the cost is thus varying from 0.24 to 0.37 €/kWh_{cumac} depending on the considered segment of dwellings. Gazeau et al. point out that the cost value estimates made by stakeholders may vary by up to 100 %. These last points put light on the necessity to take into account the uncertainty and not only dealing with average values to better describe the "real world".[10] This paper helps to

10. Recall that we take into account the variability of investment costs for "identical" work (the same OS and the same volume), without taking into account the variability of the observed energy savings resulting from this "identical" work. These being probably rather uncorrelated to the investment cost in a same SO, the

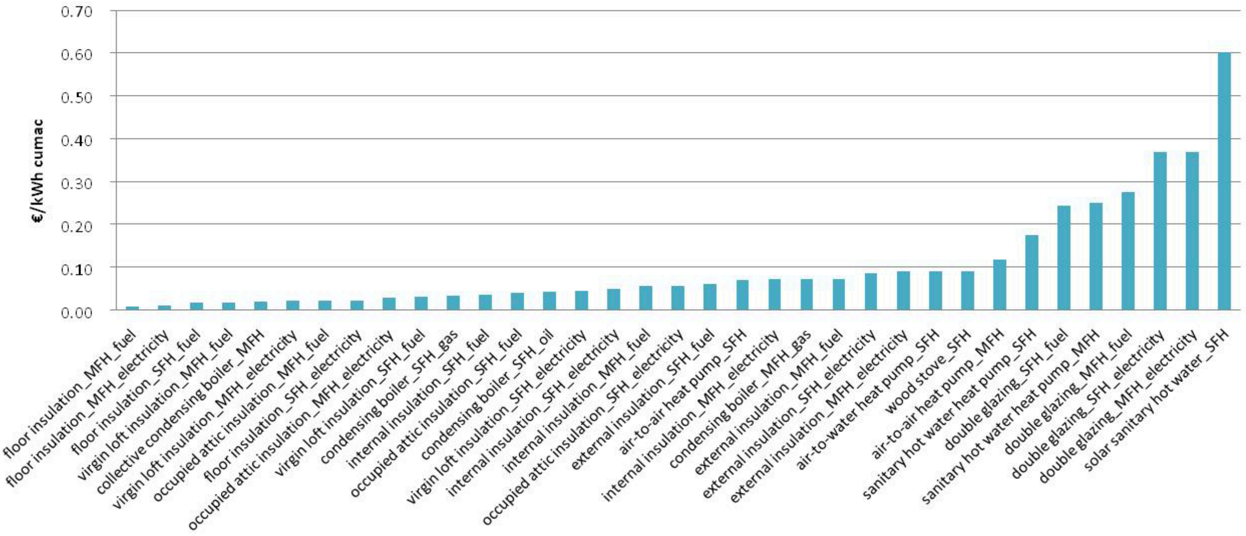


Figure 2. Average unitary cost (€/kWh$_{cumac}$) for the different segments of dwelling and measure (source: UFE, ATEE).

answer the question of uncertainty on the market side by developing an economic model embedding the cost distribution.

Economic model based on the monotone of abatement costs

Postulate that during the year *k*, the household *j* makes an investment entering the SO_i category, achieving the "unitary measure" UM_{jik}. If UC_{ijk} is the unitary cost corresponding to this Unitary Measure UM_{ijk}, we can plot the Abatement Cost AC_i of energy savings in kWh$_{cumac}$ corresponding to all unitary measures *j* in a given category SO_i classifying individual interventions according to UC_{ijk} (in €/kWh$_{cumac}$) by ascending cost. In the Figure 3a, each unitary measure is represented by a rectangle whose side x-axis is the volume of WC (in kWh$_{cumac}$) and the ordinate the unitary cost of work. The resulting curve (Figure 3a) can be modeled by a continuous function to the extent that the number of actions taken into account for each SO is large and the volume of each action represents only a very small part of the total volume, which is the case for EE measures taken into consideration here. This function is reversible and the inverse curve constitutes the abatement cost curve (Figure 3b).

As all the various SO are expressed in the same metrics (Euro and kWh$_{cumac}$), they could be aggregated into a monotonous synthetic function corresponding to all SO_i (Figure 3c). This aggregative function gives us the amount *y(c)* (in kWh$_{cumac}$) of WC actions ($\sum Q_i(c)$) implemented in the year *k* under the system of WC at an unitary cost lower than *c*.

If φ_i (*c*) is the probability for a WC action *i* that the unitary price *C* (in €/UM) would be less than a given price *c*, and δ_{ik} the global volume of this action implemented in the year *k* (expressed in UM)[11] and *T* the global quantity of WC (in kWh$_{cumac}$), the volume *y* (in kWh$_{cumac}$) of WC "cheaper than *c*" is:

$$y_i(c) = ES_i \times \delta_i \times \varphi_i(c) = T_i \times \varphi_i(c) \qquad (2)$$

with ES_i the Energy Savings per UM (Table 3). Then the relation between the unitary cost *x* (€/kWh$_{cumac}$) and the market price *c* (in €/UM) is:

$$x_i = \frac{c_i}{ES_i} \qquad (3)$$

If, as seen above, for each SO, the observed price of refurbishment can be modelled by a lognormal function (with location parameter μ_i and scale parameter σ_i). One could transform the distribution function of market price in an abatement function (Figure 4 and 5):

$$y_i = T_i \times \varphi_i(ES_i \times x) = \frac{T_i}{2} + \frac{T_i}{2} erf\ [\frac{ln(ES_i \times x) - \mu_i}{\sigma_i \sqrt{2}}] \qquad (4)$$

As the WC scheme is using different quantification of ES_i according to building type (MFH, SFH) or to efficiency some assumptions have to be made to simplify the calculation[12]:

- The hypothesis that the different stocks of δ_{SFH} and δ_{MFH} follow the same cost curve as the total cost function.[13]
- The WC actions concerning insulation follow the representativeness of the building stock (30 % of electric heating, 70 % of fuel heating).[14]

variability of the final cost of kWh saved is even significantly greater than what is shown here. It would be useful to deepen this in future work. Nevertheless, if one is interested, as here, to the decision to invest, it is legitimate to take into account the expected economy, only data available at the time of the choice (i.e. rewarded savings expressed in kWh$_{cumac}$).

11. Known by the WC register.

12. Due to space limitation in the paper, details of the calculation will not be presented here.

13. For example, concerning the double glazing's unitary cost (€/m^2) and the two housing segments (MFH, SFH): the hypotheses of a difference between the means equal to 0 and of identical variances cannot be rejected.

14. For example, concerning double glazing, the observed data are consisting of 63 % of fuel heated housing and 37 % of electric heated housing.

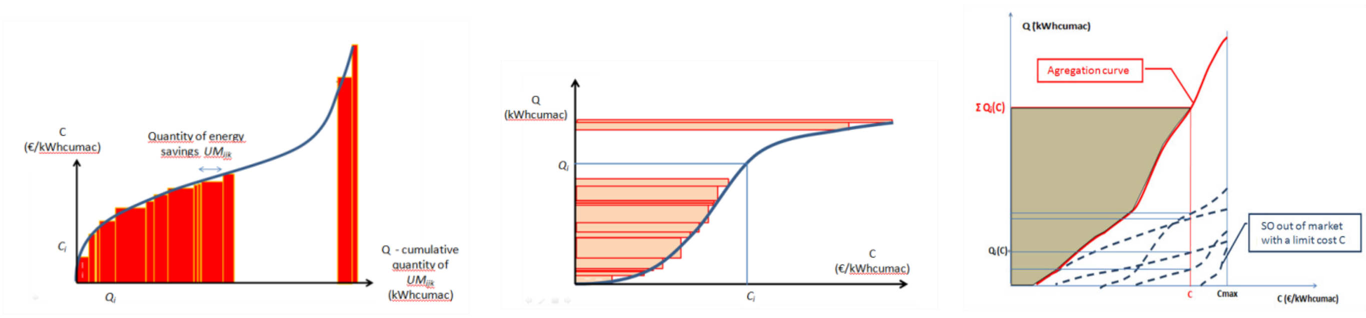
Table 3. Average unit cost of WC measures in ascending order per WC standardized actions, authors' calculation.

WC coding and EE action description (measure/building type/energy)		* Unitary cost ($c€/kWh_{cumac}$)	**Average unitary cost ($c€/kWh_{cumac}$)
BAR-EN-01	Insulation virgin loft/MFH/fuels	1.72	4.59
	Insulation virgin loft/MFH/electricity	2.16	
	Insulation occupied attic/MFH/fuels	2.23	
	Insulation occupied attic/MFH/electricity	2.81	
	Insulation virgin loft/SFH/fuels	3.15	
	Insulation occupied attic/SFH/fuels	4.08	
	Insulation virgin loft/SFH/electricity	4.38	
	Insulation occupied attic/SFH/electricity	5.69	
BAR-EN-02	Internal wall insulation/SFH/fuels	3.55	3.43
	Internal wall insulation/SFH/electricity	4.95	
	Internal wall insulation/MFH/fuels	5.68	
	External wall insulation/SFH/fuels	6.11	
	Internal wall insulation/MFH/electricity	7.12	
	External wall insulation/MFH/fuels	7.18	
	External wall insulation/SFH/electricity	8.51	
	External wall insulation/MFH/electricity	8.99	
BAR-EN-03	Floor insulation/MFH/fuels	0.85	2.31
	Floor insulation/MFH/electricity	1.08	
	Floor insulation/SFH/fuels	1.61	
	Floor insulation/SFH/electricity	2.25	
BAR-EN-04	Double glazing/SFH/fuels	24.32	23.78
	Double glazing/MFH/fuels	27.54	
	Double glazing/SFH/electricity	36.87	
	Double glazing/MFH/electricity	36.87	
BAR-TH-01	Solar Domestic hot water/SFH	60.16	na
BAR-TH-04	Air-to-water heat pump/SFH	9.02	10.60
BAR-TH-06	Condensing boiler/SFH/gas	3.31	6.81
	Condensing boiler/SFH/oil	4.23	
	Condensing boiler/MFH/gas	7.13	
BAR-TH-07	Collective condensing boiler/MFH	2.03	4.92
BAR-TH-12	Wood stove	9.10	3.67
BAR-TH-29	Air-to-air heat pump/SFH	7.02	na
	Air-to-air heat pump/MFH	11.85	
BAR-TH-48	Heat pump for domestic hot water/SFH	17.44	na
	Heat pump for domestic hot water/MFH	25.00	

* *Source: Authors' calculation based on (UFE 2012, ATEE, 2014).*

** *Source: ADEME (in Gazeau et al., 2014).*

na: not available.



(a) (b) (c)

Figure 3. (a) Monotonous energy abatement function of a standardized operation (SO), (b) resulting abatement cost curve, and (c) abatement cost curve for all the SO.

- The WC actions with different levels of efficiency were merged into the dominant performance.
- As the distribution function of price is continuous over]0, ∞[, we adopt a cost maximum of 90 c€/kWh$_{cumac}$ which is twice the median value of the most costly action.

Economic model of the WC in the period 2011–2014

In this section, we present the economic modelling of the WC scheme in the period 2011–2014 according to two different perspectives using the same dataset:

- A direct modelling of the observed market of residential refurbishment through the WC scheme (i.e. the number of measures per SO is taken directly from the WC registry).
- A theoretical modelling of the same market assuming pure economic rationality (i.e. the number of measures per SO is the result of the calculation).

MODELLING THE OBSERVED WC SCHEME IN 2012

Thirteen[15] operations in the residential sector were studied, representing ⅔ of the annual amount of WC delivered in 2012 and 80 % of the WC dedicated to the residential buildings. We considered the quantity T (in TWh$_{cumac}$) in the formulas as the total volume of WC issued in 2012 for all 13 SO studied (i.e. 73.7 TWh$_{cumac}$). The resulting total investment[16] of the households is €4,785 M for an average cost of 6.5 c€/kWh$_{cumac}$.

Please note that the merit order in Figure 5 of these 13 actions is coherent with the ranking presented above (Figure 2 and Table 3). The WC action concerning wall and roof insulation (BAR-EN-01/02) as well as condensing boilers (BAR-TH-06/07), are in the most profitable. At the opposite end of the scale are the double glazing (BAR-EN-04) and the solar thermal hot water (BAR-TH-01).

However, the probability distributions overlap significantly among the different SO (see Figure 4) meaning that there is not an obvious merit order in the residential market.

MODELLING THE WC SCHEME ASSUMING PURE ECONOMIC RATIONALITY

Each year WC only cover a part of the refurbishment market and some EE measures that meet the specifications of WC requirements are carried out outside the scheme. So, only a fraction of the Annual Potential AP_i of an SO_i is rewarded by WC:

$$transformation\ rate_i\ (\%) = \frac{T_i\ (kWh_{cumac})}{AP_i\ (kWh_{cumac})}$$

To determine the annual volume of potential energy savings per annum we introduce the notion of transformation rate (Lefebvre, 2012) as the ratio of measures rewarded by WC to all the retrofit done in this category SO_i this year k (Table 3). This ratio presents a great variability depending on the SO, from 3.4 % (most in insulation works) to 93 % (in some heating equipment). Then, for each SO, we can assign the distribution of probabilities of prices observed for the WC certified works to the global amount of works of this SO achieved in the year, assuming that the profile of rewarded measures don't differ notably from the non-rewarded measures. So we can build in the same way as above abatement curves for the whole amount of energy saving measures of the year 2012.

Further, we are able to estimate the 2012 market of WC as it should be if it had followed a pure economic rationality (ranking measures by merit order).

The same WC amount of 73.7 TWh$_{cumac}$ would have resulted in an overall investment of 776.4 M€ for the households with an average cost of 1.05 c€/kWh$_{cumac}$ if the guiding rule had been pure economic rationality. In other words, six times smaller than the observed cost in the market. Furthermore, the dominant measures by far would have been roof and internal wall insulation.

Please note that this theoretical scenario does not take into account any other barriers or drivers of the household decision-making (e.g. fall into disrepair, non-energy benefits like aesthetic or comfort considerations, household relocation …).

Evaluating the third period of WC (2015–2017)

Considering the evolution of the WC scheme for the next period (2015–2017) with modifications of ES_i and an increase of the level of obligation[17] (Table 1) we simulate the WC market

15. Added SO to the eleven studied before were: wood boiler (BAR-TH-13), low temperature boiler (BAR-TH-08), water-to-water heat pump (BAR-TH-03).

16. According to a market survey, the energy efficient retrofit of residential buildings in 2011 is valued at €13,500 M. This included the following efficiency measures: roof and wall insulation, double glazing, and space heating equipment (ADEME, 2013).

17. See (Osso et al, 2015) for details about the third period changes of the WC scheme.

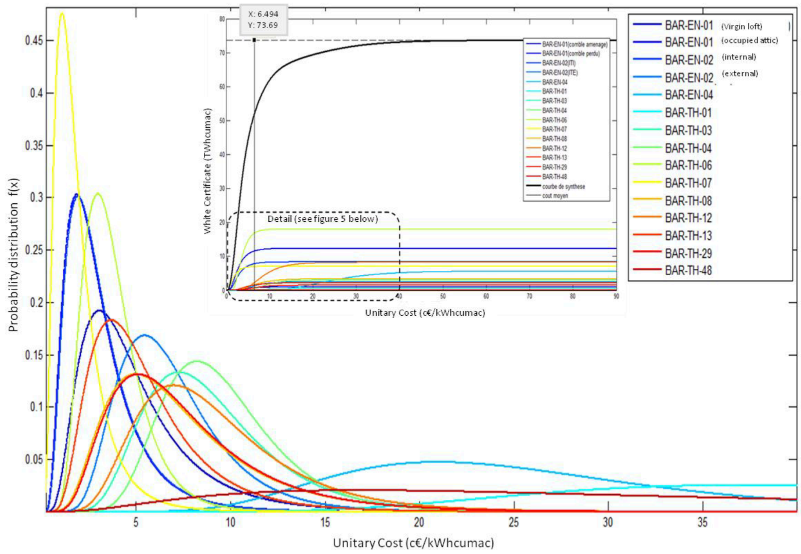


Figure 4. Probability function of the 13 WC actions and total abatement cost curve (in vignette).

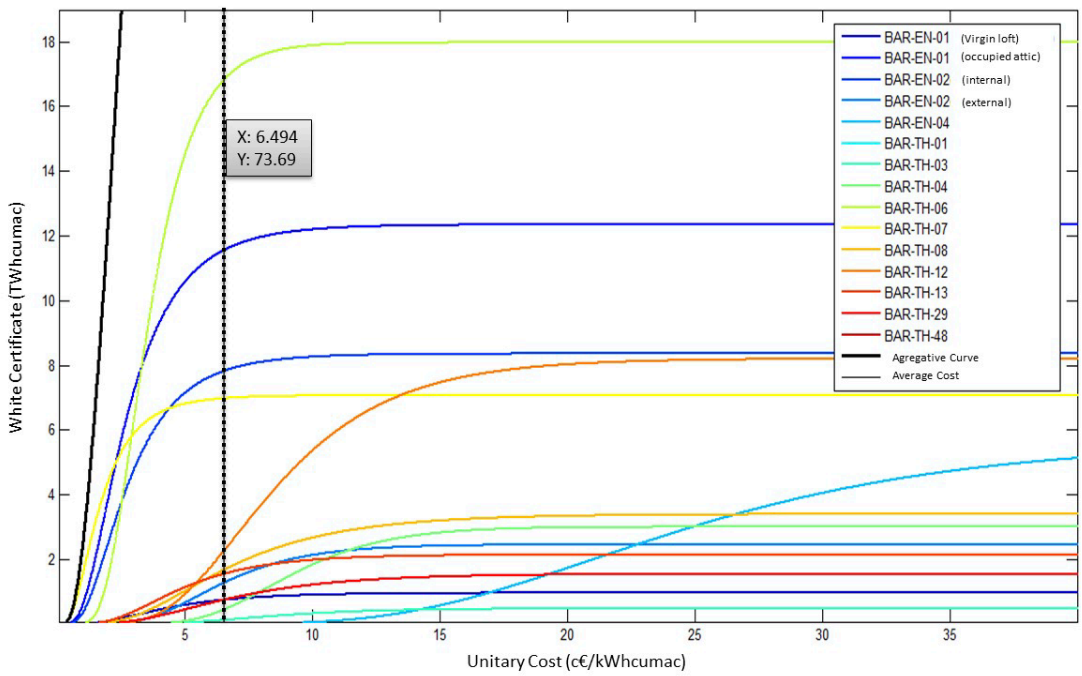


Figure 5. Focus on abatement cost curves for the 13 WC actions studied (and average cost – dotted line).

for the residential sector in 2015 using the same two modelling approaches:

- A theoretical modelling following a pure economic rationality rule.
- A modelling by a simple increase of the number of measures with a market mix similar to the one observed for the 2nd WC period.

It is assumed that the contribution from the residential sector to the overall WC target will be 142 TWh_{cumac}, i.e. about 60 % of the national level.[18]

In this analysis only 11 SO in the residential sector are allowed (as opposed to 13 previously) and it is assumed that there is no structural change in the WC scheme nor in the retrofitting market (i.e. meaning an *ceteris paribus* analysis), which is important to take into account when analysing the results.

18. I.e. 80 % of the residential sector.

Table 4. Evolution of transformation rate for the second and the third period of WC according to different scenario.

WC code	Transformation rate in the second period (2011–2014)*	Scenario for the third period (2015–2017)	
		Transformation rate according to an expansion of the second period	Transformation rate according to a pure economic rationality
BAR-EN-01 (occupied attic)	3.90 %	9.31 %	5.13 %
BAR-EN-01 (virgin loft)		9.31 %	**21.77 %**
BAR-EN-02 (internal)		9.31 %	**20.66 %**
BAR-EN-02 (external)		9.31 %	0.04 %
BAR-EN-04	14.60 %	34.85 %	0.00 %
BAR-TH-01	67.90 %**	**162.09 %**	0.00 %
BAR-TH-04	91.20 %	**217.71 %**	0.00 %
BAR-TH-06	83.70 %	**199.81 %**	0.02 %
BAR-TH-07		**199.81 %**	**18.89 %**
BAR-TH-12	24.30 %	58.01 %	0.00 %
BAR-TH-13	28.30 %	67.56 %	0.03 %
BAR-TH-29	31.00 %	74.00 %	0.01 %
BAR-TH-48	3.40 %***	8.12 %	0.02 %

*Source: *ADEME (2012), **ADEME/Observ'ER (2013), ***PAC&Clim'Info/Gifam (2013).*

PURE ECONOMIC RATIONALITY RULE

Using the abatement curve calculated with a pure economic rationality the total investment faced by the household to comply with the requisite level of WC is easily assessed. This minimum of investment is 1,429.4 M€ with an average cost of 1.00 c€/kWh$_{cumac}$ and a maximum of 1.35 c€/kWh$_{cumac}$. This slightly cheaper pricing in 2015 than in 2012 is due to the revision of energy savings per SO_i undergoing an increase of savings for the insulation measures and a decrease for space heating systems (Osso et al., 2015). In this hypothetical scenario, the WC obligation for the year 2015 will be achieved through insulation measures (BAR-EN-01/02) and condensing boiler (BAR-TH-07) and the resulting transformation rate for each SO_i is presented in Table 4.

NOTHING CHANGE, EXPANDING THE SECOND PERIOD

Another possible scenario for 2015, at the opposite of the rationality one, is simply to increase the transformation rate of the second period by a factor corresponding to the increase of the obligation (i.e. an expansion of the second period by a factor 2.39) keeping the refurbishment market structure identical.[19]

Consequently, for 4 SO_i, notably those concerning condensing boilers, the transformation rate exceeds the capacity of the current market (Table 4). Even hoping to increase the market volume in these SO_i through appropriate incentive efforts, it is unrealistic to imagine that they can be doubled in two to three years. So, it is necessary to compensate this lack of WC by increasing the transformation rate of the others SO_i. However, the transformation rate is also high for some of the other SO_i, especially for the equipment market. It is therefore not possible to maintain the same structure in the market mix as in 2012.

19. Due to the revision process, only 11 SO were within the analysis done for the third period modifying the expected factor between the two periods.

Conclusion

We have demonstrated the feasibility of a theoretical economic modeling, through an abatement curves calculation, of the WC scheme even if this is a work in progress. Indeed, the results presented here rely on a number of strong hypotheses that should be kept in mind:

- The structure of the market cost remains the same over the time and for all the EE measures that were or were not rewarded by WC.
- The analyzed cost is the total investment cost of household and not the marginal cost that could be attributed to the energy savings or EE and remaining cost to other non-energy benefits. However, as the energy savings in the WCs for the second period (2011–2014) were the total savings this methodology choice is reasonable.
- The energy savings values are taken as the standardised values defined for the SO, while in practice there may also be a large scattering for these values. Nevertheless, the standardised values can validly represent the information available to the household at the time of his decision.
- Only 13 EE measures in the residential sector representing 64% of the total WC were used as basis for the analysis.

However, what to learn from these preliminary results:

- Obviously, no merit order related to the cost of saved energy prevails in the household decision.
- Inside the same refurbishment action, the cost distribution is varies greatly, typically a factor 1 to 3 between extreme deciles (from 1 to 2 for the most homogeneous and 1 to 8 for the most varied).

To the idea that households do refurbishment gradually, starting with the most cost effective and year after year increasing the willingness to paid (with admittedly some statistical variability but insufficient to undermine the principle) does not appear to apply. Instead a portfolio of EE measures are implemented annually with very varied profitability, the return rate distribution (measured by the cost of kWh_{cumac}) remaining relatively stable time, all things being equal.

Investment decisions, in this context, are largely exogenous to energy considerations (obligation related to obsolescence, renovation during moving, family changes, and improvement of estate value or security considerations "embedding" the energy savings …) and could be viewed as constraint in the economic field. Expanding the pure economic approach to include at least some of these aspects should be a step ahead in future modeling developments.

In this case, we can establish abatement functions providing for a given period the volume of WC realizable under a certain cost, but we must give up the idea of "marginal abatement cost" related to the idea of a "merit order" which cannot be found by the private stakeholders. Nevertheless, the responsibility of the policy makers is clearly to bring the real global investment nearer to the merit order, which express the best use of the national resources in the quest of energy saving at the lowest socio-economic price. It means very likely to reduce the support of the less cost-effective operations for the benefit of the most profitable. Although no "merit order" prevails in the decision of households, it is in the public interest that public bodies seek to reconcile these individual choices of economic rationality, encouraging the most cost-effective actions.

In this aim, it would be most useful for policy makers to build actual marginal abatement costs curves detailed by types of operations and cumulative for all operations, something, which is not available in France today. The methods described in this paper are a first step in this direction.

Reference

ATEE (2013) *Certificats d'économies d'énergies [Energy savings certificates]*, Mémento du ClubC2E, 10e Edition, 564 p.

ATEE (2014) *Bâtiment résidentiel: fiches d'opérations standardisées d'économies d'énergie [Residential building: standardized energy saving operation worksheets]*, http://atee.fr/c2e/certificats-deconomies-denergie-fiches-batiment-residentiel.

Baudry P., Osso D. (2011) *Energy Saving Certificates in France: a new frame for the second period (2011-2013) and afterwards*, European Council for an Energy Efficiency Economy – eceee 2011 Summer Study – Energy efficiency first: The foundation of a low-carbon society, 6–11 June 2011, Toulon/Hyères, France, 447–454.

Bertoldi P., Rezessy S. (2008) *Tradable white certificate schemes: fundamental concepts*, Energy Efficiency 1: 237–255.

Bertoldi P., Rezessy S., Lees E., Baudry P., Jeandel A., Labanca N. (2010) *Energy supplier obligations and white certificate schemes: Comparative analysis of experiences in the European Union*, Energy Policy 38: 1455–1469.

Brechet T., Jouvet P-A. (2008). *Environmental innovation and the cost of pollution abatement revisited*. Ecological Economics, 65: 262–265.

Broc J-S., Osso D., Baudry P., Adnot J., Bodineau L. (2011) *Consistency of the French white certificates evaluation system with the framework proposed for the European energy services*, Energy Efficiency 4: 371–392.

DGEC (2015) *Lettre d'information "Certificats d'économies d'énergie" [information letter on energy savings certificates]*, February 2015, http://www.developpement-durable.gouv.fr/ IMG/pdf/ 150201_lettre_d_information _CEE.pdf.

European Commission (2012) *Directive 2012/27/EU of The European Parliament and of The Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC*, Official Journal of the European Union, L 315/1.

European Commission (2013) *Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for space heaters and combination heaters,* Official Journal of the European Union, L 239/136.

Gazeau J-C., Follenfant P., Parent B., Krieff D., Cueugniet J., Valerian F., Morel M. (2014) *Les certificats d'économies d'énergie : efficacité énergétique et analyse économique [Energy savings certificates: energy efficiency and economic analysis],* Ministère de l'Ecologie, Du Développement Durable et de l'Energie (009574-01), Ministère des Finances et des Comptes Publics (2014-M-026-02), Ministère de l'Economie, du Redressement Productif et du Numérique (2014/03/CGE/SG), 113 p.

Giraudet L-G., Bodineau L., Finon D. (2012) *The cost and benefits of white certificates schemes*, Energy Efficiency 5: 179–199.

Giraudet L-G., Quirion P. (2008) *Efficiency and distributional impacts of tradable white certificates compared to taxes, subsidies and regulations*, Revue d'Economie Politique 118: 885–914.

Langniss O., Praetorius B. (2006) *How much market do market-based instruments create? An analysis for the case of "white" certificates* Energy Policy 34: 200–211.

Laurent M-H., Allibe B., Osso D. (2011) *Energy efficiency for all! How could an innovative conditional subsidy on refurbishment lead to enhanced efficient technologies accessibility*, European Council for an Energy Efficiency Economy – eceee 2011 Summer Study – Energy efficiency first: The foundation of a low-carbon society, 6–11 June 2011, Toulon/Hyères, France, 401–412.

Laurent M-H., Osso D., Cayre E. (2009) *Energy savings and costs of energy efficiency measures: a gap from policy to reality ?* European Council for an Energy Efficiency

Economy – eceee 2009 Summer Study – Act! Innovate! Deliver! Reducing energy demand sustainably, 1–6 June 2009, Nice, France, 571–581.

Lees E. (2008) *Evaluation of the energy efficiency commitment 2005-08*, Report to DECC.

Lefebvre (2012) *Évaluation économique et environnemental des CEE. Évaluation des gisements d'économie d'énergie H. [Economic and environmental assessment of CEE. Assessment of energy savings potentials]*, ADEME-Service Climat, Ouverture de la concertation du 14 mai 2012.

McKitrick, R., (1999) *A derivation of the marginal abatement cost curve*, Journal of Environmental Economics and Management 37: 306–314.

MECSL (2014) *Arrêté du 3 mai 2007 relatif aux caractéristiques thermiques et à la performance énergétique des bâtiments existants [Order of 3 May 2007 on the thermal characteristics and energy performance of existing buildings]*, Ministère De l'Emploi, de la Cohésion Sociale et du Logement, NOR: SOCU0751906A.

MEDDE (2013) *Rapport de la France sur la transposition de l'article 7 de la directive 2012/27/UE relative à l'efficacité énergétique [France report on the implementation of article 7 of the directive2012/27/EU on energy efficiency]*, http://www.developpement-durable.gouv.fr/Directive-efficacite-energetique.html.

Mundaca L. (2007) *Transaction costs of Tradable White Certificate schemes: The Energy Efficiency Commitment as case study*, Energy Policy 35: 4340–4354.

Osso D. (2013) *Evolution des coûts de la rénovation énergétique résidentielle (2002-2012) selon BATIPRIX [Evolution of the cost of home energy renovation (2002-2012) according to BATIPRIX]*, EDF-R&D, Internal report (from BATIPRIX 2003-2013, Batiprix.com).

Osso D., Laurent M-H., Binet G., Nosperger S. (2014) EDF-R&D Internal report.

Osso D., Laurent M-H., Binet G. (2015) *Policy interactions between European directives and white certificates or how to give the right signal to the refurbishment market*, eceee 2015 Summer Study, 2-228-15, to be published.

Perrels A. (2008) *Market imperfections and economic efficiency of white certificate systems*, Energy Efficiency 1: 349–371.

Transue M., Felder F. A. (2010) *Comparison of energy efficiency incentive programs: Rebates and white certificates*, Utilities Policy 18: 103–111.

UFE (2012) *A key driving energy policy instrument: the prioritization of energy efficiency measures*, Union Française de l'Électricité, http://www.ufe-electricite.fr/.

Wikipedia (2014) *Log-normal distribution*, http://en.wikipedia.org/wiki/Log-normal_distribution.

Acknowledgments

The authors would like to thank G. Binet and S. Nosperger (EDF-R&D) for their valuable contribution in the refurbishment market survey (invoice analysis) providing a new empirical dataset.

Appendix

Table 5. Characteristics of reference housings.

Reference dwellings			
	SFH	**MFH**	**Insulated area per dwelling**
Double glazing area	16 m² (8 windows)	8 m² (4 windows)	–
Wall area	92	36	–
Virgin loft area	80	70	12.61 m²
Occupied attic area	96	84	15.14 m²
Floor area	80	70	12.61 m²
Living area/dwelling	SFH		110 m²
	MFH		66 m²
Area of collector/dwelling	SFH		1.8 m²
	MFH		1.4 m²