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Impact assessment of the « crédit d'impôt pour la transition énergétique (CITE) »

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Non-technical summary

Reminder on the history of the CITE

The French tax credit « **Crédit d'Impôt pour la Transition Énergétique (CITE) »** (Tax credit for energy transition) is an income tax credit on housing energy efficiency expenditures and renewable energy investments. Tenants and owners can claim a tax credit only for their main home. Eligible equipment and materials must meet minimum technical criteria regarding energy efficiency. Households receive a tax credit the year after completion of the dwelling's renovation. The CITE is the largest green eligible expenditure in terms of budgetary cost, within the perimeter of green eligible expenditures defined for the Green OAT.

Recent developments

Since the introduction of CITE in 2014, households can claim a **single rate of 30%** tax credit on all eligible renovations. Eligible renovation expenditures are capped at 8,000 euros for a single person and 16,000 euros for a couple. The companies carrying out the renovation works must comply with a label guaranteeing their qualification for energy efficiency renovations called the **RGE label.** As a tax credit, the subsidy is thus perceived the year after the work expenditures.

In 2016 and 2017, the budgetary cost of the CITE amounted to **1.7 billion euros per year** which is significantly higher than in 2013-2014 since subsidy rates were between 15 and 25% before September 2014. The expenditures (achieved in 2015 and 2016) **mainly** concern **insulation (73%).** Replacement of heating systems and renewable energy investments represent respectively 11% and 16%.

Evaluation method

There are no detailed micro data on the energy savings concerning the CITE renovation operations, making it challenging to carry out an evaluation. Energy savings have to be estimated. Thus the evaluation is based on the use of a simulation model, the Res-IRF model developed by the "Centre International de Recherche sur l'Environnement et le Développement" (CIRED) and we use micro ex-post data from surveys in order to get as close as possible to the actual household behaviours. The model simulates the French households' retrofitting decisions and heating systems choices based on renovation costs and an exogenous energy prices scenario. Its specificity is to try to estimate actual energy consumptions, taking into account the so called "rebound effect", i.e. the fact that while improving the energy efficiency of their dwelling, households also improve their thermal comfort and consume more than theoretically expected. Therefore, the energy savings due to the renovation works are not overestimated. They are more probably under-estimated, due to the omission of some positive effects that are not captured by the model (for instance, additional energy savings are not taken into account when the energy efficiency rating1 of the dwelling does not change). Also, some important impacts are not considered by the method used, such as joint reduction of air pollution or other externalities, or national capacity-building for the supply of energy efficient solutions and awareness of the public on energy savings.

The model is calibrated on the French housing stock and its heating energy consumption in 2012. The output includes the heating energy consumption and greenhouse gas emissions of French dwellings between 2012 and 2050.

The model allows us to simulate the impact of public policies on the energy efficiency of French dwellings by integrating the effect of these policies on households' choices through reducing renovation costs (subsidies, loans with reduced interest rate...) and increasing energy prices (carbon tax). It also integrates the effect of thermal regulations on the new housing stock.

To assess the effect of the CITE on energy efficiency investment, heating consumption and GHG emissions, we compare a simulation without the CITE and a simulation with the CITE during years 2015 and 2016, all other things being equal (it is assumed that other policies stayed in place). Since benefits from renovation are grasped during many years after the works, we assess the effects of the CITE over the whole period 2015-2050 for both scenarios.

Main results

Relevance and effectiveness of the CITE

- The CITE presents a high level of relevance with respect to the French government's objectives.
- The CITE reduces energy consumption and CO_2 emissions respectively by about 0.9 TWh and 0.12 $MtCO_2$ per year in 2015 and 2016. This corresponds to 0.3% of the heating energy consumption and 0.3% of the CO_2 emissions of the housing sector in 2015 and 2016.
- These effects last for many years: over the 2015-2050 period, 2.9 $MtCO_2$ and 43 TWh of energy consumption are avoided. The cumulative gain of CO_2 emissions over 2015-2050 triggered by additional 2015 investments corresponds to 7% of the 2015 level of CO_2 emissions of the housing sector. Collective gains concerning pollution externalities represent around 200 €/tCO_2, which, if deducted from CO_2 abatement cost, lead to a lower abatement cost of 40 €/tCO_2.

Cost distribution analysis

- The budgetary cost for the CITE is 1.7 billion euros per year for 2015 and 2016. Second round effects of the CITE on the budget of other policies and taxes have been neglected.
- The cost for households is an additional investment of 3.4 billion euros in 2015-2016. It enables long run energy bill savings that almost cover the additional cost.
- Thanks to the tax credit, investment in energy efficiency is highly profitable for

[1] Dwellings are rated in « energy classes », from A to G, according to their energy efficiency performance. Energy efficiency improvements can lead to a change in energy class, but improvements can also occur within the same energy class.

households. It allows them to save 2.2 billion euros over the 2015-2050 period.

Additional effect of the CITE

- The CITE triggers around 75,000 additional renovations (defined as the shift from an energy efficiency class to another) per year in 2015 and 2016 which represents an increase of about 11% of the number of renovations performed.
- The CITE triggers an additional amount of 1.7 billion euros of energy efficiency investments per year in 2015 and 2016 which represents an increase of about 16% of the amount of energy efficiency investment.
- The renovation operations made with the CITE are more ambitious than those made without the CITE.
- The ratio between additional investments in energy efficiency compared to the situation without the CITE and public expenditures related to the CITE budgetary cost (leverage effect of the CITE scheme) is a little above 1 for 2015 and 2016.
- The CITE improves the energy efficiency of the housing stock. The number of dwellings with a low energy consumption (A or B) increases by 39,000 at the end of 2016. The CITE incentive in 2015 and 2016 helps to keep the housing stock on a more virtuous path since dwellings with a low energy consumption increase by 71,000 by the end of 2050.
- The average heating consumption per m² of the housing stock is reduced by 0.6% in 2050.

Economic efficiency of the CITE

- We assess the economic efficiency of the CITE from a societal point of view by calculating the ratio between net costs of the renovations (investment costs minus energy bill savings) and social benefits (avoided emissions, energy savings). Long run effects of the CITE over the 2015-2050 period have been taken into account. Investments, energy savings and quantities of CO_2 avoided are discounted at 4.5%. Furthermore, the households' increased surplus due to their improved thermal comfort, and related health effects, is not taken into account.
- The **abatement cost of CO_2** avoided by the investments made in 2015 and 2016 is estimated at **240 euros per ton** discounted over 2015-2050. This value is subject to great sensitivity, varying from 0 to 500 €/tCO_2 if investment costs vary from -20% to +20%. Collective gains concerning pollution externalities represent around 200 €/tCO_2, which, if deducted from CO_2 abatement cost, lead to a lower abatement cost of 40 €/tCO_2. This cost has to be compared to the social cost of carbon trajectory over the same period. It seems reasonable with regards to recent studies and discussions for the future national strategy for reducing GHG emissions, which are likely to fix the social cost of carbon at least at around 250 euros per ton of CO_2 in 2030.
- The abatement cost per MWh saved by the investments made in 2015 and 2016 is estimated at 20 euros.

Sensitivity analysis

- The sensitivity analysis shows that the most sensitive parameters in the model are investment costs and the difference between theoretical (derived from labelling process) and realized energy savings.

- For example, the CO_2 abatement cost collapses down to negligible values (and possibly turns negative) if investment costs decrease by 20%. On the contrary, it would probably double if investment costs increase by 20%.
- If we consider “theoretical energy savings” (derived from energy consumption estimated by labelling process) rather than the refined estimate of “realized” savings, savings are higher and the abatement cost of CO_2 is very strongly reduced.
- The results are less sensitive to energy price scenarios and to the interactions with other policies. CO_2 content for electricity assumption is quite sensitive but not decisive.
- An ad hoc simplified approach provides an order of magnitude of air pollution reduction and confirms that the social benefit associated is a first order issue. If taken into account, the CO_2 abatement cost would decrease significantly.

Caveat

- The model is based on a lot of assumptions, most of which are informed by observed data.
- Results must be taken as order of magnitude.
- Conservative approach: the model most probably under-estimates actual benefits of the CITE and its efficiency.

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1. Detailed description of the CITE

The « Crédit d'Impôt pour la Transition Énergétique (CITE) » is an income tax credit on housing energy efficiency expenditures and on some renewable energy investments. The CITE was designed to support the government's objectives regarding energy efficiency and greenhouse gas emissions. Since September 2014, the CITE replaced a previous tax credit called « tax credit for sustainable development (crédit d'impôt développement durable - CIDD) » created in 2005.

The CITE is the largest green eligible expenditure in terms of budgetary cost, within the perimeter of green eligible expenditures defined for the Green OAT.

1.1. Households' eligibility

Tenants and owners can claim a tax credit only for their main home (i.e. not for their second home). The dwelling must have been built for more than 2 years.

Households receive the tax credit the year after completion of the dwelling's renovation. The tax credit is deducted from the amount of their income tax for the year after the renovation work. If they don't pay any income tax, households can get a refund on these expenditures.

Households have to keep proof of the expenditures paid, as the tax authorities may request them (invoice from the company that supplied the materials / equipment and carried out the work).

1.2. Eligible equipment

Eligible equipment and materials must meet minimum technical criteria regarding energy efficiency. The list of eligible equipment is described in the following table.

The companies carrying out the renovation works must comply with a label guaranteeing their qualification for energy efficiency renovations called the RGE label. The companies' staff has to undergo training in order to obtain the RGE label.

The minimum standards are set in absolute level, not in comparison with an average level of efficiency. They are far more ambitious than the average efficiency of materials sold in the market. Physical criteria are used to define eligible materials. For example, concerning insulation works, minimum level for thermal resistance factors are required.Those standards have been evolving over time, and are more and more stringent.

Table 1: Eligible expenditures in 2017[2]

Renovation type	Eligible equipment
Replacement of heating systems and heating control systems	High energy performance boiler
	Natural gas micro-CHP boiler
	heating control systems
Insulation	Thermal insulation material of walls (floor, ceiling, wall, roof)
	Thermal insulation material for glazed walls (windows, French windows, etc.)
	Entrance door to the outside
	Thermal insulation material
Renewable energy production equipment	Heating or hot water production equipment (solar or hydraulic energy)
	Electricity supply system (hydropower or biomass)
	Heat pump, other than air / air, whose main purpose is the production of heat or hot water
Other expenditures	Equipment for connection to an urban heat network
	Energy performance diagnosis (a single diagnosis per 5-year period for the same dwelling)
	Charging station for electric vehicles
	Individual meter for heating and hot water

[2] Refer to the decree https://www.legifrance.gouv.fr/affichCodeArticle.do?idArticle=LEGIARTI000023374187&cidTexte=LEGITEXT000006069576 (in French) for a detailed description of minimum standards for eligible equipment and materials

1.3. Tax credit rate

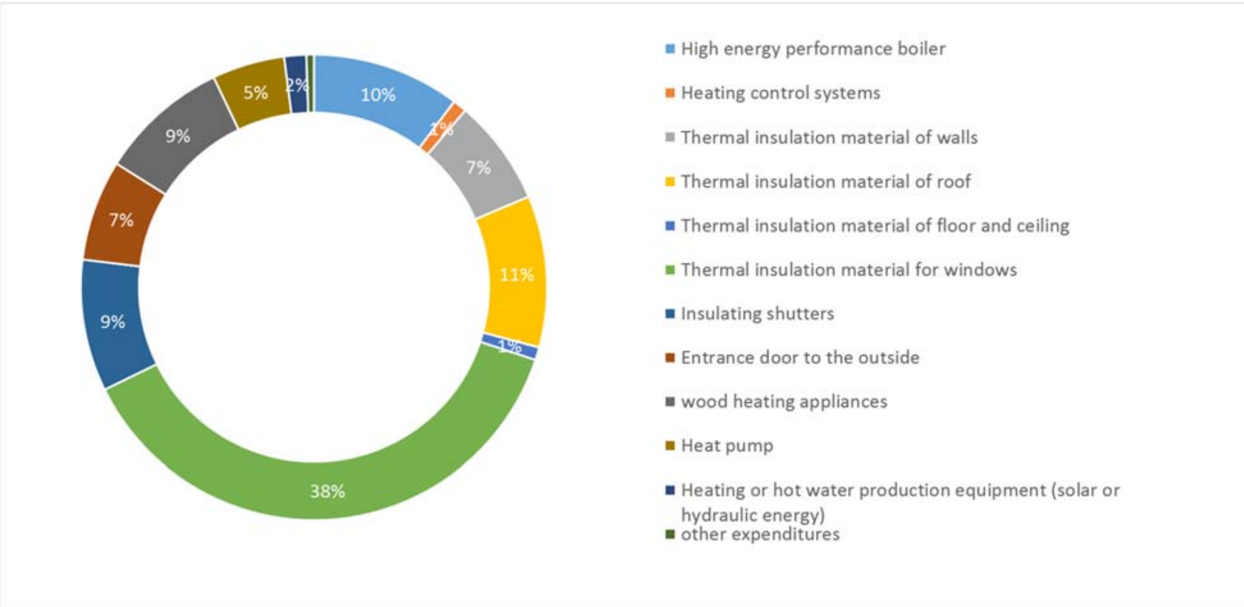
In 2016 and 2017, the tax credit rate is set at 30% of the amount of material expenditure. Labor is excluded from the base used for the calculation of the credit amount. Eligible renovation expenditures are capped at 16,000 euros for a couple, 8,000 euros for a single person plus 400 euros per dependent.

Budgetary cost and households' expenditures in 2016-2017

In 2016 and 2017, the budgetary cost of the CITE amounted to 1.68 and 1.69 billion euros for 1.5 and 1.66 million of beneficiaries. Due to its longevity and its high rate level, the use of the tax credit for renovation works is widespread[3].

The households' expenditures for 2016-2017 mainly concern insulation (73%). Replacement of heating systems and renewable energy investments represent respectively 11% and 16%. Within thermal insulation, replacement of windows accounted for a large part, which represent 4.7 billion euros of expenditures (1.4 billion euros of tax credit), *i.e.* 52% of the expenditures for insulation and 38% of total eligible expenditures.

Figure 1: Distribution of households's expenditures in 2016-20174



[3] From 2005 to 2014, a previous tax credit for energy efficiency renovations existed : the CIDD : « Crédit d'impôt développement durable »

[4] Source : https://www.impots.gouv.fr/portail/statistiques

2. Relevance of the CITE with respect to the French government's objectives regarding energy efficiency and greenhouse gas emissions

The energy consumption of the French housing sector (484TWh) represents, in 2016, 30% of the total energy consumption. Despite an ambitious energy efficiency policy, consumption has been hardly stabilized over the past years. The building sector is the most energy-intensive sector. With regards to GHG emissions, the building sector accounts for one quarter of national emissions in 2015. A major effort will have to be made to achieve the long-term objectives that France has set in terms of energy consumption and reduction of GHG emissions.

In 2015, France passed the energy transition and green growth law (*loi relative à la transition énergétique pour la croissance verte* (LTECV)), which is now the main legislation governing energy efficiency. It sets a number of environmental, economic and social objectives at the national and sectoral levels:

1. Decrease of final energy consumption by 20% by 2030 and 50% by 2050 compared to 2012. This objective is formulated at the national level (not declined by sector).

2. Decrease of GHG emissions by 40% by 2030 compared to 1990 (not declined by sector).

3. Renovation of 500,000 homes per year from 2017 onward.

4. Fade out of the most energy-intensive housing by 2025 (buildings with consumption of more than 330 KWh/m² per year).

5. Renovation of the entire housing stock at the "low energy consumption building" level by 2050 - a requirement interpreted here as a minimum performance equal to the B label of the Energy Performance Diagnosis (EPD).

6. A 15% reduction in energy poverty by 2020.

France also set targets for reducing GHG emissions as part of a national strategy called "Stratégie Nationale Bas Carbone (SNBC)" provided by the LTECV. The first SNBC decree sets a target of 27% emission reductions by 2028 (compared to 2013) for all sectors (among which the building sector is set an indicative objective of 54% reduction) and -75% by 2050 (in comparison with 1990).

France has recently reinforced this objectives with the "Plan Climat" in 2017 which:

- targets carbon neutrality for the whole economy in 2050;
- defines four key policies to reduce energy consumptions with a focus on reducing the impacts of the building sector (3 of the 4 priorities are directly targeting the building sector).

The CITE is one these four policies and the Plan Climat plans to extend it until 2019. It is one of the main incentives for households to improve the energy efficiency of their homes and to increase the number of energy efficient renovations in France which is still below the 500,000 homes per year.

The building sector is identified in the policy objectives as a main contributor to the reduction of GHG emissions and the promotion of energy efficiency. Due to low building stock renewal rate, energy retrofitting is a huge stake. Housing accounts for two third of the building sector. Therefore, the CITE presents a high level of relevance with respect to the French government's objectives.

3. Discussion about data and the necessity to use a model

The only observed data available on the renovations carried out with the CITE is the total household expenditure in eligible renovations by type of renovation. These expenditure data are aggregated at the national level and they do not allow us to make a direct detailed computation of the energy savings obtained from the renovations. Indeed, these renovations have been carried out on a large variety of dwellings and the gain related to a renovation depends on the energy performance and the state of the housing before the renovation.

Individual data including household expenditures and housing characteristics, such as date of construction, surface area, type of dwelling could help refine the analysis by better approximating the energy gain generated by a renovation. Nevertheless, without information on energy consumption before and after the completion of the work, the estimation of the energy gains would remain very approximate. No database currently regroups all this information in France.

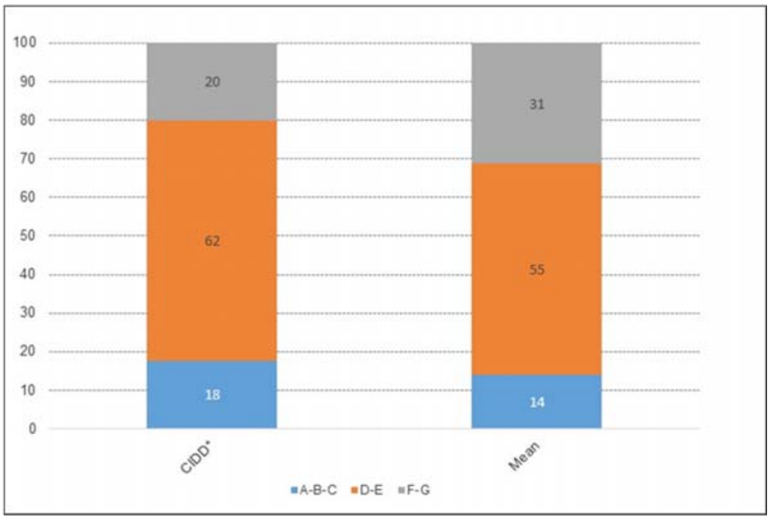
The second data source worth being mentioned (and that is used to calibrate the model), the Phébus survey, gives the state of the housing stock in 2012 and the energy consumption per dwelling on a sample of 2389 dwellings. These data also indicate whether the household received or not a tax credit to carry out a renovation during the five years preceding 2012. The Phébus data however remain insufficient to carry out an ex-post assessment of the impacts of the CITE because they do not provide the energy consumption before the renovation. In addition, the survey concerns 2012 and therefore the CIDD[5], the tax credit that preceded the CITE. This tax credit had a different subsidy rate and the eligibility criteria were different from those of the CITE. Finally, the survey only gives the total expenditure for the works carried out on the dwelling during the 5 years preceding 2012. This amount includes all dwelling improvement works, not only those which have an impact on energy efficiency. It is therefore difficult to identify the household expenditure on energy efficient renovations. Nevertheless, the study "Les ménages et la consommation d'énergie" (CGDD, 2017) uses this survey and shows that housings that benefited from the CIDD have a better energy performance (after renovation) than the average (see figure 2).

In France, energy performance of dwellings is rated from A to G according to their energy consumption per m² for heating, hot water and air conditioning.

To evaluate the impact of the CITE on energy consumption and GHG emissions, we therefore have to use an alternative approach which uses a model to convert renovation expenditures in energy savings. The specificity of the model used is to include a behavioural module that simulates renovation decisions made by households, given economical parameters such as energy prices and taxes, renovation costs and support schemes. This model does not represent every renovation gesture eligible for the CITE. It is based on a more macro view on energy renovation gestures (corresponding to the shift from an energy efficiency class to another). It is therefore not possible to use the model to provide gesture specific analysis (example: evaluate if one gesture is more profitable in terms of energy gain per euro invested).

[5] CIDD : « Crédit d'impôt développement durable »

Figure 2: Distribution (in%) of energy performance classes for dwellings that benefited from the CIDD (left) and for all dwellings (right).



Source : SOeS, Phébus survey

However, the model is calibrated so that the budget cost of the CITE and global energy consumption observed in the past are correctly re-simulated. Moreover, the model integrates dynamic building stock description and is able to estimate the impacts of policies in the long run (2050) and thus to give a more comprehensive vision of these impacts. These aspect is crucial because benefits of renovation are properly evaluated only in the long run.

The side-benefit of this approach is that:

- the model enables to identify and to assess the "additional" effect of the CITE scheme ("what would have been done without the scheme");
- it takes into account the long run effects of policies;
- it makes it possible to simulate "forward looking" scenarios, for example what would be the impact of the CITE if it is maintained after 2016. Such a scenario is assessed and the results are presented in Appendix.

The lack of data on energy savings concerning the CITE eligible expenditures makes the evaluation challenging to carry out. Energy savings have to be estimated. Therefore, the evaluation is based on a simulation model. The model relies on a simplified description of renovation gestures, but is calibrated using several statistical data, including energy consumption and CITE budgetary costs observed in the past. Its dynamic description of the building stock allows the integration of future benefits of renovation, to evaluate the additional effect of the CITE and to evaluate more prospective scenarios.

4. Description of the model and evaluation method

This section describes the general framework model. While we detail the heart of the model and its key assumptions, we do not provide a fully detailed description of the model. For a more precise description, please refer to the report by the CIRED [Bourgeois and Giraudet, 2018, forthcoming].

The Res-IRF model, version 3.0, developed by the CIRED enables to simulate the impacts of public policies on the evolution of the heating consumption and the GHG emissions of the housing stock in France. Since 2010, it is also used by the French Ministry for an Ecological and Solidary Transition to evaluate various environmental measures on the housing stock[6].

The model enables to simulate the following policy measures:

- the CITE;
- Carbon tax on energy;
- CEE (certificat d'économie d'énergie – certificate of energy savings) which is a scheme where energy suppliers are obliged to achieve energy savings for their customers;
- low VAT rate on energy efficiency renovations.

4.1. General description

The dwelling energy efficiency is characterised by a label: there are 7 different energy classes, from A – most efficient – to G, see table 2). Each class is defined by a range of "theoretical consumption", i.e. the theoretical consumption of the dwelling according to its physical characteristics (insulation, heating system, etc.). Today there are very few A or B housings, most of them are D and E (see below). From this initial state, the model simulates the French household's retrofitting decisions and heating systems choices. When a dwelling is renovated, its energy class changes.

The investment decisions are made on the basis of the comparison of the total cost of each choice. Their number and intensity are determined endogenously by the model. The renovation module constitutes the heart of the model (new construction and demolition are exogenous). The model calculates each year the number of class changes for each segment of the housing stock. The level of investment in energy efficiency renovations depends on the energy prices and the public policies that are activated in the simulation. Based on the building energy performance, the model then determines real energy consumption, taking into account the "rebound effect" which reflects the discrepancy between the theoretical consumption and the real one.

The output of the model gives the heating energy consumption and the greenhouse gas emissions of the French dwellings between 2012 and 2050 as well as investments in energy efficiency renovations.

As shown in figure 3, the behavioural module allows us to follow the evolution of the housing stock energy performance year-by-year and in the long run until 2050. It calculates each year the number of renovations for each class (which is a function of investment costs, energy prices, policies and households' characteristics) and the new

[6] See for example : CIRED, CGDD ; « Evaluation des mesures du Grenelle de l'Environnement sur le parc de logements » ; Etudes et Documents, 2011

state of the housing stock in the following year.

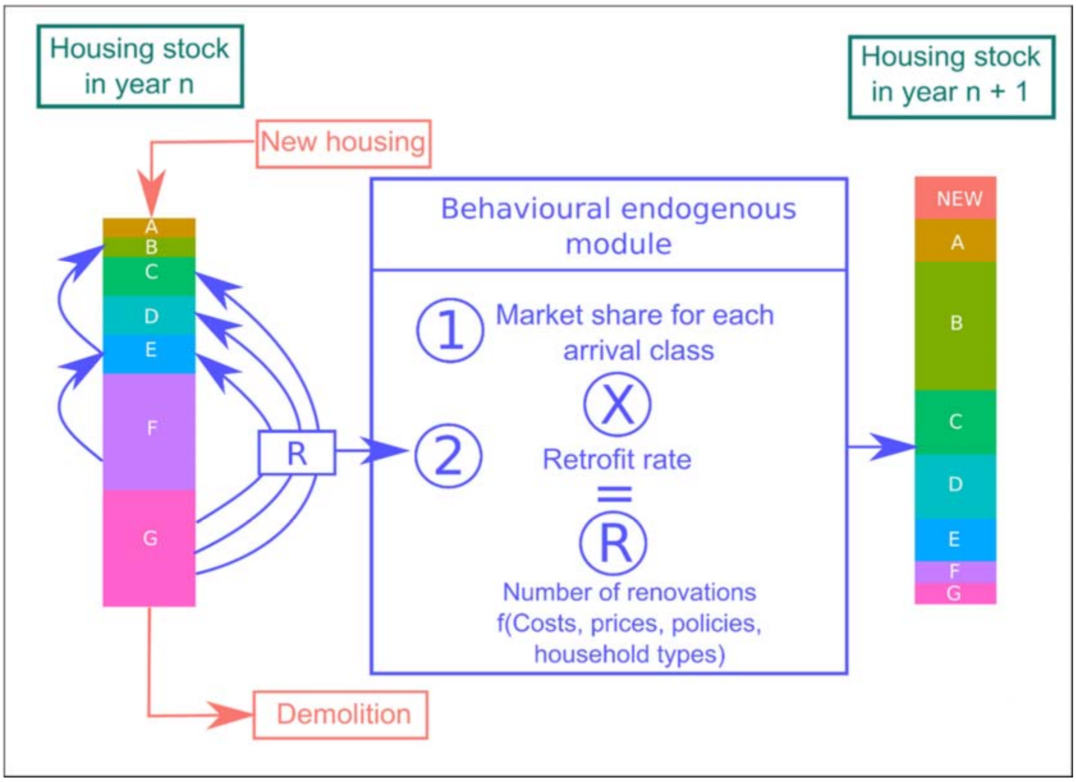


Figure 3: Housing stock dynamics in the Res-IRF model

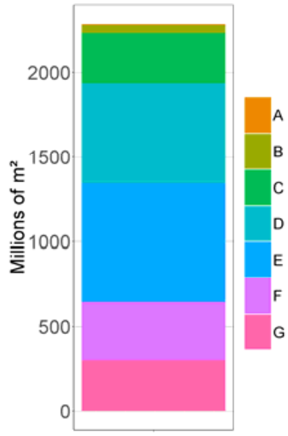
4.2. Initial building stock energy performance description

In the model, the initial state of the housing stock in 2012 is given by a French survey called "Performance de l'Habitat, Équipements, Besoins et Usages de l'énergie (Phébus) ». This survey gives the housing stock by dwelling type (apartment / house), main heating energy (electricity, gas, fuel oil, wood), energy efficiency (7 energy performance classes[7]) and also gives information on households incomes. The model has recently been upgraded to represent 5 types of households based on their income (5 income quintiles). The figure 4 shows the initial distribution of energy performance classes in the model.

The Phébus survey provides information on the energy class (A to G). It also gives more precise information by giving the theoretical consumption in KWh/m2 of dwellings. This information enables to determine the average theoretical consumption in each energy class (see table 2).

[7] In France, energy performance of dwellings is rated from A to G according to their energy consumption per m² for heating, hot water and air conditioning.

Figure 4: Housing stock energy performance in 2012



Source: Enquête Phébus, Res-IRF model

Table 2: Heating energy consumption (theoretical) by energy performance class in the model

Energy performance class	Heating energy consumption (KWh_{EP}/m²/an)
G	507
F	321
E	216
D	141
C	90
B	59
A	45

Source: Enquête Phébus, Res-IRF model

4.3. Actual energy consumption calculation and calibration

Theoretical consumption is just an assessment of the theoretical energy performance of the building. When we look at public statistics on theoretical consumption of dwellings and actual consumption recorded on household bills, we observe a significant difference. This difference can come from various factors. For example the accuracy of the labelling process can questioned. Another reason, probably more important, is the so called “rebound effect” that appears after renovation. While improving the energy efficiency of their dwelling, households choose to use a part of the gain on the energy bill to improve their thermal comfort. On one hand, the rebound effect has negative impact on future benefits expected from housing renovation, because the expected energy savings and CO_2 emissions reduction are reduced. On the other hand, the rebound effect stems from household surplus maximization. This behaviour brings them additional surplus that has not been evaluated here.

The model integrates a function which allows to pass from the theoretical consumption of the dwelling (as given by its energy class) to the actual consumption of the household.

The relationship between the theoretical and the actual energy consumption of the household used in the model was established by French studies from “EDF R&D »[8]. It links the actual and theoretical consumptions as follows:

$$EI = -0.191 * ln(BS) + 11.05$$

$$EI = \frac{C_A}{C_T}$$

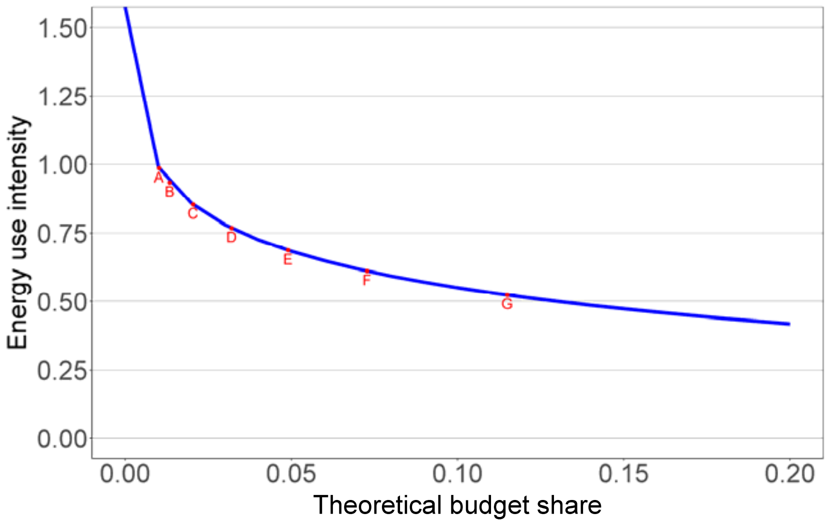
$$BS = \frac{p_e * C_T * S}{I}$$

where **EI** is the energy use intensity i.e. the ratio between the actual energy consumption per m² of the household (**C_A**) and the theoretical energy consumption per m² given by the energy class of the housing (**C_T**). **BS** is the budget share of the theoretical energy expenditures of the household (**p_e** the energy price, **S** the surface of the housing and **I** the household’s income).

Figure 4 presents the relationship between the budget share and the energy use intensity. The marks for each energy performance from A to G are calculated for an average household living in a dwelling of S = 85 m² with an income of I = 30,000 euros. We use an energy price of 0.07 euros per KWh which is the average price of gas in France in 2015 for a household. Figure 5 shows that as energy efficient renovation are performed, the household increases its energy use intensity which will reduce the impact of renovations on its heating energy consumption.

[8] Allibe, B., 2015, "Du normatif au réaliste : amélioration de l’évaluation technico-économique du bénéfice des rénovations énergétiques des logements", La Revue du CGDD, 37-46. Cayla, J.-M., D. Osso, 2013, "Does energy efficiency reduce inequalities? Impact of policies in Residential sector on household budget", Proceedings of the ECEEE Summer Study.

Figure 5: Relationship between the budget share of the theoretical energy expenses and the energy use intensity



This relationship is applied to the theoretical consumption of the initial state of the housing stock in

2012 which is differentiated in the model by energy performance class, heating energy, dwelling type and household income. It gives the total actual heating consumption by energy of the housing stock which is then calibrated at the national level on 2013 statistical data from "Centre d'études et de recherches économiques sur l'énergie (CEREN)". The model does not represent the energy consumption of other uses like hot water or electricity specific uses. However, heating consumption represents 2/3 of the energy consumption of the housing sector in France (320 Twh in 2016).

In the end, the model enables to take into account real behaviours, not only energy technical performance of renovation, to determine energy consumptions. It gives a realistic and careful assessment of the benefits expected from building retrofit.

4.4. Renovation cost assumption

The renovation costs for each energy class changes are fixed according to the two following principles:

i. The retrofit cost structure complies with the principle of increasing marginal cost. Typically, the highest the energy class, the higher the cost (per KWh/year saved) to reach it.

ii. The average investment cost obtained by the model is calibrated so that it is in line with the results of the French survey called "Observatoire permanent de l'amélioration énergétique du logement (OPEN)" which gives detailed information about renovation costs and energy savings in France over the 2012-2014 period. Therefore, average investment cost obtained by the model for year 2012 is 112 euros per m² which is close to the average renovation cost of 110 euros per m² reported in the OPEN survey.

Investments costs used in the model are presented in table 3. It indicates for example that the cost to retrofit a dwelling from class F to class B Is 286 euros per m². Each class jump in this table correspond to one or several renovation gestures that are not directly identified in the model. This report will therefore not provide gesture specific analysis.

Table 3: Investment costs matrix in the model

	F	E	D	C	B	A
G	76	136	200	270	350	441
F	0	63	130	203	286	381
E	0	0	70	146	232	330
D	0	0	0	79	168	270
C	0	0	0	0	93	198
B	0	0	0	0	0	110

This table reports the amount (in euros per m²) a household needs to invest to change the energy performance class of his dwelling from the class in the first column to the class in the first line of the table.

The model integrates a representation of technical progress by reducing renovation costs as the housing stock is renovated. The idea is that costs are reduced over time through imitation and learning. In the model, investment costs decrease exponentially with the cumulative amount of renovations so as to simulate a "learning-by-doing" process. The cost reduction rate for a doubling of renovations is set at 10%.

4.5. Renovation decision modelling and calibration

The heart of the model is constituted by a behavioural module that calculates the number of dwellings that will be retrofitted. To do so, two functions are used:

(1) A function that calculates the market share of each energy efficiency class improvement

A building retrofit is achieved when the energy efficiency class of the dwelling is improved. The market share of the gesture “renovating from the class i to the class f”, is given by the following equation:

$$\mathbf{PM}_{i,f} = \frac{\mathrm{CCV}_{i,f}^{-\backslash v}}{\sum \mathrm{CCV}_{i,k}^{-\backslash v}}$$

where CCV is the levelized total cost for each operation, and *v* a heterogeneity parameter that represent the variety of choices.

(2) A retrofit rate function

For each class of energy efficiency, the average cost to renovate to upper classes is calculated with the previous function. Then, a logistic function defines the renovation rate of this class.

These two functions are calibrated[9] for year 2012 to fit with the observed figures when available, or with assumptions if not. In particular for the retrofit rate, data from OPEN survey and USH[10] are used. Renovation costs and energy prices used in the calibration integrates major public policies that existed in 2012. Indeed, public policies and fiscal incentives (tax credit, subsidies, carbon tax...) have an impact on the levelized total cost for each operation, influencing either the investment cost (which is the case for the CITE) or the energy bill savings (e.g. carbon tax). Therefore, they induce changes in renovation decisions (see below for the CITE).

4.6. CITE calibration

Concerning the CITE, it applies only on eligible equipment cost, not the total investment cost mentioned above. Thus, the CITE rate to be implemented in the model cannot be the real one. It must be calibrated in the model to reproduce as precisely as possible the observed budgetary cost of the CITE in public statistics.

In 2012, the subsidy rate for the CITE applied in the calibration is 7%. It is the rate for which the model simulates a total cost of 700 million euros for the tax credit which was the amount of tax credit[11] delivered in 2012 (Source: DGEC). In the same way, from 2013 to 2016, the CITE is calibrated in the model to reproduce as precisely as possible the observed budgetary cost of the CITE in public statistics.

In 2015 and 2016, the years where we assess the effects of the CITE, the subsidy rate in the model is fixed to 18%. It is lower than 30% because it takes into account the subsidy cap and the fact that the subsidy does not cover all expenditures, particularly labor costs. In 2015, the model simulates a total cost of 1.65 billion euros for the CITE which corresponds to the current observed budgetary cost of the CITE.

Table 4: Observed and simulated budgetary cost for the CITE

Renovation year (model year)	2012	2013	2014	2015	2016
Observed public budgetary cost year	2013	2014	2015	2016	2017
Observed public budgetary cost (billion euros)	0.7	0.7	0.9	1.7	1.7
Simulated CITE cost (billion euros)	0.7	0.7	0.8	1.7	1.7

[9] In the model, calibration is achieved thanks to an additional investment component added to total cost corresponding to "unobserved costs" for renovation.
[10] Union sociale pour l'habitat (USH) are used to calibrate social housing retrofit rate
[11] From 2005 to 2014, a tax credit on renovation works, the CIDD, already existed.

4.7. Other assumptions

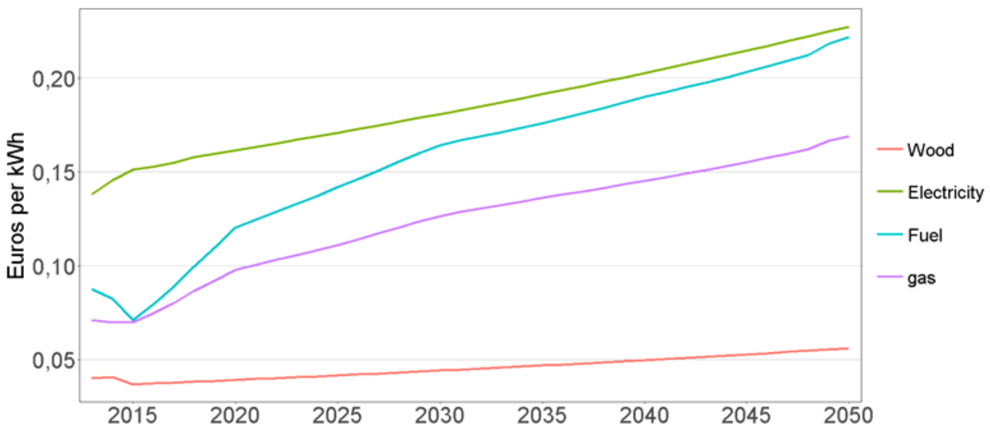
We use energy price scenarios currently used in all French public policies assessments (see table 5).

Table 5: Annual growth rate of energy prices (inclusive of all taxes but carbon tax, constant euros 2015)

	2015-20	2020-30	2030-50	Source
Gaz	0.84%	4.28%	1.59%	European Commission (EU reference scenario 2016)
Oil	9.96%	4.47%	1.40%	European Commission (EU reference scenario 2016)
Electricity	1.10%	1.10%	1.10%	DGEC (Scenario AME 2017)
Wood	1.20%	1.20%	1.20%	DGEC (Scenario AME 2017)

The prices include the following taxes: CSPE on electricity, TICGN on natural gas, TICPE on oil. The carbon tax, when activated, is added to energy prices, accordingly to their CO_2 content.

Figure 6: Energy prices evolution by heating energy (all taxes included)



To convert energy consumptions in GHG emissions, we use fixed CO_2 contents per energy (see table 6).

Table 6: CO_2 content per energy used to calculate emissions (Source: ADEME)

	g of CO_2 per KWh
Natural gas	206
Oil	271
Electricity	120
Wood	0

4.8. Evaluation method

In order to study the impact of the CITE on the energy performance of the housing stock, **two scenarios have to be compared:**

- A **"counterfactual or CF"** scenario where no CITE is activated in the model from 2015 onward. All other policies are maintained12.
- A test scenario **"CF + CI2years"** where the CITE is activated in 2015 and 2016 and stopped afterwards. All other policies are maintained.

It is important to note that the effects of the CITE last beyond the years of implementations of the scheme. Indeed, the benefits from more energy efficient buildings have to be considered over several decades in terms of energy consumption and CO_2 emission reductions. Moreover, due to a larger number of renovations during those two years (in the example of the "spot CITE" scenario), the building stock is modified, influencing the future renovation decision (while marginally). In comparison with the counter-factual scenario, this renovation acceleration during two years could be followed, when the support scheme is removed, by a period with a lower renovation rate and less investments in renovation works.

Table 7: scenario description

		2015	**2016**	**2017**	**2018**	**...**		**2050**
CF	CITE	no	no	no	no	no	no	no
	Other policies	yes	yes	yes	yes	yes	yes	yes
CF+CI2years	CITE	yes	yes	no	no	no	no	no
	Other policies	yes	yes	yes	yes	yes	yes	yes

5. Detailed results

[12] The underlying objective here is to make an assessment « all other things being equal ». The effect of CITE is thus entangled with the effect of other policies which cover the same renovation works. One may also estimate the impact of CITE by comparing a baseline scenario with no other policies ("no policy" scenario) to a situation with no policy except the CITE ("no policy +CI" scenario). Comparing the "no policy" and "no policy + CI" scenarios would therefore give an approximation most likely an upper value for the effects of CITE without interactions with other existing policies. Sensitivity tests using this alternative method are included in V.

This part addresses item by item the requirements listed in the terms of references (ToR). The indicators suggested by the ToR (part 3) are displayed in each 5 chapters mentioned in part 2 and addressed here. The chapters' order has been slightly changed for better understanding (the "cost distribution effect of the CITE" is tackled in second position instead of last one, since it is an input to figure out the leverage effect addressed in "the additional effect of the CITE" chapter). The subsections are organized as follows:

- Relevance and effectiveness of the CITE
- Cost distribution analysis
- Additional effect of the CITE
- Economic efficiency of the CITE
- Sensitivity analysis

5.1. Relevance and effectiveness of the CITE

The CITE reduces energy consumption and CO_2 emissions respectively by about 0.9 TWh and 0.12 $MtCO_2$ per year in 2015 and 2016. These effects last for several years: over the 2015-2050 period, 2.9 $MtCO_2$ and 43 TWh of energy consumption are avoided when the CITE is removed in 2017. The cumulative gain of CO_2 emissions over 2015-2050 triggered by additional 2015 investments corresponds to 7% of the 2015 level of CO2 emissions of the housing sector.

Impact on energy consumption and annual CO_2 emissions

We first compare the heating energy consumption and **CO_2** emissions of the scenarios "CF" and "CF+CI2years" in table 8. This table reports the annual differences in the consumption and emission level between the two scenarios.

The CITE reduces energy consumption and GHG emissions in comparison with the scenario without the CITE. The annual gain in 2015 and 2016 is about 0.9 TWh and 0.12 $MtCO_2$ per year. This corresponds to 0.3% of the heating energy consumption and 0.3% of the CO_2 emissions of the housing sector.

In the years following 2016, the CITE is no longer maintained in the "CF+CI2years" scenario. Thus, the differences in the consumption and the emission levels between the two scenarios is gradually reduced over time. This seems to indicate a lower renovation rate and less investments in renovation works in the "CF+CI2years" scenario after 2016. As energy prices rise, households spontaneously retrofit their dwellings in the scenario "CF" and the consumption gap between the two scenarios is reduced. Nevertheless, in 2050, the energy consumption and emissions is still lower in the "CF+CI2years" scenario where the CITE was maintained only in 2015 and 2016. This indicates that the CITE has helped keeping the housing stock on a more virtuous path.

Furthermore, over the 2015-2050 period, the cumulative energy savings and GHG emission reductions generated by the CITE amount to 43.1 TWh and 2.9 $MtCO_2$.

Table 8: Annual Differences in energy consumption and CO_2 emissions between the CF + CI2years scenario and the CF scenario

	2015	2016	2020	2030	2050	Total 2015-2050
Emissions ($MtCO_2$)	-0.13	-0.24	-0.17	-0.08	-0.02	-2.90
Energy consumption (Twh)	-0.89	-1.76	-1.59	-1.29	-0.80	-43.10

5.2. Cost distribution analysis

The model is calibrated to simulate a budgetary cost for the CITE of 1.7 billion euros per year for 2015 and 2016. Effects of the CITE on the budget of other policies and taxes have been neglected. The cost of the CITE for households is an additional investment of 3.4 billion euros in 2015-2016. It enables long run energy bill savings that almost cover the additional cost. Thanks to the tax credit, the investment in energy efficiency is highly profitable for the households. It allows them to save 2.2 billion euros over the 2015-2050 period.

5.2.1. Impact on the State finances

The direct cost for the State is the cost of the CITE. **For 2015 and 2016, it is straightforward as the model was calibrated to reproduce the observed cost of the CITE in public statistics (around 1.7 billion euros in 2015 and 2017).**

Beside the direct costs of the CITE, “second round effects” can impact the State finances.

The cost of other support schemes can be impacted. For example the CITE scheme interacts with other measures, like the Eco-PTZ. Indeed both schemes are cumulative and households who benefit the Eco-PTZ benefit the CITE too. Some of the additional beneficiaries of the CITE will receive the Eco-PTZ. Therefore, the CITE has an impact on the Eco-PTZ public cost. Rigorously, this effect should be taken into account to figure out the total impact for the State finances. Given the modest amount of the Eco-PTZ budgetary cost, this effect has been neglected.

More generally, the scheme has complex impacts on tax revenues. Energy tax revenue is impacted since the energy consumption is impacted. Indeed, electricity, natural gas and fuel are taxed at different levels. Moreover, for the two latter, the carbon tax applies. So, every change in energy consumption modifies the amount of tax revenue. Besides, a raise in building sector investment has a boosting effect in economic activity, and thus on VAT revenue. So, tax revenue effects are numerous and can be negative or positive. These revenue changes have also been neglected.

5.2.2. Impact on households: impact on investment in energy efficiency

renovation, households' energy bill and net cost

The CITE encourages households to invest in renovation works. In return, it allows them to reduce their energy consumption and their energy bill.

In 2015 and 2016, the CITE leads to additional investments of 1.7 billion euros per year (table 9). This represents an increase of 16% of total investments in renovation in 2016. The energy bill of the households is reduced by 0.06 billion euros per year in 2015 and 2016.

The period after 2016 is characterized by a lower investment level in the scenario "CF + CI2years" than in the "CF" scenario which explains why the annual differences are negative after 2016 in table 9. This is due to the higher performance of the building stock after two years of CITE with a high level of energy retrofit, which reduces the potential number of highly profitable renovation remaining.

On the contrary, the energy bill savings last after 2016 and households still save 0.07 billion euros per year in 2050 due to the CITE.

Table 9: Annual impact on investment and energy bill savings between the CF + CI2years scenario and the CF scenario

	2015	2016	2020	2030	2050
Investments (G€)	1.71	1.69	-0.07	-0.07	-0.04
Energy bill savings (G€)	0.06	0.13	0.13	0.11	0.07

In order to evaluate the impact of the tax credit on households over the period 2015-2050, we calculate the cumulative additional investments in energy efficiency and the cumulative energy savings. The households also receive the CITE tax credit for their renovation so we have to include the cumulative CITE tax credit to calculate the net cost for households. We use a discount rate of 7% (from the households' point of view) those cumulative values.

We also consider that the energy bill savings persist 10 years after 2050. We thus add 10 times the value of these gains in 2050 to the cumulative savings.

Table 10 shows the results of these calculations when the CITE is only maintained until 2016. The values correspond to the differences in investments, tax credit costs, energy bill savings and emissions between the CF+CI scenario and the CF scenario.

Table 10: Net cost for the households in the long run

	Investments (billion euros) (a)	CITE tax credit (billion euros) (b)	Energy bill savings, all taxes included (billion euros) (c)	Net cost without tax credit (a)-(c)	Net cost (a)-(b)-(c)
« CF+CI2years»-CF	2.6 (1.6)	3.2 (3.3)	1.6 (3.5)	1.0 (-1.9)	-2.2 (-5.2)

NB: Investments, CITE tax credit, energy bill savings are cumulative and discounted at 7%. The non-discounted values appear in parentheses below the discounted quantities.

Over the 2015-2050 period, the reduction in the energy bill allows the households to save 1.6 billion euros for a total additional investment of 2.6 billion euros. The net cost for households without the CITE would therefore not be profitable without the CITE tax credit that amounts to 3.2 billion euros for the 2015-2050 period. With the CITE tax credit, the net cost for households is -2.2 billion euros.

5.3. Additional effect of the CITE

The CITE triggers around 75,000 additional renovations per year in 2015 and 2016 which represents about 1.7 billion euros of energy efficiency investments per year.

Renovation operations are more ambitious with the CITE than those made without the CITE.

The CITE improves the energy efficiency of the housing stock. Dwellings with a low energy consumption (A or B) have increased by 39,000 at the end of 2016. The CITE incentive in 2015 and 2016 helps to keep the housing stock on a more virtuous path as dwellings with a low energy consumption have increased by 71,000 at the end of 2050.

The average heating consumption per m² of the housing stock is reduced by 0.6% in 2050.

The ratio between additional investments in energy efficiency compared to the situation without the CITE and public expenditures related to the CITE budgetary cost is a bit more than 1 for 2015 and 2016.

This part focuses on various indicators to evaluate the additional effect of the CITE. This is possible because the Res-IRF model has a behavioural module that allows us to simulate the evolution of the housing stock with and without the CITE (counterfactual scenario).

5.3.1 Number of beneficiaries and numbers of renovations with and without the scheme

The CITE triggers more investment in renovation works and about 75,000 additional renovations (understood as a jump from an energy class to another) per year of implementation, which represents an increase of 11%.

The period after 2016 is characterized by a slightly lower renovation rate in the “CF + CI2years” scenario. This is due to the higher performance of the building stock after two years with a higher retrofit rate, which reduces the potential number of highly profitable renovation remaining. This explains why the number of renovations is higher in the “CF” after 2016. Over the 2015-2050 period, the total number of additional renovations is 97,000.

Table 11: Additional number of renovations and investment between the CF + CI2years scenario and the CF scenario

	2015	2016	2020	2030	2050	Total 2015-2050
Number of renovations	75,000	76,000	-1,000	-2,000	-3,000	97,000
Investment (billion euros)	1.71	1.69	-0.07	-0.07	-0.04	

5.3.2. Level of performance of renovations with and without the scheme

It is interesting to determine the number of additional renovations but also whether renovations are more ambitious with the CITE than those done without the CITE. We can get an idea on the intensity of renovations in both situations by comparing the relative increase of the number of renovations (11%) and the relative increase of investments (16%) which is higher. In the model, the more ambitious the renovations are the more costly they are. It implies that **renovations are, in average, more ambitious with the CITE than those done without the CITE.**

5.3.3. “Leverage effect” of the CITE understood as additional private investment per public euro invested

The ratio between additional investments in energy efficiency compared to the situation without the CITE and public expenditures related to the CITE budgetary cost, ratio we will call “leverage effect” of the CITE, is around 1 in 2015 and 2016. This is due the fact that all the renovation works achieved in the scenario without the tax credit receive the tax credit as the additional renovation work in the scenario with the tax credit.

Table 12: Additional investment per euro of tax credit, reference = CF scenario

scenario	2015	2016
CF+CI2years	1.04	1.02

The leverage effect for one year is calculated from one single scenario (the one with the CITE) by comparing, for this year only, two different situations: with and without the CITE (just this year).

Even if this leverage effect is around 1 or less than 1, this does not mean that the CITE has no impact on renovation. Indeed, when the CITE is activated in the model, it has three possible effects:

- Some households that would not have renovated their homes choose to renovate it. The leverage effect is far more than 1 for those households. On eligible equipment, the leverage is 100/30, since the subsidy rate is 30% in the model. But works may also include non-eligible equipment and labour cost, meaning that total leverage is higher[13].
- Some households that would have renovated their homes without the CITE perform a renovation more ambitious with the CITE than without it. For example, some households can choose to renovate their home from energy class G to C while they would have only change from G to D, without the CITE. They receive the tax credit for the whole amount of the work they would have perform without the CITE plus the tax credit for the additional investment. The leverage effect for these households depends on the parameters in the model but is near 1.
- Some households that would have renovated their homes without the CITE perform the same renovation with the CITE. The leverage effect for these households is zero here. In reality, the CITE may lead to additional benefits not captured by the model: the fact that, to be eligible, works have to be made by "RGE" firms, ensures a better quality of the renovation. Moreover, consumer outreach may improve investment choices (without changing the energy class reached) and provide incentives for energy savings.

The effect of the CITE on investments depends on the number of households in each of these three categories. As far as it goes, the output of the simulation have not been analysed to determine the proportion of the three categories of situation. But previous results can give a clue on this issue: renovations number increases by 11%, meaning that there is a significant part of households in the first category. We also know that average performance of energy retrofit is better with the CITE. This means that there must be households in the second category that would have done works even without the CITE but less ambitious ones.

Phébus survey gives interesting insights on this subject. When households are asked if the CIDD had an impact on their renovation work, 57% answer that they would have performed the same renovation without the tax credit (table 13). The rest of the households declares that they would have delayed the renovation, performed less ambitious works, performed a renovation themselves without using a labeled professional or performed no work at all.

13 In the model, the subsidy rate is 18% to take into account the fact that works cost not only includes eligible equipments (see Description of the model part). On this basis, we have a 100/18 leverage effect.

Table 13: Impact of the CIDD (ex-CITE) on household's renovations

	Share of answering households
work delayed without CIDD	16%
less amibitous work without CIDD	11%
no work without CIDD	11%
work without a professional	4%
no impact of the CIDD	57%

Source: Phébus survey

5.3.4. Energy efficiency of the housing stock with and without the scheme

Two indicators are presented.

(i) Differences in the dwellings numbers by energy class

The CITE improves the energy performance of the housing stock by triggering more renovation works, i.e. more jumps from one energy intensive performance class (F,G,E) to less energy intensive performance classes. Table 14 shows the differences in the dwellings numbers by energy class between the CF + CI2years scenario and the CF scenario.

As shown in the below figure, dwellings with a low energy consumption (A or B) have increased by 39,000 at the end of 2016 due to the CITE. 155,000 energy intensive dwellings (F, G, E) have been retrofitted at the end 2016.

In 2050, dwellings with a low energy consumption have increased by 71,000 which is more than the spot increase due to the CITE in 2016. This shows that the CITE helps the housing stock to keep a more virtuous path. More ambitious jumps from energy intensive classes to less energy intensive are performed all over the 2015-2050 period.

Figure 7: Differences in the dwellings numbers by energy class between the CF + CI2years scenario and the CF scenario in 2016

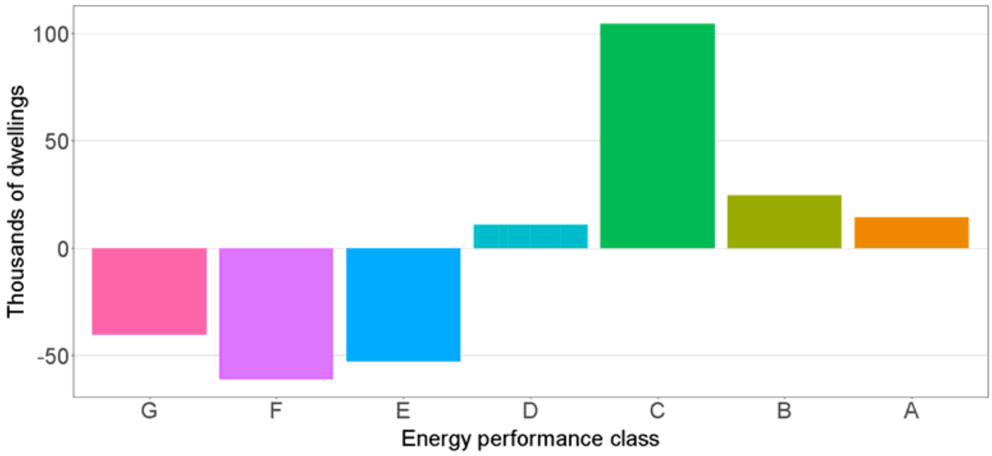


Table 14: Annual differences in the dwellings numbers by energy class between the CF + CI2years scenario and the CF scenario (thousands of dwellings)

Energy performance class	2015	2016	2020	2030	2050
A	6	14	20	45	71
B	11	25	40	69	17
C	52	104	85	13	-1
D	8	11	3	-24	-43
E	-25	-53	-67	-72	-39
F	-31	-61	-52	-22	-4
G	-21	-41	-28	-9	-2

<u>(ii) Average heating energy consumption per m²</u>

We report here the impact of the CITE on theoretical energy heating consumption per m² of the housing stock. This means that we only report the evolution of the energy efficiency of the buildings in the stock without taking into account the adjustments of households on their actual energy consumption (rebound effect after a renovation, lower heating restrictions).

The average heating consumption per m² of the housing stock are reduced by 0.9% in 2016 and 0.6% in 2050 (see table 15).

Table 15: Average heating energy consumption per m² by scenario

scenario	2015	2016	2020	2030	2050
CF	157.9	152.0	129.3	89.6	53.6
CF+CI2years	157.3	150.7	128.3	89.0	53.3

The impact on average heating energy consumption per m² is quite modest, as expected. This indicator relates to the quality of the whole building stock, while renovations only affect a small percentage of this stock (around a few percent). Moreover, the effect CITE on the renovation level only lasts during the two years of implementation.

5.4. Economic efficiency of the CITE

The average cost per ton of CO_2 avoided by the investments made in 2015 and 2016 is estimated at 240 euros per ton discounted over 2015-2050. This cost can be interpreted as the price of CO_2, constant over 2015-2050, that would be needed to make these investments profitable.

The average cost per MWh saved by the investments made in 2015 and 2016 is estimated at 20 €/MWh discounted over 2015-2050. This cost can be interpreted as additional price of MWh, constant over 2015-2050, that would be needed to make these investments profitable.

In economical terms, building energy retrofit implies investment cost (private and public financed) and enables energy bill savings. In turn, better building energy efficiency contributes to reach France environmental goals concerning energy consumption and GHG emissions reduction. Therefore, the cost efficiency can be measured by putting in balance the economical cost (investments less energy bill savings) with the quantity of energy and GHG saved. These approach enables to construct indicators like the cost to avoid 1tCO_2 emission (rebate cost) and the cost to save 1MWh.

Caveat

It must be emphasized that these indicators are quite blunt and can be misleading in terms of policy management. Indeed, policy objectives are not only focused on GHG and energy and take into account other aspects (air quality, noise insulation, poverty reduction, health improvement, etc.). But these indicators give an order of magnitude of the cost efficiency with regards to the objectives analysed here.

Methodology

To evaluate the impact of the tax credit over the entire period 2015-2050, we calculate cumulative investments in energy efficiency, cumulative CITE public costs as well as cumulative gains in households' energy expenditures (calculated with energy prices without taxes14) and cumulative avoided emissions. Following the French guidelines for evaluating public investments (Quinet report, 2013), we use a rate of 4.5% to discount those cumulative values.

We also consider that the gains on energy expenditures and emissions persist 10 years after 2050. We thus add 10 times the value of these gains in 2050 to the cumulative gains. Table 16 shows the results of these calculations when the CITE is only maintained until 2016.

The values correspond to the differences in investments, tax credit costs, energy expenditures and emissions between the CF+CI scenario and the CF scenario.

The ratio between additional investments less the gains on the energy bill and the cumulative avoided emissions (((a) – (b)) / (d)) gives the average socioeconomic cost of one avoided ton of CO_2. It is the average cost of the emission reduction over the entire period, which is interpreted as the average price per ton of CO_2 that is to be applied over the period to make the investments profitable. Similarly, The ratio between additional investments less the gains on the energy bill and the cumulative energy savings (((a) – (b)) / (c)) gives the additional cost per MWh saved. It is interpreted as the average socioeconomic cost to reduce energy consumption over the period.

Results

Table 16: Socioeconomic assessment of the CITE between 2015 and 2050 (CITE removed in 2016)

	Investments (Billion euros) (a)	Budgetary cost ot the CITE (Billion euros)	Gains on energy expenditures, without taxes (Billion euros) (b)	Energy consumption (TWh) (c)	CO_2 emissions ($MtCO_2$) (d)	Cost per ton of CO_2 (euros per ton) ((a) – (b)) / (d)	Cost per MWh (euros per MWh) ((a)-(b))/(c)
« CF+CI 2years»-CF	2.4	3.3	1.9	-25.8 (-43.1)	-2.0 (-2.9)	236	18

NB: Investments, CITE expenditures, energy expenditures, avoided emissions and consumption are cumulative and discounted at 4.5%. The non-discounted cumulative emissions and energy consumption appear in parentheses below the discounted quantities.

Over the 2015-2050, CITE reduces by 1.9 billion euros (discounted) the household energy expenditures for additional investments in renovations works of 2.4 billion euros. The socioeconomic cost of the avoided ton of CO_2 is estimated at 236 euros per ton. The socioeconomic cost of the MWh saved is estimated at 18€/MWh.

5.5. Sensitivity analysis

The sensitivity analysis shows that the most sensitive parameters in the model are investment costs and the difference between theoretical (derived from energy labelling process) and realized energy savings.

[14] Taxes on fuel and natural gas (TICPE and TICGN, which include CO_2 tax) have been removed from the prices. The CSPE tax on electricity has been kept since it is supposed to contribute to cover the cost of the development of electrical renewable energies. Therefore this tax can be seen as a component of electricity production cost.

Air pollution reduction cannot be worked out by the model. However, an ad hoc simplified approach provides an order of magnitude and confirms that the social benefit associated is a first level issue.

5.5.1. Model additional runs with alternative assumptions

Two alternative simulations were performed to test the robustness of the results described above:

(i) Even if the OPEN survey, used to calibrate assumptions on renovation costs, gives interesting elements, it also shows a wide dispersion in values, disclosing wide uncertainty. As cost assumption is key to the model functioning, a sensitivity test has been done with investment costs 20% lower.

(ii) As explained in part IV.3, the model integrates a representation of energy consumption that enables to explain the difference between theoretical consumption of dwellings given by the energy label and actual consumption. As explained above, this difference stems from several reasons, not only the "rebound effect", but also incomes and accuracy of the labelling process (actually it is not possible to disentangle the effect of the rebound effect with other effects). As it is a sensitive part of the model, we perform a test where actual energy consumption matches with theoretical energy consumption for each energy label.

(iii) As described in table 6, we used a CO_2 content for electricity of 120 g per KWh to calculate emissions related to electricity. This value depends on the energy mix used to produce the electricity needed to heat housings. The referees suggested to perform a sensitivity test with a higher value for electricity CO_2 content. We thus perform a calculation of the CO_2 emissions avoided and of the Cost per ton of CO_2 with a CO_2 content for electricity of 360 g per KWh.

Table 17 summarizes the results of these simulations. The line « CF+CI »-CF reference simulation is a reminder of the previous results of the report.

If we calibrate the model with investment costs 20% lower, the cost per ton of CO2 and the cost per MWh saved are significantly reduced and turn negative because investments are reduced by 20% while energy bill savings, CO_2 emissions reduction and energy savings are constant. An alternative sensitivity test with +20% higher costs has not been properly performed with the model. However it is possible to have a guess on the result. Inspired by the -20% test, whose effects show that investment amount decreases by 20%, energy savings slightly increases to 2 billion euros and CO_2 emission reductions slightly increases to 2.1 Mt, we can assume that in the +20% cost test, investment amount is +20% higher at 2.9 billion euros, energy savings are 1.8 billion euros and CO_2 emissions slightly lower, at 1.9 $MtCO_2$. On this basis, CO_2 abatement cost would be about 500 €/tCO_2.

If it is assumed that households don't adapt their thermal comfort after renovating their dwelling (no rebound effect), energy savings and emission reductions are higher and the abatement cost of CO_2 is 40 €/tCO_2. Even if this change is not totally due to "rebound effect" but also to other factors that were not possible to disentangle, the test shows that rebound effect is probably a sensitive parameter.

If we use a CO_2 content for electricity of 360 g per KWh, emissions avoided by the CITE increase by 50%. Investments costs and energy bill savings are not modified since electricity is not covered by the carbon tax and electricity price remains the same as in the reference scenario. The abatement cost of the CO_2 is thus reduced to 156 €/tCO_2.

Table 17: Socioeconomic assessment of the CITE between 2015 and 2050, alternative simulations (CITE removed in 2017)

	Investments (billion euros) (a)	Budgetary cost of the CITE (billion euros)	Gains on energy expenditures (billion euros) (b)	Energy consumption (TWh) (c)	CO_2 emissions ($MtCO_2$) (d)	Cost per ton of CO_2 (euros per ton) ((a) – (b)) / (d)	Cost per MWh (euros per MWh) ((a)-(b))/(c)
« CF+CI » -CF reference simulation	2.4	3.3	1.9	-25.8 (-43.1)	-2.0 (-2.9)	236	18
« CF+CI » - CF Investment costs - 20%	2.0	3.3	2.0	-25.7 (-43)	-2.1 (-3.0)	-7.0	-0.5
« CF+CI » - CF theoretical energy savings instead of realized	2.4	3.3	2.3	-29.6 (-48.3)	-2.9 (-4.2)	39	4.0
« CF+CI » - CF electricity CO_2 conten t of 360 g per KWh	2.4	3.3	1.9	-25.8 (-43.1)	-3.0 (-4.7)	156	18

5.5.2. Air pollution reduction evaluation

Air pollution due to building heating systems stems from the release of pollutants like NOx and fine particulates[15] during the process of combustion of the energy used. More specifically concerning electricity, pollution occurs upstream in power plants. Those

15 Other pollutants are also released but their related social cost is negligible.

pollutants cause health damages to the population, at global level for NOx and local level for fine particulates.

The quantity of such pollutants depends on the type of energy used (natural gas, fuel, etc.) and the type of equipment (more recent boilers are less pollutant, for the same quantity of energy used, than older ones).

The ResIRF model doesn't allow to properly take into account the quantity of pollutants emitted. Thus, to find out a ballpark figure of this quantity, a simplified approach is adopted here. We use a proxy by considering that the consumption of a KWh of each type of energy is responsible for the emission of a certain quantity of pollutants.

Table 18 Pollutant contents by type of energy

	NOx (mg/KWh)	Fine particulate (mg/KWh)
Electricity	26	0,4
Natural gas	151.2	3.24
Fuel	248.4	5.4
Wood	219.6	849.6

Source: CITEPA (Interprofessional Technical Centre for Studies on Air Pollution), CGDD calculations

The ResIRF model provides the yearly variation for consumption of each type of energy. Thus it is possible, by multiplying both quantities, to determine variations of quantity of pollutants emitted. Therefore, fines particulate reduction over the period amounts to 22.5 kt (11.5 kt when discounted by 4.5%/year). NOx emissions reduction amounts to 7.5 kt (4.2 kt when discounted). These non-discounted cumulated emissions reduction represent around 13% and 27% of 2016 household's sector emissions for NOx and fine particulates[16].

To convert those quantities into social cost, we use reference values given by France Stratégie 2008 report on externality costs. The report values are updated and given in €2017 in the below table[17].

Concerning fine particulates, as their impact is local, the social cost increases with population density. France Stratégie report gives the value for 5 ranges of population density. In the absence of any indication, we consider here that housing with heating systems functioning with natural gas, electricity and fuel are geographically distributed independently of population density. Thus an average value of the social cost is calculated, weighted by the proportion of the population living in area corresponding to

[16] According to the CITEPA, in 2016, emissions for household's sector amounted to 60.3 kt for NOx and 84.2 for fine particulates (PM 2.5). For the single year 2016, the CITE measure induced a reduction of 0.5% and 0.6% for NOx and fine particulates emissions due to household's sector.

[17] As recommended by the France Stratégie report on external costs, values increase along time at the same rate as GDP/habitant.

each range of population density.

Concerning housings with wood heating, we take the social cost for very low density zone (rural). This is a conservative approach to avoid overestimating gains.

Table 19 Social cost for air pollutants

	France Stratégie value, updated by CGDD, in €2017/g		Population breakdown
Zones	PM 2.5	Nox	
Urban, very dense (av. 6750 inhab./km2)	6.054	0.012	26%
Urban, dense (av. 2250 inhab./km2)	2.018	0.012	12%
Urban av. 750 inhab./km2)	0.673	0.012	19%
Urban, low density (av. 250 inhab./km2)	0.224	0.012	15%
Rural (av. 25 hab./km2)	0.023	0.012	28%
av. cost weighted by population breakdown	**1.984**	**0.012**	

We are thus able to calculate, for each year, the social benefit induced by the reduction of consumptions. Total benefit over 2015-2050 period, discounted at 4.5%, amounts to 410 M€. Most of total benefit (350 M€) is due to fine particulates. Most of total benefit (340 M€, therefore 290 M€ for fine particulates) is due to wood energy consumption decrease, since fine particulate content for this energy is very high. Fuel and natural gas energy decrease too but their pollutant content are lower.

These results must be taken very cautiously. They however clearly indicate that air pollution externality is not a second order issue. This co-benefit, as well as energy bill gains, can be integrated in the calculation of CO_2 abatement cost: this collective gain of 410 M€ reduces the collective cost of the CITE. More precisely, when expressed in terms of cost or benefit per ton of CO_2, it corresponds to a co-benefit of about 200 €/tCO_2. If this co-benefit is taken into account to calculate the CO_2 abatement cost, this abatement cost falls down to around 40 €/tCO_2.

6. Permanent CITE scenario

To give a better idea of what could be the impact of the CITE if this scheme were to be maintained, an alternative scenario is tested, called the "permanent CITE" scenario. It assumes that the scheme, with the same subsidy rate, is maintained constant from 2015 to 2050. We compare two scenarios:

- The **"counterfactual or CF"** scenario where no CITE is activated in the model from 2015 onward. All other policies are maintained.
- A test scenario **"counterfactual + CITE or "CF + CI"** scenario in which the CITE is activated in 2015 onward. All other policies are maintained. The tax credit is maintained at a fixed rate from 2015 to 2050.

By comparing the counterfactual and the test scenarios, we obtain the effect of the tax credit on the level of investment in energy efficiency renovations, heating consumption and GHG emissions.

Table 20: scenarios description (CI2years as a reminder)

		2015	**2016**	**2017**	**2018**	**...**		**2050**
CF	CITE	no	no	no	no	no	no	no
	Other policies	yes	yes	yes	yes	yes	yes	yes
CF+CI2years	CITE	yes	yes	no	no	no	no	no
	Other policies	yes	yes	yes	yes	yes	yes	yes
CF+CI	CITE	yes	yes	yes	yes	yes	yes	yes
	Other policies	yes	yes	yes	yes	yes	yes	yes

For each items, the previous results have been recalled to help comparing the effects of the “spot CITE” and the “permanent CITE”.

Relevance and effectiveness of the CITE

The “spot CITE” reduces energy consumption and CO_2 emissions respectively by about 0.9 TWh and 0.12 $MtCO_2$ per year in 2015 and 2016. These effects last for several years: over the 2015-2050 period, 2.9 $MtCO_2$ and 43 TWh of energy consumption are avoided when the CITE is removed in 2017.

If the CITE is maintained until 2050, 24 $MtCO_2$ and 286 TWh of energy consumption are avoided.

6.1. Impact on energy consumption and annual CO_2 emissions

When the CITE is maintained in the long run until 2050 (“CF + CI” scenario), it reduces energy consumption by 9 TWh and GHG emissions by 0.5 $MtCO_2$ in 2050 in comparison with the scenario without the CITE (“CF” scenario).

The annual gain in 2030 is about 9.3 TWh and 0.9 $MtCO_2$ which corresponds to an additional 3.2% drop in consumption and a 2% drop in emissions compared to the scenario without the CITE. The annual gain is higher in 2030 than in 2050 because in the “CF + CI” scenario, the energy savings opportunities are exploited more quickly.

Over the 2015-2050 period, the cumulative energy savings and GHG emissions reductions generated by the CITE amount to 286.3 TWh and 24.2 $MtCO_2$.

Table 21: Annual Differences in energy consumption and CO_2 emissions between the CF + CI scenario and the CF scenario

	2015	2016	2020	2030	2050	Total 2015-2050
Emissions ($MtCO_2$)	-0.13	-0.24	-0.53	-0.86	-0.52	-24.2
Energy consumption (Twh)	-0.89	-1.76	-4.75	-9.32	-9.03	-286.3

6.2. Cost distribution analysis

In the "Permanent CITE" scenario, the yearly budgetary cost increases until 2020 and then drops to reach about 0.75 billion in 2050. Additional investment is triggered until 2040.

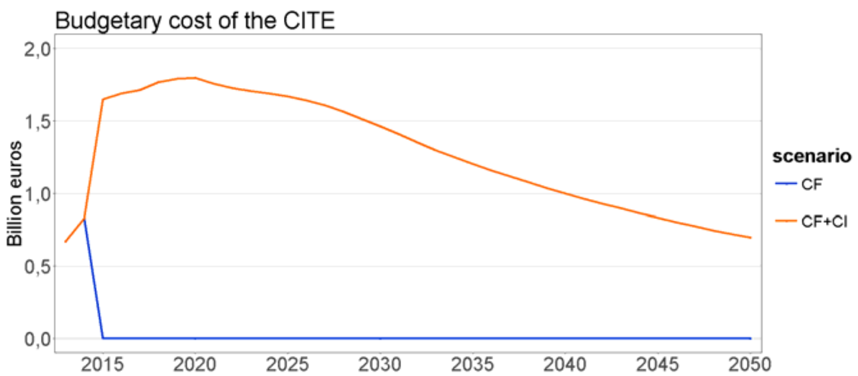
Over the 2015-2050 period, the reduction in the energy bill allows the households to save 9.2 billion euros for a total additional investment of 15.4 billion euros. As in the "spot CITE" scenario, the net cost for households without the CITE would not be profitable without the CITE tax credit that amounts to 21.2 billion euros for the 2015-2050 period. With the CITE tax credit, the net cost for households is -15 billion euros.

6.2.1. Impact on the State finances

In the long run, if the CITE is maintained at the same rate, all other things being equal (other policies maintained), the model allows us to simulate the expected budgetary cost of the CITE (below figure).

The CITE leads to an additional budgetary cost of 1.5 billion euros in 2030 and 700 million euros in 2050. The additional cost declines in time as the number of renovations declines as shown in the figure below.

Figure 8: Budgetary cost of the CITE

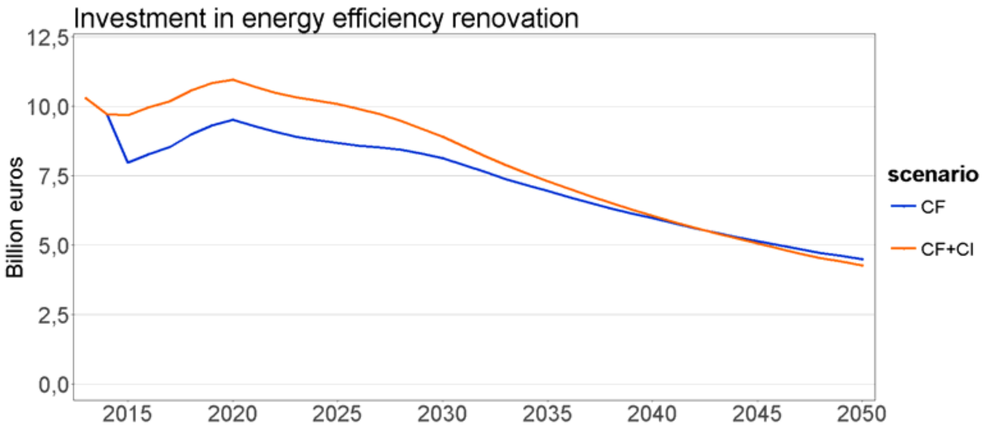


Beside the direct costs of the CITE, “second round effects” can impact the State finances, through other support schemes or taxes. They have been neglected.

6.2.2. Impact on households: impact on investment in energy efficiency renovation, households’ energy bill and net cost

When the CITE is maintained until 2050, the investment level is higher in the “CF + CI” scenario till 2042 as shown on the below figure. The profitable energy savings opportunities are exploited more quickly in this scenario which explains the higher drop in the investment in energy efficiency renovation.

Figure 9: Investment in energy efficiency renovation



The energy bill savings grow over time from 0.13 billion euros per year in 2016 to 1 billion euros per year in 2050.

Table 22: Annual impact on investment and energy bill savings between the CF + CI scenario and the CF scenario

	2015	2016	2020	2030	2050
Investments (G€)	1.71	1.69	1.46	0.76	-0.23
Energy bill savings (G€)	0.06	0.13	0.40	0.90	1.00

Table 23 shows the calculation of the net cost for households when the CITE lasts until 2050. Over the 2015-2050 period, the reduction in the energy bill allows the households to save 9.2 billion euros for a total additional investment of 15.4 billion euros. As in the “spot CITE” scenario, the net cost for households without the CITE would not be profitable without the CITE tax credit that amounts to 21.2 billion euros for the 2015-2050 period. With the CITE tax credit, the net cost for households is -15.0 billion euros.

Table 23: Net cost for the households

	Investments (G€) (a)	CITE tax credit (G€) (b)	Energy bill savings (G€) (c)	Net cost without tax credit (a)-(c)	Net cost (a)-(b)-(c)
« CF+CI2years»-CF	15.4 (24.5)	21.2 (25.2)	9.2 (28.6)	6.2 (-4.1)	-15.0 (-29.3)

NB: Investments, CITE tax credit, energy bill savings are cumulative and discounted at 7%. The non-discounted values appear in parentheses below the discounted quantities.

6.5. Additional effect of the CITE

The CITE triggers around 75,000 additional renovations per year in 2015 and 2016 which represents about 1.7 billion euros of energy efficiency investments per year.

The CITE improves the energy efficiency of the housing stock. Dwellings with a low energy consumption (A or B) have increased by 39,000 at the end of 2016. The CITE incentive in 2015 and 2016 helps to keep the housing stock on a more virtuous path as dwellings with a low energy consumption have increased by 71,000 at the end of 2050 and by 1,5 million if the CITE is maintained until 2050.

The average heating consumption per m² of the housing stock are reduced by 0.6% in 2050 if the CITE is removed in 2017 and by 6.5% if it is maintained until 2050.

The ratio between additional investments in energy efficiency compared to the situation without the CITE and public expenditures related to the CITE budgetary cost is a bit more than 1 for 2015 and 2016. It drops afterwards and reaches 0.78 in 2050.

6.5.1. Number of beneficiaries and numbers of renovations with and without the scheme

When the CITE is maintained in the long run, it triggers more than 1.3 million renovations over the 2015-2050 period which corresponds to about 37,000 additional renovations per year. This corresponds to an increase of 0.15 points in the renovation rate of the housing stock over the period.

Table 24: Additional number of renovations and investments between the CF + CI scenario and the CF scenario

	2015	2016	2020	2030	2050	Total 2015-2050
Number of renovations	75,000	76,000	76,000	50,000	-19,000	1,335,000
Investment (Billion euros)	1.71	1.69	1.46	0.76	-0.23	

6.5.2. “Leverage effect” of the CITE understood as additional private investment per public euro invested

When the CITE is maintained in the long run, the table 25 shows that the leverage effect declines over time as the housing stock is renovated and is around 0.78 in 2050. This is easily explained because energy prices rise and renovation costs drop over time (due to technical progress in the model) which leads to more and more investments independently of the CITE. The efficiency of the policy declines over time as the CITE triggers less additional or ambitious work.

Table 25: Additional investment per euro of tax credit, reference = CF scenario

	2015	2016	2020	2030	2050
CF+CI	1.04	1.02	0.91	0.92	0.78

6.5.3. Energy efficiency of the housing stock with and without the scheme

Two indicators are presented.

(i) Differences in the dwellings numbers by energy class

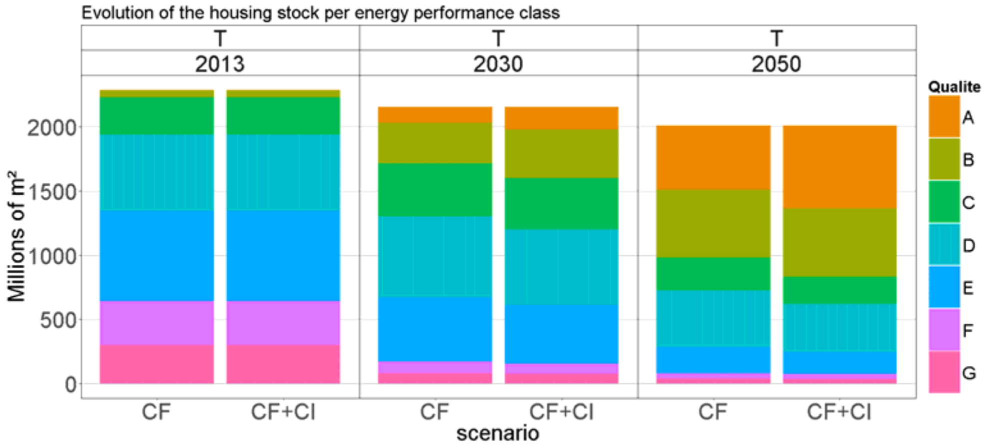
When the CITE is maintained until 2050, the effects on the dwellings numbers by energy class are multiplied. In 2050, dwellings with a low energy consumption have increased by 1.5 millions which corresponds to 5.6% of the housing stock of 2015.

Table 26: Annual differences in the dwellings numbers by energy class between the CF + CI scenario and the CF scenario (thousands of dwellings)

Energy performance class	2015	2016	2020	2030	2050
A	6	14	72	496	1359
B	11	25	128	598	119
C	52	104	251	-93	-409
D	8	11	-35	-355	-622
E	-25	-53	-183	-427	-351
F	-31	-61	-146	-135	-49
G	-21	-41	-88	-86	-49

As shown in the below figure, the energy classes A and B represents 5 points more of the housing stock in 2050 in the “CF + CI” scenario than in the “CF” scenario.

Figure 10: Evolution of the housing stock per energy performance class



(ii) Average heating energy consumption per m²

We report here the impact of the CITE on theoretical energy heating consumption per m² of the housing stock. This means that we only report the evolution of the energy efficiency of the buildings in the stock without taking into account the adjustments of households on their actual energy consumption (rebound effect after a renovation, lower heating restrictions).

The average heating consumption per m² of the housing stock are reduced by 5.3% in 2030 and 6.5% in 2050 (see table 27).

Table 27: Average heating energy consumption per m² by scenario

scenario	2015	2016	2020	2030	2050
CF	157.9	152.0	129.3	89.6	53.6
CF+CI	157.3	150.7	126.3	84.9	50.1

6.5.4. Economic efficiency of the CITE

The average cost per ton of CO_2 avoided by the investments made over the 2015-2050 period is estimated at 428 euros per ton.

The average cost per MWh saved by the investments made over the 2015-2050 period is estimated at 37 euros.

If the CITE is maintained in the long run, the cost per ton of CO_2 and the cost per MWh is higher because of increasing marginal renovation costs over time.

Table 28: Socioeconomic assessment of the CITE between 2015 and 2050 (CITE maintained until 2050

	Investments (billion euros) (a)	Budgetary cost ot the CITE (billion euros)	Gains on energy expenditures (billion euros) (b)	Energy consumption (TWh) (c)	CO_2 emissions ($MtCO_2$) (d)	Cost per ton of CO_2 (euros per ton) ((a) – (b)) / (d)	Cost per MWh (euros per MWh) ((a)-(b))/(c)
« CF+CI »-CF	17.9	26.9	12.5	-145.1 (-286.3)	-12.6 (-24.2)	428	37

NB: Investments, CITE expenditures, energy expenditures, avoided emissions and consumption are cumulative and discounted at 4.5%. The non-discounted cumulative emissions and energy consumption appear in parentheses below the discounted quantities.

When the CITE is maintained until 2050, it reduces by 12.5 billion euros (discounted) the household energy expenditures for additional investments in renovations works of 17.9 billion euros. The socioeconomic cost of the avoided ton of CO_2 is estimated at 428 euros per ton. The socioeconomic cost of the MWh saved is estimated at 37 euros per ton.

The cost per ton of CO_2 avoided is almost 2 times higher than when the CITE is stopped in 2017. Indeed, over the period, the housing stock is retrofitted and energy jumps to less energy-intensive classes become more and more expensive. Even if energy prices rise and technical progress reduces investment costs over time, the marginal cost of renovation seems to increase.

6.6. Sensitivity analysis

The sensitivity analysis shows that the most sensitive parameters in the model are investment costs initial level and the impact of technical progress on their evolution over time. The results are less sensitive to energy price scenarios and to the interactions with other policies.

Several alternative simulations were performed to test the robustness of the results described above:

- A simulation without technical progress that is to say without decreasing renovation costs over time ;
- A simulation with a higher energy price scenario where annual growth rates of energy prices are 10% higher;
- A scenario where the model is calibrated with investment costs are 20% lower. The budgetary cost of the CITE for 2015 et 2016 is kept constant;
- A scenario in which we compare the scenario where no policy are activated ("no policy" scenario) with one scenario in which no policy except the CITE is activated ("no policy + CITE" scenario).

Table 29 summarizes the results of these simulations.

Table 29: Socioeconomic assessment of the CITE between 2015 and 2050, alternative simulations (CITE maintained until 2050)

	Investments (billion euros) (a)	Budgetary cost ot the CITE (billion euros)	Gains on energy expenditures (billion euros) (b)	Energy consumption (TWh) (c)	CO_2 emissions ($MtCO_2$) (d)	Cost per ton of CO_2 (euros per ton) ((a) – (b)) / (d)	Cost per MWh (euros per MWh) ((a)-(b))/(c)
« CF+CI »-CF = Reference scenario	17.9	26.9	12.5	-145.1 (-286.3)	-12.6 (-24.2)	428	37
« CF+CI »-CF no technical progress	19.2	24.3	10.4	-122 (-240)	-11.8 (-22.7)	743	72
« CF+CI »-CF energy prices annual growth +10%	17.9	27.2	12.9	-145.9 (-288.0)	-12.4 (-23.8)	406	35
« CF+CI » - CF Investment costs -20%	15.5	26.7	13.5	-152.5 (-302.0)	-13.5 (-26.2)	151	13
« no policy +CI» -« no policy »	16.6	22.6	-11.3	-129.1 (-259.4)	-12.7 (-24.9)	419	41

NB: Investments, CITE expenditures, energy expenditures, avoided emissions and consumption are cumulative and discounted at 4.5%. The non-discounted cumulative emissions and energy consumption appear in parentheses below the discounted quantities.

The cost per ton of CO_2 avoided is quite sensitive to the choice of the scenario. It is significantly higher when technical progress is disabled because of larger and fixed renovation costs over time. With higher energy prices, the cost per ton of CO_2 avoided is conversely lower because of higher energy savings with equivalent investments and a similar decrease in energy consumption.

If we calibrate the model with investment costs 20% lower, the cost per of CO_2 is divided by more than 3 because investments are reduced while energy bill savings, CO_2 emissions reduction and energy savings are a bit higher.

The « no policy +CI» -« no policy » scenario shows similar results than the « CF+CI »- « CF » scenario which means the interactions between policies have a low impact on the CITE effects. The budgetary cost of the CITE is however lower because the number of renovations without the CITE is less dynamic without other active policies. The CITE therefore grants a lower number of renovation works.

The cost per MWh saved has a similar evolution than the cost per ton of CO_2 between the scenarios.

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8. Evaluation team and work process

8.1. Evaluation team competencies and independence

The present evaluation was carried out by the CGDD (office of the Commissioner General for Sustainable Development). The evaluation team belongs to the Energy Transition Economics unit (MA2) of the Division for Mobility and Development (MA), in the Sustainable Development Economics, Assessment and integration Department (SEEIDD).

The role of the SEEIDD in its assessment dimension is to design and carry out socio economic analyses of policy measures, ex-ante and ex-post, and to provide insights on long term impacts of these policies, with a focus on quantitative environmental impacts. The fields covered are transport, energy, housing and spatial planning. The SEEIDD makes all efforts to keep in line with the academic standards for public policies' evaluation. The MA team uses and develops tools and models in order to provide robust quantitative elements for these evaluations. The team maintains links with economics research institutes on a regular basis for knowledge sharing and coordination of knowledge improvement.

Concerning housings, the team uses the ResIRF model co-developed with the CIRED (International Research Centre on Environment and Development). For this purpose, and also for the development of another model on urban public policies, a contract between the CGDD and the CIRED organizes the co-working.

The CGDD is not in charge of designing or implementing the CITE. The Directions in charge within the Ministry for an Ecological and Solidary Transition are the DGEC (General Directorate for Energy and Climate) and the DHUP (Directorate for Housing, Urban planning and Landscape).

8.2. Observation of the referees and answers given

The referees were Philippe Quirion (CNRS) and Louis-Gaëtan Giraudet (CIRED). During the 2nd Council meeting on July 12th, 2018, the referees presented their reactions and comments on the study. The referees disclosed their ties to the CGDD. The Res-IRF model has been developed by the CIRED since 2009. Two studies have been carried out with CGDD fundings. Besides, the model has been used for peer reviewed publications (Energy journal 2011, Energy Economics 2012, Environmental Modelling & Software 2015).

The two referees emphasised the fact that the lack of data made the study difficult and confirmed that the model was well-used and well-adapted for this specific study, that the indicators made economic sense and that the interpretation of the results was cautious enough. Specifically, they suggested that the estimation of the "additional effect" was quite conservative, i.e. possibly underestimating the environmental gains, in comparison to existing *ex post* studies (Nauleau, 2015). In the same field, they mentioned leverage effects estimations found in the literature that were in the same range that those found here. Those elements tend to confirm that the evolution approach is cautious enough and does not overestimate the positive effects of the measure.

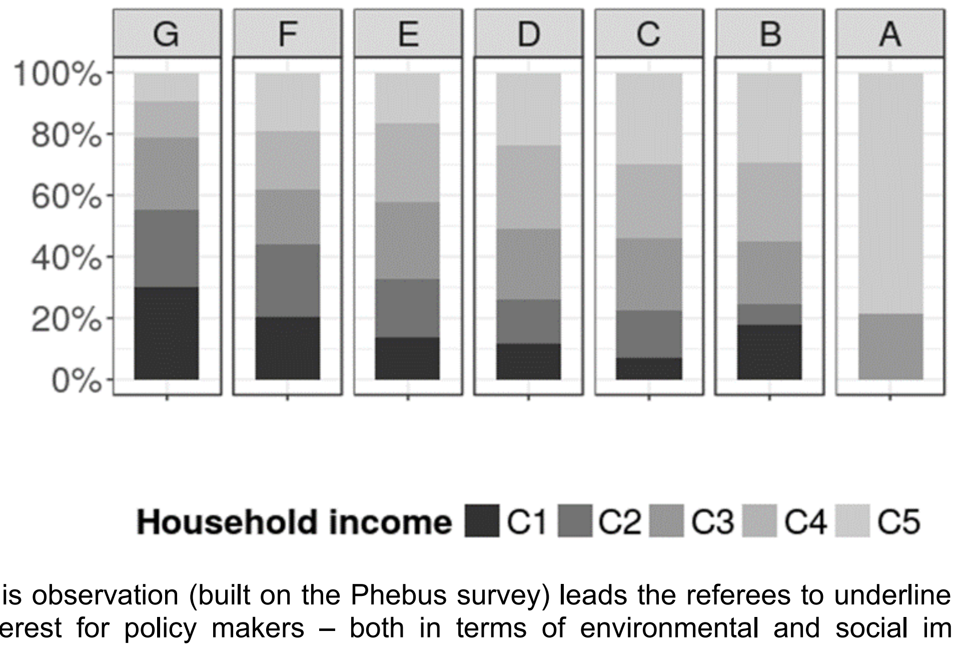
The referees raised the following issues:

- They underlined that sensitivity depends on the output considered (e.g. CO_2 vs. €/CO_2).
- They precised that instead of referring to "rebound" effect, it would be more suitable to talk about "realized" vs "predicted for unchanged comfort level" consumption.
- They also pointed out that the framework used is also, and perhaps more, adapted to longer-term measures. A simulation with the CITE maintained until 2050 is in the appendix.
- They put forward broader evaluation criteria:
    - A sensitivity test on the CO_2 electricity contents.
    - Taking into account other externalities, e.g. local pollutants.
    - Distributional issues – they underlined, although this is not in the objectives of the Green OAT, that there are synergies between economic efficiency and fuel poverty alleviation.

The answers made by the study's team to the referees' questions are the following:

- Sensitivity indeed depends on the indicator considered. If the result about energy saving or CO_2 emissions reduction is quite robust, it is true that the indicator of CO_2 abatement cost is very sensitive. This is due to a mathematical reason. Its calculation implies to compute the difference between costs (additional investments) and benefits (energy savings, but also other externalities reduction). Then, even if the range of uncertainty is quite reasonable for each term in relative value, the uncertainty for the difference is higher.

- The CGDD recognizes that the concept of “rebound” effect is sometimes improperly used in the documents displayed. In the final report the redaction has been adapted.
- The simulation with the CITE maintained until 2050 has been kept in the appendix, as suggested by the referees.
- Concerning the evaluation criteria:
  - o CO_2 electricity content: additional work has been done to provide CO_2 sensitivity test and the results are related in the report.
  - o A rough estimate of the CITE impact on local air pollution externality has been carried out and added to the report. It shows that it is a major issue and could impact significantly the CO_2 abatement cost.
  - o Concerning distributional issues, understood as the impact on different groups of households depending on their range of income for example: the issue seems indeed very interesting in terms of policy orientation. However, the green bond creation decree provides that a “report on environmental impact” of related expenses is released on a regular base. Consequently, a study of the distributional impact within household is out of the scope of the current study. The elements displayed by the referees are reported here. They presented a chart showing that in lower energy efficient buildings, the proportion of lower income households is indeed higher than in better energy efficient buildings.



This observation (built on the Phebus survey) leads the referees to underline the strong interest for policy makers – both in terms of environmental and social impacts – of measures that target specifically the least energy-efficient housings.

It is worth mentioning that the CIRED will soon release a study that assesses long-term impacts of policy schemes in housing renovation, both in terms of energy efficiency and energy poverty (with a differentiation of the impact on each income class).

8.3. Lessons learned from the CITE study as regards methodological aspects

Each impact assessment relies on data and tools (models) available and methodology. On this basis, different types of outputs/indicators can be built. Usually, a single tool or set of data cannot deliver all types of outputs/indicators.

The CITE study was based on a model, whose characteristics presents advantages and drawbacks. For example:

- the impact on energy consumption and CO_2 emissions are simulated and not observed. On one hand, it would have been more accurate to directly measure these impacts, but due to lack of data it was not possible (this is the reason why a model was used). But in any case, a kind of model would have been needed to simulate the reference situation "without CITE". On the other hand, the model, by simulating households investments decisions, allowed to assess the additional impact of the CITE and thus the leverage effect of the scheme;
- the model is dynamic and enables to evaluate long-term effects of the 2015-2016 CITE for energy consumption and CO_2 emissions; but other externalities like air pollution are not taken into account.

It is not always necessary to use a model to assess environmental impacts: easier approaches based on direct calculation, using blunt assumptions, can sometimes be sufficient.

Concerning indicators, they can be qualitative or refer to labels. When existing, it can be interesting to use an international standard or label. The credibility and accuracy of the label should however be scrutinized.

For the CITE, the official energy labels defined for France (class A to G) were used. Several surveys provided reliable data on the characteristics of these energy classes and on household's profiles and behaviours. These favourable conditions allowed building the model with robust data and making it able to produce sound and realistic simulations.

Concerning methodology, the CITE study provided cost benefit analyses for households and for society as a whole. This distinction is interesting since it gives insights on the degree of incentive given to actors (households) and on the degree of interest for society. This differentiation could be kept in mind for future studies.

More generally, the definition of the impact assessment objectives should pragmatically consider the data and tools available, since it constrains the achievable output.

The sensitivity tests performed for the CITE showed that the magnitude of the impact on CO_2 emissions was estimated rather robustly and quite probably underestimated rather than overestimated, due to methodological choices (partial capture of positive effects, rebound effect taken into account, future evolution of energy prices including carbon pricing,...). Thus any evaluative or comparative study should inform and take account of methodological choices clearly and openly.

The efficiency analysis showed that efficiency indicators may give highly variable results depending on methodological choices. Direct comparisons on such indicators would be meaningless or, moreover, could be quite misleading unless great care is taken as regards reproducible and sound methodological choices, including technical measurement choices. The interpretation of such indicators is thus not straightforward and should deserve much effort before beginning to give meaningful information.