# Switching from fossil fuel boilers to heat pumps: A multi-perspective benefit-cost analysis including an uncertainty assessment

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## Keywords

cost benefit, cost effectiveness, energy efficiency programmes, white certificates, heat pump

## Abstract

The paper presents the evaluation of a regional energy efficiency programme in France dedicated to space heating in the residential sector. The large French energy company EDF provides refurbishment advice and financial incentives to the end-users as well as training courses and certification to local installation contractors and building firms. Due to the pilot character of the programme the evaluation is particularly important, both in terms of saved energy and programme costs. Such data were monitored right from the beginning of the programme.

In this study, heat pumps for space heating that replace inefficient fossil fuel boilers are analyzed. A billing analysis with temperature normalisation is used to calculate the savings attributed to the programme. Around 90 households were interviewed regarding their individual energy consumption and building as well as household characteristics. Actual data of installation and equipment costs as well as financial incentive payments to customers are provided by EDF. The cost-effectiveness is determined from the perspective of the participant and society as well as EDF. All cost and benefit components are calculated in Euro/kWh, which allows a direct comparison of levelized costs of conserved energy with the avoidable costs of the energy supply system. Results are also expressed in benefit-cost ratios. Critical parameters like the future energy and carbon price development are considered to achieve the most accurate and reliable estimates. Uncertainties are assessed using Monte Carlo simulations. Energy savings and cost distributions are crossed with random probability distributions of the underlying assumption parameters such as the growth rates of future energy and carbon prices. The results indicate how reliable the cost-effectiveness of the programme is from each of the three evaluated perspectives.

## Introduction

The improvement of energy efficiency is an important task to reduce emissions of greenhouse gases (GHG), to improve the security of energy supply and to increase the economic competitiveness. Energy efficiency improvement measures in the building sector provide a huge potential to save energy and $CO_2$ emissions, as buildings account for more than 40 % of the whole European energy consumption (Lechtenböhmer and Schüring 2010). Manifold barriers hinder market agents to put several investment opportunities into practice, although many of the existing building refurbishment measures are highly cost-effective (Golove and Eto 1996, Schleich and Gruber 2008).

In order to cope with these challenges, the European Union adopted various directives to improve energy efficiency, increase the use of renewable energy and reduce GHG emissions. Against this background, France initiated a white certificate scheme that commits energy suppliers to deliver energy savings and verify certified amounts of saved energy. Obliged actors have the option to trade the certificates (Bertholdi et al. 2010, Baudry et al. 2011).

From 2006 onwards, Électricité de France (EDF), the largest electricity generation and retail supply company in France, has promoted a regional energy efficiency programme dedicated to space heating in the residential sector. The programme has recently attracted much interest due to its pilot character.

This study contributes to the discussion of energy efficiency programme evaluations by assessing the cost-effectiveness of the installation of heat pumps, which is a particularly important energy efficiency improvement action of the above mentioned refurbishment programme. Fuel switching from fuel boilers to heat pumps for space heating allows energy efficiency improvements, the use of a renewable energy source and the reduction of GHG emissions.

The benefits and costs of this subprogramme are analysed in this paper for different market actors as each evaluation perspective provides different information. Programme evaluations from different perspectives are widely known from the Californian evaluation practice. The reference methodology for these types of evaluations is described in the California Standard Practice Manual (CPUC 2001) as well as in the IPMVP (EVO 2007). First, from the perspective of programme participants the evaluation shows if the promoted measure types are economically attractive for customers. Second, energy companies operating in countries with white certificate schemes need to know if the measures they promote are cost-effective for them to comply with their saving obligations. Finally, an evaluation from the societal perspective is of importance for energy policy and provides information if societal objectives for energy efficiency will be met.

In the next section the paper presents background information of the refurbishment programme. Afterwards, the calculation method of the energy savings as a result of the measure implementation is pointed out. A billing analysis is used to determine the savings due to the installation of heat pumps that replace inefficient fossil fuel boilers. The evaluation of the costs of the programme is explained subsequent to that and information on the principles of the cost-effectiveness calculation is presented. Finally, the results are discussed for each of the three evaluation perspectives and uncertainties are assessed using Monte Carlo simulations.[1]

In this paper a particular energy efficiency improvement action, i.e. heat pumps replacing fossil fuel boilers, is studied following a publication by Suerkemper et al. (2011), in which a portfolio of energy efficiency measures of the mentioned programme is evaluated. This paper is a more in-depth study of this particular energy efficiency action and a new contribution to the uncertainty assessment in the field of energy efficiency.

## Programme background

The ambitious residential sector pilot programme has been offered by EDF for 5 years in two 'départements' located in the east of France. EDF agreed with the local authorities to invest several million Euros in this region by implementing the so called 'MDE 52-55' energy efficiency programme in order to save a substantial amount of energy. EDF disseminates information of energy saving opportunities for households and provides refurbishment advice as well as financial incentives, i.e. soft loans and bonus payments, to the end-users for different types of energy efficiency improvement actions. Households are provided with interest free loans if the refurbishment actions meet certain energy performance levels and with bonus payments that depend on the specific type of end-use action. Besides the heat pumps analysed in this paper, energy efficiency actions promoted are building shell improvements (roof or wall insulation, double-glazed windows), condensing boilers, wood stoves, wood boilers and solar water heating systems.

The promotion of efficient heat pumps is seen by EDF of special importance due to the expected energy saving potential of the technology, the use of renewable heat and the opportunity of helping customers to reduce their energy bills while selling at the same time more electricity. Historically, EDF was in France since the 1980s deeply involved in the development of the heat pump, by enhancing the development and diffusion of heat pumps associated with oil boilers on the French market. More recently, EDF has developed in collaboration with an industrial company a high performance heat pump dedicated to existing buildings that are characterised by a high level of energy needs for space heating.

Moreover, EDF is rewarded with white certificates in return for the achieved end-use savings. These certificates are used to meet the saving obligations imposed by the French White Certificate (FWC) scheme on energy supply companies (Bertholdi et al. 2010, Baudry and Osso 2011).

The primary motivation of EDF to implement the MDE 52-55 programme was to implement a pilot programme on energy efficiency as a demonstration case that is accompanied with a detailed evaluation, and not explicitly to achieve the most cost-effective energy savings in the residential sector. A detailed economic evaluation of this pilot programme is of importance since EDF intensifies the promotion of heat pumps to achieve its saving obligations imposed by the FWC scheme[2]. Until the end of 2010, around 120 heat pumps were installed in Haute-Marne and Meuse that can be assigned to the programme.

## Calculation method of energy savings

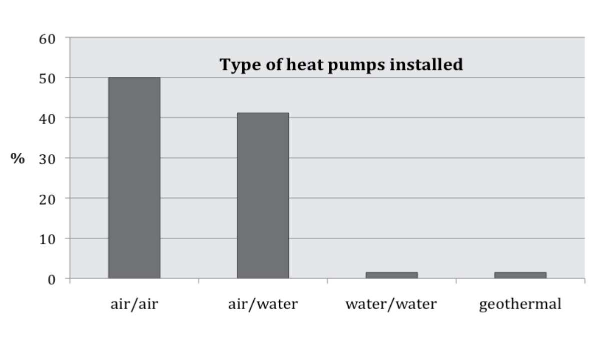
The evaluation of the savings due to the heat pump installations is based on two surveys of around 90 programme participants collected in 2009 and 2010 out of the installed heat pumps as a result of the MDE 52-55 programme (figure 1). By checking the whole sample for plausibility it turned out that a large share of the data were incomplete or implausible and, thus, had to be excluded.[3] 67 useful data sets remained for this study.

For the calculation of energy savings as a result of energy efficiency programmes several methods such as engineering models or the analysis of billing data exist. In the sample of the MDE 52-55 programme pre-retrofit and post-retrofit billing data (i.e. electricity and fuel consumption from 2006 to 2009) are available, whereas technical data of heat pumps are not suf-

1. Textbooks such as Huynh et al. (2008) or Newman & Barkema (1999) provide background information of the method of Monte Carlo simulations. Practical information for the application of Monte Carlo simulations are for example supplied by software providers such as Palisade Asia-Pacific Pty Limited with the tool @Risk (www.palisade.com.au) or by Structured Data, LLC with the tool Riskamp (www.riskamp.com).

2. EDF website dedicated to households: http://bleuciel.edf.com/energie/chauffage/energie-pompe-a-chaleur.htm

3. Data were excluded due to incomplete data sets and thus missing values for the calculations, and if the energy consumption of a household was affected due to significant other factors than the measure implementation. Such factors include changing numbers of persons living in the household, completely new residents in the specific building during the timeframe of the study, or the implementation of further energy efficiency actions than the assessed one.



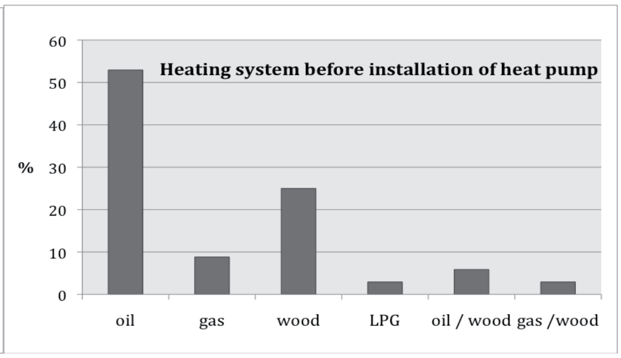




*Figure 1: overview of the programme participants' heating systems (before and after situation) from the two surveys.*

ficiently available.[4] A billing analysis is, consequently, used to determine the programme savings.[5] Beyond the overall data preparation and check for plausibility, the evaluation consists mainly of the following steps:

1. Temperature normalization of the pre-retrofit and post-retrofit energy consumption in order to avoid that weather variations affect substantially the evaluation results. The annual energy consumption of a specific year is multiplied with the ratio of normalized heating degree days of a typical meteorological year and year specific heating degree days (which differ between the two 'départements' Haute-Marne and Meuse);
2. Quantification of the energy impacts: electricity and fuel (gas, oil, wood) consumption before and after the installation of the heat pumps are compared to each other in order to determine, *ceteris paribus*, how many kWh per unit or participant are saved annually. Since fuel consumption data is not expressed in kWh but in other energy units or even in energy costs (Euro/year), conversion factors are applied to allow a comparison with electricity consumption.[6]

Equation (1) and (2) illustrate the basic calculation steps to determine the average energy savings of heat pumps:

$$ES_i = \left(E_i^{pre} \times \frac{HDD^{normal}}{HDD^{pre}}\right) - \left(E_i^{post} \times \frac{HDD^{normal}}{HDD^{post}}\right) \quad (1)$$

$$ES = \sum_{i=1}^{n} \frac{ES_i}{n} \quad (2)$$

*ES: Average energy savings per participant due to the implementation of heat pumps*

*$ES_i$: Average energy savings of customer "i" from the billing data*

*$E_i^{pre}$: Average pre-retrofit energy consumption of customer "i" from the billing data*

*$E_i^{post}$: Average post-retrofit energy consumption of customer "i" from the billing data*

*$HDD^{pre}$: Département specific heating degree days in the pre-retrofit year*

*$HDD^{post}$: Département specific heating degree days in the post-retrofit year*

*$HDD^{normal}$: Normalized heating degree days of a typical meteorological year*

*n: number of programme participants in the sample (i =1,...,n)*

The average annual electricity and fuel consumption changes per participant due to the heat pump installation are shown in figure 2. Incremental savings are evaluated for heat pumps as it can be expected that in absence of the MDE 52-55 programme many end-users would have installed low temperature boilers instead of the more efficient heat pumps.[7] Consequently, the energy consumption of heat pumps is compared with the fuel consumption of low temperature boilers in order to determine the incremental savings.

As a result of the 120 heat pumps that received financial support from EDF's programme, a total of 2,883,800 kWh/year of fuel (2,312,000 kWh incremental fuel savings) have been replaced according to our calculations by 607,500 kWh/year of electricity plus ambient heat. The fuel savings correspond to reduced $CO_2$ emissions of 627 tons per year (502 tons per year incremental $CO_2$ savings).[8] The increased electricity consumption leads to additional $CO_2$ emissions of 109 tons per year considering an emission factor of 180 g/kWh for electric heating (ADEME 2005). The emission factor for electric heating is significantly larger than the average emission factor for the French electricity mix to account for seasonal effects of electric heating. Overall, 517 tons per year of $CO_2$ emissions will annually be saved due to the 120 heat pumps installed in Haute-Marne and Meuse.

The calculated savings should, in principle, be rather conservative estimates since programme participants often increase their level of comfort after the refurbishment action, i.e. use their heating system more intensively because they know that energy is used more efficient. This effect is known as the rebound effect, widely discussed and quantified in numerous studies, such as in Greening (2000) and Sorrell et al. (2009).

4. The electricity bills of programme participants were directly available to EDF R&D. For all other fuel types, programme participants were asked in the survey to indicate their annual fuel consumption based on their bills.

5. The average COP value of the installed heat pumps cannot directly be determined from a billing analysis due to varying annual climate conditions and possible behaviour changes of households.

6. Wood consumption was expressed in stères in the survey. One stère is converted to 1,680 kWh according to Ministère de l'Emploi, de la Cohésion Sociale et du Logement (2006).

7. It is assumed that low temperature boilers represent currently the standard technology on the market.

8. CO2 factors of fuels are specified according to Ministère de l'Emploi, de la Cohésion Sociale et du Logement (2006).

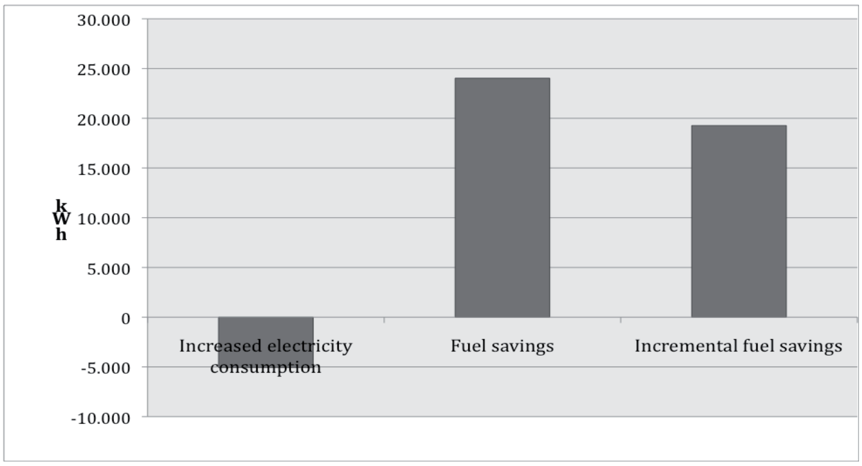



*Figure 2. Increased electricity consumption and fuel savings.*

The rebound effect is included in the consumption measured after the implementation of the energy efficiency measure and is, thus, "automatically corrected" in the results of a billing analysis.

The degree of uncertainty of the evaluation results with respect to this billing analysis is comparably large because of the moderate sample size and due to the inability of comparing the results with a control group of similar customers who did not participate in the programme (due to a lack of data). Consequently, the results of this analysis should be considered cautiously.

Gross-to-net correction factors (Wuppertal Institute 2009) are not taken into account since no surveys regarding the free-rider and spill-over effect are available for this programme. Moreover, the assessed energy savings could, in principle, be influenced by governmental incentive payments, like tax credits in force at the moment of the programme, that led to further refurbishment measures than the heat pump installation within the same time frame of this study (Broc et al. 2010). Due to the limited evaluation resources of this study, the assessed savings are not corrected for double-counting, and for the free-rider as well as spill-over effect. Concluding, the underlying assumption of this study is that the net savings are consistent with the calculated gross savings.[9]

## Programme costs

The cost-effectiveness of energy efficiency programmes depends largely on the programme costs and the specific costs of the energy efficient technologies that are promoted by the programme. In order to promote heat pumps, incentive payments are offered by EDF to customers in the residential sector. Provided that the heat pumps meet specific minimum energy performance levels[10], households receive interest free loans and fixed bonus payments. The level of incentive payments depends on the costs and specific type of heat pump implemented. The costs for EDF of providing the interest free loans are determined by calculating the net present value (NPV) of the capital income that cannot be gained anymore by EDF due to the provision of the interest free loans. These costs depend on the level and length of the soft loan and the imputed interest rate of EDF.

Beyond incentive payments, overhead costs such as administration, labour, marketing, evaluation costs of the MDE 52-55 programme, and specific transaction costs related to the FWC system are borne by EDF as the programme operator. These overhead costs should be considered in the cost-effectiveness analysis. The specific overhead costs of the MDE 52-55 programme are not determined yet. Typically, overhead costs of similar programmes range between 10 % and 30 % of total incentive payments provided to programme participants (Mundaca 2007; Lees 2008). Thus, an average share of 20 % of total incentive payments is specified as overhead costs in this study.

Finally, tax credits that are provided by the French government for heat pump installations are considered in the cost-effectiveness analysis from the perspective of the customer. It is assumed that all households demanded such tax credits as the scheme is well known by end-users in France. The specific level of tax credits provided by the state is calculated as a share of the pure equipment costs of heat pumps not including the labour cost of the installation. The level of tax credits was reduced from 40 % in 2008-2009 to a reduced rate of 25 % for air/water heat pumps. Air/air heat pumps were completely excluded from the scheme. The 40 % rate remains further for water/water and geothermal heat pumps.

The investment costs of heat pumps are an important cost component included in the cost-effectiveness analysis from the participant and societal perspective. Overall costs are available in the sample for each participant. These costs comprise all costs that accumulate until the work is completed and include costs of the efficient technology, additional material expenses and further costs of the local installation contractors such as labour costs. Using the sample data, an average cost value is determined. For the evaluation of heat pumps, incremental costs are relevant as it can be assumed that in absence of the MDE 52-55 programme house owners would have installed low temperature boilers instead of the more efficient heat pumps. Consequently, the additional savings are compared

9. This need not necessarily be the reality, but there is no other way to assess it in this study.

10. A minimal coefficient of performance (COP) depending on the type of heat pump is required (air/air >3.6, air/water & water/water >3.5, geothermal >4.5). Moreover, an additional bonus is available for variable speed (inverter) heat pump.

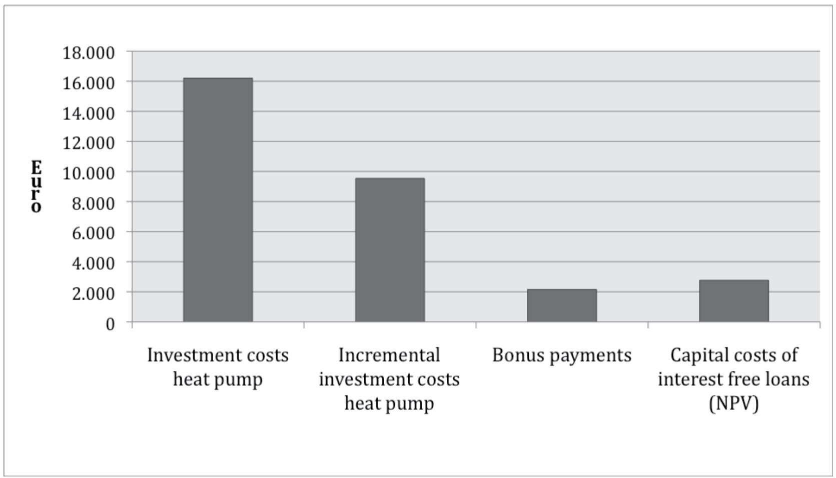



*Figure 3. Incremental (vs. reference technology: low-temperature boiler) investment costs of heat pumps, incentive payments (bonus payments and interest free loans).*

with the incremental costs in the analysis. They are determined by calculating the price difference of the efficient and the standard appliance, which are the costs of a low temperature boiler. Figure 3 summarizes the level of each cost or financial incentive component.

## Benefit-cost analysis

### GENERAL METHOD

The cost-effectiveness is determined from the perspective of the participant, the society and the energy company in charge of the programme as each evaluation provides different information about the impacts of this energy efficiency measure on stakeholders. By taking the evaluation results of all perspectives into account, most information about distributional effects between stakeholders is provided. All cost and benefit components are calculated in Euro/kWh, which allows a direct comparison of levelized costs of conserved energy (LCCE) with the avoidable costs of the energy supply system. For the calculation of LCCE, the cost stream of energy efficiency improvement measures is discounted using an appropriate discount rate to yield the net present value (NPV). The discount rate depends on the specific stakeholder perspective.[11] By multiplying the NPV with a capital recovery factor (CRF), the NPV is converted (levelized) to an equal annual payment. This annual cost value is divided by the annual energy savings to obtain LCCE in Euro/kWh. The principle calculation is described by formula (3) and (4):

$$LCCE = \frac{(NPV \times CRF)}{annual\_savings} \tag{3}$$

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{4}$$

*i: real discount rate*
*n: lifetime of the energy efficiency improvement measure*
*CRF: capital recovery factor (annuity factor)*

Table 1 compares the cost and benefit components that are monetized for the cost-effectiveness evaluation of the heat pump installation from the three perspectives. The cost and benefit components are calculated with data of EDF-R&D, EEX, IEA and Eurostat. Purely qualitative impacts as well as costs and benefits that may be relevant in other programme or energy market contexts are not included in this table.

### FUTURE DEVELOPMENT OF ENERGY AND CARBON PRICES

For the calculation of energy bill savings, energy supply system costs and external environmental costs over the entire lifetime of heat pumps, assumptions about the future development of energy and carbon prices need to be made. In this study, it is assumed that energy and carbon prices will increase over time according to table 2.[12]

A reasonable solution to account for increasing avoided costs and energy prices over time in levelized cost calculations is to adjust the current energy and carbon prices for their expected future escalation in order to determine the annual average avoided costs during the lifetime of energy efficiency improvement measures. Average avoided costs during the measure lifetime are calculated by multiplying the current energy and carbon prices with a factor described in formula (5).[13] Mean factors are calculated specifically for each energy efficiency improvement measure in dependency of the relevant discount

11. As three different stakeholder perspectives are assessed, a discount rate assumption for each cost-effectiveness test is necessary. The average lending rate of private individuals is appropriate from the participant perspective as it reflects the debt costs an average household would pay to finance an investment in energy efficiency. It is assumed to be 8 %. The interest rate that is relevant from the energy company perspective is reflected by the weighted average cost of capital (WACC). The WACC of EDF is approximately 8 %. A lower discount rate of 3 % is used from the societal perspective.

12. Growth rates of oil, natural gas and CO2 prices are calculated according to the fossil fuel price assumptions in the Current Policies Scenario of the World Energy Outlook 2010 for the year 2035 (IEA 2010b). As there is no appropriate study available, in which future electricity prices of France are estimated, it is assumed that future electricity prices will behave as the electricity price development in France between 1990 and 2009 (IEA 2010a). For wood it is assumed that prices will increase in future according to the price development in France between 2003 and 2008 (SoES 2010).

13. The application in cost-effectiveness calculations of energy efficiency measures is explained in more detail in Müller and Walter (1994).

**Table 1. Benefit and cost components included in the cost-effectiveness evaluation.**

| Perspective | Benefits | Costs |
|---|---|---|
| **Energy company - integrated electricity generation and retail supply company under French regulatory conditions** | Additional electricity sales revenue (net of taxes and T&D tariffs)<br>Avoided penalties of the FWC scheme or avoided costs of acquiring white certificates | Additional electricity costs and network tariffs (wholesale prices, T&D tariffs)<br>Incentive payments to programme participants (bonus payments and capital costs of interest free loans)<br>Programme overhead costs |
| **Programme participant** | Fuel bill savings (incl. taxes)<br>Incentive payments (received bonus payments and avoided capital costs of interest free loans)<br>Tax credits | Increased electricity bills (incl. taxes)<br>(Incremental) costs of the energy efficiency improvement measure (incl. VAT) |
| **Society** | Avoided fuel supply system costs (wholesale prices, losses)<br>Avoided external environmental costs | Additional electricity supply system costs (wholesale prices, T&D grid losses)<br>(Incremental) costs of the energy efficient improvement measure (excl. VAT)<br>Programme overhead costs |

**Table 2. Energy and $CO_2$ prices and assumed future growth rates of real prices.**

| | Electricity | Natural gas | Light fuel oil | Wood | $CO_2$ |
|---|---|---|---|---|---|
| Unit | Euro/kWh | Euro/$10^7$ kilocalories GCV | Euro/1000 litres | Euro/kWh | Euro/ton |
| **End-user prices in France 2008 - 2009** | **0.113** | **619.93** | **705.61** | **0.032** | **17.65** |
| Source | IEA (2010a) | IEA (2010a) | IEA (2010a) | SoES (2010) | Bluenext (2008 & 2009) |
| **Annual growth rate of real prices (%)** | **0.30** | **2.59** | **3.14** | **2.51** | **2.52** |
| Source | IEA (2010a) | IEA (2010b) | IEA (2010b) | SoES (2010) | IEA (2010b) |

rate, the expected future energy price development, the measure lifetime and the capital recovery factor (annuity factor).

$$m = \frac{\left(1+\frac{i-e}{1+e}\right)^n - 1}{\left(\frac{i-e}{1+e}\right)\times\left(1+\frac{i-e}{1+e}\right)^n} \times CRF \qquad (5)$$

*m: mean factor*
*i: real discount rate*
*e: annual growth rate of real energy prices*
*n: lifetime of the energy efficiency improvement measure*
*CRF: capital recovery factor*

### UNCERTAINTY ANALYSIS

Several methods exist that address uncertainty and risk in cost-benefit analysis. A sensitivity analysis is a simple method that shows how the result of a cost-benefit analysis changes if one input parameter is varied. The technique is called scenario analysis if two or more variables are changed at the same time. Limitations of these methods are that the variations of the input variables are arbitrary[14] as probabilities remain unconsidered.

This weakness is addressed by Monte Carlo simulations that take ranges of possible values as input variables into account instead of fixed estimates. The output of the model is, therefore, transformed from a deterministic single value estimate to an interval estimate in the form of a probability distribution that shows how likely the outcomes of the analysis are. In order to understand the risk and uncertainty of the cost-benefit analysis of this study, a Monte Carlo simulation is applied. The following nine key variables are regarded as uncertain in the underlying cost-benefit model of this study:

- Incremental investment costs of heat pumps,
- Incentive payments received by programme participants,
- Incremental fuel savings,
- Additional electricity consumption,
- Annual growth rates of real prices of electricity, oil, gas, wood and $CO_2$.

14. Depending on the knowledge of the evaluator.

Each of these parameters is assigned a suitable continuous probability distribution.[15] The first four variables follow a normal distribution. The mean and standard deviation are directly calculated from the sample of each variable to be used in the Monte Carlo analysis. For the modelling of growth rates of energy and carbon prices a Beta-PERT distribution is used, as it is simply based on the most likely value as well as on the upper and lower limits of a variable, whereby the most likely value is emphasized in favour of the assigned minimum and maximum values.[16] 5000 Iterations are simulated in the cost-benefit model in order to obtain a probabilistic view of the benefit-cost ratios. The outputs of the Monte Carlo analysis are shown in the next section as histograms. The histograms illustrate the likeliness of achieving a specific BCR level, i.e. showing on the Y-axis how often a specific BCR was calculated during the 5000 iterations of the simulation. The overall objective of the Monte Carlo analysis is to provide decision-makers with more information than only one single point estimate to support the interpretation of possible BCRs.

## Calculation results

### THE PROGRAMME PARTICIPANT PERSPECTIVE

The installation of heat pumps will be cost-effective from the perspective of the programme participants if the achieved cost savings over the expected measure's lifetime outweigh the costs of the specific energy efficiency measure. A benefit-cost ratio (BCR) above one indicates that an energy efficiency measure is cost-effective. An evaluation from the perspective of the programme participant is essential since customers will be unlikely to participate in an energy efficiency programme if their benefits are lower than the (incremental) investment costs of the energy efficiency improvement measure and the increasing electricity bills.[17] Benefits quantified in this study include the fuel bill savings achieved by using the heat pump over the expected lifetime, the incentive payments received by EDF and the governmental tax credits. Beyond the quantified impacts of this study, investments in building energy efficiency yield numerous further benefits for residents such as comfort gains or an increasing property value that could be of decisive importance for their investment decisions. These co-benefits are, however, not further discussed in this study.

The deterministic result of table 3 illustrates that the implementation of heat pumps is clearly profitable for customers, since avoided energy bills and received tax credits as well as incentive payments outweigh the incremental investment costs. The result is supported by the findings of the Monte Carlo simulation. The histogram in figure 4 shows that the likeliness to achieve a BCR larger than one is comparably large. The most frequently calculated value of BCR in the iterations is, however, with 1.14 significantly lower than the BCR of the deterministic analysis. The reason for this is that the histogram is skewed to the right, i.e. there's at the same time a comparably large probability to achieve a significantly larger BCR in the area of 2 to 2,5.

The deterministic calculations have been executed also a second time without considering the tax credits provided by the French government. In this case the BCR is 1,19. The installation of heat pumps is, however, not cost-effective for end-users if they receive neither the governmental tax credits nor the incentive payments by EDF (BCR: 0,85). Concluding, the calculation results show that currently some financial incentives are needed for end-users as long as the technology costs of heat pumps remain at the current levels. Increasing market shares of heat pumps may lead in future to decreasing technology costs allowing gradual reductions of the current levels of subsidies (see table 3[18]).

### THE SOCIETAL PERSPECTIVE

The economic impact on the entire society is measured by comparing the sum of incremental investment costs of the heat pumps (including the additional system costs due to the increased electricity consumption) and programme overhead costs with the avoided energy supply system costs of fuels. Moreover, the avoided external costs associated with the end-use consumption of fossil fuels are incorporated as a benefit in the evaluations. $CO_2$ emissions from end-use consumption of fuels are not covered by emission allowances and, consequently, represent external costs. The avoided $CO_2$ emissions are monetized by taking the expected average carbon price during the lifetime of heat pumps and the specific $CO_2$ factors of fuels into consideration.[19] The incentive payments provided by EDF and the governmental tax credits are not relevant from the perspective of the society as they represent transfer payments, which do not create added-value. In contrast to the energy company and customer perspective, a societal discount rate of 3 % is used in the calculations. According to this analysis, the sum of avoided energy supply system costs and external environmental costs do not clearly outweigh the incremental investment costs and programme overhead costs. The BCR of heat pumps is 0.96 according to the deterministic analysis and thus slightly lower than one. The relatively widespread histogram in figure 5 shows that the results are sensitive with respect to the uncertain variables that are specified for the Monte Carlo simulations. No clear decision can, therefore, be made regarding the cost-effectiveness from the societal perspective. The visualization of the findings may support policy makers in assessing the BCRs. As further societal benefits of energy efficiency improvements such as health improvements, the creation of new jobs and the reduction of other negative energy externalities are not taken into account in the calculation, they need clearly be identified and communicated to decision-makers.

The high initial investment costs of heat pumps may decrease over time due to economies of scale, technological learning as well as experiences in production processes. Future cost reduction potentials of heat pumps are for example estimated by

15. A first check if a probability distribution is compatible with the sample data can be done graphically by comparing the histogram of the sample data with a specific distribution function. Moreover, goodness-of-fit test statistics such as Kolmogorov-Smirnov and Anderson-Darling can be calculated to determine if a sample arises from a specific probability distribution.

16. Most likely values of growth rates of energy and carbon prices are specified according to IEA 2010 and Pégase 2010 shown in table 2. The lower limit is specified for electricity -1 %, for gas, oil, wood and carbon 0 %. The upper limit is specified for electricity 3 %, for gas, wood, and carbon 5 % and for oil 6 %.

17. Considering that individuals act as purely rational agents.

18. Lifetimes of heat pumps are specified according to the saving lifetimes of the FWC scheme.

19. $CO_2$ factors of fuels are specified according to Ministère de l'Emploi, de la Cohésion Sociale et du Logement (2006).

**Table 3. Levelized cost and benefit components per kWh of fuel saved and benefit-cost ratios from end-users' perspective (interest rate 8%, lifetime 16 years).**

| | **Incremental investment costs** including additional electricity consumption [Euro/kWh incl. VAT] | Bill savings *fuels [Euro/kWh]* | Incentive payments *[Euro/kWh]* | Tax credits *[Euro/kWh]* | **Total benefits** [Euro/kWh] | **Benefit-cost ratio** |
|---|---|---|---|---|---|---|
| **Heat pumps** | **0.0864** | 0.0733 | 0.0288 | 0.0285 | **0.1307** | **1.51** |

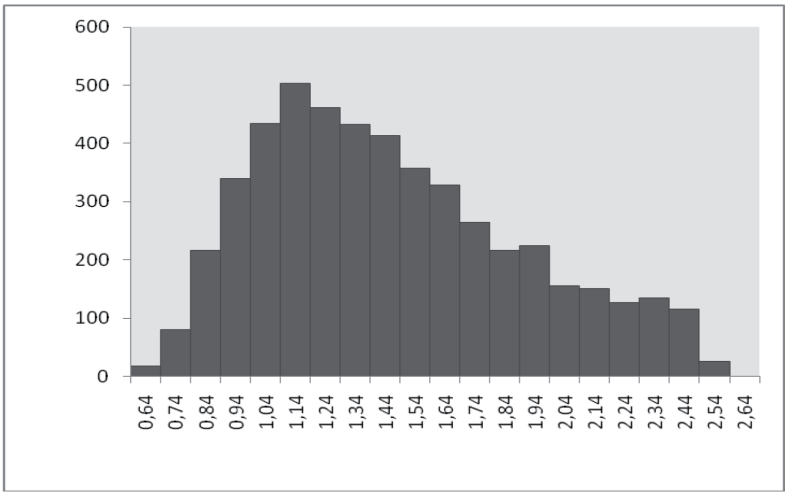



*Figure 4. Results of the Monte Carlo simulation: histogram of BCR from the end-user perspective.*

**Table 4. Levelized cost and benefit components per kWh of fuel saved and benefit-cost ratios from societal perspective (interest rate 3%, lifetime 16 years).**

| | Incremental investment costs including additional electricity system costs [Euro/kWh excl. VAT] | Overhead programme costs [Euro/kWh] | **Total costs** [Euro/kWh] | Avoided system costs fuels *[Euro/kWh]* | Avoided external CO2 costs from fuel emissions [Euro/kWh] | **Total benefits** [Euro/kWh] | **Benefit-cost ratio** |
|---|---|---|---|---|---|---|---|
| **Heat pumps** | 0.0490 | 0.0034 | **0.0524** | 0.0455 | 0.0047 | **0.0502** | **0.96** |

Weiss et al. (2008) with the experience curve approach. They derived learning rates for heat pumps that show a decrease of production costs of 25-42 % with each doubling of cumulative production. In addition to production cost reductions, the efficiency of heat pumps may improve over time. Weiss et al. (2008) constructed an experience curve for costs per kWh heat production that combines cost reductions and COP improvements. For each unit of heat produced, they estimate a learning rate of (27.7 ± 0.8) %. Both, the decreasing investment costs and the improving energy efficiency over time indicate that heat pumps will turn out to be cost-effective from the societal perspective in future.

### THE ENERGY COMPANY PERSPECTIVE

The most important driver for energy companies operating in liberalized electricity markets is to increase their profits. Therefore, the main objective for EDF is to minimize the costs of saved energy in order to achieve its saving obligations imposed by the FWC scheme in the most cost-effective way. From the perspective of EDF, incentive payments including the provision of the bonus payments as well as the capital costs of the interest free loans are considered as a cost factor in the evaluation. In addition, the overhead costs of EDF resulting from the programme implementation and the additional electricity system costs are considered as costs. Among

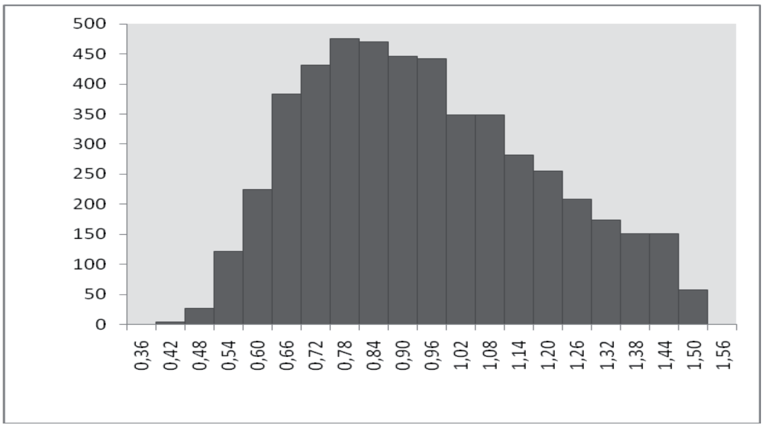



*Figure 5. Results of the Monte Carlo simulation: histogram of BCR from the societal perspective.*

**Table 5. Levelized cost and benefit components per kWh of fuel saved and benefit-cost ratios from the energy company perspective (interest rate 8%, lifetime 16 years).**

| | Incentive payments [Euro/kWh] | Overhead programm e costs [Euro/kWh] | Additional electricity costs and network tariffs [Euro/kWh] | **Total costs** [Euro/kWh] | Additional electricity sales revenue (net of taxes and T&D tariffs) [Euro/kWh] | Avoided penalties of the FWC scheme / avoided costs of white certificates [Euro/kWh] | **Total benefits** [Euro/kWh] | **Benefit-cost ratio** |
|---|---|---|---|---|---|---|---|---|
| **Heat pumps** | 0.0288 | 0.0058 | 0,0227 | **0.057** | 0.0228 | 0.0408 / 0.0065 | **0.064 / 0.029** | **1.11 / 0.51** |

the monetized benefits are the increasing revenue of electricity sales due to fuel switching.[20] More important, the opportunity costs of obliged energy companies in white certificate schemes, i.e. the costs to be paid if the energy savings would have been not realised, need to be considered in the calculations. In white certificate schemes, these are the costs of acquiring the white certificates on the market or the penalties to be paid by obliged actors in the case of non-compliance. As the penalties in the FWC scheme of 20 Euro/MWh cumac[21] are much larger than the average white certificate market price of 3.2 Euro/MWh cumac[22], an obliged actor would rather buy the white certificates on the market instead of paying the higher penalties. However, in the first and intermediate period of the FWC scheme, the liquidity of the white certificate market was limited, thereby conditioning the fulfilment of the obligation to support the customers in improving their energy efficiency (Baudry and Osso 2011).

Table 5 shows the deterministic results of the cost-effectiveness evaluation for both values of opportunity costs, i.e. the avoided penalties and the average white certificate market price.[23, 24] The level of BCRs clearly depends on the type of opportunity cost that is considered in the calculations. On the one hand, it would be more cost-effective for EDF to buy the white certificates at the market than to subsidize the installation of heat pumps in order to comply with its saving obligations. As pointed out above the acquisition of the certificates on the market is so far only a theoretical option due to the limited liquidity of the FWC market. On the other hand, it is more cost-effective for EDF to promote heat pumps in order to comply with its saving obligations than to pay the penalties. The simulation results of the Monte Carlo analysis show that 60 % of all iterations yielded a BCR larger than one if the penalties are considered as opportunity costs (figure 6). An explanation why the implementation of energy efficiency measures is in general costly for obliged actors in the FWC scheme is the lack of a cost-recovery mechanism, while at the same time regulated electricity prices for domestic customers exist in France. It is, consequently, not possible for obliged actors to pass their costs of compliance on to the end-users.

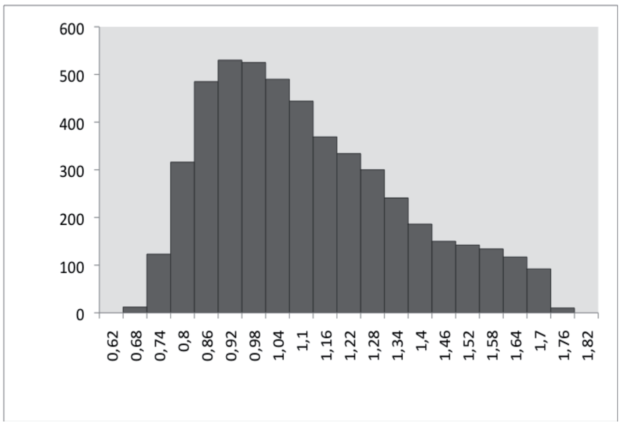
20. Concerning the benefit of additional electricity consumption, the calculations assume that the households remain customers of EDF.

21. Cumac stands for cumulated over the measure lifetime and discounted at a rate of 4 %.

22. Average weighted market price of certificates exchanged in the national registry between March 2009 and November 2010, a time frame in which the price fluctuations was relatively low (Emmy 2010).

23. In order to allow a comparison of the costs per kWh saved with the avoided penalties and the average market price of white certificates, the specific avoided penalties and the average market price of the FWC scheme that are expressed in kWh cumac must be calculated in Euro/kWh per year and expressed in relation to the savings calculated from the billing analysis.

24. The additional electricity costs and network tariffs are expressed in relation to the fuel savings.



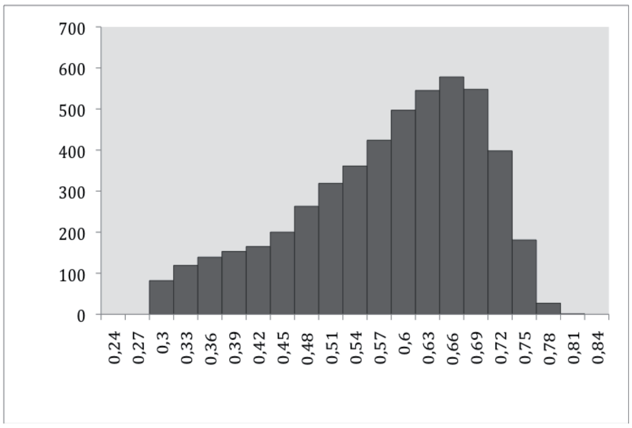




*Figure 6 and 7. Results of the Monte Carlo simulation: histogram of BCR from the energy company perspective (calculation results in figure 6 consider avoided penalties; results in figure 7 take costs of acquiring the white certificates on the market into account)*

## Conclusion

This paper presents the evaluation results of an energy efficiency programme promoted by EDF in two 'départements' of France. The cost-effectiveness of the installation of heat pumps is determined from the perspective of the programme participant and society as well as the energy company in charge of the programme. According to the results of a billing analysis, substantial fuel and $CO_2$ savings have been achieved in the two 'départements'. It is, however, emphasized that the degree of uncertainty of the calculated savings is comparably large due to a moderate sample size in combination with a lack of data of a control group. In order to partly overcome this issue, an uncertainty analysis was done on the basis of Monte Carlo simulations for nine key variables.

The evaluation results point out that the implementation of heat pumps is profitable for customers, since avoided energy bills, received tax credits and incentive payments clearly outweigh the (incremental) technology costs. If the tax credits provided by the French government are neglected in the evaluation, the installation of heat pumps will remain profitable for customers. The installation of heat pumps will, however, not be cost-effective for end-users if they receive neither the governmental tax credits nor the financial incentives from EDF. Non-energy benefits such as comfort gains and an increasing property value, which are an important motivation for many end-users to refurbish their building, are not evaluated in this study.

The economic impact on the entire society is measured in this study by comparing the sum of incremental investment costs of heat pumps and programme overhead costs with the avoided energy supply system costs and the avoided external environmental costs. The calculation results show that the installation of heat pumps is currently not cost-effective, but close to it, mainly due to the high technology costs. However, the histogram of the Monte Carlo simulation is widespread, showing a comparably large sensitivity with respect to the uncertain variables. A BCR of at least one is reached at 35 % of all iterations of the simulation from the societal perspective. In addition, learning rates for heat pumps show that investment costs tend to decrease and energy efficiency to improve over time.

The main objective for EDF is to minimize the costs of saved energy in order to achieve its saving obligations imposed by the FWC scheme in the most cost-effective way. Cost factors for EDF include incentive payments, programme overhead costs and additional marginal electricity costs and network tariffs. Among the monetized benefits are the additional marginal electricity revenues due to higher electricity sales and, more importantly, the opportunity costs of obliged energy companies in white certificate schemes, i.e. the costs to be paid if the energy savings would have not been realised. These are either the costs of acquiring the white certificates on the market or the penalties to be paid in the case of non-compliance. Since the penalty price is much larger than the certificate price, the evaluation results strongly depend on the type of opportunity costs taken into account in the calculations. On the one hand, the evaluation shows that it is more cost-effective for EDF to promote the installation of heat pumps than to pay the penalties. On the other hand, the results indicate that it would be more cost-effective for EDF to buy the white certificates at the market than to promote heat pumps. The acquisition of white certificates is in France, however, only a theoretical alternative for EDF to comply with the obligations. In practice, this is currently not feasible, as the market liquidity is limited.

A general finding is that the implementation of any energy efficiency measure is costly for obliged actors in the FWC scheme due to a lack of a cost-recovery mechanism. In France, it is not possible for obliged actors to pass their costs of compliance on to the end-users, as the energy prices for domestic customers are regulated. This is a unique feature of the French system of energy savings obligations: In all other countries that have energy savings obligations for energy companies, these are given the possibility to recover the compliance costs. With such a mechanism, all the measures assessed here would be cost-effective for EDF. The authors, however, point out that even if energy efficiency measures are not cost-effective from the energy company perspective, it should not be generalised that energy efficiency programmes are no meaningful business strategy. A central motive for many energy companies to offer energy efficiency programmes is to increase their customer loyalty and to improve their corporate social responsibility in order to generate additional revenues.

## Glossary

BCR: Benefit-Cost Ratio
COP: Coefficient Of Performance
EDF: Electricité De France
FWC: French White Certificate
GHG: GreenHouse Gas
IPMVP: International Performance Measurement and Verification Protocol
NPV: Net Present Value
VAT: Value Added Tax

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