Carbon emissions displaced by energy savings

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Keywords

marginal, average carbon emissions, electricity, ELFIN model

Abstract

The economic and carbon impacts of several efficiency measures such as household appliance efficiency, insulation in homes using electric heating, or lighting have been tested against the electric system in France. This work uses the recognised Electricity Financing (ELFIN) model as well as detailed technical characteristics of electricity plants and the electric system. It reconstructs the economic merit order in the way the dispatcher would. Efficiency measures are modelled in the same way as production plants, using hourly shapes and energy gains.

This shows the power plants displaced, both at the short term and in the longer run in competition with new generation. Results include cost savings for the electric system, peak shavings and detailed impacts on carbon emissions.

The latter result, a "marginal carbon saving" is a useful analytical tool to compare efficiency measures in competition with supply-side power stations. This helps in the case such as France where the electric system has low carbon emissions on average, but may have wide hourly variations due to the use of carbon intensive plants during peaks.

The methods and results must be carefully discussed, because the results of such modelling cannot be used directly to credit carbon emissions limitations. This is because the sum of marginal calculations differs with the emissions saved for the whole portfolio. But this tool can benefit for example the regulator of an efficiency market instrument such as 'White certificates' or the Kyoto Mechanisms, to verify the claims of utilities, or to optimise the requests to the supply industries.

Introduction

Carbon dioxide emissions abatement has become one determining factor of energy efficiency, through the UNFCCC process and in Europe with the emergence of the European Trade System (ETS). In particular, the entry into force of the Kyoto Protocol means that carbon emissions now have a cost.

But accounting for carbon emissions and savings in the electrical systems remains a difficult business. In some countries, both the base-load electricity and the supplemental sources are derived from fossil fuels. Thus savings of electricity equals savings of emissions more or less in a linear fashion. This is mainly the case in Germany and in England. But in some systems, power is produced by a more blurred mixture of sources, with large seasonal variations. In each system, and depending on the time of use, the electricity consumed will have a different impact in emission terms. In the case of France, the most carbon-intensive sources are also the most marginal, with the bulk of power coming from nuclear generation.

For policymakers, what is the best choice of efficiency programs? For operators of energy efficiency programs, what carbon emissions should be used as base case when measuring energy savings?

The average carbon content: simple, but is it accurate?

Yearly or monthly averages use available data and are simple to implement. But in the case where most sources are non-fossil based as in France, such a methodology may give the impression that extra efficiency will bring no carbon benefit. It also describes only the past state of the system and may be altered in the future if the stock of plants varies.

One first such method is to simply use the yearly average of the resource. In the case of France, where nearly 80 % of production comes from nuclear, this calculation attributes to electricity saving only a minor role for saving emissions. This would be a mistake, because still over 30 millions tons of CO_2 are emitted yearly in electricity production, and this figure is growing with the development of new gas plants and industrial cogeneration. Thus, in policy terms, a yearly national average brings a strong bias against energy efficiency.

A more differentiated calculation is based on monthly average thermal production in the system. It has been proposed by the French Energy Agency ADEME and utility EDF. This avoids using yearly average values and gives more incentive for efficiency[1]. This gives values obtained after a compromise methodology agreed upon with the utility EDF. Indicators are spread between 40 gCO_2/kWh for base load uses up to 180 gCO_2/kWh for space heating[2].

Another method in use involves a life cycle assessment. Each year or each month, each resource is accounted with emissions for the whole cycle such as the emissions to build the plant or to transport the fuel. This causes first problems with methodologies, for example, which sector should bear the burden of emissions in the case of the recovery of gases in the iron and steel industry? In the case of France, EDF accounts the full burden on the power produced this way (plus the construction of the plant in a life cycle assessment), when IPCC estimates that this should fall on the steel industry emissions balance. The same problem arises for incineration, where IPCC suggests that no emissions are accounted in the energy sector (all waste being attributed to its original sectors) and European Community discussions have considered that only half of the power is attributed to renewable biomass.

Although these life cycle assessments can be quite useful when a consensus is reached, for energy efficiency they are clearly not adequate in countries with low carbon content in electricity, such as France, Sweden or Switzerland or Scotland.

The marginal carbon abatements

This paper presents a full marginal methodology that was experimented in the case of France. It involves a detailed modelling of the electricity system, using a recognized techno-economic electricity generation model. As in the process of a Clean Development Mechanism (CDM) project, it studies one or several base cases (also called "business as usual "or BAU), and then compares the situation of the electricity system in the future, with and without the proposed projects.

Results show the power plants displaced, either existing ones in the short term, or in the longer run, through the competition of savings with new generation. Outputs include cost savings for the electric system, peak shavings, and detailed impacts on carbon emissions. This paper concentrates on the marginal carbon gains of the savings and compares the result with another method based on average emissions.

Presentation of the model and its use in the case of France

Origin of the model

The model used during the research is ELFIN (Electricity FINancing), a power expansion tool designed originally by Environmental Defense (ED), a U.S. based non-governmental organisation. The model is in use in several US states by Regulators and Utilities to assess the needs for new plants, the impacts of energy efficiency programs or the economic impacts of emissions reductions. In California, is has even once been used as an official benchmark to assess the needs for new capacity or efficiency and rank the best options[3]. This was before the catastrophic abandon of most public planning in the subsequent years.

The model has shown the importance of parameters such as the technical minimum of operation for coal or steam plants, which can influence the optimum level of these plants in a national mix of generation. Other important parameters can be the size of plants; differentiated regulation for emissions in different zones; limits of transmission between areas. The model was also used to quantify the value of meteorological predictions for the integration of wind in electric systems[4].

In France, ELFIN has allowed to model energy efficiency impacts on the electric system since 1994 with support of national energy institutions such as ADEME[5] or DGEMP. One research was also funded by the European Commission to study six small and large systems in Europe[6]. The model was also used to debate the economic and carbon emissions impacts of power exports, of efficiency in lighting[7]. Another research consisted in reconstructing the system starting in 1974 with insight on the actual electricity demand and prices. The results show that nuclear construction should have been halved to obtain an economic optimum[8].

OPERATION OF THE MODEL

The base of the modelling in ELFIN is the use of load duration curves[9]. These load duration curves use detailed demand data and are split into many sub-periods in order to obtain homogenous conditions for production plants. This mimics the work of the dispatch in the electric system for a chosen period of time, and is well recognized among regulators[10] In the present research, 36 sub periods have been used to simulate for

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[1] ADEME 2005, "Note de cadrage sur le contenu CO2 du kWh par usage en France", January. According to this note, the figures are calculated from monthly productions between 1998 and 2003. Demand side uses are described through a "seasonal coefficient" and their specific emissions weighed with monthly thermal electricity. Details of the calculation and data have not been published.

[2] These values are each deducted from a range of variation: for example 85 gCO2/kWh to 151 gCO2/kWh in the case of lighting to be used as simplified indicators.

[3] Marnay C., Kirshner D. et al. 1998 « Restructuring and Renewable Energy developments in California : using ELFIN to simulate the future California power market », Lawrence Berkeley National Laboratory, MRW Associates, Environmental Defense, LBNL 41569

[4] Milligan, Miller, Chapman 1995 « Estimating the Economic Value of Wind Forecasting to Utilities », Milligan, Miller, Chapman, National Renewable Energy Laboratory (NREL), Golden Colorado 1995

[5] Bonduelle A. et Le Strat P. 1999, « chauffage bois et émissions du secteur électrique en France », Mission Interministérielle à l Effet de Serre (MIES).

[6] FAIRE-JOULE 3 project ("Financing the Integration of Renewable Energies"), European Commission DG XII, 1997-99

[7] Bonduelle A. 2001 Emissions carbonées évitées par les économies d électricité : le cas de l éclairage in La Revue de l Energie N°529, September.

[8] Bonduelle A. 2006 La surcapacité nucléaire. Quelle aurait pu être une stratégie d équipement optimale? La Revue de l Energie N°569, January-February

[9] The load duration curve places electrical demands by size, with no account of their chronological order

[10] Kahn E. 1991 « Electric Utility Planning and Regulation », Lawrence Berkeley Laboratory, University of California, ACEEE 1991

Table 1: Emissions factors for each fuel

Fossil sources	Emission factors (IPCC)
	tC/TJ
Coal	26.8
Fuel oil	21.1
Natural Gas	15.3

each month the days, the nights and the week-ends[11]. They are built from the hourly load curves supplied by the TSO[12]. This choice matches most of the data available, most often given on a monthly basis, and thus gives a good precision when actual years are compared with the calculations.

Proposed new resources such as plants or efficiency programs are then tested with diverse conditions such as electricity demand, discounting, energy prices, emission pricing, or investment costs[13]. The model tests many combinations until it finds least cost options. The net present value of a scenario is minimized from the point of view of the electricity supplier[14].

Other parameters are spinning reserve requirements, ramping up or down some sources such as dam hydro power, or constraints on the shutdown of plants during the week or the week-end. For each sub-period,, the system tests which thermal plants that have slow start and minimum constraints are needed to meet peak demand and reserve constraints. This simulates the "forecast" of the dispatch and gives a better precision than models without such parameters, which may give results based mainly on the peaking behaviour of the system.

Carbon emissions of fossil fuel based plants are calculated using efficiency of the plant according to its operation level. Thus emissions of plants are not just one specific value of emission per kWh but take into account the regime of operation (i.e. if the plant operates between its maximum efficiency or at a slightly degraded one at 30 % of its nominal level). Emission factors are given for each fuel in table 1[15](source IPCC).

In the case of cogeneration, the loss affected to electricity production is taken as a proportion of useful energy, e.g. over 90 % efficiency for electricity production in a plant with 30 % electric power production, 60 % heat.

Modelling in the case of France

For a power expansion calculation (i.e. determining the best course of investment for the utility) the suggested precision of results is 1 % on base load energies in the year, if compared with another model with good calibrations. This figure is suggested by the practice of US regulators [16].

But in the present case, the only possible benchmark is actual years, where some actions are governed by real life constraints such as conflicts of use for dams, purchase contracts for the former National Coal Board plants (now ENDESA-SNET), or imposed build-up of wind or incineration plants. To take into account these "reality factors" that cannot be modelled with economic equations, several years were tested in the model using the same parameters for reserve margins, for default or the pricing of energy not served. Demand data, unplanned unavailability of nuclear plants and in general data outside the reach of operators such as rainfall levels were introduced as input. The slight dispersion of results stems from such modelling compromise.

Another source of lesser quality comes from broken data series that occurred after unbundling. For example, hydro-electricity data may contain or not the production of storage dams, and this may vary between years[17]. Some independent production in industry may or may not be accounted for in different sources (e.g. UCTE or RTE).

But one should note that precision has improved in recent years for independent modelling in Europe, thanks to the unbundling of transport and production of electricity. For example, load curves are now routinely published by public operators.

Matching the thermal plants

For the present research on marginal carbon, our goal was also to have a good representation of the operation of marginal plants in different month, so as to represent the seasonal emission patterns in France. This was obtained with a fairly good match shown in Figure 1.

Another specificity of France is that nuclear power stations stand way above base load in the dispatch order[18]. So they are used as a flexible production tool in some seasons when there is too much power (load following), and also as short term spinning reserve (frequency regulation). To take this into account, nuclear power has been given limited freedom in the modelling. Nuclear power stations are simulated individually with data provided by IAEA on planned and unplanned availabilities[19], with no imposed level of production. The monthly energy actually produced by nuclear is compared with the modelling during test years in Figure 2 where nuclear production follows well seasonal variations, but keeps a slight excess in the modelling (1.7 % in excess on average).

BASE CASE SCENARIOS

Three contrasted scenarios were used for the present work. These have allowed testing efficiency programs in contrasted situations in terms of carbon emissions.

The demand of energy was based on publications by the Transmission System Operator and by the Negawatt expert

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[11] Another option used by some utilities is to simulate 52 weeks to be closer to the actual vacations and allow an optimisation of maintenance. Many other modelling use only a few peak points and a limited number of periods.

[12] RTE 1996-2006 Historique des consommation en puissance (MW),

[13] ELFIN Algorithm Guide, 1996 Environmental Defense, Oakland California and updates.

[14] The function is : Net value to minimize = N1 [(Production costs)n + (Investment costs)n] / (1 + a)n
Where a is the discounting rate and n the current year. N is the duration of the modelling, in the present case 45 years starting in the year 2005. Taxation of emissions is accounted as one more variable production cost. Eventually if production is insufficient to meet peak demand, the energy not served is added as a supplementary cost.

[15] Manuel simplifié du GIEC: version révisée 1996.

[16] Kahn E. 1991 ibid

[17] UCTE statistical yearbooks, 1995-2005; RTE Statistiques annuelles 2002-2005, EDF-B101 1995-1998.

[18] In France, the minimum power is 30,8 GW and peak stands at 62.2 GW; The 59 reactors total a nominal power of 63 363 MW (source MINEFI). If unavailabilities and load following are taken into account, 200 TWh/year of nuclear production can be considered above baseload level (for a production of 430 TWh in 2005).

[19] IAEA 1995 to 2005 "Operating Experience of Nuclear Power Plants in Member States" International Atomic Energy Agency, Vienna

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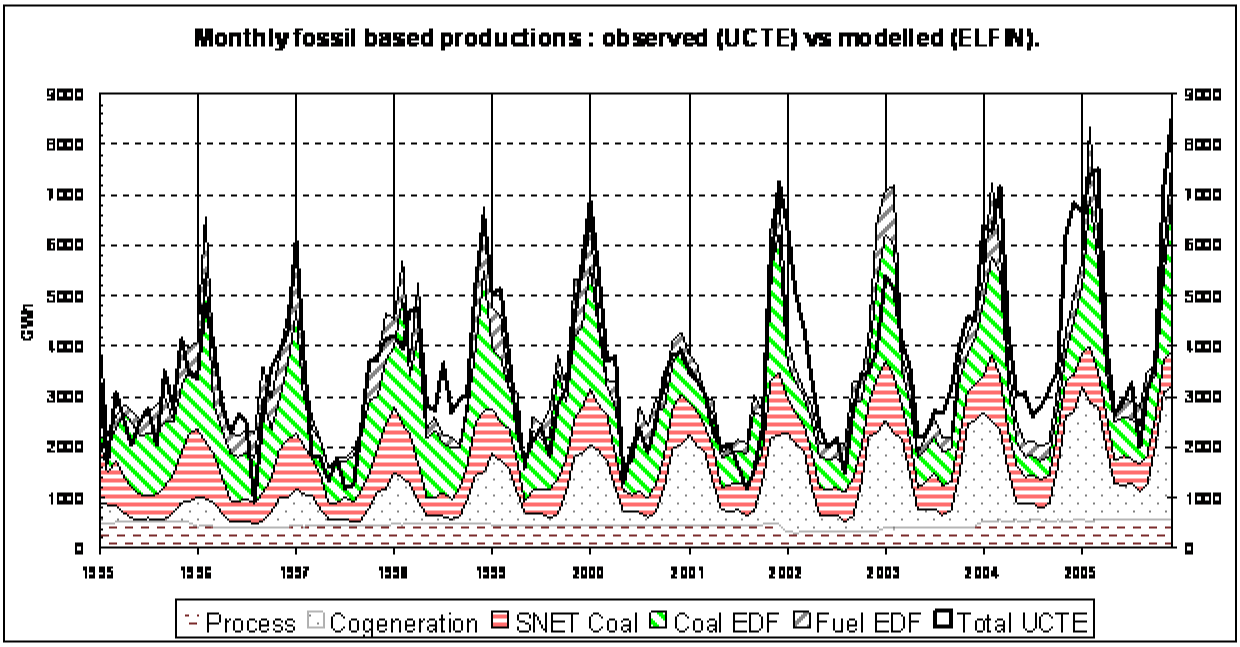

Figure 1. Marginal thermal plants 1995-2005*. Monthly operation of several thermal plant categories in ELFIN are compared with the global figure. The most important sources to study are coal and fuel oil plants operated by EDF and SNET, because they react to a price signal or to load-following instructions, when other independent sources (cogeneration, fatal sources such as incineration and process gas recovery) run mainly on fixed tariffs with less flexibility.*

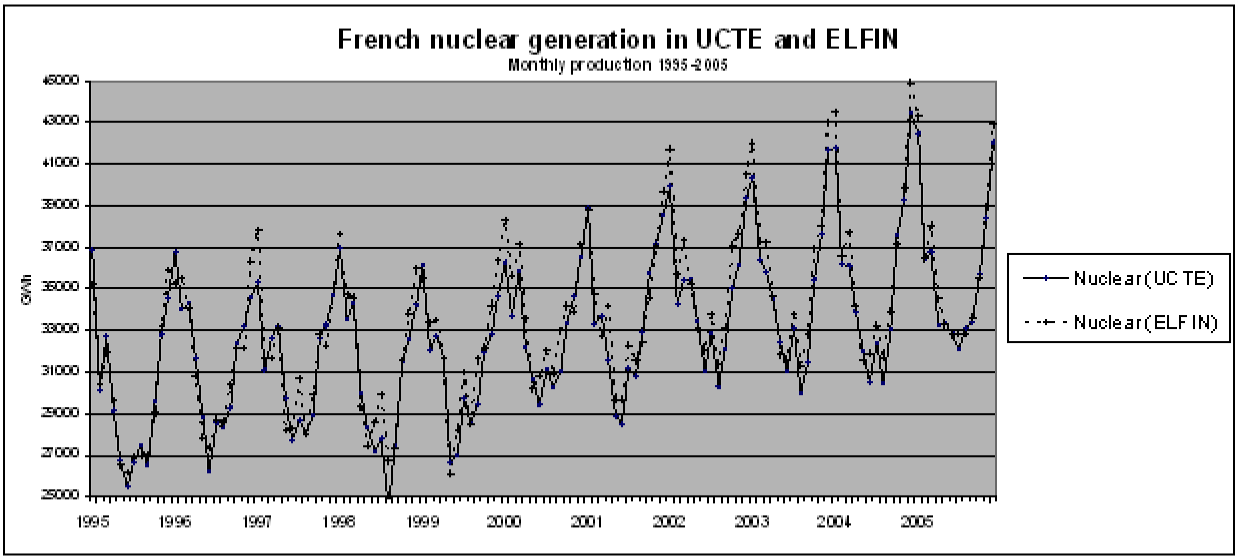

Figure 2. Nuclear power production 1995-2005*. Actual nuclear monthly production is compared to results in the model for the test years.*

group[20]. One called "R2" was based on a "low efficiency" scenario, where demand keeps on growing; another one on the so called "R3" scenario with moderate efficiency efforts and stabilisation of demand beyond 2025[21], the third with a slightly more radical approach by the Negawatt group, aiming at stabilizing and then decreasing demand. Investments and costs for new plants are those of national reference costs[22] or their equivalent at the IEA[23].

Existing nuclear plants. All three scenarios use the same operational lifetime for the existing nuclear plants, inspired by a report to Prime Minister Jospin in 2002[24] Existing plants are

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[20] Salomon T., Couturier C., Jedliczka M., Letz T., Lebot B., 2005 « A negawatt scenario for 2005-2050 » EC3E, 2005 Summer study Proceedings

[21] CPDP EPR&THT 2006, Rapport du groupe technique dit prévisionnel RTE , CNDP 2006.

[22] DGEMP-DIDEME 2004 Les coûts de référence de la Production d électricité de 2003 , Ministère de l Economie, des Finances et de l Industrie, vol 1-2-3-4

[23] IEA, NEA, OECD 2005, "Projected Costs of Genearting Electricity, 2005 Update"

[24] Charpin J-M, Dessus B., Pellat R., 2000 Etude économique prospective de la filière électrique nucléaire La Documentation française.

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kept running 40 years, with the exception of 12 older plants (30 years only) and 12 more recent ones (45 years). Quicker phase-out were considered, but a longer operation of nuclear reactors gives a conservative approach in the present research set to measure the carbon to be saved by efficiency.

Renewable Energy development has been kept in line with national commitments and proposed extension, but with long delays, to take into account slow implementation in the past. Most future new development modelled occurs after 2025 and thus have no impact on the present study.

Thermal plants. A number of combined-cycle plants are to be built in France in the next decade. The modelling uses data published in the press by public and independent operators, which may be too optimistic on delays. Another uncertainty is the closure of old coal and fuel based steam power plants. But this agenda is framed by a pollution directive that blocks the operation of the worst emitters and has obliged the operators to plan refurbishment of the plants they want to keep.

Another source of uncertainty in this area of thermal plants was that power data on the available plants are given only once a year, with fluctuations in the number of available plants happening during the year. This is not the case for nuclear plants, where data is available month by month.

Cogeneration. The number of new cogeneration plants is not yet limited by the potential for heat demand, which is still important according to public figures, but to the limited access to purchase power contracts. The present contracts do not allow much load following or reserve, but this may change in the future according to Government planning documents[25].

The purchase power contracts for cogeneration were developed extensively during the last ten years with industry, heat distribution and hospitals. They raise specific issues: First, production data is often poor. There is also uncertainty on the terms for the renewal of these contracts in the next ten years. Second, most contractors follow the patterns of mandatory tariffs and stick to the 4 000 hours of production they have been encouraged to produce. Thus, only a small part of the production is flexible or able to follow load. For projections in the short term, we keep this system, thus lowering the pool of carbon influenced by the studied efficiency programs. This way, results should not be affected in the present short term research, but in the future, cogeneration plants could be modelled as more flexible resources.

New nuclear and thermal plants. In addition to existing or planned plants and contracts, the model was used to complete the stock of plants to match the demand. In the R2 scenario (low efficiency), the build-up of nuclear was not limited, but in the observed modelling no new reactor was built but mainly coal and gas plants. This is probably due to the absence of carbon tax or cost for permits. In the R3 scenario, new nuclear reactors were imposed in the rhythm suggested by executives at EDF in a recent industry publication, to a total of 20 new large reactors[26]. The rest of the plants built by the model were gas turbines and combined-cycle plants, and wind turbines[27]. The last scenario (strong efficiency) halts new nuclear construction.

Exports and imports. Only one pattern of exports was used in the three scenarios, the continuing export of a large proportion of power with a slow decrease, as suggested by work published by the French TSO[28]. Imports were authorized in peak times, but limited to the historical maxima in the previous decade. Although figures for carbon in the research do not take into account the emissions due –for example in Germany- to peak power imported into France, imports were charged a carbon tax similar to the one in the French market for the scenario considered.

More important to the carbon results, a degree of liberty has been added for imports. These were split between commercial contracts and peak trade. The former was based on monthly exchanges and prices observed in the last ten years, the latter gives the possibility to the modelling of importing expensive peak power. This respects available power for emergency supplies. Carbon impacts of imports are calculated separately from domestic emissions. In results published in this paper we did not take into account these emissions, although they may represent 18 % of displaced power in the modelling (see example in table 4).

This is consistent with recent developments in the French-German trade of electricity where the exchange is more or less balanced with nuclear exports at mid-season prices and peak imports from German utilities. One can argue that French efficiency programs will save emissions in Germany or elsewhere in Europe. But this should be discussed in further research on the impact of the exchange on the rest of Europe, be it the avoidance of thermal generation (in the case of imports to France), or the building of new plants (in the case of less exports from France).

Carbon tax or carbon trading

The introduction of the carbon trading in the European energy industry brings another difficulty to the modelling. In particular, the mode of allocation of permits in France may lead to behaviours by the operators that are not the best outcome for the country as a whole. Old coal power plants are kept open because this will bring more allocations of permits by the state, and new gas plants are built that would not be economic were they to purchase permits in an auction. In the modelling, the price of permit or the level of a tax does influence strongly the new constructions, but for older plants with a low utilisation factor this has no impact. This case illustrates the drawback of a free distribution of emission permits to new entrants to the market. A series of such distortions have been described by Neuhof et al.[29]

To simulate the present system, in two of the projections a carbon levy has been applied on carbon dioxide emissions, starting from the value of 36.5 EURO/tC (10 EURO/tCO$_2$).

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[25] MINEFI 2005, "Rapport sur la PPI", a document presented by the Ministries to the Parliament that suggests the production means to be authorized.

[26] Dupraz B., Joudon L. 2004 Le développement de l EPR dans le marché électrique européen , RGN N°6 special Le réacteur EPR, December

[27] All construction costs are based on estimates by the French Ministry in their "reference costs" in the last edition (2003)

[28] RTE-EDF 2006, Bilan prévisionnel de l équilibre offre-demande d électricité en France

[29] Neuhoff K.,Martinez K.K, Sato M., 2006 "Allocation, incentives and distortions: the impact of EU ETS emissions allowance allocations to the electricity sector". Climate Policy 6 (2006) 73-91, Earthscan

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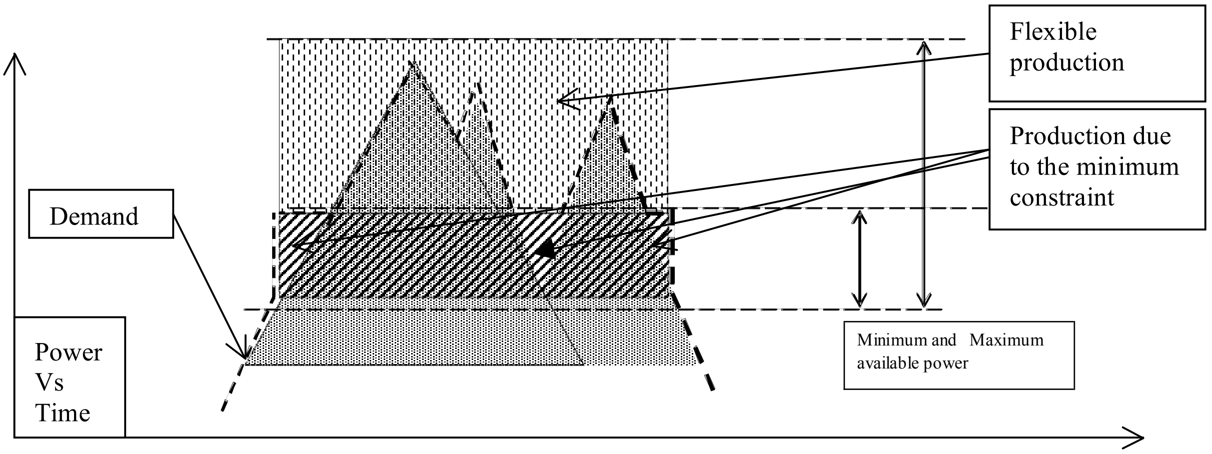

Figure 3: Example of extra carbon emissions in a steam power plant. *The electrical demand (dimmed) triggers the dispatch level (lower dotted line) of a marginal resource. The upper part of the available power is adjustable (in light grey) but the plant has to keep a minimum power level (30 % to 40 % of maximum) during all day or week. The extra production due to this inflexibility is shown in hachured. This leads to extra carbon emissions, in addition to the proportional emissions due to the specific efficiency of the plant.*

This was applied uniformly on all fossil fuel based plants based on the carbon content of the energy source. One further research -presently under discussion- will be to precise what impacts can be expected in the French-German trade during the next twenty years, due to these imperfections of the market and to these new thermal plants in a context of prolonged overcapacity. The role of new gas plants being built at present with a free allocation of permits by the French government could also be investigated. These plants seem to be marginal in carbon, as shown by table 4 for the years 2015 and 2020.

SPECIFIC FEATURE: INDIVIDUAL REPRESENTATION OF STEAM PLANTS

The model used allows for a detailed representation of plants instead of an aggregated representation, and it can include several technical parameters for each plant such as a minimum operation constraint. This allows a better description of the system when observing carbon emissions in slow start thermal plants, as shown in Figure 3.

Carbon emissions reductions are not proportional to savings. When the system as a whole is observed, carbon impact of efficiency may not be a proportion to the specific per kWh emissions of sources saved. It may emit much more for a marginal source. This difference comes from the minimum constraints of steam-based plants (figure 3); from the efficiency levels of these plants that vary according to their levels of operation; and to the spinning reserve requirements of the system that commits more plants than needed for the peak operation. Let us examine these three possible factors of influence:

- First, the minimum constraints may induce more production. For example, a 600 MW coal power plant such as the four used at EDF has a technical minimum of 270 MW. Under this power level the plant has to be shutdown. Delays of 3 to 11 hours are needed to start again after a few hours. For the cold power plant, about 10 TJ will be burned before coupling, emitting over 260 tons of carbon. It is much more economic to limit shutdowns to once a week or less. But this brings some extra carbon in the system, figured in graph 3, that does not appear in calculations which use simplified assumptions on the sensitivity of fuels.
- Second, the efficiency varies. The efficiency of such steam plants is rather even in the operation, but does decrease slowly between its maximum operation and its lower point. One reason is the need for auxiliary equipment (in the example they consume 19 MW or 3 %), which will weight up to three times more if the plant operates at a low power level. A further reason is that the turbine will lose some efficiency at a lower pressure. For example, with a throttle flow operation, the heat rate[30] decreases by 8 % at 40 % level of operation and by 12 % at 30 %.
- Third, the system needs reserve margin. As the efficiency of a steam turbine is very close between the maximum power and near the minimum, it is thus useful for the reserve and modulation needs of the grid[31]. The same 600 MW power plant will vary its load directly from the dispatcher from 330 MW to 525 MW at a high speed of 12 MW/min. To keep this high flexibility value in the system, operators will keep it on operation longer in the year (and emit more carbon) than needed on more simplified assumptions.

These three reasons make the real life operation of such plants quite different from the nominal efficiency expected from a base load plant. Their specific emissions become very system dependant when they operate in the margins. Classical comparisons of electric sources involve a linear function with a fixed cost (investment and yearly maintenance) and a variable cost (fuel and maintenance) [32]. Compared to a more detailed calculation, they are biased towards less flexible sources with the lowest marginal cost, such as coal or nuclear. One such

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[30] Plant operators use "heat rate" as the inverse function of efficiency. For example, a heat rate of 8 530 Mbtu/kWh is the same as an efficiency of 40 %.

[31] In France, nuclear power supplies aslo frequency regulation and some flexibility, but not in the same proportion. For example, the Chooz-B plants in the Ardennes operates at 98% of nominal power and fluctuates up and down to -5 % in the so-called primary tuning of frequency and up to a total 15% in a load following mode

[32] e.g. "Impact of Carbon Emission Trading on Generation Cost" in Projected Costs of Generating Electricity, 2005 Update, OECD 2005.

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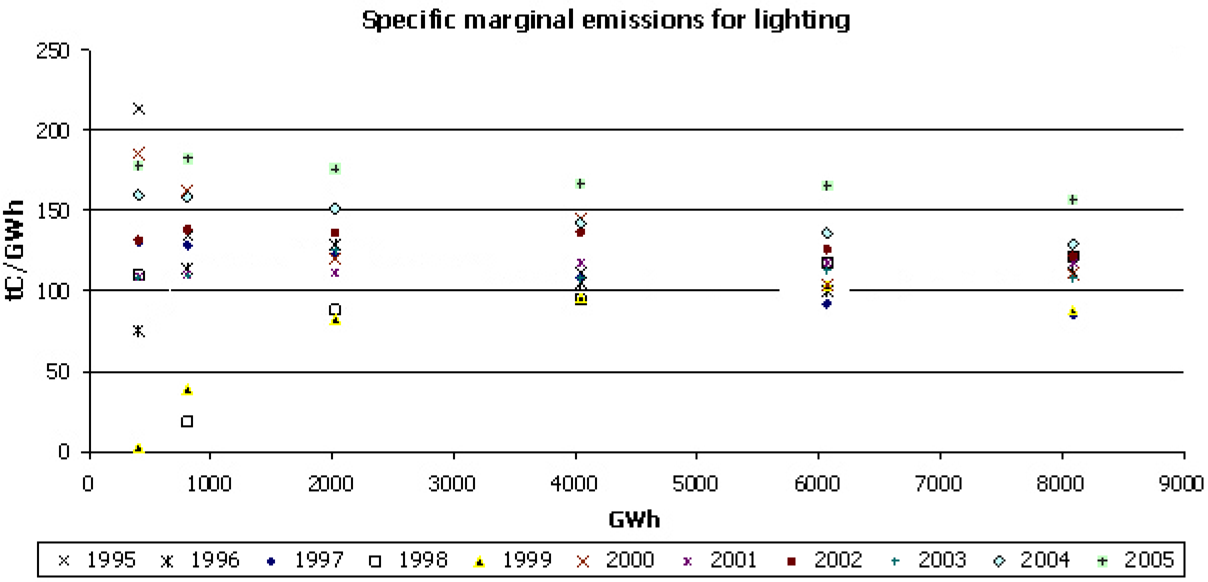

Figure 4: Carbon emissions avoided by lighting programs. *For the example of lighting, impacts on carbon emissions were calculated for different levels of savings (1 %, 2 %, 5 %, 10 %, 15 %, 20 %), and tested in the model against the actual data in the last decade. Beyond natural dispersion due to different technical conditions (hydro, demand, technical availability of nuclear plants for example), the graph shows that the volume of savings impacts the results.*

comparison was made with another model in use by the IAEA, the Wien Automatic System Package (WASP) that did not feature such technical constraints. In this example on the case of the Philippines, the two models had the same set of data except the minimum constraint on plants. Results have shown optima in the mix of plants that differed by 2 000 MW in favour of coal plants on a total power of 14 000[33]. The bias may thus have up to 20 % impact on capacities to be built.

In many cases, marginal carbon sources in Europe are thermal steam plants or gas turbines. During peak hours in the case of France, the marginal electricity sources are most often hydro electric dams and pumping storage facilities (up to 1 100 MW) supply the immediate flexibility. But if carbon emissions are considered, these resources are not variable –the hydro production is only deported on the hours with the best value to the system. In Fine the displaced resources –what we call the marginal carbon emissions- come from the thermal plants underneath the economic merit order of the dispatch. This is why a detailed representation of such plants is key to a better evaluation of emissions.

Results: Carbon displaced by efficiency

In this part we present the impacts on emissions of energy efficiency in the model, and discuss these results.

Presentation of the efficiency programs

First, a bottom-up representation was used to describe electricity demand[34]. Such representation compiles many statistics[35] and has to match the existing electricity demand at various levels such as national, regional and local[36]. For the needs of the study, twelve typical weeks have been used, each based on three days (Week-days, Saturday, Sunday). Thus the data is rather averaged both at national level and during the year. In the case of carbon emissions, this simplified assumption tends to favour less contrasted curves and may minimise slightly the emissions calculated.

Second, simple programs of energy efficiency were designed on the 20 uses studied, each defined by their weekly shape and the monthly pattern of use. These simplified programs have been set as a proportion of the use[37]. Then, consequences of the savings were tested on the 20 sectors for 6 different steps reaching from 1 % of extra efficiency improvement to 20 %. The latter figure is consistent with proposed efficiency programs at the EU level. For comparisons, absolute carbon abatements were then converted into specific carbon contents per kWh.

Two kinds of calculations were performed. First, marginal carbon savings were observed when applied to existing years where the real data is known and the model gives fairly accurate descriptions of the system. This shows the dispersion of results and allows a comparison with estimates of carbon efficiency based on past carbon emissions.

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[33] Rosekrans S., Kirshner D., Marnay C., 1999 “Issues in electricity planning with computer models: Illustrations with Elfin and WASP”, Utilities Policy, 7(4), 201–219. doi: 10.1016/S0957-1787(99)00002-8

[34] Orphelin M. 1999 Méthodes pour la reconstitution de courbes de charge agrégées des usages thermiques de l électricité , Thèse de doctorat en énergétique Centre d énergétique de l Ecole des Mines de Paris, May

[35] This involves both national demand curves (source RTE-EDF), statistics on appliance and housing (INSEE) and measured shapes.(source i.a. O. Siedler).

[36] e.g. studies by Energie Demain Consulting of efficiency potential in the Montdidier distribution center (Régie de Montdidier 2005); study of demand and efficiency potentials in the Lot (Fédération Départementale d Electricité du Lot, 2005)

[37] This assumption is correct for example for changes in lightbulbs or improvement of the shell in a house, but would need more sophistication to describe the substitution of solar thermal or the impact of advanced meters and tariffs.

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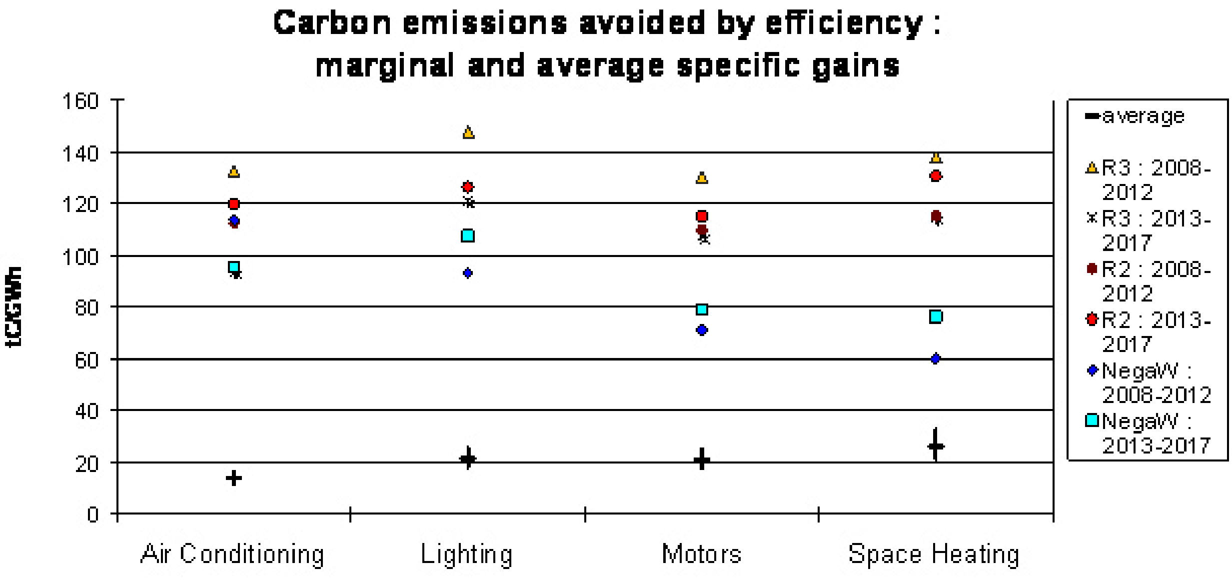

Figure 5: Comparison of marginal and average carbon emissions saved with efficiency in four power uses. *When compared in three reference scenarios, impacts on carbon emissions are much higher than respective levels of carbon of sources in use on average during the same period represented by the crosses at the bottom. The results presented are average of the first Kyoto commitment period (2008-2012) and a second period from 2013 to 2017.*

Then the system was observed in projections so as to estimate the potentials in several scenarios and their dynamic in time.

Test results on the last decade

The first result of the test on several actual years is to show that results are dependant on the size of the program. This can be inferred from the description of the steam based plants allowed in the ELFIN model.

It also gives us a realistic spread of values for our results, due to variations in ten actual years.

While the bigger programs tend to decrease slightly the calculated CO_2-savings, the main observation is that for the smallest efficiency programs, carbon emissions are fairly dispersed. They only converge for values larger than 4 000 GWh/year with still large dispersion due to the year tested. The absence of proportionality (values should not vary with size) was discussed earlier in the paper. Dispersion stems also from the individual modelling of steam-based plants, which may be switched on or off in one week. This gives a more realistic discontinued carbon result than aggregated modelling.

Comparison with the average emissions in the month or the year

The previous results were obtained by the test of past years. While this is a good way of evaluating existing programs, the policy maker that proposes to implement a new standard or a policy has to evaluate future scenarios. This is similar in the case of an investor in the Kyoto flexibility mechanisms such as Joint Implementation (JI) or Clean Development Mechanism (CDM), which has now to justify the gains of his projects compared to a baseline, and confront this calculation to the institutions of the Protocol. The following results have been calculated with the three contrasting base case scenarios described in the previous part..

The results in the marginal carbon gains have been compared with the average emissions in the system, also as estimated in the modelling. They are presented here in tons of carbon per GWh (i.e. with a conversion factor of 3.65 compared to CO_2.

Results are very dependant on the base case used. In particular, the most efficient scenario called “Negawatt” retains the same quantity of nuclear in the next decade as the other scenarios. Thus, carbon-intensive sources are already in part depleted.

For large scale savings (10 % of the use), results vary from 60 gC/kWh for space heating in the efficient “Negawatt” Scenario [38], to over 130 in a more business as usual one published by the French TSO RTE, called R3.

How much emissions can I save in my home?

In the case of a new home, the comparison of emissions between sources is calculated based on standard practice and regulation in France for a new detached house of the same surface (100 m^2). The energy need of the building is set at 100 kWh/m^2. The electric heating is a Joule effect system and not a heat pump. The latter (last column in table 2) gives much lower results for emissions, or about one third of the electric heating. But this requests a perfect system (3.5 COP minimum) seldom sold in France so far.

The modelling results show the large difference between marginal carbon modelling and average monthly emissions in the electric system of France when compared to other fuels. As for those fuels, the accounting of their carbon content is uncontroversial, be it compared with marginal or with average values.

This result can be used both on the micro side, such as consumer information, but also for wider discussions on standards

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[38] Salomon T., Couturier C., Jedliczka M., Letz T., Lebot B., 2005 « A negawatt scenario for 2005-2050 » EC3E, 2005 Summer study Proceedings

Table 2. CO_2-emissions avoided by 10 % extra savings for examples of new homes

Energy source	Oil	Gas	Electricity	Heat pump (with 3,5 COP)
Consumption (kWh/m²)	105	125	100	29
Household consumption (kWh/year)	10 526	12 500	10 000	2 857
10% savings (kWh/year)	1 053	1 250	1 000	286
Energy Specific carbon contents of final energy (gC/kWh)				
R2 scenario (BAU)	82	64	123	123
R3 scenario (medium efficiency improvement)			126	126
NegaWatt (strong efficiency improvement)			68	68
Marginal Emissions avoided by one new house (in kg C)				
R2 scenario (BAU)	86	80	123	35
R3 scenario (medium efficiency improvement)			126	36
NegaWatt (strong efficiency improvement)			68	19
Comparison with indicator base on past average				
All scenarios, (49.3 gC/kWh)	*86*	*80*	*49*	*14*
E&E_Consultant and Energie Demain 2007				

Table 3. Emissions avoided by 10 % savings for existing homes

	Fuel oil	Gas	Electric heating
Consumption (kWh/m²)	218	213	83
Consumption (kWh/year)	21 820	21 342	8 340
10% savings per year (kWh/year)	2 182	2 134	834
Specific carbon contents of final energy (gC/kWh)			
R2 scenario (BAU)	82	64	123
R3 scenario (medium efficiency)			126
NegaWatt (strong efficiency)			68
Marginal Emissions avoided by one house (in kg C)			
R2 scenario (BAU)	179	137	103
R3 scenario (medium efficiency)			105
NegaWatt (strong efficiency)			57
Comparison with indicator based on past average			
All scenarios, (49.3 gC/kWh)	*179*	*137*	*41*
E&E_Consultant and Energie Demain 2007			

or policies to encourage investment in housing. When one uses past average values of carbon in the system (table 2 and 3 last line), electricity heating is preferred to efficient boilers based on fuel or gas. A detailed marginal carbon modelling shows that responsible individual choice and macro policies should choose the opposite.

The same reasoning applies to the savings due to insulation in old homes. But in this case, the existing stock does not have the same size, type of building shell or even the same consumer behaviour if heated with gas, fuel oil or electricity. Users tend to waste more energy with gas than with expensive electricity, and even standards have once been different with more stringent efficiency requirements in electric houses during the eighties. The comparison is based on existing consumptions and not on “equivalent comfort” that could be expected from new constructions. Thus the figures in table 3 are valid only in the case of insulation or behaviour savings, but not in case of a change in the energy source.

The issue of space electric heating has been debated in France for decades now. This practice is either widely used in some other countries or regions (Norway, Quebec, Sweden) and forbidden or strictly limited in others (Geneva, Denmark, Austria). Our results show for both old and new homes, that the French compromise value of 180 gCO_2/kWh (50 gC/kWh) used by ADEME on the base of the past average[39] may be too low. It implies that the user of electric heating is credited of about one third of the carbon emissions per kWh compared to a user of gas or fuel oil. The marginal emissions calculated in the present research shows that there may still be similar quantities of carbon to abate through energy efficiency.

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[39] ADEME 2005, ibid.

Table 4: Example of sources displaced by efficiency programs

Displaced sources for efficiency in the R3 scenario : examples of a 10% extra efficiency in lighting in the years 2010, 2015, 2020							
	tC / GWh	Nuclear	Coal	Fuel	Gas	Hydro and Renewables	Imports
2010	139	**25%**	25%	19%	23%	0%	**10%**
2015	110	11%	6%	17%	51%	0%	18%
2020	103	21%	16%	2%	**47%**	0%	15%

E&E Consultant, Energies Demain 2007

Sources displaced by energy efficiency

The energy displaced varies very much according to the year. This is in part due to new gas plants brought in line between the dates shown, and to retirement of older plants under new European regulations on local pollution. There is also less overcapacity of nuclear in the system with the growth of demand. This is illustrated by examples in three years that show the energy displaced by one efficiency program (lighting) in three years of the R3 base case (see table 4).

Unused nuclear capacity does happen in the modelling (see figure in bold in table 4), but presently, most of this excess is exported or dumped cheaply on the market. Thus in the next decade, energy efficiency will displace mainly fossil thermal resources.

LONG TERM IMPACTS

For energy modelling, the long term begins when existing resource becomes marginally more expensive than new resource. At this point, the utility or the public decision maker will find a benefit in building a new resource. All three scenarios see the build-up of new resource in the first decade, in particular gas plants already in the planning, but also peaking turbines. One aspect of the research is to watch the impact of extra energy efficiency on such planning.

The model has been used at that stage to observe the optimum investment found with and without energy savings. One can observe very limited impact before 2025, for example the avoided construction of one 100 MW peaking turbine in 2017 for 10 % extra savings in lighting. More impact does happen after 2030. For example, a program of combined cycle turbines (3 500 MW) is postponed from 2031 to 2032 for a program with 10 % extra savings on lighting, and to 2034 with a 20 % gain. Impacts are similar for the tested programs.

But all this remains limited and strongly dependant on the modelling parameters, e.g. the size effect of the new resource proposed to optimisation. The calculations show more clarity when applied on much larger efficiency programs that change the nature of the scenario itself. But then speaking of "marginal savings" is no more relevant and out of reach of the present research.

One important issue is the validity domain of the calculation. Marginal impacts of efficiency can measure emissions abatements only to the point where there is still carbon-intensive resources to be removed from the system. This limit does also exist for average based calculations. A good description of technical limits for each resource (for example by taking into account reserve requirements or the level of flexibility of cogeneration contracts) will help extend that validity. This discussion and need for consensus is similar to the issue of tariffs when they are based on future projections (the marginal costing) vs the rates based on past accounting of costs.

The research does not take into consideration possible regional impacts on transmission and production. This could in particular be interesting in areas with seasonal saturation of the grid, such as Brittany or the Riviera near Nice. There, short term peak savings may save or postpone the construction of power lines, thus saving landscapes and money.

Conclusion

Many combinations of energy savings have been tested and observed during the research presented in this paper. Marginal carbon figures have been compared with more traditional figures based on average carbon content. Several conclusions can be drawn:

One possible development is to define a new way of assessing efficiency combining the marginal carbon calculations with total evaluations of carbon emissions. As our work shows, the "pool" of marginal resources is much smaller in the case of France than the production as a whole, and it is much more carbon intensive all year long than the average. Thus the impacts of energy saving policies as represented with marginal carbon savings may give a better picture than a measure of average quantities, be them from past or prospective. The existing methodologies may give inaccurate information on the impacts of their decisions on carbon savings.

Still, one legitimate criticism of the marginal carbon methodologies is that the results cannot be added together easily and that the total marginal carbon emitted by many uses will not bring the total carbon emitted by the system. This stems from the same criticism on energy efficiency programs: one cannot add energy efficiency progress on the same consumer category; relative gains have to be multiplied, and the order of implementation of the modelling matters to assess the potential of one particular policy or measure.

But these shortcomings do not forbid the use of such relative gains in percentage, because they describe quite well the possible impact of policies and the level of efforts of actors. The maximum total of efficiency improvement (or for instance carbon abatements) is found with the global combination of all policies simultaneously. In any case, individual gains in efficiency are often used for the commodity of comparing the "nuts and bolts" of measures (costs, impacts on employment, legal difficulties…) but in the end most of these measures act in synergy. The research shows also that our calculations are valid in a wide range of programs.

The method introduced in the paper does not bring final and simple answers to the discussion. The multiple figures, reference scenarios and hypothesis have still to feed the discussion more broadly. Methods could be improved and figures could still evolve. But our work clearly shows that existing methods may lead to misleading information passed to the consumers and policymakers. Thus a compromise should be passed with other means of calculation to give them usable indicators. In particular, this future information should not discourage energy efficiency as some of the present average-based indicators tend to do.

Marginal carbon emissions could also be a guide for policymaking such as standard setting. This can feed the debate between the actors on prospective policy implementation. This could also be important for projects made in the Kyoto framework such as JI or with countries without a quantitative reduction target (CDM).

Acknowledgements

This work was made possible by a research grant allocated by the French Ministry for Transportation and Construction through the Direction Générale de l'Urbanisme et de la Construction (DGUHC).

Other acknowledgements go to Mr. Daniel A. Kirshner, California (USA), for his long term support.