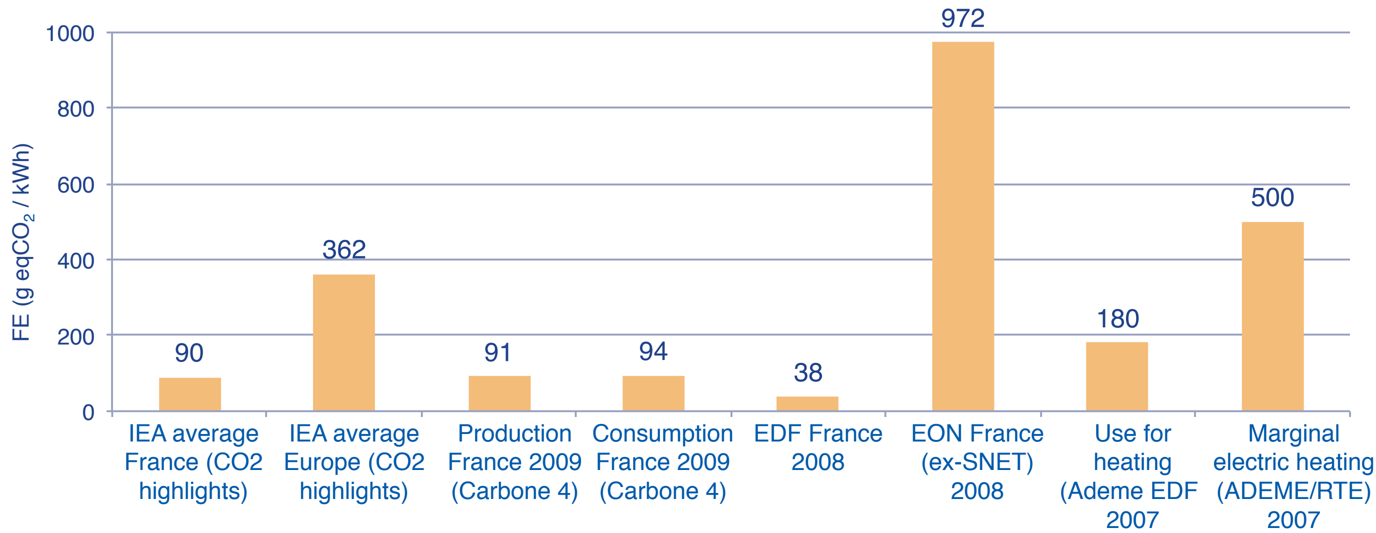
WHAT IS THE ELECTRICITY EMISSION FACTOR?



Why take an interest in the electricity emission factor?

The CO2 emission that is linked to the production of electricity represents 40% of global fossil CO2 emissions (Fig. 1). These emissions are important mainly due to the part of fossil energies in the global electric mix. Coal alone represents 70% of the global CO2 emissions of electricity production. Therefore the coal required for the production of electricity represents 25% of the global CO2 emissions.

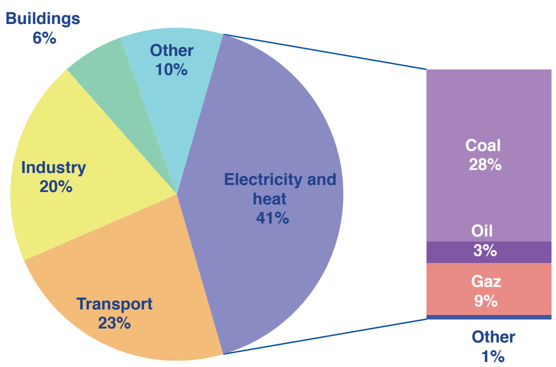


Figure 1 – *Distribution of the global emissions of fossil CO2 in 2007, incl. detailed production of electricity. Source IEA World Energy Outlook, 2009*

In France, the subject often seems to be settled by describing our part in the nuclear and hydraulic energies in the electric mix. However, if the French electric mix is very different from the global one, the CO2 emissions for the production of electricity still represents almost 12% of our national CO2 emissions (in 2008, out of a total of 391 MtCO2 of fossil CO2 emissions for France, the production of electricity represented 45 MtCO2, i.e. 11,5%[1]. Coal and gas are, in effect, used to complete the nuclear and hydraulic production (Fig. 2).
Therefore, electricity production constitutes a major issue in the politics of reduction of CO2 emissions, and this conclusion remains partly valid in France.
From the production of one hydraulic kWh (around 5 g CO2/kWh in LCA – Life Cycle Assessment training), to the production of one kWh from brown coal (>1000 g CO2/kWh in LCA), there is quite a variety of ways to produce electricity.

The share of the different means of production in the mix will determine the Emission Factor (EF) of produced electricity, i.e. the quantity of Greenhouse gas emissions produced in the complete process of electricity production.
All demands for electricity will require the implementation of the means of production with different EFs, some of which will be located abroad. The Emission Factor of this consumed electricity will then be calculated by reconstituting the anticipated share of the different means of produc-

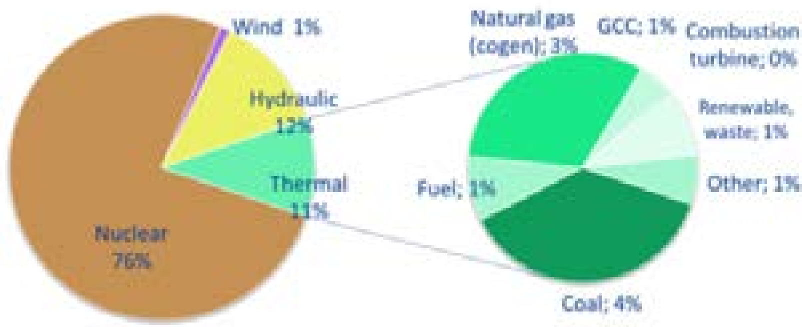


Figure 2 – *The French production mix (2008)*

1 *Chiffres clés du climat France et Monde, Edition 2011, Commissariat général au développement durable – SOeS*

tion used to provide the demand.
The subject of this note is to present the different ways of measuring the CO2 emissions of electricity. The results given are for France; however, these methods can nevertheless be applied successfully to other countries.
In this study, we are not integrating the emissions linked to the transportation and distribution of electricity, which should be added to all the proposed EF if we want to get the final EF for electricity. Low-voltage electricity in France adds about 8% to the production emissions.

Not one but several electricity Emission Factors

The average Emission Factor of production

The first Emission Factor that seems a natural proposition is the average Emission Factor of the total electricity produced in France in a given period of time.
The method is quite easy: what has to be done is to measure the CO2 emissions associated with the production of electricity during the given period for the different means of production which constitute the French mix. One then divides the obtained emissions by the number of kWh produced during the same period, which will most often be a calendar year or a month.
The EF of the different means of production are obtained by the analysis of life cycles, in order to account for all emissions (combustion + emissions linked to the production and the transportation of combustible) , and can be adjusted according to the evolution of technologies.
The calculation of this EF for France in 2009 shows us 91 geqCO2/kWh, and we can see here the calculation for the last three years (fig. 4). This EF is very close to the annual EF proposed by the International Energy Agency (IEA), which corresponds to the measurement of CO2 emissions linked to the combustion of energy for the production of electricity and heat. (Note: the IEA does not take into account the manufacturing of the means of production nor the secondary emissions, for example, freight or waste management.) The IEA EF is used in numerous studies or methodologies and is, for example, one of the EFs used in the ADEME (French Environment and Energy Management Agency) in its methods for Carbon Balance.
In order to reflect the seasonal aspect of demand and, therefore, of electricity production, this EF can also be calculated on a monthly basis (Fig. 3), or even each day or each hour, depending on the concerned means of production. RTE (Electricity Transmission Network) currently publishes this work on its website .

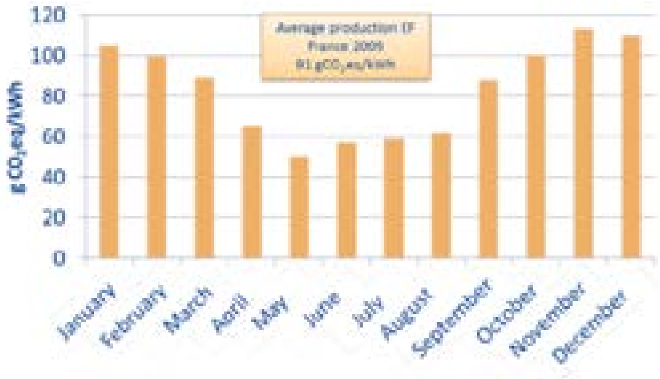


***Figure 3 –** Average monthly EF of production (2009), calculation Carbone 4, source RTE*

Calculating the EF of production is interesting in order to take stock of the CO2 emissions linked to the production of electricity in France. However, when it comes to estimating the CO2 emissions associated with the consumption of one kWh by a single user in France, this calculation can prove unsatisfactory.

The average Emission Factor of production adjusted for imports/exports

We are continuously exchanging electricity with our European neighbours. In order to calculate the CO2 emissions of the electricity consumed in France, we need to take into account these border connections. In practice, starting with the French production, we need to remove the exported electricity and add the electricity that we import.
Our imports are generally linked to a need for electrical power in peak periods. While importing, the solicitation of our border connections indicates that we are using a means of production abroad. And yet, the EF of this means of production has no reason to correspond to the EF of the average French fleet figure.
However, it is difficult and even almost impossible to track the imported electricity that we consume, that is to say to relate it to the starting up of a power station in a given country. In addition, we need to avoid counting a different EF for the input and output of electricity that is only going through our country (for instance, when Italy calls for German electricity) but is not participating in our consumption. Taking all these effects into consideration we decided in our method to take net hourly import-export into account (RTE Data). For the hours when the exchange balance is negative, we allocate the net imported electricity of an EF which is calculated with the average EF of production from each of the countries from which we import electricity. The calculation of the net importations of EF gave us,

2 Facteur d'émissions des différentes filières de production EDF : http://fr.edf.com/fichiers/fckeditor/Commun/Edf_en_france/documents/Profil_environ_kwh_EDF_2010.pdf
3 http://www.rte-france.com/fr/developpement-durable/maitriser-sa-consommation-electrique/consommation-production-et-contenu-co2-de-l-electricite-francaise#emissionCO2

for instance, 541 g CO2/kWh in 2008. (This high value is mainly due to the important part of the importations coming from Germany).
In this approach we also remove the emissions linked to imported electricity, which is allocated with the average yearly EF of French production.

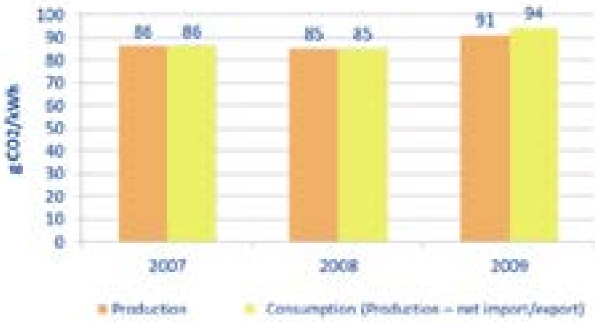


Figure 4 – *Emission Factor of the produced and consumed electric kwH in France*

Let us reiterate that this Emission Factor of consumption (like all the other EFs that we are proposing here) doesn't integrate the emissions linked to the transportation and distribution of electricity, which should be added to all the EF proposed here if we wanted to get the total FE of electricity (about 8% for low voltage electricity in France).

Producer / supplier of EF

The current electricity market in France makes it possible for the consumers to choose their electricity supplier (that could be a producer or not), or to buy electricity directly on the market from a producer (for big consumers).
In fact, it is difficult to link the consumption of one kWh of electricity to a specific means of production, as the balance of the electricity network is being made at a national level (that is to say, European), which means that the electrons travel on the network regardless of the contracts.
On the other hand, it could be interesting to encourage consumers to turn to a supplier with a lower carbon emission, in order to develop this type of electricity production. To this end, one would look for an EF supplier that reflected the production mix (or the purchase mix when the supplier does not have any means of production) of the electricity sold.

Electricity producers are in a position to accurately measure their direct emissions (in particular because of the "quota directive"). A customer can therefore ask his supplier which emissions are linked to the production of the electricity that he sells to him/her, and can then deduct from it an applicable EF. Since 2001, PwC and Enerpresse have been publishing a report that quantifies and compares the Greenhouse gas emissions of the twenty-three main electricity producers in Europe.

For example, if you are supplied electricity only from EDF France, you can then use the EF of the electricity produced by EDF France (which is different from the EF of the electricity produced in France as EDF France is not the only electricity producer in France). The latter is published monthly and yearly on the basis of the production mix of EDF for the period considered (EF EDF France 2010: 45 gCO2eq/kWh).

When the supplier sells electricity coming from his/her own installations it is easy to calculate its EF, which is the EF of his/her production mix for the period considered. In the case of a supplier who is not a producer, it will be necessary to calculate an average with the different producers of EF from whom he bought electricity, proportionate to the purchases. If the supplier buys electricity from intermediate suppliers on the market then this method is no longer applicable, as the origin of electricity becomes difficult to trace.

Horo-seasonal EF

Using an average EF, as presented above, is not suited to every purpose, even when it is adjusted for the import/export factor.
For instance, let us imagine that we want to calculate the emissions avoided by a demand reduction on a peak day (a demand reduction is an action that allows us not to consume any electricity at that moment – consumption can simply be put back). In practice, this demand reduction leads us to avoid the emissions associated with the means of production used at peak time. If we use the average EF of French production, even on a monthly basis, it will be based on the means of production that are not used at peak time. The avoided CO2 emissions will then be undervalued and will not reflect the "Carbon" interest of the reduction at the most critical moment (peak time in winter).
In order to show the usage of the means of production that depends on the power level needed on the network, we are going to cut the year into slots, each slot being characterized by its length (the affected hours) and the average power injected into the network during this time. This method is often being used by electricity suppliers for analysis; one speaks sometimes of "monotonic power" (Fig. 5 – cutting proposed by the UFE - French Electricity Union).

4 *Facteur carbone européen – comparaison des émissions de CO2 des principaux électriciens européens, Enerpresse PWC, nov 2010*

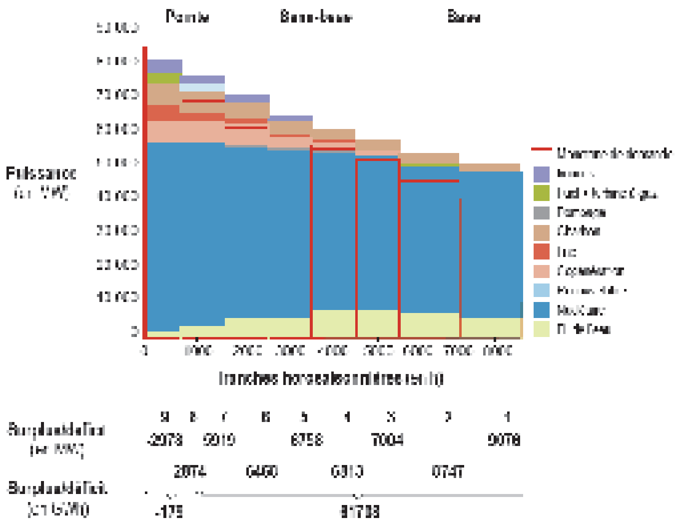


***Figure 5** - Climate challenges: new issues for electricity, UFE, February 2009*

In the graphic above, the whole year is cut into 9 slots (from 60h to 1599h; the 60h slot on the left is difficult to see), which represent the 8760 hours of the year, and for each slot the average power demand (Fig. 5). The peak matches to the three slots of maximum demand (at the extreme left) for a total of 1760 hours (including 60 hours of extreme peak). On the opposite, the base matches the last two slots on the right (3000 hours), and corresponds to the minimum power demand for the whole year. Lastly, in between, the semi-base matches the four medium slots of 1000 hours (for a total of 4000 hours) and therefore represents the minimum power demand for at least 5760 hours a year.

Yet all of these slots use identifiable means, for every time we add some power we do it in the same order. It is then possible to calculate the average EF of the mix from each slot, from the CO2 emissions associated with the different slots of power demand (Fig. 6).

***Figure 6** – Average Emission Factors of horo-seasonal slots*

5 *Défis climatiques et nouveaux enjeux électriques, UFE, février 2009*

From this approach we can calculate an EF of the production mix necessary to meet the additional demand for the hours of maximum power demand (Fig. 7).
This EF leads to an estimation of the contribution of the means of production used during these hours (1760h - slots 7 to 9) to face the most important power demand of the year.

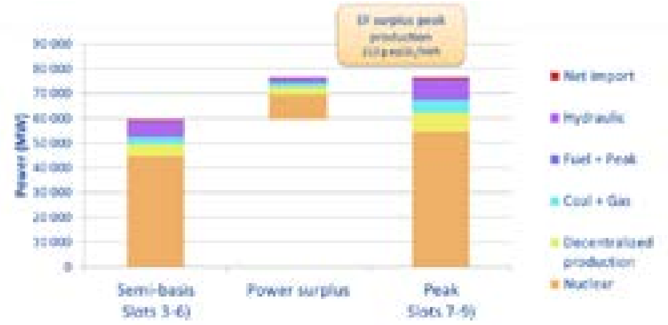


***Figure 7** – Emission Factor of the peak production mix (means of production used to face the additional power demand during peak time)*

EF by use

In analyzing the distribution of the slots for the months of the year (Fig. 6), we realize that the slots 7, 8 and 9 – which correspond to the most important power demand – are concentrated only during the Winter period (from November to March), and at the opposite end, that for the slots 1 and 2 (representing the 3000 hours for which the power demand is the lowest) the Winter period is not (if at all) represented very much.

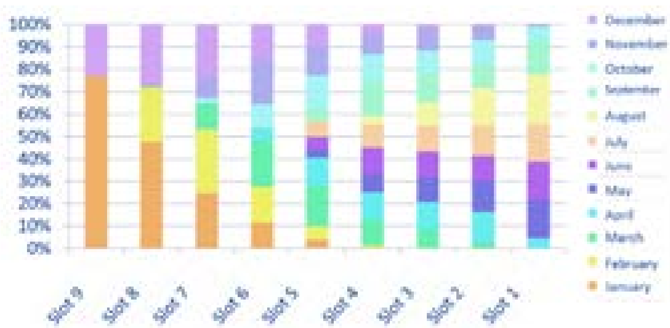


***Figure 8** – Months of the year distributed on the slots of power demand*

Thanks to the previous analysis, we understand that an additional production mix is used to meet the specific needs of winter. This assessment leads us to wonder about the possible correspondence between the use of a

given part of the production and a well identified use (lighting, transportation, heating, etc).
EDF and the ADEME have been working on this notion of ‘EF by use’ in 2004 and have defined a methodology that consists in dividing the production into two parts: a “basic” part (around 400 annual TWh) and a season-wise part (around 100TWH, primarily requested in winter). The method assigns a CO2 content to each of those two parts of production, while making hypotheses about the means that are requested. The two corresponding values are 40 (basic part) and 180 (season-wise part) grams of CO2 by kWh.
It is then convenient to assign to each use a seasonality ratio. Heating, for instance, is a use 100% specific to winter, and the EF of heating then corresponds to the seasonal EF (180 g CO2/kWh). As for lighting, it is assigned to a seasonal coefficient of 40% (base of 60%), so as to show the lighting surplus needed in winter. The calculated EF for lighting is then approximately 100g CO2/kWh.
The principle results of this method are presented in the following table (dated 2004) which was published in the EDF note.

Indicateurs de contenu en CO2 de l'électricité consommée en France (en g de CO_2/kWh_e)

indicateurs détaillés	Référence (valeur moyenne)	à titre indicatif : plages de variation	indicateurs simplifiés	
chauffage+ pompes de circ.	180	129 à 261	180	Chauffage
éclairage résidentiel	116	93 à 151	100	Eclairage
éclairage tertiaire	80	64 à 88		
éclairage publique et industriel	109	85 à 134		
usages résidentiels : cuisson	82	66 à 93	60	Usages intermittents
usages résidentiels : lavage	79	63 à 88		
usages résidentiels : produits bruns	62	50 à 81		
usages tertiaires : autres	52	41 à 77		
usages industriels (hors éclairage)	55	38 à 86		
usages résidentiels : ECS	40	20 à 72	40	Usages "en base"
usages résidentiels : froid	40			
usages résidentiels : autres	39			
usages tertiaires : climatisation	37			
agriculture-transport	38			
autres (BTP, recherche, armée, etc.)	35			

source : ADEME et EDF, 2004

***Figure 9** – Detailed results of the CO2 content by use, ADEME & EDF, 2004*

This method of ‘EF by use’ presents a major interest, which is additivity. Indeed, by multiplying the consumptions of the different uses by the EF of these uses, we get the total emissions for the production of electricity. This characteristic presupposes that we would not utilize this EF for certain uses and the average EF of the country (or of Europe, or of a supplier, etc.) for other ones, because in such a case the sum of emissions would not correspond to the real emissions.

Marginal EF

The common point to all the EFs that we have presented so far is that they are all calculated on historical data, whatever the precision or the proposed divisions are. These EFs can sometimes be unsuitable for prospective studies because the reasoning used to calculate them does not include the impact (long-term) that some uses or decisions can have on the evolution of the production mix.
It is this approach that has led to the construction of an EF known as “marginal EF”, whose objective is to determine how certain decisions by the consumer can have consequences on the CO2 emissions, decisions such as increasing the electricity consumption or by modifying the monotonic shape (increase of demand for a given use or appearance of a new use). Indeed, in such a case, one could imagine what would be the effect on the increased demand of certain means of production, or the creation of new units in the long-term.
In 2007, ADEME and RTE proposed a methodological note on the calculation of a marginal EF . This calculation is based on the solicitation of the means of production to satisfy a given additional demand. This order reflects the proportional costs of production of each installation. At the bottom of the pile we find energy inherently trapped in-system, including wind-power and run-of-river hydraulic power. We then find nuclear power, Coal and Gas Combined Cycles (GCC), and finally, fuel and combustion turbines. Thus, at any time, an increase in demand will lead to the solicitation of the least expensive means of production amongst all the available ones. On the contrary, a decrease in demand will be compensated by a reduction of power (or total closure) of the most expensive means of production amongst the ones which are used. According to the usual terminology, this is called (whether for increase or decrease) the marginal mean of production.
The marginal EF is then simply the EF of the marginal means of production.
In the mentioned note7, the marginal CO2 content for electrical heating is in the order of 500 to 600 g CO2/kWh, that is to say, three times more than the EF calculated in the previous reasoning of ‘EF by use’. However, it does not apply to all electrical heating: it applies to the additional electric heating started up in addition to the existing ones. Applying it to calculate the emissions of all electrical heating would obviously be wrong.

6 *Note de cadrage sur le contenu CO2 du kWh d’usage en France, EDF, 2005*
7 *Le contenu en CO2 du kWh électrique : Avantages comparés du contenu marginal et du contenu par usages sur la base de l’historique, ADEME RTE, 2007*

This approach of marginal EF is well adapted to analyze the marginal evolutions of the system. For example, in order to calculate as closely as possible the emissions avoided by an occasional deletion in one peak day, we should evaluate the means that would have been used to provide this production (and integrate, if necessary, the interconnections or the evolution of the peak park). In this case, the marginal approach allows a more accurate calculation of the CO2 emissions, but attention must be paid to the fact that it is not an additive approach (nor a marginal approach).

What emission factor is to be used?

Measuring the electricity emissions can be made in several ways, with values that can be different according to the used method. The choice of the EF to be used – and thus of the method – depends on the purpose of the study. The issue is always to show the emissions that are generated or avoided by such consumption or by such use of electricity, and to get as close as possible to reality.
The average EF of France seems to be well suited for a standard Carbon Balance, but the CO2 impact of the evolution of the means of heating would be better analyzed through an 'EF by use' or a marginal EF.
The question 'What is the electricity emission factor?' then has no unique answer: it depends on the question asked.

Emmanuel Blanchet
Carbone 4

	Average EF	Producer / Supplier EF	Horo-seasonal EF	EF by use	Marginal EF
Company carbon balance	🟢	🟢	🔴	🟢	🔴
CO_2 avoided by a consumption deletion (in peak day, in a specific hour, etc.)	🔴	🟢	🟢	🔴	🟢
CO_2 avoided by renewable energies	🟢	🟢	🟢	🟢	🔴
CO_2 content of a specific use	🔴	🔴	🟢	🟢	🔴
Prospective study on the CO_2 content of a new use	🔴	🔴	🟢	🟢	🟢

Figure 10 *-Table illustrating some uses of the different Emission Factors*