From final energy consumption to primary energy requirements and CO_2 emissions. An methodological approach using energy balances. Application to Catalonia, 1990–2005.

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Abstract

This paper analyzes the evolution of the uses of primary energy and the resulting CO_2 emissions in Catalonia during 1990–2005. We present a methodology that allows—using the energy balances—to "translate" final energy consumption into primary energy requirements. This methodology estimates the quantity of primary energy (and its composition) that pulls a given level of final energy consumption of the different sectors or activities. We apply the analysis and compare 2003–2005 and 1990–1992. The most relevant changes are the reduction in the primary energy required for obtaining a unit of electricity and the change in its average composition by primary energy sources: the average requirements of nuclear heat decreased significantly, but the requirements of natural gas increased considerably. We apply a factorial decomposition for studying these changes. The total changes in the needs of primary energy—an in its components—are decomposed into three effects: the change in the level of final consumption of the different sectors ("final consumption level effect"), the changes between different types of final energies ("substitution effect") and the changes in the needs of primary energy for obtaining final energies ("transformation effect"). The final consumption level effect is the most important for all the activities, causing an increase in the requirements of all the energy sources, but especially of oil, which is due to a great extent to transport. The transformation effect causes the primary energy requirements to decrease, and it is stronger in the demand sectors that depend more on electricity. The substitution effect, which has much relevance for explaining the changes in the requirements of some sources of primary energy, does not have much relevance for explaining the changes in the total requirement of primary energy. The requirements of primary energy which experience a greatest growth are the requirements of natural gas, due to that both the transformation effect and the substitution effect are important and add its impact to the activity effect. The use of nuclear energy does not increase much in absolute terms due to that the transformation effect (lower relative weigh of the electricity of nuclear origin) acts in the opposite way to the activity effect. The only source of primary energy that decreases in absolute terms is coal. This is due to the fact that in this case the activity effect is more than offset by transformation and substitution effects. Finally, the paper translates the primary energy requirements into the corresponding emissions and analyzes their evolution by means of the factorial decomposition abovementioned. It might be highlighted that fuel substitution has played a small favorable role in the reduction of emissions, but too low to compensate for the increase in the primary energy requirements. The transformation effect has played a very negative role, contributing to the increase in emissions, in the opposite way as happens in the case of the requirements of primary energy. This is due to the decreasing share of nuclear power and the increasing share of gas in electricity production: gas has more efficiency in the conversion from heat to electricity but emit CO_2 emissions.

Keywords: CO_2 emissions, Energy Balances, Energy requirements, Input–output analysis, Primary energy.
JEL Codes: C67, Q40, Q43, Q54.

1. Introduction: objective and database

The aim of this paper is to analyze the trends of final energy consumption in Catalonia over the period 1990–2005 and their implications in terms of primary energy requirements and CO_2 emissions. With this purpose, we employ a methodology for analyzing the final energy consumption data that allows the estimation of the quantity of primary energy that pulls a given level of final energy consumption used by the different sectors or activities.

The database employed is the energy balances of Catalonia for the period 1990–2005, provided by the Catalan Institute of Energy (ÏCAEN)[1]. The sources of primary energies considered in these balances are the following. First, the three fossil fuels: coal, crude and natural gas[2]. There are also different ways of obtaining electricity, such as are nuclear power, hydroelectricity, wind power and photovoltaic. In the same way as does the current methodology of the International Agency of Energy, nuclear energy is accounted for by the heat generated in nuclear power stations, while in the other cases only the energy value of the electricity actually generated is accounted for as primary energy[3]. Third, we have the capture of heat from solar energy ("solar thermal"). Fourth, various energy utilizations—sometimes as electricity and sometimes as heat—are also accounted as primary sources. These are mainly residual fluxes that ICAEN classifies as: "biomass" (forest and agrarian), "biogas" (obtained from dumps and also from mud of treatment plants, manure, and residuals from food-processing industry), "renewable waste" (incineration plants of urban solid waste) and "non-renewable waste" (hydrogen and other process residual gases, basically from chemical sector, and other industrial waste). Last, we have biofuels: bioethanol and biodiesel, which include both waste use—such as used vegetal oil—as well as the so-called "energy crops". With respect to these last, two precisions should be made. The first, terminological, is that the production of food can also be classified, obviously, as a energy crop.[4] But, given that this paper only studies "exosomatic energy" (i.e., the one controlled by humans but consumed outside our body), the only relevant "energy crops" for this paper are those that are not oriented to feed human population (i.e., to provide "endosomatic energy"). The second question to highlight is that, in order to obtain these crops, there is an important energy cost which is not included in energy balances because is part of other sectors—such as the agrarian—so the same classification as a primary source—that we maintain—might lead to confusion because it appears as if it were just added to energy supply[5].

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[1] The data for years 2004 and 2005 are estimations that might change. There are small problems in the continuity of the data time series, but they involve only energy sources with very small relative weight and does not alter the global data. These are that there is a change in the information on the use of biomass that was incomplete until the year 1997, and that for the years previous to 1996 there is not information on "non renewable waste".

[2] With respect to coal, in the data of the balances there is a distinction between lignite and other types of coal. We have considered them aggregated.

[3] It is important to take this into consideration when valuing the numbers: a unit of primary energy of nuclear energy corresponds to a much lower quantity of electricity—about the third part—than a unit of hydroelectricity.

[4] Actually, the opportunity cost of the crops for "feeding" cars can be sometimes reducing crops for feeding people.

[5] If we did all the computations, the energy used for obtaining energy as biofuels would be very great (it could even be the case that the activity—which might be viable thanks to subsidies—could consume more energy than the energy obtained).

The available energy is also increased when transformed energies are imported, such as electricity or refined oil products, a fact that is also shown by the energy balances. We will refer to the treatment of these imports in a later section.
The energy balances show the interrelations between energy sectors and also show the final consumption of energy by the different sectors or activities. The sources of final consumption considered are the same as before, except for crude oil, nuclear, hydraulic, photovoltaic and adding electricity and oil derivatives. Unfortunately, the information on sectoral final consumption that we have is very aggregated and only considers five sectors: “Primary”, “Industrial” (including construction), “Services”, “Transport” and “Residential” sectors. We do not have, at this time, disaggregated information on the different industrial sectors (which would be very important in order to place the relative responsibilities of the different activities and, moreover, could allow a more complete input–output analysis). Furthermore, we do not have estimates—and this is difficult to solve—on how the energy consumption in transport is distributed between the “transport sector” as productive sector and private transport, so we treat “transport” as a whole[6]. Besides the five aforementioned uses of final energy, the demand of “non-energy uses” (especially oil derivatives used as a row material of petrochemical industry) and the “energy export balance” should be added. We will consider non-energy uses although there are not really an energy demand. As regards the “energy export balance”, it might be considered “responsibility” of the territories importing this energy.

After this introduction, the structure of the paper is as follows. Section 2 briefly describes the evolution of final consumptions of energy in Catalonia between 1990 and 2005. Section 3 presents the methodology that we have employed for estimating the primary energy “pulled” by the final consumptions of energy. Section 4 illustrates the methodology with the data for Catalonia and describes the changes over the period analyzed in the needs of primary energy associated to the different ways of final consumption of energy. Section 5 presents the methodology employed for analyzing the contribution of different factors to the changes in total primary energy—and in its composition. Section 6 applies this methodology to Catalonia for the period considered. Section 7 describes the evolution of total emissions of CO_2 associated to the use of energy in Catalonia during the same period 1990–2005, assigning responsibilities to the different sectors. Section 8 analyzes the changes in CO_2 emissions studying the contribution of the different explanatory factors, applying the same approach used for the primary energy requirements. Last, Section 9 presents some brief conclusions.

2. Evolution of final consumptions of energy (1990–2005)

As we have already stated, an objective of this paper is analyzing how much primary energy is required (and how much emission is generated) for providing the different final consumptions of energy of firms, citizens and public

[6] It has also to be said that, when we talk about transport energy, we refer to a part—the most important, but not the only one—of the total cycle of transport. In a wider sense, we could include—from a lifecycle perspective—the energy consumption of producing cars, building and maintenance of roads, etc. (see Estevan, 2005).

administrations. We will however start giving a general perspective on the evolution of these final consumptions.
We will not consider the own use of the energy sector, because this has, in our opinion, a mere role of supplier and transformer of primary energy in available energies. We are interested in available energies for final consumption.
In Figure 1 we can see how evolves the total of final consumption of energy and the five sectors in which we can divide it, according to available data, expressed in index numbers (base 1990=100).
FIGURE 1 HERE
In this figure we can observe two very different behaviors. On the one side, primary and industrial sectors, for which there is certain reduction in energy consumption in the first 1990s, although as a whole the increase in energy consumption is very important. On the other side, services, transport and residential consumption, with an increase in energy consumption during almost all the years and relatively much more important for the whole period of sixteen years analyzed.

Table 1 shows the relative weight on final consumption of the five sectors considered. In this Table, as in most of this paper, we will employ the average values of the three initial and final years for avoiding oscillations that might be too conjunctural. We can see how, from the point of view of final consumption of energy, transport has became the most important activity, overcoming industry. At the same time, transport has been the activity that, in absolute terms, has experienced a greatest increase in energy consumption.

TABLE 1 HERE

Figure 2 compares the evolution of Catalan GDP at constant prices with the evolution of the different final consumptions of energy, now distinguishing only between the total of the three great economic sectors (primary, industry and services excluding transport), and transport and residential sectors. We can see that, as a trend, all the energy consumptions overcame GDP growth, a fact that explains the increasing energy intensity of Catalan economy.

FIGURE 2 HERE

As regards the types of final energy employed, Table 2 summarizes the most significant changes.

TABLE 2 HERE.

We can see how the final consumption of coal—already very small in 1990—practically disappears, while the other types of energy increase in absolute value. The use of gas is the one that increases most in relative value; electricity also increases its weight, but in a much more moderately.
Although we will not analyze it in detail, both evolutions—changes by activities and by types of final consumption—are obviously interrelated. While in transport, the energy consumption is based, over all the period, in the great dependence on energy products, in other sectors there are important substitutions. Thus, the industrial sector reduces significantly the use of coal,

not only in relative terms, but also in absolute terms. Both in the industrial and in domestic sectors, the type of energy that has a greater increase is natural gas, and, to a lesser extent, electricity. For the services sector the increase centers also in these two types of energy, but much more in electricity than natural gas.

3. From final consumptions of energy to primary energy requirements: methodological approach and limitations

Both the prospective on future uses of energy and the energy policy—at the moment of establishing priorities—have to consider not only which are the final consumptions of energy, but also the set of the requirements of primary energy—their magnitude and their composition—that make possible this final consumption of energy. This primary energy requirement determines the total quantity of resources that we have to be extracted from nature (domestically or in other places) and the associated environmental pressures.

Moreover, both for the prospective as for orienting the political decisions is essential to know which are the relative responsibilities in total energy use of the different activities. For example, it is important to know which is and how evolves the requirement of energy by transport, residential consumption or by a certain economic sector. The usual approach consists in disaggregating the data on final energy consumption (or demand) as we have done in previous section. This perspective gives an important information, but it its insufficient and can eventually lead to erroneous conclusions. For example, if a family uses an electric kitchen and we just measure their energy consumption in electricity, we would obviate that in order to obtain this electricity a quantity of primary energy should have been provided. A quantity that is much greater than the energy finally obtained. If we only look at final consumption we could conclude that an increasing use of electricity by households, or industries, for obtaining the same services, or the same products, increases “energy efficiency”, while in fact it is possible that total needs of energy increased. In other words, it is important to know which is the (primary) energy required in order to obtain the energy used by industries, agriculture, households, private and public services, etc.

For this purpose, we use a methodology which simplifies much the task but that allows to make a close estimation (from the available data for Catalonia) on the total evolution and the composition of the primary energy required for satisfying the needs of the different economic sectors. The methodology starts from the input–output energy relationships (in physical terms)—that provide us the energy balances of Catalonia—for estimating the direct and indirect requirements of primary energy for providing a unit of the different types of final energy. The methodology was proposed and applied for Spain in Alcántara and Roca (1995) and Alcántara and Roca (2003). Ferng (2001, 2002) applied the methodology for analyzing the uses of energy in Taiwan.

For example, per each kilogram of oil equivalent in electricity, we actually need a much larger energy quantity, because a part gets lost in distribution networks, is consumed in power stations, is used for pumping water that will be used for obtaining electricity, etc. Moreover, and even more important, the production of this electricity is, to a great extent, done in (nuclear or fossil fuels) thermal power stations in which most part of primary energy is dissipated as heat in the transformation process. In the same way, the transformation process of oil in its derivates uses energy, so that the use of one kilogram of oil equivalent as oil derivates implies the availability of more than one kilogram of crude oil.

We next explain the methodology employed and in the following section we apply it to the data of Catalonia.

The first step consists in finding the direct (primary and secondary) energy coefficients per unit of final consumption that are used in transformation processes, internal consumption or distribution losses. These would be the components of matrix *A* of energy coefficients, where *A* is a square matrix of *n* order (nxn), being *n* the total number of (primary and secondary) energy types considered.

As is usual in input–output perspective, if we want to compute the total—direct and indirect—requirements to obtain a unit of energy in its diverse types—for example, as electricity—we should compute the inverse matrix $(I - A)^{-1}$ where *I* represents the unitary matrix of *n* order. As the resulting matrix will contain primary and secondary energy sources, in order to avoid double accounting we will only consider the rows corresponding to primary sources of energy and the columns corresponding to secondary energies. Notice that some energies will appear with the same name as primary and secondary energy sources, as is the case of coal or natural gas, while others will only appear as primary (for example nuclear) or secondary (for example, electricity) energies. We will call this matrix *T*—transformation matrix of final consumption of energy to primary energies—and it is a *jxk* order matrix where *j* is the number of primary sources considered (coal, nuclear,…) and *k* is the number of final energies considered.

The primary energy requirements of a period, disaggregated by sources and responsible sectors, can be expressed as a (*jxs*) matrix *E* where *s* is the number of activities considered (primary, residential, transport,…)

$$E = T*P*\hat{C} \qquad (1)$$

T represents the transformation matrix, *P* is a matrix which represents the relative weights of each final energy type in the different activities and is of *kxs* order. $\hat{C}$ is a diagonal matrix that has as main diagonal de final consumptions of each activity and is of *sxs* order.

Before starting the computations, we will highlight some limitations of the methodology. First, a more complete analysis would require taking into account that part of the uses that are considered here as “final” uses, are in fact used for providing the “energy sector”, such as is the case of the energy used for producing the industrial inputs that are used by part of the thermal power stations or in the transport of fuels. This limitation could only be solved by using input–output tables of the economy (which for the recent Catalan economy are only available for the year 2001[7] and, besides, would require the availability of a disaggregation of sectoral data of energy use greater than the one we have). As a consequence, we are underestimating the “energy required for the availability of energy”, which in some cases can be very important. A particular case, already mentioned, is the one of an energy source that nowadays has very small quantitative importance, but that could increase its weight: the so-called “energy crops” or biofuels. The reason is that the agrarian sector is not incorporated to the energy balances, as it is not considered an energy sector,

[7] For a study on the possibilities of extending input–output tables of Catalonia to energy and environmental analysis see Alcántara (2003).

but it consumes a considerable energy quantity for the production of a crop that is considered “primary energy”. Other example is the one of photovoltaic energy. In this case the relationship between the energy obtained for final consumption and the energy invested has been widely discussed. The energy invested in this case, for example, in the manufacture of components, is not captured by our methodology.

A second limitation is due to the territorial scope. As we start from the energy balances of Catalonia, we only have information available on the imported, transformed and used energy in this region. Then, we do not consider, for example, the energy costs of extracting and transporting the oil or the coal that is imported by this region[8]. This is an additional reason why our computations underestimate the energy needed for obtaining energy. In fact, other thing that is not being considered is the energy consumptions ocurred outside Catalonia for all the (energy or not) goods that are imported, so that if the “energy cost” of the imported goods is greater than the “energy cost” of the exported ones, we will be underestimating the associated impact. Despite its relevance for the valuation of the environmental impacts attributable to Catalonia, this is outside the scope of this study.

Last, our perspective is very aggregated, so that, for example, implicitly considers that any user of electricity pulls the same needs of primary energy per each KWh used, but this is not always the case. For example, industrial facilities that autoproduce electricity or isolated houses with photovoltaic cells are not responsible of distribution losses, and these are also different depending on the tension in which electricity is distributed.

4. Application of the methodology and analysis of the changes in the transformation matrixes for Catalonia between 1990–1992 and 2003–2005

Matrix of Table 3 summarizes the information obtained from energy balances for the period 2003–2005. The “inputs” are considered in a wide sense, including the following items of the energy balances: the “transformation consumptions” in strict sense, the “own consumptions by the energy sector” and the “transport and distribution losses”. Both the “total consumption of energy” and the “energy needs” add up primary and secondary sources, so that in order to know how much primary energy is used we have to avoid this double accounting.

The Catalan economy imports and exports refined oil products and electricity. We consider that an imported unit is compensated for by an exported unit, so that we focus only in which is the net balance[9]. When imports are greater we should consider that this incoming energy implies a greater availability of primary energy. This can be done in two ways. The first option, which is the one we have employed in this paper (and the one that ICAEN uses in its balances),

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[8] These could be estimated if we knew the origin of imports, the energy consumptions of extraction in the place of origin, and the transformation and transport consumptions. The (net) import of electricity and oil derivatives of Catalonia are only valued, as we will see in the next Section, by its energy content, as if they were primary energy sources.

[9] However, while electricity might be considered an homogeneous product (and even in this case the important issue is the availability of electricity in a certain moment of time and in this sense a KWh generated in a moment of time is not the same as a KWh generated in other moment of time), oil derivatives are very heterogeneous products and this explains the strong net import and export balances observed.

is to treat these imports as a source of primary energy valued by its energy content, so that we would have two new sources of primary energy: the net balance of imported electricity and the net balance of imported oil derivatives. However, it should be noticed that oil derivatives and, even more, electricity are obtained by means of the transformation of primary energies. The second option would consist in estimating how much primary energy is needed for obtaining these energies. When there is a net export balance the problem does not exist, and in this case we consider that this exported energy is not part of the primary energy requirements of Catalonia[10].

TABLE 3 here

In Table 4 we reproduce the direct relationships matrix E, where the coefficients have been computed by dividing the energy inputs by the total availability of each type of energy. That is to say, the sum of the energy required as input in energy extraction, distribution and transformation processes, plus the energy oriented to final consumption (or to non-energy uses or net exports).

TABLE 4 HERE

Matrix of Table 5 is the inverse matrix $(I - E)^{-1}$ suppressing the columns that only correspond to primary energies and the rows that only correspond to final energies. This is the matrix that we actually use for "translating" final consumptions into primary energies. It has as much rows as primary energies considered and as much columns as secondary energies considered (recall that several types of energy appear with the same name as primary and secondary energies).

TABLE 5 HERE

The results for the years 2003–2005 show that for each unit of electricity consumed we require almost 2.6 units of primary energy. The composition of this primary energy was the next: more than half was nuclear heat (1.564); natural gas plays also a considerable role (0.650); hydroelectricity had a much lower importance (0.115)[11]; the net import balance of electricity (only 0.101), coal (0.054) and the set "oil and its imported derivatives" (0.64); the other sources played a marginal role. We can make the same kind of analysis for oil derivatives, for which, obviously, the relationship between total primary energy/final consumption is much lower and the needs are centered, as is logical, almost totally in crude oil and in (already transformed) imported oil derivatives. For various ways of consumption—like biofuels—the methodology does not capture the energy expenses (see footnote 4) and for the case of coal and natural gas they are much underestimated, because the consumptions associated to extraction are mainly done in other territories. These are however limitations already highlighted in this paper.[12]

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[10] Actually, being coherent with our methodology, in posterior computations we consider that all the necessary primary energy used in Catalonia for obtaining the exported (net) energy is part of the requirements of primary energy outside Catalonia. In any case, the difference for the analyzed period is quantitatively negligible.

[11] Recall the way of computation: see note 2.

[12] Remember that we have considered the net import balance of electricity and oil derivatives as if they were primary sources (by its energy value). As we already noticed, another option would be to estimate how much primary energy is needed to obtain these secondary energies obtained in the exterior. This would require information on the energy technologies of the places of exportation but also might be done the assumption of the same technology, so we would rather compute the energy that we would save—given our technologies—by not doing the transformation processes. Undertaking this exercise we would obtain that in the year 2005 a

We next will analyze the changes in the transformation matrixes from final energy to primary energy requirements that have occurred over the period considered. Instead of considering the years 2005 and 1990, we have rather employed the average of the three first and the three last years of the period, so that the data were not much influenced by very specific factors of a specific year, such as could be an exceptionally high or low hydroelectrical production or a stop in nuclear power production, that could imply, moreover, important changes in import–export balances.

TABLE 6 HERE

With the previously explained methodology we have obtained the transformation matrix for 1990–1992 (Table 6). The more relevant change is the reduction of primary energy that we estimate that have been used on average for obtaining a unit of electricity; from 2.96 to 2.59. Several different causes could be responsible of this reduction. An improvement in electricity distribution, which had reduced losses would influence in this sense. The other key factor has to do with the primary energy sources from which electricity is obtained. In this sense, the more important change in the mean composition by sources of primary energy that is used for obtaining a unit of electricity has been that while for each unit of electricity at the beginning of the 1990s 2.41 nuclear heat units were expend, now—due to the lower relative weight of nuclear power in the electricity mix—1.56 units are consumed. In contrast, the needs of natural gas have clearly increased from 0.12 units to 0.65 units, showing the increasing weight of the thermal power stations of these fuel. This change from nuclear energy to gas reduces the losses in the transformation of heat into electricity, given the greater efficiency of the current gas power stations. All the other changes in the composition of the electricity mix are of much less importance: coal, the total "oil and import balance of oil derivatives" and hydroelectricity decrease, while import balance of electricity and renewable resources (waste incinerators), biogas and wind energy increase. The net import balance of electricity also increases their weight and this is other of the factors (but not the only one) that contributes—in this case only in an apparent way due to that external transformations are not considered—to the reduction of the primary energy needed to obtain available energy. The reduction in the primary energy needed to obtain oil derivatives is with all probability explained by the energy "savings"—also apparent—that implies the importation of already refined products.

5. The explanatory factors of the changes in the primary energy requirements associated to final consumption: methodology

Since the 1970s, energy and environmental analysis have increasingly employed methodologies of decomposition into several factors or effects in order to analyze the changes in the use of energy and/or in polluting emissions. Some years ago, Ang and Zhang (2000) identified more than a hundred studies

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unit of electricity pulls 2.778 units of primary energy (instead of 2.503); for oil derivatives the result would be 1.204 (instead of 1.204).

doing this. When the methodology being employed is the input–output approach, it is usual to employ the term “structural decomposition analysis” for referring to this type of decomposition (Hoekstra, 2005). As we have already noted, our perspective partially uses the input–output analysis, as it starts from the matrix of energy relationships.

Our analysis explains the total changes (“total effect”) in the needs of primary energy—and its components—by means of the decomposition into three effects or factors which are: the change in the final consumption level of the different sectors (“final energy consumption effect”)[13], the changes between different types of final energies (“substitution effect”) and the changes in the needs of primary energy for obtaining final energies (“transformation effect”).[14]

As we have previously indicated in a previous section, the primary energies matrix for each period (for energy sources and responsible sectors) can be expressed as:

$$E = T*P*\hat{C} \quad (1)$$

Where *T* represents the transformation matrix of final consumptions of energy into primary energies, *P* is a matrix that represents the relative weight of each type of final energy in the different activities and $\hat{C}$ is a diagonal matrix that has as main diagonal the final consumptions for each activity.

The changes in the primary energy requirements between two periods can be expressed as:

$$\Delta E = E_1 - E_0 = T_1*P_1*\hat{C}_1 - T_0*P_0*\hat{C}_0 = \Delta T_{effect} + \Delta P_{effect} + \Delta\hat{C}_{effect} \quad (2)$$

The three effects correspond to what we have called “transformation” (changes in *T*), “substitution” (changes in *P*) and “final energy consumption” (changes in $\hat{C}$).

As have been discussed in the literature on factors decomposition, several decomposition techniques might be adopted. The more “intuitive” one is computing each effect as the changes that might have occurred if only had changed the considered factor. However, this alternative—which is often called “Laspeyres” alternative—does not give an exact decomposition, so that the total effect usually does not coincide with the sum of the different effects considered (three in our case) as there are interactions between the effects. This is the main reason why much studies apply other decomposition techniques in order to obtain an exact decomposition. We will adopt here the proposal by Sun (1998) who distributes the effects and the interactions between the different effects by applying the principle “jointly created, equally distributed”. That is:

$$\Delta T_{effect} = \Delta T*P_0*\hat{C}_0 + 1/2\ (\Delta T*\Delta P*\hat{C}_0) + 1/2\ (\Delta T*P_0*\Delta\hat{C}) + 1/3\ ((\Delta T*\Delta P*\Delta\hat{C}) \quad (3)$$

$$\Delta P_{effect} = T_0*\Delta P*\hat{C}_0 + 1/2\ (\Delta T*\Delta P*\hat{C}_0) + 1/2\ (T_0*\Delta P*\Delta\hat{C}) + 1/3\ ((\Delta T*\Delta P*\Delta\hat{C}) \quad (4)$$

$$\Delta C_{effect} = T_0*P_0*\Delta\hat{C} + 1/2\ (\Delta T*P_0*\Delta\hat{C}) + 1/2\ (T_0*\Delta P*\Delta\hat{C}) + 1/3\ ((\Delta T*\Delta P*\Delta\hat{C}) \quad (5)$$

[13] While when we presented the data on final energy consumption, we left aside the non-energy uses (as is the usual practice), we now, when analyzing the “final consumption of energy effect”, this includes the variations in “non energy uses”, in order to explain the changes in the primary energy requirements.

[14] Notice that the decomposition into factors is a rather accounting than an explanatory decomposition, as it is considered as if their evolution were independent. However, the factors might be influenced by the evolution of the other factors. For example, greater efficiency in energy transformation could stimulate a greater energy demand.

6. The explanatory factors of the changes in the primary energy requirements associated to final consumption: Catalonia 1990–1992/2003–2005

We will now comment the results for the analysis of explanatory factors of the changes between the average for years 1990–1992 and the average for years 2003–2005.

In order to consider all the uses of primary energy we have incorporated not only the different sectors of final energy consumption, but also the "non-energy uses"—specially the oil derivatives used by chemical industry—accounting not only its energy value, but also the estimated requirements of energy for obtaining it. We do not have considered, however, the net export of energy products that, in fact, are not part of the internal needs of primary energy and that, in any case, represent a very low part of the total and do not affect much the result[15].

First, we present (Table 7) the contribution of the different sectors to the requirements of primary energy in the initial and the final years. If we compare this table with Table 1, we see that, logically, all the data are greater in absolute value, but the difference is particularly great in services and residential consumption. However, for transport—which depends much less from the use of electricity—the differences are less relevant. Consequently, the "responsibility" of the transport sector in the energy demand[16] for 2003–2005 is lower than the one of industry, in contrast to what happened in the analysis in terms of final consumption.

TABLE 7 HERE

TABLE 8 HERE

Between the two periods, the needs of primary energy of Catalonia increased in more than 9 millions of toes. Table 8 summarizes the different effects that explain this increase. In this table, the disaggregation of the effects is done for the different activities (or "sectors"). It can be highlighted that—according to this perspective—the sector that most contributes to the increase is transport, but industrial, services and residential sectors also contribute considerably to the increase, as do also the non-energy uses. Recall that the analysis in terms of primary energy "amplifies" the relative role of the sectors with more weight in electricity demand: if currently, the final consumption of transport already overcomes to the consumption of industry, this is not the case in terms of the primary energy required for obtaining the final consumption, which is still greater in the case of the industrial sector.

As can be expected, the "final energy consumption effect"—due to the increase in final consumptions—is clearly the most important of the three for all the activities. From the comments of a previous section, we could also expect that the "transformation effect"—that is to say, of the reduction of the primary energy needed for obtaining a unit of the different types of final energy[17]— had in all the cases the effect of reducing the needs of primary energy, which is stronger in

[15] For years 1990–1992 this is the export of 89.9 ktoes of oil derivatives and for years 2002–2005 of 10.8 ktoes of biodiesel. We have always considered import and export balance for the whole period of three years.

[16] Recall, however, that we do not consider all the necessary energy for providing the direct energy consumption of the sector.

[17] Recall, however, that a part of this improvement is not a genuine reduction of primary energy needs, but might be explained by a greater use of imported electricity and because of a net import balance of oil derivatives.

those demand sectors that depend most on electricity. The “substitution effect”, which has much relevance—as we will see—for explaining the changes in the requirements of some sources of primary energy, has however scarce relevance for explaining the changes in the total of primary energy for the analyzed period.

TABLE 9 HERE

Table 9 shows the analysis of the total effect and of the different effects, with a disaggregation, not by activities, but by energy sources. We can see how the “final energy consumption effect” causes the increase in the needs of crude oil (and of the imported oil derivatives), a logical result due to the key role of the increase in the use of energy for road transport. The increases in the sources of electricity (mainly nuclear) and natural gas as a consequence of this factor are also remarkable. As regards the “substitution effect”, although its effect on total primary energy is very low, it explains a great part of the increase in the demand of natural gas due to the increasing relative weight of natural gas in the final consumption of industry, services and residential sectors to the detriment of oil derivatives and also (in the industrial case) of coal. Last, the “transformation effect” implies—as we said—a reduction in the total requirements of primary energy, but in more disaggregated terms, we can see that it causes the increase in the requirements of natural gas (as this fossil fuel is used much more in the production of electricity) basically to the detriment of nuclear power energy, which losses relative weight (although not absolute weight) in the generation of electricity. The reduction in the needs of crude oil responds however basically to the—previously inexistent—net import balance of (already refined) oil derivatives that in our methodology appears as a type of primary energy for obtaining oil derivatives. It can also be observed how the net import balance of electricity contributes more to the electricity supply.

It can be observed that in the previous comments we do not have done any reference to “new” energy sources such as wind, biogas or biofuels. The reason is that the comments have focused on the most important changes in absolute values and, nowadays, although these sources are experiencing a great increase, are still marginal sources in the total supply of energy.

Annex 1 contains the disaggregated tables combining demand and activity sectors and energy sources. These tables allow a more detailed analysis of the changes in matrix *E* to which we referred and of the three explanatory effects combining the two variables: type of energy source and type of activity.

7. Evolution of CO_2 emissions linked to final consumption of energy between 1990–1992 and 2003–2005: a global view

Although there are other emissions sources, CO_2 emission is mainly explained by the use of energy. In this section and the next we will consider, as we have done for primary energy, the changes between the average for the period 1990–1992 and the average for the period 2003–2005 in order to avoid conjunctural aspects that might bias the analysis.

The starting databases are again the energy balances of Catalonia. We will only consider the CO_2 emissions associated to coal, oil and its derivatives and natural gas. Other elements, such as biogas, biodiesel, and some waste, have not been considered, given its relative small importance. We have not considered either the emissions associated to net electricity imports (emissions

generated in other countries). Our estimations are very similar to the ones obtained in the Energy Plan of Catalonia, so these omissions do not affect much the results obtained.
As regards the emission factors, we have employed IPCC (1996), taking also into account the mean composition of the coals employed and of the oil derivatives imported. In short, we have employed the next factors (in CO_2 tons per toe): 4 (coal), 3.04 (crude oil), 2.34 (natural gas) and 3.12 (net imports of oil derivatives).
For this estimation we employ the same methodology previously explained. That is, we consider the primary energy pulled by the final consumptions of the different sectors and take into account the CO_2 emission factor of the different primary energies. We consider matrix Q of emissions disaggregated by energy sources and responsible sectors:

$$Q = \hat{F} * E = \hat{F} * T * P * \hat{C} \quad (6)$$

Where Q is, as E, a jxs matrix and $\hat{F}$ is a jxj diagonal matrix that contains zeros in all its elements except in those elements of the main diagonal that correspond to the energy sources whose emissions have been considered (coal, oil, imported oil derivatives and natural gas), in which appear the emission factor already specified.
As a remarkable example, our estimation gives the next average emissions of CO_2 per unit of electricity (what we can call “carbonization factor”) measured in CO_2 tons per toe; 0.95 (1990–1992) and 1.93 (2003–2005) showing the increasing relative weight of natural gas power stations to the detriment of nuclear power stations.
As in the previous sections, our comparison refers to the average of the years 2003–2005 with respect to years 1990–1992. Total emissions linked to the use of energy increased by 69.2%. In tables 10 and 11 we can see how such increase is distributed among energy sources and according to the responsibility of the different sectors. For this last aspect, the considered sectors are, as in previous sections, agriculture, industry, services, residential and transport. We have not considered the non-energy uses.
TABLE 10 HERE
TABLE 11 HERE
The emissions linked to the use of energy have increased considerably. The behavior by energy sources was foreseeable given the previous analysis: the most important contribution (more than half of the increase) is due to the use of natural gas, and the second—a bit less important—is due to the use of oil, with the particularity that this increase is completely attributable to imports of oil derivatives. The negative contribution of coal is not surprising, as it has lost importance as source of primary energy. These evolutions should not be interpreted in the sense that the greater weight of natural gas implied greater emissions, because it is necessary to observe the substitutions that have occurred both in final consumption and in energy transformation. These issues are shown in the later analysis.
As regards the different activities, it is clear that transport is the great responsible of CO_2 emissions, with almost half of total emissions. However, services and residential sectors are the ones that have increased most the emissions of their responsibility (specially emissions generated in electricity generation). The services sector has changed from amounting to 5.9% in 1990–1992 to 9% en 2003–2005, a change of 3 points, which is more or less the

reduction in industry, while the change in the relative weight of the residential sector is less than one per cent.

8. Explanatory effects of the evolution of CO_2 emissions linked to the use of energy

The decomposition into explanatory factors of the evolution of CO_2 emissions follows the same methodology applied in the case of primary energy, but applying now the computation of the corresponding emissions, so we will not repeat the expressions already written in Section 5, to which there should only be added that each term appear multiplied by the diagonal matrix of emission factors.

Tables 12 and 13 show the decomposition by effects, which are disaggregated according to two perspectives: the sectoral perspective and the perspective of the energy sources that cause emissions (Annex II shows the disaggregation crossing both perspectives).

From the aggregated point of view, the effect that is absolutely dominant is the one of final energy consumption. The transformation and substitution effects are much less important. The first acts reducing emissions, which contrasts with what happened in the case of primary energy: this is explained because the most relevant change in this aspect is the increasing relative weight of natural gas power stations (more efficient) to the detriment of nuclear power energy, what reduces the average energy cost of obtaining electricity, but increases the average intensity of CO_2 emissions per unit of electricity. However, the substitution effect reduces emissions, given that natural gas mainly substitutes coal and oil and their emissions per unit of energy are significantly lower.

TABLE 12 HERE

We can now approach the analysis from the point of view of the activity sectors here considered. The most important contribution to the growth of emissions corresponds to the transport sector, whose increase almost doubles the one of industry. However, the increases assigned to services and residential sectors are much less moderated. In order to explain this, it is important to take into account that—in Catalonia—the same increase in final consumption of energy would involve a greater increase in emissions in the cases of industry and transport than in residential sectors, and even more in services, which are much more dependent on the use of electricity. Other aspect shown by sectoral analysis is that the substitution effect, which reduces the emissions, is particularly important for the industrial sector, although it is also relevant for the residential and services sectors. However, as shows the "transformation effect", the great increase in the consumptions of electric energy more than compensated in all these sectors for the positive "substitution effect". In the transport sector, whose emissions are totally dominated by the use of oil derivatives in road transport, the substitution and transformation effects play a very limited role.

TABLE 13 HERE

As regards the origin of emissions, oil and its imported derivates can be seen as a set whose emissions increase quite considerably. This might be expected, given the predominant role played by transport in the increase in energy use. However, natural gas emissions explained by the three effects increase even more. In the case of coal, instead, total emission decreases and this is explained mainly by its substitution in final consumption by other types of energy.

9. Conclusions

In this paper we have first analyzed the evolution of final energy consumption during the period 1990–2005 and we have seen that the final consumptions of energy increase above GDP growth in real terms. The most important relative increases occur in services, residential and transport sectors. Is this last activity, which includes private and commercial transport, the one that experiences the greatest increase in absolute terms, achieving a final consumption of energy even greater than the industrial sector one.

If, instead of analyzing the final consumption of energy, we analyze the primary energy requirements that allow this final energy consumption, we can see that the transport sector, despite its great importance, “pulls” less primary energy than the industrial sector.

The primary energy needed for obtaining the different types of final energy experiences significant changes over the analyzed period. The most relevant change is the reduction in the primary energy that we estimate hat has been employed on average for obtaining a unit of electricity—from 2.96 the years 1990–1992 to 2.59 the years 2003–2005— and even more important is the change in the average composition by sources of primary energy that are employed for obtaining one unit of electricity. While at the beginnings of the 1990s 2.41 units of nuclear heat were expend per each unit of electricity, in the final years—due to the lower relative weight of the nuclear energy in the electric mix—1.56 were used. However, the needs of natural gas clearly increased: from 0.12 units to 0.65 units, showing the increasing weight of thermal power stations of this fuel.

The important changes in the total needs of primary energy of Catalonia between 1990–1992 and 2003–2005 have been analyzed by means of a decomposition into three effects or factors: final energy consumption effect (due to the changes in the levels of final energy consumption), substitution effect (due to the changes in the composition of the final energy consumption) and transformation effect (due to the changes in the energy transformation matrix that relates final consumptions of energy to primary energy requirements).

The final consumption of energy effect—due to the increase in final consumptions—is clearly the most important of all three for all the activities. The final energy consumption effect causes an increase in the requirements of all the energy sources, but particularly of oil, due to the role played by transport and also to the increase demand of oil derivatives for “non-energy uses”.

The transformation effect causes the reduction in the needs of primary energy, and this reduction is stronger in those demand sectors that depend most on electricity. The substitution effect, which has much relevance for explaining the changes in the requirements of some sources of primary energy, does not have, however, much relevance for explaining the changes in total primary energy for the analyzed period.

The requirements of primary energy that increase most are the requirements of natural gas, due to that both the transformation effect (greater share of electricity production in gas thermal power stations) and the “substitution effect” (increasing relative weight of natural gas in the final consumption of industries, services and households) are important and adds up to the final energy consumption effect. As for the use of nuclear power energy, it increases little in absolute terms due to that the transformation effect (loss of relative weight of the electricity of nuclear origin) acts in the opposite way that the final energy consumption effect. The only source of primary energy that decreases in absolute terms in coal, and this is due to that the transformation (lower use in the energy sector) and substitution (lower use in final consumption) effects more than compensate for the final consumption of energy effect. Last, we have to highlight that there is an important dependence on the import of oil derivatives already refined in years 2003–2005, while in for the years 1990–1992 the global balance in energy units of these derivatives was a net export balance.

Next, we have analyzed the evolution of CO_2 emissions—the most important of the greenhouse gases—associated to the use of energy. We have also compared the years 2003–2005 with the years 1990–1992 and have followed exactly the same methodology of decomposition into different effects.

A great part of the results in terms of emissions is directly deduced from the energy analysis. We now will not therefore repeat what we previously did, but we will highlight the differences between both results that are summarized in Table 14.

TABLE 14 HERE

The first thing to notice is that CO_2 emissions increase even more than the primary energy used, in spite of its great increase. A factor, not much important quantitatively, that acts in this way is that the final energy consumption effect is a bit greater in the case of emissions, due to the predominant role of transport.

But the key sector for explaining the difference is the transformation effect that, from the CO_2 emissions perspective, has played a negative role, contributing to the increase of emissions by a 8%, although, from the perspective of primary energy, the needs of transformation decreased. The main reason is the decreasing weight of nuclear power energy with respect to the electricity production in natural gas thermal power stations. These have a greater efficiency in the conversion of heat into electricity, but emit CO_2, in contrast to nuclear power stations that do not emit this gas (at least in a direct way). This is a good example of the different conclusions that we can achieve in an analysis in terms of primary energy with respect to an analysis in terms of carbon emissions. And it is also a good example, although this is another problem, of how some environmental pressures might decrease at the expense of the increase in other pressures.

The substitution of fuels in final consumption—basically in favor of natural gas—has played a role favorable to the reduction of emissions, while it was more or less neutral with respect to the total needs of primary energy, but it was insufficient to compensate for the "transformation effect".

As regards the decomposition by activities, all the sectors increased their emissions (taking always into account the primary energy "pulled") but transport that explains more than 45% of the increase, a share much greater than the one that has in the increase of energy demand.

In conclusion, in the case of Catalonia—similarly as in the global result for Spain and in contrast to other rich countries—we cannot talk about delinking between economic growth and use of energy, and even much less between economic growth and CO_2 emissions, even not in a "relative" or "weak sense" (that is to say, the reduction of energy intensity or carbon intensity; Roca and

Alcántara, 2001). In our opinion, this article contributes to explore the causes of this evolution.

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Annex I. Detailed tables on the decomposition into different effects of the changes in the primary energy requirements in Catalonia between 1990–1992 and 2003–2005

Total Effect (Ktoe)

	Primary	Industry	Services	Transport	Residential	Non-energy uses	Total
Coal	-0.2	-231.1	15.0	-0.9	-7.6	-0.9	-225.6
Oil	6.3	-326.7	-72.3	525.2	-189.9	308.6	251.2
Net import oil deriva.	201.0	459.7	93.6	2043.3	137.6	1136.6	4071.8
Natural gas	34.3	2083.5	970.8	91.6	1028.9	35.8	4245.0
Biomass	1.7	-37.8	7.5	-0.2	39.7	0.0	11.0
Thermo solar.	0.0	0.1	0.7	0.0	3.5	0.0	4.4
Photov. Solar	0.0	0.1	0.1	0.0	0.1	0.0	0.2
Wind	0.2	7.6	5.3	0.4	3.8	0.1	17.5
Nuclear	0.4	-140.2	563.3	-11.4	57.7	2.5	472.3
Hydro.	0.9	29.8	59.7	1.4	22.4	0.5	114.8
Net import electricity	2.1	86.2	79.8	4.6	46.9	0.8	220.5
Renew. waste.	0.7	28.9	26.8	1.5	15.7	0.3	73.9
Non-renew. Waste	0.1	49.1	3.8	0.3	2.7	0.0	56.1
Bioethanol	0.0	0.0	0.0	21.5	0.0	0.0	21.5
Biodiesel	0.0	0.0	0.0	11.1	0.0	0.0	11.1
Biogas	2.1	15.7	8.5	0.6	5.6	0.1	32.6
Total primary	**249.7**	**2025.0**	**1762.7**	**2689.3**	**1167.2**	**1484.4**	**9378.2**

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Transformation effect (Ktoe)

	Primary	Industry	Services	Transport	Residential	Non-energy uses	Total
Coal	-1.1	-50.6	-30.1	-2.8	-24.5	-0.4	-109.6
Oil	-185.6	-537.8	-134.3	-1798.6	-191.9	-996.5	-3844.7
Net import oil deriva.	166.3	430.6	91.8	1620.2	147.3	898.8	3355.1
Natural gas	19.6	699.0	435.9	70.2	342.5	21.3	1588.6
Biomass	-0.1	-4.4	-2.6	-0.2	-2.1	0.0	-9.5
Thermo solar.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Photov. Solar	0.0	0.1	0.0	0.0	0.0	0.0	0.2
Wind	0.1	6.4	3.8	0.4	3.1	0.1	13.9
Nuclear	-26.8	-1183.5	-703.9	-66.0	-572.1	-8.8	-2561.1
Hydro.	-0.8	-37.5	-22.2	-2.1	-18.1	-0.3	-81.0
Net import electricity	0.9	41.1	24.6	2.3	19.9	0.3	89.2
Renew. waste.	0.3	13.6	8.2	0.8	6.6	0.1	29.6
Non-renew. Waste	0.1	4.6	2.7	0.3	2.2	0.0	10.0
Bioethanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biogas	0.2	9.4	5.6	0.5	4.6	0.1	20.4
Total primary	-26.7	-608.8	-320.5	-175.0	-282.4	-85.4	-1498.9

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Substitution effect (Ktoe)

	Primary	Industry	Services	Transport	Residential	Non-energy uses	Total
Coal	0.0	-277.9	2.3	-1.0	-10.7	-1.3	-288.8
Oil	-8.7	-250.5	-136.3	-14.6	-224.5	-3.3	-637.9
Net import oil deriva.	-1.7	-49.5	-28.7	-2.9	-45.3	-0.7	-128.8
Natural gas	6.4	573.5	112.8	-2.6	234.2	4.9	929.2
Biomass	1.5	-59.5	6.8	0.0	32.7	0.0	-18.5
Thermo solar.	0.0	0.1	0.6	0.0	2.8	0.0	3.5
Photov. Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind	0.0	0.0	0.1	0.0	-0.1	0.0	0.0
Nuclear	-0.5	-2.4	104.0	-29.1	-71.7	0.0	0.3
Hydro.	0.0	-0.2	6.8	-1.9	-4.7	0.0	0.0
Net import electricity	0.0	-0.1	4.7	-1.3	-3.2	0.0	0.1
Renew. waste.	0.0	0.0	1.6	-0.4	-1.1	0.0	0.0
Non-renew. Waste	0.0	36.7	0.1	0.0	-0.1	0.0	36.7
Bioethanol	0.0	0.0	0.0	17.0	0.0	0.0	17.0
Biodiesel	0.0	0.0	0.0	8.8	0.0	0.0	8.8
Biogas	1.5	3.8	0.7	-0.1	-0.1	0.0	5.9
Total primary	**-1.6**	**-26.0**	**75.4**	**-28.2**	**-91.7**	**-0.4**	**-72.5**

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Final energy consumption effect (Ktoe)

	Primary	Industry	Services	Transport	Residential	Non-energy uses	Total
Coal	1.0	97.4	42.9	3.0	27.6	0.8	172.7
Oil	200.6	461.7	198.3	2338.5	226.4	1308.4	4733.8
Net import oil deriva.	36.4	78.6	30.5	426.0	35.6	238.5	845.5
Natural gas	8.2	811.0	422.1	24.1	452.2	9.7	1727.2
Biomass	0.3	26.1	3.3	0.1	9.1	0.0	38.9
Thermo solar.	0.0	0.0	0.2	0.0	0.7	0.0	1.0
Photov. Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Wind	0.0	1.2	1.4	0.1	0.8	0.0	3.5
Nuclear	27.7	1045.7	1163.1	83.6	701.5	11.4	3033.0
Hydro.	1.8	67.5	75.1	5.4	45.2	0.7	195.7
Net import electricity	1.2	45.2	50.5	3.6	30.2	0.5	131.3
Renew. waste.	0.4	15.3	17.0	1.2	10.2	0.2	44.3
Non-renew. Waste	0.0	7.8	1.0	0.1	0.6	0.0	9.4
Bioethanol	0.0	0.0	0.0	4.5	0.0	0.0	4.5
Biodiesel	0.0	0.0	0.0	2.3	0.0	0.0	2.3
Biogas	0.4	2.5	2.2	0.1	1.2	0.0	6.4
Total primary	278.0	2659.9	2007.7	2892.5	1541.3	1570.2	10949.6

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Annex II. Detailed tables on the decomposition into different effects of the changes in CO_2 emissions in Catalonia between 1990–1992 and 2003–2005

Transformation effect ($ktCO_2$)

	Primary	Industry	Services	Transport	Residential	Total
Coal	-4.58	-202.31	-120.35	-11.30	-97.81	-436.34
Oil	-564.01	-1634.85	-408.19	-5467.12	-583.18	-8657.35
Net import oil deriva.	619.10	1614.86	344.13	6012.67	555.45	9146.22
Natural gas	45.88	1633.65	1018.82	164.04	800.53	3662.92
Total	96.41	1411.36	834.41	698.29	674.98	3715.45

Substitution effect ($ktCO_2$)

	Primary	Industry	Services	Transport	Residential	Total
Coal	-0.07	-1110.97	9.01	-4.17	-42.95	-1149.16
Oil	-26.54	-761.39	-414.45	-44.44	-682.26	-1929.08
Net import oil deriva.	-6.12	-174.71	-100.62	-10.21	-159.22	-450.87
Natural gas	15.04	1340.33	263.61	-6.13	547.36	2160.22
Total	-17.68	-706.74	-242.44	-64.95	-337.08	-1368.89

Efecto actividad ($ktCO_2$)

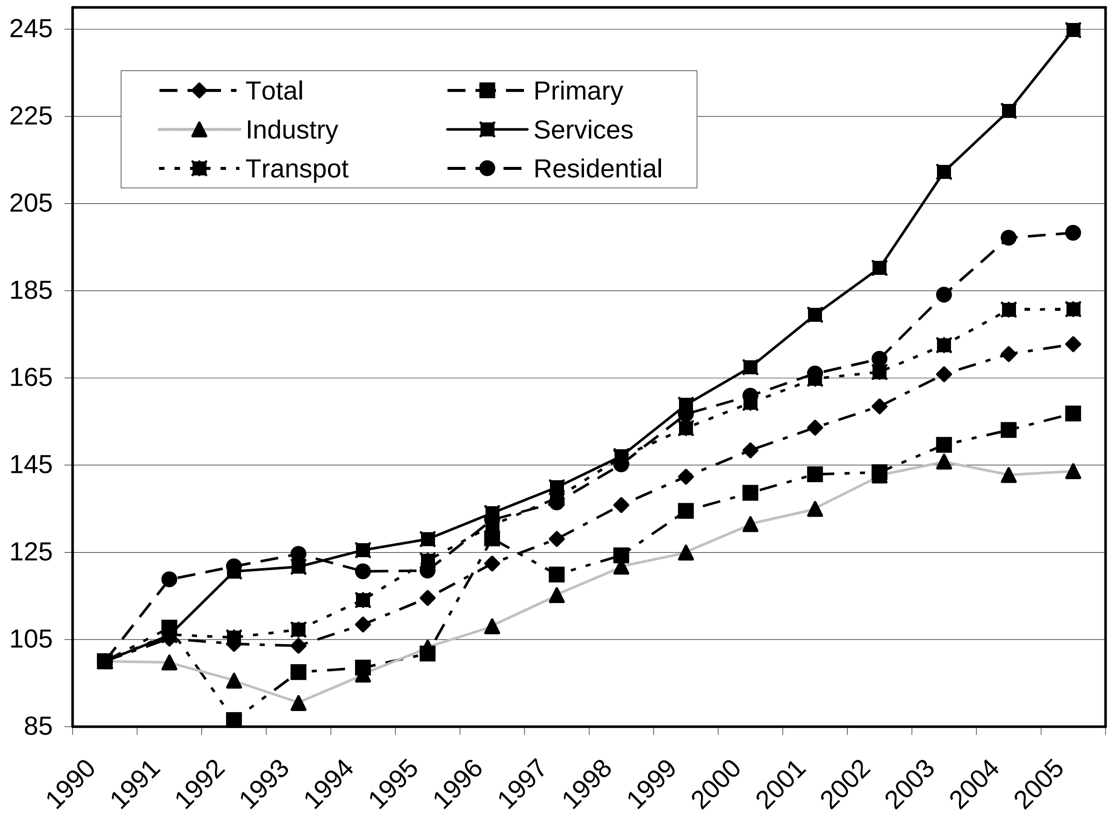
	Primary	Industry	Services	Transport	Residential	Total
Coal	3.99	389.67	171.53	12.06	110.39	687.65
Oil	609.66	1403.33	602.89	7108.12	688.07	10412.06
Net import oil deriva.	129.27	280.49	109.53	1513.00	127.94	2160.23
Natural gas	19.17	1895.26	986.40	56.23	1056.74	4013.81
Total	762.08	3968.75	1870.35	8689.41	1983.15	17273.74

Total effect ($ktCO_2$)

	Primary	Industry	Services	Transport	Residential	Total
Coal	-0.69	-927.68	59.23	-3.50	-31.22	-903.87
Oil	19.12	-992.91	-219.75	1596.56	-577.37	-174.37
Net imports oil deriva.	626.97	1434.12	291.89	6374.37	429.28	9156.64
Natural gas	80.09	4869.24	2268.84	214.14	2404.63	9836.95
Total	725.49	4382.78	2400.20	8181.57	2225.32	17915.35

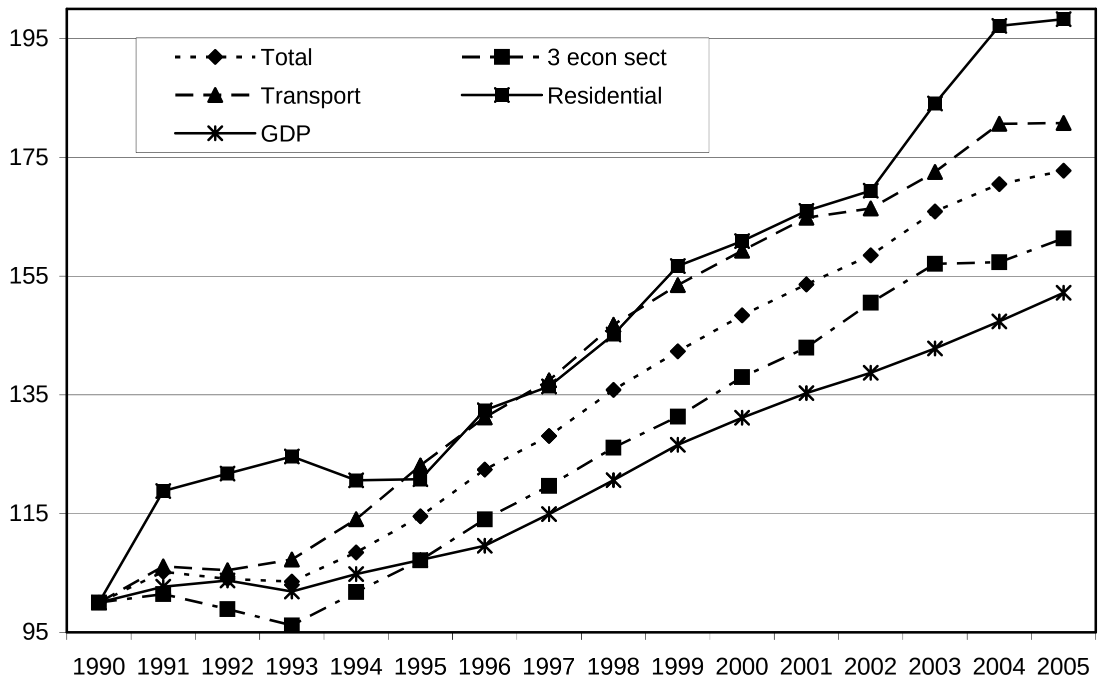
Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Figure 1. Evolution of the final consumptions of energy. total and by sectors. Catalonia. 1990–2005. base 1990=100



Source: Own elaboration based on the energy balances provided by ICAEN.

Figure 2. Evolution of the total and sectoral final consumptions of energy and of real GDP. Catalonia. 1990–2005. base 1990=100



Source: Own elaboration based on the energy balances provided by ICAEN.
Note: homogeneous series at constant prices for GDP.

Table 1. Final consumptions of energy by sectors. Absolute values. relative weight and change. Catalonia. 1990–2005

	Average 1990–1992		Average 2003–2005		Increase in absolute terms	% increase on total increase
	ktoe	% sobre el total	Ktoe	% sobre el total		
Primary	397.5	4.2	620.8	4.0	223.3	3.6
Industry	3549.7	37.3	5194.4	33.2	1644.6	26.7
Services	858.3	9.0	1795.9	11.5	937.7	15.2
Transport	3457.6	36.4	5925.6	37.8	2468.0	40.1
Residential	1248.5	13.1	2124.6	13.6	876.1	14.2
Total	9511.6	100.0	15661.3	100.0	6149.7	100

Source: Own elaboration based on the energy balances provided by ICAEN.

Table 2. Final consumptions of energy according by energy type. Absolute values and share on total. Catalonia. 1990–2005

	Average 1990–1992		Average 2003–2005	
	ktoe	**% del total**	**ktoe**	**% of total**
Coal	249.5	2.6	25.1	0.2
Oil derivatives	5396.4	56.7	8155.4	52.1
Gas	1550.8	16.3	3552.0	22.7
Non-renewable residuals	0.0	0.0	43.6	0.3
Electricity	2236.4	23.5	3744.8	23.9
Renewable	78.5	0.8	140.5	0.9
TOTAL	9511.6	100.0	15661.3	100.0

Source: Own elaboration based on the energy balances provided by ICAEN.

Table 3. Inputs and outputs of energy in Catalonia. 2003–2005 (in ktoe)

	Coal	Oil	Net import oil deriva.	Natural gas	Biomass	Thermo solar	Photov. Solar	Wind	Nuclear	Hydro.	Sal Net import electricity.	Renew. waste.	Non-renew. Waste	Bioethanol	Biodiesel	Biogas	Ref. Oil	Electricity	Intermediate consumptions	Final consumption	Non-energy uses	Energy export balance	TOTAL ENERGY CONSUMPTION
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	203.2	203.2	25.1	0	0	228.3
Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8908.6	0	8908.6	0	0	0	8908.6
Net import oil deriva.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4071.8	0	4071.8	0	0	0	4071.8
Natural gas	0	0	0	52.3	0	0	0	0	0	0	0	0	0	0	0	0	70.3	2444.7	2567.3	3552.0	10.8	0	6130.0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.3	96.4	0	0	96.8
Thermo solar.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.4	0	0	4.4
Photov. Solar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.3	0	0	0	0.3
Wind	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17.5	17.5	0	0	0	17.5
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5938.5	5938.5	0	0	0	5938.5
Hydro.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	436.0	436.0	0	0	0	436.0
Net import electricity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	382.1	382.1	0	0	0	382.1
Renew. waste.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	128.6	128.6	0	0	0	128.6
Non-renew. Waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.5	12.5	43.6	0	0	56.1
Bioethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21.5	0	0	21.5
Biodiesel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11.1	0	10.8	21.9
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25.6	25.6	7.1	0	0	32.6
Ref. Oil	1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1334.5	215.3	1550.8	8155.4	3240.8	0	12947.0
Electricity	0.5	0.5	0	6.8	0	0	0	0	0	0	0	0	0	0	0	0	48.8	575.4	632.1	3744.8	0	0	4376.8
Intermediate consumptions	1.6	0.5	0	59.1	0	0	0	0	0	0	0	0	0	0	0	0	14434.0	10379.9	24875.0	15661.3	3251.6	0	43798.7
	TOTAL (PRIMARY AND SECONDARY) ENERGY USES																						
Production	77.5	245.0	0	2.0	96.8	4.6	0.1	17.5	5938.5	436.0	0.0	128.6	56.1	0.0	21.9	32.6	8875.2	3994.7					19927.0
Energy import balance	150.8	8663.6	4071.8	6128.0	0	0	0	0	0	0	382.1	0	0	21.5	0	0	4071.8	382.1					23871.7
Energy needs	228.3	8908.6	4071.8	6130.0	96.8	4.6	0.1	17.5	5938.5	436.0	382.1	128.6	56.1	21.5	21.9	32.6	12947.0	4376.8					43798.7
																						total primary (*)	26475.0

(*) Total primary is the sum of total consumptions of energy excluding the secondary sources (oil refined and electricity) in order to avoid double accounting. The same result might be achieved adding the needs of energy. again excluding the secondary sources. From the total is also excluded the energy net export balance of biodiesel. which is not part of the primary energy used in Catalonia.

Source: Own elaboration based on the energy balances provided by ICAEN.

Table 4. Matrix of direct energy relationships. 2003–3005.

	Coal	Oil	Net import oil deriva.	Natural gas	Biomass	Thermo solar	Photov. Solar	Wind	Nuclear	Hydro.	Sal Net import electricity.	Renew. waste.	Non-renew. Waste	Bioethanol	Biodiesel	Biogas	Ref. Oil	Electricity
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.046
Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.688	0
Net import oil deriva.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.314	0
Natural gas	0	0	0	0.009	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0.559
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000
Thermo solar.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Photov. Solar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000
Wind	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.357
Hydro.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.100
Net import electricity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.087
Renew. waste.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.029
Non-renew. Waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003
Bioethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006
Ref. Oil	0.005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.103	0.049
Electricity	0.002	0.000	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0.004	0.131

Source: Own elaboration based on the energy balances provided by ICAEN. See the methodological explanation of the text of the meaning of this matrix.

Note: In this table and the next ones. the values 0 and 1 without decimals are used when the value is exact; in the other cases we have maintained the decimal values. even when the three first values are null.

Table 5. Matrix of primary energy needs linked to the different types of final energy consumption. Catalonia 2003–2005

	Coal	Natural gas	Biomass	Thermo solar	Non renewable waste	Bioethanol	Biodiesel	Biogas	Ref. Oil	Electricity
Coal	1.000	0.000	0	0	0	0	0	0	0.000	0.054
Oil	0.004	0.000	0	0	0	0	0	0	0.767	0.044
Net import oil deriva.	0.002	0.000	0	0	0	0	0	0	0.351	0.020
Natural gas	0.001	1.009	0	0	0	0	0	0	0.009	0.650
Biomass	0.000	0.000	1	0	0	0	0	0	0.000	0.000
Thermo solar.	0	0	0	1	0	0	0	0	0	0
Photov. Solar	0.000	0.000	0	0	0	0	0	0	0.000	0.000
Wind	0.000	0.000	0	0	0	0	0	0	0.000	0.005
Nuclear	0.003	0.002	0	0	0	0	0	0	0.007	1.564
Hydro.	0.000	0.000	0	0	0	0	0	0	0.000	0.115
Net import electricity	0.000	0.000	0	0	0	0	0	0	0.000	0.101
Renew. waste.	0.000	0.000	0	0	0	0	0	0	0.000	0.034
Non-renew. Waste	0.000	0.000	0	0	1	0	0	0	0.000	0.003
Bioethanol	0	0	0	0	0	1	0	0	0	0
Biodiesel	0	0	0	0	0	0	1	0	0	0
Biogas	0.000	0.000	0	0	0	0	0	1	0.000	0.007
Total primary	**1.011**	**1.011**	**1**	**1**	**1**	**1**	**1**	**1**	**1.135**	**2.595**

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 6. Matrix of primary energy needs linked to the different types of final consumptions of energy. Catalonia. 1990–1992.

	Coal	Natural gas	Biomass	Thermo solar	Non renewable waste	Bioethanol	Biodiesel	Biogas	Ref. Oil	Electricity
Coal	1.000	0.000	0	0	0	0	0	0	0.000	0.090
Oil	0.002	0.006	0	0	0	0	0	0	1.156	0.103
Net import oil deriva.	0	0	0	0	0	0	0	0	0	0
Natural gas	0.000	1.041	0	0	0	0	0	0	0.000	0.118
Biomass	0.000	0.000	1	0	0	0	0	0	0.000	0.003
Thermo solar.	0	0	0	1	0	0	0	0	0	0
Photov. Solar	0.000	0.000	0	0	0	0	0	0	0.000	0.000
Wind	0.000	0.000	0	0	0	0	0	0	0.000	0.000
Nuclear	0.007	0.005	0	0	0	0	0	0	0.010	2.407
Hydro.	0.000	0.000	0	0	0	0	0	0	0.001	0.141
Net import electricity	0.000	0.000	0	0	0	0	0	0	0.000	0.071
Renew. waste.	0.000	0.000	0	0	0	0	0	0	0.000	0.024
Non-renew. Waste	0	0	0	0	1	0	0	0	0	0
Bioethanol	0	0	0	0	0	1	0	0	0	0
Biodiesel	0	0	0	0	0	0	1	0	0	0
Biogas	0	0	0	0	0	0	0	1	0	0
Total primary	**1.010**	**1.053**	**1**	**1**	**1**	**1**	**1**	**1**	**1.168**	**2.957**

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 7. Total requirements of primary energy by sectors. 1990–1992 and 2003–2005. Catalonia

	Average 1990–1992	Average 2003–2005	Change	
				%
Primary	506.0	755.7	249.7	
Industry	5996.5	8021.5	2025.0	
Services	1914.4	3677.0	1762.7	
Transport	4128.1	6817.3	2689.3	
Residential	2336.5	3503.7	1167.2	
Non-energy uses	2204.6	3689.0	1484.4	
Total	17086.0	26464.2	9378.2	

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 8. Effects by sectors. Average of 2003–2005 with respect to average of 1990–1992. Catalonia

Changes in absolute values (ktoes)				
	Transformation	**Substitution**	**Final energy consumption**	**Total**
Primary	-26.7	-1.6	278.0	249.7
Industry	-608.8	-26.0	2.659.9	2.025.0
Services	-320.5	75.4	2.007.7	1.762.7
Transport	-175.0	-28.2	2.892.5	2.689.3
Residential	-282.4	-91.7	1.541.3	1.167.2
Non-energy uses	-85.4	-0.4	1.570.2	1.484.4
Total	-1.498.9	-72.5	10.949.6	9.378.2
Contribution to the change of primary energy (% of the total initial primary energy)				
	Transformation	**Substitution**	**Final energy consumption**	**Total**
Primary	-0.2	0.0	1.6	1.5
Industry	-3.6	-0.2	15.6	11.9
Services	-1.9	0.4	11.8	10.3
Transport	-1.0	-0.2	16.9	15.7
Residential	-1.7	-0.5	9.0	6.8
Non-energy uses	-0.5	0.0	9.2	8.7
Total	-8.8	-0.4	64.1	54.9

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 9. Effects by energy sources. Changes in absolute values (ktoes). Average of 2003–2005 with respect to the average of 1990–1992. Catalonia

	Transformation	Substitution	Final energy consumption	Total
Coal	-109.6	-288.8	172.7	-225.6
Oil	-3.844.7	-637.9	4.733.8	251.2
Net import oil deriva.	3.355.1	-128.8	845.5	4.071.8
Natural gas	1.588.6	929.2	1.727.2	4.245.0
Biomass	-9.5	-18.5	38.9	11.0
Thermo solar.	0.0	3.5	1.0	4.4
Photov. Solar	0.2	0.0	0.1	0.2
Wind	13.9	0.0	3.5	17.5
Nuclear	-2.561.1	0.3	3.033.0	472.3
Hydro.	-81.0	0.0	195.7	114.8
Net import electricity	89.2	0.1	131.3	220.5
Renew. waste.	29.6	0.0	44.3	73.9
Non-renew. Waste	10.0	36.7	9.4	56.1
Bioethanol	0.0	17.0	4.5	21.5
Biodiesel	0.0	8.8	2.3	11.1
Biogas	20.4	5.9	6.4	32.6
Total primaria	-1.498.9	-72.5	10.949.6	9.378.2

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 10. Estimation of the CO_2 emissions per primary energy sources

	1990–1992	2003–2005	Change	
	Thousands of tons ($ktCO_2$)			%
Coal	1808.9	910.1	-898.8	-49.7
Oil	19696.8	19522.4	-174.4	-0.9
Net import oil deriva.	0.0	9157.8	9157.8	---
Natural gas	4402.1	14251.5	9849.4	223.7
Total	25907.8	43841.8	17933.9	69.2
	Sectoral distribution %		% change with respect to the initial total emissions	
Coal	7.0	2.1		-3.5
Oil	76.0	44.5		-0.7
Net import oil deriva.	0.0	20.9		35.4
Natural gas	17.0	32.5		38.0
Total	100.0	100.0		69.2

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 11. Estimation of the responsibility of the different sectors in CO_2 emissions

	1990–1992	2003–2005	Change	
	Thousands of tons ($ktCO_2$)			%
Primary	1336.7	2062.4	725.7	54.3
Industry	8304.7	12696.8	4392.2	52.8
Services	1531.4	3935.4	2404.0	157.0
Transport	12034.3	20217.3	8182.9	68.0
Residential	2700.7	4929.9	2229.1	82.5
Total	25907.8	43841.8	17933.9	69.2
	Sectoral distribution %		% change with respect to the initial total emissions	
Primary	5.2	4.7		2.8
Industry	32.1	29.0		17.0
Services	5.9	9.0		9.3
Transport	46.5	46.1		31.6
Residential	10.4	11.2		8.6
Total	100.0	100.0		69.2

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 12. Explanatory effects of sectoral contribution to the change in emissions

Changes in absolute values. thousands of tons ($ktCO_2$)				
	Transformation	**Substitution**	**Final energy consumption**	**Total**
Primary	-3.8	-17.0	746.4	725.7
Industry	1141.8	-685.8	3936.2	4392.2
Services	777.8	-231.1	1857.3	2404.0
Transport	-259.7	-63.8	8506.5	8182.9
Residential	579.9	-318.5	1967.7	2229.1
Total	2236.1	-1316.2	17014.1	17933.9
Contribution to the change in primary energy (% of initial total emissions)				
	Transformation	**Substitution**	**Final energy consumption**	**Total**
Primary	0.0	-0.1	2.9	2.8
Industry	4.4	-2.6	15.2	17.0
Services	3.0	-0.9	7.2	9.3
Transport	-1.0	-0.2	32.8	31.6
Residential	2.2	-1.2	7.6	8.6
Total	8.6	-5.1	65.7	69.2

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 13. Explanatory effects of the contribution of the sources of primary energy to the change in emissions

Changes in absolute values. thousands of tons ($ktCO_2$)

	Transformation	Substitution	Final energy consumption	Total
Coal	-436.7	-1150.0	687.8	-898.8
Oil	-8658.4	-1929.3	10413.4	-174.4
Net import oil deriva.	7663.7	-399.9	1894.0	9157.8
Natural gas	3667.5	2162.9	4018.9	9849.4
Total	2236.1	-1316.2	17014.1	17933.9

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.

Table 14. Contribution to the increase in primary energy needs and CO_2 emissions by explanatory factors (%)

	Transformation	Substitution	Final energy consumption	Total
Primary energy	-8.8	-0.4	64.1	54.9
CO_2 emissions	8.6	-5.1	65.7	69.2

Note: In the analysis of primary energy the "non-energy uses" are included. If these were no included the data would mildly change. with a total increase of 53% instead of 54.9%.

Source: Own elaboration based on the energy balances provided by ICAEN and the methodology explained in the text.