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Analysis of the Changes in Primary Energy Use and CO2 Emissions in Spain: Methodology and Tentative Results

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ANALYSIS OF THE CHANGES IN PRIMARY ENERGY USE AND CO_2 EMISSIONS IN SPAIN: METHODOLOGY AND TENTATIVE RESULTS

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Introduction: Aims

The majority of the analyses of the changes in energy requirements and their consequences for the emissions of CO_2 share two characteristics which ought to be reviewed.

The first of these is to consider that the change in what is normally called "energy intensity", or total primary energy requirements per unit of Gross Domestic Product (at constant prices), is a good indicator of the changes in the efficiency of energy use. For example, according to many analysts, looking at the change in energy intensity in Spain after the oil crisis in the 70's suggests that, unlike in other countries, the economic system did not react to the changes in relative prices of energy inputs by rapidly improving energy efficiency in productive processes.[1] However, the question is more complex than this.

Of course, "energy intensity" is very influenced by efficiency of energy use both in the energy sector and in the rest of the economic sectors, but it also depends on many other factors. The changes in the relative weight of the different economic sectors strongly influences this indicator and, as other authors have described,[2] primary energy requirements are not only influenced by qualitative and quantitative characteristics of the various economic sectors, but also by the requirements for domestic use and private transport. This is why the "energy intensity" is a very poor indicator, and may even cause confusion, if one wishes to analyse those factors responsible for the change in energy use. For example, an increasing efficiency in industrial energy use could be countered by the negative effects of a greater transport consumption.

The analysis of primary energy required (and not only the "final" energy consumption, as we will argue later) must be broken down into at least three large components:

[1] According to data from the International Energy Agency, between 1974 and 1990, there was an increase of approximately 6% in the "energy intensity" in Spain; the primary energy requirements grew overall more than the GDP. (The tendency is not the same throughout this period, and between 1981 and 1987 it clearly decreased.) In contrast, in the OECD the average decrease in this figure was more than 24% for the same period, and the decrease occurred every year. cf. International Energy Agency, Energy Balances of OECD Countries, 1989-90, OECD, Paris, pp. 54 and 150.

[2] Proops, JLR, "Energy intensities, input-output analysis, and economic development", in Ciaschini, M (ed), Input-output analysis. Current Developments, Chapman and Hall, New York and London, 1988

energy requirements tied to different "economic" sectors, transport energy requirements,[1] and the energy required for domestic consumption. In fact, if one wishes to define an overall relationship between the energy requirements and the level of economic activity, it would be more pertinent to include in the numerator only the first type of energy requirement. Of course, the changes would not be explained solely by the level of "efficiency" in the use of energy, but also by the variations in the relatives weightings of the different sectors, and we could only give a deeper explanation on the basis of an input-output analysis.[2]

The second characteristic of the analysis of energy and environment which we consider unsatisfactory, and which interests us most here, are the normal criteria used to distribute the "responsibility" for CO_2 emissions. The normal method considers five types of demand for fossil fuels: in power stations, in the rest of the energy sector, in other "economic" sectors, in transport and in the home.[3] Then, it applies the appropriate conversion factors to obtain estimations of CO_2 emissions (measured in tonnes of carbon or CO_2) for each one of the five kinds of energy use.[4] This method does not seem the most appropriate to us, in as much as the "responsibility" for the CO_2 emitted from a coal-fired power station, for example, should not be assigned to the electricity sector, but rather distributed amongst those who require the electricity generated by the power station. The energy sector, both the electricity subsector and the rest of the subsectors, would therefore only be included in our analysis indirectly, in as much as the contribution of a sector to CO_2 emissions would depend not only on its "final energy consumption" but also on the efficiency of the energy sector in providing said "final consumption".

In other words, we consider that the energy consumption in the three sectors that we will consider here, "economic", transport and residential, should be translated into terms of the primary energy of the different energy sources, to take into account the primary energy required to make available one unit of energy for final consumption. That is to say, one can try to estimate what Slesser calls the *energy requirement for energy*,[5] which, for any energy used by the sectors considered would necessarily have a value greater than the unit. We are not only interested in the total value but in the breakdown by primary energy sources. The method used for this estimation is explained below, and in our analysis we will only look at some of the determinants of this previous value, and in fact make an underestimation on the basis of information about the Spanish energy sector. We leave to one side, firstly, the fact that the energy sector demands goods and services from the rest of the economic sectors,

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1 When we speak of transport energy demand, we refer to transport in general. It is extemely interesting to have data on the global energy needs of the transport sector, although part of transport, that of freight, should be added to the "economic" sectors consumption. In a future development of this article, it would also be interesting to break down the data in this way.

2 Proops, *op cit*

3 As in the previous reference, data for agriculture and services is presented together with that for the home (making up the "residential and services" consumption). However this is not the question which interests us here.

4 cf, for example, Commission of the European Communities, Energy in Europe: A View to the Future, Brussels, 1992

5 Slesser, M, "Net energy as an energy planning tool", Energy Policy, June, 1987

and that transport includes services to the energy sectors. This limitation can be overcome in later development of this paper, on the basis of economic input-output tables. And secondly, part of the energy loss ("energy cost of energy") is produced in other countries, as is clearly the case of the energy needed to extract and transport imported oil. Obviously, it is impossible to overcome this limitation on the basis of a limited analysis of the Spanish economic and energy data.

The Data Base Used

This kind of analysis can be based on two types of statistical sources. The first is that given by the energy input-output tables, and has obvious advantages,[1] but for a historical analysis such as we carry out here (for the moment we present only some results relating to the period 1980-1990), it has the great inconvenience of its lack of continuity. In the case of Spain, we only have these tables for the years 1980-85, and in the immediate future we probably will not have any others. The other source available is that of the energy balance sheets of the International Energy Agency, in its publication entitled Energy Balances of OECD Countries. This contains a series of data for the OECD countries, beginning in 1960, although the quality of the data is inferior, at least for Spain, for the years before 1980. Unlike the energy input-output tables, this source does not allow the demands of the energy sectors on the rest of the economic sectors to be taken into account, but for the years for which economic input-output tables are available these demands could be estimated in a future development of this article, by combining the information in the energy balance sheets with that given by the input-output tables, to get a better approximation of the energy required to make energy available.

The OECD balance sheets show in energy units (million TOE) data for the input (primary energy) and output (primary and secondary energy for final consumption) of the energy subsectors, and data on the use of this output by other sectors, distinguishing between transport (and different types of transport), other services, the residential sector, agriculture and industry (divided into thirteen subsectors). We will now explain the methodology used to analyse the energy demands of the three sectors to which we referred in the introduction: the transport, residential and "economic" sectors (other than transport). Although here we do not break down consumption in the economic sectors, there is no problem in obtaining data separated into 17 sectors. (We do not have very reliable data for the industrial subsectors for the years before 1980, which limits the interest in a breakdown of the data.) But it must be said that for the sectoral breakdown to be more interesting, one

[1] There are at least three studies which have analysed the distribution of CO_2 emissions in Spain, with different methodologies but all on the basis of the Spanish energy input-output tables for 1985: Jiliberto, R. & Domíngez, C, "El modelo económico ambiental de estimación de contaminantes atmosféricos MEER28", prepared for the government and presented to the Fourth National Economics Conference in Seville, December, 1992; Antón, V, de Bustos, A, Manzanedo, L. & Sierra Ludwig, V, "La emisión de CO_2 y su problemática comunitaria: un método de estimación general", Documentos de Trabajo de la Dirección General de Planificación del Ministerio de Economía; and Martín, C, & Velázquez, F. J, "Some sectorial implications of community taxes to limit CO_2 emissions: Spain as a case study", Documento de Trabajo 9209, Fundación Empresa Pública (directed towards making predictions about the sectorial impact of an "ecotax").

would have to combine the previous analysis of the energy balance sheets with the information from the economic input-output tables to take into account the direct and indirect sectoral consumption generated per unit of final demand.

One limitation of the energy balance sheets of the OECD is that they do not distinguish between natural gas consumption and that of gas obtained from petroleum ("manufactured gas"), so we have been forced to consider all gas as one energy sector. Without doubt, the final result is not greatly affected by this limitation, given the relatively small importance of manufactured gas, especially in recent years. Neither does the data allow one to distinguish between different kinds of coal on the one hand, and coal derivative products (solids and gases obtained by a transformation process), so we have also been forced to treat the different types of coal and coal derivatives always as a whole. Furthermore, the quality of the information prevents us from taking into account some minor relationships between the energy subsectors, which will doubtless not affect the order of magnitude of the results.

Methodology for converting data on final consumption into data on primary energy requirements by energy sources

A) Conversion factors

Any estimation of primary energy must first establish factors for converting between energy sources. In the case of coal, natural gas and petroleum, the conversion into a single unit, such as tonnes of oil equivalent, presents no problem in theory, but it does so in practice, since different kinds of coal may have different conversion factors, for example. We use the data of the International Energy Agency, such as presented in the above-mentioned publication of the OECD. In the case of nuclear energy and hydroelectricity, at least three criteria can be adopted, all of them reasonable depending on the objective of the analysis. The main objective of this article is to explain CO_2 emissions, and the result is the same whichever of the three methods is adopted.

a. Present IEA method

Hydroelectricity is valued by the energy content of the electricity: 1 Mwh = 0.086 TOE (Mwh = million watt-hours, thousand kilowatt-hours).

Nuclear electricity is valued by the heat generated, supposing the electricity obtained to be 33%: 1 Mwh = 0.086 TOE/0.33.

b. Opportunity cost method (old IEA method)

Hydroelectricity and nuclear electricity are both valued by the primary energy which would be needed to obtain them if fossil fuels were used, supposing for example an average efficiency of 38.5%: 1 Mwh = 0.086 TOE/0.385.

c. Non-renewable capital consumption method

This method[1] only considers the needs for non-renewable resources which are really relevant for an analysis of the decrease in natural capital or patrimony. It values them in terms of the heat generated, that is, nuclear electricity is considered the same as in the first method, and hydroelectricity is not taken into account.

In any of the above methods, we will only take into account the energy use of the solid fuels and will exclude the demand for non-energy industrial use, particularly relevant in the case of the chemical industry.

B) Estimation of the primary energy requirements of the different economic activities.

To estimate the energy required for energy, a first approximation, (in fact an underestimation, which we make here), is based on the inter-relationships in the Spanish energy sector so that each final energy consumption (primary or secondary) corresponds to a primary energy vector of six elements: coal, other solid fuels (which represent only an insignificant proportion), petroleum, nuclear energy, hydroelectric energy and natural gas. This is a underestimation because, as we have indicated, a more complete analysis would require the study of the direct and indirect demands of the energy sector on other economic sectors, including transport, to include the energy needed to be able to make this input energy available. That is, part of what is normally included as final consumption is in fact energy consumption necessary to transform the primary sources. Furthermore, we do not consider the energy consumed in other countries to provide the energy used in Spain.

Later we will be able to transform the final energy consumption data into primary energy needs. It is important to note that we only take into account the primary energy requirements for energy use in the non-energy domestic activities, so we do not assign the primary energy necessary for the exports of petroleum derivative products, for example. In the case of the relatively unimportant secondary energy imports, such as electrical energy, we apply the same conversion factors as those obtained above for the same kind of energy.

C) An example

To explain the methodology used, by way of example, we present the real data for the Spanish economy corresponding to 1990.

On the basis of the energy balance sheets of the OECD, we have elaborated the following table of inputs and outputs , expressed in million tonnes of oil equivalent:

	c	osf	p	n	h	g	r	e	ID	AE	TE
c	0.76	0	0	0	0	0.01	0	14.03	14.80	4.22	19.02
osf	0	0	0	0	0	0	0	0.08	0.08	0.40	0.48

[1] Slesser, M, ECCO User Manual, The Resource Use Institute, Scotland, 1992

p	0	0	0	0	0	0	54.77	0	54.77	0.03	54.80
n	0	0	0	0	0	0	0	14.14	14.14	0	14.14
h	0	0	0	0	0	0	0	2.18	2.18	0	2.18
g	0	0	0	0	0	0.13	0	0.27	0.40	4.60	5.00
r	0	0	0	0	0	0.06	0.19	2.08	2.33	48.43	50.76
e	0	0	0	0	0	0	0.15	1.96	2.11	10.75	12.86

The following symbols are used: c: coal; osf: other solid fuels; p: petroleum; n: nuclear; h: hydroelectricity[1]; g: gas (includes natural and manufactured gas; r: petroleum derivative products; e: electricity; ID: intermediate demand; AE: available energy; TE: total energy.

The data is expressed in Mtoe (million tonnes of oil equivalent), and indicate the "losses" in the transformation process. In some cases, these are actually losses in the sense of energy used to make energy available and no longer itself available, as for example in the use of coal in the coal sector itself or the losses of gas and electricity from transport. In other cases, they are primary energy inputs to obtain secondary energy, as in the case of coal used to obtain electricity. Together they represent the "intermediate demand" (ID) of the energy sectors. The table combines primary and secondary energy, and among the inter-relationships considered we have obviously not included all the primary energy inputs, which in fact are those which appear in the TE column (total energy) together with the secondary energy of the electricity and petroleum derivative products obtained. AE is the vector of the final available energy (used outside the energy sector).

If we divide each row of the previous table by the corresponding element of the TE vector, we obtain the following transformation coefficients for energy E:

Matrix E:

0.039957	0	0	0	0	0.002	0	1.090979
0	0	0	0	0	0	0	0.006220
0	0	0	0	0	0	1.078999	0
0	0	0	0	0	0	0	1.099533
0	0	0	0	0	0	0	0.169517
0	0	0	0	0	0.026	0	0.020995
0	0	0	0	0	0.012	0.003743	0.161741
0	0	0	0	0	0	0.002955	0,15

The inverse matrix $(I-E)^{-1}$ would represent the direct and indirect requirements needed to obtain a unit of energy of each type.

[1] In this example, we have considered the data for nuclear and hydroelectricity according to method a) of the three above-mentioned methods, as it appears in the OECD publication.

Matrix $(I-E)^{-1}$:

1.041621	0	0	0	0	0.002187	0.003979	1.341542
0	1	0	0	0	0.000000	0.000021	0.007343
0	0	1	0	0	0.013351	1.083667	0.202122
0	0	0	1	0	0.000047	0.003850	1.297983
0	0	0	0	1	0.000007	0.000593	0.200113
0	0	0	0	0	1.026694	0.000075	0.025446
0	0	0	0	0	0.012373	1.004326	0.191957
0	0	0	0	0	0.000043	0.003501	1.180485

To avoid double accounting, if we take only the first six columns of this inverse matrix, we obtain the matrix ES, composed of column vectors which represent the primary energy needs to make available a final consumption unit for each type of energy. If we added the first six rows, we would obtain an approximation (an underestimation as we have explained above) of the "primary energy required per unit of available energy. The values of this approximation are 1.04 for coal and gas, 1.09 for petroleum derivative products, and 3.08 for electricity. This last figure depends very much on which of the three conversion methods outlined in section A is used. Here we have used method a, with method b it would be 3.31, and with method c it would be 2.88. In other words, to make available 1 TOE of coal, a minimum of 0.04 TOE of energy are lost, and to make available 1 TOE of electricity, more than 3 TOE of primary energy are needed.

ES (which reflects the efficiency of the transformation of the energy sectors) is the name we give to the matrix composed of the first six rows of the matrix $(I-E)^{-1}$, and it represents the matrix for the transformation of the final energy consumption data into primary energy data.

Matrix ES:

1.041621	0	0	0	0	0.002187	0.003979	1.341542
0	1	0	0	0	0.000000	0.000021	0.007343
0	0	1	0	0	0.013351	1.083667	0.202122
0	0	0	1	0	0.000047	0.003850	1.297983
0	0	0	0	1	0.000007	0.000593	0.200113
0	0	0	0	0	1.026694	0.000075	0.025446

On the other hand, we have information on the final energy consumption of the different activities, and which we present in the form of matrix C.

Matrix C:

	"Economic"	Residential	Transport
c	3.95	0.28	0
osf	0.40	0	0
p	0.03	0	0
n	0	0	0
h	0	0	0
g	3.59	0.64	0
r	8.40	3.65	22.52
e	7.87	2.55	0.32

To obtain the matrix EP, for primary energy needs, we use the matrix product: EP = ES*C. (ES undervalues the effective primary energy needs.)

Matrix EP:

	"Economic" sectors	Residential	Transport	Total
c	14.71	3.73	0.52	18.96
osf	0.46	0.02	0.00	0.48
p	10.81	4.49	24.47	39.77
n	10.24	3.32	0.50	14.07
h	1.58	0.51	0.08	2.17
g	3.89	0.72	0.01	4.62
Total	41.70	12.80	25.58	80.08

D) Data for primary energy and CO_2 emissions

To assign responsibilities for CO_2 emissions to the different "economic" sectors and to the final domestic or transport demands, we simply carry out the following transformation: **ECO = EP*CCO**, where EP is the matrix of primary energy needs for the different activities defined in the previous example, and CCO is the vector of emission coefficients corresponding to each energy source. The coefficients are those used by the OECD.[1] One of the limitations of these coefficients is that they assume that all the derivative products from one energy source have the same coefficients, and that the coefficients for the different kinds of coal are also all the same. The OECD coefficients assume that 1TOE of coal produces carbon emissions 30.5% greater than those produced by 1TOE of petroleum, whilst in the case of

[1] OECD, Environmental Indicators, Paris, 1992

natural gas the emissions are 24.5% less than those from petroleum, for the same amount of energy.

Analysis of some results (1980-1990)

A) Analysis of primary energy needs

Table 1 shows the estimation of primary energy needs in absolute terms for the years 1980 and 1990, and the variation over this period. The information is expressed in absolute terms and according to the different methods outlined above.

Table 1. Estimated primary energy needs in Mtoe.

	1.980	1.990	Variation 1980-90 (%)
Method a (present IEA)	64.0	80.1	25.1
Method b ("opportunity cost")	67.8	81.5	20.3
Method c (non-renewable natural capital)	61.5	77.9	26.7

Notes:

1. These are energy needs to cover domestic consumption in the productive activities, in the home and in transport. They do not include the energy value of energy exports, such as petroleum derivative products.
2. Energy for international shipping is not included.
3. Non-energy use of petroleum derivative products is not included.
4. The rest of the methodological questions and limitations of the data are explained in the text.

Tables 2 and 3 break down the information according to the energy source and type of activity, respectively. For the breakdown, we have used method a, which we will use in the rest of this article.

Table 2. Estimated primary energy requirements in Mtoe, by energy sources

Conversion method a (IEA)

	1.980	1.990	Variation 1980-90 (%)
Coal	12.3	19.0	54.5
Other solid fuels	0.3	0.5	80.2
Petroleum	45.9	39.8	-13.4
Natural gas	1.7	4.6	173.5
Hydroelectricity	2.5	2.2	-13.0
Nuclear energy	1.3	14.1	960.1
Total	64.0	80.1	25.1

Notes and methodology: see table 1

Table 3. Estimated primary energy requirements in Mtoe by kinds of activities

Conversion method a (IEA)

	1.980	1.990	Variation 1980-90 (%)
"Economic" sectors*	37.3	41.7	11.8
Residential	8.7	12.8	47.1
Transport	18.0	25.6	42.2
Total	64.0	80.1	25.1

* Agricultural, service and industrial activities, not including transport
Notes and methodology: see Table 1

The information in table 2 shows an important change in the relative weight of the different energy sources. The most outstanding change is that of nuclear energy, which in ten years multiplies its importance by a factor of more than 10. Natural gas also has a higher weight in 1990, and to a lesser extent the use of coal also increases more than the average amount. Petroleum loses importance both in relative and in absolute terms, and energy from hydroelectric power stations also decreases, which is less significant given the rather unstable character of the hydroelectric power supply.

The information in table 3 allows us to see that the concept of *energy intensity* is of very limited use for energy analysis, as we said in the introduction. If we use the IEA conversion factors (method a)), the energy intensity, measured as the quotient of the primary energy and the GDP at factor cost at constant prices, shows a very moderate decrease of little more than 3%. While primary energy needs grew by around 25%, the GDP grew by a little more than 32%.[1] However, the data in table 3 allows us to distinguish a very different change in the different types of energy requirements.

The primary energy needs of the different "economic" sectors (excluding transport) grew only 11.8%, which gives a much more optimistic idea of the elasticity between energy and GDP. What we could call the "productive" energy intensity, relating primary energy required by the "economic" sectors to GDP at constant prices, fell by a substantial 15%,[2] although the strong economic growth of the second half of the 80s meant that this was not translated into a decrease in energy requirements in absolute terms. It is likely that the elasticity between energy and GDP was above all a result of the change in the structure of the GDP, rather than any "efficiency" of energy use in the different areas. In any case, this is a topic that we will not pursue now, and which, as we have indicated, must be analysed by also using the information in the input-output tables.

1 Alcaide, J, "Evolución de los sectores industriales y de servicios entre 1970 y 1990", Papeles de Economía Española, n. 50, 1991

2 It could be argued that in the denominator, the GDP at constant prices should exclude the the transport and energy sectors. This does not alter the result in a significant way.

The increase in primary energy needs for domestic consumption and for transport is relatively much more important than that derived from productive activities; in both cases it is greater than 40%. In absolute terms, this means that the increase in energy needs in the home, the result not only of an increased final consumption but also of an increased "electrification" of consumption, is almost as important as the increase for productive activities. The increase for transport needs is explained by the growing importance of road transport for people and freight (table 4), and is by far the most important as it explains almost half the increase in primary energy needs. On its own, road transport accounted for an increase in primary energy requirements of more than 8 Mtoe, and this increase has little to do with whether energy use in production was more or less efficient.

Table 4. Transport primary energy requirements

	1.980	1.985	1.990	Variation 1980-90 (%)
Road	11.6	13.1	19.7	69.8
Total	18.0	17.8	25.6	42.2
Road / total	64.4%	73.6%	77.0%	

B) CO_2 emissions

Table 5 shows the change in CO_2 emissions, estimated on the basis of the methodology already explained. The fundamental bulk of the CO_2 emissions in 1990 is still that from the use of petroleum, but this energy source loses relative importance in the total emissions (falling from more than 72% to 58%), owing to its relative decline with respect to coal and natural gas.

Although there is a very strong correlation between primary energy requirements and responsibility for CO_2 emissions, the latter also depends on what kinds of final energy are used for each activity, and the primary energy sources used to obtain secondary forms of energy. Different sources imply different emissions for the same amount of energy, and in some cases, such as hydroelectricity and nuclear power, do not generate CO_2 emissions, although in our opinion nuclear energy creates a much more serious environmental problem, and its increasing relative importance should not in any way be seen as an environmental improvement.

Table 5. Estimations of responsibility for CO_2 emissions (million tonnes of carbon)

	1.980	1.990	Variation 1980-90
"Economic" sectors*	31.1	28.0	-9.9%
Residential	7.1	8.3	+17.8%
Transport	15.0	21.1	+40.3%
Total	53.2	57.4	+7.9%

As a % of total

	1.980	1.990
"Economic" sectors*	58.5	49.2
Residential	13.3	14.4
Transport	28.2	36.5
Total	100	100

* Agricultural, industrial and service activities, excluding transport

Table 5 shows that the increases in CO_2 emissions in the decade of the 80s can be explained solely by the residential energy requirements and even more so by the energy requirements in the transport sector. The other economic sectors reduced their total emissions by almost 10%, while the most spectacular increase was that of more than 40% on the part of transport.

In general, the increase in emissions was less than that in primary energy. This happened despite the growing relative importance of coal, due to the growing use of natural gas and, above all, of nuclear energy, which as we have indicated represents a serious ecological threat which we do not discuss here. Where this substitution has less impact is in the transport sector, which is an activity characterised by a strong growth in energy needs and by the fact that this consumption continues to rely almost exclusively on petroleum.