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Breaking the Energy Coefficient: Cross-Country Analysis of the Pulp and Paper Industry

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BREAKING THE ENERGY COEFFICIENT: CROSS-COUNTRY ANALYSIS OF THE PULP AND PAPER INDUSTRY

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FOREWORD

Many of today's most significant socioeconomic problems, such as slower economic growth, the decline of some established industries, and shifts in patterns of foreign trade, are inter- or transnational in nature. Intercountry comparative analyses of recent historical developments are necessary when we attempt to identify the underlying processes of economic structural change and formulate useful hypotheses concerning future developments. The understanding of these processes and future prospects provides the focus for IIASA's project on Comparative Analysis of Economic Structure and Growth.

Our research concentrates primarily on the empirical analysis of interregional and intertemporal economic structural change, on the sources of and constraints on economic growth, on problems of adaptation to sudden changes, and especially on problems arising from changing patterns of international trade, resource availability, and technology. In this paper one of the long-standing industries and the impact of its technological changes on energy consumption are considered. Econometric analysis of cross-country and time-series data helps to reveal the impact which is widely discussed in detailed engineering reports.

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BREAKING THE ENERGY COEFFICIENT: CROSS-COUNTRY ANALYSIS FOR THE PULP AND PAPER INDUSTRY

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INTRODUCTION

The pulp and paper industry is an 'energy-intensive' and a mature sector of the economy. However, an analysis of the industry's energy consumption is made difficult by the fact that it is also a producer of energy, and that it has great opportunities of using non-purchased energy; this fact is badly accounted for in energy statistics. While it is possible to make cross-country comparisons on such sectors as iron and steel, this is almost impossible for pulp and paper, because there is no common 'international' framework to collect energy consumption data, despite the efforts of IEA ([11]). The study of the industry's energy consumption is thus based on two types of figures:

-- Purchased energy. The availability of this type of data is comparable to that of other sectors, and, with some reservations concerning the reliability of some figures, cross-country comparisons can be made.

-- Non-purchased energy. There are, as yet, no systematic surveys on non-purchased energy consumption, except that OECD is collecting data for a few countries (not all countries present these data), and cross-country comparisons of these data are limited because of different accounting methods. The available data are not broken down by energy sources and there are no details concerning the conversion coefficients.

A comprehensive study of energy coefficients has not yet been made, and this fact is acknowledged by every study available to the authors on the sector's energy consumption[1]. However, this does not mean that nothing can be said on the subject of energy coefficients; the characteristics of the sector's development make clear several aspects, as stated by many authors (e.g. [1], [4], [5], etc.):

-- the structure of the industry is a very important factor of the energy consumption;

-- the possibilities of lowering the purchased energy consumption are, theoretically at least, very high.

I. THE STRUCTURE OF THE SECTOR

The importance of the pulp and paper industry in total industrial consumption is illustrated by the figures given in international yearbooks, such as in [11]:

Table 1. Share of the pulp and paper sector in total industrial energy consumption (%), 1980.[2]

USA	FRA	FRG	ITA	UK	NOR	SWE
6.0	3.6	3.6	4.0	5.0	1.5	38.9

In all industrialized countries pulp and paper is among the five first energy consuming sectors, and it is the first one in Sweden due to obvious reasons.

The economic weight of the sector is low (around 2% of the manufacturing sector's value added in France, the FRG, and Italy, 4% in the USA and the United Kingdom, and 5% in Norway), except for Sweden (around 14% of the manufacturing sector's value added).[3]

The production of pulp of each country is given in Table 2, which shows rather different changes over time; in general the level of production corresponds to the relative size of the countries (considering the above remarks).

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[1] Studies on the energy consumption of the pulp and paper sector either deal with technical estimations ([2], [12]), or with aggregated figures on energy consumption ([13]).

[2] Production figures on pulp and paper are mostly taken from [3] and [6].

[3] Norway and Sweden export 30 to 40% of their pulp production; in all other countries this percentage is lower than 10%.

Table 2. Wood pulp production (in 1000 tons).

Year	USA	FRA	FRG	ITA	UK	NOR	SWE
1975	36808	1753	1531	741	319	1657	8415
1982	44388	1843	2021	704	144	1523	7706

The production of pulp depends in general on the size of the national forests and their level of exploitation. This does not explain the big differences in production between the United Kingdom and France, but it does for Sweden. The production of paper and paperboard is, on the other hand, more related to the size of the country (Table 3).[4)]

Table 3. Paper and paperboard production (in 1000 tons).

Year	USA	FRA	FRG	ITA	UK	NOR	SWE
1975	44896	4100	5287	3496	3615	1147	4473
1982	55064	5076	7796	4323	3186	1305	5928

The comparison of the above data indicates that the structure of the sector differs greatly from one country to another. Norway and Sweden produce pulp for the world market and their own consumption, the USA produces roughly what is needed for its paper fabrication, and the other countries rely much more on imported pulp (Table 4).

Table 4. Share of imported wood pulp in the apparent pulp consumption* (%).

Year	USA	FRA	FRG	ITA	UK
1975	7	41	52	57	87
1982	7	46	56	67	92

*This ratio is negligible for Norway and Sweden.

4) The production of paper and paperboard per GNP (in tons per thousand US $) in the year 1975 varies from 12.8 to 21.5 for big European countries.

The alternative to wood pulp as a raw material in paper making is mainly the recovery of waste paper, and Table 5 shows the differences among countries in these inputs by the respective requirements per ton of paper and board, which is defined in a simple way, i.e. by dividing the corresponding apparent consumption data by the production of paper and paperboard.

Table 5. Wood pulp and waster paper inputs per ton of paper and paperboard.

Year	USA	FRA	FRG	ITA	UK	NOR	SWE
Pulp							
1977	.86	.69	.56	.45	.59	.97	.88
1982	.82	.62	.55	.47	.48	.96	.90
Waste paper							
1977	.15	.29	.42	.46	.51	.08	.09
1982	.21	.38	.42	.48	.59	.05	.11
Total (pulp and waste paper)							
1977	1.01	0.98	0.98	0.91	1.10	1.05	1.07
1982	1.03	1.00	0.97	0.95	1.07	1.01	1.01

The differences in the sum of both inputs per ton of final product are in the range of 10% and the low coefficient for Italy is explained by the higher share (relative to the other countries, where it is marginal) of (fiber) pulp. In most countries it represents less than 1% of total pulp, except for Italy, where it is approximately 8-12%, but it is generally decreasing.

The share of waste paper depends on the level of production of wood pulp--the most important pulp producers have a low share of waste paper--, and on the availability of waste paper. European countries have a higher recovery rate than the USA. Waste paper is not exactly equivalent to wood pulp; apart from all the problems of recovery, there is a difference in quality of the fibers that can be recoverd in waste papers (the fibers are generally shorter). In general, paper produced from waste products is of lower quality than that produced from virgin pulp.

This difference in the structure of paper making (from wood pulp or from waste paper) is particularly important with regard to the energy consumption. All estimates agree on the fact that the repulping of waste paper is much less energy intensive than the pulping from wood (i.e. 3 to 5 times less energy intensive).

The structure of the pulp production itself has a major influence on the energy consumption of the sector due to a variance in the energy requirements of each type of pulp.

The Pulping Process

Due to the difference in processes, the energy requirements are determined by the structure of pulp production; this applies to energy requirements in absolute terms as well as to the share of non-purchased energy. To illustrate this point a short overview of the different processes of pulp making is necessary.

There are mainly two processes of pulp making, the chemical process and the mechanical process, and one intermediary process, named thermo-mechanical.

The pulping process starts with the debarking of wood logs; the bark is generally used as a fuel, and the logs are mechanically or chemically treated to produce pulp. The logs are then reduced to chips. The pulping process is the breakdown of wood into separate fibers; it requires large amounts of water.

The mechanical process. Wood (mainly coniferous) is ground in a bath of water with rotating grindstone. This process has a high yield (over 90% of the wood used). The lignin is generally still included in the solution produced. Most of the energy requirements of the process are supplied by electricity.

The chemical process. Wood chips are treated in a chemical bath containing sulphur compounds. The chemical operation is carried out at a high temperature, where the lignin is removed from the fibers, and only 50% of the wood used is available for pulp. The fibers are waste products, and the solution obtained, which contains lignin and chemical agents, is sent to recovery.

The semi-chemical process is an intermediary process. Wood is first treated with chemical agents, and then mechanically.

The pulp produced according to these processes differs mainly in lignin content and the length of the fibers (fibers are torn in the mechanical process and thus they are shorter than fibers obtained in the chemical process). The more lignin there is in pulp, the lower is the quality of paper.

From these characteristics it follows that the main use for mechanical pulp is the production of newsprint, whereas high quality paper is made out of chemical pulp. The latter term includes sulphite pulp, which can be bleached very easily and is used for all types of purposes, and sulphate pulp, which is hard to bleach but very resistant and produces wrapping paper and boards (Kraft). Pulps are generally blended to produce paper or board with the required qualities.

The USA, Japan, and France have a structure with a dominant share of the chemical processes (Table 6), which is especially true for the USA and Japan, where the mechanical process plays a quasi-marginal role. The FRG, Italy, and the United Kingdom, on the other hand, have a structure with a dominant mechanical process.

Table 6. Shares of the three processes (%), in 1982.

Country	Chemical pulp	Semi-chemical pulp	Mechanical pulp
USA	80	7	10
Sweden	73	3	23
France	66	6	22
Norway	30	4	58
FRG	28	3	60
Italy	11	9	77
UK	0	58	42

The share of the pulp which is bleached depends on the use of the pulp. The bleaching operation removes more lignin to the pulp, improving the physical properties of the paper. The shares of bleached pulp vary from country to country, and in general they correspond to the figures of the dependence of a country on imports of pulp (Table 7).

Table 7. Share of bleached pulp in total pulp (%).

Year	USA	FRA	FRG	ITA	UK	NOR	SWE
1970	32	32	28	10	16	19*	41*
1975	52	36	33	10	17	25	41
1980	58	41	30	4	12	17	43

*1971 data.

All these different operations have different energy requirements: Chemical pulp appears to be the most energy-intensive process, but it is often considered to be the least energy-intensive process ([4], [8]). This is explained by the fact that this process gives back waste products, which can be recovered as fuels. In fact, at almost every stage of pulp making, there are some waste products that can be used as energy. The debarking of wood logs gives wood residues (bark, sawdust, etc.) that are used as fuels in most pulp mills. But the main producer of non-purchased energy is the chemical pulping process. The wood chips are heated in a digester, either with an acid liquor (sulphite process) or with an alkaline liquor (sulphate process). The liquor in the digester contains wood products after the pulping operation, such as lignin, which is then separated from the pulp (washing operation), concentrated by evaporation, and burned in a recovery boiler to produce high pressure steam. A large part of the energy content of the liquor may be lost in the conversion to steam, but the energy produced is still non-negligible. The high-pressure steam is generally derived through a turbine to cogenerate low-pressure steam and electricity; the low-pressure steam is used in the pulping operation, and sometimes even in an associated pulp mill, in the case of the most modern plants (see [9], [13]). The chemicals contained in the liquor are recovered too, and redirected to the pulping operation.

The same happens when the pulp is bleached: the liquor obtained is generally added to the liquor from chemical pulping.

The recovery of waste products is more limited in the case of the mechanical process. There is, of course, no chemical solution, and most of the lignin stays in the fibers. Most of the energy requirements are electric power, which must in most cases be purchased.

Thus, the structure of the sector determines the energy consumption, i.e. countries with a high share of the chemical process and/or bleached pulp are likely to cover their energy needs with non-purchased energy. Even if chemical pulp and bleaching operations are very energy intensive, this does not means that the energy consumption reported in the yearbooks (see, e.g., [10] and [11]) must necessarily be higher, because they may not have an impact on purchased energy. This structure may also be reflected in the energy-mix if comprehensive data are available, as mechanical pulp demands mostly electricity, and chemical pulp demands heat.

The pulp making from waste paper goes first through a preparatory stage, where the remaining ink and glue are removed, and the fibers that form the paper are dispersed again. The treatment of the pulp thus obtained is then similar to that of pulp obtained from wood. The preparatory operations require overall much less energy than the preparation of fibers obtained directly from wood. The total energy requirements depend on the quality of waste papers, on how much ink and glue must be reoved, on how difficult this process is, etc. OCED ([13]) gives an average estimate of 300 to 400 kWh per ton for pulp produced from waste paper when 1 ton of wood pulp requires 1000 to 2200 kWh.

The Paper Making Process

It is possible that pulping and paper making operations are carried out in the same mill, e.g. in the case of integrated production plants. This also effects the level of energy consumption. In case of an integrated production, possible steam surpluses may be used in the paper making process, and an integrated mill will an any case demand less energy for the total process (from pulp to paper) than the combination of a pulp mill and a paper mill. In the case of non-integrated processes the pulp has to be dried, transported to the paper mill, and rewatered there for further treatment. If the operations are integrated,the slush pulp is immediately directed to further processing.

Paper making consists of a series of mechanical and thermal operations. In one of the intermediary operations the pulp is treated mechanically so that the fibers meet certain requirements (beating process). According to [13], this is the largest energy-consuming operation.

II. ENERGY CONSUMPTION

The pulp and paper sector is an energy consumer, an energy producer, and an energy seller. The study of the energy consumption of this sector is based on data provided by OECD ([13]) and, for the American sector, by the American Paper Institute ([9]).

Purchased Energy

These data are the best known data as far as international or national statistics are concerned. International comparisons can be made on the basis of time series from [13] and [11]. The data given in Table 8 correspond in general to the level of production of pulp and paper by countries (see Tables 2 and 3), but the industry has its country-specific characteristics of energy supply and thus the shares of each energy carrier are very different from one to another (Table 9). The assessment of total energy consumption is furthermore rendered difficult by the fact that the choice of the conversion coefficients influences the determination of the aggregate. If the conversion coefficients of OECD are applied, electricity is accounted on the based of 1 GWh = .086 toe, while the alternative conversion factor is .222. This consideration is important when comparing countries with dominant hydro-electricity, such as Norway, with others.

On the basis of the OECD coefficients ([13]) one may observe a rather low electricity input in the majority of countries, but the general tendency was toward electricity in the 1970s.

Table 8. Energy consumption (in million toe).

Year	USA	FRA	FRG	UK	NOR	SWE
1970	-	1.87	-	2.56	.93	2.97
1975	22.62	1.79	2.42	-	.67	2.41
1978	24.39	2.00	2.75	2.00	.66	2.85
1981	24.12	1.80	2.77	1.43	.66	2.78

Table 9. Purchased energy: share of energy carriers.

Country	Year	Elec-tricity	Oil	Coal	Gas	Others
USA	1972	8.7	30.0	20.2	37.8	3.3
	1977	11.9	35.1	21.2	22.0	2.8
	1981	14.7	19.6	24.9	38.7	2.0
FRA	1970	11.2	61.7	17.6	9.6	0
	1977	13.9	70.6	2.7	12.8	0
	1981	15.2	60.1	2.6	22.1	0
FRG	1973	5.5	70.0	10.3	14.2	0
	1977	7.1	60.6	7.9	24.4	0
	1981	11.9	50.8	10.1	27.2	0
UK	1970	5.9	40.5	52.9	0.1	0.6
	1977	8.9	34.6	19.7	33.1	3.8
	1981	13.5	31.5	19.3	32.6	3.1
NOR	1970	33.5	66.5	0	0	0
	1977	37.3	62.7	0	0	0
	1981	41.7	58.3	0	0	0
	1984	51.0	49.0	0	0	0
SWE	1972	31.8	64.3	0.1	0	3.7
	1977	37.8	56.6	0.1	0	5.5
	1981	41.9	49.6	0.5	0	8.0

The share of coal declined everywhere except in the USA, and the share of gas rose tremendously in the United Kingdom.

Since paper and paperboard are the final products, the energy coefficients can be expressed as the ratio between the energy consumption and total paper and board production. This coefficient, calculated on the basis of purchased energy, is decreasing in all countries (Table 10).

Table 10. Energy coefficient I: purchased energy in paper and paperboard production (in toe/ton).

Year	USA	FRA	FRG	UK	NOR	SWE
1975	.5038	.4358	.4583	-	.6888	.5391
1981	.3989	.3492	.3552	.4237	.4775	.4477

In 1975 there were large differences in the level of this coefficient; in 1981 the figures are closer to each other. Every country has experienced a decrease of the coefficient. Energy consumption figures are not available for 1975 for the United Kingdom, but between 1972 and 1981 its coefficient decreased by 37%, as against 31% for Sweden and 29% for the USA.

Yet another energy coefficient can be considered. Instead of using only the finished product as a denominator, we can take the whole 'pulp and paper' operation and divide the energy consumption by the added production of pulp and paper. This raises some homogeneity problems, but since it is a continuous process, and since some countries produce pulp in order to sell it (Norway and Sweden), whereas some import pulp to produce paper (United Kingdom), one can consider the industry as a whole with two different but aggregated products, pulp and paper.

Table 11. Energy coefficient II: purchased energy per ton of pulp, paper, and paperboard.

Year	USA	FRA	FRG	UK	NOR	SWE
1975	.2768	.3053	.3354	-	.2818	.1871
1981	.2239	.2591	.2821	.4036	.2205	.2199

Except for Sweden, the coefficients are again decreasing. As far as the levels of coefficients are concerned, those of Sweden and Norway decrease sharply when pulp is taken into account, and the two countries have now the lowest energy coefficients. The United Kingdom appears more isolated, making evident the specific structure of its industry (pulp production is marginal).

Both of the above coefficients have obvious deficiencies, but it seems that the aggregate (pulp, paper and paperboard) is a better denominator for the analysis than the final product alone. In Table 11 one does not observe two groups of countries with such different energy coefficients as given in Table 10 for the year 1981, but only one exception, i.e. the United Kingdom.

It is possible to use unequal weights for the aggregated products because energy inputs are different, but before doing so one must get a magnitude of differences in non-purchased energy use, because, as was said before, the pulp and paper sector is also an energy producer. Self-generated energy will be considered first.

It is not precisely indicated what this self-generated electricity exactly refers to. We have seen in the first part that during the production process both steam and electricity could be generated both by purchased and non-purchased fuels, and there is a danger of double-counting energy inputs if co-generated electricity is included in the figure of self-generated electricity. On the other hand, if this self-generated electricity refers to hydropower[5] (as mentioned by API ([9])), or electricity generated by fuels not accounted for in the energy balances, it has to be added to the other energy consumption figures.

The importance of self-generated electricity varies greatly according to country, but has been generally decreasing.

Table 12. Ratio of self-generated/purchased electricity.

Year	USA	FRA	FRG	UK	NOR	SWE
1972	-	0.82*	2.75*	1.36	0.03	0.40*
1977	0.95	0.64	2.18	1.05	0.06	0.27
1981	0.70	0.64	1.24	0.52	0	0.20

*1973 data.

One will notice the correlation between the electricity figures in Tables 9 and 12. Countries where purchased electricity plays an important role (Norway and Sweden) have a relatively low share of self-generated electricity.

Energy from Waste Products

Not all countries provide figures on their energy sources. For this reason we will only discuss here the USA, the FRG, Sweden, and Norway (Table 13).

[5] In the OECD study ([13]) hydromechanical power is included in non-purchased fuels. Therefore one can assume that the rest of the self-generated electricity is produced either with purchased or non-purchased fuels, and thus needs not be added to the other fuels in order to get the total energy consumption.

Table 13. Consumption of non-purchased energy (in million toe).

Year	USA	FRG	NOR	SWE
1973	21.62*	0.18	0.08	2.71
1976	23.37	0.22	0.08	2.63
1981	27.27	-	0.12	2.61

*1972 data.

Adding up these energy inputs with the figures on purchased energy (Table 8) we came to the conclusion that for the USA and Sweden the energy input estimated on the basis of purchased energy is underestimated by a factor of 2 (Table 14).

Table 14. Share of non-purchased energy in total energy consumption (%).

Year	USA	FRG	NOR	SWE
1973	44.55*	5.61	7.75	48.11
1976	48.77	7.24	8.33	52.61
1981	53.07	n.a.	15.91	48.38

*1972 data.

For the USA and Sweden the role of waste fuels is fundamental and one can generally observe a growing share of self-generated energy. Inside this category the most important energy carrier is spent liquor, i.e. 80-90% of the non-purchased energy, which is consistent with the technological characteristics reviewed in the first section. Hydro-mechanical power plays a quasi-negligible role, except for the FRG (7%), and wood residues are above 10% in countries with large forests (USA, Norway, Sweden).

The two countries where non-purchased energy is very important (the USA and Sweden) evidently have a dominant share of the chemical process (73% of woodpulp in Sweden, 80% in the USA (see Table 6)). On the other hand, the two other countries in the sample (Norway and the FRG) rely more heavily on the mechanical process (58% of woodpulp in Norway and Germany), which gives fewer opportunities for energy recovery.

The levels of the energy coefficients calculated on the basis of these data (Table 15) for the USA and Sweden are close to each other, and so are their production structures (share of each process, importance of waste paper, share of bleached pulp,etc.), and their trends are also similar. Energy inputs in Norway and the FRG are at a sensibly lower level. Some elements in the structure of the sector explain this fact: both countries have a dominant share of mechanical pulp, and a smaller part of the pulp is bleached compared to the two other countries (Table 7); the low coefficients of the FRG may also be explained by the more important share of waste paper, which is 48% in the FRG and only 5% in Norway (Table 5).

Table 15. Energy coefficient III: purchased and non-purchased energy consumption in paper and paperboard production (in toe/ton).

Year	USA	FRG	NOR	SWE
1972	0.948265	-	0.721595	-
1973	- (n.a.*)	0.4853	0.698555	-
1974	-	0.4622	0.65106	-
1975	0.95104	0.4914	0.75684	-
1976	0.928026	0.4627	0.715885	-
1977	0.914754	-	0.641057	0.995742
1978	0.924543	-	0.600484	0.94086
1979	0.854461	-	0.534229	0.954188
1980	0.845182	-	0.575355	0.92454
1981	0.840868	-	0.567771	0.863823
1982	-	-	0.57364	-

*n.a. - not available.

An analysis of the alternative energy coefficient, where the denominator includes both pulp and paper production (Table 16) shows that in general the levels of energy inputs are closer between countries, and a moderate decrease becomes evident.

Table 16. Energy coefficient IV: energy consumption per ton of pulp, paper, and paperboard production (in toe/ton).

Year	USA	FRG	NOR	SWE
1972	0.531408	-	0.288507	-
1973	- (n.a.*)	0.381436	0.282767	-
1974	-	0.36091	0.260749	-
1975	0.522592	0.381076	0.309592	-
1976	0.501963	0.362449	0.297182	-
1977	0.496463	-	0.282113	0.396229
1978	0.498178	-	0.280346	0.376239
1979	0.482934	-	0.255437	0.390084
1980	0.475709	-	0.275536	0.384081
1981	0.471951	-	0.261506	0.364067
1982	-		0.26471	-

*n.a. - not available.

The FRG and Sweden are close to each other, but the years considered are different for each country; the USA has the highest level of coefficients, and Norway the lowest. The gap between these last two countries is in the order of 70%, which is partly explained by the 'energy-intensive' structure of the USA (energy-intensive products and processes), but this is only part of the explanation, since Sweden has a somewhat similar structure to the US production and a lower energy coefficient. The gap may also be explained by the level of modernity, and one can thus assume the 'energy efficiency' of the USA to be lower than that of Norway and Sweden. One must also bear in mind that the particular coefficient chosen here aggregates both pulp and paper production with equal weights, and thus gives an 'advantage' to countries that produce pulp without further processing, i.e. relative to the other coefficient (energy/paper). One may finally include in the analysis of 'energy coefficient IV' data for the United Kingdom (Table 14). If, following [7], we consider the non-purchased energy of this country negligible, the 'energy coeffcient II' for the United Kingdom can be compared to the 'energy coefficient IV' for other countries (Table 16), and one also notices that for the last years the United Kingdom has a coefficient comparable to that of Sweden and the USA. As mentioned in [13], the United Kindgom has closed important capacities after 1978-79 in plants where the energy efficiency was the lowest, and it seems that after these closures the energy coefficients of the United Kingdom have not been as high as they were before.

III. THE ENERGY COEFFICIENTS

The energy coefficients analyzed above represent aggregated levels of energy consumption of the pulp and paper sector. At this level of the analysis, their cross-country comparison expresses the main differences in the structure of the sector, and in particular one difference, which was the consequence of the definition of the coefficient itself: the more pulp a country produces, the larger is the energy coefficient likely to be.

On the basis of the existing literature it is possible to go further into detail and try to find out what the energy coefficients are for different products and processes. The sources are, on the one hand, American publications such as [12], or estimates for the Swedish pulp and paper industry given in [14]. It is possible to get estimates of the average energy consumption figures, but a reconstructuion of the total energy consumption of the sector raises two problems:

-- these estimates are valid for a specific year, and the energy requirements for each product and technology are likely to change over time;[6]

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[6] See [13], [12], and [5].

-- the cosen products and technologies for which energy consumption estimates exist may not be consistent with the aggregated data given in sources such as [3]. An important difference is made between integrated and non-integrated mills; this difference is not visible in the production data given in [3].

Apart from these problems, the determination of an energy coefficient meets with the usual difficulties in every sector: real engineering data would distinguish consumption figures according to each type of energy, each technology used, and each accurate stage of the production process, whereas a figure given in toe per ton mixes different quantities supplied by different energy carriers (problems of the conversion coefficients), and different types of paper or pulp produced under different conditions.

In the following an attempt was made to reconstruct the aggregated energy consumption figures of the pulp and paper sector, starting from a 'product-mix' point of view. It must be mentioned that important aspects are left aside, such as the share of integrated mills in total production and their effects in lowering energy demand, the level of maturity of plants, and the problem of plant closures (the closure of plants was an important factor of decrease of the energy consumption in the United Kingdom after 1979), etc.

On the basis of the data given in [12] we have chosen lower and upper limits of energy coefficients for each product, giving a reasonably reliable range for each energy requirement. It is possible that for a specific country and a specific product an energy coefficient lies outside the adopted limits, but it is very unlikely that, taken as a set, the energy coefficients chosen are unrealistic.

Table 17. Lower and upper limits of the energy coefficients (in toe/ton).

Product	Lower limit	Upper limit
Pulp		
Bleaching of pulp	.21	.24
Semi-chemical pulp	.31	.31
Chemical pulp	.40	.47
Mechanical pulp	.33	.35
Waste paper pulp	.07	.09
Paper		
Newsprint	.26	.31
Printing paper	.31	.40
Household, tissues	.32	.42
Wrapping paper	.31	.38
Other paper and board	.27	.31

Each set of coefficients gives a reconstructed figure for the sector's energy consumption. The energy consumption obtained with the lower limits of each energy coefficient will be called reconstruction (1), and the energy consumption corresponding to the upper limits of these coefficients will be called reconstruction (2).

Comparisons between reconstructed figures and actual figures of energy consumption can be made for five countries. For the USA, Sweden, Norway, and the FRG, the energy consumptions for both purchased and non-purchased energy are given in [13]. For the United Kingdom one may assume that the share of non-purchased energy is negligible, as is stated in [7], which is not surprising in view of the particular structure of the sector. Therefore the purchased energy consumption may be taken for the total energy consumption.

The energy consumption figures, reconstructed and actual, are given in Table 18.

The lower limits of the coefficients have been adopted for Sweden, Norway, and the FRG, the upper limits fit better for the United Kingdom and the USA.

The estimates for the FRG are not too far from the actual figures, but comparisons can only be made for earlier years (1973-76) than for the other countries. The estimated consumption figures for Sweden are quite good compared to the actual figures; they are close to the real consumption figures and reflect the ups and downs of the years 1977/1979/1980, which emphasizes the 'product-mix' effect on energy consumption. The figures obtained for Norway are not satisfactory with regard to the value of the reconstructed energy consumption; despite having used the lower limits of the coefficients, the reconstructed energy consumption is still 20% above the actual consumption. However, the tendency of the two sets of energy consumption figures is the same: a decrease from 1976 to 1979 and stagnation until 1982, which reveals that the relative values of the energy coefficients are correct, but their absolute value for Norway seems to be 20% too high. The reconstructed energy consumption figures for the USA are very close to the actual figures for the years 1979, 1980, and 1981, but the difference between the two sets of energy consumption figures is around 10% for 1975 and 1977. Exactly the same applies also to the United Kingdom.

On the whole, the estimation of energy consumption figures with fixed energy coefficients gives satisfactory results, both on the level of the energy consumption (with the exception of Norway) and its evolution over a few years. It is, however, not possible to say that all important 'structure' effects have been duely considered. Furthermore, the comparisons are made over a few years, and it shows that the energy consumption is generally above the reconstructed figures at the beginning, and below them at the end, which means that there is a

Table 18. Reconstructed and actual energy consumption figures (in million toe).

Year	USA Reconstruction	USA Actual	FRG Reconstruction	FRG Actual	UK Reconstruction	UK Actual	NOR Reconstruction	NOR Actual	SWE Reconstruction	SWE Actual
1973	-(n.a*)	-	2.60	3.12	-	-	-	-	-	-
1974	-	-	2.68	3.03	-	-	-	-	-	-
1975	37.22	42.70	2.18	2.58	-	-	-	-	-	-
1976	-	-	2.81	2.96	-	-	1.10	0.90	-	-
1977	44.95	48.29	-	-	-	-	-	-	5.12	5.04
1978	-	-	-	-	1.80	2.00	-	-	-	-
1979	48.77	50.33	-	-	1.92	1.92	0.96	0.75	6.16	5.99
1980	49.71	50.25	-	-	1.72	1.75	0.95	0.79	5.90	5.72
1981	50.71	50.84	-	-	1.52	1.43	1.01	0.78	5.92	5.37
1982	-	-	-	-	-	-	0.96	0.75	5.45	5.36

*n.a. - not available.

'decrease of the energy coefficients' independent of the 'product-mix' changes. A few indications of what the other explanations of the energy consumption may be are given by the British case: At the end of the 1970s and the start of the 1980s there have been essential plant closures (see [13]), whose result was to increase the energy efficiency of the sector. Indeed, a comparison of the reconstructed and actual energy consumption figures for the United Kingdom for the years around 1970 would not be interesting, the energy efficiency of the sector being at the time well below other countries' standards.

We may extend the exercise to a country where the actual energy consumption is not available, as, e.g., to France, in order to estimate the non-purchased energy consumption. We then apply the lower limits of the energy coefficients to France; the results are given in Table 19.

Table 19. Estimation of non-purchased energy for France.

Parameter	1978	1979	1980	1981
Reconstructed consumption	2.53	2.56	2.50	2.50
Actual purchased energy consumption	2.00	2.00	1.94	1.80
Estimation of the share of non-purchased energy in reconstructed consumption	21%	22%	22%	28%

The lower limits were preferred to the upper limits, considering that European countries (except for the special case of the United Kingdom) seem to have a better energy efficiency than the United States. We then come to an estimated share of non-purchased energy approximately equal to 20%, which is intermediary between the FRG and countries like Sweden, and seems consistent with the structure of the French pulp and paper industry.

CONCLUSION

Comparisons of energy consumption figures calculated with our estimated coefficients and actual energy consumption figures do not lead to major inconsistencies and thus may be considered acceptable estimations of the energy coefficients. It is possible, with these estimated coefficients, to make obvious the effects of change in the product mix, as well as changes in the pulping process in total consumption. Some factors are left aside, especially the share of integrated mills, which is an indicator of the level of energy efficiency of the sector. This factor certainly explains a large part of the range between the upper and the lower limits of the energy coefficients, and even the low level of the energy coefficients for Norway.

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