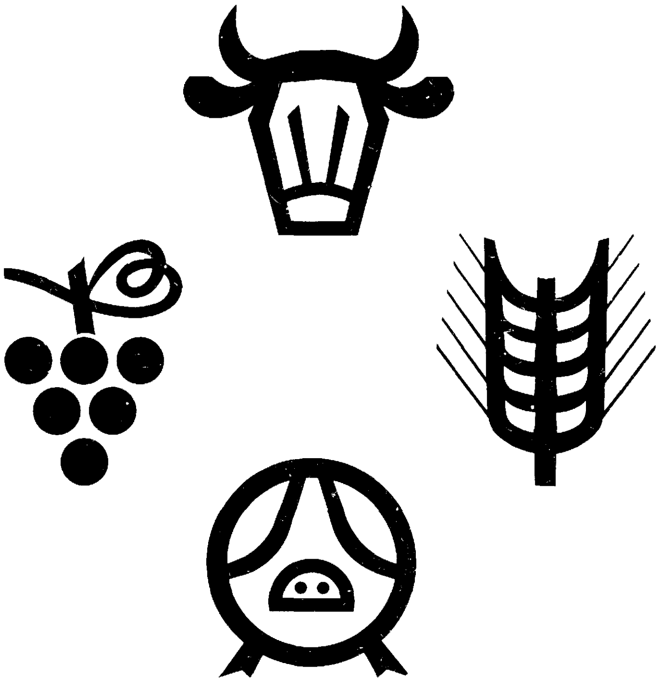
COMMISSION OF THE EUROPEAN COMMUNITIES

Information on agriculture

Energy consumption per tonne of competing agricultural products available to the EC



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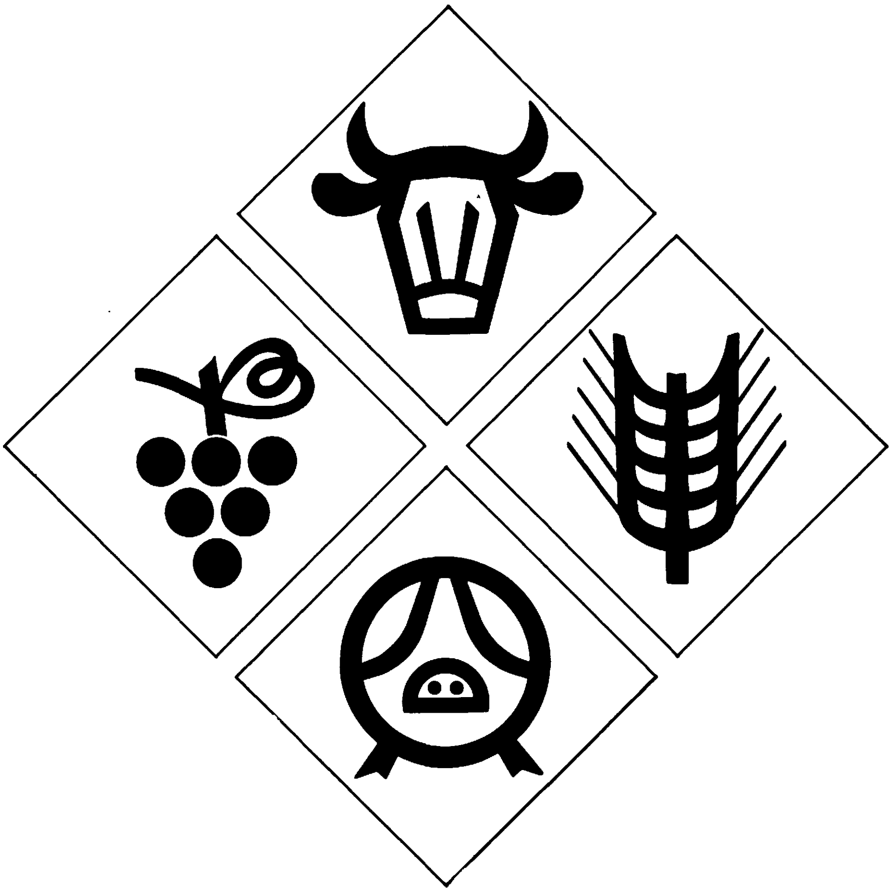

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FOREWORD

This study has been undertaken in the framework of the study programme of the Directorate General of Agriculture of the Commission of the European Communities.

The report was prepared by Dr. M. Slesser and F. Wallace of the Energy Studies Unit of the University of Strathclyde, Glasgow, Scotland.

The Division "Reports, studies, statistical information, documentation" of the Directorate-General for Agriculture participated in the work.

Original language : English

The present study does not necessarily reflect the views of the Commission of the European Communities in this area and in no way anticipates the Commission's future attitude towards this matter.

CONTENTS

Page

UNITS

t : metric tonne
kg : kilogram
ha : hectare
kwh : kilowatt-hour
J : joule
MJ : megajoule = 10^6 J
GJ : gigajoule = 10^9 J
GER : gross energy requirement
TOE : tonne of oil equivalent

EXECUTIVE SUMMARY

Energy Use in European Agriculture By Product

This study, initiated by DG VI, ascertains the energy intensity of the European Community's agriculture by product, and compares it with countries exporting, or potentially able to export, to the European Community.

It is clear that while modern European agriculture is energy intensive, for comparable yields per hectare, it is not more so than other countries. In fact, to the farm gate, European agriculture consumes rarely more than 4% of national energy consumption, even taking into account indirect energy involved in creating the inputs to agriculture. An exception is Denmark, a country with large imports of energy intensive animal feedstuffs.

Data have been collected on 26 crops in 22 countries. It confirms that intensification of agricultural output is necessarily accompanied by intensification of inputs, which when quantified in terms of the energy used to create them reveals that the ratio of energy resources expended to the metabolisable energy produced steadily rises as intensification proceeds. For example, to produce 10 GJ of metabolisable energy from one hectare (e.g. 725 kg wheat) requires (on average) inputs whose energy requirement of production totals 6 GJ - an energy ratio of 1.66. A more intensive agriculture system which produces 20 GJ/hectare (e.g. 1450 kg wheat) requires inputs equivalent to 18 GJ, an energy ratio of 1.1. A high level of intensification to yield a 100 GJ/hectare requires an energy input of 120 GJ, an energy ratio of 0.8. There seems no escape from this fact, though by appropriate use of farm wastes this relation can be weakened.

However, many overseas territories, having low population densities, can, if they wish, produce food at low intensities, and hence for lower energy requirements. Examples are Argentinian wheat and New Zealand mutton. Yet a true comparison must take into account the energy of transport. In general it is found that imported meat or meat products from America (South and North) and Australasia are less energy intensive than European products, though some European production is of a low production intensity and hence of low energy intensity.

When it comes to dairy products, European producers are no more energy intensive than those overseas, while for cereals, the difference once energy for transport has been added, is negligible. As for refined sugar, that produced from European sugar beet is actually less energy intensive than US sugar, and comparable to that from other overseas producers.

Thus, there seems no case for substituting imported foodstuffs for European products upon an energy basis. Indeed, as the world's population grows, pressure to increase food output must inevitably push up the intensification of those countries with currently low productivity systems, so that on an energy basis the trend is moving in Europe's favour, especially given Europe's low population growth.

1. INTRODUCTION

The massive step change in the price of oil by the OPEC cartel in 1973 induced many policy makers to look critically at how industrialised economies used their energy. One fact which quickly came to the fore was that the industrialised countries had achieved their high productivity in agriculture by using substantial amounts of energy, (Fig.1). In fact, for every unit of metabolisable energy provided in the resultant food, often one unit or more of fossil energy had been consumed on the farm and in the supporting agro-industries. Those living in the industrialised countries were literally eating fossil energy. More importantly, about half that fossil energy was oil and gas, whose price for the meantime was outside the control of the industrialised world and the supply of which now seemed all too finite, even in the medium term. Tables 1 and 2 give an impression of these facts.

Even a cursory look at these two tables raises a number of questions. Can the European countries continue to produce food at such a high energy requirement? Is a high energy intensive agriculture inevitable? Are there other strategies that could be adopted; for example, importing food from those parts of the world which can produce food less intensively?

This report was commissioned to answer the last question. In passing, some conclusions may be formed of the other questions.

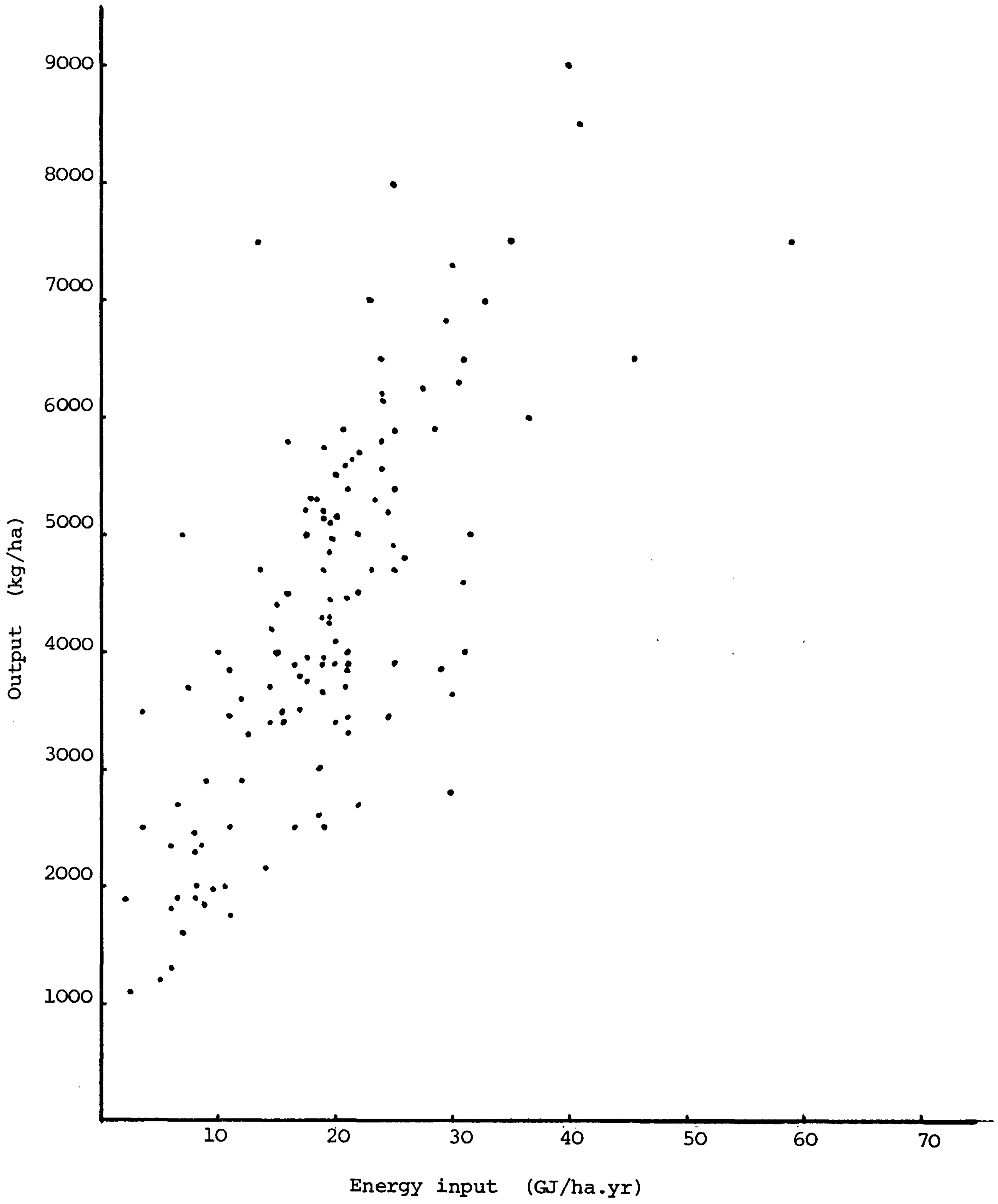


Fig.1 Plot of yield versus energy inputs for various cereal crops

TABLE 1 Gross Energy Requirement to produce typical temperate foodstuffs

Product	Country	Intensity kg/ha	$^{+}$GER GJ/t	Energy Ratio*
Beef (low intensity)	New Zealand	840	5.7	2.4
Barley	Spain	2300	7.3	1.9
Rice	Australia	7500	1.8	8.5
Rye	Canada	1600	6.9	2.0
Peas	France	11000	1.9	1.1
Pork	U S A	1000	33.1	0.6
Carrots	U K	31300	0.9	1.1
Potatoes	Netherlands	45000	1.3	2.4
Wheat	Saskatchewan, Canada	1514	1.6	8.7
Rye	Spain	1096	7.6	1.8
Maize	Germany	5647	3.7	1.1
Tomatoes	California, USA	49616	1.4	0.6
Beef	U S A	1000	76.4	0.2
Peas	New Zealand	4500	4.7	0.5
Oats	France	1500	7.2	2.0
Sugar beet	Belguim	51000	0.5	4.7
Tomatoes (Glasshouse)	U K	250000	160.2	0.01
Wheat	N Victoria, Australia	5000	1.4	9.8
Barley	Germany	4408	4.5	3.2
Pork	New Zealand	900	31	0.7
Milk (intensive)	France	2000	6.4	2.3
Lamb	U K	477	65.6	0.2
Barley	Denmark	4300	4.5	3.2
Peanuts	Georgia, U S A	3724	12.3	1.4
Potatoes	U K	17900	2.0	1.6

* $\frac{\text{Output (metabolisable energy)}}{\text{Input (fossil/fissile energy)}}$

\+ GER = Gross Energy Requirement

TABLE 2 **Direct Energy Use in European Agriculture to the "Farm Gate"**

Eurostat : Energy Statistics - Yearbook 1969-1973, 1973-1977

Country	Petroleum Products 1000 TOE				
	1969	1971	1973	1975	1977
Germany	1207	1310	1300	1320	1250
%	22	22	22	21	20
France	2443	2431	2845	2861	2868
%	64	67	42	37	39
Italy	1141	1709	1747	1854	1945
%	33	41	40	38	41
NL	332	286	336	281	303
%	17	14	15	12	13
Belgium	350	358	383	283	342
%	31	29	49	24	42
Luxembourg	13	11	12	4	13
%	62	52	52	27	52
U K	1325	1468	1561	1380	1383
%	46	46	21	20	20
Ireland	118	165	185	NA	NA
%					
Denmark	626	800	1134	934	1064
%			58	56	78

NOTE : Petroleum products are the only category of direct energy inputs recorded for the agricultural sector from Eurostats.

$$\% = \frac{\text{direct petroleum products in energy units}}{\text{total direct energy in European Agriculture and the Food, Drink and Tobacco Industries}}$$

TOE = Tonnes of Oil Equivalent

TABLE 2 contd

Direct Energy Use in European Food, Drink and Tobacco Industries

Eurostat Energy Statistics - Yearbook 1969-1973, 1973-1977

Country	Petroleum Products - 1000 TOE					Natural Gas - 1000 TOE					Electricity - 1000 TOE+				
	1969	1971	1973	1975	1977	1969	1971	1973	1975	1977	1969	1971	1973	1975	1977
Germany	2428	2725	2758	2766	2664	83	218	374	489	568	1010	1115	1245	1351	1426
%	45	46	46	44	43	2	4	6	7	9	19	19	21	22	23
France	NA	NA	2537	3013	2841	56	100	167	220	267	751	881	1039	1115	1263
%			37	42	38	1	3	2	3	4			15	15	17
Italy	1261	1300	1367	1445	1223	304	355	389	598	619	705	774	859	850	918
%	36	31	31	30	26	9	8	9	12	13	20	18	19	18	19
NL	799	542	295	228	212	351	822	1123	1208	1294	366	431	508	515	615
%	42	26	13	10	9	18	39	49	54	53	19	20	22	23	25
Belgium	480	546	6	411	9	5	8	70	128	117	220	257	295	314	343
%	43	45	0.8	36	1	0.4	0.6	9	11	14	20	21	38	27	42
Luxembourg	-	-	-	-	-	-	-	-	-	-	7	9	10	11	12
%	-	-	-	-	-	-	-	-	-	-	33	43	43	73	48
U K	NA	NA	2734	2292	2216	9	143	555	884	1037	1413	1484	1653	1651	1729
%			36	33	32	0.3	4	7	13	15			22	24	25
Ireland	NA	NA	NA	NA	NA	-	-	-	-	-	-	-	-	169	186
%						-	-	-	-	-	-	-	-		
Denmark	NA	NA	621	525	2	-	-	-	-	-	-	-	193	195	261
%			32	31	0.1	-	-	-	-	-	-	-	10	12	19

$$\% = \frac{\text{direct petroleum products/natural gas/electricity/ in energy units}}{\text{total direct energy in European Agriculture and the Food, Drink and Tobacco Industries}}$$

$$+ \quad \frac{\text{thermal equivalent of electricity}}{\text{efficiency of generation}}$$ (conversion factors from Eurostats)

NOTE: Balance of % is other energy forms, including coal, coke, refinery gas and L.P.gas

2. Energy in the food producing sector of the EEC

The countries of the Community (9), although using substantial quantities of energy for food production to the farm gate, do not use a great percentage of their national energy for that purposes. A typical figure would be 4%, (Table 3). These figures are such a small percentage of national energy consumption that before denying or limiting energy to the agricultural sector, one would naturally look to other sectors for energy economies. One of these is food processing, which uses about three times as much energy to take food from the farm gate to the market place, (Table 4).

A product by product study might reveal that some crops grown within the European environment are unnecessarily wasteful of energy, and might be better grown elsewhere. In this report the energy requirements for growing temperate crops in Europe, in countries exporting to Europe, and in countries potentially able to export, have been compared. These data form the substantive part of this report.

3. Is a high energy intensive agriculture inevitable?

It is known that by the judicious recycle of agricultural wastes, especially when coupled to appropriate biotechnologies, the energy requirements for on-farm production may be substantially reduced. This may be achieved by recycle of animal wastes, thus reducing synthetic fertiliser needs, and by producing biogas, thus producing both an energy source and a natural fertiliser, (1) (2). However these activities may increase the labour requirement of the farming activity, require additional capital, and are sensitive to the ambient temperature. The net energy of such additional systems may be zero or even negative in the colder periods of the year or in northern climates.

Whatever the means of obtaining higher yields, the economic pressure to obtain those yields is very great. In the first place there is a rising population spread upon a finite area of land. Thus in a global sense output per hectare must rise. Secondly land is being taken out of agriculture by needs of industry and housing. Thirdly, rising incomes have created an added demand for high quality protein, which typically as meat, requires up to ten times as much land per unit of metabolisable energy as cereal crops. On top of this land values have continually risen, pushed not only by the forces of demand for land for construction, but also as a hedge against inflation. Such factors contrive to create an economic environment in which more food must be produced per hectare simply to remain in business, and in relation to the food producing needs of the community. To the farmer the energy costs of intensification have, until recently, been small in comparison to the benefits of higher yields. However, energy inputs are associated with significant investment in equipment, equipment that begs to be used even as energy prices continue to rise.

Thus, short of a significant change in Community CAP and in the law of land ownership and use, we may say that high intensity agriculture is here to stay. The question is whether it need be high energy intensity agriculture. That in turn will depend on what progress may be made in introducing biotechnologies into the agricultural process, and what import choices there are. One of the motivations for this study was a need to know whether food importation was a desirable option for European consumers.

A vivid picture of the intensification of European agriculture through time may be had from the work of Weber, (3), as depicted in Figs.2 & 3, for Germany.

4. Importation of food into EEC (9)

The common Agricultural Policy aims to protect the European food producer. In essence, European farmers inheriting a finite land area, are given the chance to intensify the output from that land by buying in energy (as fuels, fertilisers, pesticides, etc.) and feed, some of which in turn are the products of systems of farming in other countries, which may also be energy intensive. In a search for a rational policy, it is essential to know both the energy intensity of Community agriculture and that of countries exporting to, or potentially able to export to, the Community. In the terms of the contract which led to this report, a specific request was made that this information be expressed by commodity, for each country of the Community and for a number of exporting countries. Appendix 1 lists the foodstuffs requested by DG VI.

Table 5 notes selected imports to the EEC, where in 1979 they were greater than 0.01% of EEC domestic use. Table 6 gives the national production of these items.

TABLE 3 - Energy Use in European Agriculture to the Farm Gate : Direct and Indirect

Country	Indirect Energy		Direct Energy		Direct + Indirect % National Use
	1000 TOE	% of National Energy Use	1000 TOE	% of National Energy Use	
Belgium (1975)	549.6	1.3	974.4	2.4	3.7
Denmark (1974/75)	1388.7	7.8	1140	6.4	14.2
France (1977)	6200	3.5	5035	2.9	6.4
Germany (1978)	4417	1.6	4238	1.6	3.2
Ireland	-	-	-	-	-
Italy (1974)	3856	2.9	2613.6	1.9	4.9
Luxembourg	-	-	-	-	-
Netherlands (1978)	not available		3570	5.4	-
UK (1978)	5107	2.4	1628	0.8	3.2

OECD Working Party No.1 of the Committee for Agriculture (Agricultural Policies).
The Energy Problem and the Agro-Food Sector, Paris, drafted 8th May 1981
EUROSTATS ENERGY STATISTICS YEARBOOK 1973-1977
"   "   "   " 1978.

TABLE 4 - Energy Requirements to the Farm Gate and from Farm Gate to Market Place

	Production to Farm Gate (GJ/t)	Transport, Processing and Distribution(GJ/t)
Pigs - carcass	41.4	52.4[a]
- deboned meat	44.2	62.5[a]
- jointed pork (wrapped)		26.6[b,c]
- smoked and cooked joints		124.6[b,c]
Cattle - carcass	52.6	32.2[a]
- deboned meat	70.6	43.3[a]
- beef pies (34% meat)		38.6[b,c]
- factory roasted beef (wrapped)		554.3[b,c]
Standard Bread	4.02 (wheat)	10.78 (bread)
Butter	19.9 (butter)	9.9 (butter)
Powdered Milk	10.0 (powder)	19.0 (powder)
Green Peas - canned	2.4	10.39
- frozen	2.4	11.36
Potatoes - fresh	0.95	2.38
- frozen chips	0.95	8.45
- dehydrated	0.95	8.56
Sugarbeets - as sugar	0.47	3.68
Apples - fresh	2.16	5.11
- juice	2.16	2.58
- apple sauce	2.16	7.67

(a) Includes energy input for slaughtering. (b) Product as sold
(c) Figure represents energy input incurred in operations in meat factories leading to production of items of food.

Data are taken from sources forming Appendix 5.

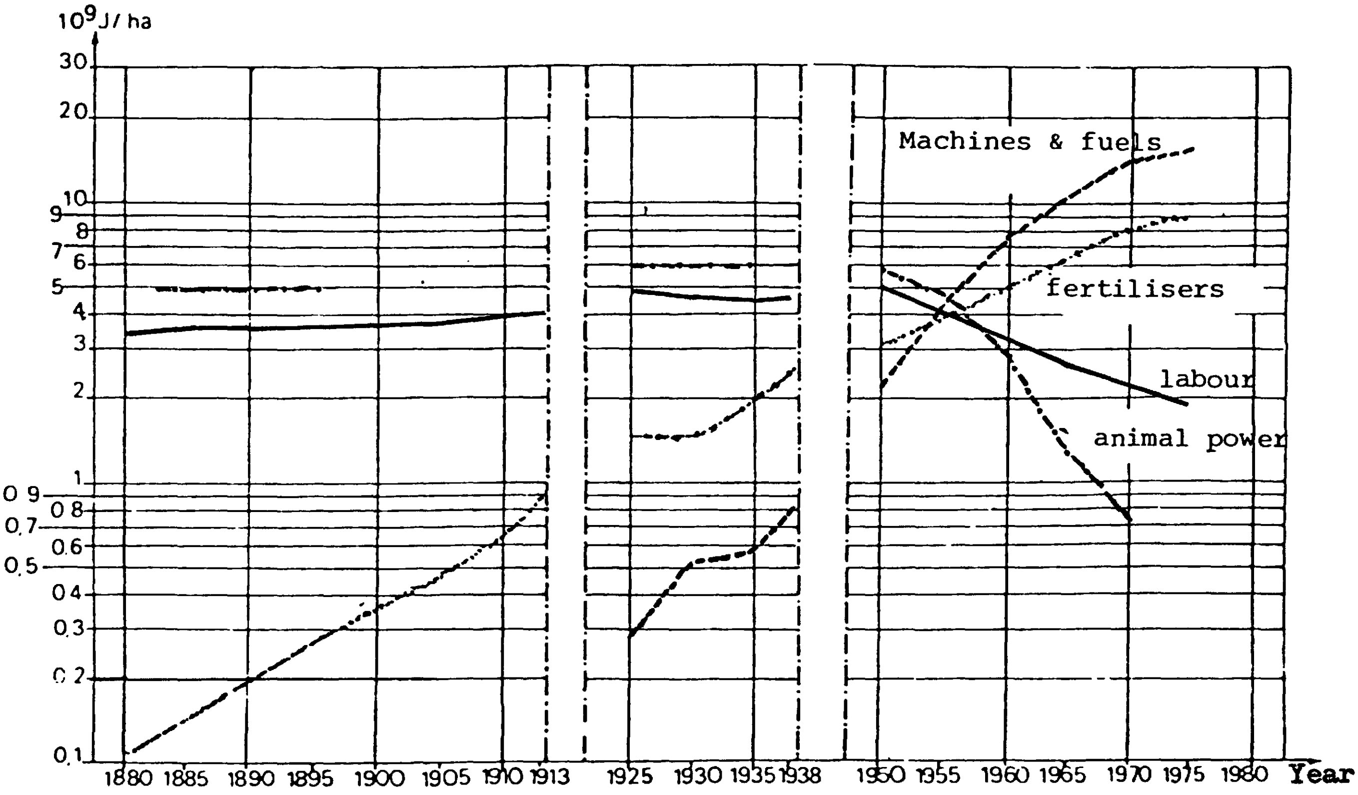


FIG. 2 Energy intensity of German agriculture 1880-1976 (Weber (3))

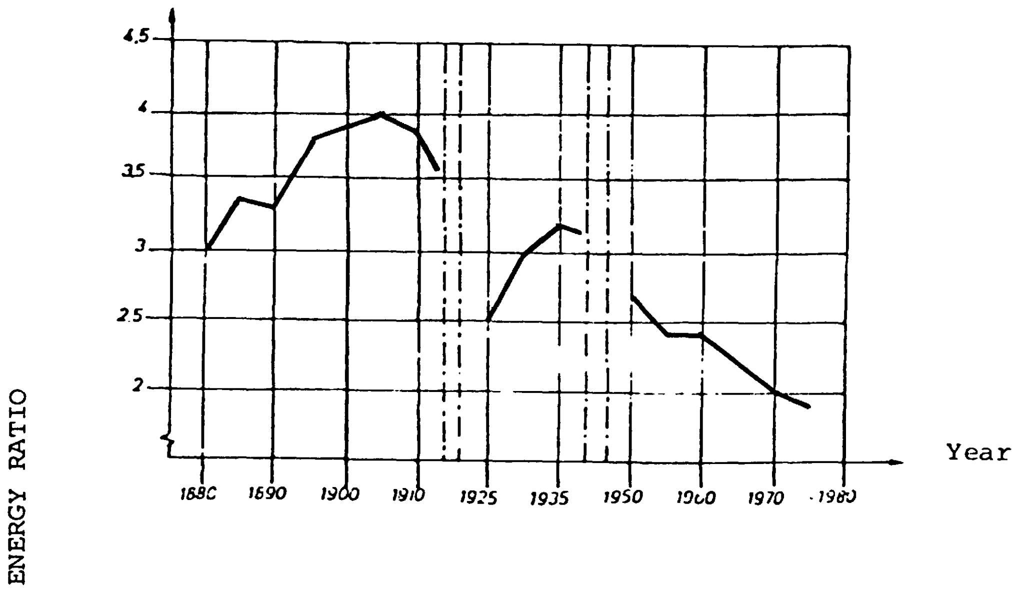


FIG. 3 Energy ratio (metabolisable energy out/fossil energy in) in German agriculture 1880-1976 (Weber (3))

TABLE 5 Selected* Imports by EEC From Other Temperate Agricultural Countries - 1979

Eurostat : Agricultural Statistics 1979

Country / Tonnes	Sweden	Switzer.	Austria	Spain	Morocco	S.Africa	U S A	Canada	Brazil	Argentina	Israel	Austral.	N Zeal.	Thailand
Beef	5533	-	14949	-	-	1483	691	-	653	67498	-	9690	4001	-
Sheep	-	-	-	-	-	-	-	-	-	10899	-	8885	218604	-
Pig	1145	-	-	-	-	-	942	480	-	-	-	-	-	-
Poultry	-	-	-	378	-	-	3005	-	-	-	771	-	-	-
Butter	576	-	655	-	-	-	-	-	-	-	-	-	115791	-
Cheese	211	47040	13457	-	-	-	-	480	-	617	-	-	1205	-
Eggs	225	-	-	-	-	-	386	938	-	-	1647	-	-	-
Wheat	-	- -	-	-	-	-	2387261	2038881	-	234933	-	-	-	-
Rice	-	-	-	8165	-	143	387221	-	915	49218	-	28708	-	34009
Maize	-	-	-	-	-	156538	9172020	21531	4012	1877772	2241	-	-	-
Barley	1891	-	-	-	-	5732	-	504047	-	4004	-	198879	-	-
Rye	-	-	-	-	-	-	12176	23194	-	542	-	-	-	-
Oats	-	-	-	-	-	-	1368	-	-	60341	-	39971	-	-
Sorghum	-	-	-	39	-	-	4524	-	-	6841	-	-	-	-
Potatoes	-	37907	14662	42216	31435	-	-	13270	-	-	17174	-	-	-
Tomatoes	-	-	-	135002	103619	-	-	-	-	-	2665	-	-	-
Onions	-	-	-	192398	6026	-	-	10553	-	5097	18735	-	-	-
Peas	17614	-	-	2785	-	-	-	-	-	-	-	-	-	-
Oranges	-	-	-	840877	197604	192627	20204	-	54811	11114	383519	2976	-	-
Tangerines	-	-	-	550778	144093	-	6802	-	-	-	7266	-	-	-
Lemons/Limes	-	-	-	158732	-	7820	22289	-	-	7312	4069	-	-	-
Grapefruit	-	-	-	-	-	39794	71954	-	-	11984	204553	-	-	-
Apples	-	2550	-	7724	10073	128405	10073	3953	-	87307	-	32440	48630	-
Sugarbeet Sugarcane	-	-	-	-	-	6134	-	-	43904	-	-	37715	-	-
Refined Sugar	605	-	19710	-	-	-	-	-	30909	-	-	-	-	-

*Figures shown represent imports greater than 0.01% of total domestic use in the EEC (1979)

TABLE 6 Production of Selected[+] Products In Temperate Agricultural Countries - 1979.

F.A.O. Production Yearbook 1979

Country / 10^3 Tonnes	Bel./Lux	Denmark	France	Germany	Ireland	Italy	Netherlands	UK	Sweden	Swizerland	Austria	Spain
Beef	-	-	1810	1480	378	1060	-	990	151	-	189	-
Sheep	-	-	163	29	41	49	-	227	-	-	-	-
Pig	-	900	1830	2688	-	950	1100	943	311	271	-	-
Poultry	-	-	1089	365	-	988	350	757	-	-	-	750
Butter	-	130	566	566	-	-	203	159	652	-	37	-
Cheese	-	-	1044	732	-	578	435	235	955	121	71	-
Eggs	-	-	807	860	-	641	449	823	111	-	-	-
Wheat	1010	-	19393	7971	-	9140	-	7140	-	-	-	-
Rice	-	-	-	-	-	1014	-	-	-	-	-	427
Maize	-	-	10293	655	-	6260	-	-	-	-	-	-
Barley	-	6680	11238	8157	1512	-	-	9550	2550	-	-	-
Rye	-	245	360	2105	-	-	-	-	-	-	-	-
Oats	-	-	1675	2999	-	438	-	535	-	-	-	-
Sorghum	-	-	340	-	-	54	-	-	-	-	-	229
Potatoes	-	-	7139	8747	-	2967	6277	6485	-	880	1494	5437
Tomatoes	-	-	825	-	-	4294	395	-	-	-	-	2050
Onions	-	-	144	-	-	540	425	256	-	-	-	905
Peas	129	-	528	-	-	266	-	511	40	-	-	47
Oranges	-	-	-	-	-	1690	-	-	-	-	-	1771
Tangerines	-	-	-	-	-	337	-	-	-	-	-	803
Lemons/Limes	-	-	-	-	-	844	-	-	-	-	-	360
Grapefruit	-	-	-	-	-	-	-	-	-	-	-	-
Apples	-	-	2950	1951	-	1800	480	370	-	430	-	1156
Sugarbeet	6250	3056	26444	18358	1404	11840	5491	7080	-	-	-	-
Sugarcane	-	-	-	-	-	-	-	-	-	-	-	-
Refined Sugar	978	-	4240	3333	-	1685	913	1196	346	-	397	-

[+] See page 4, Section 4, paragraph 2.

TABLE 6 cont'd

Country / 10^3 Tonnes	Morocco	South Africa	USA	Canada	Brazil	Argentina	Israel	Australia	New Zealand	Thailand
Beef	-	520	9925	-	2106	3092	-	2018	498	-
Sheep	-	-	-	-	-	131	-	491	505	-
Pig	-	-	7008	745	-	-	-	-	-	-
Poultry	-	-	8526	-	-	-	182	-	-	-
Butter	-	-	-	-	-	-	-	-	251	-
Cheese	-	-	-	187	-	239	-	-	90	-
Eggs	-	-	4077	320	-	-	97	-	-	-
Wheat	-	-	58289	17746	-	7800	-	-	-	-
Rice	-	3	-	-	7589	362	-	692	-	15640
Maize	-	8240	197208	4963	16309	8700	12	-	-	-
Barley	-	141	-	8460	-	329	-	3657	-	-
Rye	-	-	624	525	-	209	-	-	-	-
Oats	-	-	7757	-	-	536	-	1492	-	-
Sorghum	-	-	-	-	-	6200	-	-	-	-
Potatoes	200	-	-	2706	-	-	208	-	-	-
Tomatoes	413	-	-	-	-	-	225	-	-	-
Onions	84	-	-	130	-	300	57	-	-	-
Peas	-	-	-	-	-	-	-	-	-	-
Oranges	606	560	8306	-	9882	697	941	379	-	-
Tangerines	229	-	579	-	-	-	85	-	-	-
Lemons/Limes	-	31	695	-	-	275	49	-	-	-
Grapefruit	-	106	2491	-	-	128	503	-	-	-
Apples	-	379	3515	437	-	972	-	335	186	-
Sugarbeet	-	-	-	-	-	-	-	-	-	-
Sugarcane	-	18296	-	-	138325	-	-	21151	-	-
Refined Sugar	-	-	-	-	7000	-	-	-	-	-

5. Energy use in agriculture

5.1 Methodology of energy analysis

The concepts underlying energy analysis may be easily understood by first considering how an accountant would arrive at the profit of a farming enterprise. The information needed would comprise in any given year:

Sales (money units)
Purchase (money units)
Change in stock over year (value)
Change in capital equipment (duly amortised)
Rent, land taxes, and other charges independent of output

In arriving at a throughput, gross profit and net profit, the accountant does not need to concern him or herself with the costs or profits in the manufacture of the inputs purchased. The price in the market place contains all the costs of creating or manufacturing these inputs .... In other words, price reflects all the upstream costs, profits, royalties, taxes, rents and so forth of the inputs. This is not so when one does an energy accounting because one does not pay in energy units. What, for example, is the energy 'content' of a tonne of 14-14-4 fertiliser? It is not heat of combustion when burnt in air, as would be the appropriate measurement of, say, a fuel oil. Indeed many inputs to the farming process are incombustible. The words 'energy content' are an imprecise phrase meant to imply the energy that was utilised to make fertiliser. This suggests that the analyst must go back to the fertiliser factory and study the process of production, and so arrive at a figure for the 'energy content'. Some analysts refer to this as the 'embodied energy', perhaps a more apt phrase. However if one reflects upon the processes going on in the fertiliser factory, one quickly comes to the conclusion that there are quite a number of ways of assessing the energy used and one should go further upstream to consider also the inputs to the factory. For example, there will be capital equipment, made elsewhere at an earlier time. There will be electricity, not itself a primary fuel, made elsewhere by a highly capital intensive process using other fuels. There will be fuels used directly in the fertiliser production. For example, the most modern nitrogen fertiliser process uses natural gas which under catalytic conversion with air (which contains nitrogen) results in the formation of ammonia, the point of origin for most synthetic nitrogen fertilisers. Yet neither the fuels used, nor the natural gas feed stock are available to the fertiliser factory without prior processes.

The issue before the energy analyst, then, is to decide which system boundary to select. This is not a trivial issue. Very substantial differences occur amongst practitioners according to the conventions and system boundaries chosen. For example, if UK energy statistics are computed according to the UK Department of Energy conventions, the result is 17% different from those computed using the conventions of the EEC statistical office in Luxembourg. An awareness of the difference in conventions and system boundaries allows one to take account of these differences and account for them.

Even within the European Communities the conventions and system boundaries utilised by Eurostat are inconsistent. Fig.4 shows that they utilise different system boundaries depending on the fuel being quantified.

This issue of conventions and system boundaries was examined at the outset of the current work, and a decision made by DG VI that all energies would be computed in terms of primary energy in the ground. This convention follows that developed by the IFIAS workshop (4) on energy analysis conventions, held in 1974. The 'embodied energy' is referred to precisely, then, as the Gross Energy Requirement - GER.

Even with this decision to go back to the ultimate system boundary (the primary fuel in the ground) many imprecisions still occur. Technology is under continual development in the agricultural sector, in the agro-industries and in the fuel supplying industries. The energy to make something in 1978 is not necessarily the same as that required in 1981. The energy required per unit output to run a plant at full designed production is almost certainly less than that required to operate a plant at reduced output. This effect of changing technology, with its energy consequences, has another impact. The inputs to a given process, whether in agriculture or industry were not all made yesterday. An analysis by Stenlake (5) showed that some energy requiring inputs may have taken as much as two years from moment of production to moment of ultimate incorporation. Therefore who is to say what the precise gross energy requirement (GER) of any input is at any moment in time.

We see, therefore, that to provide a precise answer, even to a simple question as to how much energy it takes to grow a tonne of wheat in the valley of the Loire in a given year, would require an analysis so detailed as to require a report of this size for that one question alone. Even then the answer would be precise for only one harvest.

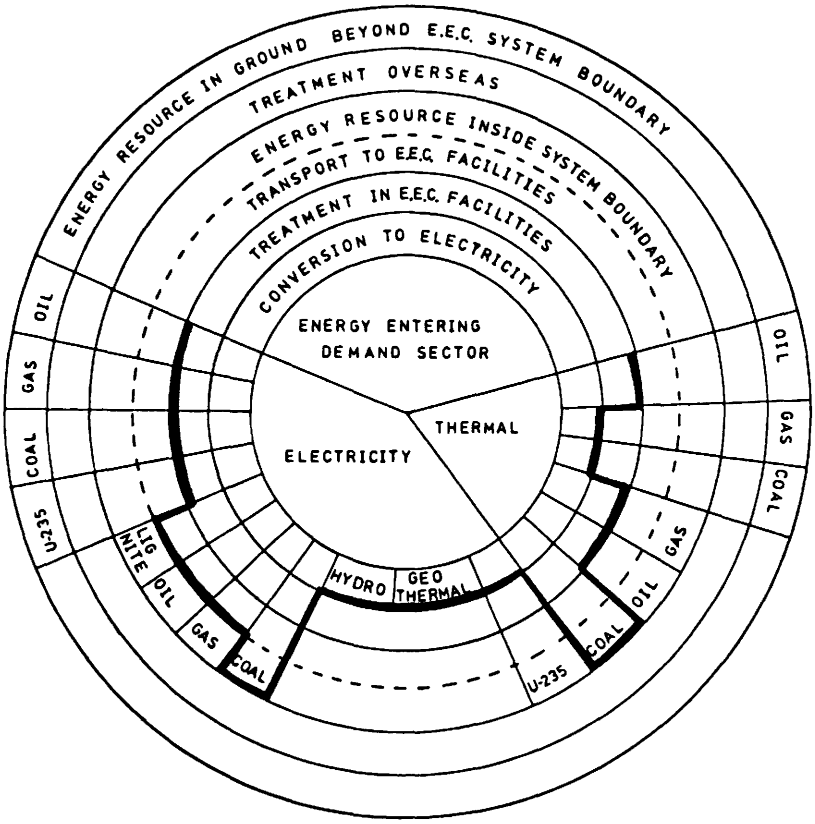


Fig. 4 System Boundary Diagram (EEC Energy Transformation System) The heavy line reflects the boundaries used in Eurostats.

We can, however, take some comfort from the fact that an aggregation of errors will tend to cancel each other, provided we know that all do not push the answer in the same direction. In energy analysis this is the case. Moreover, one does seek to minimise these errors. One can assess the aggregate energy to manufacture agricultural inputs to about a ten percent accuracy. The accuracy of the relation between inputs to farming and output of agricultural practice, however, is a different matter, and will be treated in a later section.

5.2 Changing technology of agricultural inputs

A good example of developing technology is the production of ammonia. The study by Fleming (6) extensively quoted, eg (7) (8) shows how the technology has steadily improved and the scale of operation increased, until today it can be made for about 45 MJ/kg, about 2½ times the minimum energy requirement as computed from purely thermodynamic considerations. We cannot expect much improvement, since for a process to operate at finite rate, it is a necessary condition that it be significantly removed from thermodynamic equilibrium, Fig. 5.

In the pursuit of the data for this study, we were constantly asked by those groups assisting us all over the world for our best estimates of the energy requirements for these inputs. In the end, where no national data were available, we recommended the values listed in Appendix 2.

5.3 Procedure

Consider a farming enterprise which has as its objective one single product, say beef. For energy analysis purposes we can depict this as in Fig.6. This figure shows inputs which are themselves requiring energy, so that, say, the energy, fertiliser and purchased feed can themselves be depicted as in Figs. 7, 8 and 9.

These may all be brought together in one diagram, as in Fig. 10, to yield the total primary energy required to produce the output on an area which is the sum of all areas used. Solar energy is not counted, for the purpose of the analysis is to measure the non-renewable energy use. Labour is not separately counted, for it is included in the $\dot{G}ER$ of industrial inputs.

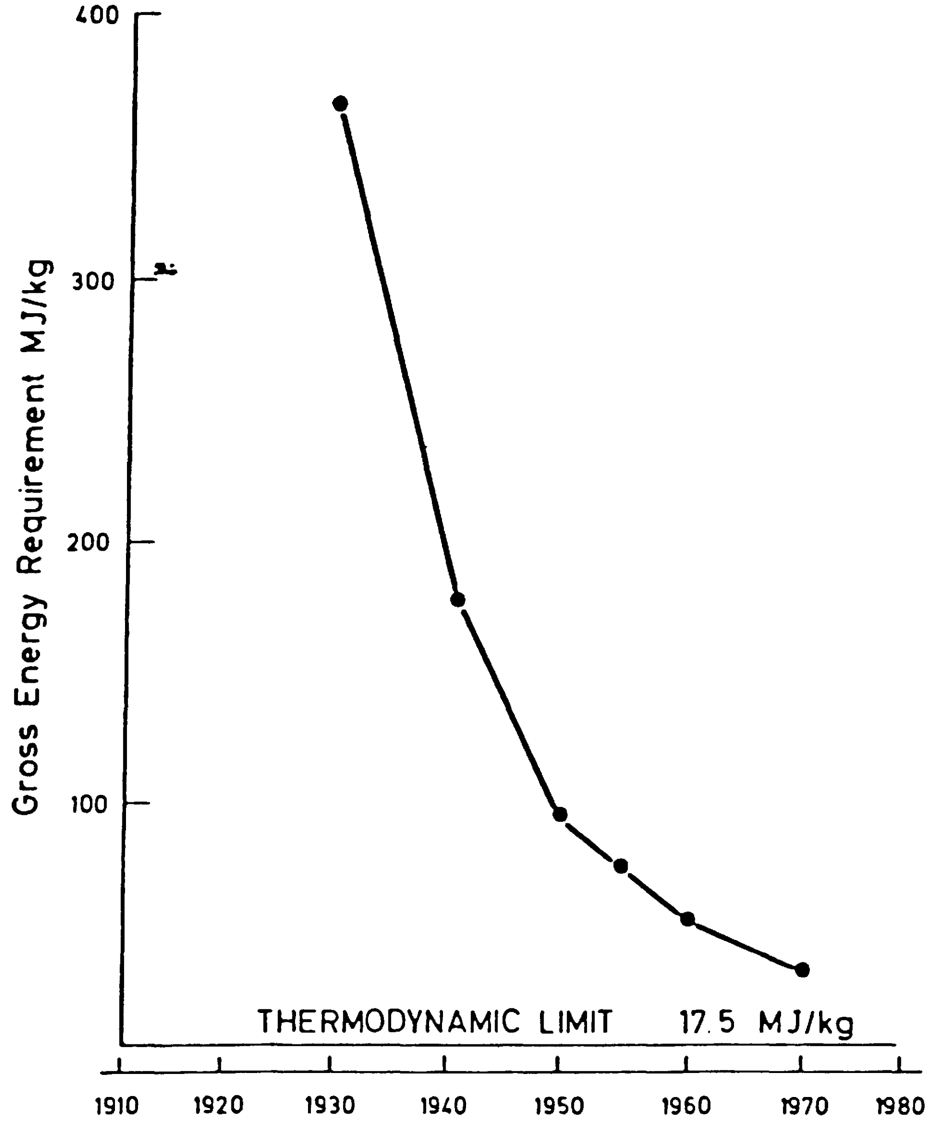


Fig. 5: IMPROVEMENT IN GROSS ENERGY REQUIREMENT OF THE PRODUCTION AMMONIA THROUGH TIME

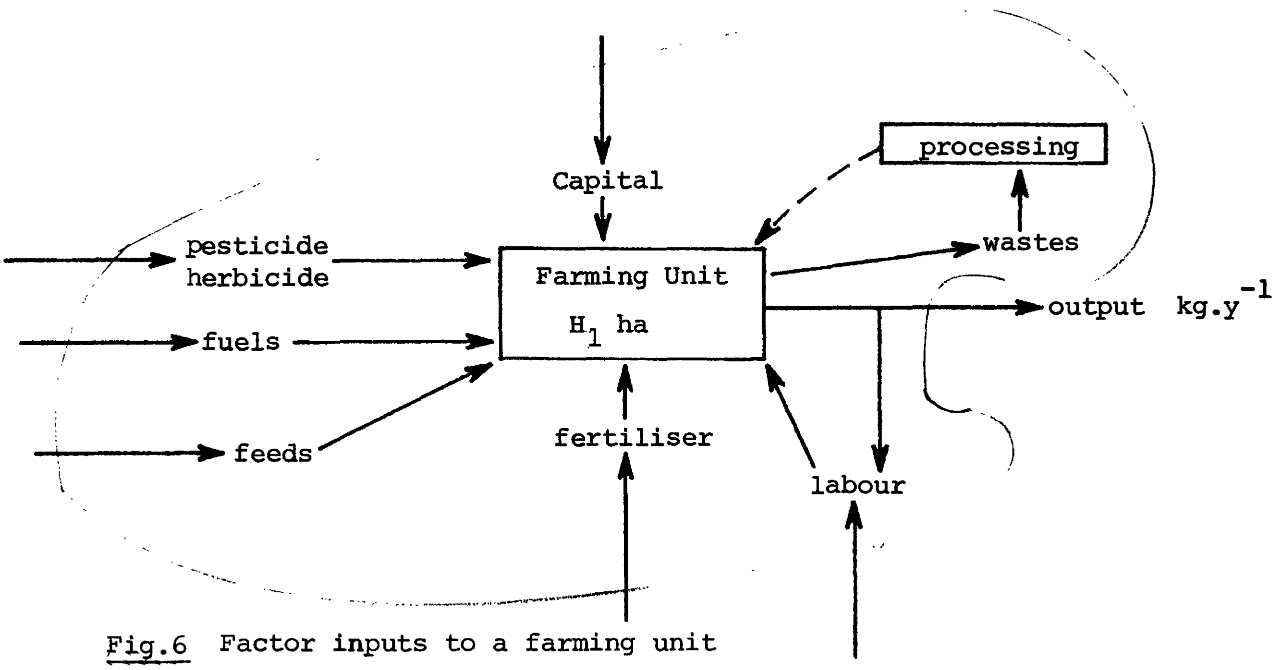


Fig.6 Factor inputs to a farming unit

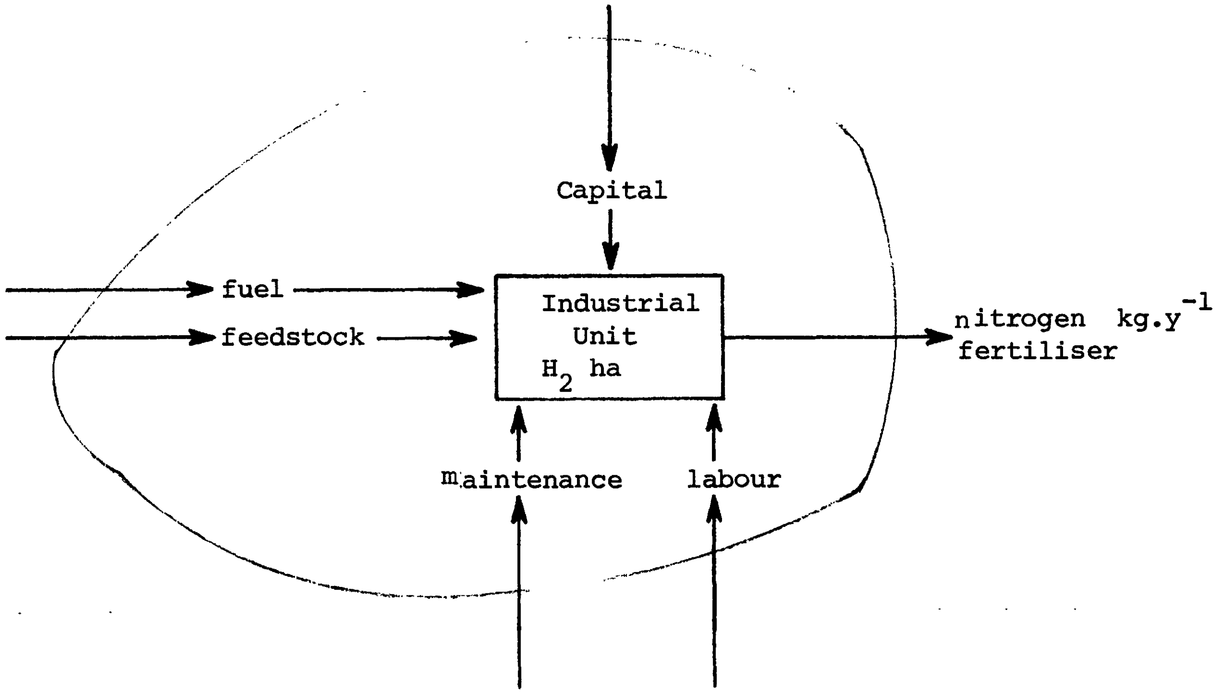


Fig.7 Factor inputs to fertiliser production

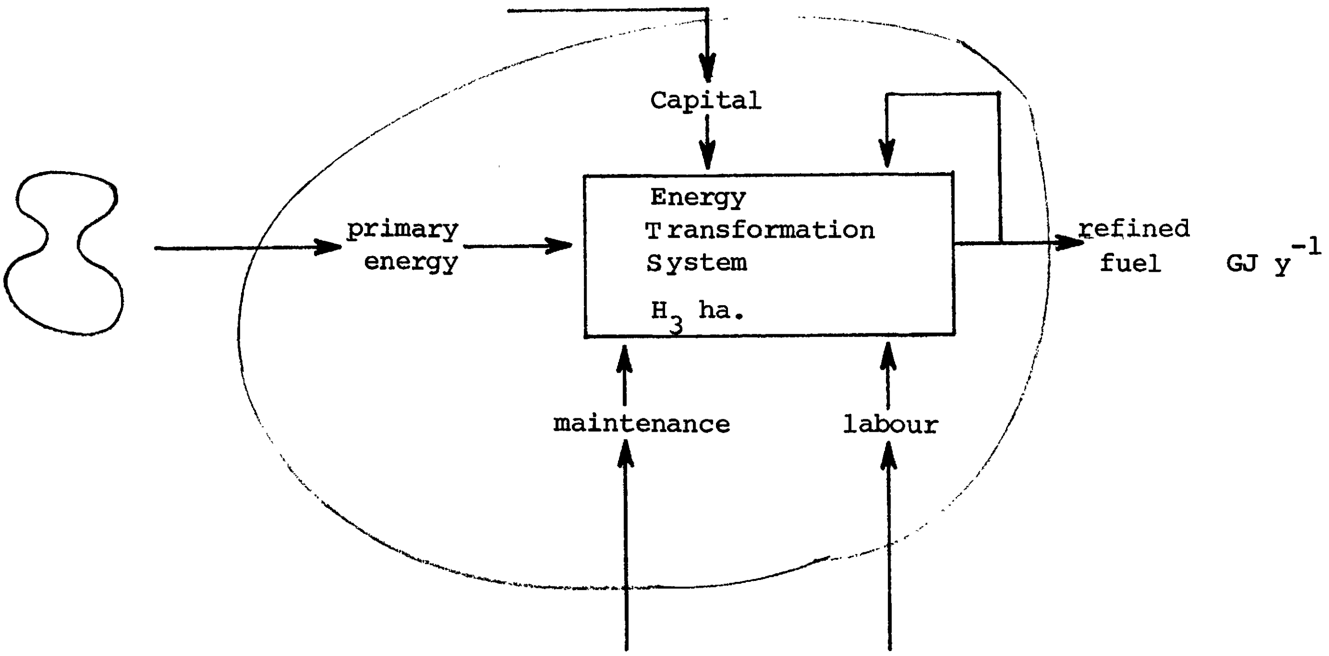


Fig. 8 One of the many energy transformation sectors

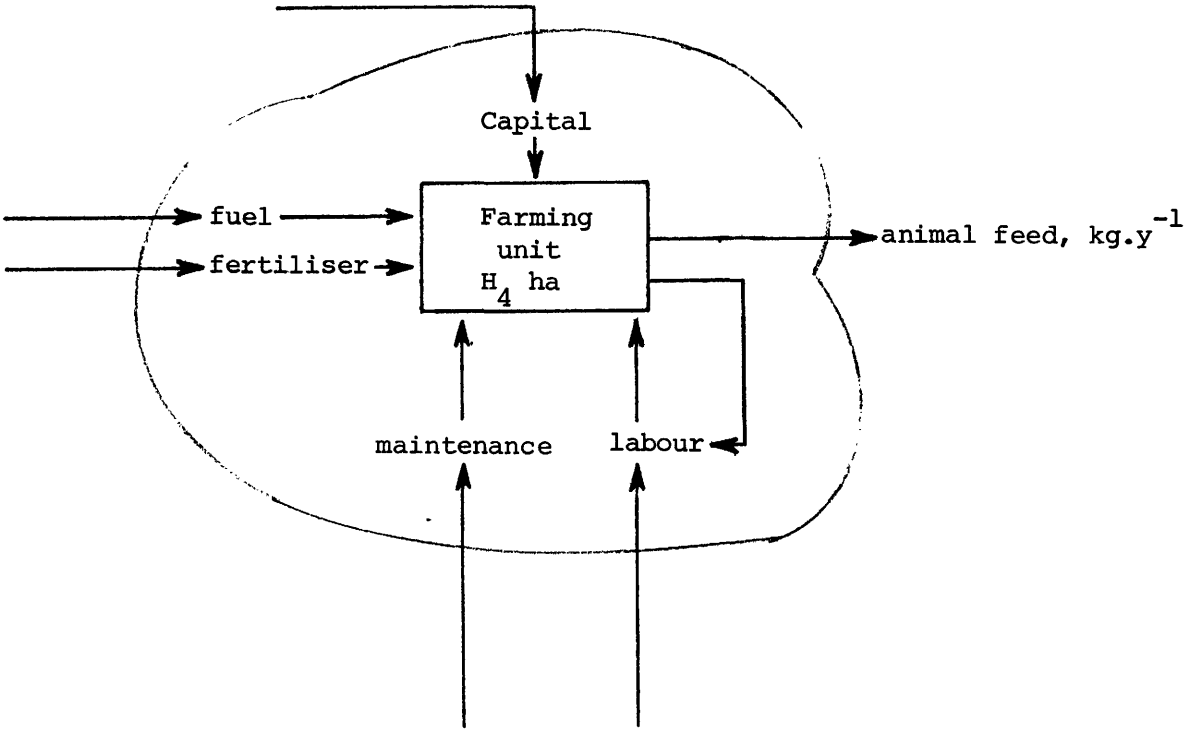


Fig. 9 Factor inputs to animal feed

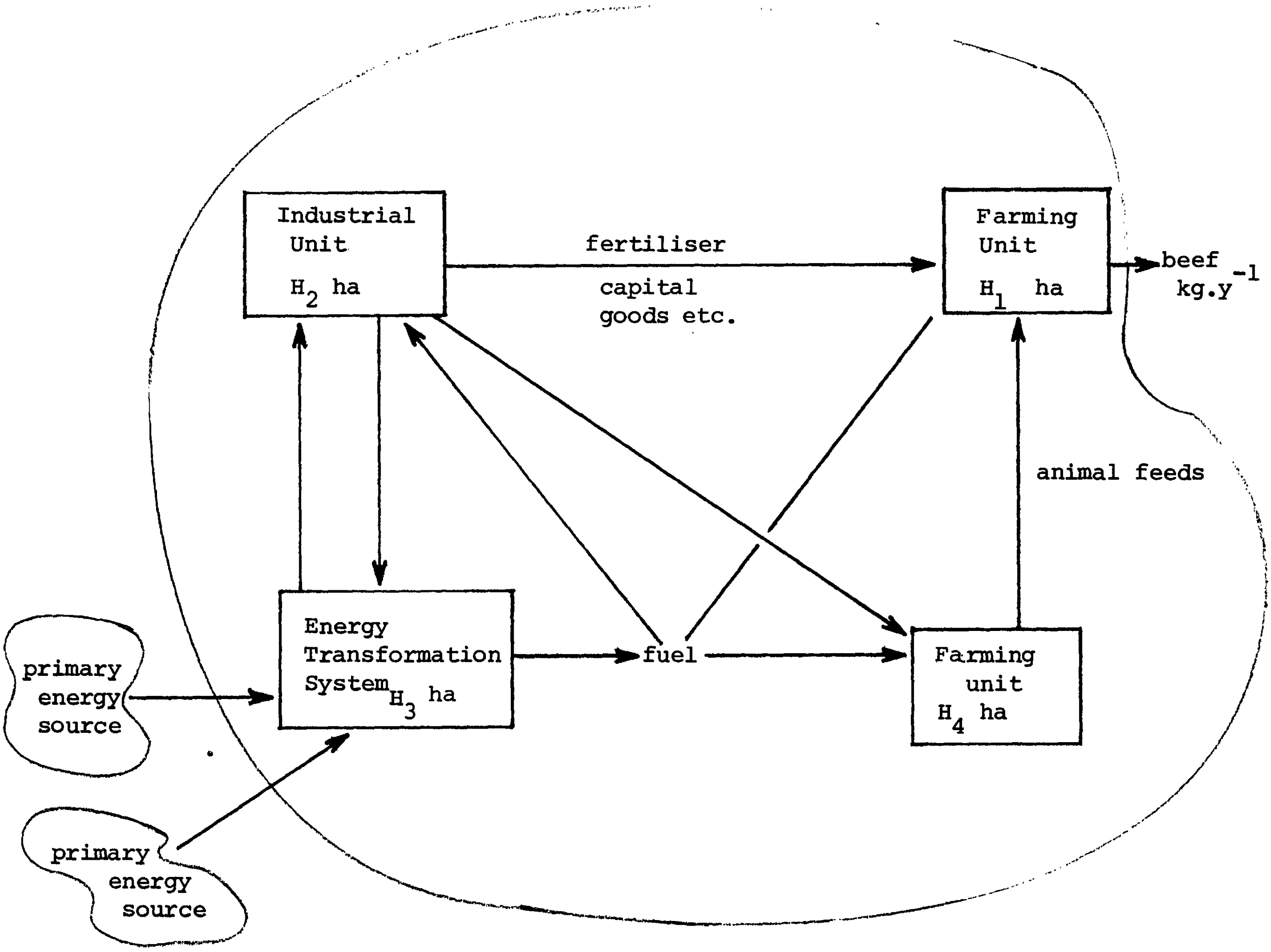


Fig.10 Primary energy inputs to beef production

$$GER = \sum \text{primary energy per year/beef per year}$$

$$= \text{MJ primary energy/kg beef}$$

$$\text{Intensity of output} = \frac{\text{kg.beef y}^{-1}}{H_1 + H_2 + H_3 + H_4}$$

In practice $H_2 + H_3 \ll H_1$ or H_4

$$\text{Intensity of output} \simeq \frac{\text{kg.beef y}^{-1}}{H_1 + H_4}$$

$$\text{Intensity of inputs} \simeq \frac{\text{Total primary energy y}^{-1}}{H_1 + H_4}$$ (non-renewable energy flux)

6. Data collection

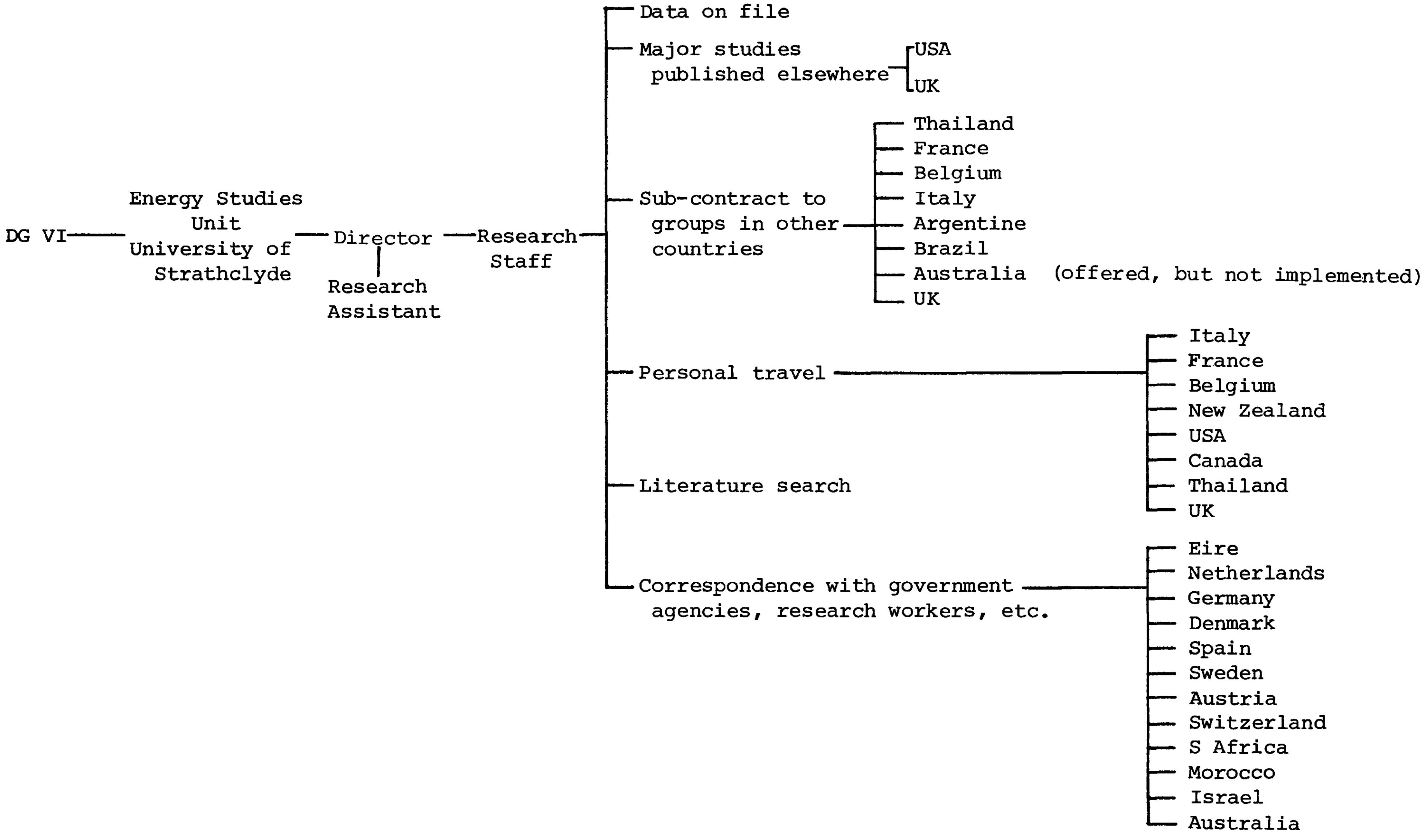
Official national data sources tend to be of two types: those that describe production inputs and yields in financial terms, perhaps related to total output of a given commodity, say wheat, and those in terms of the output of whole countries or regions. With the exception of the US Department of Agriculture, there are no official statistics that enable one to arrive at even an approximate answer to the energy required to produce specific agricultural products. Furthermore none of the aggregated procedural methods can be used, such as energy related input-output tables. These can give a figure for the whole agricultural sector, but not individual crops. Recourse therefore had to be made to process analysis. Such procedures are slow, and required a detailed level of information obtainable only by persons able to go into the field. Moreover, we required information on 26 foodstuffs grown in 22 countries; some 600 data pieces. In fact the number had to be larger, for process analysis is necessarily linked to actual systems, and these vary from one part of each country to another, vary by harvest year, and by the intensity of cultivation adopted, an intensity which may well vary inside any country by a factor of three. This enormous task was reduced to manageable proportions by the following procedure.

All food products were eliminated where the import to the EEC was less than 0.01% of total EEC domestic use in 1979. In this way 600 data pieces were reduced to two hundred. The data search for these two hundred was devolved as indicated in Fig.11.

Our objective was to obtain a range of data for each commodity in each country, so as to arrive at an impression of the range of intensities of production and the corresponding GERs.

We expected, and got, a wide variation. Appendix 3 lists all the persons contacted. Appendix 4 enumerates all literature references. It proved impossible to obtain the desired data in every case; some data will be made available later. In addition some unsought for data has been included for its information content.

Figure 11 Organisation of data search



7. RESULTS

7.1 Gross energy requirement of food production

The results are summarised in Appendix 5. Each square of the matrix contains two sets of numbers. The upper is the range of yields reported, expressed as tonnes/hectare-year; the lower, the range of GERs GJ/t.

This confusing set of data leads only to the broad conclusions that there is a close relationship between agricultural intensities and the corresponding energy requirements the world over. This fuzzy, but unsurprising picture of world agriculture, can be effectively focused by plotting the data in terms of output intensities expressed as metabolisable energy or protein content, versus the energy flux of the inputs, see Section 8.

7.2 Total energy including transport energy

The data on the energy requirements of transport are exceptionally disparate, with sources differing by as much as a factor of three. Part of this may be explained by the possibility of full or empty return journeys. For sea transport, the recession and the high price of bunker fuel have caused many boats to move more slowly, and therefore more economically in energy terms.

Given this high level of uncertainty, it seemed superfluous to conduct any detailed study of the distances by which European agricultural products were moved WITHIN Europe. Thus a decision was made to add only the transport energy from exporting countries outside Europe to major European ports, arguing that the transport energies expended on these products, once they reached Europe, were of much the same order as applied to internally produced European food.

Two ports of entry have been chosen. Marseilles for cargoes coming via the Mediterranean or Suez Canal, and Rotterdam for cargoes coming via the Atlantic. The slight difference in steaming distance for British, Danish, Belgian, Italian or German ports scarcely affects the numbers. Table 7 lists the transport energy data used. The analysis leading to these numbers together with the estimates of land and sea transport distances are given in Appendix 6.

The final results are depicted product by product sequentially in Table 8. For each product the range of European Energy requirements per tonne is listed, and then below the energy requirement including transport from various countries. Against each commodity is a comment based on a comparison of the number from this aggregated data set.

TABLE 7 Transport Energies

Gross energy requirement of transport =

	(land distance (km) x 0.5)/1000		GJ/t
+	loading and unloading energy at ports		0.16 GJ/t
+	(sea distance (km) x 0.12)/1000	grain	
	x 0.4/1000	meat, vegetables, fruit	GJ/t

TABLE 8 Total Energy Consumption (including Transport Energy) for Products Delivered to the EEC

Product	Country	GER 'to farm gate' GJ/t			Transport Energy + Cargo Handling (single voyage) GJ /t	Total GER range of products landed in EEC GJ/t	Comment
		low energy input	unweighted modal value	high energy input			
Beef	Europe	9.4	58	102	nil	9.4 - 102	IMPORTED MEAT FREQUENTLY LESS ENERGY INTENSIVE
	U S A	1	36	76	2.9	3.9 - 79	
	Brazil	1	15	29	2.8	3.8 - 32	Departs from Porto Allegre
	Argentina	2.8	4.3	4.8	3.3	6.1 - 8.1	
	Thailand		47		3.1	50	Landed Marseilles via Suez
	New Zealand		11		5.9	17	Landed Rotterdam via Cape
	" "		11		4.5	15.5	Landed Marseilles via Suez
Sheepmeat	Europe	52	66	68	nil	52 - 68	IMPORTED SHEEPMEAT LESS ENERGY INTENSIVE
	New Zealand		11		5.9	16.9	Landed Rotterdam via Cape
	" "		11		4.5	15.5	Landed Marseilles via Suez
Pigmeat	Europe	23	26	85	nil	23 - 85	IMPORTED PIG MEAT CAN BE LESS ENERGETIC
	U S A	33	38	55	2.9	36 - 58	
	New Zealand		31		5.9	37	Landed Rotterdam via Cape
	" "		31		4.5	35.5	Landed Marseilles via Suez
	Thailand		103		3.1	106	" " "
Poultry	Europe	24	38	73	nil	24 - 73	NO CLEAR ENERGETIC ADVANTAGE IN IMPORTS
	U S A		39		2.9	42	
	Thailand		57		3.1	60	Landed Marseilles via Suez

TABLE 8 (contd)

Product	Country	GER 'to farm gate' GJ/t			Transport Energy + Cargo Handling (single voyage) GJ/t	Total GER range of products landed in EEC GJ/t	Comment
		low energy input	unweighted modal value	high energy input			
Butter	Europe	24	26	58	nil	24 - 58	EUROPEAN BUTTER SHOWS NO CLEAR DISADVANTAGE VIS-A-VIS IMPORTED
	U S A		80		2.9	83	
	Australia		30		5.4	35	Landed Rotterdam via Cape
	"		30		4.3	34	Landed Marseilles via Suez
	New Zealand		66		5.9	72	Landed Rotterdam via Cape
	" "		66		4.5	70.5	Landed Marseilles via Suez
Cheese	Europe	41	43	71	nil	41 - 71	EUROPEAN CHEESE SHOWS NO CLEAR DISADVANTAGE VIS-A-VIS IMPORTED
	U S A		20		2.9	23	
	New Zealand		31		5.9	37	Landed Rotterdam via Cape
	" "		31		4.5	35.5	Landed Marseilles via Suez
Eggs	Europe	9.8	17	33	nil	9.8 - 33	LITTLE ADVANTAGE IN IMPORTS
	U S A		20		2.9	23	
Wheat	Europe	2.4	5.1	11	nil	2.4 - 11	NO ENERGY ADVANTAGE IN IMPORTING WHEAT
	U S A	2.9	4	32	1.2	4.1 - 33	
	Canada	1.1	1.7	3.9	1.4	2.5 - 5.3	
	Argentina	2.4	2.9	3	1.2	3.6 - 4.2	
	Australia	0.9	1.1	1.4	1.9	2.8 - 3.3	Landed Rotterdam via Cape
	"	0.9	1.1	1.4	1.6	2.5 - 3	Landed Marseilles via Suez
	New Zealand	1.4	2.1	2.1	1.9	3.3 - 4	Landed Rotterdam via Cape
	" "	1.4	2.1	2.1	1.5	2.9 - 3.6	Landed Marseilles via Suez

TABLE 8 (contd)

Product	Country	GER 'to farm gate' GJ/t			Transport Energy + Cargo Handling (single voyage) GJ/t	Total GER range of products landed in EEC GJ/t	Comment
		low energy input	unweighted modal value	high energy input			
Rice	Europe	0.2	2	11	nil	0.2 - 11	NO CLEAR ENERGY ADVANTAGE IN RICE IMPORTS
	Brazil	1.9	6.6	11	1.1	3 - 12.1	
	Argentina		9		1.2	10.2	
	Thailand	4.5	4.8	6.4	1.4	5.9 - 7.8	Landed Marseilles via Suez Land transport energy from Ref (9)
	Australia		1.8		1.9	3.7	Landed Rotterdam via Cape
	"		1.8		1.5	3.3	Landed Marseilles via Suez
	U S A	7	12	12	1.2	8.2 - 13.2	
Barley	Europe	2.9	4.5	8.2	nil	2.9 - 8.2	A POSSIBLE BUT SMALL ENERGY ADVANTAGE IN IMPORTING BARLEY
	U S A	2.9	4.0	5.2	1.2	4.1 - 6.4	
	Canada	0.7	2.5	3.9	1.4	2.1 - 5.3	
	Argentina		2.6		1.2	3.8	
	New Zealand	1.1	2.0	2.2	1.9	3 - 4.1	Landed Rotterdam via Cape
	" "	1.1	2.0	2.2	1.5	2.6 - 3.7	Landed Marseilles via Suez

TABLE 8 (contd)

Product	Country	GER 'to farm gate' GJ/t			Transport Energy + Cargo Handling (single voyage) GJ/t	Total GER range of products landed in EEC GJ/t	Comment
		low energy input	unweighted modal value	high energy input			
Rye	Europe	3.9	4.5	7.7	nil	3.9 - 7.7	NO ENERGY ADVANTAGE IN IMPORTING RYE
	U S A	1.4	5.2	5.3	1.2	2.6 - 6.5	
	Canada	5.8	5.8	6.9	1.4	7.2 - 8.3	
Maize	Europe	0.8	4.8	11	nil	0.8 - 11	GER IMPORTED MAIZE OF THE SAME ORDER AS EUROPEAN
	U S A	3.2	3.9	12	1.2	4.4 - 13.2	
	Canada		4.6		1.4	6	
	Brazil	1.0	4.0	8.1	1.1	2.1 - 9.2	Departs from Porto Allegre
	Argentina	0.4	1.6	2.7	1.2	1.6 - 3.9	
	New Zealand	2.1	2.2	3.3	1.9	4 - 5.2	Landed Rotterdam via Cape
	" "	2.1	2.2	3.3	1.5	3.6 - 4.8	Landed Marseilles via Suez
	Thailand		1.9		1.7	3.6	Landed Marseilles via Suez
							Land transport energy from Ref (9)
Sorghum	Europe	3.5	4.8	4.8	nil	3.5 - 4.8	GER IMPORTED SORGHUM SIMILAR TO EUROPEAN EXCEPT FOR USA WHICH IS HIGHER
	U S A	3.1	4.2	14.5	1.2	4.3 - 15.7	
	Argentina	1.4	1.5	2.0	1.2	2.6 - 3.2	
	Thailand		2.3		1.7	4	Landed Marseilles via Suez Land transport energy from Ref (9)

TABLE 8 (contd)

Product	Country	GER 'to farm gate' GJ/t			Transport Energy + Cargo Handling (single voyage) GJ/t	Total GER range of products landed in EEC GJ/t	Comment
		low energy input	unweighted modal value	high energy input			
Oats	Europe	3.0	4.5	7.2	nil	3.0 - 7.2	NO ENERGY ADVANTAGE IN IMPORTING OATS
	U S A	3.1	3.4	6.4	1.2	4.3 - 7.6	
	Canada	0.9	2.8	3.5	1.4	2.3 - 4.9	
	Argentina	2.8	2.9	3	1.2	4 - 4.2	
	New Zealand	2.1	2.5	2.5	1.9	4 - 4.4	Landed Rotterdam via Cape
	" "	2.1	2.5	2.5	1.5	3.6 - 4	Landed Marseilles via Suez
Peas	Europe	0.2	3	4.3	nil	0.2 - 4.3	FROM AN ENERGY ASPECT, PEAS ARE BEST GROWN IN EUROPE
	U S A		8.2		2.9	11.2	
	Canada		2.4		2.9	5.3	
	New Zealand	2.3	2.5	4.7	5.9	8.2 - 10.6	Landed Rotterdam via Cape
	" "	2.3	2.5	4.7	4.5	6.8 - 9.2	Landed Marseilles via Suez
Potatoes	Europe	0.2	1.7	4	nil	0.2 - 4	BALANCE OF ENERGY ADVANTAGE IS TO GROW POTATOES IN EUROPE
	U S A	1.6	1.9	3.1	2.9	4.5 - 6	
	Canada	0.7	1.5	1.7	2.9	3.6 - 4.6	
	New Zealand		2.8		5.9	8.7	Landed Rotterdam via Cape
	" "		2.8		4.5	7.3	Landed Marseilles via Suez
	Israel		2.3		0.9	3.2	Landed Marseilles

Table 8 (cont'd)

Product	Country	GER 'to farm gate' GJ/t			Transport Energy + Cargo Handling (single voyage) GJ/t	Total GER range of products landed in EEC GJ/t	Comment
		low energy input	unweighted modal value	high energy input			
Tomatoes	Europe	19	-	160	nil	19 - 160	THERE IS AN ENERGY ADVANTAGE
	USA		1.3		2.9	4.2	IN IMPORTING TOMATOES
	Argentina		3.3		3.3	6.6	
	Israel	1.3	2.4	10.8	0.9	2.2 - 11.7	Landed Marseilles
Onions	Europe	0.6	2.8	5.2	nil	0.6 - 5.2	NO ENERGY ADVANTAGE IN IMPORTING ONIONS
	USA		1.1		2.9	4	
	Argentina		0.8		3.3	4.1	
Oranges	Europe		-		-	-	NO CONCLUSION - DATA FOR EUROPE REQUIRES SPECIAL STUDY
	USA	1	1.2	3.7	2.9	3.9 - 6.6	
	Brazil	0.2	1.0	2.8	2.8	3 - 5.6	Departs from Porto Allegre
	Israel		2.1		0.9	3	Landed Marseilles
Tangerines	Europe		–		-	-	No major producer in Europe
	USA		1.3		2.9	4.2	
	Israel		2.8		0.9	3.7	Landed Marseilles
Lemons/ Limes	Europe		–		-	-	No major producer in Europe
	USA		1.6		2.9	4.5	
	Argentina		1.4		3.3	4.7	
	Israel		2.3		0.9	3.2	Landed Marseilles

Table 8 (cont'd)

Product	Country	GER 'to farm gate' GJ/t			Transport Energy + Cargo Handling (single voyage) GJ/t	Total GER range of products landed in EEC GJ/t	Comment
		low energy input	unweighted modal value	high energy input			
Grapefruit	Europe		-		-	-	No major producer in Europe
	USA	0.7	0.7	0.9	2.9	3.6 - 3.8	
	Israel		1.5		0.9	2.4	Landed Marseilles
Apples	Europe		-		-	-	
	USA	2	2.3	3.6	2.9	4.9 - 6.5	
	Canada	1.1		2.2	2.9	4.0 - 5.1	
	Argentina		5.1		3.3	8.4	
Sugar beet	Europe	0.5	0.7	1.2	nil	0.5 - 1.2	NO ENERGETIC ADVANTAGE IN IMPORTS
	USA	1.1	1.2	1.3	2.9	4 - 4.2	
Sugarcane	Europe		-		-	-	No producer in Europe
	USA		0.7		2.9	3.6	
	Thailand	0.3	0.4	0.5	3.4	3.7 - 3.9	Landed Marseilles via Suez Land transport energy from Ref. (9).
Refined Sugar	Europe	18	25	32	nil	18 - 32	From sugar beet
	USA	43	46	49	1.2	44 - 50	From sugar beet
							EUROPEAN SUGAR REQUIRES LESS ENERGY THAN IMPORTED

8. Analysis of energy data

8.1. Correlation of data

At first glance the spread of numbers in Appendix 5 suggests a disappointing level of accuracy. This spread of data, however, merely reflects the fact that in every corner of the world agricultural practice is carried out at different degrees of intensity. The so-called efficient farmer produces a great deal per hectare, and in doing so is obliged to dissipate a great deal of non-renewable energy in the form of fuel, fertilisers, pesticides and so on. The broad relationship between crop output and energy input was pointed out as far back as 1973 (10), reinforced by a wider study reported in 1977 (11). The data obtained in the present study, culled from a large number of independent sources, are plotted in Figs. 12 and 13, as output versus input. Output is expressed in two ways : as metabolisable energy in the crop and as protein content. The virtue of the latter approach is that it permits animal products to be rigorously compared with crops. The inputs are expressed as the sum total of primary energy required to create all the inputs, excluding labour and solar energy, expended per hectare of land use. Thus, for example, the area of land used to grow an animal feed crop is included in arriving at the true intensity of inputs.

One sees that there is an undoubted relation between output and input. Figs. 12 and 13, plotted on log-log paper, illustrate the relationships between output and input. The slope, being less than one, implies diminishing returns with progressive intensification. This suggests an input-output expression of the form.

output/hectare P = output per hectare when there are no added inputs
+ constant(added inputs expressed in energy terms per hectare)$^{\beta}$

where β is considerably less than unity.

Unfortunately, this particular functional form poses statistical problems and accordingly a simpler expression omitting the constant term was used for regression analysis. By definition, this implies zero output at zero energy subsidy which is only approximately true . Since however the bulk of the data relates to cases where substantial energy subsidies are involved no great error is felt to occur.

A regression analysis on the data in Fig 13 in the form $P = \alpha(ES)^{\beta}$ yields:

P (grain fruit, veg) = $2.2\ (ES)^{0.49}$ $R^2 = 50\%$ for 280 observations
P (animal) = $0.88\ (ES)^{0.44}$ $R^2 = 69\%$ for 41 observations

where P is kg/ha.yr and ES is GJ/ha.yr.

Figs. 12 and 13 show a wide dispersal of the data. There are two reasons for this. In the first place, not all analyses furnished to us were complete in every respect, and even when they were it was frequently necessary to use

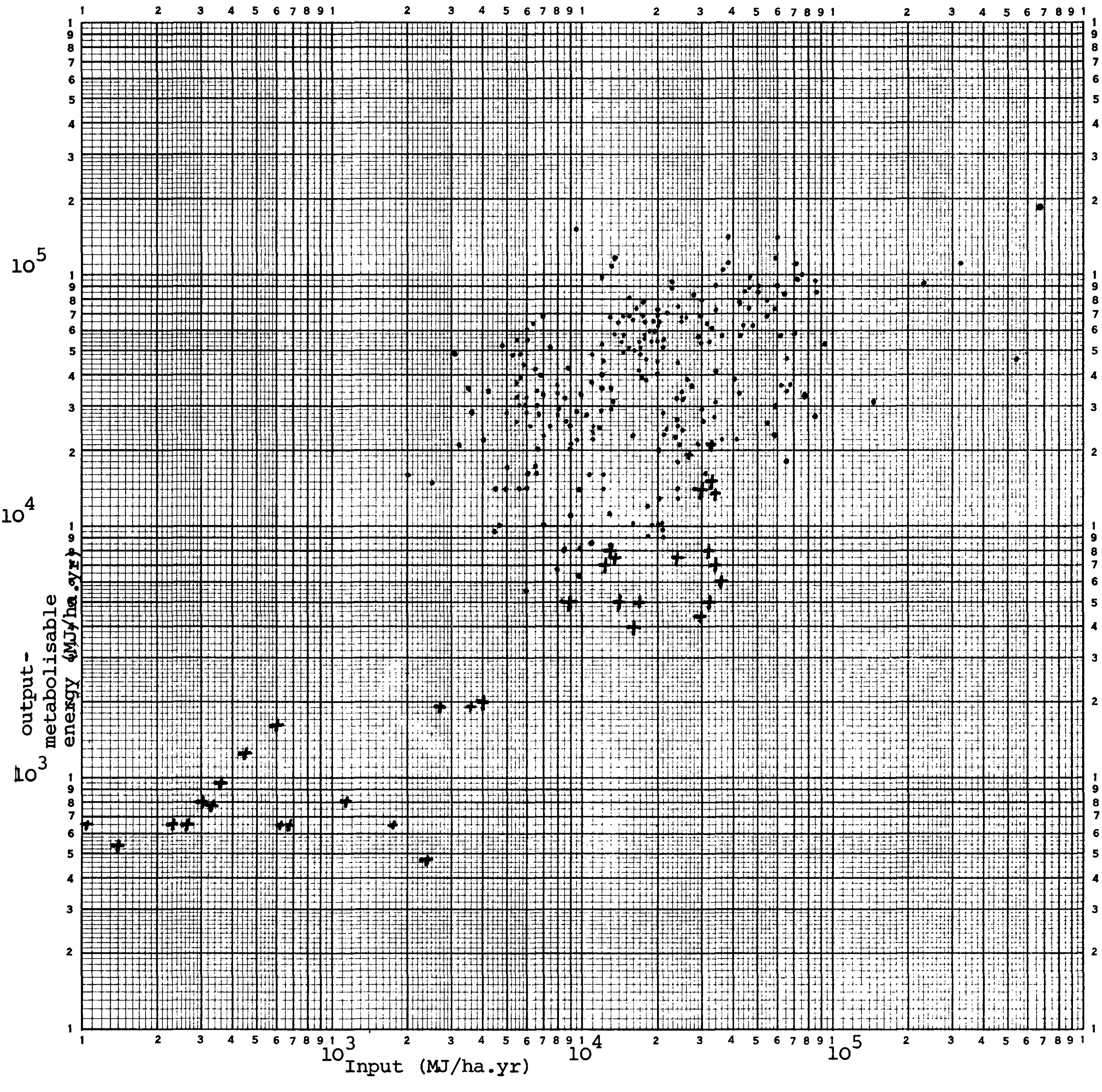


Fig.12 Metabolisable energy in all foodstuffs versus energy intensity of production

+ meat production

• grain, fruit and vegetable production

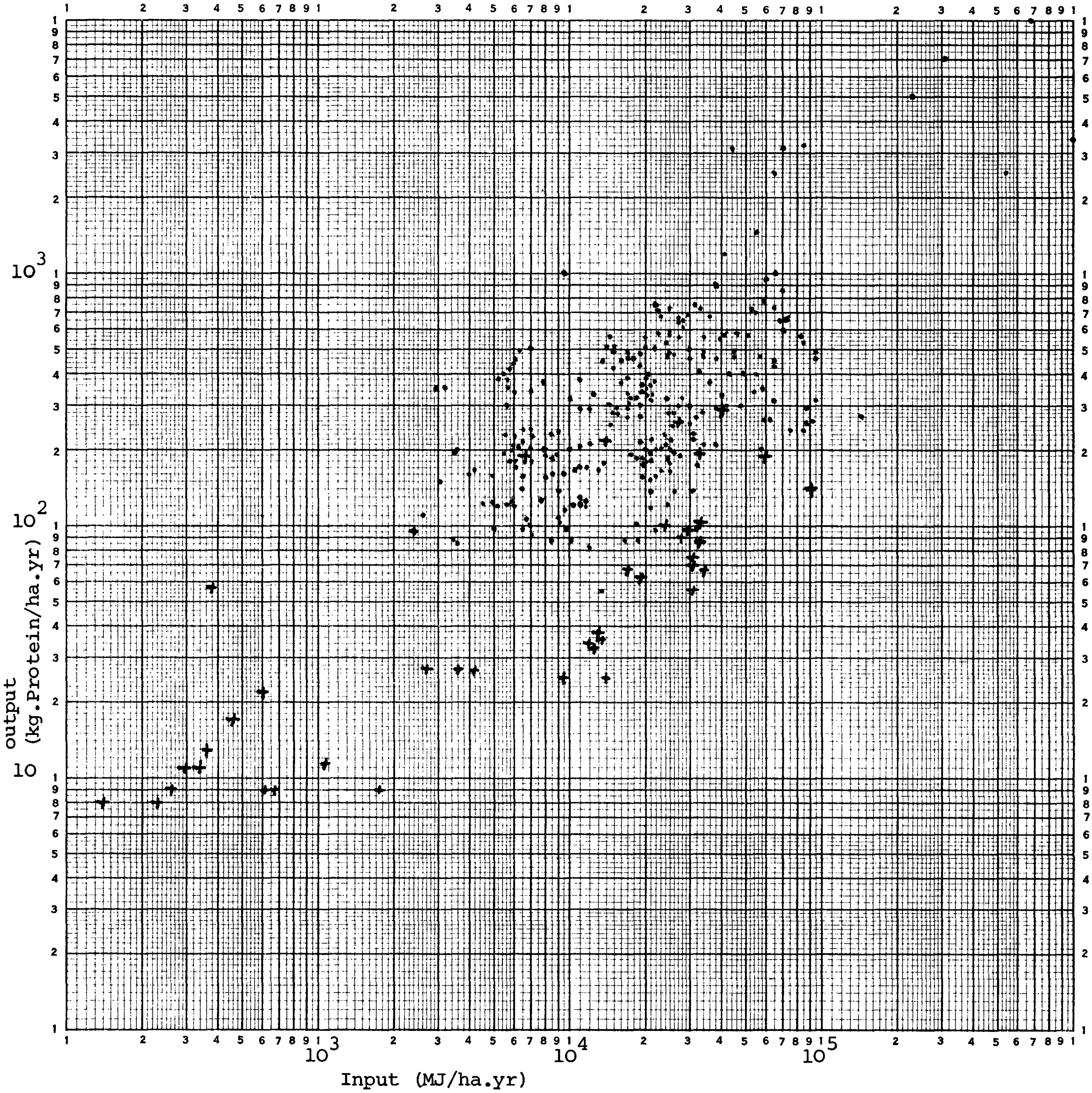


Fig.13 Protein yield for all foodstuffs versus energy intensity of production

+ meat production

• grain, fruit and vegetable production

average energy requirements for the various inputs to the farming process, simply for want of detailed data in each and every country. A second reason is that plants have their appropriate ecological niche, and farmers are not always able to cultivate those crops that do best. They are forced by the market to grow crops which are not in every case totally appropriate to their soil and climate.

If we take a particular crop, say wheat, Fig.14, we find the data is somewhat less dispersed, and certainly re-inforces the conclusions we have come to, yet in certain other crops, such as potatoes, Fig.15, the correlation is much less satisfactory, partly because we have no data which allow us to compute the different starch and protein content of various varieties of potato.

8.2 Energy efficiency of European agriculture

Appendix 5 lists the GERs for all the foodstuffs we have examined. There is no evidence to suggest that European agriculture, for the same level of output intensity (amount per hectare) is more energy intensive than that of other countries, developed or under-developed. Nevertheless the energy intensities of production in several overseas countries (with the notable exception of the USA) are much lower, but then the output intensities are also lower.

8.3 Comparison of imported food with added transport energy

Table 8 presents the data for strict comparison between the energy of production overseas plus added transport energy and European agriculture.

As far as cereal crops are concerned, there is no apparent energy advantage in growing overseas. Indeed some products from the USA are much more energy intensive, a fact that may militate against them if and when North American energy prices are raised to European levels.

There are clearly some advantages in beef and mutton produced in Australia, New Zealand and Argentina. Here farming is largely free range, with little need for winter keep, but at low intensity of output. Thus, even with the very significant energy requirement to ship mutton from, say, New Zealand (~5GJ/t) that country's mutton is less energy intensive than most European mutton.

On the debit side there are horticultural products produced under glass in northern Europe which are exceptionally energy intensive. Tomatoes are the

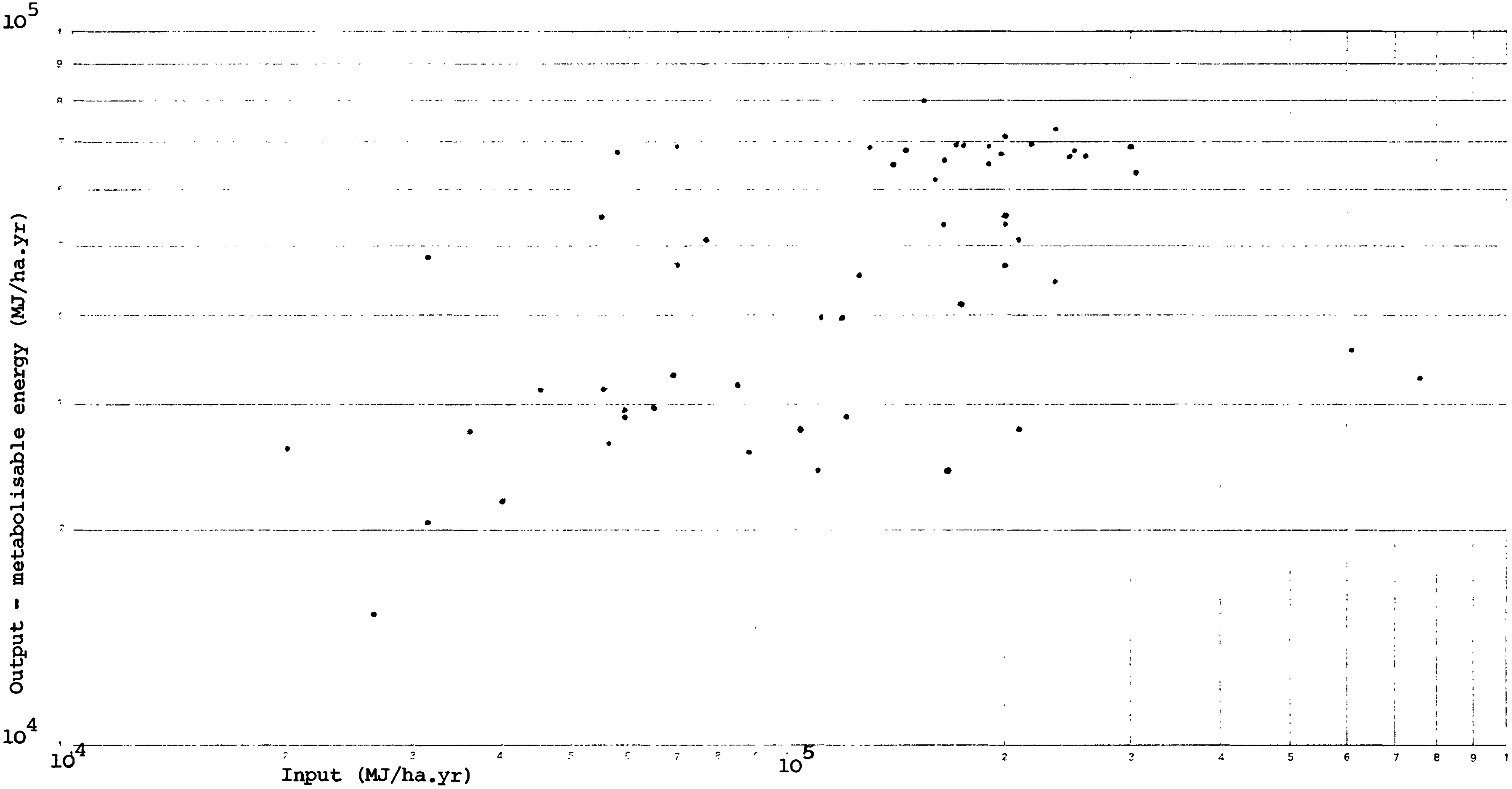


Fig.14 Metabolisable energy in wheat versus energy intensity of production

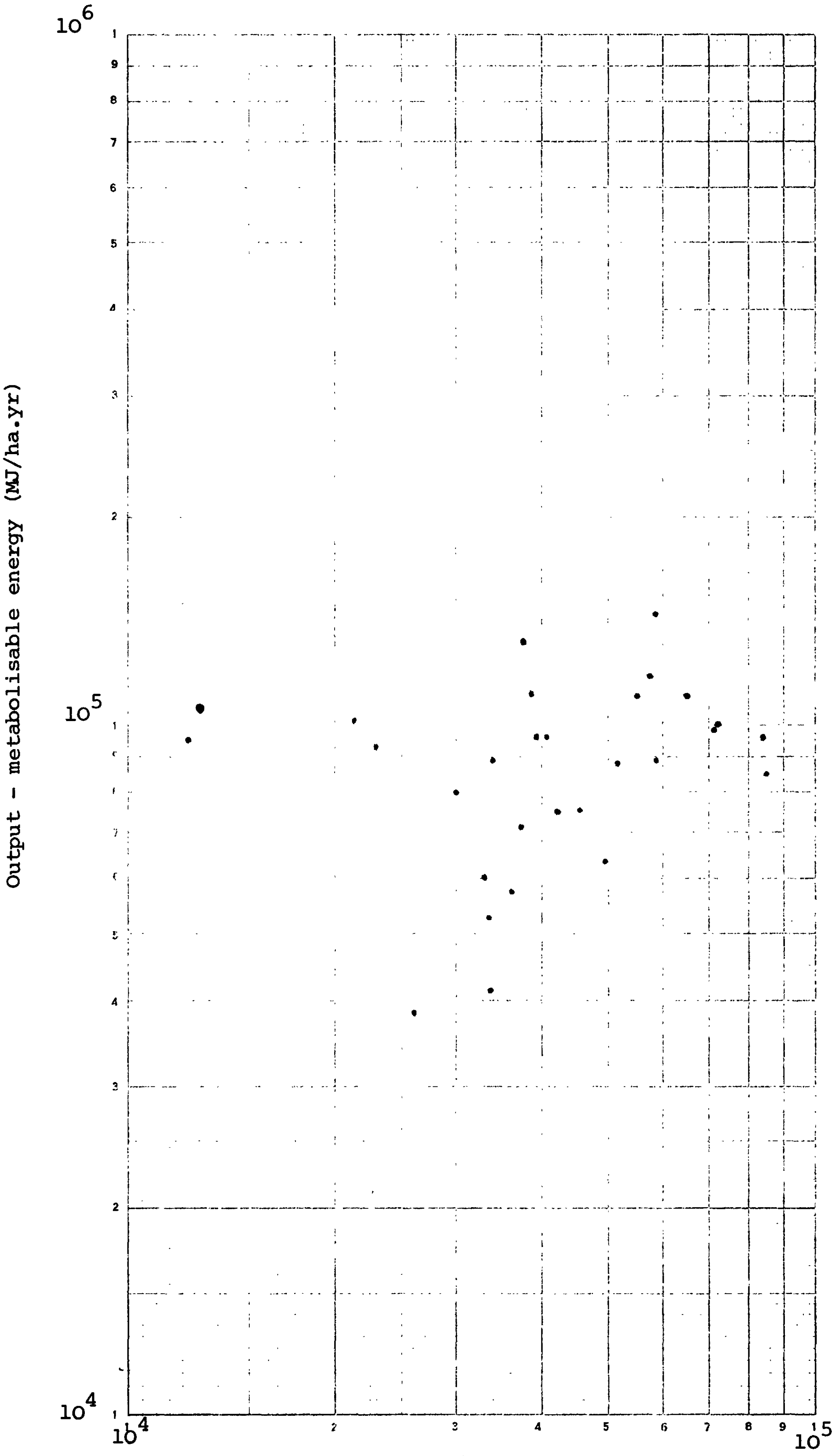


Fig.15 Metabolisable energy in potatoes versus energy intensity of production

extreme example. One tonne of Dutch or English tomatoes can require as much as 3½ tonnes of oil equivalent energy. The same amount of energy could produce a larger weight of meat, and well over ten tonnes of wheat.

8.4 Consequences of increasing imports of food

Given that the underlying reason for this study is to ascertain the energy advantage of importing food to the EEC, it is clear that one would not seek to import products which had the same or higher energy intensity as European products. Imports would therefore be restricted to those which served a special purpose, such as American wheat, or which had lower energy requirements. However from the moment imports from these overseas countries were increased, their production intensity would have to increase, thus driving upwards the energy intensiveness of their products. It is hard to say where the balance would be struck. Probably New Zealand mutton and Argentinian beef could remain substantially less energy intensive because animal wastes, if properly used, can considerably offset the energy of production.

CONCLUSION

European agriculture shows a wide spread of energy intensiveness. The evidence is that for equivalent degrees of output intensiveness, it is no more energy intensive than agriculture abroad. When transport energy is added, the majority of European foodstuffs are competitive in terms of energy intensiveness with imported foodstuffs, with the exception of mutton and beef from certain parts of the world.

The mass of data collected supports the view that output intensity in agriculture is paid for by higher energy intensiveness, and that each increment of input produces less and less additional output as intensification proceeds. Thus, given the population density of Europe (in terms of available land/capita), the answer to the question - is high energy intensive agriculture inevitable? - is in the affirmative, unless there is a deliberate reduction in animal protein production and in glasshouse products, or concerted action to recycle crop and animal wastes for their energy potential.

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APPENDICES

to

Report on Contract P EN 222

Consumption of energy in agriculture, at world level, of competing products available to the European Community

January, 1982

M Slesser and F Wallace

CONTENTS

APPENDIX 1 List of products to be examined

011	011.1	Meat of bovine species, fresh refrigerated or frozen
	011.20	" " (ovine " " " " " (caprine " " " " "
	011.30	" " pig " " " " "
	011.40	" " farmyard poultry," " " "
023		Butter
024		Cheese
025		Eggs
041		Wheat
042		Rice
043		Barley
044		Maize
045		Other cereals
046) 047) 048)		Cereal products
054	054.10	Potatoes
	054.40	Tomatoes
	054.51	Onions and similar
	054.6	Frozen vegetables
057	057.1) 057.2)	Citrus fruit
	057.4	Apples
061	061.10	Sugar (beet or cane) unrefined
	061.20	Sugar (" " ") refined
091		Margarine and cooking oils/fats

Reference numbers are to Standard Classification of International Trade Statistics of United Nations 2nd revised version 1976.

APPENDIX 2 Energy Requirements for Inputs to Agriculture

TABLE 1 Recommended Values

Input	Unit	Mega-Joules	Comment
Electricity	kwh	14	typical US,UK value after including transmission losses, 1971
Natural gas	M^3	39.1	°C, 1 bar pressure
Diesel oil	li	46.4	value at refinery gate
Gasoline (petrol)	li	42.7	value at refinery gate
Fuel oil	li	50.2	value at refinery gate
Tractor - 80hp	hour	460	direct fuel use
Tractor - 30hp	hour	150	direct fuel use
Process steam	kg	3.4	allows for boiler inefficiencies
Process water	m^3	2	catchment and treatment
Potassium: as KCl	kg	5.1	value at UK ports in 1971;
as K_2O	kg	8.0	will vary with source
as K	kg	9.7	and distance freighted
Phosphorus: as H_3PO_4	kg	5.7	Moroccan phosphates
as P_2O_5	kg	7.0	landed in UK
as P	kg	14.0	
Nitrogen: as NH_3 gas	kg	50.6	large scale modern plants
as NH_3 liquid	kg	48.3	
as HNO_3	kg	12.8	
as Urea	kg	36.0	
as $(NH_4)_2SO_4$	kg	14.5	
as $(NH_4NO_3$	kg	22.0	
as N	kg	66	global mean in 1967
Compound fertiliser	kg	16	17 : 17 : 17
Sulphuric acid	kg	nil	
Organic pesticides & herbicides	kg	128	an approximate value for 2 : 4 : D

Source:

Leach, G. and Slesser, M. 1976. Energy equivalents of network inputs to agriculture. Energy Analysis Unit, University of Strathclyde, Glasgow, Jan.1976.

Table 2 lists the figures used in French studies, and has been included for comparison.

TABLE 2

Inputs	Unit	Mega-Joules
Fuel oil	1 li	40.2
Propane gas	1 kg	50.2
Electricity	1 kwh	11.7
Fertilizer N	1 unit N	75.3
P_2O_5	1 unit P	13.8
K_2O	1 unit K	9.2
Pesticides	1 kg active matter	108.8
Lubricants	1 li	74.5

Source:

Bonny, S. (1980). Estimations des Consommations Energetiques de Quelques Productions en Systems de Grande Culture et Systems Laitiers". Document de travail, INRA, Laboratoire d'Economie Rurale. 78850-ThiVerval-Grignon.

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KEY CODE

Argentina	Arg
Australia	Aus
Austria	A
Belgium/Luxembourg	B/L
Brazil	B
Canada	C
Denmark	Dk
France	F
Germany	D
Ireland	Ir
Israel	Is
Italy	It
Morocco	M
Netherlands	NL
New Zealand	NZ
South Africa	SA
Spain	Sp
Sweden	Sw
Switzerland	Sz
Thailand	T
United Kingdom	UK
United States of America	USA

APPENDIX 5 Product Yields and Gross Energy Requirements to 'the Farm Gate'

Yield t/ha GER GJ/t	BEL/LUX	DENMARK	FRANCE	GERMANY	IRELAND	ITALY	NETHERLANDS	UNITED KINGDOM
Beef	n/f			n/a	1.3	0.04	n/f	0.6 - 1.9
		30	67 - 102		26	29 - 59		9.4 - 60
Sheepmeat	n/f	n/f	n/a	n/a	n/a	n/a	n/a	0.4 - 0.5
								52 - 68
Pigmeat	n/a			n/a	n/f		n/a	0.7
		23 - 40	82 - 85			36		24 - 49
Poultry	n/f		n/a	n/a	n/f		n/a	0.6 - 1
		38				30 - 39		24 - 73
Butter	n/f	n/a	n/a	n/a	n/f		n/a	
						58		24 - 29
Cheese	n/f	n/a	n/a	n/a	n/f		n/a	
						35 - 71		41 - 45
Eggs	n/f		n/a	n/a	n/f		n/a	
		17 - 33				9.8		
Wheat	4.8 - 5.8	n/f	3.2 - 5.3	4.5 - 4.9	4.2	2.7	5.0 - 5.3	1.1 - 4.8
	2.7 - 4.1		3.0 - 11	3.6 - 5.1	3.5	7.3	2.9 - 6.0	2.4 - 6.7
Rice	n/f	n/f	n/f	n/f	n/f	1.3 - 5.8	n/f	n/f
						0.2 - 11		
Maize (corn)	5.8	n/f	4 - 9.4	5.0 - 6.3	n/f	2.8	n/f	n/f
	2.8		0.8 - 7.7	3.7 - 6.3		11		
Barley	n/f	4.3	2 - 5	4.0 - 4.5	3.9	3.1	4.5	3.4 - 4.3
		4.5	3.3 - 6.4	2.5 - 4.8	3.7	4.7	2.9	4.4 - 8.2
Rye	n/f	n/a	n/a	n/a	n/f	n/f	3.5	3.5
							3.9	4.8
Oats	n/f	n/f	1.5	n/a	3.4	n/a	4.7	3.8 - 4.3
			7.2		4.3		3.0	4.5 - 4.7

n/a - Data not available
n/f - Data not looked for

APPENDIX 5 contd

Yield t/ha GER GJ/t	SWEDEN	SWITZERLAND	AUSTRIA	SPAIN	MOROCCO	SOUTH AFRICA	U.S.A.	CANADA
Beef	n/a	n/f	n/a	n/f	n/f	n/a	0.2 - 0.7 1 - 76	70 -77
Sheepmeat	n/f	n/f	n/f	n/f	n/f	n/f	n/f	n/f
Pigmeat	n/a	n/f	n/f	n/f	n/f	n/f	0.2 - 1 33 - 55	51 -63
Poultry	n/f	n/f	n/f	n/a	n/f	n/f	0.8 39	60 -71
Butter	n/a	n/f	n/a	n/f	n/f	n/f	0.2 80	n/f
Cheese	n/a	n/a	n/a	n/f	n/f	n/f	0.4 20	n/a
Eggs	n/a	n/f	n/f	n/f	n/f	n/f	1.5 20	n/a
Wheat	3.4 5.9	n/f	4 5.2	1.8 9.6	n/f	n/f	1.7 - 4.7 2.9 - 32	0.9 - 3.2 1.1 - 3.9
Rice	n/f	n/f	n/f	n/a	n/f	n/a	4.1 - 6.2 7 - 12	n/f
Maize	n/f	n/f	6.5 4.8	n/f	n/f	n/f	2.5 - 8.5 3.2 - 12	5.5 4.7
Barley	2.6 7.2	n/f	3.5 4.4	2.3 7.3	n/f	n/a	1.2 - 3.6 2.9 - 5.2	1.2 - 4.3 0.7 - 3.9
Rye	n/f	n/f	3.8 4.6	1.1 7.7	n/f	n/f	1.3 - 2.5 1.4 - 5.3	1.6 - 1.9 5.8 - 6.9
Oats	n/f	n/f	n/f	1.3 7.2	n/f	n/f	1.7 - 2.9 3.1 - 6.4	1.9 - 2.3 0.9 - 3.5

<u>APPENDIX 5</u> contd

Yield t/ha GER GJ/t	BRAZIL	ARGENTINA	ISRAEL	AUSTRALIA	NEW ZEALAND	THAILAND		
Beef	0.1 - 0.2 1.0 - 29	0.1 - 0.2 2.8 - 4.8	n/f	n/a	11	47		
Sheepmeat	n/f	n/a	n/f	n/a	11	n/f		
Pigmeat	n/f	n/f	n/f	n/f	0.9 31	103		
Poultry	n/f	n/f	n/a	n/f	n/f	57		
Butter	n/f	n/f	n/f	30	66	n/f		
Cheese	n/f	n/a	n/f	n/f	31	n/f		
Eggs	n/f	n/f	n/a	n/f	n/f	n/f		
Wheat	n/f	1.9 - 2.4 2.4 - 3	n/f	1.9 - 5 0.9 - 1.4	3.4 - 4.2 1.4 - 2.1	n/f		
Rice	1.1 - 4.5 1.9 - 11	3.6 9	n/f	7.5 1.8	n/f	1.2 - 1.7 4.5 - 6.4		
Maize	1.8 - 3.6 1.0 - 8.1	9.3 - 14 0.4 - 2.7	n/a	n/f	7 - 9 2.1 - 3.3	2.0 1.9		
Barley	n/f	1.9 2.6	n/f	n/a	2.8 - 5.6 1.1 - 2.2	n/f		
Rye	n/f	n/a	n/f	n/f	n/f	n/f		
Oats	n/f	2 - 2.2 2.8 - 3	n/f	n/a	2.9 2.1 - 2.5	n/f		

APPENDIX 5 contd

Yield t/ha GER GJ/t	BEL/LUX	DENMARK	FRANCE	GERMANY	IRELAND	ITALY	NETHERLANDS	UNITED KINGDOM
Sorghum	n/f	n/f	5 - 5.9 3.5 - 4.8	n/f	n/f	n/a	n/f	n/f
Potatoes	3 3 0.4	28 1.2	12 - 35 0.8 - 2.6	32 - 43 0.7 - 0.9	28 0.8	n/a	34 - 45 0.9 - 1.3	15 - 48 0.2 - 2
Tomatoes	n/f	n/f	n/a	n/f	67 19	n/a	n/a	125 - 250 88 - 160
Onions	n/f	n/f	n/a	n/f	17 5.2	n/a	45 0.6	29 - 33 0.6 - 2.8
Peas	24 0.2	n/f	2.6 - 11 1.9 - 3.8	n/f	n/f	n/a	2.9 3.2	2.8 - 4.6 2.8 - 4.3
Oranges	n/f	n/f	n/f	n/f	n/f	n/a	n/f	n/f
Tangerines	n/f	n/f	n/f	n/f	n/f	n/a	n/f	n/f
Lemons/Limes	n/f	n/f	n/f	n/f	n/f	n/a	n/f	n/f
Grapefruit	n/f	n/f	n/f	n/f	n/f	n/a	n/f	n/f
Apples	n/f	n/f	n/a	n/a	n/f	n/a	n/a	
Sugar Beet	51 0.5	40 0.7	41 - 47 0.6 - 0.7	45 - 47 0.5 - 0.7	36 0.7	n/a	45 - 47 0.5 - 1.2	35 - 38 0.7 - 0.8
Sugar Cane	n/f	n/f	n/f	n/f	n/f	n/a	n/f	n/f
Refined Sugar	n/a	n/f	n/a	4.3 32	n/f	n/a	n/a	5 18 - 25

APPENDIX 5 contd

Yield t/ha GER GJ/t	SWEDEN	SWITZERLAND	AUSTRIA	SPAIN	MOROCCO	SOUTH AFRICA	U.S.A.	CANADA
Sorghum	n/f	n/f	n/f	n/a	n/f	n/f	1.6 - 5.2 3.1 - 14.5	n/f
Potatoes	33 1.1	n/a	25 1.2	n/a	n/a	n/f	19 - 36 1.6 - 3.1	22 0.9 - 1.7
Tomatoes	n/f	n/f	n/f	n/a	n/a	n/f	49 1.3	n/f
Onions	n/f	n/f	n/f	n/a	n/a	n/f	38 1.1	50 0.7
Peas	n/a	n/f	n/f	n/a	n/f	n/f	1.6 8.3	2.3
Oranges	n/f	n/f	n/f	n/a	n/a	n/a	19 - 40 1 - 3.7	n/f
Tangerines	n/f	n/f	n/f	n/a	n/a	n/f	22 1.3	n/f
Lemons/Limes	n/f	n/f	n/f	n/a	n/f	n/a	19 1.6	n/f
Grapefruit	n/f	n/f	n/f	n/a	n/f	n/a	47 - 61 0.7 - 0.9	n/f
Apples	n/f	n/f	n/f	n/a	n/a	n/a	19 - 79 2 - 3.6	25 1.1 - 2.2
Sugar Beet	n/f	n/f	n/f	n/a	n/f	n/f	30 - 54 1.1 - 1.3	n/f
Sugar Cane	n/a	n/f	n/f	n/f	n/f	n/a	63 8.6	n/f
Refined Sugar	n/a	n/f	n/a	n/f	n/f	n/f	3.5 - 7.1 43 - 49	n/f

APPENDIX 5 contd

Yield t/ha GER GJ/t	BRAZIL	ARGENTINA	ISRAEL	AUSTRALIA	NEW ZEALAND	THAILAND		
Sorghum	n/f	2.8 - 4.5 1.4 - 2.0	n/f	n/f	n/f	1.2 2.3		
Potatoes	n/f	n/f	31 2.3	n/f	30 2.8	n/f		
Tomatoes	n/f	20 3.3	50 - 200 1.3 -10.8	n/f	n/f	n/f		
Onions	n/f	25 0.8	40 1.8	n/f	n/f	n/f		
Peas	n/f	n/f	n/f	n/f	2.5 - 4.5 2.3 - 4.7	n/f		
Oranges	2.5 - 57 0.2 - 2.8	n/a	42 2.1	n/a	n/f	n/f		
Tangerines	n/f	n/f	33 2.8	n/f	n/f	n/f		
Lemons/Limes	n/f	20 1.4	42 2.3	n/f	n/f	n/f		
Grapefruit	n/f	n/a	63 1.5	n/f	n/f	n/f		
Apples	n/f	31 5.1	n/f	n/a	n/a	n/f		
Sugar Beet	n/f	n/f	n/f	n/f	n/f	n/f		
Sugar Cane	n/a	n/f	n/f	n/a	n/f	32 - 53 0.3 - 0.5		
Refined Sugar	6.5 7.1	n/f	n/f	n/f	n/f	n/f		

APPENDIX 6 Transport Energy

A.6.1 Energy from European farm gate to consumer

To establish the energy dissipated in conveying food from the farm gate to 'Mr Average European Consumer' is akin to asking how long is a piece of string. Undoubtedly a highly detailed study could arrive at an answer for one household with a particular lifestyle. To provide an answer for all consumers is impossible.

We can get closer to an answer if we look at transport not by consumer but by product. What is the average transport energy of wheat from the farm gate to the flour mill; from the mill to the baker; from the baker to shop; and from the shop to consumer. Let that number be T GJ/tonne of wheat.

Since the purpose of this study is to compare the energy to produce wheat (say) in Europe as opposed to wheat grown abroad plus the transport to Europe, the only question that need be resolved is whether the energy to transport wheat from a European farm gate to a European consumer is different from a European port of entry to the European consumer. The answer can only be that such a difference must be trivial, and unaccountable. Hence, in ascertaining transport energy impact we have ignored internal European transport energy, and added only transport energy from the overseas farm gate to European port of entry.

A.6.2 Energy from overseas producer to European port of entry

Three modes of transport need to be considered: truck or rail from the farm to port, and ship transport to Europe.

The calculation of these transport energies present two different problems. Firstly, many of the overseas producers are situated in large continental areas, where the transport distances vary enormously. In such cases the centre of each major producing area has been taken as representative of all producers in that area. For example, American wheat is largely shipped from Chicago. The centre of the wheat producing area has been taken as 650 km from Chicago. Secondly, it is a formidable task to get detailed knowledge of the transport means in each and every case. Were the products conveyed in rail cars, twelve tonne trucks or small lorries? Were there loads on these vehicles on the return journeys? In this study it has been assumed that there were no return loads (except where very detailed information, as in Thailand, showed there were). The distinction between large trucks, small lorries and rail cars is blurred when one looks at the published data on energy used in these various forms of transport. Table A6.1 notes a number of sources, and it may be seen that the data varies widely, to the extent that it cannot serve any purpose to consider each journey in detail other than to note that it is by surface.

Reported data on ship transport also show wide variations, though this is more closely related to ship type, whether 100,000 tonne bulk carrier or smaller refrigerated cargo vessel. This data is summarised in Table A6.2.

The mileages for ship transport have been taken from a large scale map of the world. Where the Suez canal is used, Marseilles is taken as the appropriate port of entry, while voyages using the north or south Atlantic are assumed to terminate at Rotterdam. For all voyages greater than cross Atlantic, the differences in energy use between a west coast UK port and an east coast continental port are small, perhaps 0.2 GJ/t. Perhaps the greatest difference would be between Glasgow (N. Atlantic) or Bristol (S. Atlantic) (least) and Copenhagen (most).

At the start and end of each voyage there is a significant energy use in loading and unloading, estimated by Mortimer of the Open University to be 0.08 GJ/t for each.

A.6.3 Transport energy

The final calculation was done using the equation below

GER (with transport) = GER (at farm gate) GJ/t (Appendix 5)
+ (land distance (km) x 0.5) / 1000 GJ/t
+ 0.16 GJ/t (loading and unloading)
+ (sea distance (km) x 0.12) / 1000 GJ/t (grain)
or x 0.40 / 1000 GJ/t (meat, vegetables, fruit)

Land and sea distances used in the computation are given in Table A6.3.

TABLE A.6.1 Surface transport energy

		Source	MJ/t.km
Rail	1.	C J Clemow, British Railways Inst. Energy Conf.1975, London	0.08
	2.	G Hirst, Oak Ridge Lab. USA Report ORNL-NSF -EP - 44 (1971)	0.45
	3.	S N C F	0.2 - .4
	4.	100 Wagon train, Slesser 'Energy in the Economy', McMillan,London 1978	0.43
	5.	H.Nebelung, EC report VII/212/78-EN	0.5 - 1.0
Road	1.	G Hirst, Oak Ridge,Lab.USA Report ORNL-NSF-EP-44 (1971)	1.5
	2.	H Nebelung EC Report VII/212/78-EN > 2t,motorways	2.0
	3.	U S Report (ANON)	2.5

Assuming short trucking (road) distances and long rail haulage a selected "mean" of <u>0.5 MJ/t.km</u> is taken

TABLE A.6.2 Marine transport energy

	Source	MJ/t.km
Bulk carriers 100,000 t	N D Mortimer, Open University England, Report ERG 007, 1974	0.12
50,000 t	" "	0.47
	G Giocomazzi, Seaborne Energy transportation, JRC, Ispra EST/79/16	0.55
	Crafts-Lightly, J.Sci.Food Agric.1980, 31	0.22
60,000 t	H P Drewry, Shipping Consultants,London 1978	0.79
3,000	Less than 1800 km	1.1
25,000t	H P Drewry, Shipping Consultants London	0.12

TABLE A.6.3 Land and Sea Distances

SEA	km
Chicago - Rotterdam	6000
Thunder Bay (Canada) - Rotterdam	5800
New Orleans - Rotterdam	6500
Buenos Aires - Rotterdam	7350
Fortaleza (Brazil) - Rotterdam	4500
Porto Allegre (Brazil) - Rotterdam	6330
Capetown - Rotterdam	6150
Haifa - Marseilles	1700
Thailand - Marseilles (via Suez)	7200
Melbourne - Rotterdam (via Cape)	12400
Melbourne - Marseilles (via Suez)	9600
Brisbane - Marseilles (via Suez)	9700
Auckland - Marseilles (via Suez)	10700
Auckland - Rotterdam (via Cape)	14000

LAND	km
Argentina	400
Brazil : Porto Allegre	300
: Fortaleza	400
USA	650
Canada	1000
South Africa	300
Israel	100
Thailand	160
Australia	600
New Zealand	200

A.6.4 Sensitivity analysis

Consider the impact of large errors in transport energy calculations on the conclusions of this report. In Table A6.4 the GER of wheat from the USA, mutton from New Zealand, and fruit from Israel are compared with the values computed from the relation in this Appendix para.A.6.4.

TABLE A.6.4

	Average GER	Transport GER	Transport GER assuming 20% lower transport energy	Transport GER assuming 20. higher transport energy	Error as percentage of GER product landed in Europe
Wheat USA	4.3	1.2	0.96	1.44	4%
Mutton N.Zealand	11	5.9	4.72	7.08	7%
Fruit Israel	2.2	0.9	0.72	1.08	6%

European Communities — Commission

Energy consumption per tonne of competing agricultural products available to the EC

Luxembourg: Office for Official Publications of the European Communities

1982 — 82 p. — 21 x 29,7 cm

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This study, initiated by DG VI, ascertains the energy intensity of the European Community's agriculture by product, and compares it with countries exporting, or potentially able to export, to the European Community.

It is clear that while modern European agriculture is energy intensive, for comparable yields per hectare, it is not more so than other countries. In fact, to the farm gate, European agriculture consumes rarely more than 4 % of national energy consumption, even taking into account indirect energy involved in creating the inputs to agriculture. An exception is Denmark, a country with large imports of energy intensive animal feedstuffs.

Data have been collected on 26 crops in 22 countries. It confirms that intensification of agricultural output is necessarily accompanied by intensification of inputs, which when quantified in terms of the energy used to create them reveals that the ratio of energy resources expended to the metabolisable energy produced steadily rises as intensification proceeds. For example, to produce 10 GJ of metabolisable energy from one hectare (e.g. 725 kg wheat) requires (on average) inputs whose energy requirement of production totals 6 GJ — an energy ratio of 1.66. A more intensive agriculture system which produces 20 GJ/hectare (e.g. 1450 kg wheat) requires inputs equivalent to 18 GJ, an energy ratio of 1.1. A high level of intensification to yield a 100 GJ/hectare requires an energy input of 120 GJ, an energy ratio of 0.8. There seems no escape from this fact, though by appropriate use of farm wastes this relation can be weakened.

However, many overseas territories, having low population densities, can, if they wish, produce food at low intensities, and hence for lower energy requirements. Examples are Argentinian wheat and New Zealand mutton. Yet a true comparison must take into account the energy of transport. In general it is found that imported meat or meat products from America (South and North) and Australasia are less energy intensive than European products, though some European production is of a low production intensity and hence of low energy intensity.

When it comes to dairy products, European producers are no more energy intensive than those overseas, while for cereals, the difference once energy for transport has been added, is negligible. As for refined sugar, that produced from European sugar beet is actually less energy intensive than US sugar, and comparable to that from other overseas producers.

Thus, there seems no case for substituting imported foodstuffs for European products upon an energy basis. Indeed, as the world's population grows, pressure to increase food output must inevitably push up the intensification of those countries with currently low productivity systems, so that on an energy basis the trend is moving in Europe's favour, especially given Europe's low population growth.

This study is only published in English.

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