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Energy Requirements of Development Projects

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OPERATED BY
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Energy Division

ENERGY REQUIREMENTS OF DEVELOPMENT PROJECTS

Donald W. Jones
and
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EXECUTIVE SUMMARY

Most strategies for economic development include the introduction of major agricultural and industrial projects, often with the assistance of international donor organizations. For example, an industrial development strategy may include one or more new steel, chemical, or cement manufacturing plants; and an agricultural development strategy may include one or more large-scale irrigation or mechanization projects. Although these are not energy projects as such, they may have significant implications for the host nation's energy requirements.

This report focuses on the energy requirements of pumped irrigation and cement plants as examples of the energy operating requirements of large development projects. For this purpose, it calculates energy requirements to power hypothetical large-scale, pumped irrigation projects in the Sahel and other countries just south of the Sahara and the requirements to operate actual, recently opened, or planned cement plants in five West African countries and Sudan.

Based on optimistic assumptions about the nearness of the water table to the surface and the efficiency of operating pumping systems, using pumped irrigation to increase by 5% the arable land area of the countries studied would require energy equivalent to 4-1/2% to 8-1/2% of 1980 energy imports or commercial energy consumption of four of the countries; Somalia and Chad would require 15% and 22% of their 1980 oil import or consumption levels -- partly because of relatively large, marginally arable land areas and partly because of low energy imports (commercial consumption). Table 1 shows these estimates.

The introduction of one or (at most) two moderate-sized cement plants into five West African countries and Sudan requires from 12% to 40% of those countries' 1980 national commercial energy consumption for their operation. These calculations assume high levels of maintenance and developed country standards of fuel efficient operation; therefore actual fuel requirements are likely to be higher. The countries studied have few or no domestic fuel supply options other than imports. Table 2 shows the impacts of these cement plants.

These calculations are generic in the sense that they do not take into explicit account all the relevant conditions surrounding irrigation or cement production in each country, but the errors so introduced into the calculations generally bias the projected energy calculations downward, probably substantially. Although the calculations are in the nature of examples, they indicate that new development projects of only moderate size often put substantial demands on national energy supplies. The cement plants' requirements are likely to be representative of the energy usage of steel and chemical plants as well. The clear implication is that economic development will almost always require substantial additional energy inputs on a continuing basis.

ABSTRACT

This report focuses on the energy requirements of pumped irrigation and cement plants as examples of the energy operating requirements of large development projects. Based on conservative assumptions about the nearness of the water table to the surface and the efficiency of operating pumping systems, using pumped irrigation to increase by 5% the arable land area of the countries studied would require energy equivalent to 4-1/2% to 8-1/2% of 1980 energy imports or commercial energy consumption of four of the countries; Somalia and Chad would require 15% and 22% of their 1980 oil import or consumption levels -- partly because of relatively large, marginally arable land areas and partly because of low energy imports (commercial consumption). Table 1 shows these estimates.

The introduction of one or (at most) two moderate-sized cement plants into five West African countries and Sudan requires from 12% to 40% of those countries' 1980 national commercial energy consumption for their operation. These calculations assume high levels of maintenance and developed country standards of fuel efficient operation; therefore actual fuel requirements are likely to be higher. The countries studied have few or no domestic fuel supply options other than imports. Table 2 shows the impacts of these cement plants.

1. INTRODUCTION

1.1 ECONOMIC DEVELOPMENT AND ENERGY

Economic development introduces commercial-fuel-using production and consumption activities which were not conducted previously. As a process of overall modernization, development additionally involves systematic changes from human- and animal-powered energy to commercial fuel use and, in production processes which use fuel, from traditional fuels to modern fuels and power sources.[1] Large development projects characterize this augmentation and upgrading of productive capital stocks in Third World countries, but the new capital requires fuel for its operation, particularly modern fuels.

Construction of large capital facilities without making provision for the supplies of inputs to operate them can result in low capacity utilization or even shut-down of the plants themselves or serious interruptions in supply systems in other parts of the economy. For example, recent construction of a new international airport in Tanzania required extensive and unforeseen haulage of gravel by diesel trucks; the entire country's transportation fuel supply was disrupted by the demand for diesel to haul the gravel. Construction energy use aside, operating energy requirements of a single, modestly-sized industrial plant can amount to a third of national commercial energy use in a small, developing country. Indeed, for certain planning purposes, development projects should be characterized as either energy producing or energy consuming ones.

If new, highly energy intensive manufacturing plants are installed in developing countries, enough fuel may be imported routinely (or produced, in the rare case) to supply them, but possibly not without disrupting other users. Clearly, a one-third increment to commercial fuel supplies may be available for use in a new activity, but supply distribution systems may be inadequate to handle an additional load of one-third and maintain supplies to other users. The rapid introduction of new fuel-using factories also raises a financing problem. The fuel is generally purchased and used prior to the production of products which could directly or indirectly earn foreign exchange. If cement is exported it can earn foreign exchange immediately, but if it is used in industrial or residential construction, the foreign exchange paybacks will be slower; if it were used in road construction to improve agriculture's access to outside markets, several years could elapse before

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[1]Hydrocarbons and hydroelectric and nuclear power often are called "modern" fuels. Traditional fuels enjoy widespread markets, making the use of the term "commercial" fuels to distinguish coal and oil on the one hand from wood and charcoal on the other technically incorrect and misleading at best, but we bow to the convention.

production rose enough to cover the import bills for the fuels used to produce the cement. A country could experience international sector disruption from large, short-term borrowing to cover fuel imports.

This study finds that a single, moderately sized development such as a cement plant could increase the modern energy consumption of a small country by 15% to 40%. With falling oil prices recently, concern for energy as a development issue has fallen, but when installing two factories to assist in the development of a country could increase its aggregate energy consumption, energy is still a problem. Consumption increases could compensate fully for price increases, leaving heavy foreign exchange burdens. Subsequent oil price increases could be disastrous.

1.2. SCOPE OF THIS REPORT

This paper identifies some common types of capital development projects for both agriculture and industry and, as examples of energy requirements for economic development, estimates the energy requirements to operate them. Focusing on countries of the Sahelian region of West Africa along with other countries further east, we have selected one type of project each from the agricultural and industrial sectors and have identified the energy implications of either a hypothetical project or planned or recently executed actual projects. In the agricultural sector we have examined the energy requirements for large-scale pumped irrigation; in the industrial sector, we examine cement plants as an example. Irrigation is the principal method for increasing arable land in this region and for making the productivity of existing arable land more reliable. Cement is a major input for construction, which is a key sector when many new facilities are being built in connection with a country's economic development.

The magnitudes of the energy requirements to operate these types of projects are evaluated against either the energy imports or commercial energy consumption of these countries in 1980. This offers some perspective on the potential disruptiveness to the rest of the economy of meeting their energy needs. The energy requirements calculated should not, however, be taken as predictions of energy use. They are estimates of the energy required to operate the specified project or plant under generic sets of conditions which may actually vary considerably from those found in the particular country. We make every effort, however, to err in the direction of underestimating energy requirements. For example, in the case of pumped irrigation, we assume a fairly high efficiency of pump operation, sustainable only by levels of maintenance which are unlikely to be attained in a typical developing country. Additionally, we assume a standard height of lift of the water of only 13 meters, which is reasonable (or even possibly high) near river beds but is low as a general average. In the calculations of cement plant energy requirements, we have used operating specifications from new plants in the developed countries. New plants built in developing countries may install state-of-the-art equipment but the maintenance capacity required

to keep operational efficiency high may not exist. Consequently, we anticipate that although our overall estimates are unable to match the conditions of each country exactly, the errors are on the low side.

2. ENERGY REQUIREMENTS IN AGRICULTURAL PROJECTS: THE EXAMPLE OF PUMPED IRRIGATION

Pumped irrigation is the principal method for expanding the stock of arable land and for improving the reliability of yields from existing arable land in many developing countries.[2] Water availability is particularly important to realize the benefits which can be obtained from commercial fertilizer application and most higher yielding seed varieties. In drier areas, such as the Sahelian countries of West Africa, pumped irrigation may be considered as a large scale undertaking to address major problems in the long term viability of agriculture.

While irrigation pumping is not notoriously energy intensive, it is one of those activities in which small unit costs become very large when the activity is undertaken on a major scale. This section develops some generic estimates of energy inputs required to increase the arable land by 5% in six countries just below the Sahara which have perennial aridity problems. The assumptions surrounding the estimates have been tailored to the general region in terms of pumping depths, water requirements and pump types, but do not fully address country-specific intricacies such as aquifer recharge capacities, specific pumping depths in particular regions, etc. We have made every effort, however, to err on the side of making low energy requirements predictions. The following section describes the details of the energy requirements calculations and shows how to recalculate energy requirements with modified assumptions. The subsequent section presents generic calculations based very generally on the situations of the six African countries. The last section discusses the appropriateness of the mechanical operating assumptions and the generic, regional assumptions for the specific countries. For example, modifications of the assumptions for greater country specificity generally would increase the figures for pumping depths; and the pump operating assumptions presume better maintenance than is likely to be performed.

2.1. CALCULATIONS OF ENERGY REQUIREMENTS

Irrigation involves a choice between electric, gasoline and diesel pumping systems. Diesel pumps were selected as the example for this study because of a presumption of greater flexibility of diesel systems relative to electric pumping (i.e., electricity distribution systems are unnecessary) and because diesel engines appear to be used more frequently than gasoline engines in West Africa. Because irrigation can be undertaken in small blocks or large, we make calculations for both small and large diesel engines. The small-engine calculations are representative of 10 to 20 horsepower engines operating at 70% to 80% loads; the large-engine calculations describe engines as large as 1,000 horsepower. The pump efficiency specifications range from 0.70 to 0.85, which are generous. These engine sizes, pump efficiencies and lift depths are

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[2]Pingali and Binswanger (1984).

similar to those noted by Keller et al. in their study of U.S.A.I.D.-supported irrigation in Senegal.[3]

Figure 1 graphs the diesel fuel requirements to put one millimeter of water on one hectare of land with a small diesel engine (with an efficiency factor of 0.25) and with a large engine (efficiency of 0.35). Figure 2 presents the same calculations scaled to gallons and acre-feet of water. The figures are used as follows. Determine the area to be irrigated; multiply that by the depth of water to be put on that land; multiply that product by the distance the water must be lifted by the pump. Find the number resulting from those multiplications on the horizontal axis of the graph; read upward to the large engine or small engine line; read off the vertical axis the diesel fuel requirements. For example, consider putting 100 mm of water on one hectare, lifting the water a height of 10 meters: 100 x 1 x 10 = 1,000 = 10^3. Find the 10^3 point on the horizontal axis, read up to the N_e = 0.35 line for the large diesel engine, then read across to the vertical axis and find that just under 10 liters of diesel fuel are required to accomplish this. Somewhat more than 10 liters would be required with smaller engine (the N_e = 0.25 line). Appendix I reports the calculations in detail.

2.2. COUNTRY RESULTS

Table 1 presents sample calculations of energy requirements for diesel pumped irrigation undertaken on a large scale in countries of the Sahel and several other countries farther to the east. The numbers of that table are based on calculations from Fig. 1, assuming that 560 mm of water are lifted 13 meters. The numbers in Table 1 are percentages of the countries' 1980 energy imports or commercial energy consumption which would be required to increase the arable land by 5%. The percentages vary across countries for only two reasons: 1) 1980 arable land areas varied; and 2) 1980 energy imports or commercial energy consumption varied. We have assumed identical depths of groundwater and irrigation water requirements (560 mm). The irrigation water requirements may vary because of differences in rainfall and evaporation as well as differences in crops. Groundwater depth, and hence lift, varies both between and within countries. We also ignored aquifer recharge problems ("draw-down"), which may cause further differences in groundwater depths at the same locations over time.

The particularly high percentage of 1980 commercial energy consumption required for the hypothetical irrigation in Chad and Somalia are reflections of their low commercial energy consumption and imports rather than indications of particular physical or economic difficulties in irrigation or especially large areas of arable land in those countries. The two figures for Sudan indicate the requirements to increase all arable (currently irrigated plus currently unirrigated) by 5%, and requirements to increase only the currently irrigated portion by 5%. In

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[3]Keller et al. (1982), pp 46-48.

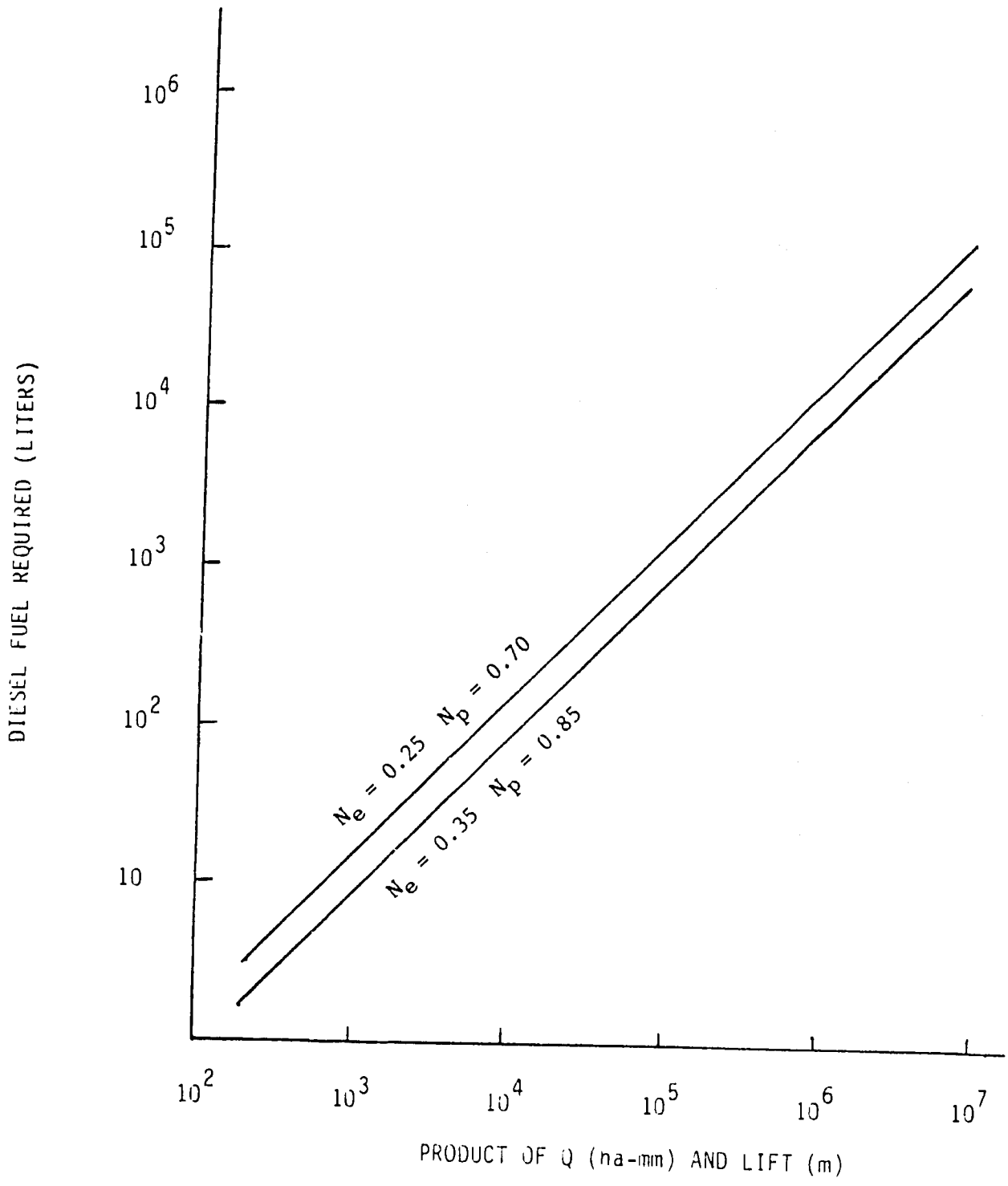

Fig. 1. Metric calculation chart for energy requirements of pumped irrigation: diesel fuel required vs. product of quantity of water pumped and lift.

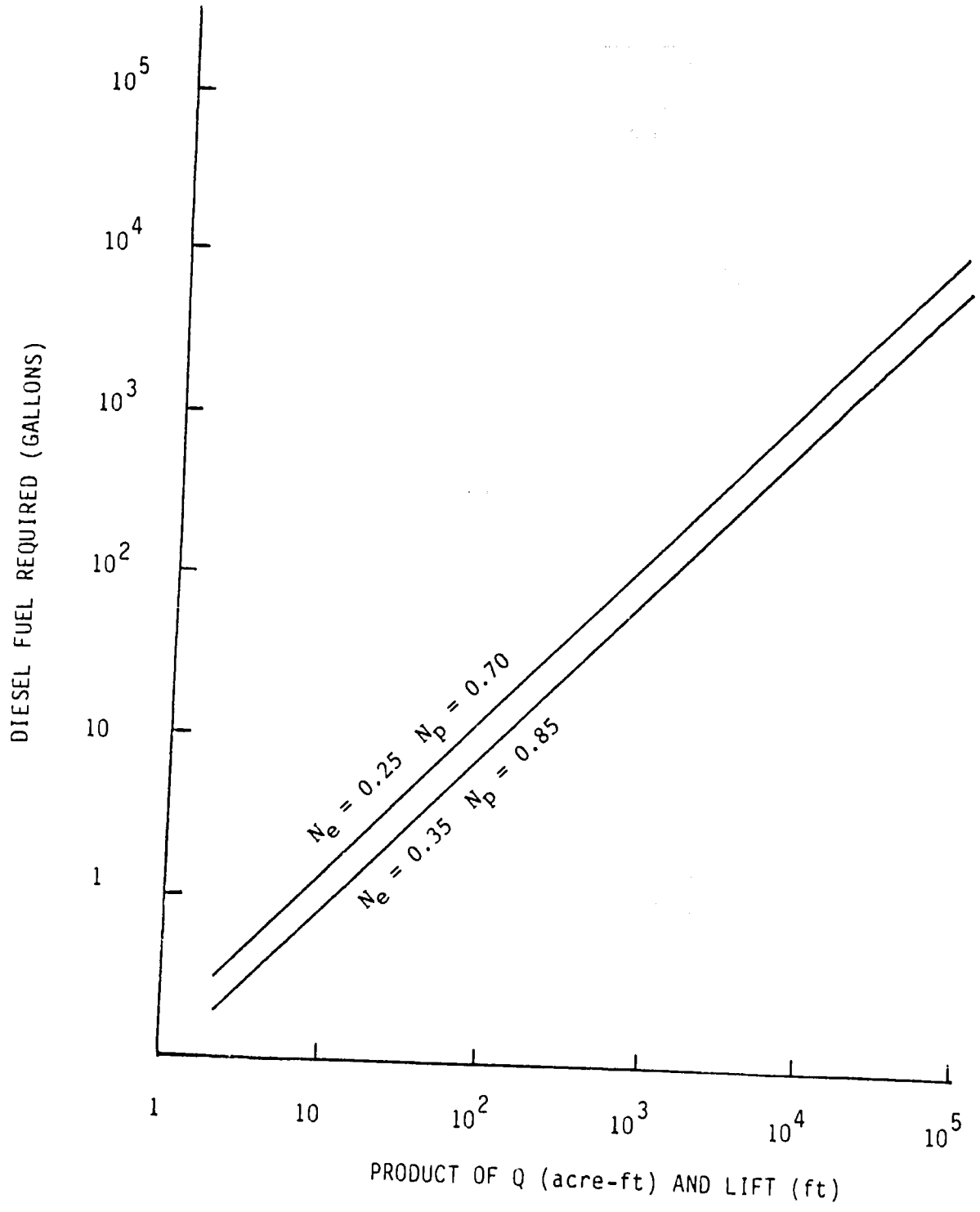

Fig. 2. U.S. calculation chart for energy requirements of pumped irrigation: diesel fuel required vs. product of quantity of water pumped and lift

Table 1. Energy requirements to increase arable land by 5% through pumped irrigation*

	Irrigation Energy Requirements as % of Imports or 1980 Commercial Energy Consumption
Chad	22.60[a]
Mali	8.10[a]
Mauritania	4.52[a]
Niger	8.50[a]
Somalia	15.86[b]
Sudan	4.88[b]
	0.75[c]

*Calculations assume 560 mm per hectare per year of water coverage and 13 m lift.

[a]Energy requirements as percent of 1980 commercial energy consumption.

[b]Energy requirements as percent of 1980 commercial energy imports.

[c]The energy requirement to increase the currently irrigated area in Sudan by 5%.

Mali, Mauritania, Niger and Sudan, the energy requirements amount to somewhere between 4-1/2% and 8-1/2% of total commercial energy requirements.

The oil price increases of 1979 may have unduly influenced energy consumption in these countries in 1980, and to check for this bias, two alternative bases of commercial energy consumption were examined, with the results presented in Appendix III. First, we calculated the percent adjustment to 1980 commercial energy consumption required to maintain 1979 per capita consumption. To allow for the possibility that commercial energy consumption was unusually high in 1979, we also calculated the percent adjustment to maintain the 1978-1979 growth trend in per capita consumption through 1980. For most of the countries of Table 1, little difference would be made by using either of these alternative measures of commercial energy consumption. The largest adjustment is for Somalia, which would require a 5% increase in the 1980 figure to maintain 1979 consumption, or a much larger 35% increase to maintain the 1978-79 trend through 1980. At 15.86% of 1980 energy imports, Somalia's irrigation energy requirements are the second highest of any country in Table 1, but using the alternative energy import bases would reduce that percentage only to 15.10% or 11.75%, leaving the basic message for Somalia unchanged.

2.3. MODIFICATIONS OF ASSUMPTIONS

2.3.1. Groundwater Depths

Some scattered information on groundwater depths is available which offers a more substantive reference for the limitations of the 13-meter pumping height assumption. The 13-meter lift of the water appears to be particularly low for Niger, Somalia and parts of Sudan. For some parts of Mali it is a little low, for others, somewhat high. Margat reports groundwater depths in the multi-layer aquifer of the Continental intercalaire, in the Niger sedimentary basin (in Niger) of 100 m to 700 m, with drawdowns upon exploitation of only 10 m in some areas, but up to 100 m in others.[4] Morris et al. cite depths of 2.5 m to 20 m in the southwest part of Niger, and around 8 m in the Komadougou Valley in the southeast near Lake Chad.[5] For central Somalia, Pozzi et al. list well depths mostly in the range of 100 m to 115 m, although some are under 90 m and others are over 125 m.[6] Estimates of groundwater depths in Sudan vary widely. In the Tokar Delta, on the Sudanese Red Sea coast, groundwater is found in depths from 3 m to 12 m,[7] but in Kordofan Province,

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[4]Margat (1982).

[5]Morris et al. (1984), pp 72, 76.

[6]Pozzi et al. (1983).

[7]Hussein (1982).

depths of most wells are in the 80 m to 120 m range, with some depths to groundwater in excess of 200 m.[8] In three regions surveyed in southwestern Mali, groundwater depths were from 1 m to 30 m, around 10 m, and from 1 m to 15 m, with drawdowns of 5 m to 6 m which would, of course, increase the effective pumping height if large-scale pumping were undertaken.[9]

There is considerable variation within countries in groundwater depths, with some areas probably out of economic pumping range. Depths are lower near rivers, often under the 13 meters assumed. In some areas of Mali in particular, however, river blindness keeps people at a distance from the actual river. The 13-meter pumping height assumption excludes the potential drawdowns of aquifers upon large scale exploitation. Additionally, the groundwater depths noted above do not include the head of the water pipes above ground or friction losses. Overall, an average 13-meter lift does not seem an excessive assumption for these countries.

2.3.2. Maintenance and Pumping Practices

As noted above, we assume a level of maintenance on engines and pumps which would be found in a developed country. Borst describes widespread maintenance and spare parts problems in U.S.A.I.D.-supported irrigation projects in Africa,[10] and Keller et al. describe "grossly inadequate" maintenance on pumps in Senegal (which cannot differ much in practice from the countries examined here), severe enough to shorten equipment life by five-sixths.[11] Keller et al. note additionally that pipe installation and repair practices usually add 2 m to 3 m of unnecessary lift to the water.[12] We have not made allowances for such deviations in our energy requirements calculations.

Furthermore, we have assumed a water flow sufficient to permit efficient operations that may not be valid for small pumping operations. For example, Lovejoy, in a study of small systems for village water supplies, notes a study carried out by the Government of Cyprus that found overall diesel/pump efficiencies of only 4%, which is lower than the 6% to 9% often quoted in World Bank studies and far below the 17% to 29% used in our analysis.[13]

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[8]Rodis et al. (1968), pp 23, 25, 36-43.

[9]Bahr (1980-81).

[10]Borst (1984), pp 14-21.

[11]Keller et al. (1982), pp 50-51.

[12]Keller et al. (1982), p. 52.

[13]Lovejoy (1985).

3. ENERGY REQUIREMENTS IN INDUSTRIAL PROJECTS: THE EXAMPLE OF CEMENT PLANTS

Large industrial projects often are seen as the pride of a country's leadership and of donor agencies supporting them. Steel, chemicals (including fertilizer) and cement plants are seen not only as contributors to national stature but also as basic industries which provide the infrastructure for development. They produce a high proportion of producer goods and may be important in saving foreign exchange.[14] These also happen to be exceptionally energy intensive industries, even when operated at high economic efficiencies.[15] In fact, the normal operating energy requirements of modest-sized manufacturing plants can make a large dent in the commercial energy supplies of a typical, small developing country. As a result, introducing such plants raises the danger of a disruption in a country's national energy system.

We have chosen cement plants as an example of the energy demands of typical large industrial projects. The products of steel and chemical plants can vary much more than do the products of cement plants, and the production processes and energy inputs vary accordingly.[16] Consequently, much more information on products and processes (often unavailable) would be required to calculate energy requirements for steel and chemical plants.

The following section summarizes the calculation procedure for the energy requirements; more details are in Appendix II. The subsequent section reports the calculated energy impacts of actual, new or planned cement plants in five West African countries and Sudan. A discussion of possible modifications of energy source assumptions underlying the calculations indicates that few, if any, options exist in the intermediate-term future which would reduce most of those countries' dependence on imported fuels for cement plant operation.

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[14]Although they can, of course, lose foreign exchange.

[15]See the energy intensity comparisons for United States four-digit SIC industries for 1967, in Meyers et al. (1974), Table 1-4, pp 22-23. Subba Rao et al. (1981, Table 12.6, p. 217) offer energy-intensity figures for 2-digit SIC industries in India for 1978/79; they accord with the United States figures.

[16]See Cameron et al. (1980) on energy use in production of various chemicals, and Flanagan et al. (1980) on energy use in iron and steel; both are for production in the United States. More on energy use variations in steel, with an international comparison, is offered by Meunier and de Bruyn Kops (1984), particularly Table 8, p. 26, and Table 9, p. 31. On variations in feedstocks in Egyptian fertilizer production, see Choksi et al. (1980), pp 160-170.

3.1. CALCULATION OF ENERGY REQUIREMENTS

Energy consumption data on state-of-the-art cement manufacture were taken from Fog and Nadkarni.[17] Appendix II reports energy use per ton of cement for currently operational plants, most new equipment, and what is anticipated for the most recent and future plants. The latter figures, being the most optimistic about energy efficiency, were used in the calculations of energy requirements reported here. Information was obtained on capacities of, and raw materials used in, currently constructed and anticipated cement plants in five countries of West Africa and Sudan.[18] The only fuel use described in U.S. Bureau of Mines reports assumes that the plant in Benin was oil-fired. This assumption was made for the other plants as well. The anticipated tonnages were multiplied by the ton of oil equivalent (toe) of energy requirements to produce cement according to the calculations noted above.

3.2. COUNTRY RESULTS

Table 2 reports the plant descriptions and the energy requirements to operate them as percents of 1980 national commercial energy consumption. The cement plants are neither unusually large by international standards nor inefficiently small, but the relative amounts of national energy consumption they could require, in efficient operations, are large in most cases. The 1.2 million ton per year plant in Togo would cause the largest bite into the energy supplies of any country examined, at almost 40% of 1980 total national consumption. The plant is planned to produce exports to Ghana and the Ivory Coast as well as to supply domestic demands, so some foreign exchange earnings are envisioned, although as noted above, that may be insufficient to prevent noticeable disruptions in the domestic energy system. The plants in Benin and Niger also are large enough to be major claimants on national energy supplies. The Upper Volta (Burkina Faso) plant may produce cement from imported clinker rather than from limestone, which would drastically reduce the energy requirements. The plants in Sudan have a large total capacity, but their energy inputs are measured against a much larger base, reducing their share of national consumption.

Cement production offers some room for interfuel substitution among coal, oil and gas, and between those three fuels on the one hand and electricity on the other.[19] Charcoal is also a viable alternative to the fossil fuels in cement production. Niger, Sierra Leone and Togo are in the World Bank "Group 4" countries, which have neither proven oil and gas reserves nor a sustainable fuelwood supply. None of these countries is a coal producer (Niger has some currently undeveloped lignite reserves),

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[17]Fog and Nadkarni (1983), pp 6-12.

[18]U.S. Bureau of Mines (1984), pp 798, 849, 1081, 1090-91, 1100-01.

[19]Fog and Nadkarni (1983), pp 18-21.

le 2. Energy requirements to operate recently opened and planned cement plants

	Energy Input Requirements as % of 1980 Commercial Energy Consumption	Project Description/ Plant Size
	33.5	500,000 tons/yr; near completion in 1982
	16.5	300,000 tons/yr; scheduled for 1983
eone[a]	3.4	120,000 tons/yr; open in 1982
	6.5	a. 750 tons/day 250,000 scheduled for 1983 b. 500,000 tons/yr; under study
	39.1	1,200,000 tons/yr; started in 1979 to supply Togo, Ivory Coast and Ghana
olta	12.3 from limestone 1.4 from clinker	150,000 tons/yr; plant under study; may use imported clinkers

Bank "Group 4" countries: no proven oil and gas reserves sustainable supplies of fuelwood.

Project descriptions from U.S. Bureau of Mines, Minerals Yearbook 1982, Vol. III, Area Reports: International. Washington: USGPO, 1984.

and only Sudan has substantial installed hydroelectric capacity (148,000 kW). Sierra Leone and Togo each have 2,000 kW of installed hydroelectric capacity; Sierra Leone is reported to have an additional 0.34 toe per person of potential hydro capacity, and Niger is reported to have 0.70 toe per person hydro potential (using 1980 populations).[20] On balance, the countries which look to be the hardest pressed by the additions to national fuel demands of the reported cement plants are not well placed to meet the energy demands from domestic sources.

Again, we emphasize that the operational assumptions regarding the plants reported in Table 2 are for higher levels of maintenance than are likely to be forthcoming. On that account the calculated energy requirements will be low. On the other hand, the plants may not be operated at capacity, which will reduce the energy demand but represents no fundamental solution of problematic energy supplies to power development projects.

The energy use calculated does not include energy used in transportation to deliver cement to users. Both Walstedt and Stewart report transport costs (not energy use) on cement to vary from less than 10% of factory cost to as much as 45%, with the differences largely attributable to differences in haulage distances.[21] Subba Rao et al. calculate (for India, 1979) the energy intensity, per rupee of output, of transport and railways at 30% of the cement and refractory industry, so roughly, another 10% could be added to operation energy use to account for transportation on final outputs.[22]

Examination of different energy consumption bases yields larger percentage adjustments to the 1980 figures than was the case for the countries for which pumped irrigation was considered (the adjustments are shown in Appendix III). However, even after these large adjustments, the percent of national commercial energy consumption that these cement plants can claim are still impressive: e.g., the 33.5% shown for Benin in Table 2 falls to 26.6% or 25.6% and the 39.1% for Togo falls only to 30.5% or 27.3%, still large shares. Additionally, since the plants will be operating in the post-1980 environment, it is not obvious that either of the retrospective adjustments of Appendix III give a more accurate picture of national commercial energy consumption in the 1980s than does a simple 1980 base. A 1981 base might be better on that score, and only

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[20]Dunkerley et al. (1983), Table 28, p. 86.

[21]Walstedt (1980), Table 4.6, p. 150; Stewart (1985), Table 4, p. 647. Both sources also show the strong tradeoff between plant size and production cost, indicating that the transport savings from dispersed plants making more localized deliveries are exceeded by production cost savings from larger outputs over wide delivery ranges.

[22]Subba Rao et al. (1981), Table 12.6, p. 217, show the Indian cement and refractory industry as using 15,344 kcal per rupee of output and transport and railways as using 4,540 kcal per rupee of output.

Togo shows a marked increase in commercial energy consumption from 1980 to 1981. But the point remains that, despite the base against which these cement plants' energy consumptions are measured, they claim substantial portions of most of their nations' modern energy consumption.

4. CONCLUSION

Pumped irrigation and cement plants are typical of projects undertaken in national economic development strategies, and their energy requirements are instructive of the energy demands of economic development in general. This report found that modest expansion of arable land -- only 5% -- could increase modern energy consumption by as much as 4-1/2% to 8-1/2 of national consumption, and that a cement plant could use from 25% to 35%. When a single manufacturing plant can use a third of a nation's commercial energy in its ordinary operation, it is clear that energy supply is a problem of first order concern in economic development. While there are alternative development strategies to heavy industrialization, even modest industrialization, which is crucial to development, requires that very serious attention be given to the supporting energy requirements.

APPENDIX I

APPENDIX I: CALCULATIONS OF FUEL REQUIREMENTS FOR PUMPED IRRIGATION

A. Diesel Fuel Required (Liters)

Requirements = $2.536 \times 10^{-3} \times Q \times L \times 1/N_t$,

where

Q = quantity of water pumped (ha-mm)
L = height of water lifted (meters)
N_e = efficiency of diesel engine (ranges from 0.25 to 0.35)
N_p = efficiency of pump (ranges from 0.7 to 0.85)
N_t = $N_e \times N_p$ (ranges from 0.175 to 0.2975)

B. Diesel Fuel Required (Gallons)

Requirements = $2.518 \times 10^{-2} \times Q \times L \times 1/N_t$,

where

Q = quantity of water pumped (acre-ft)
L = height of water lifted (ft)
N_e = efficiency of diesel engine (ranges from 0.25 to 0.35)
N_p = efficiency of pump (ranges from 0.7 to 0.85)
N_t = $N_e \times N_p$ (ranges from 0.175 to 0.2975)

APPENDIX II

APPENDIX II: CALCULATIONS OF ENERGY USE IN CEMENT MANUFACTURING

A. Range for Current Equipment

Fuel Use (Oil, Gas, Coal or Coke)

Range = 750 kcal/kg to 2100 kcal/kg

Electricity Use (Based on 2500 kcal/kwh or 9920 Btu/kwh, Power Plant Efficiency = 34.4%)

Range = 80 to 160 kwh/tonne
= 0.02 to 0.04 toe/tonne
= 0.15 to 0.29 BCOE/tonne (Barrel of Crude Oil Equivalent)
Avg = 0.030 toe/tonne

B. Range for Most New Equipment

Fuel Use

Range = 750 to 950 kcal/kg
= 0.075 to 0.095 toe/tonne
= 0.55 to 0.70 BCOE/tonne

Electricity Use

Range = 100 to 120 kwh/tonne
= 0.025 to 0.030 toe/tonne
= 0.18 to 0.22 BCOE/tonne

C. For New and Future Cement Plants

Fuel = 0.085 toe/tonne
Electricity = 110 kwh/tonne = 0.0275 toe/tonne for 34.4% efficiency power plant
Total Energy Use = 0.113 toe/tonne = 0.825 BCOE/tonne

D. For Production from Clinker (Electricity Only)

Total Energy Use = 50 kwh/tonne = 0.0125 toe/tonne = 0.092 BCOE/tonne

APPENDIX III

APPENDIX III: ALTERNATIVES TO A 1980 COMMERCIAL ENERGY CONSUMPTION BASE

The percentage figures in Tables 1 and 2 are shares of national commercial energy consumption, or of total energy imports, for calendar year 1980, which was the first full year after the rapid oil price increases of 1979. There is some concern that picking 1980 as a reference year against which to measure the energy requirements of the large scale irrigation projects and the cement plants may give an inflated impression of the overall impact of the energy requirements of those projects if 1980 consumption was particularly low. Appendix Tables 1 and 2 address this issue. Appendix Table 1 gives adjustment factors by which 1980 per capita commercial energy consumption must be adjusted if it is to be as great as consumption in 1979, or simply the inverse of the percent of 1979 per capita consumption which 1980 consumption reached. If one believes that 1979 consumption might be a more satisfactory reference against which to measure the projects' energy requirements, the figures of Tables 1 and 2 can be divided by the numbers in the first column of Appendix Table 1.

An alternative reference base is what 1980 per capita commercial energy consumption would have been if the rate of increase between 1978 and 1979 had been maintained through 1980. This is an admittedly short period from which to extrapolate, but it does offer an alternative reference. It is not clear that a longer period would have been more satisfactory, since it is difficult to determine how much of the increase in per capita commercial energy consumption is attributable to switching from traditional fuels, having the form of a market penetration curve, and how much is attributable to ceteris paribus price and income changes. The figures of the second column of Appendix Table 1 show more variation among countries than do the simple 1979 per capita consumption figures of the first column.

Appendix Table 2 presents the total and per capita commercial energy consumption figures for the countries shown in Appendix Table 1. There is no apparent, dramatic decline in per capita consumption between 1979 and 1980 for most of the countries; Benin, Sierra Leone and Togo are exceptions. However, five of the countries experienced per capita consumption declines in 1981, one maintained its 1980 level, and two others increased by only a single unit. Two countries enjoyed increased consumption, and one of them, Togo, increased sufficiently to raise a question about the data.

Between the two tables, we conclude that the simple use of 1980 commercial energy consumption data against which to measure the macroeconomic impact of development projects' energy requirements does not seriously distort the judgement regarding their impacts. Calculated impacts may be a bit smaller if 1979 consumption were used, would be a bit smaller still if the questionably extrapolated 1978-79 growth trends are used, and usually larger if 1981 consumption figures were used. The most accurate picture probably would be given by using the 1981, or even

later, consumption figures, but use of the 1980 figures is consistent with the effort of the study to present a conservative estimate of the energy impacts of these development projects.

Appendix Table 1. Adjustments to 1980 commercial energy consumption

	Required to maintain 1979 per capita consumption	Required to maintain 1978-79 capita consumption trend through 1980
Chad	0.99	1.00
Mali	1.00	1.03
Mauritania	1.01	1.03
Niger	0.98	1.08
Somalia	1.05	1.35
Sudan	1.01	1.02
Benin	1.26	1.31
Sierra Leone	1.12	1.15
Togo	1.28	1.43[a]
Upper Volta (Burkina Faso)	1.07	1.19

[a]To maintain 1979-81 trend; see figures from Appendix Table 2.

Appendix Table 2. Commercial energy consumption, 1978-81

	1978	1979	1980	1981
Chad	91[a] (21)[b]	97 (22)	102 (23)	102 (22)
Mali	184 (28)	195 (29)	204 (29)	192 (27)
Mauritania	266 (172)	280 (176)	285 (174)	284 (169)
Niger	215 (43)	249 (48)	258 (49)	243 (44)
Somalia	296 (74)	450 (99)	457 (99)	454 (93)
Sudan	1549 (89)	1606 (90)	1659 (89)	1674 (89)
Benin	173 (51)	184 (53)	150 (42)	157 (43)
Sierra Leone	293 (89)	306 (91)	281 (81)	310 (87)
Togo	222 (92)	260 (105)	216 (82)	351 (130)
Upper Volta (Burkina Faso)	168 (26)	195 (29)	188 (27)	199 (28)

[a]Total national consumption in thousand metric tons of coal equivalents.

[b]Per capita consumption in kg of coal equivalents.

Source: Statistical Office, Department of International Economic and Social Affairs, United Nations, 1981 Yearbook of World Energy Statistics. New York: United Nations, 1983. Table 1, pp 2-13.

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