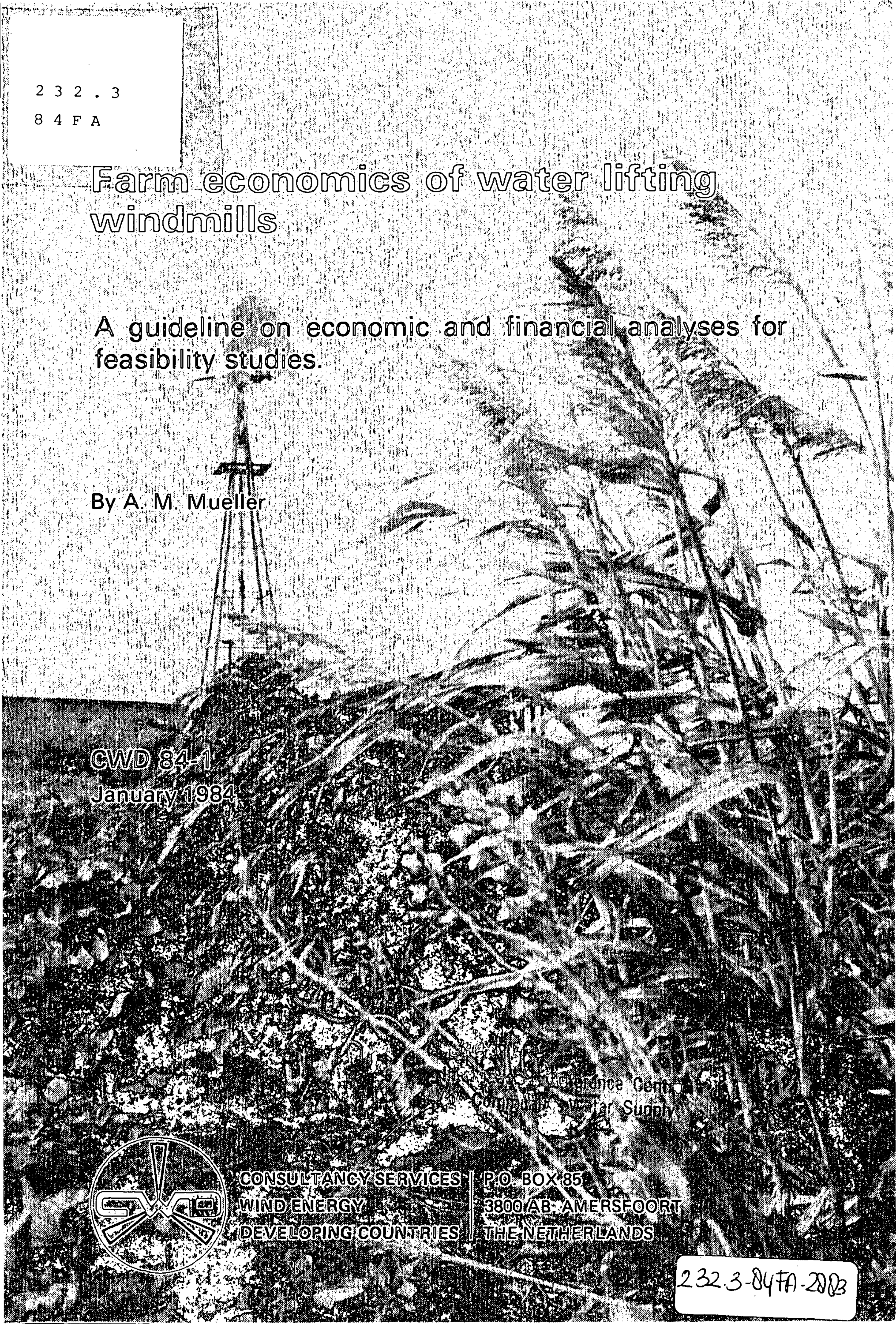
Farm economics of water lifting windmills

A guideline on economic and financial analyses for feasibility studies.

By A. M. Mueller



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APPENDICES

1. FOREWORD

This publication is intended as a guideline for the farm economic (micro economic) aspects of feasibility and evaluation studies for those wind energy projects which will use windmills for water lifting. Small scale lift irrigation is the most complex application of water lifting windmills, and the guideline was written with this in mind. However, it could also be used to study the economic aspects of using windmills for drinking water supply (Appendix I), salt pans, and drainage. The generation of electricity is not discussed.
Since this is a publication on farm economics, no attention is paid to the national economic impact a wind energy project could make in a certain country or region. To assess this impact fully, a separate national economic study would be required.
The success of a wind energy project depends not only on its national and farm economic feasibility, but also on many other factors not mentioned in this guideline.

The examples used in this publication are based on the situation in Sri Lanka, using 1983 prices (1 US$ = Rs 22.-). Because small kerosene pumps are so widely used in Sri Lanka, they will be used as the basis of comparison.

A glossary with economic terminology is annexed for the convenience of the non-economist reader.

Note: In the mean time another CWD publication titled "Cost Comparison of water-lifting windmills and diesel-powered pumps used for small scale irrigation" by Alexander M. Mueller and Wim A.M. Jansen has become available. That publication could be used together with or instead of chapter 3 of this publication.

2. INTRODUCTION

The farm economic analysis of windmills for lift irrigation is made from the farmers point of view. He is the man who finally decides whether or not to use lift irrigation and whether a windmill is the best water lifting device for his agricultural, technical, social, economical and financial situation.
In this manual both the economic and financial aspects of such a decision are stressed. There is a significant difference between the two. Here, the term economic is used for that type of analysis in which costs, or costs and benefits of different pumping systems are compared. The term financial is reserved for those analyses in which expenditures, or expenditures and incomes, of different systems are compared (see Glossary for definitions). In general one can say that the economic analysis selects the most cost effective or the most profitable alternative, whereas the financial analysis shows the cash flow.

A farmer cannot spend more money than he has or can borrow. Therefore it may very well be that he cannot select the cheapest or most profitable alternative for his water lifting problem, because he does not have the money to finance it. Since cash flow can be a serious constraint, it is not enough to find out only which is the 'best' water lifting device. One must also check whether or not the farmer can raise the money to buy it, especially as the investment in a windmill is much higher than for most other water lifting devices.
In order to determine the likelihood of a farmer's buying a windmill, one has to make one's analysis as realistic as possible. In this guideline three different situations that a potential windmill farmer might face are considered. They are:

Situation 'Equivalent Benefits'
In the area concerned, engine pumps* are being used widely and successfully by farmers belonging to the target group**. It is expected that windmills will be able to pump enough water to meet the requirements of the present cropping pattern at the present yield level.
It can therefore be assumed that farmers would realize the same benefits if they were to use windmills instead of engine pumps. In the analysis, only costs are compared. Benefits are not taken into account, as they are supposed to be the same for both pumping systems.

Situation 'Different Benefits'
In the area concerned, engine pumps are also being widely used by farmers belonging to the target group. But, due to the wind pattern, the output of the windmill is expected to differ from that of the engine pump. It is likely, therefore, that in order to use windmills optimally the farmers will have to adopt either a slightly different cropping pattern, or

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* Driven either by diesel, petrol, kerosene, or electricity
** Those farmers for whom the project is intended

cultivate a different command area during a certain part of the season, resulting in different benefits. Here, costs as well as benefits of the two water pumping systems are analysed.

Situation 'Without Lift Irrigation'
At present, no modern type of lift irrigation is widely used by farmers belonging to the target group in the area concerned. These farmers rely on rainfed cultivation in the wet season and then work either at some off-farm jobs during the rest of the year, or switch to a traditional, very labor intensive type of lift irrigation in a very small area. Under these circumstances one cannot help but feel that more valuable crops could be grown, or that better and more secure harvests could be realized, or that a larger area could be cultivated, if the rains were supplemented with modern lift irrigation. This would make some meaningful cultivation in the dry season possible and provide year-round employment for the farm family.

In many cases, especially during the pre-feasibility (reconnaissance) phase of wind energy projects, the information required to decide which of the three situations described above is most applicable for the analysis is lacking. However, it is important to get an idea about the applicability of wind energy for water lifting, and whether or not detailed investigations in the country and area concerned can be justified. For this purpose a fourth 'Blank' situation is added:

Situation 'Blank'
There is no information available about the current agricultural practices in the area considered, and there are no detailed wind data.

2.1. Execution of the farm economic analysis

The first thing one must do is determine which of the three described situations is most applicable for the analyses. If this decision cannot be made yet, as will be the case for a pre-feasibility study or analysis, one should start with the analyses described under 'Situation Blank' and see whether further investigations are justified.
After the situation has been determined one should refer to the corresponding diagram (at the rear of this publication) which gives an overview of the procedure. The diagrams should be read from left to right and from top to bottom. The data required to perform the calculations in the rectangular boxes are specified in the computer card-shaped boxes found directly above. The diamond-shaped boxes represent decisions that must be made based on the results of the calculations. The oval-shaped boxes represent conclusions and may indicate further actions to be taken. The triangular-shaped box indicates the end of the procedure. The arrows in the diagrams indicate the flow of information and the sequence of the operations.
The extent of the analysis depends upon the available data. It is important to note here that the execution of a next step generally requires a whole set of extra data. These data are given in the computer card-shaped boxes located on the line just above the rectangular box in which the step is mentioned. During fact finding missions the time and money spent to produce more information is justified only if it seems likely that that information will be sufficient to execute the next step.

3. SITUATION 'BLANK'

3.1. Break-Even Wind Speed

See diagram 1. The only analysis that can be made is the Break-Even Wind Speed Analysis. This determines the wind speed at which the pumping costs for a windmill and those for an engine pump are equal. If it appears that the actual average wind speed in the area under investigation exceeds the break even wind speed during that period of the year in which water must be pumped, it is worthwile to continue analysing the situation in more detail. As can be seen from the diagram, the required information is contained in two sets. The first set consists of more or less technical relationships which are generally applicable and which can either be determined at home, or are given here straight away:

Formula for price per kWh_{hydr} of windmill

The price per kWh_{hydr} of a windmill can be calculated using the following formula:

$$P_w = \frac{0.15\ I}{0.07\ m\ \bar{V}^3} \qquad (Rs^*/kWh_{hydr}) \qquad (1)^{**}$$

where:

P_w	= price per kWh_{hydr} of windmill	(Rs)
I	= investment in windmill, tank and piping per m^2 rotor area	(Rs)
m	= number of months per year that the windmill must pump	(-)
$\bar{V}$	= average wind speed during the m months	(m/s)

One kWh_{hydr} is equivalent to 36.7 m^3 water lifted over 10 m, or 367 m^3 lifted over 1 m.

Fuel or electricity to water efficiency of engine pumps

Small diesel pumps in the 2 - 4 kW (2.5 - 5 HP) range have an overall diesel to water efficiency of 5 - 10%. Since 1 liter of diesel contains about 10 kWh thermal energy, this means that the production of 1 kWh_{hydr} requires some 1 - 2 liters of that fuel.

* In this publication Rupees (Rs) are used to indicate local currency.

** Please note: In general, formula (1) is only applicable during periods of over one month and in systems that are properly matched with the wind regime of the period and location considered. See Appendix II for the derivation of this formula.

Small petrol pumps in the 2 - 4 kW range have an overall petrol to water efficiency of about 4 - 5%; kerosene pumps have a 2 - 3% efficiency. Kerosene and petrol also contain about 10 kWh. This means that the production of 1 kWh_{hydr} requires 2 - 2.5 ltr. petrol with a petrol pump and 3.5 - 5 ltr. kerosene with a kerosene pump. Small electric pumps have an electricity to water efficiency of about 20 - 40%.

It should be noted that these relations are rough approximations. Much depends on the quality and maintenance of the engine and pump, the installation, and the matching of the pump to the pumping head.
The economic comparison of windmills and engine pumps is very sensitive to the fuel or electricity consumption, as the saving of this fuel or electricity by the use of windmills is what it is all about.

The second set of data has to be collected in the country and area concerned:

Local price of fuel or electricity
That is the price the farmer has to pay for diesel, kerosene, petrol or electricity (depending on the type of engines presently used), including cost of transport to the pumping site.

Local price of windmill (including pump), water tank for at least a half day's storage, additional piping and installation (per m^2 rotor area)
This is the price a farmer has to pay, including taxes, subsidy, and transport. Currently, it is in the range of US$ 120 - 150 for locally made windmills with soil-crete tanks, and about double that amount for commercial windmills with high technology (concrete, steel, or brick) tanks.

Indication of the range of the average wind speed in the area during the period of the year that lift irrigation is considered
For this analysis no detailed wind data are required, but an idea of the range is needed in order to draw conclusions. Information can be obtained from meteorological stations in the vicinity. Spot measurements can be used to check the wind data.

Determining Break-Even Wind Speed

This analysis is presented as a graph, with the price per kWh_{hydr} on the vertical scale and the wind speed on the horizontal scale.
The total price per kWh_{hydr} of an engine pump is independent of the average wind speed. It appears as a straight line in the graph.

For a small, fuel-powered pump this price can be calculated using formula (2):

$$P_f = \frac{0.2 \times FP}{ef} \qquad (Rs/kWh_{hydr}) \qquad (2)^*$$

where: P_f = price per kWh_{hydr} of fuel-powered pump (Rs)
FP = fuel price per liter (Rs)
ef = fuel to water efficiency of pump (%)

For a small, electric pump the total price per kWh_{hydr} can be calculated using formula (3):

$$P_e = \frac{1.5 \times EP}{ef} \qquad (Rs/kWh_{hydr}) \qquad (3)^*$$

where: P_e = total price per kWh_{hydr} of electric pump (Rs)
EP = electricity price per $kWh_{electric}$ (Rs)
ef = electricity to water efficiency of pump (%)

The price curve of the kWh_{hydr} generated by the windmill can be plotted by calculating these prices for several wind speeds, using formula (1). These prices decrease sharply with the wind speed, since the wind speed appears in the third power in this formula.
(One can also use logarithmic paper to present the graph. The curve would then appear as a straight line.)

The break-even wind speed is found at the point where the price line of the engine pump and the price curve of the windmill intersect.

Conclusions

If it is likely that the actual average wind speed is higher than the break-even wind speed, there is a good indication that wind energy is worth considering. The result of the analysis can be used as a justification to spend more time and money for more detailed investigations.
If the break-even wind speed is higher than the expected average wind speed, one should check whether or not it is possible to use a different type of windmill which is cheaper per m^2 rotor (e.g. a locally produced windmill instead of an imported commercial one), or whether a tax reduction or subsidy could be arranged. One should also try to get more reliable wind data on the area, especially on the period for which lift irrigation is considered. If none of these factors seem promising, the conclusion has to be that, from the farmers point of view, windmills are economically not feasible under the present price conditions.
At the present stage of development of windmill technology and of the price level of fuel, electricity and interest, the likely outcome of this break-even point analysis will be that windmills can pump water at a lower

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* See Appendix II for derivation of this formula

cost than engine pumps if the average wind speed is higher than 3.5 m/s, for remote areas where fuel cost is very high due to transport may be even 2.5 m/s.

3.1.1. Example Break-Even Wind Speed

Here, the Break-Even wind speed will be determined for an area in Sri Lanka where windmills must compete with kerosene-powered pumps.
At home (or from this guideline) one can make calculations from the data indicated in the computer card-shaped boxes on the first line of diagram 1.

Formula for the price/kWh$_{hydr}$ of windmills
This formula is presented as formula (1) here.

Fuel or electricity to water efficiency of engine pumps
As kerosene pumps are used in Sri Lanka, one can assume an efficiency of 2.5%.

One must have data from Sri Lanka to make the calculations indicated in the second line of computer card-shaped boxes.

Local price of fuel or electricity
In Sri Lanka the consumer price of kerosene oil is Rs 5.20 per liter.

Local price of windmill including pump, water tank for at least half a day's storage, and installation (per m² rotor area)
A locally produced windmill with a rotor diameter of 3 m costs Rs 12,500 in Sri Lanka. This includes pump, transport, and installation. The foundation costs Rs 500. An inexpensive ferro-soil-crete tank of 25 m³ capacity costs Rs 4,000. Additional piping will add another Rs 1,000, bringing the total investment to Rs 18,000.*
A rotor with a 3-m diameter has a rotor area of $0.25 \times \pi \times 3^2 = 7$ m², meaning the investment in a windmill is $18{,}000 \div 7 =$ Rs 2,570 per m² rotor area.

Indication of the average wind speed range in the area during that period of the year that irrigation is considered
In the center of Sri Lanka's Dry Zone (Anuradhapura) the average wind speed during the period May - September, when lift irrigation is practised, is about 4 m/s.

All data are now available for:

Determining Break-Even Wind Speed

The price per kWh$_{hydr}$ of the kerosene pump can be calculated using formula (2):

$$P_f = \frac{0.2 \times 5.20}{0.025} = \text{Rs } 41.60$$

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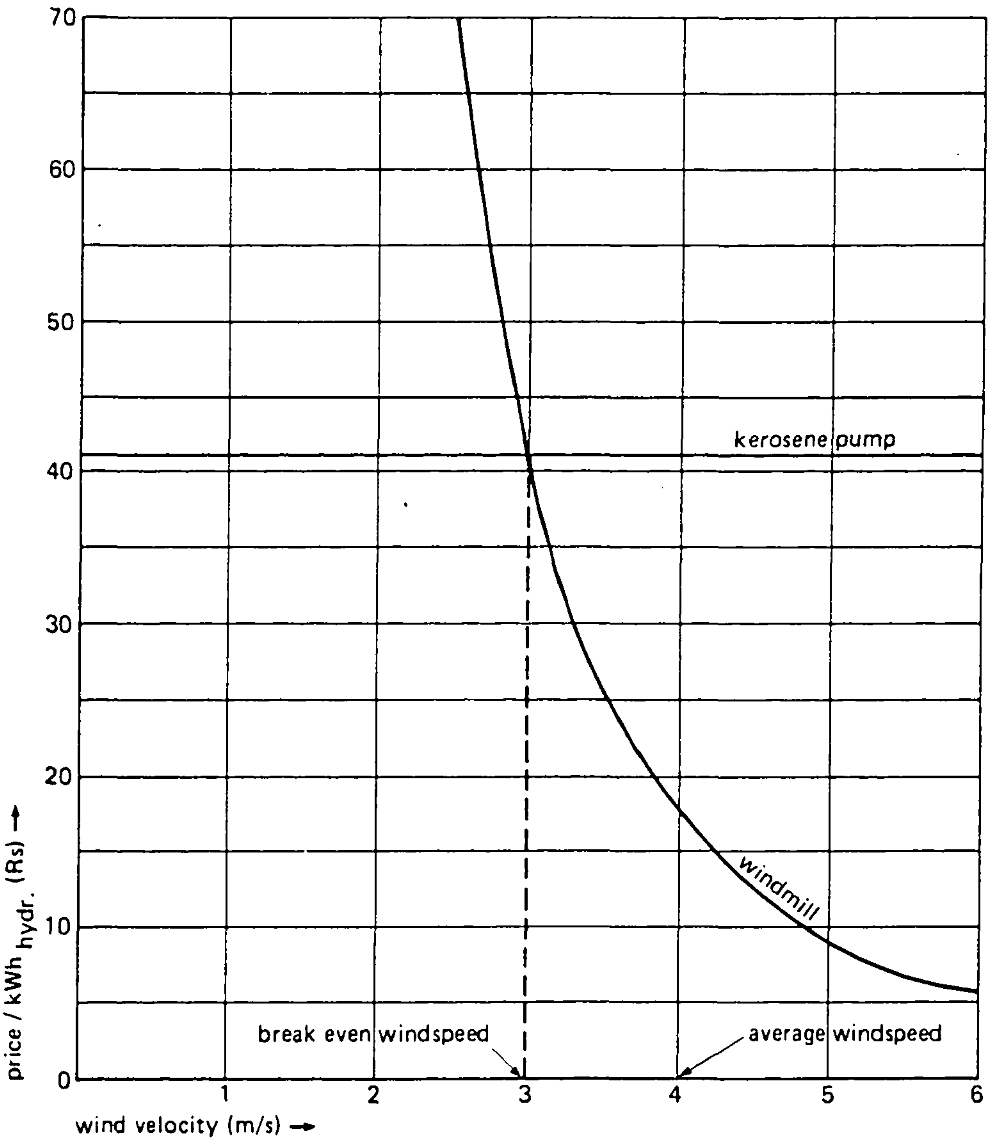
* *subsidized cost; unsubsidized cost would be Rs 19,500*

Using formula (1), points of the price-curve of the windmill are calculated for different wind speeds over a 5-month period (May - September) each year:

$$P_w = \frac{0.15 \times 2{,}570}{0.07 \times 5\ \bar{V}^3}$$

$\bar{V}$ (m/s)	1	2	3	4	5	6
P_w (Rs/kWh$_{hydr}$)	1,101.43	138.68	40.79	17.21	8.81	5.10

Having these results, one can draw the diagram with the price per kWh$_{hydr}$ on the vertical scale and the wind speed on the horizontal scale:



One can see that the break-even wind speed is below the actual average wind speed, indicating that the windmill can pump water at a lower cost than a kerosene pump.

4. SITUATION 'EQUIVALENT BENEFITS'

See diagram 2. In this situation modern lift irrigation is already widely adopted by farmers in the target group. The switch from engine pumps to windmills should have no influence on the benefits, since the present command area and cropping pattern can be maintained, and the same gross margins can be realized or changed in such a way that benefits are not affected*. In the analysis, therefore, one only has to compare costs and expenditures of the two water lifting systems.
Providing that the investments in the water source (dug well, tube well), the land levelling, and the water distributing system have already been made, and that they are the same for the windmill and the engine pump, they are not taken into account here.
As can be seen from diagram 2, there are two major analyses:
I) the Average Annual Cost calculation and II) the Cash Flow analysis.
For the latter one an extra set of information is needed.

4.1. Average Annual Costs

The first method of analysis indicated in diagram 2 is the Average Annual Costs calculation. With this calculation, annual investment costs of a different economic life can be compared. The investment with the lowest Average Annual Costs is considered best.
The Average Annual Costs are calculated on the basis of constant prices. It is assumed that there is no inflation or that inflation is the same in all sectors of the economy. If real price changes are expected for specific items, prices will, of course, have to be adjusted.

In the first four computer card-shaped boxes the required data are specified for determining the size and cost of the windmill pumping system.

Water demand

Determining the water demand is, in itself, a rather complicated procedure. One must know the extent and the time of the peak water demand to calculate the required size of the windmill, and also know the total irrigation requirement to calculate the fuel or electricity cost of the engine pump.
In [12] and [28] a calculation method is presented. Since lift irrigation is currently practised, an idea about the water demand could probably be obtained through the number of hours per day that the engine pumps are used or through the amount of fuel or electricity that is consumed. A reasonable estimate of the peak water demand is 80 - 100 m^3/day/ha, depending on the irrigation efficiency and the type and phase of the crop.

Source of water

In choosing a windmill, it is important to know whether or not the maximum depth of the water table is less than 7 m. For depths of up to 7 m, a suction pump installed above ground level can be used. For depths of more than 7 m, either the suction pump must be lowered or a submerged pump must

* Please note: the validity of this analysis depends on the acceptability of the supposition.

be fitted, resulting generally in more trouble and higher costs. It is also important to know whether or not the water must be pumped from shallow wells, surface water, or tube wells. This is especially important for tube wells, since they require specially designed pumps for their small diameters. To calculate windmill output and fuel or electricity consumption, one must know the total pumping head. The total pumping head consists of the suction head, the delivery head and the friction head. For more on friction in PVC and PE pipes, refer to Appendix III.

<u>Monthly average wind speeds in the area during the irrigation period</u>
Since wind powers the windmill and since the wind speed appears in the third power in the wind power formula, this information is vital (see Appendix II). Wind data should be available from weather stations. Sometimes data from airports can also be used.
It is important to visit the stations to see whether or not their anemometer is well exposed, at which height measurements are taken, and at which intervals*. If the height of the measurement differs from the height of the centre of the windmill rotor, the wind data change also. Vegetation, buildings, and the ground itself cause the wind to slow at low altitudes. Wind speed increases, however, as altitude increases.
The rate of increase in wind speed in relation to height depends greatly upon the roughness of the terrain and the changes in this roughness. The 'roughness height' z_o can be determined for various types of terrain, noting that h is the height of the obstacle:

flat	: beach	$z_o = 0.0005$ m
open	: low grass, airports, empty crop land	$z_o = 0.03$ m
	: low crops, obstacles at 20 h	$z_o = 0.10$ m
rough	: high crops, trees, obstacles at 15 h	$z_o = 0.25$ m
very rough	: forests, orchards, obstacles at 10 h	$z_o = 0.50$ m
closed	: villages, suburbs	$z_o = 1.0$ m
towns	: town centres, open spaces in forests	$z_o > 2$ m

These values can be used in the standard formula for the logarithmic profile of the wind shear

$$V(z) = V(z_r) \cdot \frac{\ln (z/z_o)}{\ln (z_r/z_o)} \tag{4}$$

where $V(z)$ = the desired wind speed at the required height (m/s)
$V(z_r)$ = the known wind speed at height r (m/s)
z_o = the 'roughness height' (m) [17]

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* Because the readings of such instruments are rather inaccurate, wind data obtained from anemometers that indicate instantaneous wind speeds should generally be distrusted.

For more information on wind measurements, refer to [17].
Now, using either formula (1) or Appendix IV, we can determine the size (diameter) of the windmill.

Local price of windmill and tank
This is the price the farmer has to pay, including taxes and subsidies of windmills, complete with pump, tank (if required), additional piping, transport to the farm, and installation.

Windmills

This can mean either imported, commercial windmills or locally manufactured ones. The price of locally-manufactured windmills* can be obtained by filling in the local prices for materials and labor, overhead, and so on for the 3 m and 5 m diameter mills, as given in Appendix V. The price of a windmill, including profit, transport, and installation is roughly twice the material costs.

Tanks

For most irrigation applications a storage tank is recommended. The price of the tank depends on the type of construction and on its size.
Technically, cheap tanks are possible only in areas with a very heavy clay soil. Costs can then be negligible.
In undulating areas, earth-lined bund tanks can be built for about US$ 5/m^3 [14]. The tanks do not have to be elevated and no soil has to be transported. The cheapest solution in flat areas is probably ferro-soil-crete tanks, which cost about US$ 8/m^3 [22]. Ferro-cement and brick tanks can be as expensive as US$ 20/m^3 [14].
A storage tank is mainly meant as a buffer to equalize the daily windmill output and the daily demand.
A tank with a storage capacity in the range of half the daily output seems, so far, to be sufficient [30]. Water storage for windless periods of several days is not economically feasible in most cases.

Piping

If the windmill is not erected where the engine pump was installed, and if the tank must be constructed (in the highest point in the field) away from the windmill, additional piping might be needed.
For calculations, some average figures can be taken.

With the data collected so far one can determine the size and the cost of the windmill pumping system (windmill, tank, additional piping) with Appendix IV and Appendix V.

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* If the research & development costs of these windmills are absorbed by governmental institutions, they are usually not charged to the farmer. Nevertheless, private windmill producers have to recover these costs as well.

For the calculation of the Average Annual Costs, one needs more information. This is specified in the other computer card-shaped boxes on the first line of diagram 2.

Economic life of windmill and tank
Currently, intermediate technology windmills are expected to last for 10-12 years, commercial mills for 15-20 years, and high technology tanks (concrete, bricks or steel) for 20 years.

Yearly maintenance costs of windmill and tank
It is best to make a maintenance budget based on real prices and travelling costs. If this is not possible, maintenance costs can be expressed as a percentage of the investment (e.g. 3% for a commercial windmill, 5% for a locally made windmill, and so forth) In remote areas maintenance costs are higher due to travel; importation of spare parts can be time-consuming, difficult, and expensive.

Local price of engine pumps
This is the price of the engine pump, including transport and installation, that is most current and with which one will want to compare the windmill alternative. Cost of installation might include a stone pump house/fuel store, especially for heavier pumps that cannot easily be taken home for safeguarding.

Economic life of engine pumps
Pump life depends on the number of running hours and the level of maintenance. If no better information is available, 6 - 8 years is proposed for diesel or electrical pumps and 3 - 5 years for kerosene or petrol pumps.

Yearly fuel or electricity costs of engine pumps
This can be calculated using the technical relation between the amount of water that has to be lifted, the fuel or electricity consumption, and the fuel or electricity price.

Fuel-powered pump:

$$FC = \frac{0.1}{ef} \times \frac{Q\ H}{367} \times FP \qquad (Rs) \tag{5a}^*$$

where

FC	= fuel costs per season	(Rs)
ef	= fuel to water efficiency	(%)
H	= total pumping head	(m)
Q	= total irrigation requirement per season	(m^3)
FP	= fuel price per liter	(Rs)

Electric pump:

$$EC = \frac{Q\ H}{ef \times 367} \times EP \qquad (Rs) \tag{5b}^*$$

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* For the derivation of this formula refer to Appendix II

where EC = electricity costs per season (Rs)
ef = electricity to water efficiency (%)
H = total pumping head (m)
Q = total irrigation requirement per season (m^3)
EP = electricity price per $kWh_{electric}$ (Rs)

Note: The economic and financial comparison of windmills and engine pumps is extremely dependent on the yearly fuel or electricity costs. Since avoiding these costs by harnessing wind energy is what this comparison is all about, they must, therefore, be assessed as carefully as possible.

Yearly maintenance costs of engine pumps
These are normally expressed as a percentage of the fuel or electricity costs, sometimes as a yearly minimum. (For diesel pumps 20 - 25% is often used, for kerosene pumps 30% was found in Sri Lanka [2]).

Interest rate
One should use the interest rate that is relevant for the farmer. Either formal credit (banks, government, cooperatives) at commercial or concessional rates, or informal credit (suppliers, family, and so on) at much higher rates.

Real price changes
These only need to be taken into consideration in those rare cases where there is a strong indication that the price of one or more items important for the analysis (e.g. agricultural produce, fuel, or steel) will become relatively cheaper or more expensive than all other items. Nevertheless, it should be noted that it is not very likely that this will happen over a long period of time. If a real price change is expected for a certain item, the yearly costs should be adjusted, using the following formula:

$$C_t = C_1 \ (1 + d)^{t-1} \quad \text{(Rs)} \qquad (6)$$

where C_t = real cost in year t (Rs)
C_1 = present cost (Rs)
d = real price change (%)
t = number of the concerning year (-)

Now all the information required is available to calculate the Average Annual Costs of both the windmill and the engine pump:

Calculating Average Annual Costs

Since their respective life spans can be different, costs for each year of the life of both the engine pump and the windmill water-lifting system should be determined. These costs comprise the maintenance costs and for the engine pump also the fuel or electricity costs. The years in which these costs occur are counted from 1 onwards. The investment precedes the operation of the pumping systems. These investments take place at the end of year 0. For a given year an additional investment might be required to replace the windmill's pump or to overhaul the engine pump. The costs for these replacements are added to the costs of the year in which they occur. If a real price change is expected for one or more items, the yearly costs will have to be adjusted using formula (6).

Now that one knows the costs for both systems, one will want to decide which system is best. As it matters to people not only what the cost is, but also when this cost occurs, the present value of each year's costs will have to be calculated by discounting them with the present value factor for that year at the given rate of interest (see glossary: Present Value of a stream of future income).
Finally, all the discounted costs are added to the initial investment and multiplied by the annuity factor corresponding with the life span (see glossary: Annuity Factor).
This formula will yield the Average Annual Costs (AAC) (see glossary: Annual Average Costs):

$$AAC = \frac{i\,(1+i)^n}{(1+i)^n - 1} \times \left\{ I + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} \right\} \text{ (Rs)} \qquad (7)$$

where

AAC	=	Average Annual Costs	(Rs)
i	=	relevant interest rate	(%)
I	=	investment	(Rs)
n	=	economic life	(years)
C_t	=	cost in year t	(Rs)

Conclusions

In case the Average Annual Costs are higher for the windmill than for the engine pump, one will either have to conclude that windmills are not economically feasible or check the data again. It may also be possible to design or select a cheaper windmill, or to find some sort of subsidy. Here, the AAC calculations again will have to be done, this time to find out if the AAC for the windmill is lower than that for the engine pump. If it is not, one will have to conclude that windmills are not economically feasible under the present conditions.
But if the AAC for the windmill is indeed less than that for the engine pump, windmills are economically more attractive than engine pumps. However, whether or not farmers in the target group will purchase windmills is still unclear. Accordingly, the investigation of the cash flow analysis must be continued to determine if the actual financing is a constraint.

4.1.1. Example Average Annual Costs

Using diagram 2, start with collecting the data required to determine the size and cost of the windmill pumping system. These data are indicated in the first four computer card-shaped boxes:

Water demand

A farmer wants to put 0.6 ha under chillies, onions, and vegetables during the months May - September. The peak water demand falls in June - July and is about 55 m³/day. The total irrigation requirement for the season is about 5000 m³.

Source of water

The depth of the watertable in the open dug well slowly goes down during the irrigation season, sinking to a low of about 5 m in August. The total pumping head then is 7 m.

Monthly average wind speeds in the area during the period of irrigation

May-3 m/s, June-4 m/s, July-4.15 m/s, August-4.35 m/s, September-3.9 m/s. The data refers to wind speeds at a height of 10 m.

Local price of windmills

Using the formula in Appendix IV, the diameter of the windmill should be calculated first.
The peak demand in June - July is 55 m^3/day, with an average monthly wind speed of 4 m/s. The head is 7 m.

$$\text{Diameter} = 1.2 \sqrt{\frac{Q \times H}{\bar{V}^3}} = 1.2 \sqrt{\frac{55 \times 7}{4^3}} = 2.9 \text{ m}$$

Windmills 3 m in diameter, with a 10 m tower, are produced locally and sold at a subsidized price of Rs 12,500. This price includes pump, transport, and installation, but not the cost of laying a foundation, which will be about Rs 500. All other, imported windmills are much more expensive and are therefore not considered here.
A low cost (about Rs 4,000) design is available for a ferro-soil-crete tank with a 25 m^3 capacity.
The amount of additional piping required depends very much on the location, but it is expressed here as Rs 1,000. The total investment for the windmill pumping system will thus be Rs 18,000.

Now one can continue with collecting data to calculate the Average Annual Costs of the windmill and engine pump:

Economic life of windmill and storage tank

Both are expected to last for 10 years, provided they are well maintained with the funds budgeted for that purpose.

Yearly maintenance costs of windmill and storage tank

A realistic maintenance budget is Rs 500 per year for the windmill and Rs 100 per year for the tank. Total Rs 600 per year.

Local price of engine pumps

A 2.5 HP kerosene pump costs Rs 6,500 including transport and installation. These pumps are widely used in rural Sri Lanka by farmers of the target group.

Economic life of engine pumps

In rural Sri Lanka, kerosene pumps in the 1.5 - 2.5 HP range have an economic life of 4 - 5 years. Five years has been assumed in this example.

Yearly fuel or electricity costs of engine pumps
These costs can be calculated using formula (5a).
Fuel to water efficiency of the kerosene pump is 2.5%, total pumping head is 7 m, total irrigation requirement for the season is 5,000 m^3, and the price of kerosene is Rs 5.20 per liter.

$$FC = \frac{0.1}{ef} \times \frac{Q\ H}{360} \times FP = \frac{0.1}{0.025} \times \frac{5{,}000 \times 7}{360} \times 5.20 = Rs\ 2{,}022$$

Yearly maintenance costs of engine pump
These total Rs 600 per year, or 30% of the yearly kerosene costs.

Interest rate
For those who qualify for Bank of Ceylon loans, special annual interest rates of 12.5% are in effect for kerosene pumps and windmills. For those who do not qualify, commercial annual interest rates of 22% and higher apply. For this example, 12.5% has been assumed.

Real price change
No significant real price changes are expected.

Calculating Average Annual Costs

Yearly costs of windmill (Rs)

Year	0	1	2	3	4	5	6	7	8	9	10
Investment	18,000	-	-	-	-	-	-	-	-	-	-
Maintenance		600	600	600	600	600	600	600	600	600	600
Total	18,000	600	600	600	600	600	600	600	600	600	600

Yearly costs of kerosene pump (Rs)

Year	0	1	2	3	4	5
Investment	6,500	-	-	-	-	-
Maintenance		600	600	600	600	600
Fuel		2,022	2,022	2,022	2,022	2,022
Total	6,500	2,622	2,622	2,622	2,622	2,622

Now one can calculate the Average Annual Costs for both the windmill and the kerosene pump using formula (7):

Windmill

$$AAC = \frac{0.125(1 + 0.125)^{10}}{(1 + 0.125)^{10} - 1} \times \{18,000 + \frac{600}{1 + 0.125} + \frac{600}{(1 + 0.125)^2} + \dots + \frac{600}{(1+0.125)^{10}}\} = 3,851$$

Kerosene pump

$$AAC = \frac{0.125(1+0.125)^5}{(1 + 0.125)^5 - 1} \times \{6,500 + \frac{2,622}{1 + 0.125} + \frac{2,622}{(1 + 0.125)^2} + \dots + \frac{2,622}{(1 + 0.125)^5}\} = 4,448$$

Conclusion
The AAC of the windmill is lower than the AAC of the kerosene pump.
The conclusion is that using a windmill is economically more attractive than using a kerosene pump. Nevertheless, since a windmill represents a considerably higher investment than an engine pump, one must continue calculating the cash flow.
The farmer may not be able to find enough money for such a high investment, or he may have to repay the loan within a much shorter period than the life of the windmill, which would make annual expenditures prohibitive during the first years.

4.2. Cash flow (expenditures only)

A complete cash flow would show the amount of money that will be received (income) and that will have to be spent (expenditures) during each year of the life of the windmill and the engine pump. In this 'Equivalent Benefits' situation, however, one is limited to expenditures since income is assumed to be the same for both pumping systems. There is one exception: the loans for windmills and engine pumps will be different since this income is specific for the investments. In order to take this difference into account, one must subtract the loans from the income.
Since cash flow is calculated on the basis of current prices, inflation and real price changes have to be taken into account.

See diagram 2. The required additional information is listed in the three computer card-shaped boxes on the line above the rectangular box labelled 'Cash flow analysis'.

Inflation
This is the expected rise of general price levels in the county concerned. From recent statistics, one can determine the inflation rate in the recent past. For most developing countries, 15 - 20% is a moderate estimate.

Credit conditions

First one must know the current conditions required for farmers to obtain loans for their engine pumps. Important factors are: the maximum amount of the loan (expressed as an absolute value or as a percentage of the investment, or depending on the size of the farm), the amortization scheme (e.g. spread over five years, repaying 1/5 each year), the interest rate, and the additional terms. Secondly, one has to find out whether or not it is likely that the same credit conditions will apply to windmills. For an example of a windmill credit scheme, see [21].

Available means of the farmer

Banks are not generally willing to finance the full amount of an investment, so farmers must have some money of their own to purchase an engine pump or a windmill. Since it is impossible to know all financial circumstances of all farmers, one will have to make an assumption. For instance, assuming that banks will finance windmills under the same terms as engine pumps, one can find out the minimum personal capital investment a farmer will have to make to purchase an engine pump, and then use that figure in the analysis. If engine pumps are generally not financed through bank loans, one can assume that the farmer in the analysis has saved enough money to purchase one outright. Now he has the option either to buy this pump and pay the yearly fuel or electricity bill, or to borrow additional money to buy a windmill.

Cash flow analysis (expenditures only)

As explained, this 'Equivalent Benefits' situation can be limited to the outflow side of the cash flow or, in other words, the yearly expenditures. These expenditures for the engine pump and the windmill consist of:

Investment

This is the price of the engine pump or the windmill including tank, installation, and so on. This investment will only occur at the end of year 0. See 4.1.

Maintenance

The yearly maintenance costs have already been calculated in 4.1. They will have to be adjusted for inflation.

$$\text{maintenance cost}_t = \text{maintenance cost}_1 \times (1 + i)^{t-1} \quad \text{(Rs)} \qquad (8)^*$$

where

$\text{maintenance cost}_t$	= maintenance cost in year t	(Rs)
$\text{maintenance cost}_1$	= present maintenance costs	(Rs)
i	= rate of inflation	(%)

* See Appendix II for the derivation of this formula.

Fuel or electricity costs (engine pump only)
The yearly fuel or electricity costs, including general inflation and real price increases (if applicable), are calculated as:

$$\text{fuel or electricity costs}_t = \text{fuel or electricity costs}_1 \times (1 + i)^{t-1} \times (1 + d)^{t-1} \text{ (Rs)} \qquad (9)^*$$

where

fuel or electricity costs_t	= fuel or electricity cost in year t	(Rs)
fuel or electricity costs_1	= present fuel or electricity costs	(Rs)
i	= rate of inflation	(%)
d	= rate of real price change	(%)

Interest
For the cash flow analysis, only the interest on borrowed capital is counted (no interest on personal capital has to be paid to anybody and is therefore not considered an expenditure).

Amortization
This (repayment of loan, not interest) is considered an expenditure since it has to be paid to the bank or other lender as agreed.

Loan
The money received as a loan in year 0 is not an expenditure, but income. It must be taken into account, because the loan for the windmill is different from the loan for the engine pump.

Now a cash flow table for the windmill and for the engine pump can be filled in for each year of the life of both systems.

At the end of year 0 the investment is made and the loan received. The loan is entered with a minus sign. The difference of investment and loan has to be met by the farmers means. Starting with year 1, the cash flow (expenditures) consists of maintenance, fuel or electricity (for engine pump only), interest and amortization. Maintenance costs and fuel or electricity costs have to be corrected each year for inflation and real price changes using formulas (8) and (9) (see example).

Conclusions
If, for all years, the annual expenditures for the windmill are lower than for the engine pump, we have a clear case: there is no financial or economic reason why farmers should not purchase windmills when they have to replace their present engine pump.
However, it is more likely that the expenditures for the windmill will be a little higher than those for the engine pump during the first years, and

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* See Appendix II for the derivation of this formula.

that the situation will reverse thereafter. The interest on the big windmill investment decreases more over the years than the interest on the engine pump, nor is this interest affected by inflation. Whether farmers buy a windmill or an engine pump depends in this case on the benefits that are generated by lift irrigation and on their own financial situation. If the farmer's income (cash inflow) or personal savings cannot meet the additional expenditure for a windmill, he must be able to borrow the extra money needed, or he will go bankrupt. Final conclusions are difficult in this case since no calculations of income are available. To be sure, one has to perform the analysis described under Situation 'Different Benefits' in which incomes are calculated as well. In general, one can say that the poorer the farmers are, the less likely they will be to accept greater expenditures during the first years. If the full extent of the benefits could be estimated, one could have a more accurate idea of how big the extra expenditures really are in comparison.

Even if windmills were cheaper than engine pumps and there were no cash flow constraints, farmers might still be reluctant to adopt this new technology because of the risks involved. Windmills are a large investment. They may be attractive under present conditions, but these conditions can always change.

4.2.1 *Example Cash Flow (expenditures only)*

This example is a continuation of example 4.1.1 (see diagram 2). The additional data required for the cash flow analysis must be collected as indicated in the three computer card-shaped boxes just above the rectangular box labelled 'Cash flow analysis'.

Inflation
The expected annual inflation rate is 15%.

Credit conditions
Annual interest at 12.5%, repayment of a windmill loan in 8 years, repayment of a kerosene pump loan in 4 years.

Available means of farmer
The farmer has saved Rs 3,000 to invest in his new water lifting device.

Now all information is available for the cash flow analysis.

Cash flow analysis (expenditures only)

Investments
Windmill Rs 18,000, kerosene pump (2.5 HP) Rs 6,500 (see 4.1.1)

Maintenance
For the first year this is Rs 600 for both a windmill and a kerosene pump. For the following years, an inflation rate of 15% has to be taken into account.

Fuel costs
During the first year, fuel costs for a kerosene pump will be Rs 2,022. No real price change is expected, but general inflation has to be taken into account for the following years.

Interest at 12.5% for the remaining loan.

Loan
The farmer will have to borrow Rs 15,000 for a windmill, or Rs 3,500 for a kerosene pump.

Amortization
Linear repayment: 1/8 of the loan annually for a windmill or 1/4 of the loan annually for a kerosene pump.

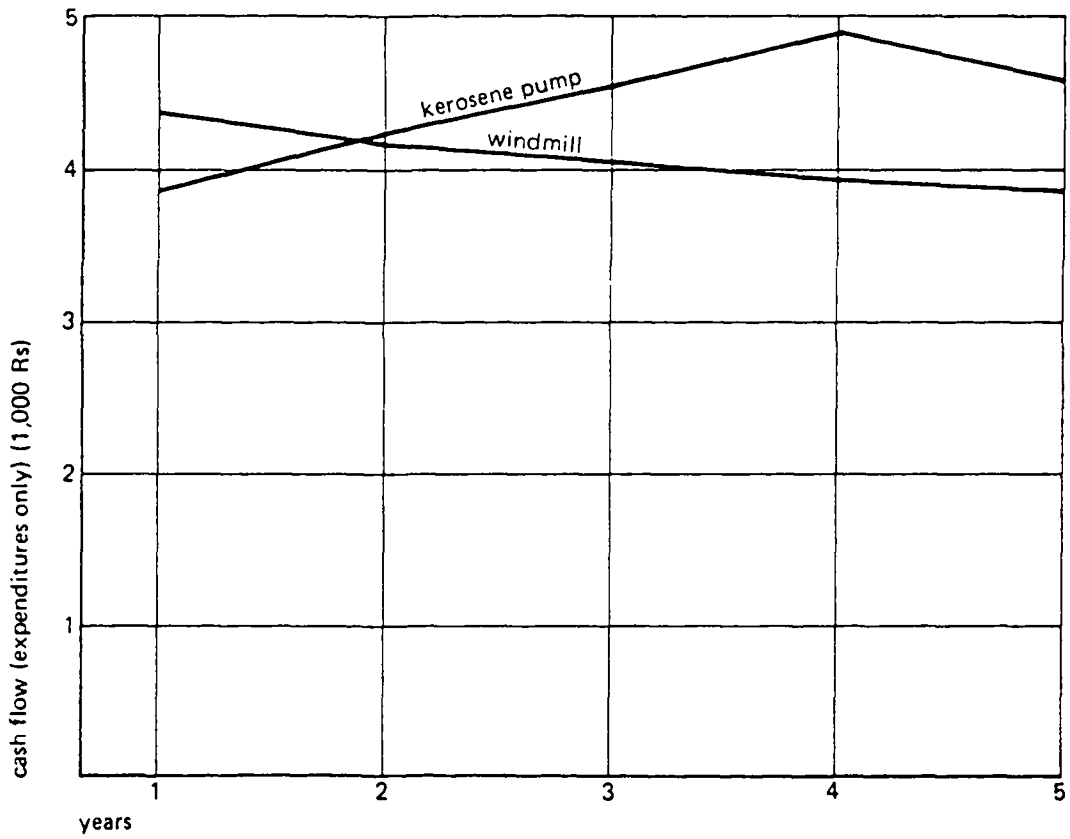
Now one can fill in the cash flow tables for a windmill and a kerosene pump:

Cash flow (expenditures) windmill (in Rs)

Year	0	1	2	3	4	5	6	7	8	9	10
Investment	18000	-	-	-	-	-	-	-	-	-	-
Maintenance		600	690	794	912	1049	1207	1388	1596	1835	2110
Interest		1875	1641	1406	1172	938	703	469	234	-	-
Amortization		1875	1875	1875	1875	1875	1875	1875	1875	-	-
Loan	- 15000	-	-	-	-	-	-	-	-	-	-
Total	3000	4350	4206	4075	3959	3862	3785	3732	3714	1835	2110

Cash flow (expenditures) kerosene pump (in Rs)

Year	0	1	2	3	4	5
Investment	6,500	-	-	-	-	-
Maintenance		600	690	794	912	1,049
Fuel		2,022	2,325	2,674	3,075	3,536
Interest		438	328	219	109	-
Amortization		875	875	875	875	-
Loan	- 3,500	-	-	-	-	-
Total	3,000	3,935	4,218	4,562	4,971	4,585



Conclusions

One can see that the expenditures during the first year are larger for the windmill than for the kerosene pump. From the second year onwards it is the other way round. Nevertheless, this means that no final conclusions can be made. Farmers who have, or can borrow, the extra money needed to finance the windmill are better off from the second year onwards. Whether this extra expenditure is much compared to the farmers' income cannot be seen for lack of information. If one wants to calculate incomes as well, one has to follow the analysis as outlined under situation 'Different Benefits' (5). The difference between the investment and the loan at the end of year 0 of Rs 3,000 for both cases is equal to the available means of the farmer.

5. SITUATION 'DIFFERENT BENEFITS'

See diagram 3. In this situation, as in situation 'Equal Benefits', lift irrigation is widely practiced by farmers belonging to the target group. But, here, the assumption that the switch from engine pumps to windmills will not affect the benefits cannot be maintained. One cannot, therefore, only compare the costs; the benefits will have to be taken into account as well. The proposed windmill pumping system must be compared with the current engine-powered system.
The investments in the water source (dug well, tube well), land levelling, and the water distribution system are not taken into account as they have already been made, and they are same for the engine pump and the windmill irrigation system.
As can be seen from diagram 3, there are three analyses: I) the Average Annual Net Benefits, II) the Cash Flow Analysis and III) the Pay Back Period. The calculation of the Pay Back Period is presented as this method is easy to understand for both farmers and policy makers.

5.1. Average Annual Net Benefits

With this calculation, net benefits of investments with a different economic life can be compared. The investment with the highest Average Annual Net Benefits is considered best. The calculations are made on the basis of fixed costs. Inflation is assumed to be zero, or to be the same in all sectors of the economy. If real price changes are expected, adjustments will have to be made.
Start by collecting the data required to determine the size and price of the windmill pumping system, as specified in the first four computer card-shaped boxes in diagram 3.

Water demand for the actual cropping pattern under the engine pump and for the proposed cropping pattern under the windmill cropping pattern (see 4.1)

Source of water (see 4.1)

Average monthly wind speeds in the area during the period of proposed windmill irrigation (see 4.1)

Local price of windmills (including taxes and subsidies) with tank, additional piping, transport to the farm, and installation (see 4.1)

With this information one can determine the size (diameter) and the price of the windmill pumping system using Appendix IV and Appendix V.
For determining Average Annual Net Benefits, one also needs the following information indicated in the other computer card-shaped boxes on the first line of diagram 3.

Economic life of windmill and tank (see 4.1)

Yearly maintenance costs of windmill and tank (see 4.1)

Local price of engine pumps including transport and installation (see 4.1)

Economic life of engine pumps (see 4.1)

Yearly fuel or electricity cost of engine pumps (see 4.1)

Yearly maintenance costs of engine pumps (see 4.1)

Interest rate (see 4.1)

Real price changes (see 4.1)

To determine the relative benefits of the engine pump and the windmill irrigation systems, one must know:

Gross margins per crop per ha, excluding fuel or electricity costs for water lifting
The gross margin is the income farmers receive if they sell the yield of a certain crop, minus all variable costs, e.g. tillage, fertilizer, seed or planting material, agrochemicals, hired labor. The gross margin is the remuneration for all fixed costs, consisting of land (+ water), family labor, capital (of which the water-lifting device is a major part), and management. To compare engine pumps and windmills the fuel or electricity costs must be specified separately.
Gross margins are regularly computed in many countries by Government Institutions, the agricultural departments of banks generally know them. One has to keep in mind that gross margins can vary considerably with the level of management: if plowing, planting/seeding, fertilizing, spraying, weeding, irrigation, and harvesting are not done properly and in time, the gross margins can drop seriously. Differences between the anticipated and actually realized gross margins are caused mostly not so much by a rise in costs as by benefits that are far lower than expected. It might, therefore, be advisable to calculate for both a 'good' and an 'average' level of management.

Typical cropping pattern under the engine pump
In reality, of course, every farm is different: a different area is cultivated, and not all farmers grow the same crops in the same proportions. For the purpose of this analysis, a 'typical' cropping pattern must be identified. In some areas, it might be necessary to identify more than one typical cropping pattern. A separate analysis then has to be made for each. This typical cropping pattern specifies how many hectares of which crops are grown, and in which sequence. It might help to make a diagram with time on the horizontal axis and the area cultivated on the vertical one (see example 5.1.1)

Proposed cropping pattern under the windmill
As the water supply of the windmill does not coincide with the traditional irrigation season, a different cropping pattern is proposed under the windmill. Designing such a cropping pattern is a tricky exercise since many factors have to be taken into consideration (on which no specific data are

generally available). For instance: capacity of the source of water each month, depth of the watertable each month, water demand of crops during each stage of growth, labor availability and requirement per crop per period, availability of inputs like seed or planting material, fertilizer and agrochemicals, and the gross margin per crop per ha (see above) under the expected level of management and marketing. The farmer looks for the cropping pattern with the highest feasible gross production value within the technical, financial, and social constraints given, and whose risk is acceptable to him. Practically speaking, it seems advisable to stick to actual farming practice as much as possible and introduce as few changes as possible.
In general, it will be necessary to consult an agronomist who is familar with the area. The proposed windmill cropping pattern can be presented in the same way as the actual engine pump cropping pattern.

With this information it is possible to determine the gross production value per farm per season as the gross margins per ha of the different crops, multiplied by the areas cultivated.
In addition to the gross production value of agriculture, the engine pump and/or the windmill might generate other benefits.
In parts of India, for instance, the sale of irrigation water is an established enterprise: farmers possessing a productive well and water lifting capacity in excess of their own needs sell water to neighbours at commercial rates. Some windmill farmers in India use their water storage tanks for fish farming or the cultivation of blue-green algae.

Now all data are available for:

Calculating Average Annual Net Benefits

For each year of the life of both the engine pump and the windmill pumping system, benefits and costs have to be determined.

Benefits

The benefits consist of the gross production value per farm per season plus revenues from fish farming or the sale of water, if applicable. So as not to complicate the calculations unnecessarily these benefits will be assumed constant over the years.

Costs (see 4.1 Average Annual Costs)

The Average Annual Net Benefits of the windmill and the engine pump lift-irrigation system can be determined with the formula

$$\text{AANB} = \frac{i\,(1+i)^n}{(1+i)^n - 1} \times \{-I + \sum_{t=1}^{n} \frac{(b_t - c_t)}{(1+i)^t}\} \quad \text{(Rs)} \qquad (10)^*$$

where AANB = Average Annual Net Benefits (Rs)
I = Investment (Rs)
b_t = benefits in year t (Rs)
c_t = costs in year t (Rs)
i = relevant interest rate (%)
n = life time windmill/engine pump (years)

Conclusions

If the Average Annual Net Benefits for the engine pump are higher than those for the windmill, one has to conclude that windmills are not economically feasible under the present conditions. If possible, a more cost effective windmill could be designed or a more profitable cropping pattern could be introduced. If the Average Annual Net Benefits for the windmill are higher than those for the engine pump, windmills are economically more attractive than engine pumps. However, it is not clear yet if farmers of the target group will purchase windmills. Windmills are a considerably higher investment than engine pumps. It may happen, then, that the farmer either cannot raise sufficient capital or that he may have to repay a loan within a much shorter period of time than the life of the windmill, making expenditures during the first years prohibitive. Therefore, one has to continue investigating the cash flow analysis, in order to find out whether or not the actual financing is a constraint.

5.1.1. *Example Average Annual Net Benefits*

See diagram 3. Collect the data specified in the first four computer card-shaped boxes to determine the size and price of the windmill pumping system:

Water demand

For the windmill cropping pattern (see below), the peak water demand is 55 m^3/day in the period June - July. The total irrigation requirement for a season is 5000 m^3.
For the kerosene pump cropping pattern (see below), the total irrigation requirement for a season is 8,500 m^3.

Source of water (see example 4.1.1)

Monthly average windspeed in the area during the irrigation period (see example 4.1.1)

Local price of windmills (see example 4.1.1)

* See Appendix II for the derivation of this formula.

With this information the size and the price of the windmill pumping system can be determined. See Appendix IV, Appendix V, and example 4.1.1.

Economic life of windmill and storage tank (see example 4.1.1)

Yearly maintenance cost of windmill and storage tank (see example 2.1.1)

Local price of engine pumps (see example 4.1.1)

Economic life of engine pumps (see example 4.1.1)

Yearly fuel or electricity cost of engine pumps
With a kerosene to water efficiency of 2.5%, a kerosene price of Rs 5.20 per liter, an irrigation requirement of 8,500 m^3 and a pumping head of 7 m, this is (formula (5a)):

$$FC = \frac{0.1}{ef} \times \frac{Q\ H}{360} \times FP = \frac{0.1}{0.025} \times \frac{8{,}500 \times 7}{360} \times 5.20 = \text{Rs } 3{,}438 \text{ per season.}$$

Yearly maintenance costs of engine pumps
These costs are estimated at 30% of the kerosene costs, or Rs 1,030.

Interest rate (see example 4.1.1)

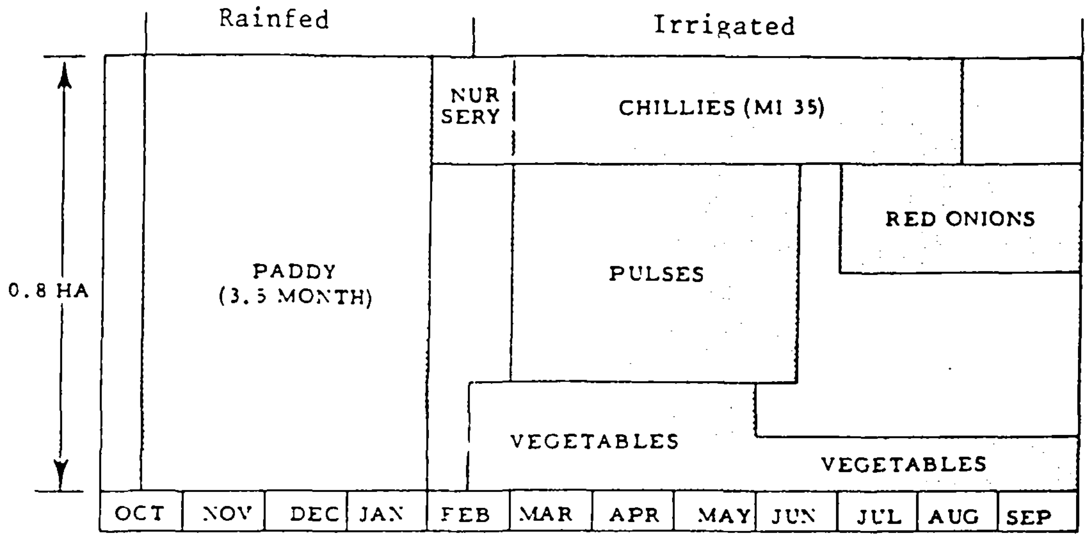
Real price change (see example 4.1.1)

To determine the benefits of the engine pump and windmill irrigation systems, one should know:

Gross margins per crop per ha excluding fuel or electricity costs

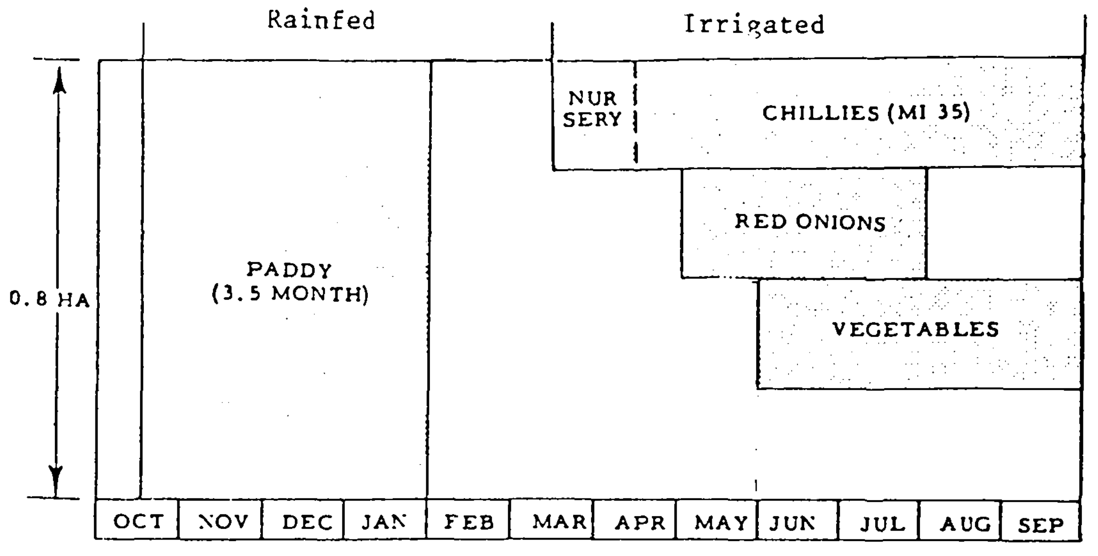
chillies	*: Rs 15,000*
red onions	*: Rs 30,000*
pulses	*: Rs 6,750*
vegetables	*: Rs 3,200*

Typical cropping pattern under the engine pump
After the rainfed paddy (rice) has cleared the field at the end of January, the soil is prepared, in March, and 0.2 ha chillies, 0.4 ha pulses, and 0.2 ha vegetables are planted. In June a second vegetable crop (0.1 ha) is planted and in July 0.2 ha red onions are planted:



<u>*Proposed cropping pattern under the windmill*</u>

After the rainfed paddy, a short term crop requiring little water, e.g. sesame can be planted to prevent weeds and to produce a small income (which is neglected here). In the middle of April 0.2 ha chillies are planted, followed by 0.2 ha red onions in May. In June 0.2 ha vegetables are planted; the rest of the 0.8-ha plot is left fallow:



No fish farming or sale of irrigation water.

The yearly benefits of the windmill and fuel-driven pumping systems can be determined now. They consist of the gross production value of both systems and are supposed to be constant over the years (same yields, no real price changes).

Benefits of the windmill pumping system (in Rs per season)

Crop	area (ha)	gross margin/ ha (Rs)	gross production value (Rs)
chillies	0.2	15,000	3,000
red onions	0.2	30,000	6,000
vegetables	0.2	6,750	1,350
Total			Rs 10,350

Benefits of the kerosene-driven pumping system (in Rs per season)

Crop	area (ha)	gross margin/ ha (Rs)	gross production value (Rs)
chillies	0.2	15,000	3,000
pulses	0.4	6,750	2,700
vegetables	0.2 + 0.1	3,200	960
red onions	0.2	30,000	6,000
Total			Rs 12,660

Now all data are available for:

Calculating Average Annual Net Benefits

Cost

The yearly costs for the windmill are the same as in example 4.1.1:

Yearly costs of windmill (Rs)

Year	0	1	2	3	4	5	6	7	8	9	10
Investment	18,000	-	-	-	-	-	-	-	-	-	-
Maintenance	-	600	600	600	600	600	600	600	600	600	600
Total	18,000	600	600	600	600	600	600	600	600	600	600

The yearly costs of the engine pump in this 'Different Benefits' situation are:

Yearly costs of kerosene pump (Rs)

Year	*0*	*1*	*2*	*3*	*4*	*5*
Investment	*6,500*	-	-	-	-	-
Maintenance	-	*1,030*	*1,030*	*1,030*	*1,030*	*1,030*
Fuel	-	*3,438*	*3,438*	*3,438*	*3,438*	*3,438*
Total	*6,500*	*4,468*	*4,468*	*4,468*	*4,468*	*4,468*

The Average Annual Net Benefits can be calculated now for both pumping systems using formula (10):

Windmill

$$AANB = \frac{0.125\ (1 + 0.125)^{10}}{(1 + 0.125)^{10} - 1} \times \{ - 18,000 + \frac{10,350 - 600}{1 + 0.125} + \frac{10,350 - 600}{(1 + 0.125)^2} + \ldots\ldots + \frac{10,350}{(1 + 0.125)^{10}} \} = Rs\ 6,499$$

Kerosene pump

$$AANB = \frac{0.125\ (1 + 0.125)^{5}}{(1 + 0.125)^{5} - 1} \times \{ - 6,500 + \frac{12,660 - 4,468}{1 + 0.125} + \frac{12,660 - 4,468}{(1 + 0.125)^2} + \ldots\ldots + \frac{12,660 - 4,468}{(1 + 0.125)^{5}} \} = Rs\ 6,366$$

Conclusion

As the Average Annual Net Benefits of the windmill pumping system are higher than those of the kerosene pump, one can conclude that lift irrigation with windmills is more profitable than lift irrigation with engine pumps, especially since higher average benefits are realized on a smaller area, and thus less family labor and less water are required. However, whether farmers in the target group will purchase windmills is unclear. Therefore, to find out whether or not financing is a constraint, the investigation with the cash flow analysis must be continued.

5.2. Cash Flow

The cash flow shows the amounts of money that will be received and that have to be spent per period (year) for a certain activity.
The cash flow analysis is clearly not a method for selecting the best economic alternative. It is merely a way to check whether the financing of an investment is arranged in such a way that the farmer will be able to pay his bills. The only requirement, therefore, is that the cash flow remain above the minimum cash requirements of the farmer. If necessary, these minimum cash requirements will have to be estimated in order to draw conclusions. If the cash flow produced by the most profitable pumping system remains below this minimum for a few years, the farmer can work successfully with it only if he has money enough to get through the difficult period or if he can obtain additional credit. The farmer might otherwise be compelled to go for a less profitable system which has a cash flow permanently above his minimum requirements. In general, one can say that it is more important to smaller farmers that investments 'make money' from the very first year onwards.
It is, therefore, of the utmost importance to check the estimated cash flow of a proposed pumping (or any other) device which is intended to help the farmer in the target group.

In addition to the data collected for the Average Annual Net Benefits (5.1), the following information is required as indicated in the three computer card-shaped boxes above the rectangular box labelled 'Cash flow analysis':

Inflation (see 4.2.)

Credit conditions (see 4.2.)

Available means of farmer (see 4.2.)

Now all information is available for the:

Cash flow analysis

With all these data a complete cash flow analysis can be made, consisting of total cash inflow and total cash outflow during every year of the economic life of both pumping systems.

The cash inflow consists of the benefits (gross production value, agriculture, fish farming, and sale of irrigation water). The cash outflow consists of maintenance, fuel or electricity (engine pump only), interest on borrowed capital, and amortization (repayment of the loan).
The benefits, the maintenance, and the fuel or electricity costs have to be corrected for the expected inflation and real price changes (formulas (8) and (9)).
The investment is made at the end of year 0. At the same time the loan is received. The difference between the investment and the loan has to be met by the farmer from his means.

The cash flow is calculated as the difference between inflow and outflow (see Example 5.2.1).

Conclusions

If the cash flow of the windmill is higher than that of the engine pump during every year of their life, there is a clear case for windmills. However, it is more likely that the cash flow of the windmill will be smaller than that of the engine pump during the first years, and that this situation will reverse. Whether a farmer, in that case, will still be in the position to select the economically more attractive windmill, depends on his minimum cash requirements and the possibilities of borrowing some extra money to get through the first years. The minimum cash requirements must be assessed separately, as indicated in the computer card-shaped box above the diamond-shaped box labelled 'Cash flow windmill > minimum cash requirements farmer during all years'. They will be, of course, different for each farmer. To get an idea of the requirements, one can assume that the daily wage of agricultural loborers is sufficient to maintain a subsistence level standard of living. Assuming that these laborers work 150 days a year one can then estimate the yearly minimum cash requirements of farmers.
The cash flow of the windmill is not likely to be lower than that of the engine pump every year of their life time, since this cash flow calculation is performed only if the Average Annual Net Benefits are higher for the windmill than for the engine pump.

5.2.1. *Example Cash Flow*

This example is a continuation of example 5.1.1. See diagram 3.
Collect the required additional data for the cash flow analysis, as indicated in the three computer card-shaped boxes just above the rectangular box labelled 'Cash Flow analysis':

Inflation

The expected annual inflation rate is 15%.

Credit conditions

Annual interest is 12.5%. The windmill loan of Rs 15,000 has to be repaid in 8 years, the kerosene pump loan of Rs 3,500 in 4 years.

Available means of farmer

The farmer has saved Rs 3,000 toward his water-lifting device.

Now all data are available for the:

Cash flow analysis

Cash inflow

Loan

For the windmill the farmer would have to borrow Rs 15,000, for the kerosene pump Rs 3,000. These loans appear only at the end of year 0 of the cash flow tables.

Benefits

Since there is no fish farming or sale of irrigation water, the benefits of the windmill are equal to the gross production value of agriculture calculated in example 5.1.1. The benefits have been supposed to be the same for each year, i.e. no increase in production, no real price changes, but they will have to be adjusted to accommodate the anticipated 15% annual inflation rate using formula (8):

$$\begin{aligned} \text{windmill benefits}_2 &= \text{windmill benefits}_1 \times (1 + 0.15)^{2-1} \\ &= 10350 \times 1.15 = 11903 \end{aligned}$$

$$\begin{aligned} \text{windmill benefits}_3 &= \text{windmill benefits}_1 \times (1 + 0.15)^{3-1} \\ &= 10350 \times 1.32 = 13688, \text{ etc.} \end{aligned}$$

The benefits for the kerosene pump are calculated in the same way, starting with Rs 12,660 for the first year.

Cash outflow

Investment

The investment for the windmill pumping system is Rs 18,000 and for the kerosene-powered pumping system Rs 6,500. These investments appear only at the end of year 0 of the cash flow table.

Maintenance

During the first year, the maintenance costs total Rs 600 for the windmill and Rs 1,030 for the kerosene pump. The maintenance costs should be the same for each year, but they will have to be adjusted to accommodate the anticipated 15% annual inflation rate using formula (8):

$$\begin{aligned} \text{windmill maintenance}_2 &= \text{windmill maintenance}_1 \times (1 + 0.15)^{2-1} \\ &= 600 \times 1.15 = 690 \end{aligned}$$

$$\begin{aligned} \text{windmill maintenance}_3 &= \text{windmill maintenance}_1 \times (1 + 0.15)^{3-1} \\ &= 600 \times 1.32 = 793, \text{ etc.} \end{aligned}$$

The maintenance costs of the kerosene pump are calculated in the same way, starting with Rs 1,030 for the first year.

Fuel costs

The fuel costs (for the kerosene pump only) are subject to the anticipated 15% annual inflation rate as well as to real price changes, which are expected to be 0 in this example. During the first year, the fuel costs total Rs 3,438. The fuel costs for subsequent years are calculated using formula (9):

$$\begin{aligned} \text{fuel costs}_2 &= \text{fuel costs}_1 \times (1 + 0.15)^{2-1} \times (1 + 0)^{2-1} \\ &= 3438 \times 1.15 \times 1 = 3954 \end{aligned}$$

$$\begin{aligned} \text{fuel costs}_3 &= \text{fuel costs}_1 \times (1 + 0.15)^{3-1} \times (1 + 0)^{3-1} \\ &= 3438 \times 1.32 \times 1 = 4547, \text{ etc.} \end{aligned}$$

Interest
For both devices, the interest costs during every year of their life are 12.5% of the remaining debt. These costs are not subject to inflation or real price changes.

Amortization
The windmill loan is amortized in annual increments of Rs 1,875 over an 8-year period: 1/8 × 15,000 = 1,875.
The kerosene pump loan is amortized in annual increments of Rs 875 over a 4-year period: 1/4 × 3,500 = 875.
Amortisation rates are not subject to inflation or real price changes.

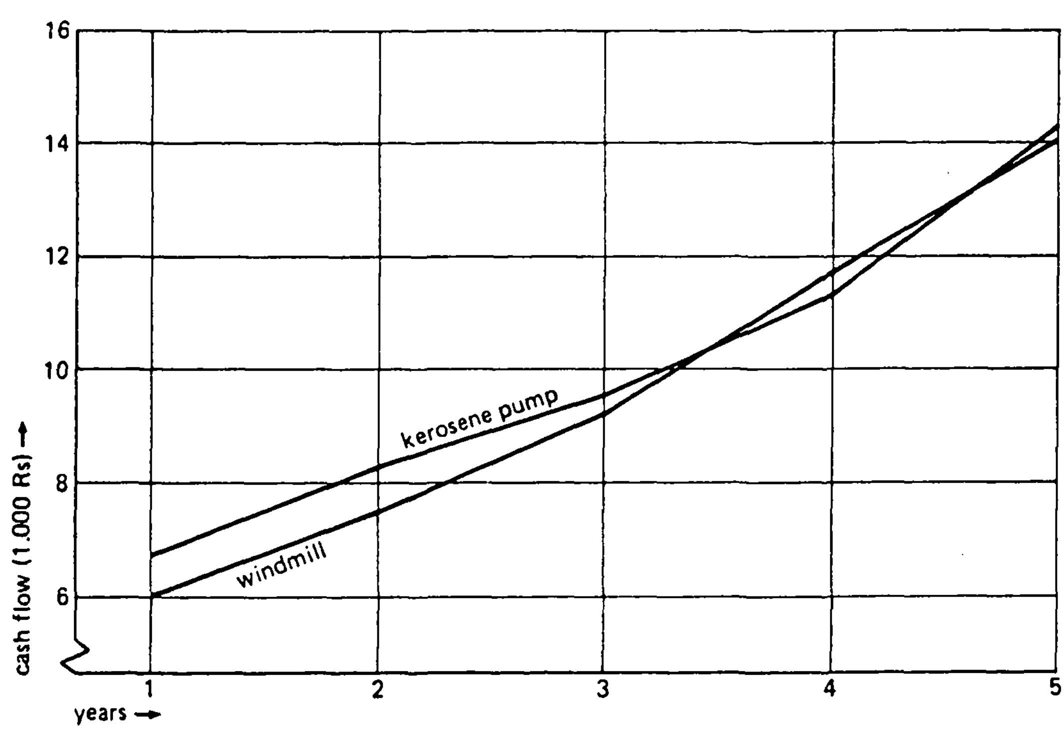
The cash flow is calculated as cash inflow minus cash outflow:

Cash flow windmill (Rs)

Year	0	1	2	3	4	5	6	7	8	9	10
Loan	15000	-	-	-	-	-	-	-	-	-	-
Benefits	-	10350	11903	13688	15741	18102	20818	23940	27531	31661	36410
A: Cash inflow	15000	10350	11903	13688	15741	18102	20818	23940	27531	31661	36410
Investment	18000	-	-	-	-	-	-	-	-	-	-
Maintenance	-	600	690	793	912	1049	1207	1388	1596	1835	2110
Interest	-	1875	1641	1406	1172	938	703	469	234	-	-
Amortization	-	1875	1875	1875	1875	1875	1875	1875	1875	-	-
B: Cash outflow	18000	4350	4206	4074	3959	3862	3785	3732	3705	1835	2110
A-B: Cash flow	- 3000	6000	7697	9614	11782	14240	17033	20208	23826	29826	34300

Cash flow kerosene pump (Rs)

Year	0	1	2	3	4	5
Loan	3,500	-	-	-	-	-
Benefits	-	12,660	14,559	16,743	19,254	22,142
A:						
Cash inflow	3,500	12,660	14,559	16,743	19,254	22,142
Investment	6,500	-	-	-	-	-
Maintenance	-	1,030	1,185	1,362	1,567	1,801
Fuel	-	3,438	3,954	4,547	5,229	6,013
Interest	-	436	328	219	109	-
Amortization	-	875	875	875	875	-
B:						
Cash outflow	6,500	5,779	6,342	7,003	7,779	7,814
A-B:						
Cash flow	- 3,000	6,881	8,217	9,740	11,475	14,328



Conclusion

At the end of year 0 the cash flow is - 3,000 for both pumping systems. This is the difference between the investments and the loan. This difference has to be met by the farmer from his means. The cash flow of the windmill is lower than that of the kerosene pump during years one, two, three, and five. The Average Annual Net Benefit calculation shows that in the long run the windmill is economically a better option than the kerosene pump. Whether farmers can take advantage of this option depends on their minimum cash requirement and on their financial situation. As indicated in diagram 3, one has to assess the:

Farmers' minimum cash requirements

For the purpose of this example, the yearly minimum cash requirements of a small-scale farmer in Sri Lanka will be estimated at 150 times the daily rate for agricultural laborers (about Rs 20), which results in a total of Rs 3,000.

It is evident, then, that even the windmill can generate enough cash during its first year. On top of that, one must keep in mind that the planted area under the kerosene pump in this example is larger than that under the windmill, and thus requires more labor and water.

5.3. Pay-Back Period

The financial pay-back period represents how long it takes to recoup investment costs financially. Taking the country's general investment climate into consideration, this financially period is then compared with the total economic life of the investment. Its calculation is based on cash flow and so is not a proper method to select the best economic alternative (that is the Average Annual Net Benefit Calculation).
But since the pay-back period is the criterion upon which most farmers base their investment decisions, this calculation is presented here as well.

Pay-back period calculation

The pay-back period is based on the cash flow analysis. It simply counts how many years it will take for the cumulative cash flow plus the amortizations to equal or become greater than the investment:

$$\sum_{t=1}^{p} cf_t + a_t \geqq I \tag{11}$$

where

p	= pay-back period	(years)	
cf_t	= cash flow in year t	(Rs)	(see example
a_t	= amortization in year t	(Rs)	Pay-Back Period)
I	= initial investment	(Rs)	

Conclusion
Since the pay-back period is a rather crude calculation, the conclusions are rather approximate as well. One can do two things with them:

- compare the pay-back period with the economic life - the pay-back period should be considerably shorter;
- evaluate the length of the pay-back period in the context of the investment climate. If the economic situation in a country seems unstable enough to negatively affect the assumptions on which the calculations have been based (such as prices for fuel or electricity, gross margins, etc.), long pay-back periods are undesirable.

5.3.1. Example Pay-Back Period

Based on the cash flow analysis made for the 'Different Benefits' situation, one can now perform the pay-back period calculations:

Windmill

Year	*Cash flow*	*Amortization*	*Σ Cash flow + amortization*	*Investment*
1	*6,000*	*1,875*	*7,875*	*18,000*
2	*8,217*	*1,875*	*17,967*	

The pay-back period for the windmill is two years.

Kerosene pump

Year	*Cash flow*	*Amortization*	*Σ Cash flow + amortization*	*Investment*
1	*6,881*	*875*	*7,756*	*6,500*

The pay-back period for the kerosene pump is less than one year.

Conclusion
From the point of pay-back period, there is not much difference between a windmill and a kerosene pump. Both are repaid within 20% of their life.

6. SITUATION 'WITHOUT LIFT IRRIGATION'

This is a more complicated situation, since lift irrigation with modern water-lifting devices, e.g. engine pumps, has not yet proven to be a practical, profitable, or socially acceptable enterprise within the target group. If one wants to make a case for windmills, one has to prove, first, that the additional investments required for lift irrigation can be justified by the additional benefits and, second, that windmills can lift water more profitably than any other water-lifting device.
This is done by comparing windmills, and all other water-lifting devices currently in use, with the predominant method of income generation (agriculture + off-farm employment). For the sake of simplicity, it will be assumed that windmills and engine pumps are the only alternatives. The Additional Average Annual Net Benefits, the Additional Cash Flow, and the Pay-Back Period for both the windmill and the engine pump must all be calculated.

6.1. Additional Average Annual Net Benefits

With this analysis one can compare the additional benefits of investments having a different economic life. The analysis is made on the basis of fixed costs. Inflation is expected to be zero or to be the same in all sectors of the economy and so is not taken into account. If real price changes are expected, adjustments will have to be made. The investment having the highest Additional Average Annual Net Benefits is considered best.

Diagram 4 gives an overview of all data required, calculations to be performed, decisions to be made, and conclusions to be reached.

Before the Additional Average Annual Net Benefit can be calculated, one must:

a) determine the cropping patterns, gross production values, peak and total water demands, and additional benefits of windmill and engine pump irrigation systems;
b) estimate the investments for complete windmill and engine pump irrigation systems.

For a), the following data, specified in the first six computer card-shaped boxes of diagram 4, are required:

Average farm size in target group
Farms often consist of several plots: highland, lowland, land close to and further away from home, land close to and further away from the source of irrigation water, and so on.
Farms can also be divided among the members of the family: head of the household, wife (or wives in polygamous families), grown sons, and so forth.
One now wants to know the size of the area that has to be irrigated, an area preferably consisting of a single plot situation around or near the source of water.

Availability of labor per farm
This depends on the family structure: extended or polygamous. Some statistics are generally available.

Availability of irrigation water
This can be surface water, e.g. rivers, streams, and lakes, or groundwater. With groundwater, one has to know whether or not open, shallow wells are already present or can be constructed, or if tubewells are required. With streams, it is important to know whether or not they will be flooded when it is time to irrigate. And with (tube) wells, one has to know their capacity. For existing shallow wells, a pump test is advisable (Appendix VI); farmers are generally very optimistic about the capacity of their wells, especially if these wells have only been used for drinking water. Water quality is also important since irrigation with saline water can be disastrous (Appendix VI).

Gross margins per crop per ha, excluding fuel or electricity costs for water lifting (see 5.1.)

Water demand (see 4.1.)

With this information one can design a cropping pattern for windmill and for engine pump irrigation. If the availability of irrigation water is not a limiting factor, the availability of land or labor (or capital) will be. If family labor is limiting, it might be possible to hire extra help. But as management problems increase with the hiring of labor, and more capital becomes involved (the laborers have to be paid before the harvest and a larger area is cultivated), it might be wise to start with a rather small plot of ½ to 1 ha so as not to complicate matters unnecessarily. After all, the main reason for lift irrigation is to pull these people through the dry season. If things work out well, command areas can be extended later.
The designing of cropping patterns is a complex excercise (see also 5.1.). These cropping patterns should combine food crops to provide for the farm family and cash crops to help amortize the loan and maintain the windmill (and fuel or electricity for the engine pump). Calculate the gross production value and the peak and total water demand and move on to:

Present income during the proposed irrigation period
If farmers switch to lift irrigation, they would probably have to give up some other activity. To calculate the additional benefits of lift irrigation, one has to know the economic value of these other activities. It might be some dry farming, traditional irrigation, handycraft or off-farm jobs. It is assumed that this income is equivalent to the minimum cash requirements of the farmer.

Using this information, determine the cropping patterns and the gross production values of both irrigation systems (see 5.1). Then, determine the peak and total water demand (see 4.1). Lastly, the additional benefits of both irrigation systems are calculated by subtracting the farmer's current income during the period proposed for irrigation from the gross production values.

To estimate the total investment for the windmill and engine pump systems, one needs the following additional information:

Cost of well, water distribution system, and land levelling
If there is no surface water available, one will have to use groundwater. If there is already a well for drinking water, this well has to be tested for its capacity (Appendix V): it might need improvement to be used for irrigation. If no well exists, a shallow or tube well has to be made and tested (yield and quality, see Appendix VI).
Somehow, the water lifted from the well or stream has to be directed towards the fields. This could be done either by means of open channels (lined or unlined) or using PVC or polyethylene piping. Once within the field, the water can be directed to the plants by means of furrows, basins, or with polyethylene spargers [23]. Some degree of land levelling is required for all irrigation systems. When starting lift irrigation as a new enterprise, all these investments must be made and their costs will have to be estimated.

Depth of watertable (see 4.1)

Monthly average wind speed of area and period (see 4.1)

Local prices of windmills with tank, including installation (see 4.1)

Local prices of engine pumps, including installation (see 4.1)
The installation costs of electric pumps will also include connection to the mains and all charges for the required paperwork.

Now the size of the windmill and engine pump required can be determined and the investment in the complete irrigation systems for the proposed farms can be estimated. The irrigation systems comprise the (improved) well if no surface water is available, the pump (windmill or engine pump), the tank (windmill), the land levelling, and the water distributing system.

For the calculation of the Additional Average Annual Net Benefits one needs the following additional data indicated in diagram 4:

Economic life of windmill (see 4.1)

Yearly maintenance cost of windmill (see 4.1)

Economic life of engine pump (see 4.1)

Yearly maintenance cost of engine pump (see 4.1)

Yearly fuel or electricity cost of engine pump (see 4.1)

Interest rate (see 4.1)

Real price changes (see 4.1)

Now all data are available for:

Calculating Additional Average Annual Net Benefits

The calculation of these AAANB is performed similarly to that for the Average Annual Net Benefits (see 5.1, formula (10)). The only difference is that the additional net benefits due to lift irrigation are used instead of the benefits and additional costs due to lift irrigation are used instead of the costs.

Conclusions

A lift irrigation system - windmill, engine pump, or any other - can become a profitable enterprise if its Additional Average Annual Benefits are positive. The system with the highest AAANB is the most attractive economically.

6.1.1. *Example Additional Average Annual Net Benefits*

See diagram 4 for the specifications of the required data (computer card-shaped boxes) and the sequence of calculations (rectangular boxes):

Average farm size in target group

These small-scale farmers in Sri Lanka's Dry Zone cultivate anywhere from 0.8 to 1.2 ha of land.

Availability of labor per farm

Enough to cultivate 0.6 - 0.8 ha of irrigated crops other than rice.

Availability of irrigation water

Some farms in Sri Lanka's Dry Zone are situated along a stream from which irrigation water can be pumped. No (improved) wells are required for these farms; the streams are flooded during the proposed irrigation period May - September. Most farms, however, have a small well for drinking-water. Pump tests show that those wells generally have to be deepened or enlarged if they are to be used for irrigation. Water quality has been analysed and it is adequate (Appendix VI).

Gross margins per crop per ha excluding fuel or electricity costs for water lifting (see example 5.1.1)

In this example, it will be assumed that the cropping patterns developed in example 5.1.1. are appropriate for use with the same gross production values and the same water demands.

Water demand (see example 5.1.1)

Present farm income during the proposed irrigation period

From May to September no commercial cultivation is possible in Sri Lanka's Dry Zone because of the lack of water. Only a very small plot with vegetables can be grown with hand watering. Labor is abundant in this part of the year, so wages are low and jobs are hard to find. It will be assumed, for the purpose of this example, that the head of the family will find work 10 days per month at the rate of Rs 20 per day.

Thus, from May to September he will earn Rs 1,000. Agricultural revenues will not be considered since so few farmers cultivate anything during the dry season. There are no other sources of income.

The additional net benefit due to lift irrigation are:

Windmill : Rs 10,350 - 1,000 = 9,350.
Kerosene pump : Rs 12,660 - 1,000 = 11,660.

Cost of well, water distribution system, and land levelling
Rs 4,000 must be spent to improve the well.
The levelling is done with family labor during those days that no off-farm employment is available. The water distribution system consists of 60 m flexible polyethylene tubing with a diameter of 50 mm (commonly used in Sri Lanka for this purpose), and costing Rs 2,000. The crops will be planted in small basins filled with the PE tubing.

Depth of watertable (see example 4.1.1)

Average monthly wind speed (see example 4.1.1)

Local prices of windmills, including pump and tank (see example 4.1.1)

Local prices of engine pumps (see example 4.1.1)

The total investment costs of the proposed windmill and kerosene pump irrigation systems are as follows:

Windmill irrigation system		
Windmill	*Rs*	*12,500*
Foundation	*Rs*	*500*
Tank	*Rs*	*4,000*
PE piping	*Rs*	*2,000*
Improved well	*Rs*	*4,000*
Total investment	*Rs*	*23,000*

Kerosene pump irrigation system		
Kerosene pump	*Rs*	*6,500*
PE piping	*Rs*	*2,000*
Improved well	*Rs*	*4,000*
Total investment	*Rs*	*12,500*

The investments will be made at the end of year 0.

For all other data required, refer to examples 4.1.1 and 5.1.1.

In this 'Without lift irrigation' situation, the yearly costs for the windmill and the kerosene pump are:

Yearly costs of windmill (Rs)

Year	0	1	2	3	4	5	6	7	8	9	10
Investment	23,000	-	-	-	-	-	-	-	-	-	-
Maintenance	-	600	600	600	600	600	600	600	600	600	600
Total	23,000	600	600	600	600	600	600	600	600	600	600

Yearly costs of kerosene pump (Rs)

Year	0	1	2	3	4	5
Investment	12,500	-	-	-	-	-
Maintenance		1,030	1,030	1,030	1,030	1,030
Fuel		3,438	3,438	3,438	3,438	3,438
Total	12,500	4,468	4,468	4,468	4,468	4,468

The additional benefits due to lift irrigation have already been calculated as:

Windmill : Rs 9,350.
Kerosene pump : Rs 11,660.

The Additional Average Annual Net Benefits are calculated using formula (10):

Windmill

$$AAANB = \frac{0.125\ (1 + 0.125)^{10}}{(1 + 0.125)^{10} - 1} \times \left\{ - 23{,}000 + \frac{9{,}350 - 600}{1 + 0.125} + \frac{9{,}350 - 600}{(1 + 0.125)^2} + \right.$$

$$\left. + \ldots\ldots + \frac{9{,}350 - 600}{(1 + 0.125)^{10}} \right\} = Rs\ 4{,}596$$

Kerosene pump

$$AAANB = \frac{0.125\ (1 + 0.125)^{5}}{(1 + 0.125)^{5} - 1} \times \left\{ - 12{,}500 + \frac{11{,}660 - 468}{1 + 0.125} + \frac{11{,}660 - 468}{(1 + 0.125)^2} + \right.$$

$$\left. + \ldots\ldots + \frac{11{,}660 - 468}{(1 + 0.125)^{5}} \right\} = Rs\ 3{,}681$$

Conclusion

Since both AAANB's due to lift irrigation are positive, lift irrigation is a profitable enterprise. The Additional Average Annual Net Benefits of the windmill irrigation system are some 25% higher than those of the kerosene pump. If the assumptions are realistic (and continue being so for the next 10 years) and if the farmer can finance the rather large investment, lift irrigation is a profitable enterprise and, in the long run, windmills are a more profitable device than kerosene pumps. The Additional Cash Flow analysis can determine whether or not financing will be a constraint.

6.2. Additional Cash Flow

Even if lift irrigation is economically feasible, it is still not certain that farmers will be willing to take all the extra risk and to spend all the extra hours in the field to make it work. In order to get some idea of how the farmer will react, it might be useful to analyze the additional cash flow. It will have to be well above that of off-farm jobs or other activities, especially if field work is more unpleasant during that time of the year because of higher temperatures.

The Additional Cash Flow analysis shows the extra flows of money (incomes and expenditures) which are expected per period (year) in relation with a certain activity. These flows are calculated on the basis of current costs, and thus include inflation and real price changes. The cash flow can show whether or not the most profitable water-lifting system is also feasible financially.

For the analysis, one needs the following additional information as specified in the three computer card-shaped boxes of diagram 4, located just above the rectangular box labelled 'Additional Cash Flow Analysis':

Inflation (see 4.2)

Credit conditions (see 4.2)

Available means of farmer (see 4.2)

Now all data are available for the:

Additional Cash Flow analysis

The cash flow for this situation is calculated along the same lines as the 'Different Benefits' situation (5.2), with the difference that the additional benefits are used instead of benefits and the additional costs are used instead of the costs.

Conclusions

Since it is assumed that the farmers' minimum cash requirements are met by their current income without lift irrigation, the only condition of the Additional Cash Flow is that it must be positive the whole life of the investment. If the Additional Cash Flow is negative at any point, the investment is financially feasible only if enough additional credit will be available.

However, it seems likely that farmers will assume the extra risk and work the extra hours in the field <u>only</u> if the Additional Cash Flow is considerable.

6.2.1 *Example Additional Cash Flow*

This example is a continuation of example 6.1.1. The addtional required data are specified in the three computer card-shaped boxes of diagram 4, located just above the rectangular box labelled 'Additional Cash Flow Analysis':

Inflation
The expected annual inflation rate is 15%.

Credit conditions
Interest is 12.5% per year. The windmill loan of Rs 15,000 has to be repaid in 8 years, the kerosene pump loan of Rs 4,500 in 4 years.
For the well, a loan of Rs 3,000 is available, to be repaid in 8 years.

Available means of farmer
The farmer has saved Rs 5,000 to invest in his lift irrigation system.

Additional cash flow calculation

To calculate the components of the cash flow table, refer to example 5.2.1.

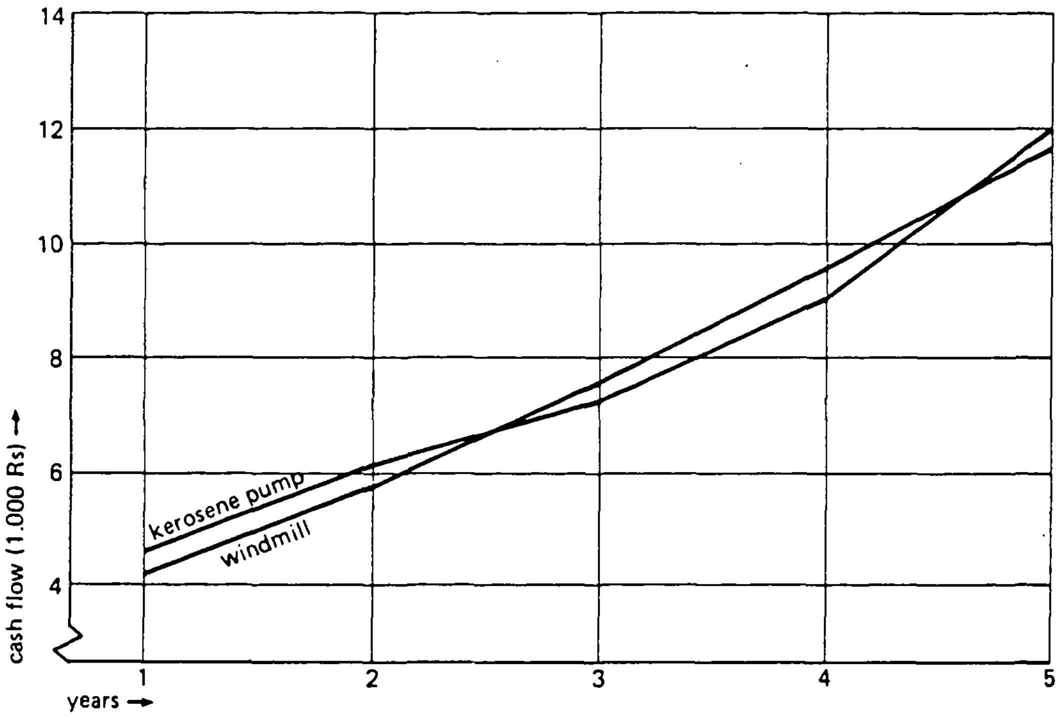
Cash flow windmill (Rs)

Year	0	1	2	3	4	5	6	7	8	9	10
Loan well	*3000*	-	-	-	-	-	-	-	-	-	-
Loan windmill	*15000*	-	-	-	-	-	-	-	-	-	-
Benefits	-	*9350*	*10752*	*12365*	*14220*	*16353*	*18806*	*21627*	*24871*	*28601*	*32892*
A: Cash inflow	*18000*	*9350*	*10752*	*12365*	*14220*	*16353*	*18806*	*21627*	*24871*	*28601*	*32892*
Investment	*23000*	-	-	-	-	-	-	-	-	-	-
Maintenance	-	*600*	*690*	*793*	*912*	*1049*	*1207*	*1388*	*1596*	*1835*	*2110*
Interest well	-	*375*	*328*	*281*	*234*	*188*	*141*	*94*	*47*	-	-
Amortization well	-	*375*	*375*	*375*	*375*	*375*	*375*	*375*	*375*	-	-
Interest windmill	-	*1875*	*1641*	*1406*	*1172*	*938*	*703*	*469*	*234*	-	-
Amortization windmill	-	*1875*	*1875*	*1875*	*1875*	*1875*	*1875*	*1875*	*1875*	-	-
B: Cash outflow	-	*5100*	*4909*	*4730*	*4568*	*4425*	*4301*	*4201*	*4127*	*1835*	*2110*
A-B: Cash flow	*- 5000*	*4250*	*5843*	*7635*	*9652*	*11928*	*14505*	*17426*	*20744*	*26766*	*30782*

Cash flow kerosene pump (Rs)

Year	0	1	2	3	4	5	6	7	8
Loan well	3000	-	-	-	-	-			
Loan kerosene pump	4500	-	-	-	-	-			
Benefits	-	11660	13409	15420	17733	20393			
A: Cash inflow	7500	11660	13409	15420	17733	20393			
Investment	12500	-	-	-	-	-			
Maintenance	-	1030	1185	1362	1567	1801			
Fuel	-	3438	3954	4547	5229	6013			
Interest well*	-	375	328	281	234	188	141	94	47
Amortization well*	-	375	375	375	375	375	375	375	375
Interest k.p.	-	563	422	281	141	-			
Amortization k.p.	-	1125	1125	1125	1125	-			
B: Cash outflow	12500	6906	7389	7971	8671	8377			
A-B: Cash flow	- 5000	4754	6020	7449	9062	12016			

* The amortization schedule stretches over 8 years; the kerosene pump has to be replaced after 5 years.



Conclusions

At the end of year 0 both cash flows are - 5000. This is the difference between the investment and the loan which has to be met by the farmer from his means.

From the first years onwards both additional cash flows are positive, indicating that there are no financial constraints for the farmer. The additional cash flow of the windmill is larger than the one of the kerosene pump during the third and fourth year.

6.3. Pay-Back Period

The pay-back period is based on the cash flow calculation explained in 5.3.

6.3.1. *Example Pay-Back Period*

Based on the cash flow analysis made for the 'Without lift irrigation' situation, the pay-back period calculations can now be made.

Windmill

Year	Cash flow	Amortization	Σ Cash flow + amortization	Investment
1	4,250	2,250	6,500	23,000
2	5,843	2,250	14,593	
3	7,635	2,250	24,478	

The pay-back period of the windmill irrigation system is thus a little less than three years.

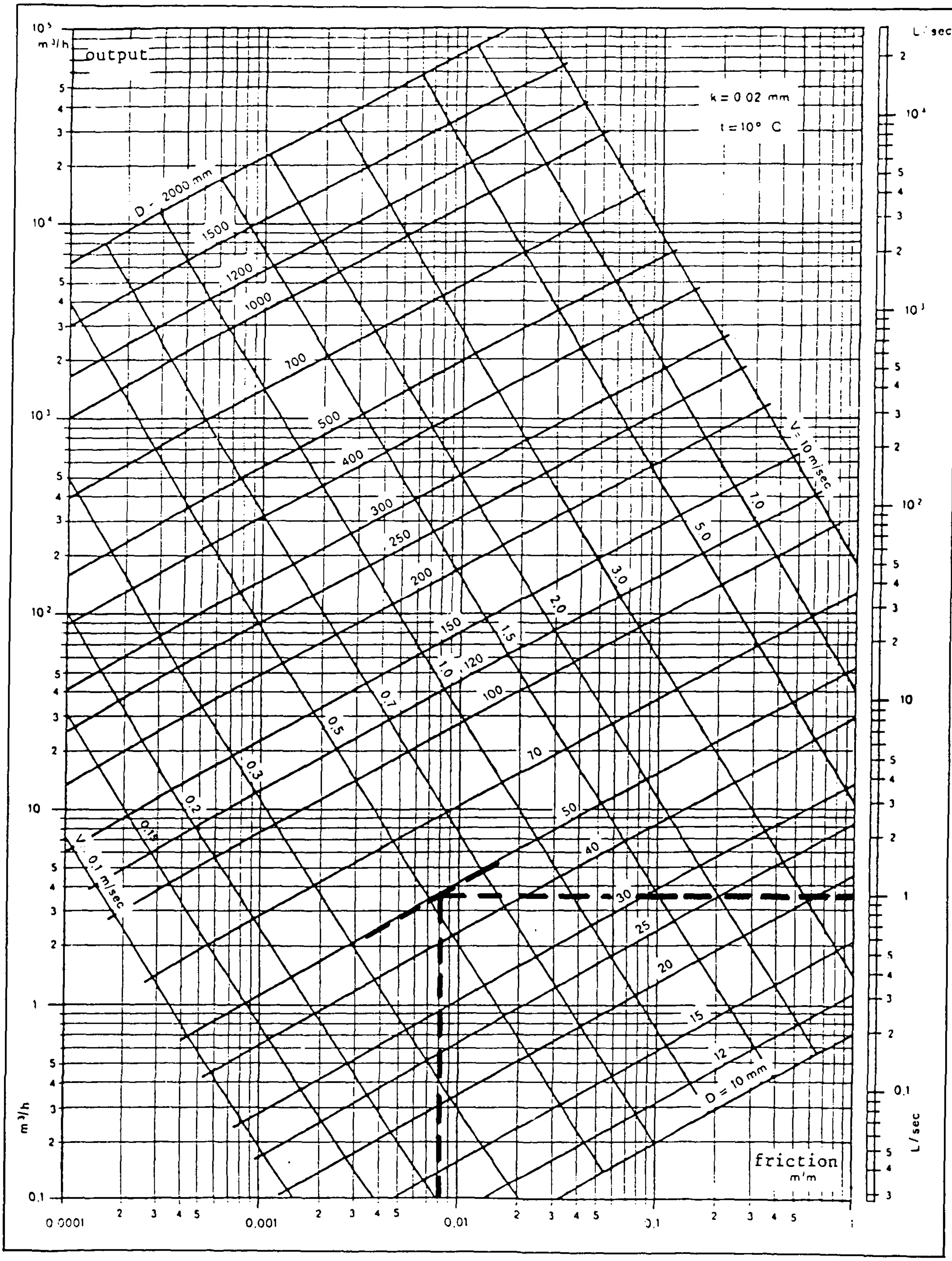
Kerosene pump

Year	Cash flow	Amortization	Σ Cash flow + amortization	Investment
1	4,754	1,500	6,254	12,500
2	6,020	1,500	13,774	

The pay-back period of the kerosene pump irrigation system is thus a little less than two years.

Conclusion
The pay-back periods of both lift irrigation systems are good when related to their economic life. Whether or not it is acceptable to the farmer depends on the economic outlook in the country.

APPENDIX III FRICTION LOSSES IN PVC AND PE PIPES (m head loss/m pipe)



Example: *the flow of 1 ℓ/s through a PVC or PE pipe with a diameter of 50 mm results in a head loss (friction) of 0.008 m/m. The head loss over 100 m is therefore 0.8 m.*

APPENDIX V

COSTS OF WINDMILLS

Here a detailed cost breakdown is presented for two intermediate technology level windmills: the 12PU500, a 5 m Ø water-pumping machine developed by WOT (the Dutch Working Group Deveopment Techniques in the Tool/ORP project in India), and the WEU 1/3, a 3 m Ø water-pumping windmill developed by the Sri Lankan Wind Energy Unit in close cooperation with SWD, the Steering Committee Wind energy Developing Countries.

These windmills are designed for local manufacture in developing countries.

The cost breakdown of each windmill begins with an analysis of the material costs. This analysis is based on information obtained from Kenyan hardware shops in early 1982. The results give an indication of the expected price level of both machines.

In this annex the customer's price for the windmills is given: that is the factory price, including 15% sales tax. The total costs of a windmill delivered and installed at the site are also presented.

This material breakdown can be used to estimate prices of windmills in other countries.

For comparison, a graph with prices per m^2 rotor area for some other windmills in other countries is also included in this appendix.

BREAKDOWN OF MATERIAL COSTS OF A WEU I/3 FOR KENYA

Material		Tower	Head frame	Main vane & side vane	Hinge	Rotor	Transmission	Pump	Total	Price/unit	Cost (8202)
Angle	25 • 25 • 3 mm	44 m	-	-	-	-	-	-	44 m	KSh. 70.-/6 m	514.-
Angle	32 • 32 • 4.5 mm	27 m	-	-	-	-	-	-	27 m	KSh. 115.-/6 m	518.-
Angle	40 • 40 • 6 mm	38 m	-	-	-	-	-	-	38 m	KSh. 205.-/6 m	1,300.-
Angle	50 • 50 • 6 mm	-	3.3 m	-	0.4 m	-	-	-	3.7 m	KSh. 670.-/6 m	167.-
Flat	1" • 1/4"	-	-	3.2 m	0.5 m	9 m	-	-	12.7 m	KSh. 80.-/6 m	170.-
CI pipe	1/2"	-	-	-	0.32 m	-	7 m	-	7.32 m	KSh. 148.-/6 m	181.-
CI pipe	3/4"	2.5 m	-	4.7 m	0.3 m	-	9 m	-	16.5 m	KSh. 187.-/6 m	515.-
CI pipe	2"	-	-	-	-	0.15 m	-	-	0.15 m	KSh. 522.-/6 m	13.-
CI pipe	4"	-	0.72 m	-	-	-	-	-	0.72 m	KSh. 1635.-/6 m	196.-
Rod	1/2"	-	-	2.1 m	-	-	-	-	2.1 m	KSh. 85.-/6 m	15.-
Shaft	1¼"	-	-	-	-	-	0.75 m	-	0.75 m	KSh. 1125.-/6 m	141.-
MS sheet	3 mm	0.63 m^2	-	-	-	-	-	-	0.63 m^2	KSh. 240.-/m^2	152.-
MS sheet	6 mm	-	0.06 m^2	-	-	-	-	0.18 m^2	0.24 m^2	KSh. 470.-/m^2	113.-
MS sheet	10 mm	-	-	-	-	0.1 m^2	0.03 m^2	-	0.13 m^2	KSh. 760.-/m^2	99.-
CI sheet 24 guage		-	-	1.41 m^2	-	2.2 m^2	-	-	3.61 m^2	KSh. 80.-/m^2	289.-
Mild steel various sizes		-	-	-	-	-	5 kg	-	5 kg	KSh. 12.-/kg	60.-
Pillow blocks with grease cups		-	-	-	-	-	3 •	-	3 •	KSh. 210.-/piece	630.-
PVC pipe	4"	-	-	-	-	-	-	0.3 m	0.3 m	KSh. 300.-/6 m	15.-
PVC elbow	2"	-	-	-	-	-	-	1 •	1 •	KSh. 70.-/piece	70.-
PVC tee	2"	-	-	-	-	-	-	3 •	3 •	KSh. 120.-/piece	360.-
CI socket	2"	-	-	-	-	-	-	3 •	3 •	KSh. 35.-/piece	105.-
CI red tee	3" • 2"	-	-	-	-	-	-	1 •	1 •	KSh. 200.-/piece	200.-
Air vessel 8 l		-	-	-	-	-	-	2 •	2 •	KSh. 180.-/piece	360.-
Leather		-	-	-	-	-	-				60.-
Paint, primer, thinner, etc.											420.-
Bolts, nuts, washers, springs, welding rocks, etc.											480.-
										Total	7,143.-

Source: [16]

Cost estimate of the WEU I/3 (prices early 1982)[1] for Kenya

Material costs		KSh. 8,200.=
Material KSh. 7140 (previous table)		
Losses 15% " 1060		
Labour costs		1,225.=
Cutting, grinding, drilling:	10 hrs at KSh. 30 = KSh. 300	
Welding	: 13 " at " 35 = " 455	
Machining	: 3 " at " 50 = " 150	
Fitting and painting	: 8 days at " 40 = " 320	
Overhead		800.=
TOTAL		10,225.=
Profit 20%		2,000.=
Factory price		12,225.=
Sales tax 15%		1,835.=
CUSTOMER PRICE		KSh. 14,060.=
Installation costs (at distance of 100 km)		3,450.=
- One surveying trip:	200 km at KSh. 5 = KSh. 1,000	
- One installation trip:	200 " at " 10 = " 2,000	
Foundation material + labour (by windmill owner)	" 300	
Installation labour costs	" 150	
Profit on installation (20%, excl. foundation)		630.=
TOTAL COST INSTALLED WINDMILL		KSh. 18,140.=

[1] 1 US$ = Ksh. 10.50

Source: [16]

BREAKDOWN OF MATERIAL COSTS OF A 12PU500 FOR KENYA

Material		Tower	Head, tail & aux. vane	Rotor	Transmission	Pump	Delivery parts	Total	Price/unit	Cost (8202)
Angle	32 * 32 * 4.5 mm	41.53 m	-	-	-	-	-	41.53 m	KSh. 115.-/6 m	796.-
Angle	40 * 40 * 4.5 mm	26.00 m	18.10 m	13.50 m	-	-	4 m	61.60 m	KSh. 155.-/6 m	1,592.-
Angle	50 * 50 * 6 mm	-	0.48 m	0.70 m	-	-	-	1.18 m	KSh. 270.-/6 m	54.-
Flat	1" * 1/4"	-	-	-	0.54 m	-	-	0.54 m	KSh. 80.-/6 m	8.-
Flat	1½" * 1/4"	7.82 m	5.28 m	31.38 m	0.85 m	-	4.64 m	49.97 m	KSh. 95.-/6 m	792.-
Flat	1½" * 3/8"	-	-	-	0.17 m	-	-	0.17 m	KSh. 200.-/6 m	6.-
Pipe	5/8"	-	-	-	-	0.40 m	-	0.40 m	KSh. 100.-/6 m	7.-
Pipe	3/4"	-	-	-	4.70 m	0.90 m	6.50 m	12.10 m	KSh. 190.-/6 m	384.-
Pipe	4"	2.65 m	-	-	-	0.56 m	7.00 m	10.21 m	KSh. 1635.-/6 m	2,783.-
Pipe	6"	-	-	-	-	0.46 m	-	0.46 m	KSh. 2370.-/6 m	182.-
Rod	3/8"	-	-	-	-	0.77 m	-	0.77 m	KSh. 60.-/12 m	4.-
Rod	1/2"	-	-	-	-	-	0.74 m	0.74 m	KSh. 85.-/12 m	6.-
Rod	3/4"	-	0.65 m	-	-	-	-	0.65 m	KSh. 220.-/12 m	12.-
Shaft	1"	-		-	0.20 m	-	-	0.20 m	KSh. 500.-/6 m	17.-
Shaft	2"	-		-	1.37 m	0.04 m	-	1.41 m	KSh. 2000.-/6 m	470.-
Sheet	1 mm 4" * 8"	-	0.85 *	3.4 *	-	-	-	4.25 *	KSh. 270.-/sheet	1,148.-
Sheet	2 mm 4" * 8"	-	-	0.28 *	-	0.42 *	-	0.70 *	KSh. 480.-/sheet	336.-
Wood & leather (for platform, cross-head, piston, pump rod guides)										250.-
Nylon	1½"	-	-	-	0.80 m	-	-	0.80 m	KSh. 150.-/m	120.-
Gun metal		-	-	-	-	0.04 m	-	0.04 m	KSh.	100.-
Pillow blocks	2"	-	-	-	2 *	-	-	2 *	KSh. 194.-/piece	388.-
PVC pipe	4"	-	-	-	0.70 m	-	-	0.70 m	KSh. 300.-/6 m	35.-
MS socket	4"	-	-	-	-	1 *	1 *	2 *	KSh. 140.-/piece	280.-
MS T-socket	4"	-	-	-	-	-	1 *	1 *	KSh. 480.-/piece	480.-
Paint, primer, thinner, etc.										550.-
Bolts, nuts, washers, springs, welding rods										530.-
									Total	11,300.-

Source: [16]

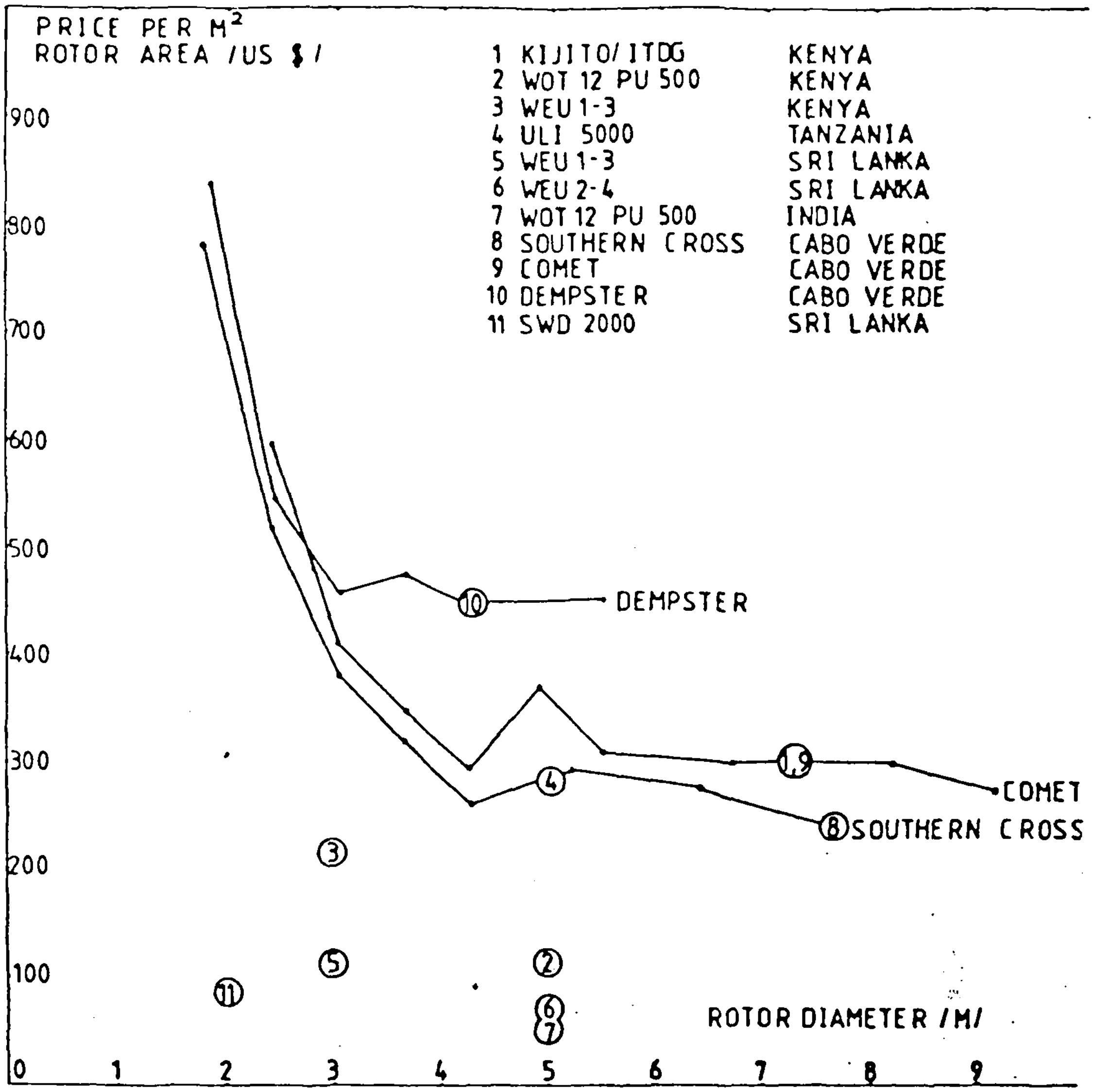
Cost estimate of the 12PU500 (prices early 1982)[1] for Kenya

Material costs	KSh. 13,000.=
Material KSh. 11,300 (previous table)	
Losses 15% " 1,700	
Labour costs	1,470.=
Cutting, grinding, drilling: 12 hrs at KSh. 30 = KSh. 360	
Welding : 16 " at " 35 = " 560	
Machining : 3 " at " 50 = " 150	
Fitting and painting : 10 days at " 40 = " 400	
Overhead	1,000.=
TOTAL	15,470.=
Profit 20%	3,000.=
Factory price	18,470.=
Sales tax 15%	2,770.=
CUSTOMER PRICE	KSh. 21,240.=
Installation costs (at distance of 100 km)	3,800.=
- One surveying trip: 200 km at KSh. 5 = KSh. 1,000	
- One installation trip: 200 " at " 10 = " 2,000	
Foundation material + labour " 550	
Installation labour costs " 250	
Profit on installation (20%, excl. foundation)	650.=
TOTAL COST INSTALLED WINDMILL	KSh. 25,690.=

[1] 1 US$ = KSh. 10.50

Source: [16]

Prices per m^2 rotor area for several windmills in different countries



The price of a windmill per square metre of rotor area is a measure of the cost effectiveness. In table 1 the price per square metre of rotor area is given for a number of water pumping windmills. Prices are given for windmill + pump, excluding installation costs.

Country of manufacture	Delivered	Windmill	Rotor diameter	Local price	Exchange rate	Price in US $	Price per m^2 swept area
Kenya	Kenya	Kijito (ITDG)	7.3 m (24')			12.500	299
Kenya	Kenya	WOT 12 PU 500	5 m	21.000 Shs	9.2 Shs = 1$	2.336	119
Kenya	Kenya	WEU I-3	3 m	14.000 Shs	9.2 Shs = 1$	1.521	215
Tanzania	Tanzania	ULI 5000	5 m	50.000 Shs	9 Shs = 1$	5.555	282
Sri Lanka	Sri Lanka	WEU I-3	3 m	17.500 Rs	22 Rs = 1$	795	113
Sri Lanka	Sri Lanka	WEU II-4	5 m	30.000 Rs	22 Rs = 1$	1.363	69
India	India	WOT 12 PU 500	5 m	11.000 Rs	11 Rs = 1$	1.000	51
Australia	Cabo Verde	Southern Cross	7.6 m (25')			11.000	242
USA	Cabo Verde	Comet	7.3 m (24')			12.500	299
USA	Cabo Verde	Dempster	4.3 m (14')			6.400	447
Sri Lanka	Sri Lanka	SWD 2000	2 m	6.000 Rs	22 Rs = 1$	273	87

Table 1: Price per square meter rotor area for various water pumping windmills

Source: Eindhoven University of Technology

APPENDIX VI

TESTING THE RECHARGE CAPACITY OF DUG WELLS AND THE QUALITY OF WATER

Dug wells

To evaluate whether or not a well can be equipped with a windmill, and to select the appropriate windmill size, a kind of "steady state yield" is a useful criterium. This is the average rate at which a well can be pumped without being emptied. Even though a windmill does not pump at a constant rate, at high wind velocities, it might still empty a well. This cannot be fully prevented; but the larger the storage capacity in the well, the smaller the chances of its being pumped dry.

There are several methods of testing a well's recharge capacity, two of which are described here.

Method based on well geometry

This method is easy to understand. It is presently being used by the Wind Energy Unit in Sri Lanka. The idea behind the test is that the recharge capacity of a well can be determined by the amount of water and the time necessary to refill it. One must know, then, the well diameter (d_w), the water level after the well has been emptied or at least the water level has considerally been lowered (h_1) (that is after pumping has been finished), the water level after recharging has almost been completed (h_2), as well as the time elapsed (t). In a formula this reads:

$$Q = \frac{\frac{1}{4}\pi \, d_w^2 \, (h_1 - h_2)}{t} \quad (m^3/\text{hours})$$

where Q = recharge of the well

Although this method is very attractive because of its simplicity, the fact that it determines the well recharge over the full recovery period is a major drawback. During actual pumping, the recharge rate can be much higher than the values found using the formula because the well's water level is constantly low. This method, therefore, gives a pessimistic value. And, one has to be careful determining the relevant well diameter; it might be much smaller than the well diameter at the surface.

The "optimum yield" approach

Here, a pump of known capacity is used (Q_p). The time necessary to empty the well from a certain level (not necessarily the maximum one) to a second chosen level is recorded (t_p) as well as the time necessary for the water to rise to the first level again (t_r).

The optimum yield of the well can be found from:

$$Q_R = Q_p \frac{t_p}{t_p + t_r} \qquad (m^3/\text{hours})$$

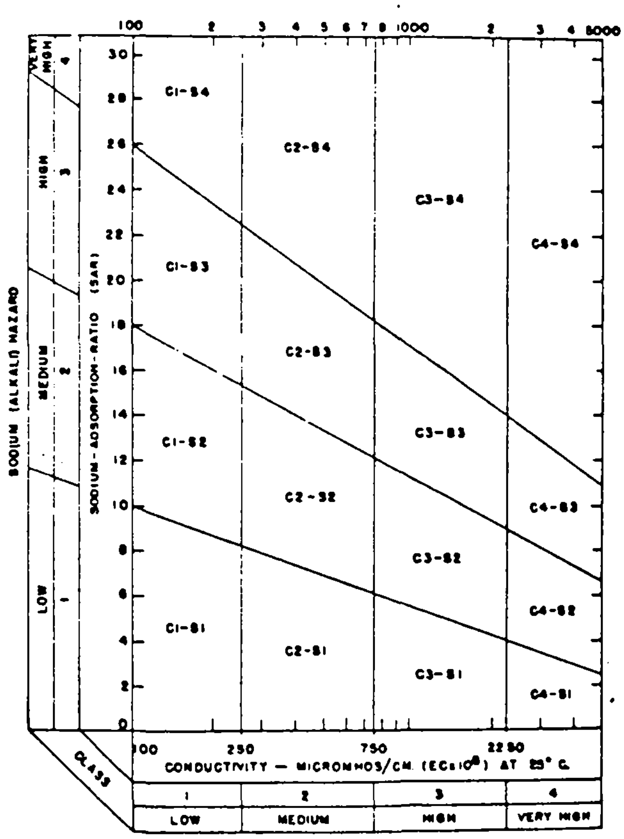
where $\quad Q_R$ = optimum yield

This optimum yield is the steady state yield being sought. Again, this method is very simple. The only problem is that one must know the pumping rate; but this is generally the case and it can be measured very easily.

Source [29].

Water quality

The suitability of water for irrigation is measured by the Sodium-Adsorption-Ratio (SAR) and electric conductivity, both of which have to be determined in the laboratory. The results can be evaluated using the diagram below:



Refer [12] for more information.

In addition, it is important to measure the borium content and check for pesticide pollution before using water for irrigation.

GLOSSARY

ACCOUNTING PERIOD
The interval between successive entries in an account. The accounting period is generally a year, but it can be any other convenient time period.

ACCOUNTING PRICES
These are economic, shadow prices which reflect the value of commodities or services to the economy as a whole. Essentially, they are represented by the opportunity costs.

ADDITIONAL AVERAGE ANNUAL NET BENEFITS
The economic analysis used in the situations described in this guideline as being 'Without lift irrigation'. It is a method of comparing investments with different economic lives that will replace a current activity. Calculated on the basis of fixed costs, thus assuming that inflation is the same in all sectors of the economy. Real price changes are taken into account.
See Appendix II for formula.

AMORTIZATION
Repayment of a loan (not the interest).
(Amortization is not a cost in the cost/benefit analysis, but it is an expenditure in the cash flow, or financial, analysis).

ANNUAL EQUIVALENT
A stream of equal amounts paid or received annually for a period so that by discounting at an appropriate interest rate it will have a specified present value. Determined by multiplying an initial value by the capital recovery factor.

ANNUITY
An amount paid or received annually, or at other regular intervals, for a stated period of time. Often used in the sense of equal installments.

ANNUITY-FACTOR
See: Capital Recovery Factor.

ASSETS
Property or claims owned by an individual or enterprise. 'Current' assets consist of cash and items expected to be converted into cash soon, usually within the year. 'Fixed' assets are durable items used for production.

AVERAGE ANNUAL COSTS
The economic analysis used in situations described in this guideline as having 'Equivalent benefits'. It is a method of comparing the cost-effectiveness of investments with different economic lives.

Calculated on the basis of fixed costs, thus assuming that inflation is the same in all sectors of the economy. Real price changes are taken into account.
See Appendix II for the formula.

AVERAGE ANNUAL NET BENEFITS
The economic analysis used in situations described in this guideline as having 'Different benefits'. It is a method of comparing the profitability of investments with different economic lives. Calculated on the basis of fixed costs, thus assuming that inflation is the same in all sectors of the economy. Real price changes are taken into account.
See Appendix II for the formula.

BENEFITS
Used in this guideline in the economic analyses for any goods and services produced that will further the objectives of the farmer. It is distinguished from the term 'income' used in the financial analysis since there are incomes (like loans) which are not benefits, while revenues from the sale of irrigation water are benefits as well as income.

BENEFIT/COST RATIO
Ratio of the sum of the discounted benefits and the discounted cost of a project, using the opportunity cost of capital for the discounting. If $B/C \geqq 1$ the project is feasible. Not recommended.

CAPITAL
In an economic sense, goods created by the process of investment that are capable of producing economic wealth. Capital in this sense is one of the three classic factors of production (land and labor being the other two). It is thus real capital.
In an accounting sense, capital is the stock of funds and other assets owned.

CAPITAL RECOVERY FACTOR
The annual fee that will repay a loan of 1 currency unit in x years with compound interest on the unpaid balance. Also called the 'partial payment factor'. The expression $[i(1 + i)^n] \div [(1 + i)^n - 1]$, where i = the rate of interest and n = the number of years, is the reciprocal of the present worth of an annuity factor. Generally obtained from a set of compounding and discounting tables, this factor permits calculating the equal installments necessary to repay (amortize) a loan over a given period at a stated interest rate. The total payment is a varying combination of both interest and repayment (amortization) of principal.

CAPITALIZE
In credit transactions, to add any interest due during the grace period to the principal of a loan so that the borrower need not pay any interest during the grace period. When repayment begins, the amount borrowed plus the interest capitalized become the principal that must be repaid.

CASH FLOW

The financial analysis which shows the amount of money to be received (income) and to be paid out (expenditures) per period. Calculated in current prices, it thus takes inflation and real price changes into account. The difference between cash inflow and cash outflow.

C.I.F. PRICE

The landed cost of an import on the dock or other point of entry in the receiving country. Includes cost of international freight and insurance and often cost of unloading. Exclude any charges after the import touches the dock as well as all domestic tariffs and other taxes or fees. Compare with F.O.B.

COMMAND AREA

The area that can be irrigated by a particular group of irrigation works.

COMPOUNDING FACTOR FOR 1

What an initial amount of 1 becomes when growing at compound interest. Also called the 'compound interest factor' and the 'amount of 1.' The expression $(1 + i)^n$ where i = the interest rate and n = the number of years. Usually obtained from a set of compounding and discounting tables, it is also called the 'future value factor single payments'.

COMPOUNDING FACTOR FOR 1 PER ANNUM

The growth of equal year-end deposits of 1, all growing at compound interest. Also called the 'compound interest factor for 1 per annum' and the 'amount of 1 per annum'.

The expression $[(1 + i)^n - 1] \div i$ where i = the rate of interest and n = the number of years. The reciprocal of the sinking fund factor. Generally obtained from a set of compounding and discounting tables, this factor permits calculating the value to which a constant amount deposited at the end of each year will grow by the end of a stated period at a stated interest rate. It is also called the 'future value factor uniform series'.

CONSTANT

Refers to a value, most often a price, from which the overall effect of a general price inflation has been removed. A 'constant' price is a price that has been deflated to real terms by an appropriate price index. May refer to market and shadow prices. Compare with Current.

COST

Used in this guideline in the economic analyses for any goods or services that a farmer uses that will obstruct progress toward his objectives. Contrary to benefit. Distinguished from expenditures since there are costs which are not expenditures (depreciation), and there are expenditures which are not costs (amortization). Fuel and interest payments are costs as well as expenditures.

COST EFFECTIVENESS ANALYSIS

An appraisal technique used primarily in social programs in which benefits cannot be reasonably measured in money terms, or to compare investments with the same benefits but different economic lives, as the Average Annual Costs method. The discounting is normally done at the opportunity cost of capital. If cost effectiveness analysis is used within a project to choose among alternative technologies to determine the most cost effective means to produce intermediate project outputs, it is most often done in the form of the constant effects method and called 'least-cost analysis'. The preferred alternative is the one that has the lowest present worth, and the preference may change when different interest rates are used to determine the present worth. The interest rate at which the present worths of two different alternatives are the same is known as the crossover discount rate. It is impossible to obtain a measure of project worth from cost effectiveness analysis since the analysis is done without reference to the value of the project output to users.

CRITICAL PATH DIAGRAM

A diagram that plots the sequence of activities for project planning and scheduling, shows which activities must be completed before others can commence, and indicates which activities cannot be delayed without delaying the whole project. Variously referred to as 'critical path method' (CPM), 'program evaluation and review technique' (PERT), or 'network analysis'.

CROPPING INTENSITY

Total cultivated area on a farm divided by total crop land. When there is multiple cropping, the cropping intensity may be greater than 1. Often reported as a percentage. Thus, a farm where 7 hectares are cultivated as a result of multiple cropping, but where there are only 5 hectares of total crop land, has a cropping intensity of 1.4 (7 ÷ 5 = 1.4), or 140 percent.

CROPPING PATTERN

The area devoted to, and the sequence of, crops produced by a single farmer or in a whole region.

CURRENT

Refers to a value, most often a price, that includes the effects of general price inflation. A past value or price as actually observed; a future value or price as expected to occur. Compare with Constant. In economic literature, a constant price is usually specified if it is intended, otherwise one infers that a current price is intended.

DEBT SERVICE

A payment made by a borrower to a lender. May include one or all of: (1) payment of interest; (2) repayment of principal; and (3) loan commitment fee.

DEBT SERVICE RATIO
(Net income + depreciation + interest paid) ÷ (interest paid + repayment of long-term loans). A financial ratio used to judge credit worthiness.

DECISION TREE
Used in an analytical technique, the diagram by which a decision is reached through a sequence of choices between alternatives. So called because the diagram resembles a tree lying on its side.

DEFLATION
The act of adjusting current prices to constant prices.
The arithmetic (division) is the same as for discounting.

DEPRECIATION
The anticipated reduction in the value of an asset that is brought about through physical use or obsolescence. In accounting, depreciation refers to the process of allocating a portion of the original cost of a fixed asset to each accounting period so that the value is gradually used up ('written off') during the course of the asset's estimated 'useful life'. Allowance may be made for the ultimate estimated resale value of the fixed asset (its residual value) so that it remains useful to the enterprise until the end. There are two principal types of depreciation methods: 'straight-line' depreciation, which allocates the cost of a fixed asset in equal amounts for each accounting period, and 'accelerated' depreciation, which allocates a larger proportion of the original cost to earlier accounting periods and a smaller proportion to later periods. In discounted cash flow analysis, depreciation is not treated as a cost. Instead, the cost of an asset is shown in the year it is incurred and the benefits are shown in the year they are realized. Since this is done over the life of the project, no depreciation allowance is needed to show the proportion of the value of the asset used in any given year.

DEVELOPMENT PERIOD
With respect to a project, the period after the investment period when production builds up toward full development. In agricultural projects, often three to five years, but longer if the project involves cattle herds, tree crops, or other investments with long gestation.

DISCOUNTED CASH FLOW ANALYSES
Analysis based on the net incremental costs and benefits that form the incremental cash flow. It yields a discounted measure of project worth such as the net present worth, internal rate of return, or net benefit-investment ratio.

DISCOUNT FACTOR

How much 1 at a future date is worth today. Also called the 'present worth factor' and the 'present worth of 1'.

The expression $1 \div (1 + i)^n$ where i = the rate of interest (discount rate) and n = the number of years. The reciprocal of the compounding factor for 1. Generally obtained from a set of compounding and discounting tables, this factor permits determining the value today of an amount received or paid out in the future. The process of finding the present worth of some future value is generally referred to as 'discounting'. Since the discount factor is the reciprocal of the compounding factor for 1, it is common to hear expressions such as 'discounted at an interest rate of 14 percent'.

ECONOMIC

Often used in the sense of national-economic. Here used for the set of analyses that compare costs, or costs and benefits, of different activities: Average Annual Costs, Average Annual Net Benefits and Additional Average Annual Net Benefits.

ECONOMIC PRICES

See Accounting prices.

EQUAL INSTALLMENTS

The amount of debt service when a loan is repaid in a series of payments of the same total amount, but with varying portions of principal and interest. The equal installment is computed by the capital recovery factor. Equal installments are rarely used in developing countries for agricultural projects.

EVAPOTRANSPIRATION

Loss of water due to evaporation of the soil and transpiration of the plants.

EXPENDITURE

In this guideline, used in the financial analyses for amounts of money that must be spent for a certain activity at a certain time. Distinguished from costs, since there are expenditures (like amortization) which are not costs, and there are costs (like depreciation) which are not expenditures. Contrary to income.

FINANCIAL

Often used in the sense of analysis using market prices. In this guideline used for those analyses (Cash flow, Additional Cash flow, and Pay-Back Period) in which expenditures or expenditures and incomes of different activities are compared.

FINANCING

The method by which the money for an investment is brought together: the farmer's own savings, formal loans from banks, and informal loans from relatives and moneylenders.

F.O.B. PRICE
Free on board price. The price of an export loaded in the ship or other conveyance that will carry it to foreign buyers. Compare with C.I.F.

FUTURE VALUE FACTOR SINGLE PAYMENTS
See: Compounding factor for 1.

FUTURE VALUE UNIFORM SERIES
See: Compounding factor for 1 per annum.

INCOME
Used in this guideline in the financial analyses for amounts of money that will be received at a certain time. Distinguished from benefits since there are incomes (like loans) which are not benefits. Contrary to expenditure.

INCREMENTAL
Extra, Additional.

INDEPENDENT
Projects or project design options that can all be undertaken. Distinguished from mutually exclusive projects or project design options, for which accepting one alternative necessarily excludes accepting another.

INFLATION
An increase in the general price level of an economy. Inflation occurs when the quantity of money in circulation rises relative to the quantity of goods and services offered. The result is "too much money chasing too few goods" and prices are bid up. At high rates of inflation, people tend to lose confidence in money, and the quantity of money in circulation increases relative to expenditures in current prices as people tend to hold (hoard) goods rather than money. Inflation is associated with a rise in gross national expenditure at current prices that is greater than the increase in the REAL supply of goods and services available. In project analysis, the customary analytical approach is to work in constant prices rather than current prices and to assume that inflation will affect the prices of all costs and benefits equally, except for specified costs and benefits that are varied in comparison with the others so that the relative prices of these specified costs and benefits change. Using constant prices allows the analyst to avoid making risky estimates of future inflation rates and to simplify the analytical procedures.

INFLOW, CASH
In cash flow analysis: amounts of money received per period.

INPUT
A good (such as seed or fertilizer) or service (such as agricultural labor) used to produce an output (such as crops or livestock).

INTANGIBLE

In project analysis, refers to a cost or benefit that, although having value, cannot realistically be assessed in actual or approximate money terms. Intangible benefits include health, education, employment generation, electricity used for home lighting, and the value of domestic water supply.

INTEREST

A payment for use of money, generally stated as a percentage of the amount (principal) borrowed. The rate of interest is also used for discounting; in that use it generally is referred to as the discount rate. "Simple interest" is the interest paid in one period; compound interest is interest paid not only on the amount borrowed but on the interest earned in previous periods. For methods of computation, see Compounding Factor for 1 and Discount factor.
In this guideline, interest is a cost as well as an expenditure.

INTERNAL RATE OF RETURN (IRR)

The rate of discount at which the present value of benefits is made equal to the present value of project costs (can only be used in case no initial exclusivity occurs).

LEAST COST METHOD

Used to compare projects with identical benefits or with intangible benefits (e.g. hospital).

LIFE, ECONOMIC

Period during which a fixed asset is capable of yielding services to its owner. Distinguished from 'physical life', a period often longer, during which a fixed asset can continue to function notwithstanding its acquired obsolescence, inefficient operation, or high cost of maintenance. Usually calculated as the period that has the lowest average depreciation and maintenance costs.

LINEAR PROGRAMMING

A mathematical method of determining an optimal combination of inputs to maximalize (or minimalize) on objective in which the input variables involved are subject to constraints. In agricultural projects used to optimize cropping patterns.

LOAN

Money borrowed from banks (formal loan) or relatives/moneylenders (informal loan).

MUTUAL EXCLUSIVITY

A situation whereby a number of projects compete ultimately for one and the same scarce input with the result that implementation of one project prohibits the carrying out of the other projects.
This is applicable for most irrigation sites: they can be irrigated this way or that way, but not both ways at the same time.
In case of mutual exclusivity, the Net Present Value should be used to select the best project, not the Internal Rate of Return.

NET PRESENT VALUE (NPV)
Total of the stream of discounted benefits minus the total of the stream of discounted costs of a project. Gives no ranking order for independent projects. Recommended for mutually exclusive projects: select the project with the highest NPV.

NET PRESENT WORTH
See Net Present Value.

OFF-FARM INCOME
Income earned by a farm family from off-farm labor: employment somewhere other than its own farm.

OPPORTUNITY COST
Cost of an input measured in terms of returns obtainable from the best alternative use. Usually expressed in the form of an interest rate.

OUTFLOW, CASH
In cash flow analysis: amounts of money that are spent per period.

OUTPUT
A good or service produced by an activity. In project analysis, the product of the project.

PAY BACK PERIOD
Time required to recover the initial investment with the benefits of that investment (vague and crude criterion; many formulas in use). In this guideline a financial pay back period is used, showing the time required to earn back the investment by the cash flow plus amortization.

PECUNIARY ECONOMICS
Economics in which costs and benefits are expressed in money; used in contrast with Physical Economics.

PHYSICAL ECONOMICS
Economics in which cost and benefits are not expressed in money, but in physical units like energy. Used in contrast to Pecuniary Economics.

PRESENT VALUE OF AN ANNUITY
How much 1 received or paid annually is worth today. Also called the "present worth of 1 per annum" and the "discount factor for a stream of income". The expression $[(1 + i)^n - 1] \div [i(1 + i)^n]$ where i = the rate of interest and n = the number of years. The reciprocal of the capital recovery factor. Generally obtained from a set of compounding and discounting tables, this factor enables determination of the present worth of a constant amount received or paid each year for some length of time in the future. Its use is direct and simple if it

is used for a constant stream of money that begins in the first year of a project and lasts to some future year. It may also be used to determine the present worth of a constant stream of money that began some time other than the first year, say in the 7th year of a project, and continues through the 15th year, although this will take some additional manipulation.

PRESENT WORTH
See present value.

PRICE INDEX
A series that records changes in a group of prices relative to a given, or base period.

REPAYMENT CAPACITY
The part of the incremented income that is available for amortization and interest on the loan of the incremental investment.

SENSITIVITY ANALYSIS
Analysis to check how sensitive the economic or financial feasibility of a project is to changes in major parameters (e.g. free prices, material costs, interest).

SHADOW PRICES
See Accounting prices.

SINKING FUND FACTOR
The level of deposits required each year to reach 1 by a given year.

The expression $i \div [(1 + i)^n - 1]$, where i = rate of interest and n = number of years. Reciprocal of compounding factor of 1 per annum.

SUBSIDY
A transfer payment. A direct subsidy is a payment made by a government to a producer. An indirect subsidy may occur when manipulation of the market produces a price other that that which would have been reached in a perfectly competitive market. The benefit received by a producer or consumer as a result of this difference is an indirect subsidy.

VALUE ADDED
Difference between the value of the output of a production unit and the value of all inputs purchased from outside that unit. The capital and labor attached to the production unit are considered internal input.

WORKING CAPITAL
The capital necessary to purchase goods and services that are used for the production activities of an enterprise and which are then turned over during the production cycle. For farms, the capital to purchase supplies (such as labor). The working capital is recovered when the crop is sold and is available in a subsequent production cycle.

LIST OF SYMBOLS

AAANB	Additional Average Annual Net Benefits
AAC	Average Annual Costs
AANB	Average Annual Net Benefits
a_t	Amortization in year t
b_t	Benefits in year t
C_t	Real costs in year t
C_1	Present costs
c_t	Costs in year t
cf_t	Cash flow in year t
d	Real price change (%/year)
EC	Electricity Costs
ef	Fuel or electricity to water efficiency of pumps (%)
EP	Electricity Price per $kWh_{electric}$
FC	Fuel Costs per Season
FP	Fuel Price per liter
g	Gravity (m/s^2)
h	Height of obstacle (m)
H	Total pumping head (m)
i	Relevant interest rate (%/year)
I	Initial Investment
m	Number of months per year that a windmill has to pump
n	Economic life (years)
P_f	Price per kWh_{hydr} of fuel-powered pumps
P_w	Price per kWh_{hydr} of windmills
P	Pay Back Period (years)

Q	Total irrigation requirement per season (m^3)
t	Number of the concerning year
$\bar{V}$	Average windspeed (m/s)
V(z)	The desired windspeed at the required height (m/s)
$V(z_r)$	The known windspeed at height r (m/s)
z_o	Roughness height (m)

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A brief introduction to the Netherlands program for assistance to developing countries in the utilization of wind energy.

February 1984

The basis for a sound economic development of many countries in the Third World is the development of agriculture. The oil crisis in 1973 once again stressed the vital role of energy in this development process and thus caused a world-wide revival of the interest in the utilization of renewable energy sources. In the Netherlands wind energy still appeals to many people and in 1974 a study was made to analyse the possibilities of utilizing wind energy in developing countries. It appeared that in many countries wind energy could play an important role in satisfying the energy need for water pumping, particularly for irrigation purposes.

In 1975 the Netherlands government founded a national organization in order to coordinate the Netherlands activities on wind energy for developing countries.
This organization operated under the name Steering Committee Wind Energy Developing Countries until 1984. In that year the name of the organization was changed into CWD Consultancy Services Wind Energy Developing Countries.
CWD promotes the interest for wind energy in developing countries and aims to help governments, institutions and private parties in the Third World with their efforts to utilize wind energy.

The CWD pursues this aim in three ways:

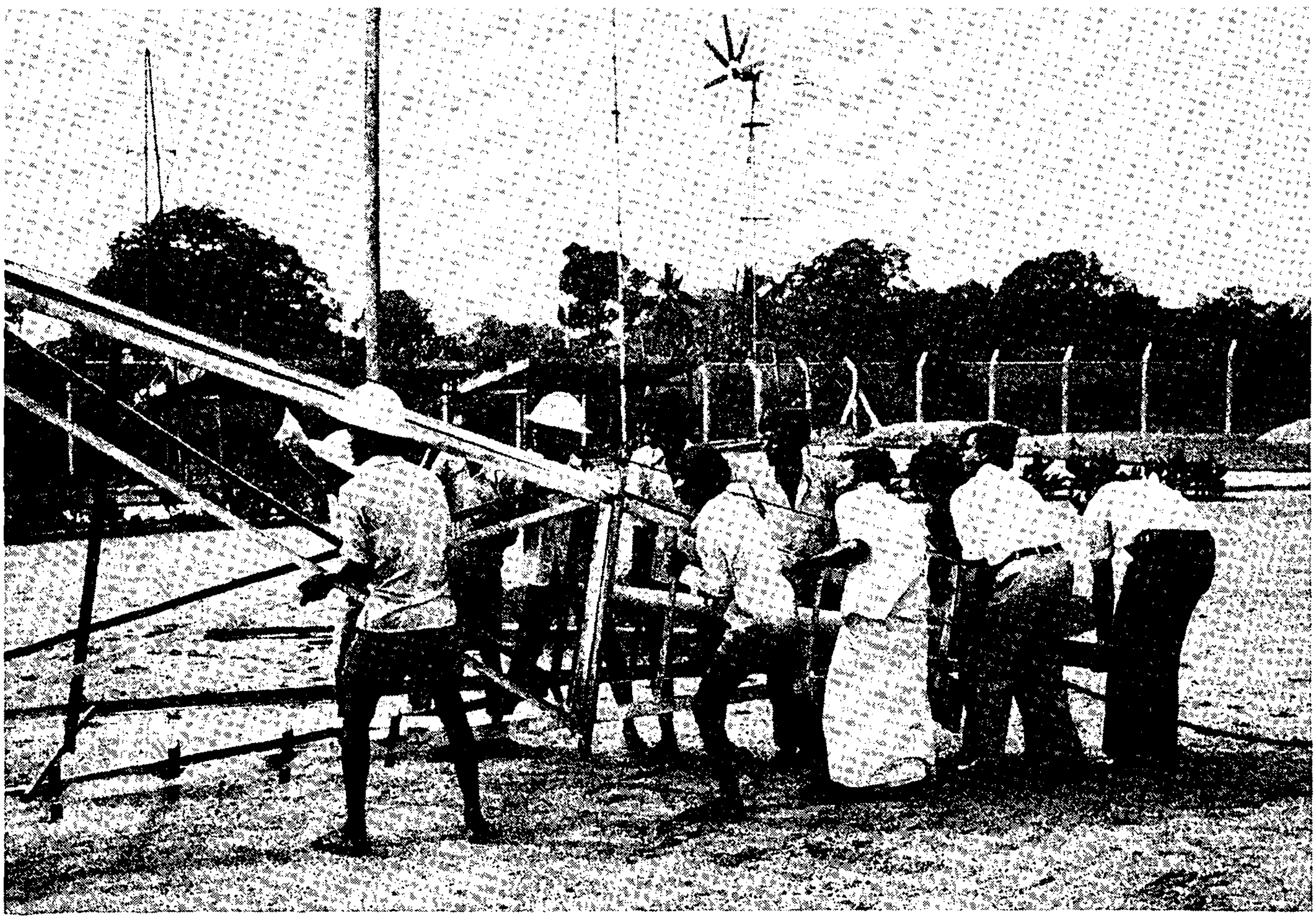
1. provision of assistance to wind energy projects in developing countries
2. wind energy research, mainly undertaken in the Netherlands
3. transfer of knowledge on wind energy use.

The parties that currently participate in CWD are:
Eindhoven University of Technology (Wind Energy Group)
Twente University of Technology (Windmill Group)
DHV Consulting Engineers.

Each participant has its own, more or less well defined, field of research and the co-ordination is in the hands of DHV Consulting Engineers.

In the field of agriculture CWD closely collaborates with the Institute of Land Reclamation and Improvement (ILRI).

CWD has regular contacts with the Working Group on Development Technology (WOT) at Twente University.
Also contacts exist with the Dutch national wind energy research program, co-ordinated by the Energy Research Centre (ECN).



The installation of a ∅ 5 m windmill in Colombo, Sri Lanka; in the background the ∅ 3 m WEU-I windmill.

RESEARCH ACTIVITIES

The research activities are undertaken with the following purposes:
- to develop windmill components as well as complete prototypes
- to support the country projects
- to train future experts for country projects

Rotors

A large number of rotors have been designed and tested, both at open air test stands and in a large windtunnel. Good results have been achieved with horizontal axis curved metal plate rotors, as predicted by theory. For low Reynolds numbers (< 100,000) curved plate profiles turn out to be better than airfoils.
Designing with higher tip speed ratios ($\lambda > 1$) results in lighter rotors and thus lighter and cheaper windmills.

Pumps

The optimum matching of a pump to the quadratic torque-speed characteristic of a wind rotor has been pursued by the development of variable torque reciprocating pumps and the application of centrifugal pumps. This optimum matching results in much higher overall outputs than with the traditional (constant torque) piston pumps. The closing of valves and the operation of air chambers has been analyzed.

Generators

For deep wells electrically driven pumps are considered as a serious alternative to direct mechanically driven pumps. Two types of generators have been tested to drive these pumps:
- a self exciting induction generator
- an induction generator equipped with a permanent magnet rotor

Also two control systems for alternators have been developed.
Research is done on autonomous systems, windmills for electricity generation working in combination with diesel powered generators.

Safety Systems

A reliable safety system has been developed and tested for wind speeds up to 30 m/s. The system operates by means of a small auxiliary vane that pushes the rotor out of the wind against the normal directional vane that is hinged on a leaning axis. A complete theoretical model is being studied.

Wind measurement

An electric counter with extremely low energy consumption has been developed for contact-anemometers.

Theory

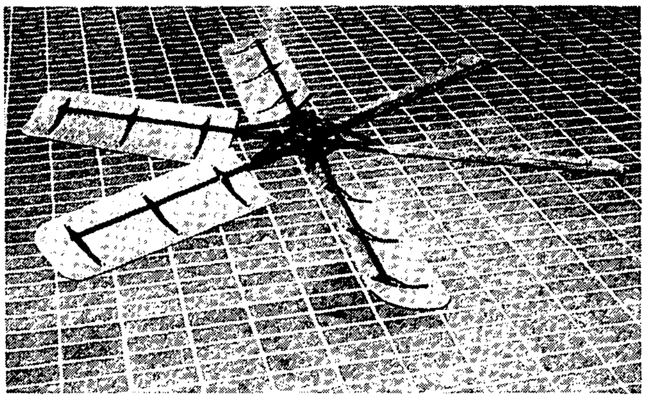
Theoretical models have been developed or refined on:
- rotor performance
- forces on rotor blades
- output in different wind regimes
- matching of rotor with generator or pump
- dynamic behaviour of pumps.

Windmill prototypes

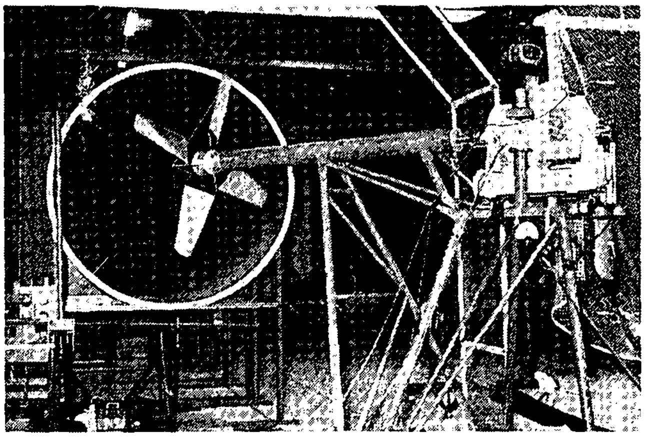
The following prototypes have been developed:

	diameter	number of blades	tip speed ratio	remarks
CWD 2740	2.74 m	6	2	piston pump
CWD 4000	4.00 m	8	2	piston pump
CWD 5000 RS[1]	5.00 m	4	5	centrifugal pump; Rotating Shaft
WEU I	3.00 m	6	2	piston pump
WEU II[2]	5.00 m	8	2	piston pump
Cretan	6.00 m	8	1	piston pump
Under development:				
CWD 5000 HW	5.00 m	8	2	piston pump; for High Wind regime
CWD 5000 LW	5.00 m	8	2	piston pump; for Low Wind regime
CWD 2000	2.00 m	6	2	piston pump
CWD 1000 EL	1.00 m	2	4	Electricity generation

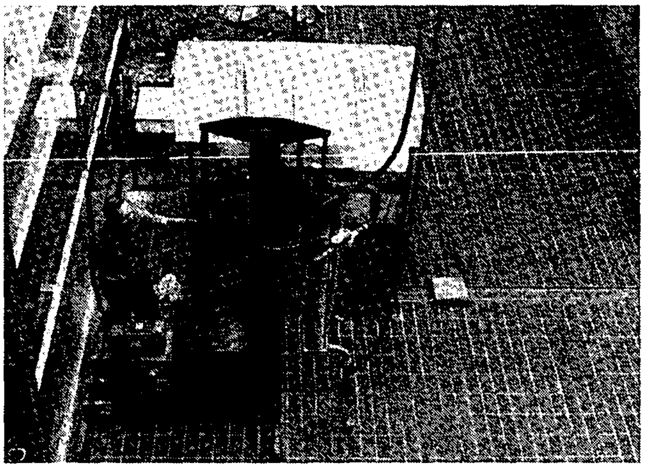
[1] developed as testmodel only
[2] partially based on WOT-designed 12 PU 500
[3] developed by WOT with financial aid from CWD



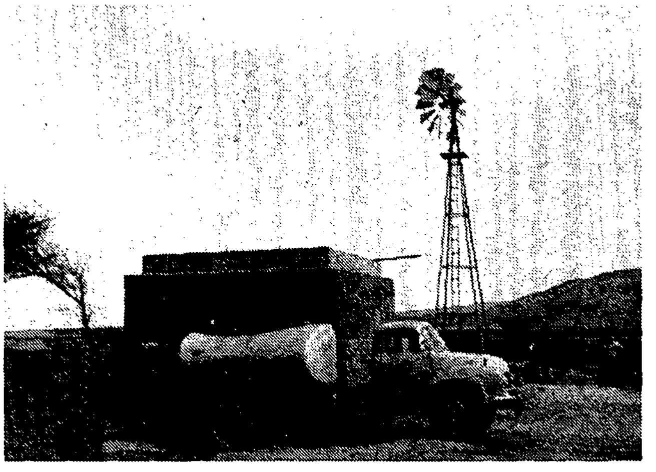
Rotor of CWD 2740 prototype



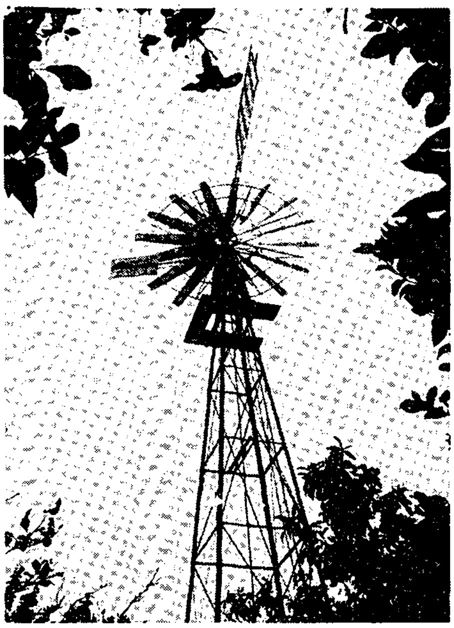
Windtunnel (∅ 2.2 m) at Delft University of Technology for testing rotor models



Pump test stand at Eindhoven University of Technology



Project for rural water supply and irrigation on the Cape Verdian Islands



Prototype installed in Hammamet, Tunisia, irrigating an orchard.

COUNTRY PROJECTS

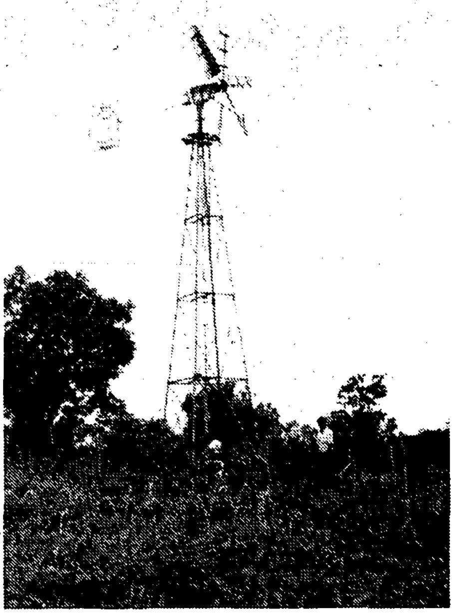
CWD gives assistance in the execution of wind energy programmes in close co-operation with interested ministries, institutions or private parties. The country projects encompass assistance in a number of fields:
— measurement and analysis of wind data
— selection of favourable areas
— selection and construction of prototype windmills
— training and education in the field of wind energy
— selection of application purposes
— organisation of pilot projects.
— maintenance
— agricultural application analysis
— production engineering assistance
— economic programming and
— credit systems

The guiding principles for the country projects are:
— water pumping has the highest priority
— local production of as many components as possible
— construction methods and materials must be appropriate to the local technical level.

CWDis involved in projects in the following countries:

Sri Lanka

In March 1977 the Wind Energy Utilization Project was started with financial support from the governments of Sri Lanka and the Netherlands. The execution is in the hands of the Wind Energy Unit of the Water Resources Board.
The project is staffed by Sri Lanka engineers, technicians and workers, while CWD experts provide assistance. About 150 windmills were produced in the last two years, mainly by local workshops. Part of these windmills were sold at subsidized rates. Presently a small 2-m diameter windmill for irrigation by small farmers is under development.



WEU-I prototype irrigating in Sri Lanka

Republic of Cape Verde

Since 1981 CWD supplies two wind experts in a large renewable energy project with emphasis on wind power, executed by the Ministry of Rural Development. The project focusses on training of staff in installation, repair and maintenance of windmills.
A high-wind-prototype for waterlifting of 5 m diameter is under development.

Pakistan

Stimulating contacts with Merin Ltd. in Karachi led to CWD's consultancy to start production of windmills. The WEU-I prototype developed in Sri Lanka was selected and in 1980 a CWD expert paid a three-month visit for technical assistance.

Tanzania

The Ujuzi Leo Industries in Arusha have been supported in improving their windmill design via a two-month course in the Netherlands and short-term expert visits.

Tunisia

In support of the ASDEAR (Association pour le développement et l'animation rurale) CWD supervised in 1980 the construction of three CWD 4000 prototypes as a start of production in series by a local entrepreneur.
In support of the SEREPT-company CWD designs a 5-m diameter windmill for water pumping, meant for series production.

Peru

As a part of an agricultural project, supported by the Netherlands Ministry of Development Co-operation, a CWD 2740 prototype has been built. Since 1981 technical backstopping has been given to a Dutch expert in a bilateral co-operation program.

Feasibility Studies

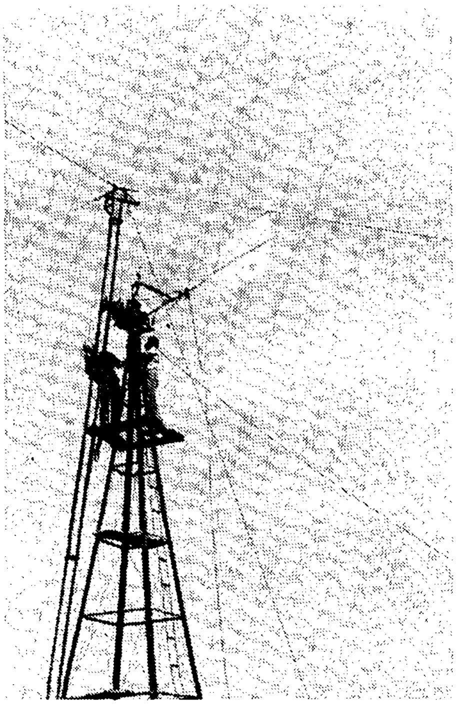
CWDhas carried out feasibility studies on the use of wind energy in the following countries or areas:
Sri Lanka (1976), Cape Verde (1980), Tanzania (1977), The Sahel (1976), Djibouti (for GTZ, 1981), Yemen Arab Republic (1980), Sudan (1980), Maldives (for ADB, 1980), Kenya (1982), Netherlands Antilles (1982).

Explaining the particulars of windmill testing at the Asian Institute of Technology, Bangkok.

TRANSFER OF KNOWLEDGE

Local knowledge is gathered in country projects and during visits of experts from abroad. Particularly the failures of windmill projects in the past deserve great attention. A first analysis of the causes for failure resulted in the following list:
— import restrictions on spare parts
— lack of funds
— lack of local know-how and of care for maintenance
— introduction of (subsidized) electric and diesel pumps
— drop of ground water table
— reduction on the number of windmills, making repair a non profitable job
— fear for repairs on top of a high tower
— termination of production and of supply of parts by manufacturers.

Installation of windmills on Cape Verde.



Knowledge in wind energy technology and related fields is transferred by CWD to developing countries by:
— publications
— drawings and construction manuals of prototypes
— visits and consultancies
— education and training

CWD also functions as a clearing-house for information and experience with wind energy systems: the experience with the WEU I windmill in Sri Lanka has been transferred to Pakistan for example.

Another facet is the supply of experts for lecturing purposes such as for the six-month UN-ESCAP Roving Seminar on Rural Energy Development in 1977. In the summer of 1980 and 1981 CWD sent an expert to the Asian Institute of Technology, Bangkok, to give introductory and advanced courses on wind energy and to coach MSc students.

PUBLICATIONS

CWD has been issueing publications on various topics related to wind energy applications: feasibility reports, theoretical aspects, design of rotors, economics of windmills, irrigation with windmills, etc. (see CWD-publications list).
CWD publications can only be ordered by letter to CWD with payment in advance. Research institutes in Third World countries may ask for a copy of three publications free of charge.

ADDRESSES

General address CWD:

DHV Consulting Engineers	P.O. Box 85, 3800 AB Amersfoort	The Netherlands, Tel.: 033 - 68 91 11 Telex 79348 dhv nl

Addresses of the other participants:

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Twente University of Technology Windmill Group	Department of Mechanical Engineering P.O. Box 217, 7500 AE Enschede	The Netherlands, Tel.: 053 - 89 40 98

Address of ILRI:

International Institute for Land Reclamation and Improvement	P.O. Box 45, 6700 AA Wageningen	The Netherlands, Tel.: 08370 - 19100

Address of WOT:

Working Group on Development Technology (WOT)	Twente University of Technology Vrijhof 152, P.O. Box 217, 7500 AE Enschede	The Netherlands, Tel.: 053 - 89 38 70

Address of ECN:

Netherlands Energy Research Foundation (ECN)	P.O. Box 1, 1755 RG Petten	The Netherlands, Tel.: 02246 - 62 62

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CWD Publication list (February 1984)

For ordering instructions please read the last page.

Serial number		Prices (mail included) US $	Dfl
CWD 76-2	**Literature survey; horizontal axis fast running wind turbines for developing countries.** **By W.A.M. Jansen, 43 p., March 1976** *Literature survey on theoretical aspects of rotor design and lay-out. Drag lift ratios and power coefficients are discussed.*	4.-	9,-
CWD 76-3	**Horizontal axis fast running wind turbines for developing countries.** **By W.A.M. Jansen, 91 p., June 1976** Brief review of the theories that form the basis for calculation of the design and the behaviour of a windmill, together with a report on tests of several rotors.	8.-	19,-
CWD 77-1	**Rotor design for horizontal axis windmills.** **By W.A.M. Jansen & P.T. Smulders, 52 p., May 1977** Basic aerodynamical aspects of rotors are explained. With help of formulas and graphs the design procedures for blade chord and blade setting are given. (Also available in French as CWD 80-1 and Portuguese as CWD 83-2)	5.-	11,-
CWD 77-2	**Cost comparison of windmill and engine pumps.** **By L. Marchesini & S.F. Postma, 49 p., December 1978** A method to compare costs of irrigation with windmills and with conventional engines, with help of break-even and sensitivity analyses	4.-	10,-
CWD 77-3	**Static and dynamic loadings on the tower of a windmill.** **By E.C. Klaver, 39 p., August 1977** Some design considerations and the basic formulas needed for estimation of the dimensions of the tower structure.	3.-	8,-
CWD 77-4	**Construction manual for a Cretan windmill.** **By N.J. van de Ven, 59 p., October 1977 (WOT/CWD)** Detailed description for the construction of a sail wing windmill for water pumping, with wooden tower and head and steel pipe shaft. Illustrated with sketches, exploded views and photographs.	5.-	12,-

Serial number		Prices (mail included) US $	Dfl
CWD 77-5	**Performance characteristics of some sail- and steel-bladed wind rotors. By Th. A.H. Dekker, 60 p., December 1977** Report on experiments in an open windtunnel with several rotortypes. C_p-λ and C_q-λ characteristics are presented	5.-	12,-
CWD 78-1	**Feasibility study of windmills for water supply in Mara Region, Tanzania. By H.J.M. Beurskens, 89 p., March 1978.** Report on a study on wind energy potential in Mara Region, on water needs and potential windmill sites, on local production aspects and energy costs. A project proposal is elaborated.	8.-	18,-
CWD 78-2	**Savonius rotors for water pumping. By E.H. Lysen, H.G. Bos & E.H. Cordes, 46 p., June 1978.** Report on experiments with a wood and sail Savonius rotor detailing design aspects, theory on coupling to a pump and test results.	4.-	10,-
CWD 78-3	**Matching of wind rotors to low power electrical generators. By H.J. Hengeveld, E.H. Lysen & L.M.M. Paulissen, 85 p., December 1978.** Theoretical guidelines to the design of a small scale wind electricity conversion system with emphasis on the electrical part of the system and its matching to the rotor.	8.-	18,-
CWD 80-1	**Conception des pales des éoliennes à axe horizontal. (version française de CWD 77-1). Par W.A.M. Jansen et P.T. Smulders, 52 p., Décembre 1980.** Aspects fondamentales aéro-dynamiques des hélices. Procédure-modèle pour la conception des pales de l'hélice, pour les cordes et pour l'angle de calage.	5.-	11,-
CWD 81-1	**Wind energy for water pumping in Cape Verde By H.J.M. Beurskens, 162 p., February 1981.** Report on wind energy activities in Cape Verde, ground water resources, wind regime, local production possibilities and economic aspects of wind energy utilization. Proposals for a project are elaborated. (Also available in Portuguese as CWD 81-3)	14.-	34,-
CWD 81-2	**Wind energy in Sudan. By Dr. Yahia H. Hamid & W.A.M. Jansen, 71 p., July 1980.** Report on the windmill potential in Sudan detailing energy situation, wind and water situation and cost aspects, as well as a proposal for a wind energy centre in Sudan.	6.-	15,-
CWD 81-3	**Energia eólica para a bombagem de água em Cabo Verde (versao portuguesa de CWD 81-1). Por H.J.M. Beurskens, 162 p., Fevereiro de 1981.** Estudo de actividades actuais de energia eõlica em Cabo Verde, recursos de agua freãtica, utilização e aspectos econõmicos de energia eõlica. E elaborado uma proposta de projecto.	14.-	34,-

Serial number		Prices (mail included) US $	Dfl
CWD 81-4	**Aspects of irrigation with windmills** **By A.E.M. van Vilsteren, 100 p., January 1981 (TOOL/CWD)** Study on lift irrigation with windmills for smallholder agriculture in third world countries, dealing with irrigation practice, agricultural and social aspects and economic calculation methods.	9.-	21,-
CWD 82-1	**Introduction to wind energy (basics and advanced)** **By E.H. Lysen, 310 p., May 1983 (2nd edition).** Introduction to wind energy, with emphasis on water pumping windmills, dealing with a.o. site selection, wind-regime analysis, rotor design, economics.	25.-	57,-
CWD 82-2	**A model for the economics of small-scale irrigation with windmills in Sri Lanka.** **By J.A.C. Vel & L.R. v. Veldhuizen, 115 p., October 1981** Economic comparison between different cropschemes using windmill irrigation in Sri Lanka. Sensitivity analyses and differentiation between national economic aspects and farmer's viewpoints.	10,-	24,-
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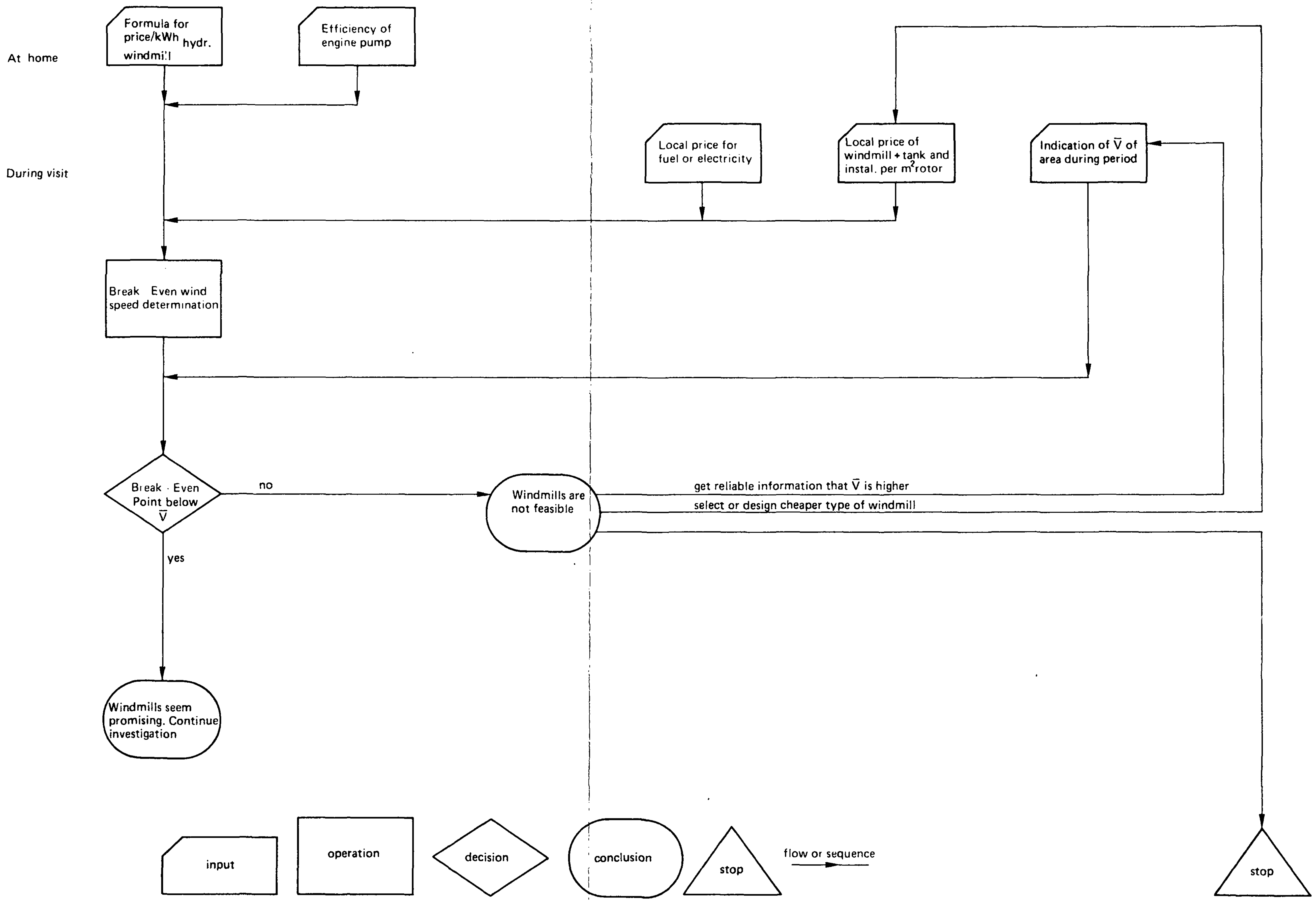
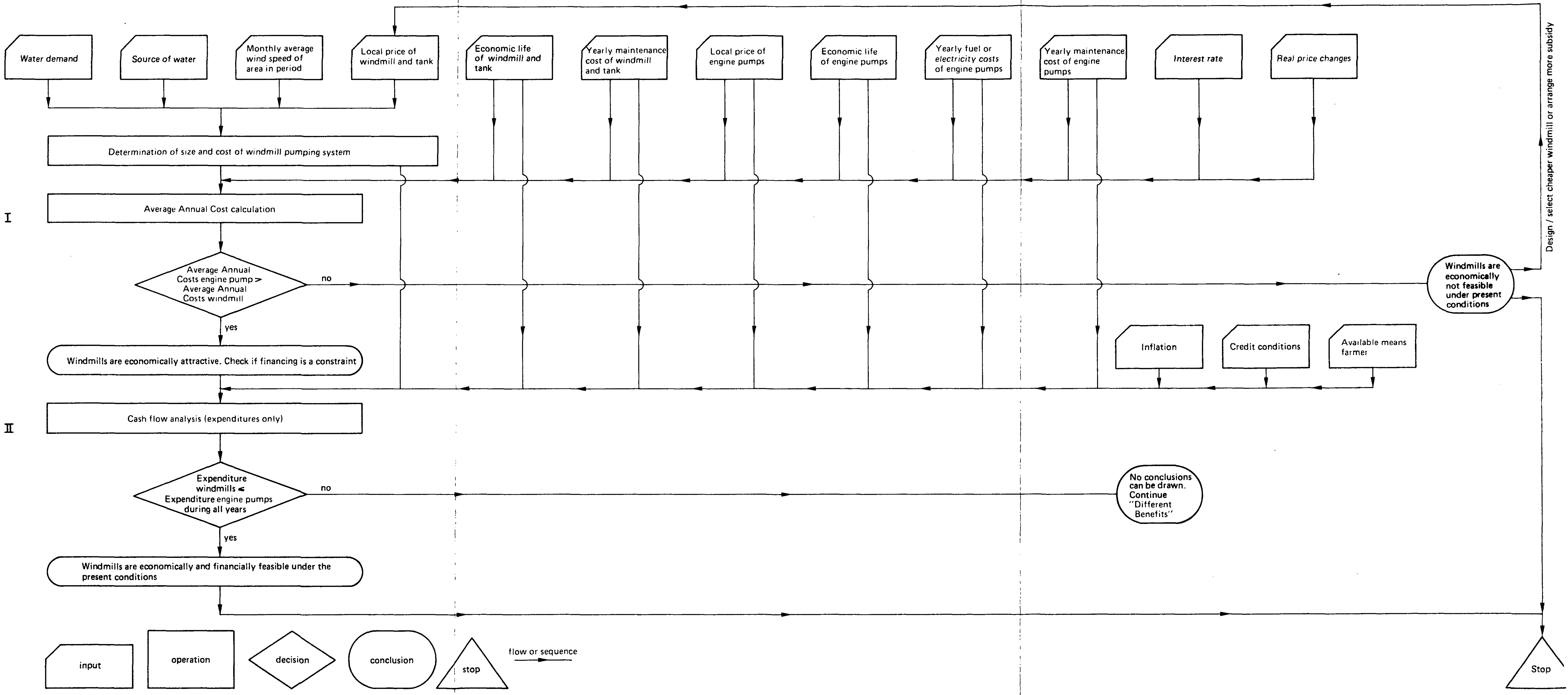


DIAGRAM 2 SITUATION 'EQUIVALENT BENEFITS'
FARM ECONOMICS OF WATER – LIFTING WINDMILLS



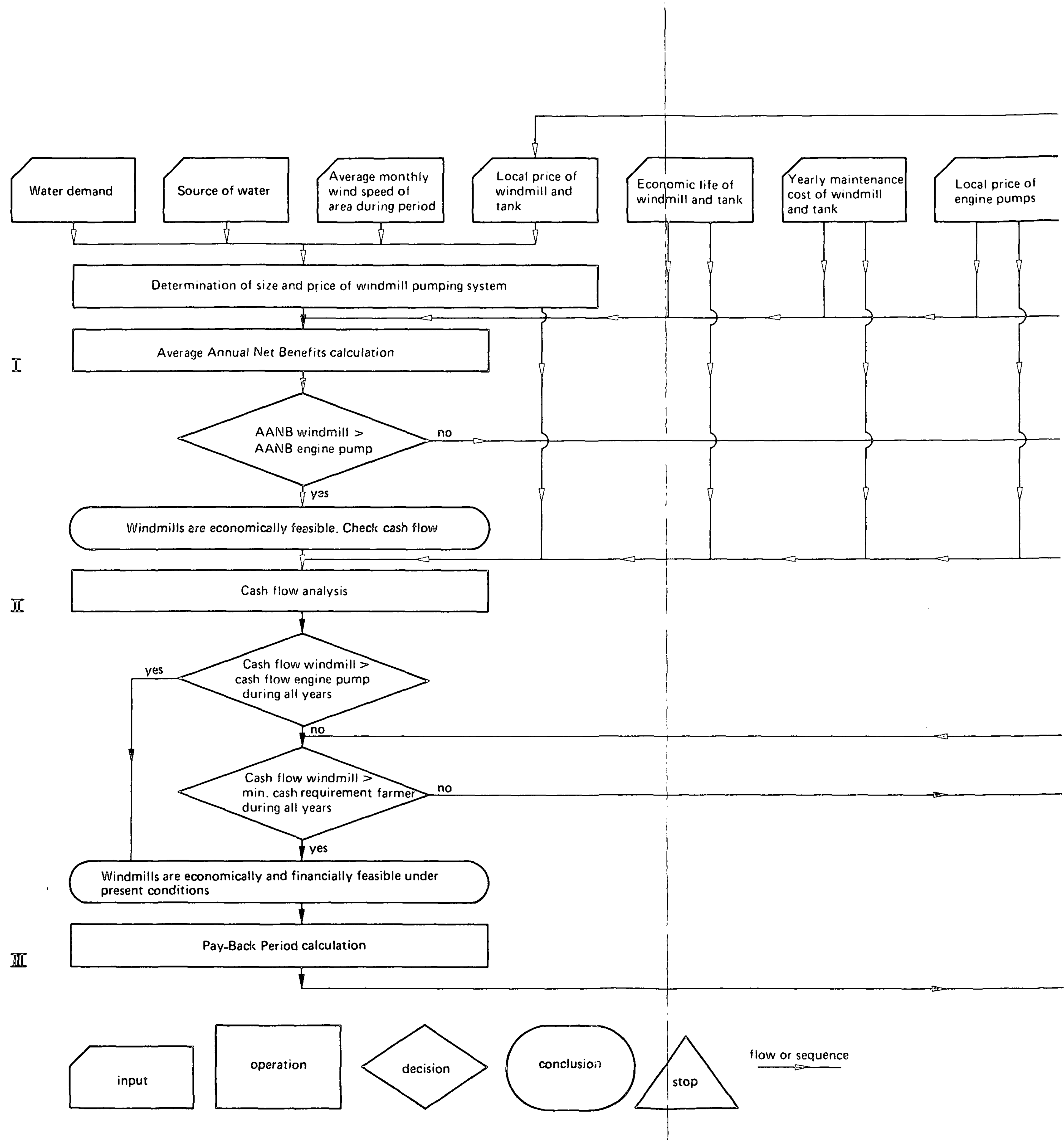
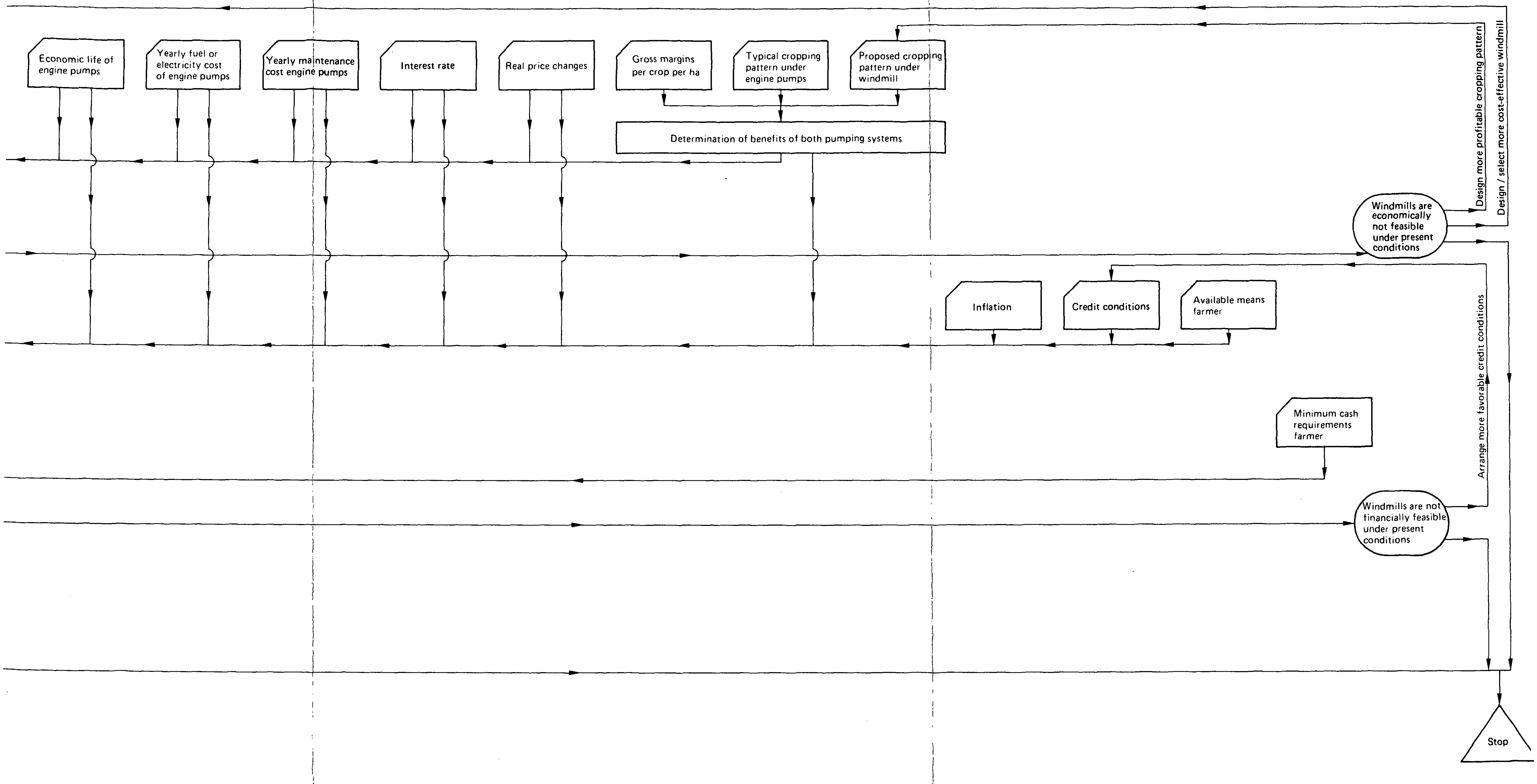
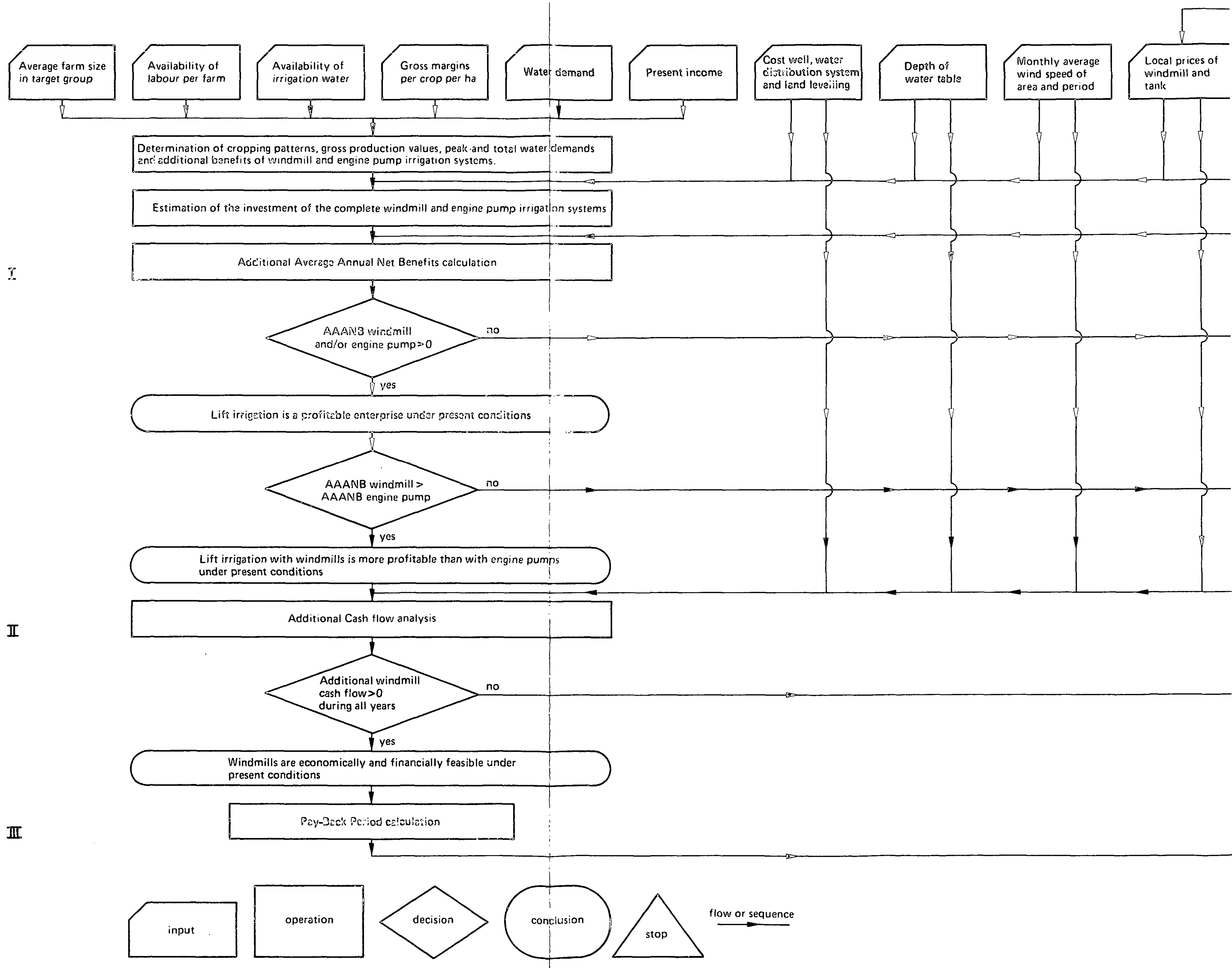

Water demand
Source of water
Average monthly wind speed of area during period
Local price of windmill and tank
Economic life of windmill and tank
Yearly maintenance cost of windmill and tank
Local price of engine pumps
Determination of size and price of windmill pumping system
I
Average Annual Net Benefits calculation
AANB windmill > AANB engine pump
no
yes
Windmills are economically feasible. Check cash flow
II
Cash flow analysis
Cash flow windmill > cash flow engine pump during all years
yes
no
Cash flow windmill > min. cash requirement farmer during all years
no
yes
Windmills are economically and financially feasible under present conditions
III
Pay-Back Period calculation
input
operation
decision
conclusion
stop
flow or sequence

DIAGRAM 3 SITUATION 'DIFFERENT BENEFITS'
FARM ECONOMICS OF WATER – LIFTING WINDMILLS





Average farm size in target group
Availability of labour per farm
Availability of irrigation water
Gross margins per crop per ha
Water demand
Present income
Cost well, water distribution system and land levelling
Depth of water table
Monthly average wind speed of area and period
Local prices of windmill and tank
Determination of cropping patterns, gross production values, peak-and total water demands and additional benefits of windmill and engine pump irrigation systems.
Estimation of the investment of the complete windmill and engine pump irrigation systems
Additional Average Annual Net Benefits calculation
I
AAANB windmill and/or engine pump>0
no
yes
Lift irrigation is a profitable enterprise under present conditions
AAANB windmill > AAANB engine pump
no
yes
Lift irrigation with windmills is more profitable than with engine pumps under present conditions
Additional Cash flow analysis
II
Additional windmill cash flow>0 during all years
no
yes
Windmills are economically and financially feasible under present conditions
Pay-Back Period calculation
III
input
operation
decision
conclusion
stop
flow or sequence

DIAGRAM 4 SITUATION 'WITHOUT LIFT IRRIGATION'
FARM ECONOMICS OF WATER – LIFTING WINDMILLS