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Economic Evaluation Methods of Solar Powered Water Pumping System

Eltayeb Mohammed Bakheet
WASH Department, African Humanitarian Action organization,Elfasher, Sudan

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Abstract:
Providing clean, environmentally safe water for livestock in sufficient quantities continues to be a major concern for farmers and ranchers. Abundant water in remote locations in needed to insure that grasslands are grazed evenly. The power source for solar water pumping, have no moving parts, requires no maintenance and last for decades. A properly used solar pumping system will be efficient, simple and reliable. Solar powered pumping systems are used principally for three applications town and city water supply, livestock watering and irrigation.
The aim of this study is to economical evaluationmethodsas well as aspects of economic evaluation of Solar Powered Water Pumping System. While the cost of solar energy has declined rapidly in the recent past, it still remains much higher than the cost of conventional energy technologies. Like other renewable energy technologies, the methods presented here could help illustrate the economic evaluation of solar energy technologies with other technologies at present.
Keywords: Photovoltaic (PV), Solar Energy, Water pumping system, economic evaluation.

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1. Introduction
Water is the source of life, and the availability of water has become more crucial than ever before. The demand for water grows along with the world's population. The need for water to irrigate land, which will then produce more food, as well as clean water for drinking purposes, is crucial in coping with the world's population growth.
A source of energy to pump water is also a big problem in many developing countries.
Developing a grid system is often too expensive because rural villages are frequently located too far away from existing grid lines. Depending on an imported fuel supply is difficult and risky; foreign exchange rates fluctuate and the economy of many developing countries can then plummet. Even if fuel is available within the country, transporting that fuel to remote, rural villages can be difficult. There are no roads or supporting infrastructure in many remote villages where transportation by animals is still common. Transportation by animals limits load capacities, and some loads, diesel generators, for example, may be impossible to bring to such locations.
The use of renewable energy is attractive for water pumping applications in rural areas of many developing countries. Transportation of renewable energy systems, such as wind machines and photovoltaic (PV) pumps, is much easier than other types because they can be transported in pieces and reassembled on site {1}.
Another relatively new technology harnesses solar energy. This technology, referred to as *photovoltaic* (PV), converts the sun's energy into electricity through electromagnetic means when the PV module is exposed to sunlight. The solar radiation energy is converted into DC power and requires an inverter to convert it into AC power. This technology has uses similar to electrical wind turbines, and has become the power supply for such applications as operating lighting and refrigerating vaccines in health clinics. PV has also been used to power rural communications. This technology is ideal for water pumping applications because

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energy storage is not required for night pumping as the energy is stored in the form of water [1].

Over the last few years, many studies were focused on PVWPS sizing, based on the potential of solar energy and water demand. However, many sizing studies neglect the importance of the economic evaluation methods [8].

2. Water Pumping

Water pumping is one of the simplest and most appropriate uses for photovoltaic. From crop irrigation to stock watering to domestic uses, photovoltaic-powered pumping systems meet a broad range of water needs. Most of these systems have the added advantage of storing water for use when the sun is not shining, eliminating the need for batteries, enhancing simplicity and reducing overall system costs. Many people considering installing a solar water pumping system are put off by the expense. Viewing the expense over a period of 10 years, however, gives a better idea of the actual cost. By comparing installation costs (including labor), fuel costs, and maintenance costs over 10 years, you may find that solar is an economical choice. A solar-powered pumping system is generally in the same price range as a new windmill but tends to be more reliable and require less maintenance. A solar-powered pumping system generally costs more initially than a gas, diesel, or propane-powered generator but again requires far less maintenance and labor[4]. The cost of solar pumped water per cow ranged from $0.03 to $0.15 per day. The cost per gallon of water pumped ranged from $0.002 to $0.007 per gallon [2].

3. Economic Evaluation Methods

3.1 General Aspects

Installation of any pumping system requires a long-term financial commitment, and it is important to assess those factors that affect the economic and financial viability of the system. In considering economic viability, a distinction must be made between financial and economic assessments. The economic approach is based on the true value to society as a whole, using benefits and costs free from taxes, subsidies, interest payments, etc. On the other hand, financial viability is a concern from the purchaser's point of view. Financial viability involves evaluation of taxes, subsidies, and loan payments. The long-term effects of the loan should be evaluated by spreading the capital cost over the loan period. Neither the financial or economic approach can convert all relevant factors to monetary terms, so the final decision should be made based on careful consideration of all the technical, economical, financial, and other related external impacts.

In regard to technical aspects, the pumping system must be reliable and must fulfill the water demand. In many cases, the water resource can be the main factor in determining the type of pumping system needed. If the well yield is too low, the only option may be using small pumps (for example, hand pumps or small mechanically or electrically powered pumps). In this case, the well yield is the primary limiting factor.

When a water resource is adequate, the main factor for selecting a mechanized pumping system may be the energy resource, which has an economic aspect. For wind-powered pumps, the determining factor in selection is the availability of wind. For PV pumps, the determining factor is the availability of solar radiation energy. The scarcity of fuel and maintenance personnel in a remote rural village can be also a determining factor for diesel -engine-driven pumps. The economic viability of such systems can be affected because of a lack of fuel and/or maintenance. Days could pass with no pumping capability until a technician can come to fix the system, or until fuel can be brought to the pumping site.

The familiarity of local technicians with the selected system, the frequency and ease of operation and maintenance of the system, and the availability and cost of spare parts are important considerations in the selection of energy systems. PV systems are inherently more reliable and maintenance-free than other types, but spare parts can be scarce and local technicians might be unfamiliar with servicing procedures. Wind pumps are usually the best option for windy areas, as long as the demand is met.

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Another important factor is the borehole cost. Drilling is often expensive in remote locations, and it is advisable to use a higher-capacity pump in a high-yield single borehole, rather than a small pump in the same borehole. In such a case, more water can be pumped from the same borehole and the cost of water will be low. So, in this case, the energy source would be the main issue in choosing the type of system (PV, wind, or diesel). Therefore, various factors should be considered in water pumping options during the prefeasibility study {1}.

3.1.1Financial Versus Economic Viability

Usually, any water pumping system could be acceptable on the basis of meeting the technical requirements. The viability of each pumping option; however, may depend on the acceptability and affordability of the system, and the community's willingness and ability to pay. A complete financial and economic evaluation of alternative systems is recommended before committing to one system.

From a financial standpoint, the purchaser (end user) views the water pump much like any other investment, as the amount of annual loan payments, rather than the lifetime economics of the pumping system. So the purchaser evaluates the financial viability of the system by including all taxes and subsidies associated with it by spreading the loan (investment cost) over the loan period. From the government's point of view; however, the economic approach is used to compare projects over their economic life. Thus, both financial and economic appraisals are equally important and must be used, according to the emphasis given to the project. If the project is part of the distribution of wealth, designed to alleviate poverty in rural areas, an economic appraisal can be more appropriate than a financial assessment. This is because such a project is a part of a government investment project, and adding taxes, subsidies and interests are not important in the assessment. In contrast, a project that is community-initiated and financed in part or in whole by the local users requires a financial appraisal to evaluate various alternative systems.

Whichever approach is used, according to the particular emphasis given to the project, different pumping alternatives have to be evaluated by taking costs and benefits from the system into account throughout the project's lifetime. The economic appraisal method is emphasized in this paper, because this analysis is relatively easy to convert into a financial evaluation by simply including the appropriate figures (such as taxes, subsidies, and interest payments) in the evaluation.

An economic evaluation is basically a means to identify which alternative pumping option achieves the maximum benefit at the least cost. As stated earlier, all relevant benefits cannot be reduced to monetary terms; the final decision should be based on the technical, economical, and other external impacts combined.

The main difference between the approach of an economic and an external impacts evaluation is the valuing of the factors. An economic evaluation of water pumping systems is based on the monetary values of the system, where all costs (investment, recurrent, and replacement) and income generated from the system are recorded, based on the time value of money. These costs are then evaluated to determine the most viable system from all available alternatives.

The external impacts evaluation method applies only to non-monetary values that can directly or indirectly affect the selected pumping system. These two evaluation methods, combined with a technical evaluation, are the main criteria in the selection of the best alternative source of energy for water pumping systems. The selected pumping system can be considered the best choice when the selected system meets these three criteria. The approaches used to evaluate the economic and the external impacts of alternative water pumping options.

3.1.2 Aspects of Economic Evaluation

Economic decision-making includes both generating and evaluating alternatives. Since choosing an alternative always requires a decision, economic decision-making can proceed only if alternatives have been established. The aim of selection must be to find the best possible result for the least possible sacrifice. The task of the evaluator

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is to find the most profitable among the possible energy alternatives.

In national energy planning, the following three basic policy decisions are usually required for successful energy management.

1. The appropriate level of demand-for-energy requirement that must be served to achieve social goals, such as economic development and basic human needs.

2. The optimal mix of energy sources that will meet the desired demand based on several national objectives, such as minimum cost, independence from foreign sources, continuity of supply, conservation of resources, elimination of wasteful energy consumption, environmental considerations, and price stability. The analyses are complicated by uncertainties about future trends of demand and supply, relative costs and prices, and incompatibility of different energy sources.

3. A pricing policy based on such criteria as economic efficiency in resource allocation, economic second-best considerations, sector financial requirements, social equity considerations, environmental impacts, and other political constraints.

The process of economic development is closely related to the rapid increase in the quantity of commercial energy consumed. Increased energy consumption and energy efficiency are two conditions necessary for sustained economic development. The complexity of energy–economics interactions indicate that energy sector investment planning, pricing, and management interactions should be integrated with national energy planning. In energy planning and policy analysis, the main emphasis is on the detailed comprehensive analysis of the energy sector, its linkages with the rest of the economy, and the main interactions within the various energy sub-sectors themselves.

The economic evaluation of investments in renewable energy projects should be seen as a technological–economical decision-making process. An investment project, which may not be profitable for an individual business, can be extremely worthwhile for the overall economy when the social benefits it generates are taken into consideration. If we regard economics as the quantitative study of the theory and practices of producing and distributing wealth, and thus the basis for decision-making in social affairs, then “techno-economics” attempts to provide the quantitative basis for decision-making in technical affairs. The essential point is that due attention is given to both technical and economic aspects of the problem. The various effects of all the possible external benefits and costs in the techno-economic evaluation of renewable energy systems can be classified into four levels of decision-making processes.

1. Formulation of criteria for the preliminary selection of the alternative renewable energy system.

2. Formulation and technical optimization of an alternative renewable energy system and selection of the most favorable renewable energy system.

3. Economic evaluation of the conventional and renewable energy system.

4. Determination of the optimal solution based on the criteria of development policy, and social and institutional factors.

Selecting an alternative source of energy for rural areas depends on many factors. The main factors include cost, reliability and quality of service, hours of operation, and convenience of operation. Options for the source of energy include a grid or a decentralized system. In economic evaluation, in order to select the lowest-cost option, each power source alternative must provide an equivalent level of service. Load size and load density are critical factors in selecting between a grid and a decentralized solution. The most common decentralized alternatives to grid supply are diesel generators, small-scale hydropower plants, biomass- based energy sources, wind, and PV systems. Least-cost comparisons between central grid supply and isolated sources are not easy because of the quantity of the supply and the difficulty of quantifying these sources into monetary terms.

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On the other hand, investments in long-term projects are characterized by uncertainties regarding project life, operation and maintenance costs, revenues, and other factors that affect project economics. Because future values of these variable factors are usually unpredictable, it is difficult to make reliable economic evaluations. It is also difficult to draw general conclusions regarding the relative desirability of various options. First, both the costs of technology and relative operation vary frequently. Second, sustainability may change depending on the type of end use.

The traditional approach to project investment analysis is to apply an economic evaluation of projects to "best estimates" of project-input variables as if they were certain. Then the results are presented as a single value in deterministic terms. When projects are evaluated based on uncertain inputs, decision-makers will have insufficient information to measure and evaluate the risk of investing in the project. The macroeconomic and social advantages of renewable energy technologies, such as environmental attractiveness, reduction of dependence on imported energy sources, or resource savings, and the hidden costs of conventional energy systems are not adequately represented in microeconomic evaluations. The general market pricing mechanism does not seem to work adequately in such cases. In a distorted market, the government has to compensate by internalizing the external impacts of economic processes.

Therefore, efforts to estimate the full costs of energy systems to the society are necessary.

Knowledge of the full costs of energy could enable the government or institutions to take corrective action to help the market mechanism achieve an optimal allocation of resources.

Although the external impacts of energy systems cannot be adequately quantified and expressed in monetary terms, their inclusion would improve the competitive position of renewable energy sources and later to the extended usage of the system. Therefore, it is necessary to use technically correct and practical methods for evaluating the economic aspects of energy systems.

3.2 Economic Evaluation Methods

A complete compilation of all expenditures and incomes is required for the economic assessment of an investment project. This should include data reflecting the economic conditions where the investment is planned and all associated expenditures and returns, followed by a financial analysis. A quantitative formulation of the idea, together with the decision-making criteria, applicability of the method, and remarks on its limitations should be presented. Various investments and the resulting annual costs and benefits must be indexed according to their time-order of accrual for the proper calculation of financial acceptability.

Some of the traditional methods for analyzing investment costs (some of which will be described in further detail) include

- Life-cycle cost (LCC)
- levelized costs (LC)
- Net present value (NPV)
- Internal rate of return (IRR)
- Benefit-to-cost ratio (BCR) or savings-to-investment ratio (SIR)
- Net benefits or savings (NB or NS)
- Annuity and cost annuity comparison
- Critical value method
- Payback period.

Life-cycle cost

The LCC method of comparison is a first-order indication when a system is considered for a particular application. LCC is also the most widely used evaluation method. In practice, when the pumping system is to supply drinking water, it is important to establish the comparative LCC of wind or PV versus a diesel pump. This is necessary because the economic benefits of supplying water are difficult to quantify. For example, if each system can reliably furnish the same quality of service, it is safe to assume that they provide equal benefits. In this case, the lowest-cost option is preferred.

In LCC analysis, the NPV of all capital and recurrent costs of the wind or PV pump is compared to the NPV of all the costs of a diesel pump. For

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example, if the NPV costs of a PV pump are less than the costs of the other alternatives, PV should be the first choice.

Mathematical relationships used to calculate the LCC of any investment project are presented in Section 3.2.1.

Levelized cost

LC is a present-value average of a stream of changing variable costs. All that is involved in this method is to find a single-cost constant (LC) that discounts to the same present value as the stream of variable costs over a period of years being studied.

Mathematical relationships used to calculate the LC of any investment project are presented in Section 3.2.2.

Net present value

An investment project is only profitable when its NPV is greater than or equal to zero. When there are several alternatives, such as wind, PV, and diesel pumps, the NPVs of different projects should be compared with one another, and the investment with the highest NPV should be selected. NPV can be used to reliably evaluate financially favorable investment projects and compare investment alternatives according to capital yields anticipated to be above the minimum acceptable discount rate.

Internal rate of return

The IRR method is not methodologically accurate when comparing two investment projects with different capital requirements and/or different service lives. A direct comparison of IRRs in such cases can give only an estimate of the alternative projects if it is assumed that additional and follow-up investments can be made at an interest rate equal to the IRR of the original investment.

Benefit-to-cost ratio, savings-to-investment ratio, or net benefits or savings

These three evaluation methods are basically the same. The BCR approach attempts to evaluate projects by measuring the benefits converted into a monetized value, based on market information of the willingness to pay, and the costs, based on market information of the willingness to accept, for the resource sacrificed and undesired items received from the project. The BCR should be greater or equal to 1 in order for the project to be viable.

Converting all benefits into monetary terms may be difficult and requires further external evaluation to make decisions. On the other hand, if the alternative options have the same quality of service, the BCR approach can be used to compare alternative projects.

Savings-to-investment ratio (SIR) is the other form of BCR, but this approach is used to make decisions about whether to invest the available money in the project or to save it. In this case, the rate of return of the project must be higher than bank interest in order for the project to be viable. Similarly, net benefits or savings should be positive to favorably consider the project under the net benefits (NB) or net savings (NS) approaches.

Annuity and cost annuity comparison

An investment project is considered profitable when its annuity is not negative. If there are several mutually exclusive investment alternatives to be compared, then the alternative with the highest annuity should be adapted, as long as it is greater than or equal to zero. The cost annuity comparison method is a shortened form of the annuity method, without the inclusion of income in the calculation. Using this method, if there are several alternative investment projects, the alternative with the lowest-cost annuity should be selected.

An investment project is considered favorable if the capital invested plus a minimum acceptable rate of interest is recovered by means of anticipated returns within the service life or within a maximum acceptable payback period, as long as the payback period is shorter than the economic life.

Sensitivity analysis

Sensitivity analysis is used to evaluate the effects of uncertainty. It is used to quantify the economic consequences of a potential but unpredictable development in important parameters. Economic parameters include inflation rate, discount rate, equipment capital cost, fuel cost, expected lifetime, quantity of wind and solar radiation energy, etc. Once the LCC of the pumping system is determined, using the common base-case assumption, the

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economic viability of the pumping system is evaluated in worst- and best-case situations. By varying the economic parameters between the worst and best conditions, the viability limits of different pumping systems can be easily compared. Therefore, sensitivity analysis is used to determine how the NPV life-cycle cost varies from the base case as the economic parameters change.

Sensitivity analysis helps to quantify the economic consequences of potential but unpredictable developments in important parameters.

Sensitivity analysis can also be used for more formal risk analysis where probabilities may be assigned to variables. This can enable the decision-maker to tell, at a glance, the choices he or she has made.

Common base-case assumptions should be considered in all these investment cost-analysis methods. The common financial assumptions include salvage value, operating hour, debt service, fuel costs, inflation, and discount rates. The second of these assumptions is where the most important specifications for the typical system in each application are developed. The key technical assumptions common to the base-case analyses include component life (economic life), major maintenance, and engine overhaul. Graphs can be constructed to show the overall best- and worst-case viability of different pumping systems over a given load range. The best-case wind/PV viability graph is developed by compounding the extreme sensitivity limit using the lowest discount and interest rates, the highest fuel cost, the shortest diesel economic life, and the highest wind/solar radiation of the sensitivity limit range. The worst-case is developed using the other extremes of the ranges.

Break-even analysis

Many economic comparisons are forms of break-even analysis. Sensitivity analysis involves an indifference level for a given cash flow element at which two alternatives are equivalent, which is the break-even point of the alternative systems. Break-even analysis shows the point at which alternative pumping systems are equally advantageous; neither system is considered expensive or inexpensive. A break-even comparison detects the range over which each alternative is preferred. The decision-maker only has to choose the most likely preferred system for the required application. For example, in the break-even analysis of wind/PV and diesel pumps, the population size or the pumping head limits for each pumping option can be determined. Break-even analysis can also be used to determine the profitability limit of a single system or product. For example, if the unit water cost of a PV pump is predetermined, based on affordability to the end user(s) or due to some other criteria, the maximum pumping head or population size limits can be estimated using this method.

3.2.1 Life-Cycle Cost

LCC is the sum of all the costs and benefits associated with the pumping system over a given economic lifetime or over a selected period of analysis, expressed in the present value of money, that is the present worth (PW) of the costs and benefits of the system. All the future costs and benefits are discounted to the present-day value and added to the present-day investment costs, and the net present value is the LCC. The LCC, for *n* years' period of analysis, can be expressed mathematically in the form:

$$LCC = \sum_{t-1}^{n} PW_{benefits} - \sum_{t-1}^{n} PW_{costs} \;\ldots\ldots\ldots\ldots\{3.1\}$$

Where the present-worth costs $PW_{costs}$are the present worth of the replacement and recur rent costs. The present-worth benefits $PW_{benefits}$are the present-worth incomes of the pumping system, such as water charges, tariffs, etc. The total $PW_{costs}$are the sum of total capital costs and PW of replacement and recurrent costs. Similarly, total $PW_{benefits}$are the sum of all PW incomes.

Equation 3.1 is used to evaluate a single pumping system in terms of its benefits and costs.

This method is similar to BCR, SIR, or NB or NS. The only difference between these methods and the LCC is that they use the ratio of present-worth benefits (savings) to present worth costs (investments). Here, the benefits must be greater

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than the costs for the pumping system to be worthwhile.

For public projects, such as for a community water supply, the selection of a pumping system should be made based on a comparison with alternative pumping systems. The LCC analysis of a single pumping option by itself cannot be sufficient to make economic decisions.

Therefore, it is necessary to compare the system with other alternative pumping systems. For such cases, the present-worth costs of each alternative should be determined and the lowest- cost option considered. There are two ways of comparing alternative water pumping options:

(1) to compare the unit water costs of each pumping option, and (2) to compare the per capita capital costs of the systems. Once the total PW is known, the annual equivalent life cycle cost (ALCC) will be determined. The ALCC is the reverse process of discounting (that is, dividing the LCC by the uniform series costs present-worth factor). These factors are shown in the brackets in Equations 3.4 and 3.5.

The present worth of a future single cost or benefit (C_f) payable in n years, which is inflated at a fixed percentage of e each year and discounted at a rate of d, is:

$$PW = C_f\left[\frac{(1+e)^{n-1}}{(1+d)^n}\right] \ldots\ldots\ldots\ldots \{3.2\}$$

If the real discount rate is used, Equation 3.2 can be written in the form:

$$PW = C_f\left[\frac{1}{(1+i)^n}\right] \ldots\ldots\ldots\ldots \{3.3\}$$

Where i ($i= d\text{-}e$) is the real discount rate. The relations in the brackets in Equations 3.2 and 3.3 are for single-cost (benefit) present-worth factors.

The present worth of a payment or benefit $C_a$occurring annually for a period of n years inflating at a fixed rate of e per year and discounted at a rate of d is:

$$PV = C_a\left\{\frac{1}{(d-e)}\left[1-\left(\frac{1+e}{1+d}\right)^n\right]\right\} \text{ for } e \neq d, \ldots\ldots \{3.4a\}$$

or, $PW = C_a\left(\frac{n}{1+e}\right)$, e=d …………………{3.4d}

For the real discount rate, where i = d-e, Equation 3.4 can be written as:

$$PW = C_a\left[\frac{(1+i)^n-1}{i(1+i)^n}\right] \ldots\ldots\ldots\ldots \{3.5\}$$

The equation in the brackets is the uniform series costs (benefits) present-worth factor.

Real discount rates usually can be used in economic calculations. The evaluator has to be careful in using real discount rates, by just directly subtracting the inflation from the discount rate. In a country with hyperinflation, the $C_f$and $C_a$factors from Equations 3.2 to 3.5, will be diverted from the real discount rate. Therefore, in such cases, the evaluator needs to use Equations 3.2 and 3.4, instead of Equations 3.3 and 3.5. Figure 3.1 shows comparisons of C_f and $C_a$for different discount and inflation rates with the real discount rate. At higher inflation, the graph tends to get flatter than the real discount rate and, therefore, Equations 3.3 and 3.5 are not good to use for economic evaluation at higher inflation.

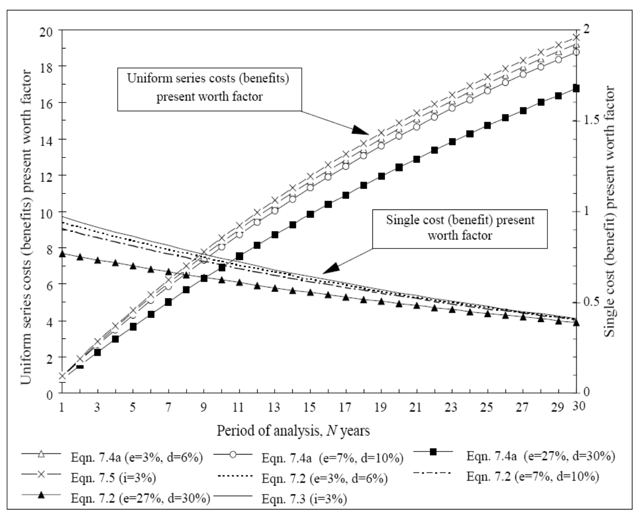

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Figure (3.1): Comparisons of $C_f$and C_a using real discount rate and inflation and discount rates separately using Equations 3.2

3.2.2 levelized costs (LC)

The levelized cost (LC) of a power plant is calculated as follows:

$$LCOE = \frac{OC}{CF*8760} * CRF + OMC + FC \ldots\ldots\ldots\ldots\{3.6\}$$

$$with\ CRF = \frac{r*(1+R)^T}{(1+R)^T - 1} \ldots\ldots\ldots\ldots\{3.7\}$$

where OC is the overnight construction cost (or investment without accounting for interest payments during construction); OMC is the series of annualized operation and maintenance (O&M) costs; FC is the series of annualized fuel costs; CRF is the capital recovery factor; CF is the capacity factor; r is the discount rate and T is the economic life of the plant [3].

3.3 Cost Appraisal Procedure

The methodologies mentioned in Section 3.2 can be used to identify the lowest-cost pumping system, but the economic evaluation approach by itself is not sufficient to select the optimal system. The lowest-cost solution may not be the best choice, because, as mentioned previously, factors other than cost should also be taken into consideration. Reliability, for example, is a key factor and the user may be prepared to pay more for greater reliability.

Thus, cost appraisal is necessary before making the final choice.

Reliability of fuel supply, availability of local maintenance, spare parts, and skilled personnel are the main criteria for economic analysis. For rural villages where there are few roads and unskilled personnel, the ideal power system must not require frequent maintenance visits or refueling. The reliability of fuel supplies and availability of spare parts should be taken into account when considering a diesel pumping option. According to field survey results, diesel driven pumps operating in developing countries are usually about 10–20% efficient. This is mainly a result of poor maintenance and mismatched subsystems. Such cases impose unnecessary penalties on communities in the form of extra costs.

3.4 Data Collection Procedure for Economic Evaluation

The main parameters needed for economic evaluation are the discount rate, inflation, subsidies, taxes, equipment costs on-site, construction and installation costs, estimation of operation and maintenance, and labor costs throughout the economic life of the system. These parameters vary from country to country and cannot be standardized. The variation depends on several factors, including inflation stability, national policy towards renewable and conventional pumping systems, efficiency of construction companies, level of free competition in the construction business, site accessibility, and location.

The most difficult part of an economic evaluation is not the methodology, but how to collect reliable information for the evaluation. A significant problem is improper recording of expenses by the end users and contractors. In many cases, doing the job quickly is the main priority. As a result, all costs are not properly recorded and lump-sum figures are used. This type of practice distorts the actual investment cost of a project. There is also improper recording of recurrent costs, and projecting recurrent costs over the time span of the economic analysis. Money collection may not be properly made and actual yearly income not known exactly. Tariffs may not be prepared based on the investment and recurrent costs.

Such problems are not limited to cost recording; there are also similar problems in technical data recording. In many developing countries it is not unusual to find boreholes without a geological log and no recorded well-testing information.. In some cases, there are no water meters connected to the system, thus it is difficult to estimate the daily water output. Water meter reliability can also be a problem.

In economic data collection, one has to understand the following issues. First, the data collector must recognize that precise cost data are not always readily available. The data collector needs to collect

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all available documentation about the correct costs of the project from archives of end users, contractors, and/or suppliers. Once the actual investment costs are found, the next step is to determine recurrent cost data. These include costs related to operation and maintenance, labor, and replacement. Operation costs are basically operators' salaries, fuel costs, and other associated costs. Maintenance costs include both preventive and overhaul costs, as well as maintenance personnel expenses (such as daily allowance, travel expenses, and salary for the maintenance period) and spare parts. In many cases, recurrent costs records may not be easily available and it may be necessary to interview operators, end users, water committees, community participation promoters, and/or development workers.

Once the actual investment and recurrent data are collected, the next step is to find the correct discount and inflation rates, subsidies, taxes, and actual fuel costs. Although subsidies and taxes are not relevant to an economic evaluation (they are viewed as transfer of payments or flows of funds to the society as a whole), the data can be used for financial analysis.

The economic opportunity cost of capital is traditionally used as the discount rate in choosing a project among different alternatives, rather than interest rates, because the use of discount rate is more applicable for public projects. The discount rate is "the minimum acceptable rate of return used in discounting benefits and costs occurring at different times to a common time." It reflects the investor's time value of money (or opportunity cost). Real discount rates reflect time value apart from changes in the purchasing power of the money (that is, inflation or deflation) and are used to discount constant money cash flows. Nominal discount rates include changes in purchasing power of the money and are used to discount current money cash flows. Discounting is a procedure for converting a cash flow that occurs over time to an equivalent amount at a common time. The real discount rate i is the nominal discount rate d minus the inflation rate e (that is, $i = d - e$). Usually, the discount rate is used instead of the nominal discount rate, otherwise the term real discount rate is used to include inflation or deflation.

The most difficult part of determining the economic opportunity cost of capital is to find the right discount and inflation rates, shadow prices for foreign exchange, and labor costs, because in countries where there is no free market, exchange rates are artificial. Such information is available from the government's economic planning office. Shadow prices are not used unless there is a marked difference in cost between the economic and financial perspectives. In such cases, cost adjustments are necessary for imported items and for those costs that contain a substantial amount of unskilled labor. As a result of the valuation of the foreign exchange and rising taxes and duties, there are alternative valuations of unskilled local labor.

Once the actual investment and recurrent data are collected, and the correct discount and inflation rates, subsidies, taxes, and actual fuel cost information are available, the next step is to estimate the possible income from the project over its economic life. Income can be estimated by either converting monetary values or in-kind values, such as the amount of water production over the project's economic life. To figure such information, one must first determine if there is a water meter installed in the system and if the water meter is working properly. Typically, one-year water output data can be taken and multiplied by the economic life for diesel pumping systems. This assumes that the system efficiency will be the same over its economic life through proper operation and maintenance, thus the water production would also be the same. However, this assumption cannot be true for wind and PV pumps, since the water output depends on the availability of wind and solar radiation energy, and these can vary from year to year. In this case, it is recommended to use typical one-year weather data. This allows for the estimation of the amount of water produced over the system's economic life (simply by multiplying the amount of water produced in one year by its economic life). It is also useful to use average water

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production data over a few years (the longer the better) to estimate the total water production over the system's economical life.

CONCLUSION

Since the increase in price per increase in unit power output of solar system is greater than that for a diesel, gasoline, or electric system, solar power is more cost competitive when the irrigation system with which it operates has a low total dynamic head. For this reason, solar power is more cost-competitive when used to water pumping system as compared to an overhead sprinkler system. Solar power for water pumping system is cost-competitive with traditional energy sources for small, remote applications, if the total system design and utilization timing is carefully considered and organized to use the solar energy as efficiently as possible. In the future, when the prices of fossil fuels rise and the economic advantages of mass production reduce the peak watt cost of the solar cell, solar power will become more cost-competitive and more common.

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Author Profile

Eltayeb Mohammed received theB.Scdegree in mechanical engineering from university of Nyala, Nyala, Sudan, in 2013; In 2015,he joined the University of Nyala, mechanical engineering department,astechnical assistance. Currently he is working at African Humanitarian Action organization {INGOs} in Sudan as WHSH project engineer.