Initial investments and operation costs, technical and financial aspects having an impact on cash-flows over the life time operation of SMALL HYDROPOWER PLANTS

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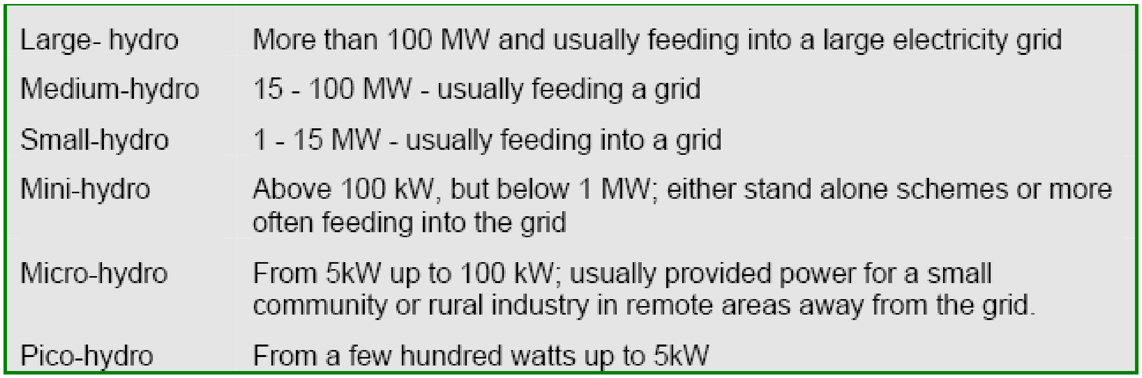
1. Introduction

Hydropower is the largest and most mature application of renewable energy, with some 678,000MW of installed capacity worldwide, producing over 22% of the world's electricity (2564TWh/yr) in 1998. Of this, 27,900MW is at small-scale sites, generating 115TWh/year. In Western Europe, hydropower contributed 520TWh of electricity in 1998, or about 19% of EU electricity (avoiding thereby the emission of some 70 million tones of CO_2 annually). Despite the large existing hydropower capacity, there is still much room for further development as most assessments assume this is only around 10% of the total world viable hydro potential.

In this context, the paper deals with the study of initial investments and operation costs, technical and financial aspects having an impact on cash-flows over the life time operation of Small Hydropower Plants.

Water can be harnessed on a large or a small scale - Table 1, below outlines the categories used to define the power output form hydropower.



Large- hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15 - 100 MW - usually feeding a grid
Small-hydro	1 - 15 MW - usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1 MW; either stand alone schemes or more often feeding into the grid
Micro-hydro	From 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid.
Pico-hydro	From a few hundred watts up to 5kW

Table 1: Classification of hydropower by size.
kW (kilowatt) - 1000 Watts; MW (megawatt) - 1 000 000 Watts or 1000 kW

As previously stated, we deal specifically with Small Scale Hydropower systems, since large-scale hydropower plants are usually not considered as RES exploitation systems by ecologists. Large dams have acquired a reputation for damage to ecosystems. They hood and silt in natural stream areas and deplete oxygen from the water. Their reservoirs are dead-water or slack-water pools whose water is hostile to native fish species.

Downstream, they create alternating periods of no water followed by powerful surges that erode soil and vegetation.

Small Hydropower Plants (SHP) are mainly "run of river", i.e. not involving significant impounding of water and therefore not requiring the construction of large dams and reservoirs, though where these exist and can be utilized easily they do help. There is no general international consensus on the definition of SHP; the upper limit varies between 2.5 and 25 MW in different countries, but a value of 10MW is becoming generally accepted and has been accepted by ESHA (the European Small Hydro Association).

The definition for SHP as any hydro systems rated at 10MW or less will therefore be used here. SHP can be further subdivided into “mini hydro” (usually <500kW) and “micro hydro” (<100kW).

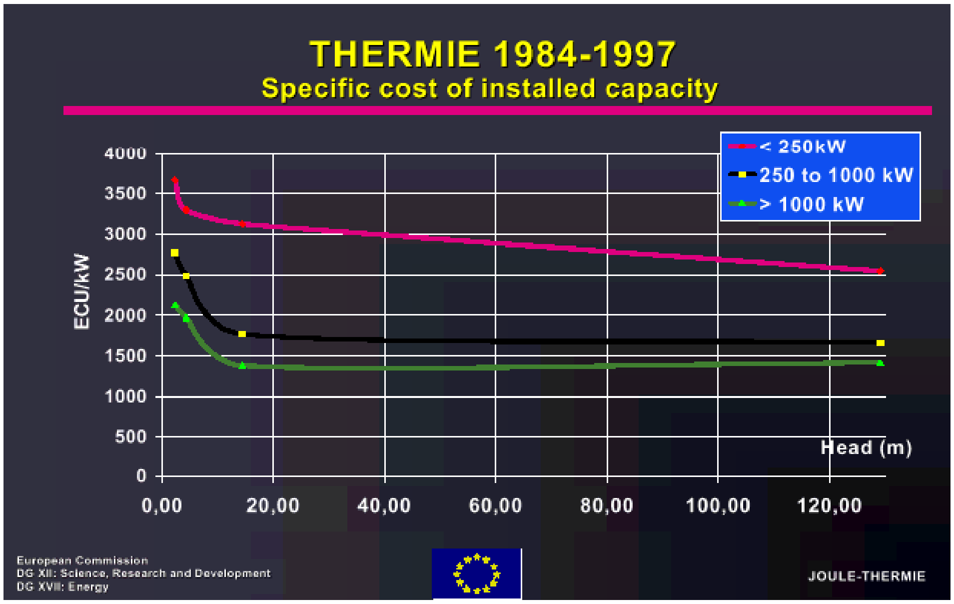
2. Initial investments and operation costs for SHP

Hydropower plants are characterized by high initial capital-investment (according to World Bank total costs are between 1800 USD and 8800 USD per kW for heads from 2,3 to 13,5 m and 1000 USD to 3000 USD for heads between 27 and 350 m) and low operation and maintenance cost. The investment costs include: construction (dam, channel, machine house), parts for electricity generation (turbine, generator, transformer, power lines), and others (engineering, ground property, commissioning).

Paradoxically, using modern conventions for financial and economic appraisal, most new SHP installations appear to produce rather expensive electricity as the high up-front capital costs are usually written off over only 10 or 20 years (yet such systems commonly last without major replacement costs for 50 years or more). In contrast, an older hydro site where the capital investment has been written off is cheap to run as the only costs relate to occasional maintenance and replacements.

As an example, the unit cost of owning a typical small low head hydro site in the UK might be typically €0.07/kWh during the first ten years while the capital investment is being repaid, but subsequently, because of the low running costs, the unit costs could fall to around one tenth of this level (say €0.007/kWh). Clearly the output for the first decade will be more costly than power bought from the grid in most cases, although after the capital investment has been paid off, the hydro plant power prices become exceedingly attractive. Unfortunately, most potential investors take a short-term view and are put off by the initial high costs.

Decisions to use a technology are generally driven primarily by economics, so naturally there is a need to drive down the costs of SHP. Least cost hydro is generally high head hydro (see Figure 1), since the higher the head, the less water is required for a given amount of power - so smaller, less costly equipment is needed.



Source: Ref. 4.1.5.

Fig. 1 *Effects of hydraulic head and size on installation cost*

However, high head sites tend to be in areas of low population density where the demand for electricity is small, and long transmission distances to the main centers of population can nullify the low cost advantages of remote high head systems. High head sites are also relatively rare, and most of the best ones in the developed world have already been exploited.

Normally, small-scale hydro installations in rural areas of developing countries can offer considerable financial benefits to the communities served, particularly where careful planning identifies income-generating uses for the power.

The major cost of a scheme is for site preparation and the capital cost of equipment. In general, unit cost decreases with a larger plant and with high heads of water. It could be argued that small-scale hydro technology does not bring with it the advantages of ‘economy of scale’, but many costs normally associated with larger hydro schemes have been ‘designed out’ or ‘planned out’ of micro hydro systems to bring the unit cost in line with bigger schemes.

The specific aspects of the SHP technologies includes innovations such as:

- using run-of-the-river schemes where possible - this does away with the cost of an expensive dam for water storage;
- locally manufactured equipment where possible and appropriate;
- use of HDPE (plastic) penstocks where appropriate;
- electronic load controller – allows the power plant to be left unattended, thereby reducing labor costs, and introduce useful by-products such as battery charging or water heating as dump loads for surplus power; also does away with bulky and expensive mechanical control gear;
- using existing infrastructure, for example, a canal which serves an irrigation scheme;
- setting of power close to village to avoid expensive high voltage distribution equipment such as transformers;
- using pumps as turbines (PAT) – in some circumstances standard pumps can be used ‘in reverse’ as turbines; this reduces costs, delivery time, and makes for simple installation and maintenance;
- using motors as generators – as with the PAT idea, motors can be run ‘in reverse’ and used as generators; pumps are usually purchased with a motor fitted and the whole unit can be used as a turbine/generator set;
- use of local materials for the civil works;
- use of community labor;
- good planning for a high plant factor (see above) and well balanced load pattern (energy demand fluctuation throughout the day);
- low-cost connections for domestic users (see following chapter on this topic);
- self-cleaning intake screens - this is a recent innovation which is fitted to the intake weir and prevents stones and silt from entering the headrace canal; this does away with the need for overspill and de-silting structures along the headrace canal and also means that, in many cases, the canal can be replaced by a low-pressure conduit buried beneath the ground - this technology is, at present, still in its early stages of dissemination.

Usually equipment for low head and low output becomes very costly and equipment cost ranges from 40 to 50 % of total cost in conventional hydro installations. As far as costs of civil construction-components are concerned, no standard cost unit can be given. Dams, canals and intakes will obviously cost a very different share of the total for different sites. Much depends on the topography and the geology, and also on the construction method applied and the materials used. Just to mention some examples the total cost of new small hydro power plants in Germany was 5-9 Euro/W and are divided in most cases 35% (construction) - 50% (electricity parts) - 15% (other). There are of course some differences between countries, e.g. costs of 8 kW turbine (Banki type with regulation) in Czech Republic is approximately equivalent to 3500 Euro, or 0,45 Euro/W. The high investment costs is the largest barrier in development of small hydro power schemes. Despite this obstacle and long pay-back times (7-10 years in some countries e.g. Slovakia) small hydro power plants are often cost-effective because of their long life-time (often more than 70 years) and low maintenance costs. As a general rule, total costs of operation and maintenance without major replacements account for approximately 3 to 4% of capital costs for small and micro-hydropower installations. Maintenance costs (insurance and water abstraction charges, where they apply) are a comparatively minor component of the total - although they may be an important consideration in marginal economic cases.

Programs promoting the use of micro-hydro power in developing countries have concentrated on the social, as well as the technical and economic aspects of this energy source. Technology transfer and capacity building programs have enabled local design and manufacture to be adopted. Local management, ownership and community participation has meant that many schemes are under the control of local people who own, run and maintain them. Operation and maintenance is usually carried out by trained local craftspeople.

Where the power from a micro-hydro scheme is used to provide domestic electricity, one method of making it an affordable option for low-income groups is to keep the connection costs and subsequent bills to a minimum. Often, rural domestic consumers will require only small quantity of power to light there houses and run a radio or television. There are a number of solutions that can specifically help low-income households to obtain an electricity connection and help utilities meet their required return on investment. These include:

- Load limited supply. Load limiters work by limiting the current supplied to the consumer to a prescribed value. If the current exceeds that value then the device automatically disconnects the power supply. The consumer is charged a fixed monthly fee irrespective of the total amount of energy consumed;
- Reduced service connection costs. Limiting load supply can also help reduce costs on cable, as the maximum power drawn is low and so smaller cable sizes can be used;

- Pre-fabricated wiring systems. Wiring looms can be manufactured 'ready to install' which will not only reduce costs but also guarantee safety standards;
- Credit. Credit schemes can allow householders to overcome the barrier imposed by the initial entry costs of grid connection. Once connected, energy savings on other fuels can enable repayments to be made;
- Community involvement. Formation of community committees and co-operatives who are pro-active in all stages of the electrification process can help reduce costs as well as provide a better service. For example, community revenue collection can help reduce the cost of collection for the utility and hence the consumer.

3. Technical and financial aspects having an impact on cash-flows over the life time operation of SHP

There are a lot of implications, due to the life time operation of a SHP, on the cash-flow of such energy production company, which can be grouped as follows:

3.1. Environmental implications

SHP are in most cases 'run-of-river', which means that any dam is quite small, usually just a weir, and generally little or no water is stored. Therefore these installations do not have the same kind of adverse effect on the local environment as large hydro.

Turbines need to be protected from all the debris that are commonly found in rivers, whether natural (e.g. leaves, branches, even tree trunks) or man-made (supermarket trolleys, plastic fertilizer bags or general garbage); this is done using screens. A major operating cost element is cleaning these screens, especially in low head situations where large flow rates pass through.

In most cases, new hydro installations are designed to leave sufficient water bypassing the turbines - which is not difficult except in times of low flow. Another area that requires care is the need to avoid harming fish and riverside flora and fauna, but modern turbine installations are designed with this problem in mind. Some low head systems allow fish to pass through the turbine generally unscathed, but various forms of screening (either physical screens or even electrical and ultrasonic) are also used. Figure 2 illustrates a common fish-ladder with vertical slots and bottom orifices that yields very good results. The composition of fish species may be altered, since reproduction for some species may be hindered if the operation involves changes in the water level during the spawning period. Artificial reservoir tends to contain a less varied composition of species than a natural lake. Changes in the water flow and water-flow pattern may radically alter nutrient and spawning conditions downstream. The primary production as well as the direct accessibility of nutriment for fish will change. Changes made to the downstream floods, as a result of water control, may be decisive. At dam and turbine outlets a surfeit of gas may occur, principally of nitrogen, which can cause death among fish.

Fig. 2 *Fish Ladder*

A watercourse is an ecological system where changes within one component may create a series of spread-effects. For instance, changes in the water flow may affect the quality of the water and the production of fish downstream. Dam barriers may greatly change the living conditions for fish. In addition to the emergence of a major or completely new lake, the dam may divide upstream fish from downstream fish, and block their migration routes.

Environmental changes may be traced far downstream, at times even out into the sea. In the tropics there may be great seasonal variations as to the amount of precipitation, and in dry periods evaporation from lakes and reservoirs may be considerable. This may affect the water level of the reservoirs more dramatically than in temperate areas. The watercourse and its watershed mutually influence each other. The watercourse, for example, may affect the local climate and the ground-water level in surrounding areas. The sedimentation taking place in a reservoir can often lead to increased erosion downstream, i.e. an increase in the total erosion. Changes in water flow and water level will also lead to changes in the transportation of sediments. During the construction phase the transport of mud and sediments will be especially large downstream from the construction area. Excavation and tunneling may lead to greatly reduced water quality and problems for those dependent on the water.

3.2. Influence on ground water level

The groundwater level is important for the ecosystem‘s composition and development of plant and animal species. Groundwater is particularly important as a drinking-water source in most countries. The filling of a reservoir of hydro power plant and the flow of a watercourse are of great importance to the groundwater level and for the feeding of the groundwater reservoirs. A reservoir, together with the changes and variations of the water level caused by its operation, will change the groundwater level in surrounding areas. These areas may in turn influence the quality of the water and the sediment transport of the watercourse as a result of area run-off and erosion.

3.3. Excessive fertilization

Whenever nutrients are trapped in a reservoir, the result may be excessive fertilization - eutrophication - in the reservoir. It may lead to an increased growth of algae or large amounts of higher-order aquatic plants. A substantial production of organic matter in the reservoir, or the supply of external organic matter, may cause anaerobic conditions - lack of oxygen - in the deep-water layers.

On the whole, shallow lakes with a large surface area are most at risk, partly because the reserve of oxygen in the deep-water layers is limited in proportion to the productive area in the top layers. In deep, narrow lakes the oxygen content in the deep-water layers will be sufficient to recycle organic matter sinking down, provided there is a regular circulation of the waters. This is not always the case in the tropics. If the watercourse is initially rich in nutrients, the risk of eutrophication will increase. Evaporation may cause a concentration of nutrients, leading to excessive fertilization or eutrophication. Tropical soil normally has low humus content. This aspect, combined with the great seasonal variations as to the amount of precipitation, and the fact that precipitation often comes in heavy showers, may cause considerable erosion. The transportation of eroded sediments will be halted and deposited in a reservoir. The reservoir’s lifetime may in this way be reduced. Transport of sediments and nutrients tends to play a crucial role in the ecosystem of a watercourse. The population’s utilization of nature and natural resources may be completely dependent on floods and waterborne sediments and nutrients.

3.4. Transport of nutrients

A reservoir serves as a trap for nutritious elements and mud flowing in, possibly leading to a considerable reduction of the total transport of nutrients downstream. In addition, the annual variations in supply downstream may undergo changes. This may reduce the biological production all the way to the sea. There are grave examples of marine fishing being impaired in the wake of a major dam development.

3.5. Flora and fauna

Submerging and water-flow changes, moreover, will lead to changes in the fauna and vegetation beyond the watercourse as such. Large reservoirs will exert a considerable direct impact on the flora and fauna of the hydro power plant area through submerging the area permanently or periodically. Animals may to some extent move to new habitats beyond the reservoir area, provided that suitable conditions are to be found. But normally the types and species of nature existing in areas being submerged must be considered as lost. It is difficult to predict in general terms how changes beyond the submerged area will turn out. Local climatic changes and changes to the ground-water level may affect the flora and fauna. Valuable types and species of nature may be lost. A general activity increase in the area, such as traffic, noise etc. may also affect the fauna in a negative way. This especially pertains to the construction period. Further, a reduced water flow or changed flow pattern downstream may influence the flora and fauna. The effects may be direct ones in that the flora and fauna react to the water flow, or the effects may be indirect owing to changes in the ground-water level and the transport of nutrients.

3.6. Dam breach – uncontrolled flooding

A dam breach seldom occurs, but owing to the enormous consequences which it may involve, the impacts of a breach should be assessed. The risk of casualties and damaged property or technical installations must be considered the most serious consequences, but the impacts on the natural environment can also be considerable. Statistically, the combination of a flood in the upstream watershed of the dam and faults in the spillway are the most frequent causes of accidents. Secondary causes are foundation errors or water seepage. At high water levels in the reservoirs, landslides of earth and rocks from the embankment above or inside the reservoir may cause flood waves so massive that water may spill over the total or partial width of the dam. If the dam is an embankment dam, this may lead to the dam itself being damaged. Special care should be taken if a major dam is planned in an area exposed to earthquakes.

3.7. Risk issues

Risk issues are fundamental in modern energy systems. Often the investors hire a risk manager, from the project stage of the new power plant investment. Modeling the risks influence implies the probabilities theory, i.e. for a project estimated at 190 millions Euros, the real costs could settle in the range 155 ÷ 225 millions Euros. The chances to be less than 190 millions Euros are only 30 % and lower than 210 millions Euros relative high (90 %).

Risks exist both in public and private investment, being different only who is supporting them. For the public case solely the state budget takes the risks, while for the private investment risks being shared between the participants.

Magnitude of risk depends on the size of the project, the average of the potential loss, the probability of loss emergence and on the degree of exposure of each participant to the respective loss.

Risks may be grouped on the following categories:

3.7.1. Before-investment risks, during the project preparation period. They may imply supplementary costs or can even lead to the relinquishment of the project:

- risks resulting from the feasibility study;
- risks relied to obtaining the agreements, notifications, licenses, authorizations, credits.

In many countries, such projects are subject of public debate, even may be submitted to local interest referendums.

By submitting necessary documents and obtaining the agreements, notifications, licenses, authorizations, credits, the before-investment risks diminish progressively and when all the necessary legal and financial documents are acquired the risks tend to zero.

Private investors look for avoiding these risks, trying to pass them to the public authorities, including supporting costs for the feasibility study, only some final adapting and completing details being undertaken on their charge.

3.7.2. Risks during the construction period

- Geological-geotechnical risks, due to the insufficient investigation of the geological site characteristics, being also the most unpredictable and costly. The extra costs revert to the investors, to the project management company, but also to the entrepreneurs and even indirectly to the banks or financiers.
- Hydrological risk, at floods; it could be a major risk, caused by the under dimensioning of the high water flow dischargers or deficiencies in mounting and running of the gates and vanes, respectively the loss of their control and it can be shared between the project management company and the entrepreneurs. From case to case, the risk may be covered partially by insurance contracts.

During the construction period and even after commissioning it can occur ecological risks, due to the necessity of reducing the ecological impact, the costs being covered by the project management company.

The financial consequences or of other nature, determined by ecological accidents due to the entrepreneurs activities are covered as costs by them selves.

The risk of under evaluation, respectively exceeding the investment evaluation depends on the risks mentioned above. In order to diminish these aspects, the financers prefer and sometimes even impose concluding unique engineering-procurement-construction “turnkey contracts”, associated with the increasing by 10 ÷ 30 % of the investment costs.

3.7.3. Risks in the normal exploitation - production period

- market and commercial risks, result from the uncertainty relied to the free market price or weaknesses of the selling energy contracts. Thus, the project management company may conclude, before engaging the credits, “power purchase agreements” and “energy sales agreement”, on long term (10 ÷ 15 years), grounded on the principles “take and pay” or “take or pay”. Consequently, both dealer and buyer have limited access to the free market, i.e. the dealer isn’t allowed to conclude other contracts with eligible consumers unless it has extra energy, confronted to its contractual obligations.

- risks relied to energy production less then the average established in the design stage, due to the low quality hydrological data or the over consideration of these data; the risk is shared by the project management company and the local energy production company, grounded on certain clauses in the sale-purchase energy contract.
- risks relied to energy production less then the average, due to a droughty (low natural precipitation) period; the level of this risk is predictable and the costs are covered by the project management company, by special clauses in the contract with the local energy production company.
- risks associated to non accomplishing the guaranteed parameters for equipment (power, efficiency, low long-time behavior, high costs for maintenance, repairs of damages etc.), failures due to weak quality design activities, manufacturing and assembling tasks. All these aspects are covered as costs inside the contract by the equipment suppliers and mounting company.
- earthquake risks, covering mainly the dams and weirs of the water accumulating lakes; it can be avoided by an adequate design, depending on the national and regional regulations for earthquake characteristics geographical areas. It is important to mention one special effect of the earthquakes on dams and grounded foundations, called as “liquefaction phenomenon”.
- clogging risk, due to the solid sedimentation effect, leading to increasing deposits on the bottom of the water lake.
- ecological risks, caused by the permanent and occasional production, maintenance and repair activities, costs being associated with the requirement to diminish, limit and even clear up the impact of these ecological consequences.
- risks associated with the premature attrition of the equipment being in contact with water, in the presence of the erosive mixed liquid-solid flow, or caused by the chemical aggression of the water.
- risks caused by inadequate production, maintenance and repairing activities.

3.7.4. Financial risks
- inflation risk; can be diminished or strike out through indexing stipulations in the commercial contracts.
- interest rate risk, also being diminished or strike out through indexing stipulations in the commercial contracts.

This reviewing of the principles risks confronting the small hydro-energy production investment projects reveals the necessity of profound analyze and assessment of the potential consequences and of the chances that the above mentioned risks to produce their undesired technical, economical and financial effects.

The good knowledge on the real professional, technical, economical and social environment is essential, in order not to overlap the risks and to take exaggerate, useless protection measures. It is obvious the antagonist relationship between low risks and high efficiency, the optimal situation being the one that succeeds to reach an acceptable compromise.

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4.2. Web links

4.2.1. Small Hydro as an Energy Option for Rural Areas of Perú by Teodoro Sanches ITDG Latin America http://www.itdg.org.pe/Programas/energia/articulos/shaaeofra.pdf
4.2.2. Links To Related Small Hydro Sites: http://smallhydropower.com/links.html
4.2.3. Microhydro web portal: http://www.microhydropower.net/index.php
4.2.4. Hydro Power Links: http://home1.swipnet.se/~w-19094/hyd_link.htm
4.2.5. European Small Hydropower Association http://www.esha.be/
4.2.6. The IEA Hydropower Agreement: http://www.ieahydro.org
4.2.7. International Small-hydro Atlas http://www.small-hydro.com/
4.2.8. Czech Republic: http://web.telecom.cz/hydropower/index.html
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4.2.15. International Network on Small Hydro Power: www.inshp.org