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# The evolving context for hydropower development

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**Abstract**

The paper describes the historic development of hydropower, showing a gradual transition from a techno-economic to a more holistic approach with participatory decision making. Concentrating on the past two decades, the trends in hydropower development are discussed and the complexity of the planning is shown. Finally, the competitiveness of hydro with other options to cover the electricity needs is discussed. Based on the analysis done, it appears that the switch from public to private sector funding is the major factor for the decline of hydropower construction. Credits for reduced $CO_2$ emissions, compared with thermal plants, and ancillary services, can partly compensate for it, especially for base and mid load plant. 

*Keywords:* Hydropower; Planning; Electricity; Competition; Multi-criteria

## 1. Hydropower in the past, at present and in the future

Hydropower projects have been built successfully for over a hundred years. During this long period societal attitudes and needs have changed and science has made good progress. This impacted on the planning, construction and operation of hydropower projects.

The first generation hydropower plants were wooden water wheels used for motive power. Around 1880 the first small single purpose hydroelectric plants were built. Over the years more and more projects became multi-purpose, making best use of dam projects for irrigation, hydropower, water supply, and flood control.

With progress in technology and increasing electricity demand, the maximum size of hydro projects increased. A milestone in the development of hydropower was the construction of Grand Coulee in the USA in the mid-thirties. Although this project was built primarily for irrigation, turbines were installed to improve the economics of the project, and by the mid-forties almost 1600 MW had been commissioned.

Further milestones are the construction of 12 000 MW Itaipu scheme on the Brazilian-Paraguayan border in the late seventies, and the development of the Three Gorges project in China, a multi-purpose scheme for flood control and navigation, with a planned hydropower capacity of 18 000 MW. The project is currently under construction.

After World War II the pace at which hydro plants were built accelerated, first in the industrialized world and China, and 10–15 years later also in developing countries. Worldwide, most hydro projects were commissioned between 1955 and 1985. Since then there is a marked decline in construction activity for which there are basically two categories of reasons:

(a) *Financial reasons*

- The best dam sites have already been exploited and thus remaining sites are generally less attractive.
- Improvements in thermal plant efficiency and increased availability of natural gas have led to stronger competition of thermal-electric projects, particularly by gas-fired combined cycle plants.
- Low fossil fuel prices in the eighties and nineties, which further contributed to the advantages of thermal plants.
- Increased reliance on private sector funding, requiring projects with short lead times, low capital costs, low levels of risk and reasonable operating costs. While the running costs for hydro are low, it typically has a long lead-time, high capital cost and is more risky than thermal plant.

(b) *Environmental and social reasons*

- Increased understanding and awareness of complex technical, environmental and social issues,

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which are inherent to hydropower projects; and realization that the development of hydropower projects involves a trade-off between the benefits gained against losses. Compared to, say, 20 years ago, far more comprehensive environmental and social studies are to be undertaken, increasing both the development cost and duration. Some projects which were feasible from a largely techno-economic point of view in the past turned out to be unfeasible once delays and required compensation costs were considered
- Increased public concern about environmental and social consequences of hydropower has led to the existence of both local and well-organized globally acting NGOs. Their campaigns have resulted in delays and cancellation of projects, especially of schemes supported by international development agencies. As a result these agencies are now reluctant to become involved in new hydropower projects.

Looking into the future, there are good reasons to expect a revival for hydro in the medium to long term:

- The depletion of oil and natural gas deposits will lead to higher generation costs for thermal plant in the future, putting hydro in a relatively better position.
- By offsetting thermal generation, hydropower is a leading technology in efforts to reduce greenhouse gases. With the introduction of carbon trading, thermal plant will become more expensive, improving the chances of hydro development.
- HVDC (high voltage direct current) transmission over long distances is becoming cheaper and electricity networks are getting interconnected and growing, improving the prospects for large scale hydro plants in remote areas.
- The ancillary services in electrical networks[1] that can be provided by hydro are increasingly acknowledged and financially rewarded. This adds to the revenues and makes hydro more attractive.
- Due to the growth of the world population, especially in developing countries, new dams will have to be built for irrigation and water supply. The addition of a hydropower component to such a project is economic and has practically no additional environmental or social impacts.
- It is widely believed that, as part of the long-term changes in the energy sector, hydrogen is the fuel of the future. Remote hydro can become one of the major carbon-free financially viable producers of hydrogen.

## 2. Trends and complexity of hydropower development

### 2.1. Planning in the past

Until recently, the terms of reference for planning studies for hydropower projects generally required a future demand (water, power) to be covered in a least-cost manner. The planning procedure was to develop alternative technical solutions, to select the least-cost option, and to mitigate the environmental and social impact of the plan or scenario to a minimum. 'Least-cost' was defined as the minimum present value of investment, operating and maintenance costs over a specified planning period, applying real term discount rates of 10–12% (in developing countries), and often ignoring external costs associated with control and mitigation of the environmental and social impacts.

In the industrialized countries some form of public discussion and feedback on design has been ensured through legislative and regulatory processes involving hearings. In the developing countries, however, decisions on development options have generally been taken in isolation by governments and utilities together with the international funding agencies, following the previously mentioned 'least-cost' approach.

The reaction to this techno-economic planning approach has been the call for a more 'sustainable development' and to the formation of interest groups which wanted more attention to be paid to non-technical and non-economic issues. For a considerable time these groups, generally non-governmental organizations (NGOs), were seen as project 'opponents' seeking to obstruct development.

The more stubborn the reaction of the technocratic world to this opposition, the more fanatic and spectacular became the opposition of the NGOs. Of course, this has been ideal food for the media and opposition politicians. The result has been that many projects, in particular large infrastructure projects, stalled during the planning process as decision-makers and/or funding agencies did not want to burn their fingers. Painful examples from the recent past are the withdrawal of the development banks from large irrigation (India) and hydropower projects (Nepal).

Other large projects were implemented in spite of considerable opposition but turned out to be no longer the 'least-cost' project as a result of costly delays and modifications during the implementation phase.

Disregard for civil rights of 'primitive' people living in the forest and rural communities has led to numerous flagrant violations of human rights during the planning, construction and operation phase of hydropower

[1] Typical ancillary services are: spinning (or synchronous) reserve, coverage of steep load gradients (ramp rates), load regulation (fast load following), steadier operation thermal plant (fuel savings, extended life), savings in start-up and shutdown cost of thermal plant, synchronous condenser operation (reactive power control), frequency regulation, increased system reliability, improvement of system black start.

projects, which are typically built in remote areas rather than in urban areas. Those in charge of decision making were often a clique of upper-class urban families or insensitive military or autocratic rulers used to commandeering 'lower' ranks. Appropriate Operational Directives of the World Bank have addressed this problem and have been instrumental in better protecting the rights of minority groups.

### 2.2. Evolution of the planning approach

Planning should avoid unnecessary expenditure and effort on projects, which in the end will not be carried out. Planning procedures must therefore be geared toward maximized acceptance (or minimized regret).

To ensure broad acceptance of projects or development alternatives, it is important to present and discuss, as early in the planning stage as possible, all the pros and cons of competing scenarios. The discussions must involve interested parties, including the persons directly affected by the project, relevant government authorities and NGOs, taking into account technical, economic, financial, environmental, social, institutional, political and risk factors.

A difficulty in developing countries is that many candidate hydropower projects are located in rural areas, with generally low levels of school education. While the people affected are generally able to give their opinion about issues that directly affect them, they may not be able to fully participate in the strategic decision making of the project. They need assistance from trustworthy and independent middlemen, who can talk with them in their own language and inform them about the issues at stake and the possible repercussions of alternative developments for their livelihood, making them better informed before decisions are taken.

The interested parties should jointly formulate a limited number (say 5–8) of alternative plans to cover the future electricity demand. These plans should be diverse with respect to their impacts and should include plans featuring demand side management measures (such as promotion of energy saving lamps) as well as the 'no-project' option.

Subsequently, the necessary analysis would be undertaken to quantify and evaluate the alternative developments in sufficient detail to be able to outline the consequences of each plan. Workshops should then be organized in which all interested parties can discuss the results and try to reach consensus about the best plan to be adopted for implementation. This is typically a multi-criteria exercise, taking into account technical, economic, financial, environmental, social, institutional, political and risk factors.

This would be a very 'democratic' approach, rather novel and considered even as unacceptable in some countries if decision-making is normally carried out at an autocratic political level without direct consultation of the people affected. Thus there may be limits as to how 'open' this kind of study can be made in practice. The development banks should nevertheless pursue a policy which ensures maximum participation of project stakeholders, and if this is altogether rejected by a particular government, then the international funding agencies should refrain from becoming involved.

There are major differences from previous planning practices. It is holistic and attempts are made to reach a consensus of all parties concerned *at as early a stage as possible*, thus avoiding last-minute surprises after years of development expenditures, as has happened with several major hydropower projects in the recent past.

### 2.3. The role of private developers

With few exceptions the development, ownership and operation of hydropower projects in the past has been the responsibility of governments and national utilities. In industrialized countries such projects were financed from internal sources or balance sheet borrowings; in developing countries concessional capital from multilateral and bilateral agencies was used.

In the last ten years irrevocable changes have occurred to this pattern. Governments everywhere are experiencing greater difficulty in raising finance for large infrastructure projects. This is particularly true of power sector investments, which are increasingly being perceived as 'commercial'. In developing countries there has been an accompanying shift in concessional lending priorities from physical infrastructure to social infrastructure. With an accelerating demand for power sector investment capital, the private sector has been encouraged to fill the void through private sector financing and ownership.

In summary, the increasing role of private sector development leads to:

- emphasis on financial project efficiency, resulting in reduced availability of time and funds for planning, investigation and construction work, and also an emphasis on cost-cutting operation and maintenance procedures;
- externalization of the indirect costs associated with the project to the maximum extent possible;
- levying of water (or power) tariffs which guarantee an attractive financial internal rate of return on the investment, these rates typically being higher than those projects financed conventionally in the past from grants and concessional loans;
- off-loading of as much risk as possible onto other parties, particularly onto the Government.

It is clear that there is a strong need for adequate regulation and control in order to:

- maintain standards of safety and workmanship;
- guarantee reasonable tariffs and Government benefits;
- avoid the Government being exposed to undue levels of financial risk;
- mitigate environmental and social impacts.

Private developers want to limit up-front planning and preparation cost to a minimum and will try to shift as much of the costly design work to a point in time where they have secured financing of the scheme. Financial closure requires an accurate cost estimate and time plan for implementation. Public opposition could delay or even halt the implementation of a project and it is therefore in the interest of a developer to select a project which can be assured of broad endorsement by the public but which may not necessarily be the 'least-cost' option. This can only be achieved through public consultation in the planning process as described above.

Particularly in developing countries, private developers see themselves exposed to major political risks, e.g. the threat of nationalization or difficulties in converting local currency revenues into the hard currencies needed to repay the loans. The international development agencies are in some cases willing to 'insure' the developers against that sort of political risk. This implies that the agency's operational directives need to be followed, particularly those dealing with environmental and social concerns as well as public participation and consultation.

It goes without saying that the projects to be developed by the private sector must still be embedded into an overall water resources development plan for the country concerned and that the development of this plan similarly requires participation and consultation of the public on a wide variety of issues. Here government authorities and international development agencies can and should play a major role.

## 3. Summary of trends in the development of hydropower projects

### 3.1. The complexity of hydropower development

Table 1 summarizes the main differences between the old and the new approach for the development of hydro projects and Fig. 1 shows a sample of factors, which typically influence hydropower development. As can be seen, the process is complex, multi-disciplinary, and with many trade-offs.

Another complex but overriding objective is the sustainability of projects selected. What exactly does sustainability mean? The Rio principles (Article 21) state the following: human beings are at the center of concern; development should be met in an equitable way that considers future and present generations; development requires the environment to be integrated with the development process; environment on its own is an insufficient goal. It also stresses that concerned citizens must participate in the decision-making process.

It seems therefore important for assessing whether a projects is sustainable or not to:

- Develop a limited number of credible forecasts about the impact, use and usability of the project for future generations (perhaps look 100 years ahead).
- Discuss those scenarios with the people concerned, and check whether they consider the project to be acceptable to their children and further future generations.
- The same project may be considered sustainable in one country, but unsustainable in another, depending on the needs and priorities of the people concerned. The important thing is here that the decision whether a project is sustainable or not is a choice that must be made by the people concerned.
- It may well be that it is concluded that future generations may have to come up with funds to rehabilitate or decommission the project, while the benefits of the scheme were largely enjoyed by the present generation (for example due to heavy sedimentation). That is clearly 'unequitable', and can be solved by setting aside part of the net profits from the early stages of the project to later carry out such works.

## 4. Design with built-in flexibility to adapt to future needs

It is increasingly recognized that the design should be flexible enough to cope with, or can be adapted to, a possibly changing role of the project in future.

Typical examples of such changes are:

- Gradual increase of the importance of recreation over time.
- Increasing need for flood control, as a result of increased value of downstream infrastructure development and/or climate change.
- increasing importance of the lake as a 'new' habitat, with new wetlands created by sediment deposits at the tail end and maturing of lacustrine biodiversity.
- Changes in the releases of water to the downstream river as a result of changes in water demand and a better understanding of downstream ecological requirements.
- Addition of hydropower capacity to be able to generate more power in hours of peak demand, when electricity prices are highest.
- Gradual increase of reservoir sedimentation and the effect on the services provided by the dam.

Table 1
Trends in the development of hydro projects

| Old approach | New approach |
|---|---|
| *A hydro project is a technical scheme to*<br>provide basic technical infrastructure to improve supply of power | *A hydro project is part of a bundle of technical, environmental and social measures to*<br>Cover electricity needs in an efficient and sustainable manner<br>Improve the welfare of people in the region—particularly those directly affected by the project<br>Improve environmental protection |
| *Planning is government responsibility*, often assisted by international development agencies | *Planning involves many partners/stakeholders*<br>Government<br>People affected<br>NGOs<br>Private sector developers<br>Financing institutions |
| *Least-cost planning procedure*<br>Identify least-cost project to cover power needs<br>Carry out unavoidable social and environmental impact mitigation at minimum cost<br>Carry out detailed studies | *Multi-criteria planning procedure*<br>Project(s) must be part of sectoral development plan, and/or comply with the rules/criteria of a strong national or regional licensing or regulatory body<br>Projects must be sustainable<br>Rigorous study of project alternatives, including the No-Project option<br>Prepare comprehensive comparison matrix showing pro's and the con's of each alternative from technical, environmental, social, economic, financial, risk and political perspectives<br>Reach consensus among stakeholders about overall best alternative to be developed ('broad public acceptance' instead of 'least-cost')<br>Carry out detailed studies |
| *Public sector project*<br>Developed and owned by government<br>Funding partly from international development agencies | *Private/public sector project*<br>Developed and owned by private sector, with or without government participation<br>Financed largely from commercial sources<br>International development agencies act as catalyst for project funding by providing guarantees<br>Performance bonds or trust funds to improve compliance with proposed measures for social and environmental impact mitigation |

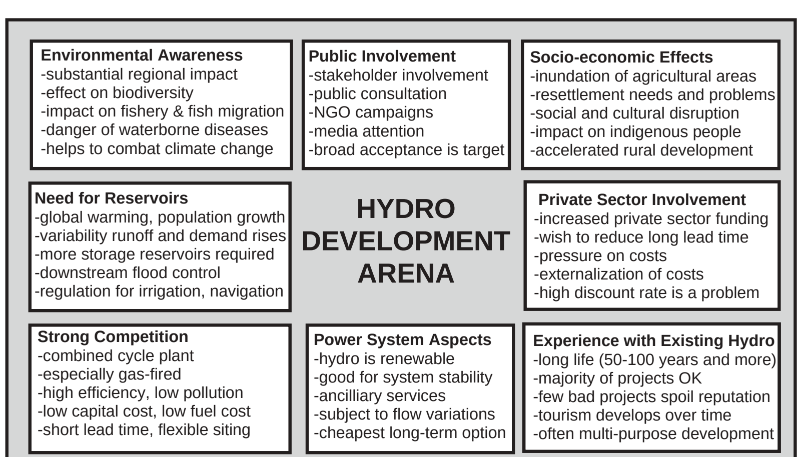


Fig. 1. The hydro development arena.

- the effects of climate change on the safety of the dam and on the value of the hydropower output.

In view of the generally long life of hydropower projects (at least 50–100 years) there can be several other changes, some of which cannot be anticipated today.

The design should have a high degree of built-in flexibility in order to enable the project to change its role whenever in future that will be required. Factors which make a project flexible can be, depending on the type of dam project:

- Multilevel intake, so that water releases from the project can be taken from the zone with the best water quality.
- Re-regulating weir, downstream of the dam, so that power projects can release water at will over the day (or week) without upsetting downstream flow patterns. In some cases the re-regulating reservoir can also function as plunge pool for spillway releases.
- *Bottom outlet*. While its prime function is one of dam safety (to be able to empty the reservoir if this is required), it can also help to improve the quality of lake water when used in conjunction of spilling operations, mixing excellent quality water released from the spillway with poor quality water from the bottom of the reservoir.
- *Sediment flushing device*. Depending on the project this may be needed immediately, at a later stage, or not in the foreseeable future. The aim is to keep the sediments away from the power intake.
- *Power house extension*. If possible, the design of the powerhouse shall be so that it can be expanded at a later stage to add capacity.
- *Large head range for turbines*. To be able to adapt the hydropower generation to a possibly increased range of operating levels in the reservoir (as dictated by other uses), the turbines should be designed for as large a head range as reasonably possible.
- *Spillway capacity extension*. Climatic change may lead to higher floods in future. For future projects it seems beneficial to at least indicate in the design where and how additional spillway capacity can be arranged.
- *Flood and flow forecasting system*. A sophisticated flow forecasting system should form part and parcel of major modern dam projects. Improving weather forecasts should make it possible to forecast critical flow situations well in advance. This could for example trigger a rapid drawdown of the lake in anticipation of a major forecasted flood, reducing downstream flood damages to a minimum.

## 5. Hydropower and its competitors

Hydropower supplies about 18% of the world's electricity needs, offsetting mainly fossil fuel fired thermal generation. The avoided green house gas emission is substantial, equivalent to the combined emission of all passenger cars in the world.

Hydropower schemes are robust, high efficiency, long-term investments with lifetimes of usually 50–100 years and more. They are not mass products. Each plant features unique site conditions. This makes planning and construction quite expensive and generally a long period is needed to develop and build a project. However in the long term no power technology is as cheap as hydro. Once the loans for the construction of the project have been paid back, the annual cost to operate and maintain the scheme are of the order of 1% of the investment costs.

It should be noted that, depending on the locality, hydro plants may have considerable social and environmental impacts which may jeopardize the project's overall viability even if the project appears to be attractive from a strictly financial point of view.

Hydropower competes with thermal, nuclear and increasingly also with alternative forms of power plant and demand saving measures (DSM). Each technology has its pro's and con's:

- *Thermoelectric plant* burn fossil fuels. Apart from the exposure to rather unpredictable future fuel prices, all thermal technologies emit substantial amounts of green house gases, responsible for global warming, and other gases, which for example cause acid rain. The main competitors at present are coal-fired steam plant, and gas- or oil-fired combined cycle and gas turbine plant. If cheap gas is available the combined cycle plant is the prime choice and hard to beat because it combines low investment, short construction time and good fuel economy with rather low local environmental impact and free siting. Its lifetime is about 20–25 years. Only exceptionally attractive hydro schemes can compete. The chances for hydro improve if penalties for emissions are levied, as shown in Table 5.

  Hydro has good chances to successfully compete with coal plant, which has high investment costs, a long construction time and high levels of emission, particularly of green house gases. The typical lifetime of a coal plant is 25–30 years.
- *Nuclear plant* is not popular due to unsolved nuclear disposal problems and the threat of nuclear accidents with far reaching consequences. If the choice is between hydro and nuclear, then hydro will win easily.
- *Wind power* is becoming a serious contender, especially in countries which provide tax-incentives for wind power. While the energy costs may be in the range of medium priced hydro, it should be understood that wind energy is intermittent. A power system penetration rate of not more than typically

Table 2
Thermal plant characteristics

| Plant fuel | Installed capacity MW | Turnkey cost US$/kW | Fixed OMR cost US$/ kW/a | Variable OMR cost US¢/kWh | Planned maintenance Days/a | Forced outage % of time | Efficiency at full load % |
|---|---|---|---|---|---|---|---|
| *Combined cycle turbine* | | | | | | | |
| Gas | 98 | 750 | 3.8 | 0.20 | 37 | 5 | 47 |
| Gas | 595 | 480 | 2.4 | 0.13 | 40 | 8 | 50 |
| Light oil | 98 | 800 | 6.4 | 0.26 | 37 | 6 | 45 |
| Light oil | 595 | 600 | 3.0 | 0.17 | 40 | 9,7 | 47 |
| *Gas turbine* (*single cycle*) | | | | | | | |
| Gas | 37 | 350 | 3.1 | 0.12 | 25 | 7 | 33 |
| Gas | 203 | 300 | 2.6 | 0.10 | 30 | 5 | 34 |
| Light oil | 37 | 400 | 3.5 | 0.14 | 30 | 7 | 31 |
| Light oil | 203 | 320 | 2.8 | 0.12 | 40 | 8 | 32 |
| *Coal-fired steam plant* | | | | | | | |
| Imported coal | 600 | 900 | 5.6 | 0.24 | 35 | 9,5 | 38 |
| Local coal | 50 | 1800 | 11.3 | 0.47 | 37 | 8 | 31 |

OMR = Operation, Maintenance and Repair (without fuel).

Table 3
Fuel prices

| Fuel | Unit | Gjoule/unit | Price per GJ (US $) | | |
|---|---|---|---|---|---|
| | | | Low | Medium | High |
| Natural gas | GJ | 1.0 | 2.0 | 3.0 | 4.0 |
| Heavy oil (2% S) | Ton | 40.2 | 1.7 | 3.2 | 5.0 |
| Diesel | Ton | 43.5 | 2.3 | 3.4 | 5.1 |
| Lignite | Ton | 13.0 | 0.8 | 1.2 | 1.5 |
| Local coal | Ton | 26.5 | 0.8 | 0.9 | 1.1 |
| Imported coal | Ton | 28.5 | 1.2 | 1.4 | 21 |

Table 4
Emission penalties

| Pollutant | | Cost per ton US $ Medium | High | Main effects |
|---|---|---|---|---|
| Toxic emissions | | | | |
| Sulfur dioxide | $SO_2$ | 170 | 220 | Respiratory illness, acid rain |
| Nitrogen oxides | $NO_x$ | 1200 | 6000 | Respiratory illness, acid rain, smog |
| Dust | $PM_{10}$ | 100 | 200 | Respiratory illness |
| Greenhouse gas | | | | |
| Carbon dioxide | $CO_2$ | 5 | 25 | Global warming |

Note: the values for $SO_2$ and $NO_x$ are recent medium and high trading values experienced in the USA. Actual values in developing countries could be quite a bit lower, especially for $NO_x$. The values for dust are based on a recent study done by the consultant for a CIS country. The values for $CO_2$ are taken from reference 4.

10% is possible, otherwise power system capacity shortages will occur during windless periods. Wind power also has environmental impacts, such as noise, interference with TV reception, birds killed by the rotor blades, and visual impact on the landscape.

- There are several types of *Solar Generation*. The two most popular choices are photovoltaic (PV) and hybrid thermal solar plant. PV is still an order of magnitude too expensive, although of course it is the option of choice for very small loads in areas distant from the grid, where it sometimes competes with micro-hydro installations. In hybrid solar thermal power plants, patterned after a steam plant, such as those built in the Mojave desert in California,

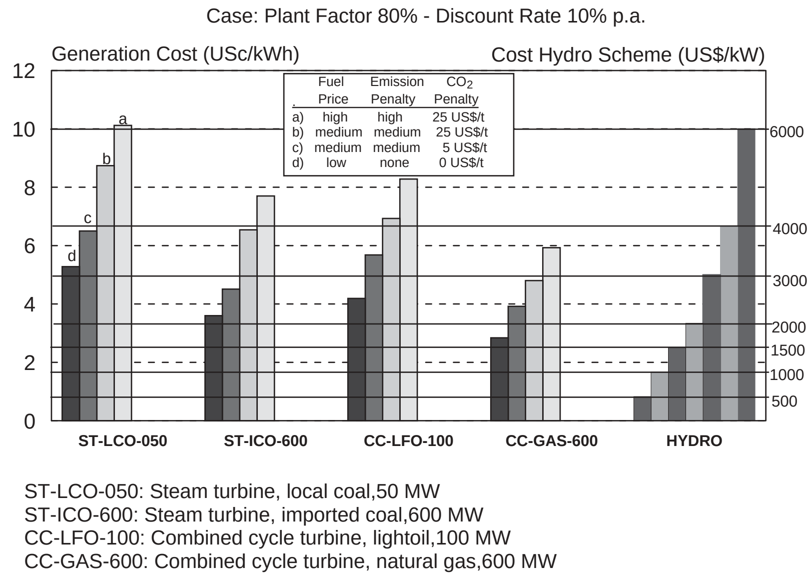


Fig. 2. Cost Comparison Hydro and Thermal.

Table 5

| Discount rate % p.a. | Plant use factor % | Market conditions | | | | |
|---|---|---|---|---|---|---|
| | | Fuel price → | Low | Medium | Medium | High |
| | | Toxic emissions penalty → | None | Medium | Medium | High |
| | | Greenhouse penalty/ton $CO_2$→ | 0$ | 5$ | 25$ | 25$ |
| (a) Break even rates for hydro competing with thermal (Capital cost in US$/kW) | | | | | | |
| Scenario for small grid, natural gas not available | | | | | | |
| 10 | 80 | Base load | 2600 | 3400 | 4200 | 5000 |
| 10 | 40 | Mid load | 1600 | 2300 | 2700 | 3200 |
| 10 | 10 | Peak load | 900 | 1100 | 1200 | 1300 |
| 15 | 80 | Base load | 1900 | 2400 | 2900 | 3400 |
| 15 | 40 | Mid load | 1200 | 1600 | 2000 | 2500 |
| 15 | 10 | Peak load | 700 | 800 | 900 | 1000 |
| (b) Break even rates for hydro competing with thermal (Capital cost in US$/kW) | | | | | | |
| Scenario for large grid, plenty of gas available | | | | | | |
| 10 | 80 | Base load | 1700 | 2400 | 2900 | 3600 |
| 10 | 40 | Mid load | 1200 | 1500 | 1900 | 2200 |
| 10 | 10 | Peak load | 700 | 800 | 900 | 1000 |
| 15 | 80 | Base load | 1200 | 1600 | 2000 | 2400 |
| 15 | 40 | Mid load | 800 | 1000 | 1300 | 1500 |
| 15 | 10 | Peak load | 500 | 600 | 600 | 700 |

generation at day time is largely from solar heat, whereas the solar energy is supplemented by gas-firing in the evening hours. This kind of plant can produce power at about 7–10 US ¢/kWh in areas with sufficient solar radiation and not too much cloud. The environmental impact of the plant is low. Good hydro can easily compete with this technology.

- *Demand Side Management* (DSM) can be very attractive. The scope for savings is largest in countries like the USA where per capita use of electricity is high, but even in these cases the per annum reduction in growth rate is not more than 2%. In developed countries this may temporarily lead to stagnation of the electricity demand as typical growth figures are in the order of just a few percent. In developing nations, however, growth rates are often of the order of 7–15% per year, and while DSM should be vigorously pursued, it is clear that new power plants are needed to cover the rapidly growing demand, including hydropower schemes if they are the most attractive supply option.

The main competitor of hydro is still the thermo-electric plant. A parametric study was executed to determine the specific generation cost of thermal plant and to compare it to equivalent hydro plant. The main assumptions made for thermal plant are summarized in Tables 2–4.

Such figures can be used to find the approximate maximum investment that hydro schemes can have in order to compete with thermal plant. For example, in Fig. 2, left side, the break-even with a 100 MW oil-fired combined cycle for the low fuel price scenario, no emission penalties, 80% plant factor and a 10% discount rate is about US$ 2600 per kW. For a gas-fired 600 MW combined cycle station the break-even rate would be roughly US$ 1700 per kW.

The analysis was done for two discount rates, 10% p.a., reflecting typical conditions for a public sector project of a state utility in a developing country, and 15% p.a. as a typical rate for a private sector development.

A few interesting conclusions can be drawn from the charts in Fig. 2, Tables 5 a and b:

- The change from public to private sector development has reduced the maximum investment cost for which hydro plant is viable by about 40%.
- In practically all scenarios, hydro competes with combined cycle (base and mid load) and turbine plant (peak load), when gas is available, otherwise oil-fired. Coal plant is only feasible in large grids, in a scenario with low coal prices and relatively high prices for gas and oil.
- For a $CO_2$ penalty for thermal plant of US$25 per ton, the break-even rate increases by about 30% for base and mid load plant, and about 10% for peaking plant.

If a hydro plant also provides ancillary services, then break-even rates could increase by another US$200 to US$500 per kW.

It appears that the switch from public to private sector funding is the major factor for the decline of hydropower construction. Credits for reduced $CO_2$ emission of thermal plant and ancillary services can partly compensate for it, especially for base and mid load plant.

## Further reading

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