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Hydropower – The Sustainability Dilemma

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1. Introduction

Since the development of the agriculture, at least, hydropower has been used for irrigation and other engines such as watermills and domestic lifts (provision of water). It was only in the late 19th century, after the discovery of the electrical generator, that hydropower could be converted into electricity. The early 20th century was the turning point of the hydroelectricity, as we know. Since then, the hydroelectricity sector has technologically advanced and the current engineering arrangements are considerably improved compared with the pioneers.

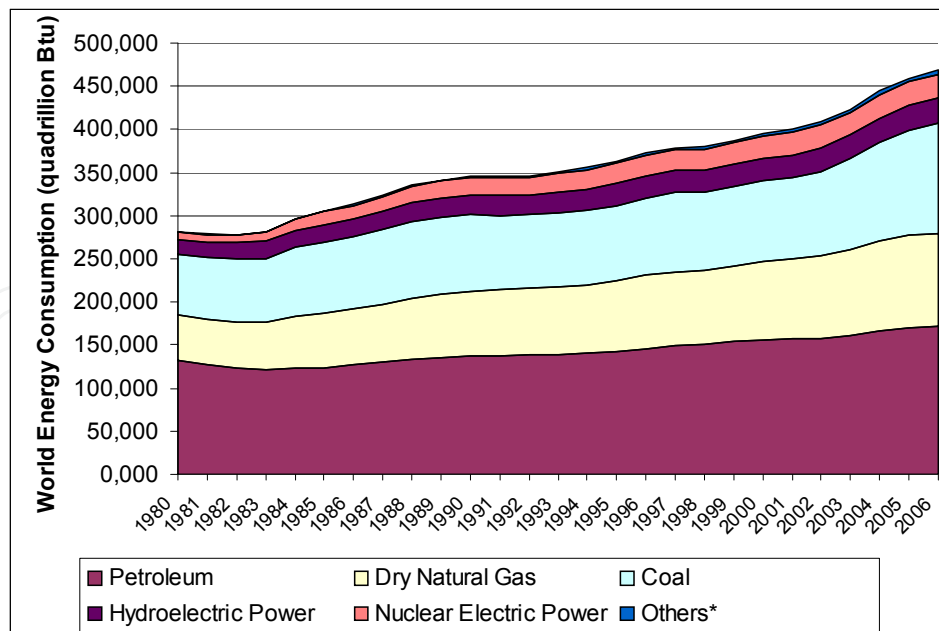
Most of this improvement is related to the scale of the hydropower plants, which have increased from some kilowatts to gigawatts. Nowadays, the produced hydroelectricity is transmitted for considerable distance between where it is created to where it is consumed and the complete arrangement includes reservoirs, turbines, generators, power houses and long distance power lines. It involves more complex, local, regional and global impacts, which have to be considered in a sustainability analysis.

As a renewable resource, the hydropower was historically treated as a clean source of energy. However, the scientific researches launched in the last decades have produced arguments that brought another balance to this discussion. In this context, this chapter aims to explore the impacts of the hydropower plants under the sustainability's viewpoint. Despite the use of the "hydropower" term, our focus is on the hydroelectricity and its projects, which represent the major parcel of the sector.

2. The economic growth and its energy demands

Energy is an important factor of production, which is one of the main objects of the economy. The other economic piece is consumption. Based on the binomial "production and consumption", the economics mainstream has established the agenda of the global capitalist system that has been running almost in the entire world. Therefore, the energy has an essential role in this context. The world energy consumption is shown in Figure 1.

A country's energy system has complex impacts on its economy. In general, a contraction of energy supply restrains the economic activity, which can provoke impacts like the reallocation and even rationing of energy, as well as changes in technology to emphasize energy efficiency.



Source: IEA (2011).

Fig. 1. The World energy consumption, 1980 – 2006.

Given the relationship between energy and the economy, many development models place strong emphasis in the energy-economic production correlation. Various studies associate energy availability with gross domestic product (GDP) (Nilsson, 1993; Schipper, 2000). But, according to Cohen (2005), the energy-economic development relationship merits closer analysis because GDP hides a series of economic problems, including inequity among regions and social classes, not to mention uncounted environmental costs. All these characteristics is the key to energy planning geared to the true economic goals of a country or region.

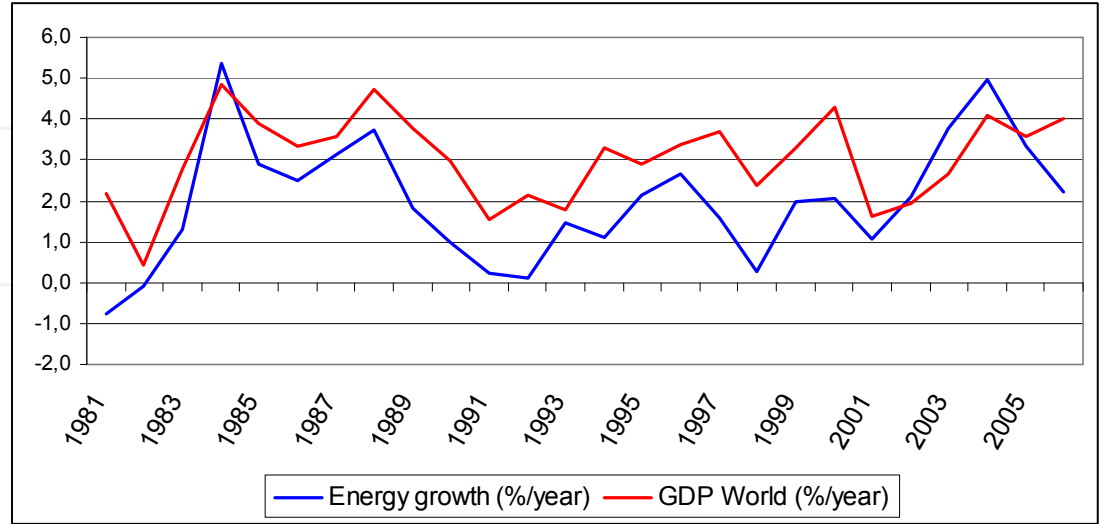
Princen (1999) argues that excessive energy consumption in northern hemisphere nations and among southern hemisphere elites needs to be brought into closer balance with energy use in southern countries and less-privileged classes. This notion has gained increasing acceptance within environmentalist circles. Still public policies in developed countries have tended to focus almost exclusively on energy efficiency without addressing the overall consumption, which will continue to drive high energy use, even with efficiency improvements. This same pattern is being emulated by developing countries, which strive to increase energy supply (sometimes from cleaner sources) more than managing and reducing demand, as signaled by Sunkel (1979), and corroborated by many researchers over the last few decades.

The possibility of electricity savings illustrates that consumption do not need exactly to track economic growth and that, indeed, countries have the potential to reduce energy consumption per unit GDP (Totten et al., 2010).

A comparison between the world GDP and energy demand growth is presented in the Figure 2.

Note that the rise of the GDP is followed by the energy demand, although the level of the growth rate is different in each case. In average, for the period of 1980 until 2006, each $n\%$ of raising the world GDP was followed by the energy demand raise in $n-1\%$.

Even though the world energy demand is increasing, as shown in Figure 1, the Hydropower is decreasing its share.



Source: adapted from World Bank (2011) and USEIA (2011).

Fig. 2. The world GDP and energy demand growth.

3. The economics context of “hydropowering”

There is a significant participation of the OECD countries, covering mainly the developed countries, concentrating about 42% of hydropower worldwide. Asia, in turn, owns 26% of hydropower, and hydropower production in China is the most significant one. Latin America also stands out with 20% of hydropower worldwide.

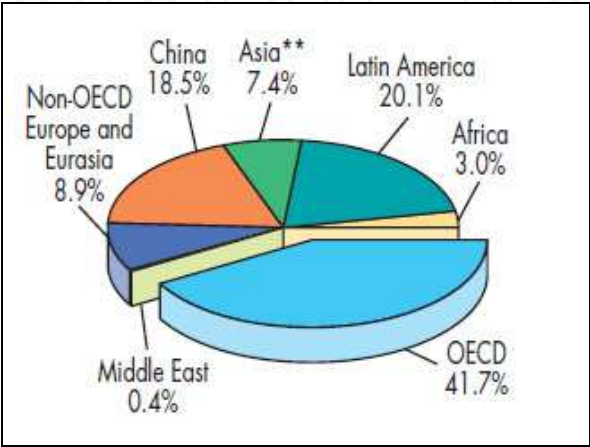
Producers	TWh*	% of world total	Installed capacity (GW)**
People’s Rep. of China	616	18.5	168
Brazil	391	11.7	78
Canada	364	10.9	75
United States	298	9.0	100
Russian Federation	176	5.3	47
Norway	127	3.8	30
India	107	3.2	37
Venezuela	90	2.7	15
Japan	82	2.5	47
Sweden	66	2.0	16
Rest of the world	1,012	30.4	324
World	3,329	100.0	952

Notes: *2009 data; ** end-2008 data. Source: IEA (2011) and WEC (2011).

Table 1. Top-ten hydroelectricity producers on the world.

Table 1 presents the annual energy produced, total share in world production and the installed capacity of 10 countries which produce energy from hydroelectric sources in the world. It is observed that 67.1% of the world's electricity is produced from the burning of fossil fuels, while 13.4% is generated from nuclear power plants. Only 19.5% of the electricity generated worldwide is produced from renewable energy.

The distribution of hydroelectric production, estimated at around 3,329 TWh (2009), is shown in Figure 3, according to the major regions in the world (IEA, 2011).



Notes: Includes pumped storage. **Asia excludes China.
Source: IEA (2011).

Fig. 3. Regional shares hydro production, 2009.

The use of water resources for a significant production of electricity is spread by several countries with very different levels of development. In addition to Canada, United States, Norway, Japan and Sweden, which are among the 10 largest producers of hydroelectricity, other European countries like France (60 TWh / 21 GW) and Italy (42 TWh / 18 GW) are also prominently featured in the global context.

China, Brazil, Russia, Canada and USA lead the countries which have the biggest hydroelectricity plants in the world. The areas of these countries and the existence of large drainage basins could explain this concentration. However, in terms of the electricity production related to the total power demand, countries like Norway, Brazil, Venezuela, Canada and Sweden appear between the countries to which hydroelectricity represents the main source.

4. The hydropower’s role in this context, as a renewable source of electricity

Hydropower remains the largest source of renewable energy in the electricity sector. On a global basis, the technical potential for hydropower is unlikely to constrain further deployment in short and medium terms. Hydropower is technically mature, it is often economically competitive with current market energy prices and it is already being deployed at a rapid pace. Situated at the crossroads of two major issues for development, water and energy, hydro reservoirs can often deliver services beyond electricity supply. The significant increase in hydropower capacity over the last 10 years is anticipated in many scenarios to continue in short terms (2020) and medium terms (2030), with various

environmental and social concerns representing perhaps, the largest challenges to a continuous deployment if not carefully managed.

Hydropower production represented about 16% (1,010 GW) of global electricity production in 2010 and accounted for about 76% of electricity from renewable sources. An estimated 30 GW of capacity was added during the year, with the existing global capacity reaching an estimated 1,010 GW. Asia (led by China) and Latin America (led by Brazil) are the most active regions for new hydro development (REN21, 2011).

5. The agenda of hydropower for next decades

In the case of hydroelectric projects planned or forecasted in the medium term, the available information is not accurate. However, it is possible to be shorter in the initiative of some regions. In this context, it stands out in African countries like the Democratic Republic of Congo (Congo Democratic Republic) with 43 GW planned, and Nigeria (Niger) with 12 GW planned. In America, Brazil, with 68 GW planned and Canada, with 15 GW, are the ones that shall expand their hydroelectric capacity. In Asia, China, with 65 GW planned, Turkey, and Vietnam with 23 GW, 14 GW are where the main initiatives are focused

Anyway, in the long run, the forecast growth of hydroelectricity in the world energy supply is not expressive. According to WEC (2011), the share of hydroelectricity in Total Primary Energy Supply (Total Primary Energy Supply) might grow from 2.3% to 2.4% in the Business-as-Usual scenario, and 3.5% of the scenario based on the premise of stabilizing the concentration of greenhouse gases at 450 ppm equivalent CO₂.

The expansion of hydropower is limited due to the reduction of areas with greatest potential, most of which are already exploited, leaving regions of lower potential, where the social and environmental impacts are of greater magnitude. On the other hand, the supply of new sources of electricity generation such as wind and solar ones, has contributed to the falling costs of these modes, making it an increasingly competitive scenario for the new investments.

6. The best alternative: non generation?

The most efficient investment in energy supply is one that concentrates on reducing the consumption at the maximum efficient point. There are several ways to apply this issue. Regarding this, Leite and Bajay (2007) estimate that the energy consumption could be reduced by 20% solely through energy-efficiency measures. That research focused on the main consuming sectors, industry, other commercial users, residential consumers and agriculture, in a non developed country scenario. Totten et al. (opus cit) present evidence that a value-adding water planning process can be achieved by shifting from the focus on supply expansion to one that concentrates on efficient delivering services at and near the point of use.

Some studies have already demonstrated the potential of investments in existing dams, upgrading their power production. A range from 20% to 40% of new energy could be provided by investments in existing dams (Bermann et al., 2004). However, it is a proposal that must be considered as a part of a whole energy plan, since the refurbishment or upgrading could not fulfill, in isolation, the growing energy demand.

7. Discussing the main environmental impacts of hydropower

The modern economy's critical dependency on energy underscores the need for a more rational and effective use by society as a whole. Large projects in the energy sector come up against financial, environmental and social restrictions. Regarding hydroelectric plants, these issues are more critical and involve conflicts with various actors: landowners (livestock ranchers), farm workers, traders, the urban and rural population that has to be moved, as well as loggers, indigenous communities, social movements and non-governmental organizations (NGOs). This web of interests makes analysis of these projects complex.

The impact on ecosystems and biodiversity shall also be highlighted. The direct and indirect effects include the alteration of the natural habitat (in this case, largely a change in the freshwater ecosystem), consequently impacting biotic interaction; saturation of adjacent soils; micro-climate alterations; and compartmentalization of habitats (formation of islands in the reservoirs and the segregation of tracts along the transmission lines). Such effects have unpredictable results on biodiversity, which in turn is hard to measure, contributing to the underestimation of environmental impacts in environmental assessments (Sousa Junior & Reid, 2010).

In terms of hydrology, the formation of a reservoir increases the hydrostatic pressure on springs situated along river banks and on rivers that are dammed. Such situation leads to alterations in the natural feeding and draining of aquifers. Consequently alterations to aquifers lead to ecological and economic impacts, as they modify the land use patterns. This has occurred at some hydroelectric plants, requiring the projects to compensate for land that had not been included for expropriation. For instance, according to Muller (1996), in Samuel dam (Brazil), groundwater elevation also resulted in the hydromorphization of about 8000 ha.

Goodland et al. (1993) analyzed various hydroelectric plants in tropical forest regions and identified situations in which such projects should be avoided. These situations include projects in pristine forest regions, places where the local population would have to be removed, areas of species endemism, and areas where there would be a possibility of biodiversity lost, among others.

Other important environmental impacts of the hydropower projects are presented and briefly discussed below:

- **Productive flooding areas**

The flooding area of a hydropower dam can cover productive sites determining losses on agricultural and livestock activities. Cultivated areas can be flooded, with lost net income currently derived from farming and ranching in those areas. Also sites with great potential for tourism can be covered. In these cases, a survey of the immediate added value plus the potential over the period of the reservoir operation would represent the opportunity cost of the activities.

- **Greenhouse gases emissions**

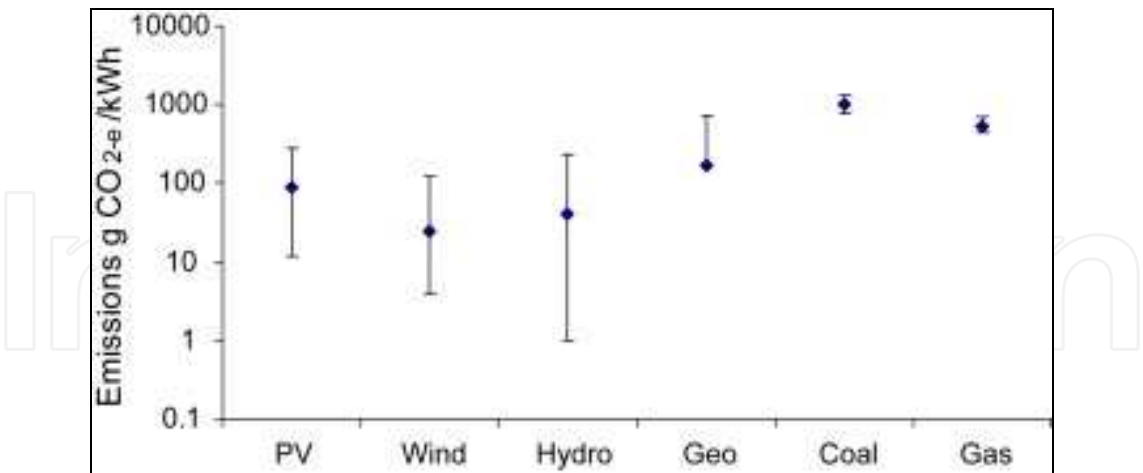
There are also impacts from inundated forest biomass. Not cutting down the forest, in addition to making it difficult to use the reservoir for other purposes, alters the water

quality and favors the proliferation of insects, both of which affect public health and human migration patterns. Historically, there have been few cases of pre-flooding forest clearing.

Significant amounts of methane are produced by hydroelectric dams. According to Fearnside (1995), these amounts in some cases can be higher than power plants running on fossil fuels (in terms of carbon equivalent). This carbon is released when the reservoir is initially flooded. After the first decay, organic matter settling on the reservoir bottom decomposes in anoxic conditions, resulting in a build-up of dissolved methane. This is released into the atmosphere mainly by degassing after water flows through the reservoir turbines. A continuous supply of organic matter is provided by the seasonal changes in reservoirs levels, what means that there is a regular flow of methane from them, especially those located on tropical regions.

The precise contribution of hydroelectric reservoirs to GHG emissions is still a matter of discussion. There is controversy, even in the scientific world, as can be seen in the debate that has lasted for over ten years on the methodologies and results of GHG emission estimates for tropical reservoirs in Brazil (Fearnside, 1995; Rosa et al., 1996; Fearnside, 2004; and Rosa et al., 2004). The main point of contention is the accounting of gases, mainly methane, emitted by the hydroelectric plants’ spillways and turbines. Methane, concentrated at depths of around 30 meters, is said to be quickly moved at lower pressures and higher temperatures, becoming volatile in contact to the atmosphere (Fearnside, 2004; Kemenes et al., 2007).

Furthermore, greenhouse gases are also released during the production of materials and fossil fuels used on the dams building process. A set of average greenhouse gases emissions from several energy technologies is shown in Figure 4, considering the full operational life cycle of each one.



Source: Evans et al. (2008).

Fig. 4. GHG emissions from energy technologies.

Note that, although the hydropower is well positioned, in terms of GHG emissions average, its upper limit reaches values around the lower limit of the Gas technology emissions. Indeed, the range of hydropower GHG emissions is the largest one: it varies from the small run-of-river plants to the big dams emissions.

- **People's resettlement**

As long as the social aspects are concerned, specifically in relation to the riverside people affected by the undertakings, they are generally disregarded before the perspective of the irreversible loss of their production and social reproduction conditions, established by the formation of the reservoir. The undertakings cause the compulsory displacement of those people and the resettling process, when there is any, doesn't ensure the maintenance of life conditions that existed before.

The construction of a hydropower plant has often represented the destruction of life projects for those people. It imposes their discharge from the land without offering compensations that could at least ensure the maintenance of their reproduction conditions in the same level as before the implantation of the enterprise. The wearing away of the reservoirs, due to the lack of control of the territorial occupation pattern in its headwaters, is sometimes subject to processes of deforestation and removal of the riparian forest.

Regarding indigenous areas, the main direct and indirect impacts of the construction of large hydroelectric reservoirs are resettlement of communities (affecting lifestyle), flooding of areas (including places of spiritual value), loss of hunting and farming plots, and an increase in infectious disease (Santos and Andrade, 1990).

- **Breaking the fish fauna mobility**

The impact on ecosystems and biodiversity must also be highlighted. The direct and indirect effects include the alteration of the natural habitat (in this case, largely a change in the freshwater ecosystem), consequently impacting biotic interaction; saturation of adjacent soils; micro-climate alterations; and compartmentalization of habitats (formation of islands in the reservoir and the segregation of tracts along the transmission lines). Such effects have unpredictable results on biodiversity, which in turn is hard to measure, contributing to the underestimation of environmental impacts in environmental assessments.

- **Impacting the multipurpose use of the water**

The regulation bodies sometimes face some difficulties to ensure the multiple usage of waters, due to the historical character of prioritizing the electric generation instead of the other possible uses such as irrigation, leisure, fishing, among others. This issue has a political approach in the sense of which group or sector sets the water agenda. In the financial point of view, the electricity generation is generally the most profitable activity among other water uses and when no equitable rule is established, this sector prevails over the others. The constraints could be related to the water level control, the transportation barrier on the rivers or reservoirs, the limitation of the water withdrawals and the imposition of limits to the leisure uses.

- **Impacts from non-dam infrastructure**

Non-dam infrastructure required for the construction of the plant, which includes transmission lines, sub-stations, maintenance areas, and roads, are in fact part of the plant's activities and hence should be considered when analyzing its feasibility. For instance, a 500 kV transmission line in general takes up a space of 65 meters in width. These works very often affect archaeological sites, indigenous villages, forest parks or ecological reserves as much as the plant itself.

Box 1 brings a case of energy expansion running in Brazil, under environmental criticism.

To increase supply, Brazil began damming Amazonian rivers on a large scale in the mid-1980s. The country turned to the North because nearly all the hydropower potential in the densely populated Southeast had been exhausted by that point. Nevertheless, Amazon dam projects face divisions in public opinion. Industrial projects, particularly energy projects, now face higher standards and scrutiny since the promulgation of new environmental regulations and the advent of stricter environmental licensing procedures. At the same time, the multiple economic and political interests in large projects have limited the impact and efficacy of these environmental procedures. The new planning approach in the country's electricity sector points to the need for socio-environmental evaluation at the stage when potential projects are being compiled in inventories, long before specific projects are in advanced planning stages. We would add that to enable this sort of pro-active planning, old inventories of priority projects in the Amazon need to be discarded in favor of up-to-date lists that reflect a more comprehensive and holistic vision of energy development, particularly in undeveloped watersheds like the lower Xingu, where is building up the Belo Monte Hydropower Complex.

Source: Sousa Junior & Reid (2010).

Box 1. The Brazilian's electric expansion plan over the Amazon region.

8. Hydropower and social issues

Historically and coincidentally, many hydropower plants are installed in social spaces originally conceived by riverside people for them to produce their subsistence through fishing and agriculture. The projects for the construction of hydropower plants end up occupying the spaces for social/cultural reproduction of land owners and non-owners alike (sharecroppers, tenants, holders, wage earners, etc.) and determining the beginning of conflicts. The essence of which is the seizure of the geographical space as a form of specific commodity for hydroelectric power generation; and the social and socio-cultural reproduction use as a way of life. On the one hand, the entrepreneurs try to hide or muffle conflicts, trying to go on with their projects and using essentially economic criteria. On the other hand, the affected people, along with religious and environmental authorities, try to make the conflicts evident, showing that certain rights are not being considered. They use essentially environmental, social and humanitarian criteria.

It is a logic that invades regions that are not totally included in the market economy and that supposedly need incentives for their inclusion. The hydropower plants are directed towards the development of extensive territorial areas that have not been included in the market economy yet. Besides, the same logic will only be conceived when the invaded space offers conditions for capital reproduction and exploitation of the natural space as a commodity: *"The projects identify entire regions, very extensive basins, rich meadows transformed in energy mines"* (Vainer & Araújo, 1992, p.71). As a rule, the regional development programs assume that the region has some kind of ability for hydroelectric installation to become feasible.

There is a great range of issues that involves hydroelectric projects. Another aggravating factor is the difficulty of participation of those interested in the decision making process about the installation of the undertaking or not. The involvement of society in the issues related to hydroelectric installation is limited, when it exists at all.

The predominance of a reductionist and hegemonic conception determines that the ways of life and the forms to use natural resources act according to the market logic and that they prevent the communities affected by dams from being acknowledged as “*subjects that are active and have discussion and deliberation margin*” (Zhou et al., 2005, p.98-9).

The non-identification of the subjects and their interests, their history and culture by the investing agent, actually constitutes a previously defined element to conceive the invisibility phenomenon for riverside people. According to Leroy (2002, p. 9), “*for the government, the multilateral Banks, the construction companies and the consultants that elaborate Environmental Impact Studies, they don't exist*”, and, since they don't exist, they are not considered in the decision making process, and their interests and proposals are not taken into account. Using the invisibility strategy means denying the rights and duties of the investing agent himself in relation to families and riverside communities and cities. Operating the invisibility resource means not to observe the existence of subjects, cultures, developed social organization, building and being rebuilt in the identified area while fit to receive the hydroelectric plant. It ends up favoring the involuntary displacements of people and the withdrawal of families from agricultural work to try to encourage the regional development.

Using invisibility as a tool to control the costs of investments and non-acknowledgement of the social groups historically constituted in a certain region, reduces the range of politics as a field for negotiations and possibilities, although it doesn't mean the non-existence of both social and environmental problems.

9. How risky can the hydropower investments be?

Several variables can affect the economic feasibility of a hydropower project. Nevertheless, these variables are not taking into account when projects are launched. These include the construction time, real costs and the future prices of energy. Since the analysis does not include all categories of social costs (due to data or information constraints) and risk factors, it has almost certainly underestimated their possible total value. Therefore, we cannot conclude decisively whether the project passes the basic test of economic feasibility – a net present value greater than zero. Generally these factors are more important, and relevant, in large dams projects, although they can affect projects at any scale.

Cost overruns and delays are clear factors that impact the feasibility of large infrastructural projects. The WCD report (WCD, 2000) cites an average cost overrun of 56% in a review of 81 large dams worldwide. Though the variation is wide – the worst cases are from India – the numbers show that planning and technical difficulties are endemic to large dams. Another important and typical problem is corruption in public contracts, particularly when these processes lack transparency, which has been the case of many Brazilian projects, notably Itaipú, the world's second largest hydroelectric plant. McCully (2001) presents various cases in which dams were delayed and fraught with corruption. The author cites the Itaipú dam as the worst case of cost overruns. Schilling and Canese (1991) estimated that an amount of around \$20 billion was spent on the project, while the original budget was \$3.4 billion.

Technical difficulties often delay dam construction and decrease economic returns by delaying the onset of revenues. The WCD report (cited before) showed that of 99 projects

studied, 50% were completed on time, 30% with delays of one to two years, and 15% with delays of three to six years. Four other projects had delays longer than 10 years. The Tucuruí dam, another Brazilian case, was slowed for over nine years due to financing and other difficulties.

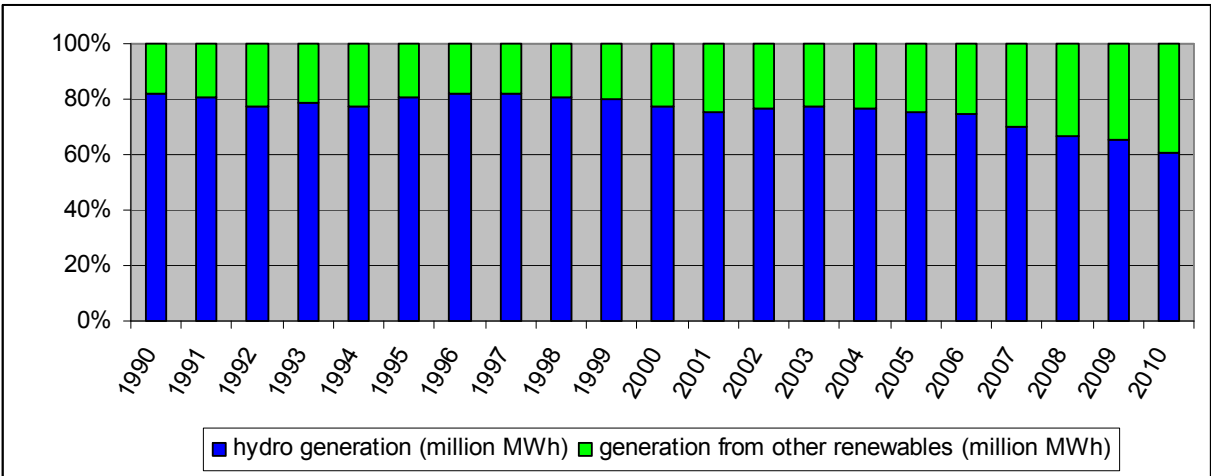
Another critical issue when analyzing the financial risk of these projects is related to the use of the discount rate in the benefit-cost analysis (see Box 2).

The value of time in benefit-costs analysis can make a great difference in terms of weighting short- and long-run values. Some authors advocate the use of minimum values when analyzing sustainability. Fearnside (2009) proposes evaluations for a period of 100 years with discount rates at 1%/y, in cost-benefit analysis of tropical forest carbon storage projects. Row et al. (1981) propose 4% as the discount rate for long-term forestry projects. The financial assessment generally uses 10%/y as proposed by the World Bank (Belli et al., 2001).

High discount rates tend to overestimate the short-term values. Environmental conservation projects, when analyzed with high discount rates become less attractive to traditional investors. Similarly, infrastructural projects, when analyzed at discounted rates around 12%/y can appear unattractive unless costs are spread over the first 10 years. When costs are concentrated in the first years of construction, these projects are difficult to justify economically.

Source: Sousa Junior & Reid (2010).

Box 2. Discount rates and their influence on an environmental economics analysis.



Source: IEA (2011).

Fig. 5. Hydropower generation vs other renewable sources, USA.

In general, investors avoid projects with such an elevated degree of risk. In this sense, private projects are usually more feasible. In the case of public projects, such risks can be assumed for political reasons and spread across the entire base of taxpayers (or utility ratepayers) in the form of subsidies from the public treasury or approval of electricity rates high enough to pay back the construction costs. In most cases governments assume part of the financial risk and transfer it to the general public through tax exemptions and subsidized credit granted to the firms selected to build the dams.

In another direction, as pointed out by Totten et al. (opus cit), many hydropower schemes are at risk from irregular flow regimes resulting from drought and climate change, while increased land-use intensity leads to sedimentation rates that diminish the reservoir storage capacity.

According to IEA (2011), in the USA, despite being the hydroelectric power the main renewable energy source, it is tightly to decline while other sources are going up. The main reason is the hydropower susceptibility to climate oscillations and possible changes (Figure 5).

10. When is hydropower an object of strong or weak sustainability?

One of the most effective indicators to assess the sustainability of projects for power generation is emergy. The term "emergy" can be understood as a combination of the words "embodied" and "energy". Originated from the systems ecology, the term defines the amount of embodied energy over the life cycle of the product or process, taking the solar thermal energy as a primary source of energy to the Earth.

According to Odum (1983), the creator of the concept, emergy *"is the available energy of one kind that has to be used up directly and indirectly to make the product or service."* From the solar transformity (amount of solar energy needed to generate one calorie of a particular good or service), it is possible to establish comparison tables between energy modals and other goods or services in order to support the analysis on the use of one or other modalities. From the solar energy, whose transformity is 1, by definition, the range reaches its maximum point for human services, information and formation of species.

From the standpoint of energy efficiency, a high transformity service or good should not be used for the production of goods or services of lower transformity. As an example, it would be inefficient to use electricity to heat water.

A comparison in terms of emergy, between energy sources is shown in Table 2.

Electric power source	Energy yield ratio
Solar voltaic cell electricity	0.41
Ocean-thermal power plant	1.5
Wind electro-power, strong steady wind regime	2-?
Coal-fired power plant	2.5
Rainforest wood power plant	3.6
Nuclear electricity	4.5
Hydroelectricity, mountain watershed	10.0
Geothermal electric plant, volcanic area	13.0
Tidal electric, 25 ft tidal range	15.0

Source: Odum & Odum (2001)

Table 2. Emergy yield ratios among electric power sources.

As can be seen in Table 2, hydroelectricity is a prime source of high transformation, portability, versatility and flexibility of use. According to Odum (1996), its use should be restricted to activities of greater complexity, ensuring efficient use of natural resources as a principle of sustainability

The terms "weak sustainability" and "strong sustainability" are derived from the concept of sustainable development, which was arisen from the discussions that followed the World Environment Conference in Stockholm, 1972. Assuming the most widespread concept of sustainable development as one which, acting on a foundation of efficient usage, meets the current demands without compromising the demands for future generations, it is clear that various actions and initiatives which were taken from this concept, interpreted in a context or localized scale, lead to conceptual distortions when viewed holistically. There is therefore, a considerable difference in human activities in terms of sustainability, which allows the inferences that some of them contribute in a more solid way, "strong" while others contribute in a less cohesive one, "weak" for sustainable development.

According to Neumayer (1999), the fundamental difference between the concepts of weak and strong sustainability is the concept of replaceability of natural capital in both concepts: the first considers this possibility and rejects the second. Nowadays this difference of concepts is one of the pillars of the rift between traditional economics and ecological economics.

The analysis of sources of electricity generation is used to meet certain demands, this distinction may consider sustainability, especially when performed in a broad context, which involves since the offer of resources, the end use of electricity and even the products resulting from this usage, when it comes to production systems. In this sense, it is possible to identify situations where the inclusion of sources of electrical generation meets the assumptions of strong or weak sustainability, in a preliminary analysis. Thus, an electricity generation project is the object of **weak sustainability** if:

- it disregards, or just considers in a little emphatic way, the possibility of generating it by a more efficient power, viewing the use of natural resources and/ or generation or socio-environmental impacts, or even of less value in terms of emergy;
- it generates little or no local benefits and is directly or indirectly attached to a context of widening inequality;
- it is primarily for the productive sector demands, market-based government grants;
- it meets the demands of sectors whose energy usage is wasteful, to which efficient programs could provide the biggest part of the new energy requirements.

On the other hand, an electricity generation project is the object of **strong sustainability** when it:

- is the most efficient source, from the viewpoint of using natural resources and generating social and environmental impacts;
- meets activities which demand energy whose power transformations are smaller than the projected source;
- contributes to reducing inequalities and caters primarily to local needs;
- meets the demands of sectors whose energy usage is efficient, and therefore, the added power will have high marginal productivity

Regarding to hydroelectric generation projects, they can be established on a basis of weak or strong sustainability, depending on how the issues presented are dealt with. In general, the greater the scale of the hydroelectric project is, the more it approaches the weak sustainability criteria presented here. However, this does not mean that small-scale projects such as small hydro power plants are always established based on strong sustainability.

11. Some important assets: the WCD reports and hydropower

The former World Comission on Dams (WCD) has developed an important role on bringing light to the hydropower conflicts.

The main recommendations of the WCD (Dubash et al., 2001) are summarized on Table 3.

Principle	Explanation
Gaining public acceptance	Decision-making processes and mechanisms are used that enable informed participation by all groups of people, and result in the demonstrable acceptance of key decisions. Where projects affect indigenous and tribal people, such processes are guided by their free, prior and informed consent.
Comprehensive options assessment	Alternatives to dams often do exist. To explore these alternatives, needs for water, food and energy are assessed and objectives are clearly defined. The appropriate development response is identified from a range of possible options. In the assessment process, social and environmental aspects have the same significance as economic and financial factors.
Addressing existing dams	Opportunities exist to optimize benefits from many existing dams, address outstanding social issues and strengthen environmental mitigation and restoration measures. Benefits and impacts may be transformed by changes in water use priorities, physical and land use changes in the river basin, technological developments, and changes in public policy expressed in environmental, safety, economical and technical regulations.
Sustaining rivers and livelihoods	Understanding, protecting and restoring ecosystems at river basin level is essential to foster equitable human development and the welfare of all species. Options assessment and decision-making around river development prioritize the avoidance of impacts, followed by the minimization and mitigation of harm to the health and integrity of the river system.
Recognizing entitlements and sharing benefits	Joint negotiations with adversely affected people result in mutually agreed and legally enforceable mitigation and development provisions. Successful mitigation, resettlement and development are fundamental commitments and responsibilities of the State and the developer. Accountability of responsible parties to agree mitigation, resettlement and development provisions is ensured through legal means, such as contracts, and through accessible legal recourse at national and international levels.
Ensuring compliance	Ensuring public trust and confidence requires that governments, developers, regulators and operators meet all commitments made for the planning, implementation and operation of dams. A set of mutually reinforcing incentives and mechanisms is required for social, environmental and technical measures.

Sharing rivers for peace, development and security	Storage and diversion of water on transboundary rivers have been a source of considerable tension between countries and within countries. As specific interventions for diverting water, dams require constructive cooperation. Consequently, the use and management of resources increasingly becomes the subject of agreement between States to promote mutual self-interest for regional cooperation and peaceful collaboration. External financing agencies support the principles of good-faith negotiations between riparian States.
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Table 3. WCD’s recommendations for hydropower projects.

In addition to the principles established by the WCD, the Commission also presented guidelines for reservoir implementation (WCD, 2000), which are elaborations of the principles. Guideline 11 presents criteria for good economic risk analysis (WCD, 2000). According to Fujikura and Nakayama (2002), this is one of the easiest of the guidelines for governments and investors to implement, given that the analytical tools are readily available and in compliance with the guideline does not entail a final decision on whether or not to build a given dam. Nevertheless, in most cases, especially in developing countries, no risk analysis of any kind is presented to society. Further risk studies could be developed incorporating factors for which data have so far been unavailable. Such contributions would enrich the debate and clarify aspects of the projects which would remain obscure without them.

12. Sustainability and hydropower: is there a real dilemma?

The hydropower is one of the most efficient technologies to generate electricity and it has an important role in the world energy matrix. Even when considering just the renewable sources, the most advanced hydropower techniques are at the top in terms of sustainability. However, the implementation of a hydropower plant has to be analyzed under a comprehensive framework which needs to incorporate the local, regional and global context.

To evaluate the sustainability profile of a hydropower project it is important to consider: i) the macro context in which a hydropower project is conceived, e. g. the energy matrix, the environmental opportunities costs for more efficient alternatives, etc.; ii) the participatory framework of the decision making process; iii) the social context and how the project could address this issue; iv) the physical-chemical-biological problems resulting from its implantation and operation, and its interaction with the environmental characteristics of the place where it is built.

Another important discussion under the sustainability coverage is about the virtual use of water and the ecological dumping. A good part of the hydroelectric power in the world (in absolute numbers) is addressed to the commodities production (mineral and agricultural) in subsidies contexts. This follows the classic pattern of privatizing the benefits and socializing the costs of development and infrastructural projects, especially, but not only, in non developed countries.

Unfortunately, the decision-making process on planning and building hydropower plants has not been as open and participatory as demanded by society. The pervasive costs and

problems mentioned above speak for themselves with regard to the necessity of the countries to adopt better standards in the way hydroelectric plants are planned and built. However, the electricity sector generally took shape around a technical bureaucracy that centralizes decision-making to the exclusion of institutions with related interests. The inner circle of institutions linked directly to the electrical sector in the hydropower intensive countries – government bodies, generation companies, and electricity research bodies, as well as regulatory bodies, share decision-making among themselves.

Furthermore, as reported by The Economist (2003), if the World Bank and other international agencies were to far away from financing big dams, many bigger countries would go ahead on their own. When it happens, "it is a racing certainty that their dams will involve more kickbacks and corruption – and that they will ignore the WCD guidelines altogether" (The Economist, 2003). Nowadays, it is factual.

To meet sustainability, the planning process, which is based on management of supply to meet the constant and unmanaged expansion in demand, has to be changed to reach overall efficiency. This includes investments on the demand management and new production arrangements with renewable energy sources. In this context, micro and small hydropower schemes could be interesting whether they are linked to local demands and irrelevant environmental impacts.

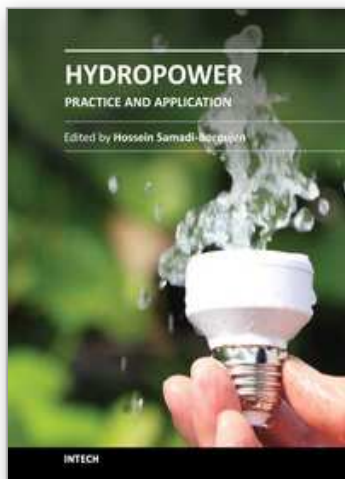
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Hydroelectric energy is the most widely used form of renewable energy, accounting for 16 percent of global electricity consumption. This book is primarily based on theoretical and applied results obtained by the authors during a long time of practice devoted to problems in the design and operation of a significant number of hydroelectric power plants in different countries. It was preferred to edit this book with the intention that it may partly serve as a supplementary textbook for students on hydropower plants. The subjects being mentioned comprise all the main components of a hydro power plant, from the upstream end, with the basin for water intake, to the downstream end of the water flow outlet.

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