Hydropower: An Essential Partner of Renewable Energy Source

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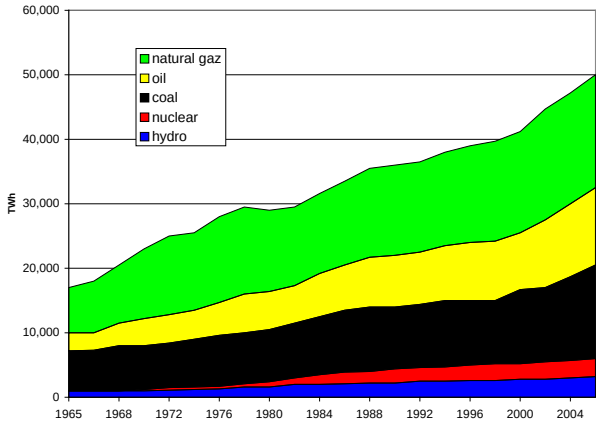
Abstract
In 2006, the 17 percent of the world's electricity that was generated from hydropower represented nearly 90 percent of renewable electricity generation worldwide; Hydropower is an important source of renewable energy and produces extremely small quantities of carbon dioxide. Between 1998 and 2008, renewable electricity production in the world rose from 2,794.9 to 3,762.6 TWh, i.e. an additional 967.6 TWh. As a final conclusion, despite hydropower's high initial costs, its long-term overall costs tend to be low. The average cost of electricity production by hydropower is still very attractive for the moment. In the next future, hydropower will keep his position, in front of the other renewable sources of electricity, on the same level with biomass, better that wind power and much cheaper than solar energy.

Keywords: Hydropower, Renewable Energy, Development

1. Introduction
Humans have been harnessing water to perform work for thousands of years. The Persians, Greeks, and Romans began using waterwheels about 2,000 BC. The primitive wheels, powered by river current, provided water for simple applications such as irrigation and the grinding of grain in mills. The 2,300-year-old Dujiangyan irrigation system in China's Sichuan Province, credited with allowing the Chinese Empire to be unified for the first time, is still in use today. Such devices have a very low level of efficiency, however, and they use only a small part of a stream's available energy from its velocity or motion, also known as the velocity head. The vertical height that water falls is called here the head; the higher the head, the greater the kinetic energy the water has as it falls on the waterwheel or turbine below. Engineers use the head and the volume of the water flow to calculate the amount of power a hydropower project can produce; this is known as the potential power.
The evolution of the modern hydropower turbine began in the mid-1700s when the French hydraulic and military engineer Bernard Forest de Bélidor (1698–1761) wrote the four-volume Architecture hydraulique. In 1869, the Belgian electrician Zénobe Gramme set up the first prototype of a dynamo—an electric generator that produces direct current and an electric engine. In 1881, a brush dynamo connected to a turbine in a flour mill provided street lighting at Niagara Falls, New York.
Since the 1880s, hydropower has been used mainly for electricity generation rather than for irrigation or millwork. By 1925, 40 percent of the world's electric energy production came from waterpower (Lejeune and Topliceanu 2002, [1]), although by 2006 it had diminished to 17 percent (United States Energy Information Administration [USEIA] 2008a [2]). This downward trend is not due to a change in the world's electric energy production from waterpower, which actually increased by 74 percent from 1980 to 2006. Rather, it is due to the world's total energy production, which more than doubled during the same period (USEIA 2008a[2]).

2. Hydropower in the Electricity Generation
In 2006, the 17 percent of the world's electricity that was generated from hydropower represented nearly 90 percent of renewable electricity generation worldwide (USEIA 2008b [3]). Thus it is by far the most widespread form of renewable energy.

Since 1965, the world's total energy consumption from oil, natural gas, coal, nuclear power, and hydropower (only the last of which is considered as a renewable resource) increased from 46.52 million gigawatt-hours (GWh) to 127.93 million GWh. A gigawatt-hour is a measure of the total energy used over a period of time, equal to 1 million kilowatt-hours; 1 GWh is enough to power approximately 89 U.S. homes for one year (USEIA 2009b [4]) or 198 homes in the European Union for one year (Bertoldi and Atanasiu 2007, [5]). As of 2007, the world's primary energy consumption was for oil, followed by coal (at 35.6 percent and 28.6 percent, respectively), and consumption in those areas has been growing. But their growth has been curbed by the growth in energy consumption from renewable sources, including hydropower (6.4 percent; BP 2009 [6]).



(1 TWh= 1 terawatt-hour = 1,000 gigawatt-hours) *Source*: BP (2009) [6].
Figure 1. Historical Trend in World's Primary Energy Consumption by Source, 1965–2006

The consumption and the production of hydropower vary by country. Four countries, China, Canada, Brazil, and the United States, have been both the world's largest consumers of hydropower and its largest producers (Table 1). Conditions such as the amount of rainfall an area receives and drought can affect the production of hydropower. For example, the United States' production of hydropower decreased from 2007 to 2008 because of drought-related issues. On the other hand, government policies to invest in hydropower, such as China's Three Gorges project, can greatly increase production. From 2007 to 2008, China's production increased by 20.3 percent, skewing the world's net increase in production because the increase was so much higher than other countries (BP 2009) [6].

Country	*Consumption (GWh)*	*Consumption relative to the world total (%)*	*Production (GWh)*
China	1.54 million	18.5	552,000
Canada	972,000	11.7	370,000
Brazil	957,000	11.5	361,000
United States	659,000	7.9	248,000
Russia			162,000

Table 1: Main consumers and producers of hydropower as of 2008 (BP 2009, 38; USEIA 2008b [3]).

Hydropower is an important source of renewable energy and is the subject of much debate. It produces extremely small quantities of carbon dioxide (mostly from power plant construction and from decaying organic matter that readily grows in the stagnant water of reservoirs); the amount is even less than that of the alternative wind, nuclear, and solar energy sources. Hydropower is also clean, and its supply is generally stable since water is abundant in many places. One of the greatest drawbacks of hydropower is the cost. Hydropower's initial investment costs from dam and power plant construction are relatively high (in part this is because project planning is site specific due to the many geographic variables involved). Other costs include the installation of (or hook up to) transmission lines, the operation and maintenance of the facility, and the costs (both financial and social) of resettling people

displaced by the dam and its reservoir. The loss of agricultural land and the potential damage to ecosystems are also important factors to be considered (Willams and Porter n.d. [7]).
Despite hydropower's high initial costs, the long-term costs tend to be low because the energy source (flowing water) is renewable and free. In the United States, it costs an average of 85 cents to produce 1 kilowatt-hour with hydropower, which is 50 percent cheaper than nuclear power, 40 percent cheaper than fossil fuels, and 25 percent cheaper than natural gas (Wisconsin Valley Improvement Company n.d. [8]). A kilowatt-hour is the unit that electric companies use to charge residential customers for their energy use over time.
Renewable electricity production (including pumped storage hydro plants) rose to 3,762.6 TWh in 2008 i.e. 18.7% of the total electric energy production. This share in electricity output was larger than that of nuclear power (13.5% in 2008), but much less than the fossil fuel electricity (67.7%).The remaining 0.2% was provided by the incineration of non renewable waste.

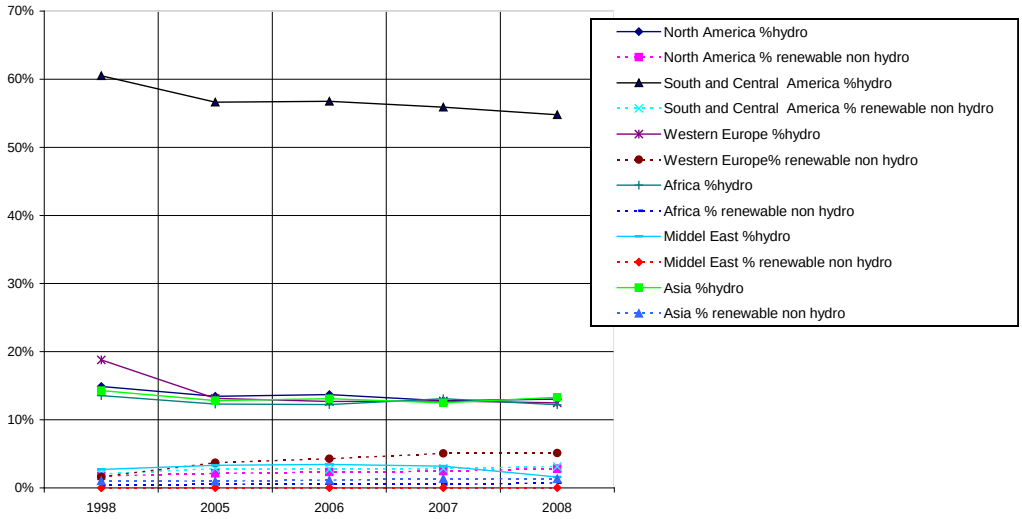
3. Sources of renewable electricity production

There are six different sources of renewable electricity. Hydroelectricity is the main source with a 86.3% share of the total renewable production. Biomass, which includes solid biomass, liquid biomass, biogas and renewable household waste, is the second source with 5.9% a little ahead of the wind power sector (5.7%), followed by geothermal power (1.7%), solar power including electro-solar and photovoltaic plants and ocean energies (0.01%) (Table 2).

Source	TWh	%
Hydropower	3247,30	86,31%
Biomass	223,50	5,94%
Wind power	215,70	5,73%
Geothermal	63,40	1,69%
Solar including photovoltaic	12,10	0,32%
Marine energies	0,54	0,01%
Total	**3762,54**	**100,00%**

Table 2: Structures of electricity production renewable sources in 2008

The distribution per regions of the percentage of hydro and renewable non-hydro electricity generation in the world is given in Figure 2. The part of the hydropower in the generation of electricity is around 14% in every region of the world except in South America where it is 55%. The percentage of renewable sources of electricity derived from hydropower is still, for the moment, about 5%.



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4. Findings about renewable electricity production and hydropower

Between 1998 and 2008, renewable electricity production in the world rose from 2,794.9 to 3,762.6 TWh, i.e. an additional 967.6 TWh, which equates to almost double the amount of electricity produced in France. Between 2007 and 2008, the renewable sectors gained enough momentum to gain another half percentage point share in the breakdown of total electricity production. China, that leads the field of countries having supported this growth, is now the leading world producer of renewably sourced electricity with 599.4 TWh in 2008. The commissioning of the last phase of the Three Gorges Dam has largely contributed to the 100 TWh increase in hydropower produced in China in the span of a year. Hydroelectricity, whose limits are far from being reached, is the country's top renewable source of energy. An additional 6,900 MW will shortly come on line with the country's third largest dam, the Longtan Dam. Hydropower represents 86.3% of all renewable production leaving biomass (5.9%) and wind power (5.7%) trailing a long way behind.

Nonetheless, the wind power sector has continued to put in a remarkable performance with a mean annual growth of 29.4% between 1998 and 2008. The 100,000 MW mark for installed capacity worldwide was passed during the 1st half of 2008 and the GWEC (Global Wind Energy Council [9]) forecasts cumulated capacity of 240,300 MW as of 2012. In China, wind power output has risen from 6.5 TWh in 2007 to 14.2 TWh in 2008. It has even been a resounding success in the United States, where production has risen from 34.6 TWh in 2007 to 52.4 TWh in 2008, i.e. a 51.5% increase. Furthermore, the United States has become the world's top wind power producer, ahead of Germany that leads the field in renewable energies in Europe. Its very active policy of supporting these sectors has enabled it to increase renewable electricity share by over 10 points from 5.2% in 1998 to 15.4% in 2008. Renewably sourced electricity production has risen at the same time from 28.8 to 98.1 TWh, about a mean annual increase of 13%.

In Europe, the renewables' share has also increased steadily. It has risen from 14.2% in 1998 to 17% in 2008, once again much of it through wind power, whose mean annual growth in the EU between 1998 and 2008 was 26.6%. Wind power, especially offshore wind power growth potential will not peak for a long time. Furthermore, the offshore wind power tests on floating foundations currently under way off the coast of Norway could open up a new high potential development channel for wind power, once its currently prohibitive high installation costs can be brought down.

In contrast, growth of the biomass sector across the world slowed down slightly between 2007 and 2008 as only an additional 8.1 TWh was produced in 2008 over 2007, compared to the increase of 14.1 TWh between 2006 and 2007.

The other renewable sectors (solar, geothermal, and ocean energies), continued climbing up along the growth curve, adding to electricity production at a lower scale. Solar output rose in 2008 to a similar level as that of wind power in 1997, confirming the build-up and organization of the sector. World installed capacity passed the 10,000 MWp (megawatt-peak) mark in 2008, and could exceed 20,000 MWp in 2010. Electricity capacity, which rose to 7,910 MWp in 2008, put on an 85% spurt over 2007. The EPIA (European Photovoltaic Industry Association) reckons that even in its "conservative" scenario, worldwide installed capacity should be in the vicinity of 21,600 MW in 2010 and will embark on a very high growth levels after that. The growth photovoltaic electricity output has actually accelerated as it rose by 49% between 2007 and 2008 compared to the mean annual rate of 39.4% between 1998 and 2008. In 2008, solar power (photovoltaic and electro-solar sectors combined) produced an additional 4.2 TWh over 2007, for 12.1 TWh.

Off-grid photovoltaic also kept up its momentum. The newly installed capacity in the ten countries surveyed in this inventory (Argentina, Brazil, India, Kenya, Mali, Morocco, Mexico, the Philippines, Senegal and South Africa), rose to 17.8 MWp in 2008 as against 16.8 MWp in 2007 (up 5.6%). Stand-alone photovoltaic systems were installed in 166,443 homes, bringing the total number of electrified households through photovoltaic in the ten countries targeted by the survey to over 1.8 million. However, it has to be noted with great regret that as the current economic crisis has led to a drop in aid being made available for decentralized rural electrification programs in developing countries. As a consequence, isolated site photovoltaic installation could suffer more from the financial crisis during 2009 than the other renewable electricity sources.

The crisis has also had an impact on global electricity production, whose growth between 2007 and 2008 was only 1.8% whereas the mean annual rate between 1998 and 2008 was 3.5%. Nevertheless,

growth in output in a number of countries has been extraordinary. Over the past 10 years, China achieved a mean annual growth rate of 11.5% and in South Korea, it was 7.5%. However, the current rise in worldwide electricity production continuously increases greenhouse gas emissions, as electricity production from fossil-fuel plants is still about four times higher than that of the renewable electricity sources. The share of nuclear power in global production is shrinking, despite a slight recent increase in production. The sector's mean annual growth over the 1998-2008 period is only 1.1%.
Conditions in the developed and developing world affect the economics of a hydropower project. In the analysis of the cost of the different systems of power generation in the United States, it appears that, besides being a renewable source of energy, hydroelectric plants are by far the most economical. The mean cost of generation by U.S. hydropower plants is only 40 percent of that by fuel oil (Wisconsin Valley Improvement Company n.d. [8]).
In Africa, several large hydro projects are in the planning stages or under construction: the proposed Grand Inga complex in the Democratic Republic of Congo: an $80 billion complex that is expected to produce from twice to four times the electricity of the Three Gorges project; the construction of the Lom Pangar dam in Cameroon; the rehabilitation and upgrading of the Kariba dam on the Zambezi River between Zambia and Zimbabwe; the construction of the Gibe III hydropower plant in Ethiopia; and that of the Gurara Water Transfer Project in Nigeria. These come in spite of the closures of the Tanzanian hydro plants in 2006 and the 14-MW Masinga dam in Kenya in 2009, due to recurrent droughts (Browne 2009 [10]), and the diminished capacities of the Inga 1 and Inga 2 dams, due to poor maintenance. In 2008, the World Bank invested more than $1 billion in small-scale and micro-hydro projects in the developing world. These projects displace less people than the large ones and they also reduce the cost of transmitting electricity to rural areas, across vast distances, and over natural barriers such as the Sahara Desert (Browne 2009 [10]),).
Renewable energies thus still have a lot to offer and many countries have just begun to realize this. China intends to become the leading photovoltaic panel and wind turbine manufacturer. Its highly competitive stance will no doubt force European and American manufacturers to struggle for market share. Renewable energies will become even stronger, for we are no longer witnessing a ripple but a ground swell.

5. Conclusion

As a final conclusion, despite hydropower's high initial costs, its long-term overall costs tend to be low because the energy source (flowing water) is renewable and free. The following figures give two overviews of the cost of the electricity generation in 2009 and in 2016. Sources of those figures are compilations from data of EIA (US Energy Information Administration, OECD (Organization for Economic Co-operation and Development) and the Institute for Energy Research. The mentioned cost of electricity production by nuclear power plant does not include the costs of the wastes treatments and the impacts of future regulations and reviews of licensing. The average cost of electricity production by hydropower is still very attractive for the moment. In the next future, hydropower will keep his position, in front of the other renewable sources of electricity, on the same level with biomass, better that wind power and much cheaper than solar energy.

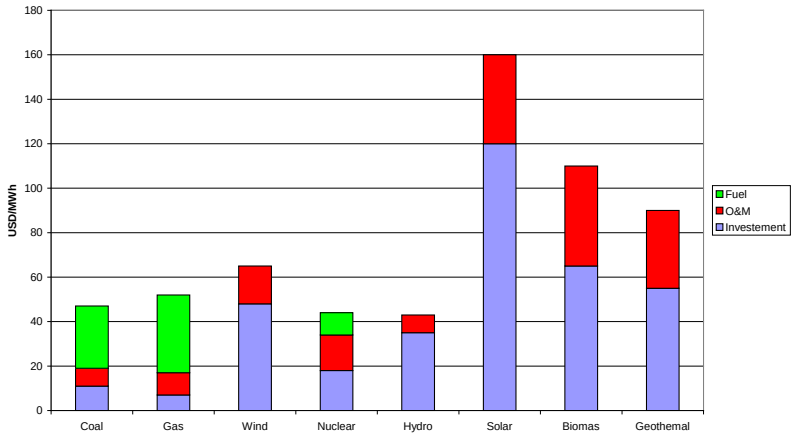

Figure 3: Average Cost of Electricity Production by Source in 2008 in USD per MWh

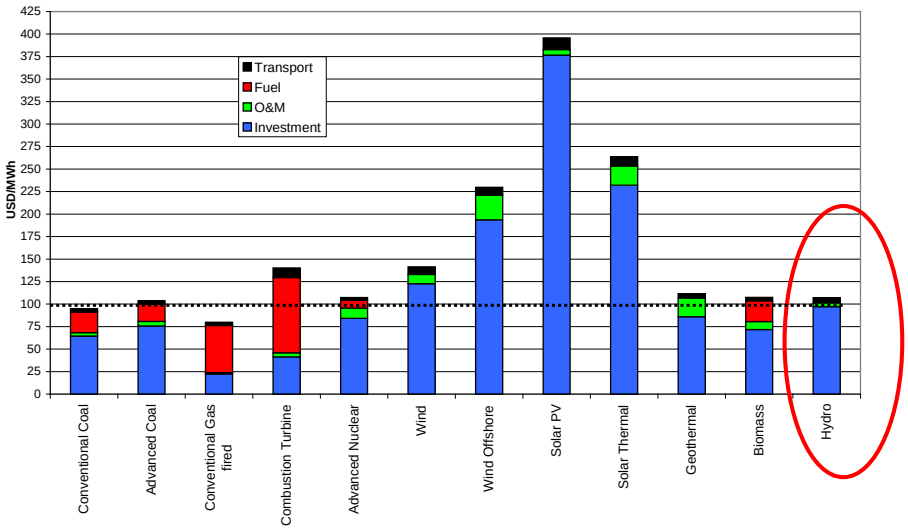

Figure 4: Future Cost of Electricity Production by Source in 2016 in USD per MWh

[1] Lejeune, André, & Topliceanu, I. (2002). *Energies renouvelables et cogeneration pour le development durable en Afrique: Session hydroelectricite* [Renewable energy and cogeneration for the development of sustainable development of Africa: Hydroelectricity session]. Retrieved January 13, 2010, from http://sites.uclouvain.be/term/recherche/YAOUNDE/EREC2002_session_hydro.pdf

[2] United States Energy Information Administration. (2008a). [Table 6.3]. *World total net electricity generation (billion kilowatthours), 1980–2006*. Retrieved December 23, 2009, from http://www.eia.doe.gov/iea/elec.html

[3] United States Energy Information Administration. (2008b). *World's top hydroelectricity producers, 2008 (billion kilowatthours)*. Retrieved December 23, 2009, from http://www.eia.doe.gov/emeu/cabs/Canada/images/top_hydro.gif

[4] United States Energy Information Administration. (2009b). *Table 5: U.S. average monthly bill by sector, census division, and state 2007*. Retrieved January 14, 2010, from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

[5] Bertoldi, Paolo, & Atanasiu, Bogodan. (2007). *Electricity consumption and efficiency trends in the enlarged European Union: Status Report 2006*. Retrieved January 14, 2010, from http://re.jrc.ec.europa.eu/energyefficiency/pdf/EnEff%20Report%202006.pdf

[6] BP. (2009). *BP statistical review of world energy: June 2009*. Retrieved October 8, 2009, from http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/statistical_review_of_world_energy_full_report_2009.pdf

[7] Williams, Arthur, & Porter, Stephen. (n.d.). *Comparison of hydropower options for developing countries with regard to the environmental, social and economic aspects*. Retrieved December 17, 2009, from http://www.udc.edu/cere/Williams_Porter.pdf

[8] Wisconsin Valley Improvement Company. (n.d.). *Facts about hydropower*. Retrieved December 27, 2009, from http://new.wvic.com/index.php?option=com_content&task=view&id=7&Itemid=44

[9] Global Wind Energy Council GWEC: Market forecast 2010-2014 from http://www.gwec.net/fileadmin/documents/Publications/Global_Wind_2007_report/market%20forecast%202010-2014.JPG

[10] Browne, Pete. (2009, September 30). The rise of micro-hydro projects in Africa. *The New York Times*. Retrieved January 14, 2010, from http://greeninc.blogs.nytimes.com/2009/09/30/the-rise-of-micro-hydro-projects-in-africa/,