Statements on Energy from Moving Water

by the Energy Committee at
the Royal Swedish Academy of Sciences

Introduction

The Royal Swedish Academy of Sciences (Kungl. Vetenskapsakademien, KVA) is an independent organization, with knowledge in science as well as in economical, social and humanistic fields. KVA has established an energy committee (http://www.kva.se/KVA_Root/swe/society/energy/index.asp) with the objective to gather and synthesize knowledge about main energy issues with emphasis on scientific and technological aspects. The perspective is global with some focus on EU and Sweden.

The energy committee gathers knowledge from different sources, both within and outside the academic world, for instance by means of hearings, seminars and symposia. The results of its work are distributed to main players in the energy field and to the general public. One of the major projects in the portfolio is focused on water and energy. It was carried out in collaboration between the KVA Energy Committee, and Environmental Committee (http://www.kva.se/KVA_Root/eng/society/environment/index.asp) and the European Academies Science Advisory Council (EASAC). With the main purpose to identify and analyze current status and main questions, possibilities and constraints for the future of energy production from various water environments, an International Symposium on “Energy from moving water” was held at Kulturhuset in Stockholm on 12 November 2007, followed by a Hearing on 13 November 2007 at the Academy. More information about these two events can be found at the web page of the Academy, www.kva.se.

The present statements are based on the presentations and the discussions in the 12 November Symposium and 13 November Hearing, 2007. They have been elaborated by a working group consisting of Drs. Georgia Destouni, Harry Frank, Dick Hedberg, Sven Kullander and Karl-Göran Mäler. The statements have been discussed in the KVA Environmental Committee and approved by the Energy Committee.

Project background

The Academy project on energy from moving water aimed to identify and analyze the current status and main questions, possibilities and constraints for the future of energy production from various water environments, including:

- inland surface waters for hydroelectric energy
- oceans for tidal and wave energy, and energy from marine currents and thermal gradients
- groundwater – for geothermal energy

The traditional hydropower (or hydroelectric power) is available due to the Earth’s hydrologic cycle and represents the most obvious connection between water and energy. It is also the most developed technology that still has a large remaining potential for increased energy production from moving water.

The main focus of the Academy project and these statements about energy from moving water is therefore on hydropower. In addition, the project and statements adress also ocean energy from tides, waves, currents and thermal gradients, as well as geothermal energy, the human use of which may depend on and be constrained by the actual flow and heat transport velocity of groundwater.

In general, the statements below summarize main development perspectives and recommendations for the technologically mature, yet still far from fully developed hydropower option, considering also its environmental, socio-economic and safety implications, as well as for the ocean and geothermal energy options, which yet require considerable technological development to become globally significant.

The Energy Committee's key statements about energy from moving water

1. Hydropower – energy role

Hydropower is a key energy resource. It presently constitutes the most important source of renewable electrical power generation. In the most recent world energy assessments with data for 2005, hydropower stands for around 87% of the total electricity generation from renewable energy sources (WEC -World Energy Council, 2007; IEA - International Energy Agency, 2007); with regard to the total electricity generation and primary energy supply, it stands for about 16% and 2%, respectively (IEA, 2007).

Hydropower is unique in providing a necessary development support for other renewable energy sources. The storage capacity of hydropower offers the operational flexibility needed for quickly responding to fluctuating electricity demands. This improves electricity grid stability and reliability as well as supports the deployment of intermittent renewables, such as wind and solar power.

2. Hydropower – physical-economical development possibilities

The annual world production of energy from hydropower was in 2005 less than 20% of the estimated annual energy that could be exploited within the limits of current hydropower technology, i.e. of the global technically exploitable capability, as defined by WEC (2007). Furthermore economically exploitable capability is defined as the annual energy that can be exploited within the limits of current hydropower technology under present and expected local economic conditions. The main economical constraints of large-scale hydropower development projects are the high initial capital costs as well as the lengthy lead times for planning, permissions and construction; these constraints are much smaller for small "run-of-river" hydropower stations. Estimates of economically exploitable capability may also, or may not exclude the potential that would be unacceptable for social or environmental reasons.

Specific estimates of hydropower capabilities for some selected country examples, along with corresponding continental and world data (from WEC, 2007) are summarized in Table 1 below. Comparison between these hydropower estimates (WEC, 2007; Table 1) and comparable estimates by other organizations (EREC - European Renewable Energy Export Strategy, 2002; IEA, 2007) shows that the WEC (2007) estimates are on average around 5% smaller than the contemporary estimates of IEA (2007) for actual current hydropower capability, and around 17% and 22% greater than the earlier estimates of EREC (2002) for remaining technically and economically feasible capability, respectively. These differences reflect a greater uncertainty in the estimates of remaining technically/economically feasible capability relative to the estimates of actual current capability, which are more robust. Nevertheless, all the current estimates point at a large potential of further hydropower development in the world (Table 1).

Table 1. Hydropower data for some selected example countries and by continents, as obtained by the reported estimates of WEC (World Energy Council, 2007; based on sources: WEC Member Committees, 2006/7; Hydropower & Dams World Atlas 2006 , supplement to The International Journal on Hydropower & Dams , Aqua~Media International; estimates by the Editors). The figures listed here are rounded.

	Total technically exploitable capability at end 2005 (Of which actual in generation 2005) (TWh)	Remaining undeveloped, economically exploitable capability (TWh) (Total economically exploitable capability in % of the technically exploitable capability at end of 2005)
China	2 475 (335)	1 415 (71%)
USA	1 750 (270)	230 (29%)
Brazil	1 490 (335)	475 (55%)
Russia	1 670 (165)	685 (51%)
India	660 (95)	505 (91%)
Norway	200 (135)	50 (94%)
Sweden	100 (70)	15 (85%)
Asia, inc. Russia, Turkey (and Iran, Iraq)	7 365 (885)	3 685 (62%)
South America	3 035 (595)	1 225 (60%)
North and Central America	3 010 (675)	500 (39%)
Africa (inc. Jordan, Lebanon, Syria)	1 860 (90)	990 (58%)
Europe, exc. Russia, Turkey	1 045 (540)	245 (75%)
Australasia/Oceania	190 (40)	75 (60%)
World total	16 500 (2 830)	6 700 (58%)

Asia is the continent with the highest technically and economically feasible potential, with China and India being the countries with the greatest part of that potential. The corresponding potential in Europe is considerably lower, with much of it already developed. In Sweden and the EU in general, further hydropower development is expected to concentrate on small-scale hydropower (defined as facilities with installed capacity <10MW) since most of the sites suitable for large-scale hydropower schemes (>10MW installed capacity) have already been developed. Outside Europe, small-scale hydropower has large potential for rural electrification in developing countries.

3. Hydropower – social-environmental development constraints

The future of hydropower development may be considerably constrained by the environmental and social impacts that are associated with the construction of dams (WCD – World Commission on dams, 2000). The main social constraints are those related to change in land use and displacement of people from the flooded area upstream of the dam. The main environmental impacts of a dam are those of sedimentation, changes in fish passage and changes in water flows and quality, which in turn affect the status and dynamics of freshwater ecosystems and biodiversity, and the ecosystem services that they provide for instance for the tourism and fishery sectors.

Due to these social and environmental constraints, the consideration of large-scale hydropower as a renewable source of energy is questioned. As a consequence, development may in practice be unacceptable also for some of the estimated remaining economically exploitable hydropower capability in a country or region (Table 1), for social and/or environmental reasons. For Sweden, for example, the WEC (2007) estimate in Table 1 includes at least some of the presently socially-environmentally unacceptable potential. Specifically, the estimated nearly 15 TWh remaining economically exploitable capability (similarly estimate also by IEA (2007)) is considerably larger than the around 5-10 TWh that is nationally judged as practically feasible for further hydropower development in Sweden (Hearing on Energy from Moving Water, 2007). The latter estimate excludes new large-scale hydropower development in the presently unexploited main Swedish rivers. It accounts only for small-scale hydropower development, and possible capacity additions to and modernizations of already existing hydropower plants. Our knowledge about and quantification capabilities for valuating the ecosystem services and the possible irreversible effects of hydropower on those services is currently quite limited. As long as this is the case, the precautionary principle should apply, which implies a need to protect the last unexploited Swedish rivers from hydropower development.

4. Hydropower - safety concerns

The possibility of a dam failure threatening people and ecosystems downstream is an additional important concern that affects the exploitation capability of hydropower. The Swedish National Audit Office (SNAO; Riksrevisionen) has recently examined the action taken by the Swedish State to ensure the safety of hydroelectric-power dams in Sweden (SNAO, 2007). The overall audit question was: *Has the State fulfilled its responsibility for the safety of hydroelectric-power dams?* The SNAO found that the development of dam safety has not primarily been determined by standards established by the State; instead, dam owners themselves have decided the focus and extent of their work on safety. Even though the State has progressively implemented measures that have strengthened and clarified its responsibility for dam safety, SNAO is of the opinion that there is still need for improvement and further development of the action taken by the Swedish State to ensure the safety of dams. In general, reduction of the failure and fatality risks associated with hydropower dams does not only require use of best knowledge and technologies, but also effective co-operation between dam owners, society representatives and other stakeholders.

Furthermore, the factors controlling dam safety must now be reconsidered with regard to ongoing climate change. This reconsideration may affect both old and new projects, even though new dams are expected to be safer than old ones due to better geological, technical and hydrological knowledge and implementation and prediction capabilities. In general, it is estimated that most of the around 810 GW of hydro-equipment in operation in the world today will need to be modernized by 2030 (WEC, 2007). This modernization can and should also be considered and used as an opportunity to increase hydropower generation at relatively low cost by adding new capacity to or improving the performance of existing plants, while also improving the water ecosystem conditions.

5. Hydropower – policy and development conflicts

In order to respond to the major challenges of securing future energy supply while minimizing climate change impacts, the EU has adopted binding minimum targets of 20% renewable energy by 2020 and launched a directive proposal suggesting a framework for reaching these targets (Commission of the European Communities, 2008). The demand of significant increase in renewable energy from current 7% (EREC, 2007) to 20% in 2020 encourages energy production from hydropower and other types of energy production from moving water (discussed more below).

However, new environmental policies may significantly constraint this development. Specifically the European Water Framework Directive 2000/60/EC (WFD; Council of the European Communities, 2000) generally demands protection, restoration and no further deterioration of aquatic ecosystems. As changes in fish passage and ecosystem status are common impacts of hydropower, there is here a clear conflict between local environmental and global energy targets. This conflict has also general renewable energy implications, with regard to the necessary support that hydropower provides for the deployment of other renewables, such as wind and solar power, which lack its energy storage capacity and flexibility.

The WFD was adopted in 2000 and establishes a common framework for water environment action in the EU. It requires all EU Member States to achieve good physical, chemical and ecological status and prevent further deterioration in their inland and coastal waters, preferably by the end of the first WFD-demanded water management cycle in 2015, with an ultimate deadline in 2027. The WFD may block both large- and small-scale hydropower development options, however it also aims to preserve a variety of water uses through economically efficient, integrated water resource management, requiring collaboration between different stakeholders and public consultation with regard to the management plans and programmes of measures that are to be established for achieving good water status. The WFD may then at least be consistent with adding capacity to and increasing the efficiency of existing hydropower plants in the EU, provided that water ecosystem conditions are improved or at least maintained.

Globally, the largest and increasing needs of water are primarily for growing the food required to feed the world population and its projected increase. An increase in energy production from biomass, as is for instance required by an EU target of 10% use of biofuels in the transport sector by 2020 (Commission of the European Communities, 2008), may lead to hard competition and conflicts for both water and land between the food and the energy production (Académie des Sciences, 2006). In addition to its energy importance, hydropower contributes to freshwater storage, which can be used for irrigation and drinking water supply and may reduce vulnerability to floods and droughts and aid in resolving conflicts between different water uses and users.

6. Ocean energy

From the five different types of existing ocean energy generation systems: tidal, wave, marine currents and temperature and salinity gradients, only tidal energy has so far reached a mature status of providing electricity commercially in different parts of the world. Globally, tidal electricity represented 0.02% (WEC, 2007) of the total electricity production from renewables in 2001 (2 968 TWh) with a capacity in operation of 240 MW (IEA-OES, 2007). This production is expected to be increased relatively soon by new developments in progress. The estimated global annual theoretical potential is 300 TWh (IEA-OES, 2007). Wave is the next mature technology for harnessing ocean energy, with no commercial energy production yet, but with a significantly advanced pre-commercial development status. Moreover, wave energy has a high theoretical potential varying from 8 000 to 80 000 TWh (IEA-OES, 2007). At present, however, only 140-750 TWh is economically exploitable annually with commonly available technological designs according to Wavenet (2003; cited in WEC, 2007). This capacity could rise to 2 000 TWh (Thorpe, 1999; cited in WEC, 2007) if potential technological improvements are realized. Energy from marine currents is also at a pre-commercial development state but this stage is less advanced than that of wave technology (IEA-OES, 2007). The theoretical global annual marine current energy resources are estimated to exceed 800 TWh (IEA-OES, 2007). Estimates of theoretical annual exploitable potential for ocean thermal gradients and salinity gradients are 10 000 TWh and 2 000 TWh, respectively (IEA-OES, 2007). In general, all these estimates of ocean energy potential are rather speculative high-end theoretical estimates because the involved technologies are still at early research and development stages. Considerable research and development efforts and resources are needed for further developing and testing the actual practical feasibility and economic viability of these technologies.

7. Geothermal energy

There are several types of geothermal resources, including magma and hot dry rock in addition to groundwater, with the latter being the reason for including also geothermal energy in these statements. Hydrothermal reservoirs constitute the most significant type of geothermal energy production today, utilizing crustal hot spots in which high-temperature pressurized groundwater has accumulated and serves as a medium for removing thermal energy from the Earth's crust.

Energy from geothermal resources has two distinct applications: electricity production and direct heat use. Worldwide, geothermal electricity represented 1.8% of the total electricity production from renewables in 2001 (2 968 TWh) and its generation is concentrated in only about 25 countries (WEC, 2007). Electricity production from geothermal energy may be increased in the future but at present it is mainly restricted to countries and regions with hot spots on active plate boundaries or with active volcanoes. Further technological developments may increase the potential in those regions and even extend the potential to other regions of the world without hot spots, but the economic viability of such developments remains to be proved.

In contrast, the economic potential of geothermal energy for direct heat applications has increased in the last two decades due to the development of ground-source heat pumps. The total amount of energy produced from geothermal resources for direct heat uses was 76 TWh in 2004 (WEC, 2007). This production is widespread geographically over 70 countries in the world.

In general, the current exploited geothermal resources for both electricity and heat supply are only a small fraction of their estimated great theoretical potential. Globally the technical potential is estimated to be hundred times that of hydropower (World Energy Assessment, 2001). Similary to the situation for ocean energy, this theoretical estimate is also practically untested and considerable research and development efforts and resources are needed for mapping out the geothermal resources, as well as for improving and practically testing the economic viability and large-scale feasibility of the technologies for surveying and harnessing it.

8. General conclusions and recommendations

Conventional hydropower production in 2005 was around 2830 TWh and represented 87% of all renewable power worldwide. The world's total technically feasible hydropower potential has been estimated to be about 16500 TWh/year, while the economically feasible part of that potential is estimated to be around 9500 TWh/year. Up to 7000 TWh of additional renewable power would thus, in theory, be possible to get from further hydropower development according to these estimates. However, in reality, there are many social-ecological, safety, legal and policy constraints and concerns that need to be accounted for when assessing the actual possibilities and desirability of further hydropower development. These constraints and concerns remain yet to be rationally weighed into realistic cost-benefit and feasibility assessments, which include also relevant valuation and accounting of the ecosystem services and social-ecological externalities that are affected by and associated with hydropower and its possible alternatives for renewable energy production. The situation is complex and strong political governance is needed to initiate and support the research, development and application efforts that are required for identifying and pursuing a sustainable and rational role and magnitude of hydropower as part of the general policies, strategies and practices for increased production of renewable energy in the future.

Most of the hydropower development potential is found in developing countries, whereas Sweden and the EU already have exploited most of the readily accessible resources. However, also existing dams require modernization and improvements, for safety reasons and for adaptation to expected future climate change. For both new hydropower projects in developing countries and modernization projects in countries with already far developed hydropower capabilities, it is essential to support research and development efforts for enabling increasing hydropower generation and efficiency, while water ecosystem functions and conditions are maintained or improved.

Besides traditional hydropower, less mature technologies for energy production from moving water have large theoretical potential for renewable energy production, for instance with regard to wave power. Even if significant energy production cannot be expected from these sources in the next few decades, strongly increased research and development efforts are recommended for investigating the feasibility and enabling a sustainable use of this renewable energy potential.

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