Implications for water of the world energy scenarios

Pedro Linares*, Gonzalo Sáenz de Miera†

March 15th, 2009

Abstract

There is an increasing concern in the energy sector about how confront its growing water demand, in an environment in which water is expected to become a scarcer good. Indeed, the increase in energy demand will require more water for cooling power plants, for growing biofuels, or for extracting and refining fuels. On the other hand, the intensive use of fossil fuels for energy contributes significantly to a climate change that will reduce in some countries water inflows, and in most of them will make them more irregular. This paper tries to assess the changes in water demand to be expected from the future energy scenarios for the different parts of the world, particularly in relation to the future water supply. Results show that…

1 The future energy scenarios

The International Energy Agency prepares very year an outlook of the future energy scenarios, in which both the demand and supply of energy by energy area is detailed, for the different energy sources. In this study, we have used the 2007 World Energy Outlook (IEA, 2007), which presents three major sets of figures: one for the "current" energy use, 2005; a reference scenario for 2030 – basically a business-as-usual scenario, and an "alternative" scenario, in which the impact of energy efficiency and climate change policies is simulated.

The figures for each of these scenarios are presented in Tables 1 and 2, in which the primary energy and the electricity demand are presented, respectively.

---

* Instituto de Investigación Tecnológica y Cátedra BP de Desarrollo Sostenible, U. Pontificia Comillas, Alberto Aguilera 23, 28015 Madrid; CBG, Harvard Kennedy School.; y FEDEA. E-mail: pedro.linares@upcomillas.es

† Iberdrola, S.A.

Table 1. Primary energy demand (Mtoe)

	2005	2030 Reference	2030 Alternative
Coal	2892	4994	3700
Oil	4000	5585	4911
Gas	2354	3948	3447
Nuclear	721	854	1080
Hydro	251	416	465
Biomass and waste	1149	1615	1738
Other renewable	61	308	444
TOTAL	11429	17721	15783

Source: IEA (2007)

Table 2. Electricity production (TWh)

	2005	2030 Reference	2030 Alternative
Coal	7334	15796	10716
Oil	1186	929	844
Gas	3585	8068	6602
Nuclear	2771	3275	4144
Hydro	2922	4842	5403
Biomass and waste	231	840	1166
Wind	111	1287	1800
Geothermal	52	173	190
Solar	3	161	352
Tide and wave	1	12	24
TOTAL	18197	35384	31240

Source: IEA (2007)

As previously mentioned, the IEA World Energy Outlook also presents this figures disaggregated by region, and in fact the analysis carried out in this paper is based in these. However, and due to space limits, we do not include them here, and rather direct the interested reader to the original report.

2 Demand of water for energy

When we talk about the demand of water for energy, we must distinguish between two separate concepts: water for use, and water for consumption. The first one relates to the simple circulation of water, which is then restored to the original medium, whereas the second is the water really "consumed", and which is therefore not available for further uses, be it because it has evaporated, or because it has been polluted, or because it has been incorporated to other products (e.g. crops).

Of course, when we consider a sufficiently large timescale, there is never a net consumption of water, since "consumed" water will return, one way or another, to the hydrologic cycle. However, in this paper we will consider shorter timescales, given that one of its objectives is to compare the consumption of water for energy purposes with its availability in the world, which is usually measured not as total water, but as water available in a given moment.

The demand of water for energy may serve different purposes, depending on the activity. Besides, this demand may affect the amount of water, but also its quality (which evidently also affect the quantity available for other uses).

In the following box we summarize the impact of energy production and use on water, according to the US Department of Energy (2006).

Energy cycle stage	Quantity of water	Quality of water
Extraction and production		
Oil and gas exploration	Water to drill, fracture and complete	Impact on underground water quality
Oil and gas extraction	Large volume of produced, polluted water	The water produced may pollute surface and underground water
Coal and uranium mining	Mining may generate large volumes of polluted water	Wastes and drainages may pollute surface and underground water
Electricity generation		
Thermal (fossil, nuclear, biomass, solar, geothermal)	Cooling and cleaning water	Thermal and atmospheric pollution of water
Hydro	Losses due to evaporation	Impacts on temperature, quality and ecology of water
Photovoltaics and wind	Lesser impacts during construction	
Refining and processing		
Oil and gas refining	Water for refining	Possible pollution problems
Biofuels	Water for irrigation and refining	Waste water from irrigation and refining
Hydrogen and synfuels	Water for synthesis or reforming	Waste water
Transport and storage		
Oil and gas pipelines	Water for hydrostatic tests	Waste water
Coal slurry	Water for transport	Waste water

Energy cycle stage	Quantity of water	Quality of water
Maritime transport		Spills
Underground oil and gas storage	Oil for storage preparation	Sludges

Regarding the impact on the amount of water available, the largest part of the water related to energy consumption is due to four major uses: water for cooling thermal power plants, water evaporated from large reservoirs, water for biofuel irrigation, and water used for extracting and refining fossil fuels.

As for biofuels, we should point out that their water consumption may vary a lot. Thus, whereas in the US ethanol is produced from irrigated corn, other biofuels may be produced from other crops which do not require irrigation and which water demand may be much lower (e.g. Cynara cardunculus). Other interesting issue is that of the opportunity cost: if the biofuel is substituting other crop, then its water demand should be calculated as the difference between the current situation and the former one. In fact, we might even have situations in which substituting food crops by biofuels might even reduce water demand. As is easily seen, this is a complex issue which requires considering several parameters and assumptions. Therefore, and also due to the lack of reliable scenarios for biofuels (most of the IEA figures under the biomass category belong to forest biomass used for firewood), biofuels have not been considered in this analysis.

Therefore, the uses of water considered have been those related to the extraction and refining of fossil fuels, and to power generation. Specific consumption figures are presented in tables 3 and 4. In both cases we present minimum and maximum values, since there is a large variation depending on the process chosen.

It should be pointed out here that these figures should be used with caution, given that they belong mostly to US conditions, and are therefore in some cases difficult to extrapolate to other countries or regions. This can be considered as a major limitation of this assessment, and in fact more region- and technology-specific data would be very much welcome to improve the reliability of our estimates.

Table 3. Specific water consumption for fossil fuel extraction and refining (,000 m^3 per Mtoe)

	Minimum	Maximum
Uranium mining	1667	1667
Coal mining	6042	8333
Oil extraction	125	29167
Oil refining	1042	5000
Tar sand extraction	7500	7500
Gas processing	250	250

Source: Gleick (1994)

Regarding extraction and refining, we consider that all the water used is consumed, generally due to the level of pollution it gets, which makes it impossible to return it directly to the original medium.

Table 4. Specific use and consumption of water for power generation (m^3 per GWh)

	Use		Consumption	
	Minimum	Maximum	Minimum	Maximum
Thermal, open loop	75700	190000	1100	1100
Thermal, closed loop	1100	2300	1100	1800
Nuclear, open loop	94600	227100	1500	1500
Nuclear, closed loop	1900	4100	1500	2700
Combined cycle, open loop	28400	75700	380	380
Combined cycle, closed loop	870	870	680	680
Geothermal	7400	7400	5180	5180
Solar thermal	2775	3404	2775	3404
Hydro			5400	26000

Source: EPRI (2002)

In this case we see how there is a clear distinction between use and consumption. Cooling open loop, thermal power plants requires a high volume of water, although this water is returned to the original medium only with a minor change in temperature. In the case of hydro, water never even leaves the original medium or suffers significant changes in its temperature (although sometimes its ecology is changed), and use has been considered negligible. However, a large consumption appears related to the evaporation that takes place in large reservoirs – the figures included here are averages, and therefore will be possible overestimated for those regions where hydro electricity is produced mainly from run-of-the-river plants.

3 Impact of energy production on water consumption

3.1 The use of water for energy compared to the current use

In order to put into perspective the water consumption related to energy production, we compare these consumptions with the current use of water. In table 5 we present the amount of annual renewable water inflows, the annual use of freshwater, and the fraction of freshwater used in industry.

Table 5. Current use of water in the world (billions m^3)

	Annual renewable water resources	Annual freshwater use	Annual freshwater use in industry
OECD- North America	6826.2	599.9	254.6
OECD-Europe	2499.0	252.2	125.5
OECD-Pacific	1294.7	133.2	21.5
China	2829.6	549.8	141.3
India	1907.8	645.8	35.2
Rest of Asia	9980.3	620.0	31.7
Middle East	295.2	168.6	4.7
Latin America	17934.2	187.1	23.2
Transition economies	5872.3	306.7	87.3
Africa	5723.5	213.2	9.1
TOTAL	55162.9	3676.5	734.0

Source: Pacific Institute (2008)

Finally, and based on the regional data for energy consumption, and on the specific consumption of water for energy production presented in the last section, we are able to make a first estimation of the impact of energy production on the global hydrological balance.

First, we analyze the amount of water used (not consumed) for energy compared to the total amount of renewable water resource. This is shown in Table 6.

Table 6. Demand of non-consumptive water for energy compared with current total supply of water

	2005	2030 Reference	2030 Alternative
OECD- North America	0% - 5%	0% - 8%	0% - 7%
OECD-Europe	0% - 11%	0% - 15%	0% - 13%
OECD-Pacific	0% - 20%	0% - 19%	0% - 15%
China	0% - 22%	0% - 29%	0% - 26%
India	0% - 14%	0% - 47%	0% - 37%
Rest of Asia	0% - 6%	0% - 22%	0% - 16%
Middle East	0% - 1%	0% - 3%	0% - 2%
Latin America	0% - 26%	0% - 54%	0% - 46%
Transition economies	0% - 0%	0% - 0%	0% - 0%
Africa	0% - 3%	0% - 4%	0% - 4%
TOTAL	0% - 1%	0% - 2%	0% - 2%

We see that, in general, the non-consumptive use of water does not represent a significant volume, although this changes when we look at specific regions. Thus, we see that for India, Latin America or China, future energy scenarios might imply a large fraction of the available resources. This situation might even become critical if we consider the seasonal character of hydro inflows, and therefore this may become an obstacle for energy production in some regions, unless water demand is properly taken into account when choosing among the different fuel production or power generation technologies – especially those related to cooling power plants –.

Now, we should also remark that this is more a temporal problem in the availability of water for energy than our central research topic, that is, to what extent energy production may affect the availability of water for other purposes. It this regard, it is more interesting to analyze particularly the amount of water really consumed by the energy-related processes, since non-consumed water may be used later for other purposes.

Table 7 shows the share of water consumption related to energy production compared to the total renewable water supply, by region.

We must remark however that the IEA World Energy Outlook does not provide regional figures for fuel production under the alternative scenario, and therefore for some situations it is impossible to compare the results between the reference and alternative scenario.

Table 7. Water consumption for energy compared to current total supply

	2005	2030 Reference	2030 Alternative
OECD- North America	0% - 1%	0% - 1%	0% - 0%
OECD-Europe	0% - 1%	0% - 1%	0% - 1%
OECD-Pacific	0% - 1%	0% - 1%	0% - 1%
China	0% - 1%	1% - 2%	0% - 2%
India	0% - 0%	0% - 1%	0% - 1%
Rest of Asia	0% - 0%	0% - 0%	0% - 0%
Middle East	1% - 15%	1% - 27%	0% - 1%
Latin America	0% - 0%	0% - 0%	0% - 0%
Transition economies	0% - 1%	0% - 1%	0% - 0%
Africa	0% - 0%	0% - 1%	0% - 0%
TOTAL	0% - 0%	0% - 1%	0% - 1%

Water demands for energy are not significant compared to the total supply, except for the Middle East, where, basically due to the scarcity of the annual inflow, the increase in energy demand expected for 2030 in the reference case may endanger the satisfaction of other water demands. The comparison with the alternative scenario is not meaningful, since the decrease in the demand of water is due exclusively to not accounting for oil production at the regional level under this scenario.

These figures do not seem relevant, but again we should remark that, although in some cases water inflows may be significant, what really matters is water consumption, and this should therefore be the real yardstick against which to compare water demands for energy production. In fact, in some cases it may be difficult to increase consumption if annual inflows are difficult to manage.

Table 8. Water demand for energy compared to current total consumption

	2005	2030 Reference	2030 Alternative
OECD- North America	2% - 9%	3% - 9%	2% - 5%
OECD-Europe	3% - 11%	3% - 11%	2% - 9%
OECD-Pacific	3% - 7%	4% - 9%	2% - 6%
China	2% - 5%	5% - 12%	2% - 8%
India	0% - 1%	1% - 2%	1% - 2%
Rest of Asia	0% - 2%	1% - 3%	0% - 2%
Middle East	1% - 26%	2% - 47%	1% - 1%
Latin America	2% - 16%	4% - 26%	3% - 15%
Transition economies	2% - 11%	2% - 15%	1% - 5%
Africa	1% - 10%	2% - 14%	1% - 4%
TOTAL	1% - 7%	3% - 11%	2% - 9%

In this case we see that water demand for energy becomes more significant. In many regions it may reach up to 10 to 20% of total consumption, which in turn may start to pose problems of competition with alternative uses, particularly irrigation and therefore food supply. As in the last case, we see that situations in Middle East and Latin America may become serious, and therefore it will be more important to use there those technologies which allow to produce energy with a minimal water demand. At the global level, the share of water demand for energy purposes does not increase much, with the alternative scenario resulting in a lower increase.

Finally, we may also compare the demand of water for energy with other industrial uses, in order to get a better idea of the competition that may arise between energy production and other industries regarding water demand.

Table 9. Water demand for energy compared to current industry consumption

	2005	2030 Reference	2030 Alternative
OECD- North America	5% - 20%	7% - 22%	4% - 11%
OECD-Europe	6% - 22%	6% - 22%	5% - 17%
OECD-Pacific	17% - 41%	24% - 54%	15% - 38%
China	8% - 21%	20% - 45%	9% - 31%
India	7% - 18%	19% - 44%	11% - 36%
Rest of Asia	8% - 33%	17% - 57%	9% - 33%
Middle East	44% - 932%	84% - 1693%	22% - 53%
Latin America	19% - 126%	34% - 213%	27% - 125%
Transition economies	6% - 37%	8% - 51%	4% - 16%
Africa	26% - 223%	45% - 336%	25% - 95%
TOTAL	7% - 36%	13% - 54%	11% - 48%

Here we see how some serious cases start to appear, besides from those already mentioned of Middle East and Latin America. However, these figures should be handled with care, given that the increase in the share of energy compared to the rest of industrial demands may result either from the increase in energy production by itself, or by the current demand of water for industry.

Thus, we can distinguish between the situation in China, the economies in transition, or OECD-Pacific, where industry already demands large quantities of water, and where hence there may be serious issues of competition for the water. This is particularly relevant in the case of China, where a large industrial development is expected for the future.

The cases of India, rest of Asia, and particularly Africa, arise in turn mostly from the currently low share of industry in water demand. That means however that, confronted with the large expected increase in water demand for energy purposes, adequate infrastructures should be deployed to facilitate the use of this water.

3.2 Influence of energy use on the availability of water

All these energy scenarios have been assessed against the current availability and consumption of water. However, and mostly due to the increase in energy production from fossil fuels and their consequent impact on climate change, we should expect a change in the availability of water for the future, a change that will be more drastic at the regional level, according to the estimations of the Intergovernmental Panel on Climate Change (IPCC, 2007).

That would further aggravate some of the problems detected, particularly in regions such as Asia, Africa or Middle East, where the availability of water may decrease. In other regions, we should possibly expect significant interregional variations, which cannot be captured by the geographical scope of this study. These problems will get worse with time, given that both the impacts of climate change on water availability, and energy consumption, will be larger.

In general terms, future estimations point not only to a decrease in the water inflow in some areas and increases in others, but also to a change in the seasonal pattern of these inflows, possibly with a larger concentration of rainfall. That can have several impacts: a lower availability of water for consumption, a lower production capacity of hydro power plants, and finally maybe a higher need of regulation of the inflows. Anyway, a rigorous analysis of this issue would require more disaggregated data at the regional level, both of the impact of climate change or of the impact on energy production.

4 Conclusions

Our first conclusion must be to acknowledge that there are several caveats about the results presented in this study, mostly due to the high level of aggregation of data, and also to the difficulty of estimating reliably some of the demands of water associated to energy production – particularly those related to biofuels, and to evaporation from reservoirs –. Regarding the latter, an update of the much useful but outdated Gleick (1994) study, and a particularization of its findings for different regions and technologies would be very much welcome, particularly for those countries or regions where potential problems with water demand may arise.

However, and in spite of all these limitations, it does seem possible to take home some general ideas about the impact of the current and future use of energy on water resources.

In general terms, we might say that the water demand for energy is not expected to increase dramatically at a global level for the energy scenarios considered, particularly under the alternative scenario. Therefore, and in a first take, it does not seem that energy will become a critical factor regarding global water demand. Although this of course depends on the evolution of alternative uses, it seems clear that there are other water uses which have a larger share of consumption, and therefore a larger potential to create problems (and also to generate savings).

But this is not to say that there might not be some regions with problems: Middle East and Latin America already show causes for concern, due to their high water demand for energy as a fraction of their current water consumption. Also regions like China, the economies in transition, or the Pacific may witness the rise of a competition for the use of industrial water, which is particularly relevant for those regions like China, from where a significant industrial development in the future is expected. Another issue to contemplate with caution is the possible temporal decoupling between water inflows and non-consumptive use of water which may arise in regions such as India, Latin America or China if care is not taken when choosing the right power generation technologies.

In these cases (and also in general terms), it seems necessary, given the large variation of water demand for energy depending on the technology chosen, to try to prioritize to some extent the use of less-water-intensive technologies in order to avoid the problems mentioned.

This need for prioritization increases if we take into account that, to a large extent due to energy production from fossil fuels, the expected change in climate will modify the availability of water resources, basically reducing the existing resources in already less-endowed regions, and generally affecting the regularity of the inflows. This will further aggravate the severity of the problems detected, and potentially may create other problems not considered here. It should be reminded that the availability of data makes us stop the study in 2030, a year in which the changes in the availability of water resources due to climate change will probably not be that relevant. In the longer term, these changes will be more significant, and energy demand will also increase, what will probably reinforce the trends identified. That makes even more necessary the effort to use energy technologies less intensive in water consumption, and at the same time to try to reduce the participation of fossil fuels for energy production.

References

EPRI (2002). *Water and sustainability (Volume 3): U.S. Water consumption for power production – The next half century*. EPRI Topical Report, March 2002.

Gleick, P.H. (1994). Water and Energy. *Annual Review of Energy and the Environment*, 19: 267-299.

IEA (2007). *World Energy Outlook*. International Energy Agency, Paris.

IPCC (2007). *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)], IPCC, Geneva, Switzerland, 2007

Pacific Institute (2008). The World's Water 2006-2007. http://www.worldwater.org/data.htm, visitado en Julio 2008.

US DOE (2006). *Energy Demands on Water Resources. Report to Congress on the Interdependency of Energy and Water*. U.S. Department of Energy, December 2006.