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Implications for Water of the World Energy Scenarios

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Implications for water of the world energy scenarios

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Abstract

There is an increasing concern in the energy sector about how to confront its growing water demand, in a global setting 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, thus increasing the risk of water stress. This paper tries to assess the new water uses related to the different energy scenarios, and the relative weight that energy uses of water will have on different regions under each one. Results show that, although there should not be significant problems at the global level, a careless selection of energy technologies and management of water resources might create problems in some regions, such as Middle East, China, Latin America or some parts of Asia. The right economic signals should be devised to avoid these potential crises.

1 Introduction

Water and energy are two essential elements for human development. Without water, life is not possible for human beings, who depend on it for their survival and also for their physical, economic, social and cultural welfare. In turn, energy access promotes economic development and improves living conditions by enabling the provision of health services, education and information and communication technologies.

And these two essential elements are very much interrelated. Energy is required to obtain water, and water is a necessary input for the extraction, processing and use of energy. Water can be considered as a productive factor in hydroelectric power generation and is a cooling medium in all processes of

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thermal generation. In this sense, it should be remarked that the power sector is now, after agriculture, the main user of water in most advanced economies. The projected increases of energy demand will therefore require more water, adding further to the numerous situations of water stress currently taking place across the world.

Although the world has huge resources of fresh water, its unequal distribution, poor management, unsustainable economic and demographic trends, and climate change generate problems at regional and global level. At the local level, water shortages are multiplying. Unsustainable management practices through all uses, and population growth have originated a situation where water withdrawals exceed the renewal capacity of water resources. The pattern and intensity of human activity have disrupted –through impacts on quantity and quality – the role of water as the prime environmental agent. In some areas depletion and pollution of economically important water resources have gone beyond the point of no-return, and coping with a future without reliable water resources systems is now a real prospect in some parts of the world, according to many. According to the World Bank, 80 countries now have water shortages that threaten their health and their economies, while more than 2 billion people have no access to clean water or sanitation. In this context, due to a growing water stress, it could be expected a greater competition for water resources not only among uses (agriculture, energy, industry…) but also among regions, especially those where river basins runs through different national borders.

This paper addresses one aspect of this problem, the demand for water from the energy sector. As mentioned before, energy demand is expected to increase very much in the near future, and this may create or strengthen water stress situations in some areas of the world. This analysis has only been carried out before at a local level, mostly in the US (USDOE, 2006). However, given the future prospects, it seems advisable to extend the scope of the assessment to the global level, to try to identify regions where water use by the energy sector may also create problems. Section 2 describes the energy scenarios used. Section 3 reviews the water demand for the different energy sources, and Section 4 presents the results on water use of the future energy scenarios considered. Finally, Section 5 offers some conclusions and recommendations.

2 The future energy scenarios

The International Energy Agency prepares every year an outlook of the future energy scenarios, in which both the demand and supply of energy by energy area are detailed, for the different energy sources. The Outlook generally presents figures for current energy use (2007, for the 2009 Outlook) and for 2030 under different scenarios. These scenarios include a business-as-usual one, which is used as reference, and an alternative scenario, in which additional environmental and energy policies are adopted.

Unfortunately, the most recent outlook does not use the same aggregation of countries for the reference and alternative scenarios, which makes it impossible to compare energy demand for the different regions of the world under these two alternative scenarios for 2030. Therefore, in this paper we use data from two different outlooks: we use figures from the 2009 outlook for the current (2007) and reference 2030 scenario, and then we use the 2007 outlook for the energy demand estimation corresponding to the 2030 alternative scenario, as an environmentally-conscious scenario with which to compare results for 2030.

As may be seen in Table 1, there are significant differences between the alternative scenario from the 2007 outlook and the one from the 2009 one (a scenario in which carbon emissions are restricted so that a concentration of 450 ppm in the atmosphere is not exceeded). Basically, fossil fuel demand is further reduced in the 450 ppm scenario, and nuclear and renewables are further increased, compared to the reference scenario. The total level of energy demand also decreases. Now the question is which of these two alternative scenarios may be more credible, something evidently difficult to gauge. Following the recent developments at the Copenhagen Conference of the Parties, we might expect the 450 ppm scenario difficult to attain. If we add that, as mentioned before, there are no consistent regional data for the 450 ppm scenario, it seems more reasonable to use the alternative scenario from the 2007 outlook.

In the following tables, we present the primary energy and electricity demand on a global level, for these three scenarios: one for the "current" energy use, 2007; 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.

Table 1. Primary energy demand (Mtoe)

	2007	2030 Reference	2030 Alternative	2030 450ppm
Coal	3184	4887	3700	2614
Oil	4093	5009	4911	4250
Gas	2512	3561	3447	2941
Nuclear	709	956	1080	1426
Hydro	265	402	465	487
Biomass and waste	1176	1604	1738	1952
Other renewable	74	370	444	720

TOTAL	12013	16790	15783	14389

Source: IEA (2007, 2009)

Table 2. Electricity production (TWh)

	2007	2030 Reference	2030 Alternative	2030 450ppm
Coal	8216	15259	10716	7260
Oil	1117	665	844	459
Gas	4126	7058	6602	5688
Nuclear	2719	3667	4144	5470
Hydro	3078	4680	5403	5659
Biomass and waste	259	839	1166	1448
Wind	173	1535	1800	2779
Geothermal	62	173	190	292
Solar	5	402	352	850
Tide and wave	1	13	24	34
TOTAL	19756	34292	31240	29939

Source: IEA (2007, 2009)

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. The same logic is followed: the figures for 2007 and for the reference 2030 scenario are taken from the 2009 outlook, whereas the figures for the alternative 2030 scenario are taken from the 2007 report. However, and due to space limits, we do not include them here, and rather direct the interested reader to the original reports.

3 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, 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 almost never a net consumption of water, since "consumed" water will in most cases 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 at a given moment.

The demand of water for energy may serve different purposes, depending on the activity involved. Besides, this demand may not only affect the amount of water, but also its quality (which evidently also affects 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
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 largely. 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 thus for 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 biofuels for food crops 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 (thousand 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 mining, extraction and refining, we consider that all the water used is consumed, generally due to the resulting level of pollution, 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 with only minor changes 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.

4 Impact of energy production on water consumption

4.1 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 figures 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 amount of freshwater used in industry, from Gleick et al (2008). The original data are given by country, and they have been aggregated for the same regions contemplated by the World Energy Outlook. There is however a time inconsistency, in that these latest water data belong to a 2006 update and the original country data are even older, whereas the energy consumption corresponds to 2007. We have been unable to resolve this inconsistency, although we do not expect it to be very large.

Table 5. Current use of water in the world (billion 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: Own elaboration based on Gleick et al (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. Although this water is not consumed, and therefore should not compromise alternative uses of water, these figures are relevant if considered in the opposite direction: a large amount of water used for energy purposes can also be seen as a reduced availability of water for energy production, and therefore as a possible limitation for it.

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

	2007	2030 Reference	2030 Alternative
OECD- North America	0% - 11%	0% - 12%	0% - 13%
OECD-Europe	0% - 19%	0% - 17%	0% - 15%
OECD-Pacific	0% - 22%	0% - 27%	0% - 26%
China	0% - 19%	0% - 49%	0% - 37%
India	0% - 6%	0% - 22%	0% - 16%

Rest of Asia	0% - 1%	0% - 3%	0% - 2%
Middle East	0% - 29%	1% - 55%	0% - 46%
Latin America	0% - 0%	0% - 0%	0% - 0%
Transition economies	0% - 3%	0% - 5%	0% - 4%
Africa	0% - 1%	0% - 2%	0% - 2%
TOTAL	0% - 5%	0% - 8%	0% - 7%

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, China or the Middle East, future energy scenarios might imply the use of 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 these 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 problem concerning 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. In 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 (oil, coal and gas) 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

	2007	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% - 13%	1% - 18%	0% - 1%
Latin America	0% - 0%	0% - 0%	0% - 0%
Transition economies	0% - 1%	0% - 1%	0% - 0%
Africa	0% - 0%	0% - 0%	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 – or alternatively the extraction of oil. 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. Again, this will depend largely on the technology chosen for oil extraction.

These figures do not seem relevant, but again we should remark that the comparison with renewable water resources may not be appropriate. The total amount of renewable water resources gives the maximum theoretical amount of water actually available for a country, taking into account all internally generated surface water annual runoff and groundwater recharge derived from precipitation falling within the nation's boundaries, and external flow entering from other nations which contributes to both surface water and groundwater. The extent to which this theoretical maximum can be developed to meet social and economic demands depends on a variety of economic and technical reasons.[‡] Therefore, the usable volumes available to meet economic uses will be considerably inferior to renewable sources.

According to the United Nations World Water Development Report 3 (World Water Assessment Program, 2009), about 75% of total annual runoff is accessible to humans. This indicator varies by region: Asia (95%); Eastern Europe, the Caucasus and Central Asia (45%); Latin America (66%); Middle East and North Africa (96%); Sub-Saharan Africa (93%); and OECD (69%).

Four additional limitations are inherent in the information provided by the renewable water resources indicator. First, seasonal variability in precipitation, runoff and recharge, which is important to regional and basin-level decision making and water storage strategies, is not well reflected in annualized quantities. Second, many large countries have several climatic settings as well as highly disparate population concentrations. Third, there is no data in the figure of renewable water resources that identifies the volumes of 'green' water[§] that sustain ecosystems – the volumes that provide water resources for direct rain-fed agriculture, grazing, grasslands and forests – nor does it account for the volumes of water that are potentially available from non-conventional sources (reuse, desalination, non-renewable groundwater).

Finally, to obtain the real water supply of a region or country it should be taken into account the role of "water regulation" in this supply, which is usually carried out by dams, since this may improve the development of

[‡] For example, Falkenmark and Rockstrom (2004) point out that, globally, approximately 27% of the world's surface water runoff occurs as floods. It is not a usable water resource even though it would be counted as part of the annual renewable surface water runoff component of renewable water resources.

[§] Soil moisture that confers direct support to rainfed cropping systems.

water resources. It is remarkable that some countries – e.g. Spain with 1,196 dams - have a reduced scope to increase their water resources supply through new regulation capacity. Besides, increasing concerns on environmental and social impact of water regulation infrastructures will mitigate, in general terms, the capacity to increase the share of renewable water sources used for meeting economic demands by these means.

Therefore, we may conclude that what really matters is water consumption, and this should therefore be the real yardstick against which to compare water demands for energy production. This comparison is presented in Table 8.

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

	2005	2030 Reference	2030 Alternative
OECD- North America	2% - 8%	3% - 8%	2% - 5%
OECD-Europe	3% - 10%	3% - 10%	2% - 9%
OECD-Pacific	3% - 7%	4% - 8%	2% - 6%
China	3% - 6%	5% - 12%	2% - 8%
India	0% - 1%	1% - 2%	1% - 2%
Rest of Asia	0% - 2%	1% - 3%	0% - 2%
Middle East	1% - 23%	2% - 31%	1% - 1%
Latin America	2% - 15%	4% - 20%	3% - 15%
Transition economies	2% - 11%	2% - 13%	1% - 5%
Africa	1% - 9%	2% - 13%	1% - 4%
TOTAL	2% - 7%	2% - 9%	2% - 9%

Now 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 in these regions to use 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 muc even under a business as usual energy growth.

Leaving aside the above considerations, 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

	2007	2030 Reference	2030 Alternative
OECD- North America	5% - 18%	6% - 19%	4% - 11%
OECD-Europe	6% - 21%	6% - 20%	5% - 17%
OECD-Pacific	18% - 40%	23% - 48%	15% - 38%
China	10% - 25%	20% - 46%	9% - 31%

India	8% - 21%	19% - 42%	11% - 36%
Rest of Asia	9% - 33%	19% - 49%	9% - 33%
Middle East	42% - 837%	65% - 1114%	22% - 53%
Latin America	20% - 120%	29% - 164%	27% - 125%
Transition economies	6% - 37%	8% - 47%	4% - 16%
Africa	26% - 220%	44% - 293%	25% - 95%
TOTAL	8% - 34%	12% - 46%	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.

4.2 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; 2008).

In this context, observational records and climate projections developed by IPCC provide evidence that freshwater resources are vulnerable and will be strongly impacted by climate change. Observed warming over several decades has caused changes in the large-scale hydrological cycle such as: increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff.

Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes and parts of the tropics, and decreases in some subtropical and lower mid-latitude regions. By the middle of the 21st century, annual average river runoff and water availability are projected to increase as a result of climate change at high latitudes and in some wet tropical areas, and to decrease over some dry regions at mid-latitudes and in the dry tropics. Many semi-arid and arid areas (e.g., the Mediterranean basin, western USA, southern Africa and north-eastern Brazil) are particularly exposed to the impacts of climate change and are projected to suffer a decrease of water resources due to climate change.

Globally, the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits. By the 2050s, the area of land subject to increasing water stress due to climate change is projected to be more than double that with decreasing water stress.

On the demand side, water stress will increase in the future due to important demographic and economic growth, which will increase the need of fresh water supply to meet demand. It will be especially important for agriculture sector (69% of worldwide water use is for irrigation), which will have to increase the supply of high water intensive products (e.g. meat and milk) to feed a growing volume of population form developing countries with higher incomes.

All these elements 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.

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. Some regional studies are currently being undertaken.

5 Conclusions

Our first conclusion must be to acknowledge that, in spite of the relevance of this issue and therefore of the need for good figures, there are several caveats about the results presented in this study, 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.

Furthermore, the interpretation of the results should take into account limitations inherent to the information provided by the renewable water resources indicator, which constitutes a indicator of the maximum theoretical amount of water actually available for a country.

However, and in spite of all these limitations, it does seem possible to take 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, which implies a greater importance of renewable energy and energy efficiency compared to reference 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.

Finally, it seems essential, in order to prioritize appropriately and incentive the right technologies, to increase and strengthen the use of economic instruments – particularly the use of the right prices for water – to guide the use of water and energy towards a path of exploitation, consumption and investment which provide the maximum welfare for society, while ensuring citizens' access to these essential services.

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