CHAPTER 17

Energy supply for the coming decades and the consequent water demand

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ABSTRACT: Electricity production and water consumption are key factors for a country to achieve economic growth and greater welfare. However, there is an important need of water consumption for electricity production through most current technologies and there are a lot of regions suffering from water scarcity. In the future, technology innovation will be a key issue to overcome this problem.

Within the energy sectors, electricity is the one with significant water consumption, although from a global perspective (compared to other sectors like agriculture and industry) it is not a problem. The faster electricity production mix will shift towards technologies using less water (most renewable technologies and others such as combined-cycle) the lesser water will be consumed per energy unit produced or demanded.

Some renewable technologies like concentrating solar thermoelectric or biofuels that could be a good solution for poor countries must improve their efficiency in order to reduce their water demand and become a real alternative in areas where they suffer from water scarcity.

Keywords: freshwater use, renewable technologies, thermodynamic cycle, cooling processes

1 INTRODUCTION

Energy, as well as population growth, agricultural efficiency rates, water use[1] and resource use, is among the most important factors that could jeopardize the sustainability of our presence on the earth in the long run. Additionally, most of these factors are related, and the nexus energy-water is a clear example. A complete analysis of the nexus energy-water, should take into account both sides of the problem: *water for energy* and *energy for water*. Without an accurate analysis though, it could be concluded, in terms of sustainability, that the issue *water for energy* could be considered more important because it ends up affecting water consumption more than the issue *energy for water* does. Then, it could be thought that the more water we need in order to produce a unit of energy, the more water through energy we will need to produce/deliver a unit of water. This is a true statement, but it is not an important issue in terms of resource use. It is important to improve the efficiency of water use, both from the supply side (technology) and from demand side (responsible and efficient consumption) and so to reduce the use of energy to obtain water. While it is important to develop water efficient processes to obtain energy, water use for energy is not a critical point in terms of global sustainability as we will see in this chapter. Besides, the critical problems of long term sustainability of energy use has to do with other things but not to water use if we take a global perspective. However, from a local perspective it could be a problem to place

[1] During this chapter I will include the concepts of *use*, *consumption* and *withdrawal* of water. The last will be used to refer to that water taken from a source (river or lake) but given back to same source afterwards, and then, not consumed. The term *consumed water* will be used to refer to the real consumption of water, that is, the water that is finally lost. The term *water used* will be mentioned in a general way, that is, it could be referred to anyone of the other two terms or the sum of both.

electricity power plants in areas that are suffering from water scarcity. Most poor countries suffer from water scarcity or lack water infrastructure. As they need to grow, they will need energy which could be a problem that could jeopardize their potential economic growth or damage their, in some cases, already poor environmental equilibrium.

The relation between water and energy is very old in human history. From the first mills used to produce mechanical work to the steam machine, mankind has taken advantage of this relation. But it is due to the invention of electricity when the use of water to produce energy increased dramatically. The old physical concept of moving a wheel using water is applied now to move an alternator-generator and producing electricity. Then, in electricity, most of current technologies need water to complete their thermodynamic processes, while in the hydrocarbons sector we also need water for pumping and other processes. However the specific water consumption[2] in the hydrocarbons sector is minimal compared to that in the electricity sector.

While water use for energy is not a problem from a global perspective, it could be a problem locally, in areas where water resources are being used up, depleted or consumed over the natural rate of recovery. In order to demonstrate these conclusions, in this chapter, I will include a forecast of the energy demand over the coming decades and the energy supply and water needs to cover it, pointing out the main conclusions.

2 THE ENERGY ISSUE

Since the end of the past decade, we have been seeing what could be called *an energy revolution*. Technology improvements will, in the medium or longer term, ensure that economic growth can be based on energy sources that will allow us to reduce our dependence on oil and gas. The key issue that triggered this revolution was, without any doubt, the challenge of climate change. Up to this moment, in the energy political agendas, the most important issues were oil and gas prices as well as dependence. A happy consequence of these challenges (price, dependence and climate change) is that all of them take us to the same or similar strategies and actions to be taken. That is, to invest in new technologies and to foster technology change and substitution. This fact will make reaching political consensus and the common effort and policies that have to be launched easier. Then, the energy problem could be summarized as in the following statement. Firstly, we should achieve a decrease in our dependence on fuels like oil and gas, without risking the security of supply and in doing so avoiding a solution with too high energy prices that could jeopardize economic growth. We cannot forget that economic growth is not only needed to create wealth but also it is needed to carry out the huge investments in alternative technologies we need for the future. Lastly (last but not least at all), this revolution should allow us to evolve to a low emissions economy, up to the level of 450–550 ppm (IPCC, UN Intergovernmental Panel on Climate Change). According to IPCC, with this level of CO_2 emissions, it is expected that the average temperature increase will be at most between 2°C and 3°C.

3 THE FORESEEABLE ENERGY DEMAND FOR THE COMING DECADES AND HOW WE ARE GOING TO COVER IT

The International Energy Agency (IEA) considers that the total primary energy demand will grow at an average of 1.6% annually until the year 2013, while the final energy demand will grow at a rate of 1.4% annually. That means that in 2030 we will be consuming 17,014 Mtoe (million tonnes of oil equivalent) while in 2006 we consumed 11,730 Mtoe. This projection will make jump the CO_{2e} emissions[3] from $27{,}889 \times 10^6$ t (t = tonne = 1,000 kg) to $40{,}553 \times 10^6$ t in 2030,

[2] Consumed water to produce a unit of energy.

[3] CO_{2e} means CO_2 equivalent, in order to take into account the rest of the greenhouse gases, being CH_4(methane) the most known besides CO_2.

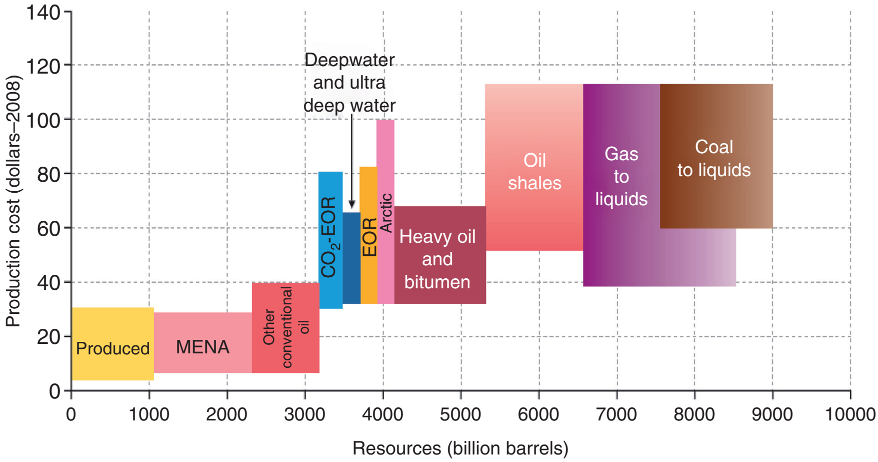


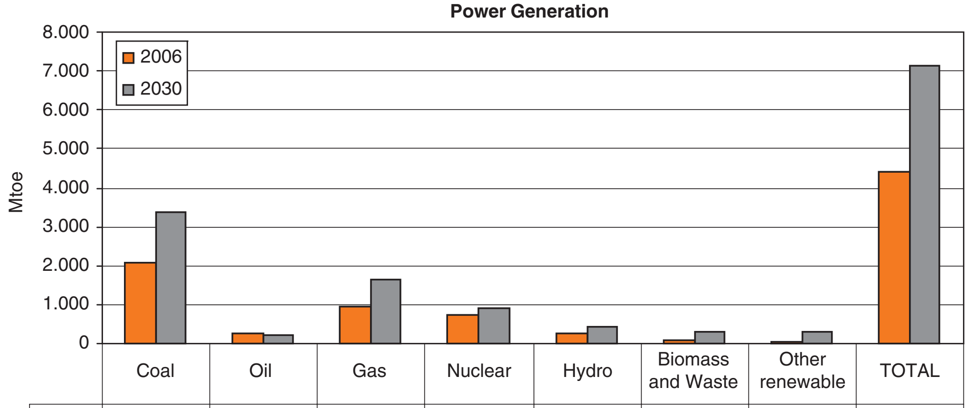
Figure 1. Long-term oil supply cost curve. Ultimately recoverable oil resources.[4]
Source: International Energy Agency (IEA, 2008).

with an annual growth rate of 1.6%. Electricity consumption accounts for 16.6% of our world current energy consumption. The IEA expects this figure to jump to 21.2% in 2030, which is a logical consequence of the higher average living standards of the world in 2030 compared to now. However, the higher weight of electricity on the total energy consumption means, keeping the current technology, more water consumption.

3.1 *Oil and gas sector*

From an strategic point of view, it is possible to maintain that the world is not running short of oil and gas and will not be at least for this century. The challenge facing both oil and gas sectors is related mainly with a lack of investment in production to match the demand growth, coming mainly from Asian countries like China and India. This fact will take us to a so-called peak-oil. That means that in the next decades we will live in a world with high oil and gas prices due to the pressure of demand over the supply. However, if we take a look on Figure 1, what is called *the ultimately recoverable conventional oil resources* (which include initial proven and probable reserves from discovered fields, reserves growth and oil that has yet to be found), amounts to a figure of 3.5 trillion (3.5×10^{12}) barrels. Only a third of this total has been produced up to now. If we take into account non conventional oil like extra-heavy oil, oil sands and oil shales, the figure amounts to 6.5 trillion (6.5×10^{12}), and finally, if we add coal-to-liquid and gas-to-liquid, the potential increases up to about 9 trillion (9×10^{12}) barrels. On the other hand, the production of these non conventional resources will bring the price significantly high. To sum up, the problem of oil (and it could be applied the same rational to gas, taking into account non conventional sources like methane hydrates), has not to do with reserves, but with the production rate and investment, the price and geostrategic issue due to reserves concentration in some areas of the world and, of course, the problem of climate change due to the CO_2 emissions. During the next decades, the world will keep on basing its growth on the conventional technologies or fuels like oil, trying to introduce alternative technologies in order to diminish its dependence. Yet, the speed of this progressive substitution will depend on governmental policies, prices and alternative technology improvements. The higher the price of conventional fuels the bigger the chances for alternative technologies. That is why, in spite of oil being the fuel that

[4] This curve draws the price without royalties and taxes. So, we have already produced around 1 trillion (10^{12}) barrels at an average cost of US$ 30/barrel (prices 2008).



	Coal	Oil	Gas	Nuclear	Hydro	Biomass and Waste	Other renewable	TOTAL
2006	2.075	277	947	728	261	81	55	4.424
2030	3.375	204	1.664	901	414	286	287	7.130

Figure 2. Expected current and future (2030) power generation (electricity) in the world.
Source: International Energy Agency (IEA, 2008).

grows less, in the forecast of IEA for 2030, still it accounts for the biggest part of world total energy demand.

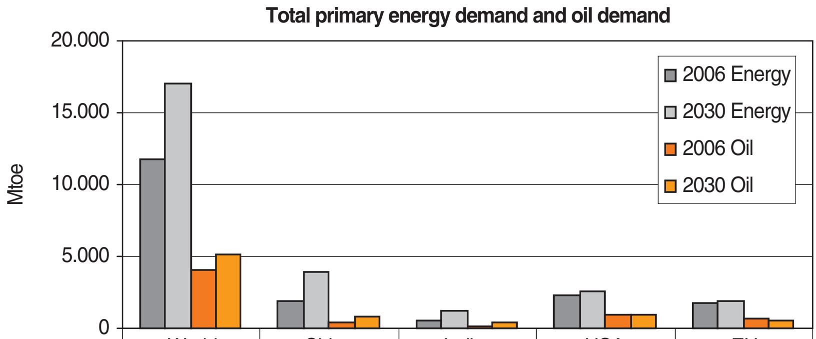
The Enhanced Oil Recovery (EOR) technologies (and other more advanced technologies like ERC and MRC: Extreme Reservoir Contact and Maximum Reservoir Contact), consist on the recovering oil from the fields above the actual average rate (35%). In the future, it will be used CO_2 to recover oil at this rate and above it, so that it will bring about significant water savings. However, in this chapter, in order to figure out the *water for energy* used in the oil sector in a worse or bad case scenario, we will consider that it is being used the current technology (that is, using water).

3.2 *Electricity sector*

Electricity will contribute during the next years with the main part of the solution to the energy challenges. This is because the main innovations on alternative technologies have taken place in this sector. There are technologies like wind, for example, that have achieved a good degree of economic viability over the last decades, something that has not happened in other subsectors within the energy sector. Besides, hydro power technology has been working all over the world for the last century. These facts, as well as others like the nuclear option, makes possible in the electricity sector, to invest in clean technologies and to achieve a good amount of electricity CO_2-free. Besides a whole bunch of renewable technologies which are close to achieve economic viability (taking into account technology improvement, high prices of conventional fuels and other issues like CO_2 prices), some not renewable but CO_2-free/minimizing technologies like CCS are advancing quickly in its way to economic competitiveness. This, together with the fact that societies increase the weight of electricity in their energy portfolio as they achieve higher levels of welfare, makes electricity technologies a key issue for the future. Besides, in this chapter we are focusing on water use for energy and it is the electricity sector, compared to other, the one that uses more water for a produced unit. Figure 2 shows that coal will be responsible for the main part of the electricity demand increase in the coming years.

3.3 *Energy key elements: EU, China, India and the USA*

Tackling successfully the challenge of climate change, will depend on the success achieved in three countries: China, India and USA. If we take a look at Figures 2 and 3, we realize that it is in these countries where the energy issue game is being played. Even if Europe were able to reduce



	World	China	India	USA	EU
2006 Energy	11.730	1.898	566	2.319	1.821
2030 Energy	17.014	3.885	1.280	2.566	1.903
2006 Oil	4.029	352	136	937	668
2030 Oil	5.109	814	346	881	602

Figure 3. Foreseeable total energy primary demand and oil demand.
Source: International Energy Agency (IEA, 2008).

a good amount of its emissions, China will write off this savings with some years growing at rates around 8%.

In 2030, the world will have doubled (in the IEA reference scenario) the CO_2 emissions from $20{,}000 \times 10^6$ t up to $40{,}500 \times 10^6$ t. Out of this increase, coal will contribute with an increase from $8{,}300 \times 10^6$ t to $18{,}600 \times 10^6$ t, that is, from a 42% to a 46% of the total emissions. China will increase its share on the total emissions from a 10.7% in 1990 to a 29% in 2030. USA will decrease its share from the 23.1% to a 14.3%, India from the 2.8% to an 8.1% and the EU from the 20% to a 9.2%. Besides, coal will be responsible of 77% of the China's emissions increase, 67% in India and 54% in USA.

Europe is making a huge effort to reduce its emissions. It is expected that in 2030, the EU emissions will be even below the 1990 level; however within the same period, in a business as usual scenario, China will have increased its emissions 32 times the decrease achieved by EU in the same period. To make the problem more difficult to solve, China will keep on relying on coal due to sovereignty as well as political and social issues. This is why, technologies like CCS are so important to try to curve the emissions of countries like China, India and USA, all of them producing a good amount of electricity from coal, and with a big amount of reserves on their land. This is the main reason why the production of electricity from coal will not decrease as it could be logical to think if we take into account that this is may be the worse conventional electricity technology from a CO_2 emissions point of view.

4 WHAT WILL BE THE WATER NEEDS FOR THE ENERGY PRODUCTION IN THE FUTURE?

As we said before, power plants use water to complete its thermodynamic cycle, using water as a heat carrier in most technologies. The shift towards combined-cycle gas turbine (CCGT) technologies over the last decade and the increase of this technology in the electric generation mix, entail an important amount of water savings, because CCGT avoids the use of water as a heat carrier in the first part of the cycle, so that, this kind of technology is more efficient in water use per MW·h produced than other conventional technologies.

Table 1. Water Withdrawal and Consumption for Electric Power Generation.

		Water Use Intensity (m^3/MW·h) Steam Condensing	
Plant-type	Cooling Process	Withdrawal	Consumption
Fossil/biomass steam turbine	Open-loop	75–190	0.75–1.14
	Closed-loop	1.14–2.28	1.14–1.82
Nuclear steam turbine	Open-loop	95–227	1.51
	Closed-loop	1.90–4.16	1.51–2.72
Natural Gas Combined-Cycle	Open-loop	28.4–76	0.38
	Closed-loop	0.87	0.68
Concentrating Solar	Closed-loop	2.83	2.80

Sources: EPRI (2002), MMA (2004) and other self-made calculations.

Besides the thermodynamic cycle, power plants use water for cooling purposes. For both reasons, power plants need to use water and to take it from a source like the sea, a river, etc. Most of this water that a plant needs to take or withdraw is used in the process but not consumed, because it is reused in the process or returned to the river where it had been taken. *Consumed water* would be the lost water after the whole process. There are plants that base its cooling process on water withdrawn from the sea, thus, our concern has to deal with those plants taking water from fresh sources.

Power plants also consume water for cycle make-up, washing equipment, coal ash transportation. However, with the exception of water used for fuel processing in gasification combined-cycle plant, among the mentioned process using water in a power plant, only cooling processes have a consumption of water that should be taken into account for the purpose of this chapter. The rest of processes have a very small consumption of water compared to it.

Then, water withdrawal will be strongly determined by the type of cooling process used. Power plants need to condense large amounts of low pressure steam water for return to plant's heat source for re-boiling. This step is achieved through an exchange of heat with a large quantity of cooling water. The warmed cooling water is either returned to the source where it was taken or cooled itself for re-use via evaporative heat transfer in a cooling tower or pond. In either case, a portion of water is lost or, what we have called *consumed water*, via evaporation to the atmosphere.

There are two main types of conventional cooling systems. In the once-through cooling or open loop process, a large quantity of water is withdrawn from its source and after returned to it at a quantity similar to that removed. The loss is due to the evaporation and only a small part (around 1%) could be considered as consumed. Usually, in these systems, the cooling process is design on the basis of a maximum allowable temperature increase above the natural water temperature of the source set by the environmental regulations.

In the closed loop systems, plants withdraw a much smaller quantity of water, because it is recirculated, but most of water is lost or consumed via evaporation in a cooling tower or pond. There are though other systems called *dry* using air-cooled condensers.

Then, the primary goal of cooling processes (used also in refineries, petrochemical plants and other industrial processes to remove heat) is to remove the heat absorbed in the circulating cooling water systems. Table 1 shows the water use and consumption in the power generation sector for each technology. The circulation rate of cooling water or water withdrawal in a typical 700 MW coal-fired power plant (working 6,000 equivalent hours) amounts to 75–190 m^3/MW·h if the plant uses an open-loop and 1.14–2.27 m^3/MW·h if it uses a closed-loop. The consumed water will be 0.75–1.14 m^3/MW·h and 1.14–1.82 m^3/MW·h respectively. The above mentioned plant will end up using through the year 315–800 Mm^3 with a water consumption of 3.1–4.8 Mm^3 if it uses an open-loop and 4.8–9.5 Mm^3 with a consumption of 4.8–7.6 Mm^3 if it uses a closed-loop. In the

Table 2. Water consumption for hydrocarbons and their substitutes.

Fuel type and process	Relationship to water quantity	Water consumption per-unit-energy (L/MW·h)[a]
Conventional Oil & Gas		
– Oil Refining	Water needed to extract and refine;	90.4–258.4
– NG Extraction Processing	water produced from extraction	25.8–28.7
Biofuels		
– Grain Ethanol Processing	Water needed for growing feedstock	155.04–2,067.2
– Corn Irrigation for EtOH	and for fuel processing	32,300–408,272
– Biodiesel Processing		51.7–64.6
– Soy Irrigation for Biodiesel		178,296–775,220
– Lignocellulosic Ethanol and other synthesized Biomass to Liquid (BTL) fuels	Water for procession; energy crop impacts on hydrologic flows	310–1,938 [b,c] (ethanol) 180.9–1,162.8 [b,c] (diesel)
Oil Shale	Water need to Extract/Refine	
– In situ retort		12.9–116.3[b]
– Ex situ retort		193.8–516.8[b]
Oil Sands	Water need to Extract/Refine	258.4–646

[a]Ranges of water use per unit energy largely based on data taken from the Energy-Water Report to Congress (DOE, 2007).
[b]Estimates based on unvalidated projections for commercial processing.
[c]Assuming rain-fed biomass feedstock production.

case a dry system were used, there would be no water consumption, but the efficiency of the plant would be lower than in the other cases, so that it would use more primary fuel to produce the same electricity and then the CO_2/MW·h ratio would be worse too.

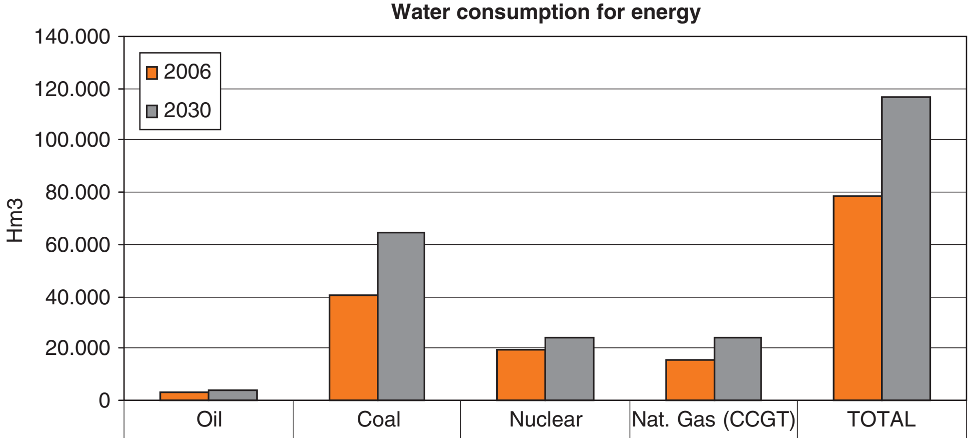
Water consumption of petroleum and gas industry is difficult to quantify in the production or upstream activities. In the case of oil production some fields used to inject natural gas or are currently injecting water in order to extract oil and make the pressure up inside the field, but eventually, the quantities of fluid injected will depend on the geological structure of the field. For example, in fields that are using water to extract oil and need to make the field pressure up, like those on the North Africa, could be used a ratio of 8 L/barrel[5]. Besides, the oil extraction activity produces large amounts of water coming out together with the oil. The new technologies use CO_2 to do so, and mainly the EOR-CO_2 is one of the future ways to increase the efficiency of this activity. The variety of cases is so wide that to set a figure or a ratio for this activity could be misleading. In any case, the use of water in conventional oil production could be considered as not significant compared with other energy activities.

Petroleum refineries also have very large cooling systems. A typical refinery has a water consumption of 0.5 m^3/t of processed oil, although in some cases this figure could jump up to 1.5 m^3/t of processed oil.

When talking about other non conventional oil, like oil sands, the use of water becomes significant as shown in Table 2. Alternative fuels to oil have a significant consumption of water compared to it. For example, in the case of biofuels or synthetic fuels like CtL (Coal to Liquid), water is used for agricultural irrigation and fuel processing and to complete the synthesis process respectively. Biofuels need a good amount of water, but in the future, second generation biofuels can overcome this challenge and reducing significantly the water needs.

Tables 1 and 2 show a summary of water consumption by technologies and activities in the energy sector.

[5] The figure belongs to a real field although the reference is omitted for reasons of confidentiality.



	Oil	Coal	Nuclear	Nat. Gas (CCGT)	TOTAL
2006	2.982	40.322	19.230	15.894	78.428
2030	3.781	64.822	23.800	24.240	116.642

Figure 4. Water consumption for energy in the main electricity production technologies.

Using the projections and forecast of energy demand for the next decades we can approximately draw the water consumption of water for energy in the next decades and draw some conclusions from it.

In Figure 4, it has been drawn some of the energy activities along with their water consumption. Oil has a not significant consumption and most of it takes place in the refining activity. As it has been pointed out through this chapter, the main water consumption takes place in the electric generation activity. In absolute figures (Mm^3 of water consumption), coal is the first consumer, followed by nuclear and natural gas power plants. In order to simplify the analysis and draw the Figure 4, it has been taken average specific data of water consumption per energy unit produced for every technology. This assumption implies a worse case scenario because technology will improve in the next years and environmental requirements will push companies to choose those systems that minimize water consumption. In any case, although the water consumption, in absolute figures, is huge (in the case of coal, for example, its consumption is even bigger than the overall consumption of fresh water in a country like Spain), they are very small if we compare them with the world water consumption in other activities like agriculture or industry.

For example, we can compare these data with the consumption of water in Spain which is around 35,000–40,000 Mm^3 (MMA, 2004), or with the world consumption of blue and green water to produce food which is 5,300–6,000 km^3/yr, or with the water consumed in irrigated land which is 2,000–2,500 km^3/yr (according with different figures obtained in several chapters of this book). We can see that the water consumption in electricity production, now and in the future, is not enough significant as to be considered as a problem.

However, the amount of water a plant needs does not represent a problem in global terms, but it can be a real problem in some areas of the world where they suffer from water scarcity. Even in the area of renewable energy, one of technologies with a very brilliant future as it is the solar concentrating thermoelectric power plant needs a good amount of water to work. A typical 50 MW plant needs 1 Mm^3 of water withdrawal with a 25% of consumption. Taking into account that this technology works with direct radiation and in some areas where there is high sun radiation (like in the South of Europe or North of Africa), there is also water scarcity, a high target of installed capacity in those areas will be a challenge that we have to overcome. The only way to do it is through the improvement of technology in order to make it more efficient in its water consumption needs.

5 CONCLUSIONS

The fast growth of fresh water demand due to increase of population, economic development and environmental requirements have made many areas of the world vulnerable to water shortages. This fact affects agriculture, industry but also energy industry and mainly electricity production which needs to be produced close to demand and uses water to complete its processes. The dependence on electricity production and water availability can jeopardize some economies to grow and to achieve a good level of wealth or standard of living. In the future, technology innovation will be a key issue to overcome these challenges. While water consumption from a global perspective is not a problem, it will in some areas suffering from water scarcity, adversely affecting these areas in their potential economic growth.

Within the energy sectors, electricity is the one with significant water consumption, although from a global perspective (compared to other sectors like agriculture and industry) it is not a problem. The faster electricity production mix will shift towards technologies using less water (most of renewable technologies and others like combined-cycle) the less water will be consumed per energy unit produced or demanded.

Some of renewable electricity technologies like concentrating solar thermoelectric must improve its efficiency in order to reduce its water demand and become a real alternative in areas where they suffer from water scarcity. Biofuels, aside from other challenges like deforestation and feedstock prices interference, will have to look for processes reducing water consumption too. In this case, second generation biofuels can solve this problem.

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