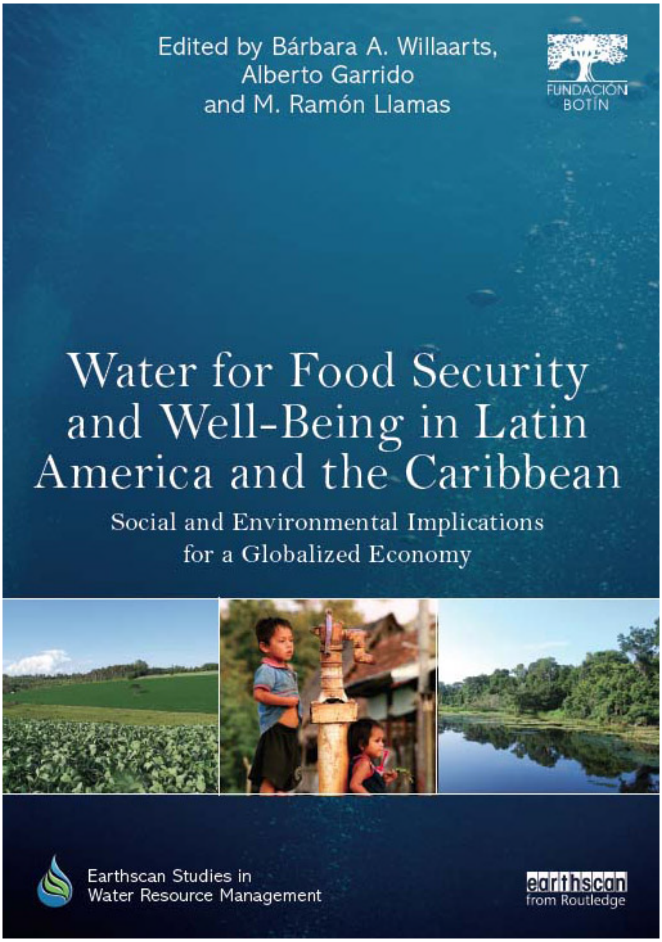


**Chapter 9**

Water, energy, bioenergy, industry and mining

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# 9

# WATER, ENERGY, BIOENERGY, INDUSTRY AND MINING

**Authors:**
Emilio Custodio, Dept. Geo-Engineering, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain
Alberto Garrido, Water Observatory – Botín Foundation, and CEIGRAM, Technical University of Madrid, Spain

# Highlights

- Hydropower is the main energy source in the Latin American (LA) region as a whole (52%), although not in all countries and its relative weight has decreased. It still has growth potential, but new projects will face growing physical, economic and social barriers, including environmental restrictions, the rights of native and local inhabitants, and biodiversity conservation. In some locations hydropower may reduce water availability and security for other uses.

- Fuel energy production may compete for a large part of available water resources in some of the highly populated and semi-arid and arid areas, even when they use closed-cycle water cooling or are placed at coastal areas. Nuclear energy and other forms of energy production are less developed and their effect on water resources is local. Some interesting geothermal energy production exists.

- Mining and related industrial sectors stand amongst the fastest-growing industries in the region. They may be water resource intensive and consequently affect water availability and security when located close to urban areas or in arid areas. So their water needs and consumption, together with their wastewater and mining residues, are becoming stressful factors and a significant source of pressures in numerous basins in the region. In some cases non-renewable groundwater reserves are consumed. In some areas artisanal and small mining activities cause some serious pollution problems to downstream water resources, as is the case of gold mining.

- Industry, energy production and mining together consume 8 to 15% of water resources in the seven considered LA countries.[1] Water consumption relative to available water resources is respectively 4 to 9% for industry, 2 to 5% for energy production (hydroelectric energy water consumption not included) and up to 6% for mining. Water economic productivity in Chile may range from 3 to 10US$/$m^3$.

- Crops grown for biofuels are increasingly becoming major export products, with a large production in Brazil, and Argentine being now the second largest exporter. Many countries in LA are promoting the cultivation of crops for biodiesel and bio-alcohol. Water resources and land used for these crops compete with land for food production. Especially concerning are projects in dry areas where intensive irrigation is needed.

1 This chapter focuses mainly on Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico and Peru.

## 9.1 Introduction

This chapter focuses on two topics that are usually considered separately. First, the amount of water required by energy-producing plants. Second, two economic sectors – mining and industry – are also water-demanding and are experiencing tremendous growth in the Latin American (LA) region. A detailed treatment of both would request at least a chapter for each of these topics, but being the focus of the volume water and food security, a review of data and their analysis from this narrower perspective has been chosen.

For the most part this chapter refers to continental LA, and specifically to the seven Ibero-American countries (Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico and Peru) that have provided data from their country reports.[2] However, the discussion goes beyond political boundaries in order to consider different geographical and climatic areas. Except for the large islands of Cuba, Hispaniola (the Dominican Republic and Haiti) and Puerto Rico, the Caribbean area consists of small islands with specific characteristics that introduce quite different circumstances for water resource security, which in some cases involve seawater desalination as an important complementary source. For this reason, they will not be included in what follows. Unless otherwise indicated, in this chapter only mobile water resources (blue water) are considered. Water use refers to water supplied to the activity and water consumption is the part of water used that is not available afterwards due to evaporation, impaired quality or disposal into the sea or a water body that has no further possible use downstream.

Water is needed for many human activities beyond drinking purposes, urban services and the production of food and fibres. It is also used for industrial processes – including food processing and fuel production – and for mining. Additionally, water resources are used for energy production and consumed whilst energy is also needed to make water available for use and for the treatment and safe disposal into the environment thereafter. There is competition for using and securing water resources between all these demands. The important related topic of water security in urban areas is considered in Chapter 8. Except for agriculture, bio-fuel production – a particular form of water intensive agriculture – and hydroelectricity – which uses large water flows but consumes a small part – the other activities often demand a moderate fraction of LA countries' water resources.

Although water consumption for energy, industry and mining may only be a small percentage of the countries consumption, it could be locally significant, especially in small basins and in the arid and hyper-arid areas of LA. This consumption may also be economically and socially important, and therefore water quantity and quality should be guaranteed. Industrial and mining activities may generate wastewater and by-products that could have a large negative impact on water resources quality and on the environment. Circumstances are quite different from one country to another and even inside a given country, as shown along this book, so generalizations may be meaningless. Thus, country

2 These country reports include data and analyses carried out by the project partners. A summary of the consortium and specific represence is include in the volume´s foreword and introductory section.

comments give only a coarse and blurred picture – sometimes too biased – that has to be afterwards considered in more detail taking into account actual territorial circumstances and local situations.

Data and analysis provided here serve to give a general overview of the situation in the first decade of the 21st century. Most LA countries are under fast development and, in spite of fluctuations and some political instability in some of them, conditions have and will continue to improve. The associated industrial and mining development – partly fostered by current high prices for minerals in many of the LA countries – contributes to increased water resources use and consumption and energy demand but also to a more efficient use in economic terms. Estimates of future evolution trends can be found in WEC (2010) and Jiménez-Cisneros and Galizia-Tundisi (2012).

This chapter does not try to present a detailed bibliographical review of energy – including bio-energy, industry, mining activities and water use but instead to contribute to an evaluation of how the associated water needs may affect water and food security in LA. This is done by examining existing data in the reports of the partner countries amongst other sources of information and personal experience. Partners' reports are cited as LA-country (2012) except when specific data are attributed to particular authors (see footnote 2). A general overview is first presented, followed by specific comments on water use and consumption in energy production, industry and mining, which leads to some considerations on water security from the point of view of the activity undertaken and subsequently of general human water needs.

## 9.2 General overview

Table 9.1 shows some basic data on water use for energy, industry and mining. Hydroelectricity has a large water use (demand) but only a small fraction is consumed. While traditional mining may demand rather large water quantities that are disposed of, modern mining is predominantly a water consumer since internal recycling is important. However, the fraction of water that is disposed of may be unusable and, what is more, may impair water quality downstream, which is equivalent to additional water consumption.

The economic productivity of water is an important driver for water rights acquisition in areas where the resource is scarce, but there are other factors to be considered such as legal restrictions, existing rights – local customs and rights may already be in place amongst natives – and social pressure.

The average economic productivity of water use has been estimated for Chile (Table 9.2) and is markedly higher in industry and the mining sector, e.g. for copper production the value may exceed 50US$/$m^3$. This in turn explains the pressure they impose in order to get water resources when they are scarce, as is the case in the northern part of the country. This may also account for the fact that the companies involved have a greater capacity to purchase water rights in order to secure their supply (see Chapter 13). The very low productivity of water for energy production derives from the fact that in Chile a large fraction of energy production is hydroelectric power that uses large water flows but only consumes a small fraction. If actual water consumption is considered, which is highly variable from one plant to another, the economic productivity of water becomes much higher. Besides, many hydroelectric plants use water resources in remote areas, where no other significant productive uses exist except forestry, fishing and landscaping. Associated externalities are a cost that is often not accounted for. Jiménez-Cisneros and Galizia-Tundisi (2012) gives an average water use productivity in Mexico of 78US$/m$^3$, varying from 1.3US$/m$^3$ in agricultural states to 100US$/m$^3$ in the Federal District, where urban and industrial uses dominate.

**Table 9.1 General data for the first decade of the 21st century (values rounded up)**

| | SURFACE AREA | POPULATION | USABLE WATER | | | WATER USED | | WATER CONSUMED | | | % OF WATER CONSUMED FOR | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1000km$^2$ | Million | km$^3$/yr | mm/yr | % GW | km$^3$/yr | mm/yr | km$^3$/yr | mm/yr | m$^3$/cap./year | ENERGY [3] | INDUSTRY | MINIG | TOTAL |
| MEXICO | 1,973 | 117 | 550 | 279 | 29 | — | — | 80 | 40 | 683 | 5 | 4 | 0.07 | 9 |
| COSTA RICA | 51 | 4.7 | 110 | 2,157 | 30 | 25 | 490 | 0.5 | 10 | 106 | — | — | — | |
| COLOMBIA | 1,142 | 46 | 2,640 | 2,312 | 20 | 1,200 | 1,051 | 11 | 10 | 239 | 2 | 5 | — | 7 |
| BRAZIL | 8,515 | 197 | 10,110 | 1,188 | 19 | — | — | 58 | 7 | 294 | — | — | — | |
| PERU | 1,285 | 29 | 2,046 [1] | 1,592 | 13 | 32 | 25 | 20 | 16 | 690 | 2 | 4 | 2 | 8 |
| CHILE | 756 | 17 | 1,060 | 1,402 | 14 | 140 | 185 | 15 | 20 | 882 | [2] | 9 | 6 | 15 |
| ARGENTINA | 2,780 | 40 | 1,750 | 629 | 14 | 650 | 233 | 190 | 68 | 4,750 | [2] | 6 | | 6 |

1 1.8% of this amount in the Pacific area, where most human and industrial activities are done
2 Included in industry
3 Consumption by evaporation in surface reservoirs for hydroelectricity in generally not considered

*Source: own elaboration based on LA–Argentina (2012), LA–Brazil (2012), LA–Chile (2012), LA–Colombia (2012), LA–Costa Rica (2012), LA–Mexico (2012), LA–Peru (2012).*

**Table 9.2 Economic productivity of used water in Chile**

| USE | AGRICULTURE AND FORESTRY [1] | HUMAN SUPPLY | INDUSTRY | MINING | ENERGY |
|---|---|---|---|---|---|
| US$/m$^3$ | 0.3 | 2.4 | 7.4 | 4.5 | 0.02 |

1 Soil (green) water not included

*Source: LA–Chile (2012).*

# 9.3 Energy and water

## 9.3.1 Energy for water

Energy is needed to abstract, pump, transport and treat surface and groundwater. The specific energy consumption (kWh/m$^3$) may become significant due to:

- pronounced altitude differences, such as sloping land in urban areas, physical barriers to be overcome in mountainous areas, or when groundwater levels are deep in highly transmissive and intensively exploited aquifer systems, especially under arid conditions
- long distance transportation to supply large urban and industrial areas from remote sites

- high salinity or presence of unwanted components, such as nitrates, fluoride or arsenic; energy-consuming treatments such as membrane processes are used to reduce their concentration
- sewage water treatment before discharge, to a degree that depends on the assimilation capacity of the surroundings and the environmental requirements; energy consumption increases with treatment intensity, and especially when the water is to be reused via water reclamation
- improved irrigation methods that need pressurized water.

In order to produce the energy needed, water resources are also used and consumed. In order to have a complete picture, the energy consumed during the construction of the water works and that for their maintenance and repair should also be included and distributed along the life time of the works. This includes energy to produce the cement and iron consumed and for excavation, drilling and earth movement. Generally this energy is a small fraction of that spent on the cumulative water production over time, but not always, and should appear in the energy footprint, albeit seldom known or considered.

### 9.3.2 Water to produce energy

Large water flows are needed to produce any source of energy except for wind and sea energy and direct conversion of solar radiation. Results from a wide-ranging survey are shown in Table 9.3. Some comments on the common energy sources follow.

**Table 9.3** **Energy and water in Latin America and the Caribbean (LAC) in 2005**

| ENERGY SOURCE | PRIMARY PRODUCTION ($10^{15}$ J) | ELECTRICITY GENERATION ($10^3$GWh) |
|---|---|---|
| TOTAL WORLD | 460 | 10,100 |
| TOTAL LAC | 25.4 | 909 |
| COAL AND LIGNITE | 1.3 | 29 |
| OIL (1) | 14.6 | 88 |
| NATURAL GAS | 5.0 | 105 |
| NUCLEAR | 0.2 | 20 |
| HYDROPOWER AND GEOTHERMAL | — | 629 |
| BIOMASS (2) | 4.3 | 36 |
| SOLAR AND WIND | — | 2 |

1 1.2 x$10^{15}$J of production are from non-conventional fossil sources using 4.0km$^3$ of water
2 2.7 x$10^{15}$J of production is non-traditional

*Source: modified from WEC (2010).*

#### 9.3.2.1 Hydroelectricity

Hydroelectricity is a renewable energy that still has a large potential for further development in LA. It is often considered environmentally friendly but there are important side effects to be evaluated. Hydro-energy plants modify the natural water regime and this has quantity, quality, environmental and health consequences – externalities – and may imply a loss of other opportunities for water use, as well as human displacements and the creation of territorial barriers. On the beneficial side, dams may facilitate the interconnection of otherwise isolated areas and evaporated water helps to stabilize the local climate.

Although hydroelectricity is often presented as an example of a non-consumptive water use, there is an associated consumptive use of water that should be taken into account. This refers mostly to the fraction of the used water lost to evaporation, especially when extensive water storage areas are needed in flat areas located in warm and arid climates. Evaporation rates up to 1m/year are common and may be exceed 2.5 m/year in some areas. In flat areas this may be significant for downstream river basin resources. These water losses can be added to the water consumption footprint of energy production.

Water resources consumption due to evaporation associated with hydroelectric production range from 0.04 to 210m$^3$/GWh, with median values ranging from 2.6 to 5.4m$^3$/GWh (Torcellini et al., 2003; Freedman and Wolfe, 2007; WEC, 2010), depending mostly on the surface area exposed to evaporation, relative to the stored volume, climate, timing of storage, and the altitude difference between the reservoir level and the turbine discharge point. Water consumption increases from mountain environments to lowlands. From data in Mekonnen and Hoekstra (2011) considering thirteen hydroelectric plants in South America, covering very large to medium-size ones and from deep storage reservoirs to shallow ones, the following water specific consumptions in m$^3$/MWh produced can be gathered: 22 to 36 in Argentina (flat areas), 2 to 111 (median 12) in Brazil (from flat areas to narrow valleys), 0.1 in Chile (a narrow valley in a cold area), and 0.1 to 1.0 in Colombia (deep valleys). Comparing with total usable water resources, evaporation from these dams is a negligible quantity in Chile and Colombia, 0.13% in Brazil and 0.3% in Argentina, at the country level. Larger percentages refer to the river basin where the dams are located. Other results derived from other sources are: 0.9m$^3$/MWh (70m$^3$/yr/GW installed) in Colombia (Jiménez-Cisneros and Galizia-Tundisi, 2012), which means a river flow loss of approximately 0.5 to 1%; 14 and 24m$^3$/MWh for the large hydroelectric plants of Itaipú (95,000GWh, 14GW) and Tacuruí (8.4GW) in Brazil; 0.6m$^3$/GWh (4% of usable water and 25% of water used) in Costa Rica (LA–Costa Rica, 2012). For reversible hydroelectric plants used for energy regulation these values can be higher.

#### 9.3.2.2 Thermoelectricity

Electricity production in thermal plants may demand and consume large water flows. Thermal efficiency depends on thermodynamics – predominantly on the maximum temperature – and may vary from approximately 0.30–0.35 for nuclear and old coal plants, 0.40–0.45 for critical state coal and oil plants and 0.45–0.50 for combined-cycle gas turbines. The heat that is not converted into electricity is transferred to the environment by means of water. Air cooling greatly reduces water consumption but is expensive and thus it is mostly restricted to areas with scarce water flows, such as in some geothermal plants and isolated coal mines.

Thermoelectric plants may use an open cooling water cycle when a large water flow is available, generally a river, or sea water for plants on the coast, as is the case in Mexico.

Waste heat is transferred to the water with a temperature increase of a few degrees, which has to be compatible with ecological restrictions at the disposal site. Discharged water slowly cools to environmental temperature by evaporation, which implies some flow decrease and an increase in salinity. Water use may vary from 30 to 60$m^3$/s/GWe (We=W of electrical power), depending on the admissible temperature increase in the outflow water, or a little less for thermally efficient nuclear plants. Flows can be halved in sea water cooled plants when a higher temperature increase in discharged water is allowed.

When water resources are scarce, the other commonly used cooling method is the closed water cycle, in which heat is transferred to an external water flow closed circuit that is cooled by water evaporation in natural or forced convection, high cooling towers. Water consumption is the sum of evaporated water, leakages and the renewal of water in the circuit to prevent salinity build-up via evaporation. Approximately 0.5 to 0.7L/s/MWe are consumed, depending on plant thermal efficiency, which equates to 1.8 to 2.5$m^3$/MWhe, and 8$m^3$/MWhe for older plants. Some average water consumption values are given in Table 9.4. In most cases the presence of a thermoelectric plant may produce a significant decrease of resources in small river basins or aquifers. Water disposed of may affect local water salinity and also carry with it corrosion products and in-plant treatment chemicals that may be of some concern if not duly treated before discharge. Water recycling in the cooling system is generally three to ten times the water use for a low salinity water supply. These figures are within the same range of results from other studies carried out in the US (Averyt et al., 2011) and Spain (Hardy et al., 2012).

**Table 9.4** **Average water consumption rates for thermoelectric plants with closed cooling**

| TYPE OF PLANT | COAL | OIL | COMBINED CYCLE TURBINE | NATURAL GAS AND MIX | NUCLEAR | HYDROPOWER |
|---|---|---|---|---|---|---|
| $m^3$/MWhe | 1.8 (1) | 1.2 | 1.2 | 0.7 | 2.7 (2) | 1.0 (3) |

1 Part of water used for handling of ashes
2 Lower operating temperatures
3 The value for hydropower is actually highly variable while the other figures have a small range

*Source: modified from WEC (2010).*

### 9.3.2.3 Geothermal electricity generation

Geothermal electric energy production is significant in some countries such as Mexico, Costa Rica, El Salvador, Nicaragua and Guatemala, and is currently receiving a push in Chile, even though some former projects were not completed due to legal and environmental restrictions. Geothermal production uses closed water cooling units that require water. Air cooling is used when geothermal water is too saline and no other sources of fresh water are available. Waste heat per unit of power is greater than in conventional thermoelectric plants due to the lower thermodynamic efficiency. Most of the water produced is re-injected to avoid pollution problems and to recharge the geothermal aquifer. Some production data are shown in Table 9.5.

**Table 9.5 Geothermal energy in some representative LA countries**

| COUNTRY | MEXICO | EL SALVADOR | NICARAGUA | COSTA RICA | GUATEMALA |
|---|---|---|---|---|---|
| EXISTING POWER (MWe) | 850 | 105 | 70 | 125 | 24 |
| % OF COUNTRY ELECTRICITY | 3.2 | 20 | 17.2 | 10.2 | 3.7 |

*Source: own ellaboration.*

Water consumption is highly variable. As a reference, in the Salton Sea geothermal fields (3.2GWe) in the USA, water use is 2.2hm$^3$/yr or approximately 1.2L/MWe. Studies carried out in Australia indicate that this consumption may be about 2.5L/s/MWe (Clark et al., 2010). Thermo-solar energy production also needs cooling water, which ranges from 0.26 to 0.9m$^3$/MWh.

#### 9.3.2.4 Energy from biomass

Biomass is generally used for heating, including industries, especially those that produce it, such as sugar, paper and cellulose factories, but in small quantities it is also used for electricity production. Part of this bioenergy is derived from forest products, mostly consuming soil (green) water, and vegetal wastes from agricultural production. Water is needed for in-plant energy production, mostly to generate process heat and electricity, with little thermodynamic efficiency compared to large thermal plants. This is due to the often low working temperatures and the small, non-optimal units. Energy is also needed for collection, transportation and temporal storage of wastes and products. Similar processes are applied in the less common plants used to transform forest bio-matter into gas and liquid fuels. World biofuel (biodiesel and ethanol) production reached 100hm$^3$ in 2010 (HLPE, 2013). This source claims that seventeen LA countries have adopted biofuel policies with specific targets and mandates for transport fuels. Biomass transformation is reported to produce 2% of energy in Costa Rica, 4% in Chile and is significant in Mexico.

### 9.3.3 Water and land needs to produce biofuels

Renewable energy production is a priority for the 21st century and an important part of it is solar energy captured through biosynthesis. This requires vegetal biomass that consumes large quantities of water, besides land and nutrients. In humid climates crop production is mostly rain-fed but in semi-arid and arid areas irrigation is needed, and consequently this is a source of conflict for the often scarce available water resources.

The planned production of bio-matter to be transformed into fuel – biodiesel and bioethanol amongst others – is currently important in some LA countries (Balat and Balat, 2009; Saulino, 2011). It has been well established in Brazil since the 1970s, and has recently received a push in Argentina (Nass et al., 2007; CADER, 2010, 2011), Colombia, Peru and there is some small production in Paraguay. This refers mostly to the intensive cultivation of maize, sugar cane, other grains, sunflower, and soybeans. Besides water for irrigation, when it is needed, and that used to produce the nutrients – often imported from other areas – water is also needed for the production process in a factory, plus the energy embedded in the facilities and the machinery. The social and economic benefits and the energy balance are not always clear, even if private gains are obtained and there is a good prospect for exporting, mostly to the United States, Europe and Japan. Many different interests and points of view are involved. For many there is a threat to food security and income on a national scale and worldwide, and further the energy used in the production is considered a waste of fossil fuel.

Bioethanol (bioalcohol) was considered as an alternative motor fuel in Brazil as early as the 1930s. Its industrial production started in the 1970s with the programme PROALCOOL. Up to 10% of ethanol can be mixed with gasoline without modifying the motor or it can be used directly or with up to 10% gasoline in modified engines. In LA it is predominantly produced in Brazil, but also in Argentina since 2009 (Babcock and Carriquiry, 2012) for domestic consumption, and is starting in Peru, Colombia and Costa Rica, mostly from sugar cane. Current production in $hm^3$/yr for Argentina, Brazil, Colombia and Peru are respectively 0.28, 29, 0.3 and 0.14 (USDA, 2011). The characteristic sugar cane's specific mass production is 75,000kg/ha/yr, and yields 6–8 $m^3$/ha/yr of alcohol. Approximate data for sugar cane is provided in Table 9.6.

Bio-alcohol can also be produced from corn, other grains and lignocellulose, but at a higher cost. Some data on prices are given in Table 9.7.

**Table 9.6** **Sugar-cane production and crop area**

| COUNTRY | No.mills | CANE PRODUCTION ($10^6$ t/yr) | SURFACE ($10^3$ ha) | % CROP AREA | BIO-ALCOHOL ($hm^3$/yr) |
|---|---|---|---|---|---|
| BRAZIL | 350 | 460 | 9,000 | 4 | 20 [1] |
| ARGENTINA | 30 | | 50 | 1.5 | 0.2 |
| PERU | 1 | 9.3 | 69 | 1.3 | 0.1 [2] |

1 85% for internal use, of which 90% is as biofuel
2 ongoing project; 90% for export to the EU
*Source: own elaboration based on technical unpublished data.*

**Table 9.7** **Approximate costs of producing bio-alcohol and comparative cost of oil**

| | SOURCE BIOALCOHOL | | | | | OIL |
|---|---|---|---|---|---|---|
| | SUGAR-CANE | CORN | BEAT | WHEAT | LIGNO-CELLULOSE | |
| US$/L | 25-50 | 60-80 | 60-80 | 70-95 | 80-110 | 80 |

*Source: own elaboration based on technical unpublished data.*

Costs and possibilities are country specific and depend on factors ranging from rainfall and water availability to soil value and the calculation methods used. Crops need nutrients and may produce important externalities, so the real gain and sustainability is open to debate. Brazil claims the energetic value of the bio-alcohol they produce is approximately

8–10 times that of the fuel used in the production. Crop yield has improved by a factor of 1.6 and fossil fuel consumption in the production has decreased by a factor of 0.75.

Biodiesel is produced from oleaginous plants (mostly soybeans) in Argentina (Hilbert el al. 2012), and from palm oil and castor oil in Brazil. It is added to diesel fuel at 5%–7%, with the prospect of attaining up to 10%. Current production in $hm^3/yr$ in Argentina, Brazil, Colombia and Peru is 2.90, 2.65, 0.54 and 0.03 respectively (USDA, 2011). Although Brazil started production earlier (in 2005), Argentina having only started in 2009 (Hilbert et al., 2012) is currently the world's second largest producer after the USA and the main world exporter.

Water consumption in the factories producing biofuel varies between 4 and 6L/L (volume of water/volume of biofuel), which could be cut down to 2.5 by improvement in production. These data can be compared to 2.5 to 5.5L/L to produce petrol, and the 1.9L/L minimum thermodynamic requirements to produce inorganic alcohol. However, the main water consumption is due to irrigation, which ranges from 0 in fully rain-fed areas to 800 to 2000L/L for irrigated crops in arid areas. National water values often only consider water resources (blue water) consumed and thus results vary greatly according to the country or region.

A key element of biofuels production is related to the land and soil (green) water needs. HLPE (2013) compiled the following ranges in $ha/m^3ge/yr$ (ge = gasoline equivalent): for ethanol it is required 0.300 from sugar cane, 0.465 from corn and 0.470 for cellulosic material; for biodiesel, 1.540 from jatropha and 0.310 from palm oil. This means that to produce 1 $hm^3/yr$ of sugar cane approximately 300,000ha of cropland is needed.

## 9.4 Water for industry

Industry covers a large and variable group of activities, many of which depend on the specific economy of the country or region. Industrial areas are highly variable in LA, from heavily industrialized zones, such as São Paulo (Brazil), Mexico City and Monterrey (Mexico), where the metal sector and petrochemical industries are present, to other areas in which industry is relatively less important and a large proportion of the factories are for food processing. Water needs and the environmental impact are thus quite different. Often thermo-power plants and treatment plants for minerals that are not in the mining area, such as smelters, are considered as industrial plants.

A large proportion of industrial factories are small to medium size, in or around towns, and thus water demand and use is generally included in urban water and the disposal of used water goes to the municipal sewage system. Whilst large self-supplied factories and industrial areas can be found, most of them are oil refineries, chemical plants (which include fertilizer production and natural and artificial textiles), sugar factories ('ingenios') and biofuel production plants processing rain-fed or irrigated agricultural production. In some cases tanneries (leather factories) may be important, as is the case in some areas of

Mexico, Peru and Argentina. Food-processing industries often use water from the supply network while the production of bottled water and refreshments is partly supplied by the municipal network and partly self-supplied, as commented in Box 8.8 of Chapter 8.

Even if factories generally demand a small fraction of the total resources, they may pose important burdens on their surroundings since they are competing for the scarce local resources. This may become locally unpopular and provoke reactions from citizens and the mass-media. Furthermore, in the absence of strict environmental regulations or when the enforcement of such regulations fails, whether it be due to powerful lobbying groups or public administration weaknesses, factories are likely to pollute both surface and groundwater.

Water use data vary from country to country and over time due to continuous improvements in water use efficiency, to reduce production costs and due to environmental pressure to save scarce water resources. Some industrial processes are especially water intensive, such as the production of paper, cellulose, petrochemicals and artificial fibres. In Chile, a 40 $m^3/t$ water demand for paper production is mentioned, where it was formerly of 110$m^3/t$ (LA–Chile), and this value can still be greatly reduced further, as shown by the experience in Spain. In Mexico, about 50% of water for industrial use is for cooling and 35% for industrial processes, and an important fraction of it is wasted. Also in Mexico, the main oil-related industry uses approximately 230$hm^3/yr$, about half surface water and half groundwater. The water/product ratio is 1.0 for refining, 0.6 for basic gas and oil products and 4.7 for petrochemical products. The water needs for fuel production and processing are shown in Table 9.8. The industrial water use in Mexico for the principal water demanding industries is given in Table 9.9. Self-supplied industries use 3,100$hm^3/yr$ (45% groundwater) and thermoelectric units use 4,100$hm^3/yr$ (12% groundwater), and both of them use 9% of the country's water resources.

**Table 9.8** **Water needs for fuel production, including processing**

| FUEL MINERAL | COAL | URANIUM | CRUDE OIL | NATURAL GAS |
|---|---|---|---|---|
| $m^3$/MJ content | 335 | 184 | 3,809 | 218 |

*Source: WEC (2010)*

**Table 9.9** **Industrial water use in Mexico for the main water-intensive sectors.**

| INDUSTRY | SUGAR | CHEMICALS | OIL | PAPER AND CELLULOSE |
|---|---|---|---|---|
| % of industrial water use | 40 | 22 | 7 | 8 |
| % of industrial water consumption | 35 | 21 | 6 | 8 |

*Source:Jiménez-Cisneros and Galizia-Tundisi (2012)*

River pollution due to the combined effect of wastewater from urban centres and industry produces important problems in some areas. Worldwide known problems are those of Lerma River and Chapala Lake (Mexico DF), Tieté River (São Paulo, Brazil), the highly polluted Tigre, Matanza–Riachuelo and Reconquista river stream systems around Buenos Aires (Argentina) where a special organization has been formed to try to control it (Autoridad de Cuenca Matanza–Riachuelo, ACUMAR), and downstream Bogotá (Colombia). Except for coastal Buenos Aires the other urban areas are continental and their effect on water resources is therefore greater.

In Mexico, in order to treat 2,500hm$^3$/yr of wastewater 1,650GWh/yr are used; of this total 900hm$^3$/yr are from factories, consuming 600GWhe/yr (Jiménez-Cisneros and Galizia-Tundisi, 2012). Total energy consumption for the water cycle is approximately 13,500GWhe/yr, or 7.1% of Mexican energy consumption.

## 9.5 Water for mining

Mining is an important sector in many LA countries. It is a key source of income and employment and is a sector which is on the rise given the increasing world demand for some metals (see Chapter 5). LA countries are very important world producers of silver, copper, molybdenum, zinc, aluminium, strontium, gold, iron and nickel. In Chile, copper contributes 90% of the economic value of the country's mining, US$ 9 billion to the GNP and produces US$ 45 billion in exports. LA countries supply 51% of the world's silver, 45% of its copper and overall 25% of the world's metal market. The production of lithium, a series of secondary metals and coal are also important, as well as gems. Classical mining areas are those of San Luis Potosí (Mexico), Zacatecas (Mexico), Ouro Preto (Minas Gerais, Brazil), and several Andean areas of Chile, Peru, Bolivia, Argentina and Colombia. La Guajira (Colombia) is an important world coal producer. There are large companies but also numerous small, even artisanal ones, especially for precious metals and gems. They attract 32% of the world's economic investments in mining. Mining activities can be seen as both producers and consumers of water, this second aspect being a serious problem in some areas. Most new mines exploit large and deep pits. Some new mining activities exploit existing natural brines in 'salares' (salt pans) to extract dissolved substances such as lithium and potassium, and also nitrates in some cases.

Mining by means of underground galleries or deep open pits may intersect aquifers or induce the infiltration of river or lake water. This is avoided as much as possible, sometimes with artificial impermeable barriers, but often water drainage cannot be controlled or is the result of operation failures. Pumping out this water is often a costly, energy intensive activity and water has to be disposed of. This produces desiccation problems in some areas and inundation in others, alongside quality problems since pumped water may be acidic or have excessive loads of some undesirable components. This water and that produced inside the mine area, including tailings (mine dumps) drainage, has to be disposed of. A fraction of mine water production is often used for mine operation and dust control.

Open pits become evaporation surfaces that may consume 1 to 2m/yr of water depth, depending on the area. Rainfall may be scarce in many of the arid mining areas of the Americas, often less than 100mm/yr or even as low as a few mm/yr, and thus this may compromise during a long time and even forever the future water resources, as has been observed in the arid and hyper-arid areas of Peru, northern Chile, western Bolivia and northwestern Argentina.

Water is needed for the operation of the mines, mostly to supply mineral leaching areas and mineral processing, but also for dust control. This is a moderate quantity but may become a serious demand in arid and hyper-arid areas. Mineral concentrates are often transported from inside the mining plants and to further away facilities in order to process the final product or to ship it. This transportation can be done by means of pipelines as slurries, thus using large water flows that are often not returned to the mine. This increases mining water needs – a serious challenge in arid areas – and may be a water quantity and quality disposal problem at the processing plant.

Numerous improvements for in-mine water use efficiency through recycling have been introduced to reduce water use. However, mining continues to be a serious challenge in many arid areas where it is necessary to provide enough water to the mining sector whilst preserving human supply, protecting the local environment and avoiding the spread of air and water-borne contamination. Long water transfers have been or are being planned to make mining possible, although excess water disposed of by the mine may become an added problem to the local environment. Current use of water in mining is given in Table 9.10.

**Table 9.10 Current water consumption in mining (values rounded up)**

| COUNTRY | MINING | WATER CONSUMPTION | | |
|---|---|---|---|---|
| | % of GNP | $hm^3/yr$ | % [3] | Comments |
| CHILE | 12 | 260 | 8.8 | growing; mostly for copeer [1] |
| PERU | 6 | 210 | 2 | growing |
| MEXICO | 1.6 | 55 | 0.07 | [2] |
| ARGENTINA | 3.2 | | | |

1 Economic productivity of used water: 4.4US$/$m^3$; 1950$hm^3$/yr used; other sources show up to 300$hm^3$/yr

2 27$hm^3$/yr consumed, 26$hm^3$/yr disposed of; 74$hm^3$/yr recycled; 2% of employment

3 Percentage of available water resources

*Source: Jiménez-Cisneros and Galizia-Tundisi (2012), LA–Chile (2012); LA–Mexico (2012); LA–Peru (2012).*

The most important supply problems appear in the arid and hyper-arid western coastal areas of South America, especially in the Tarapacá (Region I) and Antofagasta (Region II) areas of Chile. Important water rights purchases have been made at prices between 75,000 and 225,000US$/L/s (see Chapter 13). In 2006 this prompted one of the large companies operating in the area to invest approximately 160 million US$ to obtain 500L/s of fresh water at a coastal seawater desalination plant for leaching sulphide mineral concentrates. With a total investment of 870 million US$, water is pumped up to an altitude of 3200m through a 170km pipeline.

Mining carried out by large companies is generally much less water consuming and produces less water quality degradation per unit of production and per unit value of production than small-scale and artisanal (informal) mining. This last point is common practice in many areas, especially in the Andean region and to exploit secondary mineral accumulations ('placeres') in alluvial deposits and other sediments, or through small underground mining. They are widespread in the wet areas of eastern Peru and Colombia. This mining contributes more employment per unit of production and per unit value (but under poor working and health conditions) than large mines, but it may be highly detrimental to the local environment and water resources. To extract gold, amalgamation with mercury (quicksilver) and cyanide treatment is carried out, and consequently serious mercury and cyanide pollution is produced in rivers, lakes and groundwater. These small-scale and artisanal activities are often poorly controlled, and become important environmental (Hajeck and Martínez Anguita, 2012) and social problems to which governments often turn a blind eye, especially if the native population and poor people are involved in the mining.

Although environmental restoration is possible and mining permits are currently under consideration, the current situation shows that the impact of past activities, failings and unaccounted situations often appear during and after mine operation. Post-mining correction activities carry the risk of not being executed since in many cases the responsibility is passed from the mining companies to governments as money transfers.

One of the largest water resources problem, affecting especially groundwater resources and their relation with the water cycle, is the lack of knowledge and trained personnel, during the mine's operation and especially after its closure. Trained persons are scarce in many countries and are employed preferably to support direct mining activities, which is the priority and are much better paid posts. Thus, it is not rare that governmental organizations in charge of environmental control and regulation are not able to keep a stable workforce due to the higher salaries offered by mining companies. This is a common situation in LA.

Water consumption in copper mining is currently 0.3 to 1.2m$^3$/t of treated mineral, with an average value of 0.75m$^3$/t. This is a clear improvement compared to 2 m$^3$/t some years ago; there are hopes that this will be reduced to 0.05m$^3$/t. Current consumption is approximately 75 to 100 L/kg of refined copper and the apparent water economic productivity is approximately 80US$/m$^3$.

Gold production in Colombia is 56t/yr. In the Porce River basin, in the highlands (LA–Colombia, 2012), with 4,000 hm$^3$/yr of water resources, gold mining uses 0.5hm$^3$/yr to produce 3t/yr by using 80–100t/yr of mercury, but actual water consumption is from 0.5 to 1.5hm$^3$/kg of gold produced when the flow needed to dilute the pollutants is considered. Water productivity is around 460US$/m$^3$.

Oil extraction is an important mining activity in LA, mainly in the large basins on the eastern side of the Andes Range, from Peru to Colombia–Venezuela, including the central Amazonia in Brazil, as well as in a series of formations in Mexico and southern

South-America, in Argentina and Chile. Water use for abstracting the oil is generally small and highly variable, depending on the circumstances. Oil is abstracted jointly with large flows of often saline and highly contaminated water, which is mostly re-injected to enhance production or is just disposed of safely. Failings or accidents may contaminate groundwater resources and later surface water resources too, for a long time. Secondary and tertiary oil recovery is done by water injection, generally using small flows. Also small flows are needed for advanced gas recovery by 'fracking', which is currently being considered in LA. Chemicals used are an environmental concern and a poorly understood source of pollution. $CO_2$ injection into deep formations to reduce its emissions into the atmosphere is being considered in Brazil. This needs water for treatment and cooling, and especially to produce energy for the capture process at the plant. The water resources impact of these small amounts will likely be important in the future in water scarce areas.

As is the case of diverse regions of the world and especially in arid and semi–arid areas, as discussed in Chapter 2, in some of the dry areas of LA groundwater reserves in some of the large aquifers are being depleted due to intensive exploitation, at a rate much higher than renovation (Custodio, 2010, 2011). This groundwater withdrawal due to mining activities is happening in the hyper-arid areas of the Andean Region, comprising coastal Peru, northern Chile, southwestern Bolivia and northwestern Argentina, where groundwater renovation is scarce or nil. Groundwater abstraction is for the most part to supply the mining of metal ores and also for brine extraction in salt pans ('salares') used to exploit some solutes such as lithium, potassium and nitrates. The sustainability of small springs and groundwater discharges that are important for some human settlements and of ecological and touristic value, such as high altitude wetlands ('bofedales'), is of special concern. Rainfall in the intermediate depressions is a few mm/yr on average and the scarce recharge is produced occasionally by some sporadic floods in gullies whose headwaters are in the highlands ('altiplano'). Even though rainfall in the altiplano is scarce, a combination of almost bare soil of low humidity retention (mostly young acidic ignimbrites) and rainfall retention in the seasonal snow cover favour some recharge that manages to sustain some springs which yield water with a very long turnover time (Acosta et al., 2013).

## 9.6 Discussion and conclusions on water security for energy production, industry and mining activities and for human uses in LA

What have been presented in the preceding sections are general considerations on water use and consumption in the different sectors of energy production, industry and mining, with specific references to LA countries and regions, and especially to the seven countries that have contributed reports. For many aspects data have not been found and an in depth bibliographical search has not been performed. Thus, part of the comments and warnings are qualitative and their relative importance remains speculative. Additionally it should be noted that part of the data was obtained from reports that have not been checked or are not always well defined.

Not all of the sectors – energy production, industry and mining – are similarly present in all LA countries. In Argentina, Brazil, Paraguay, Chile, Colombia and Costa Rica hydroelectricity is an important energy source, while in Mexico coal, oil and thermoelectricity contribute a larger fraction of the country's needs. Only Argentina has operating nuclear plants, although their contribution to the country's total energy needs is small.

Hydroelectricity may consume water by evaporation in the storage reservoirs, which is often a small fraction of river flow, but in some cases it may be large enough to affect downstream water security by reducing flow, increasing salinity and modifying seasonality. Specific water consumption for energy production varies over a wide range, from less than 1m$^3$/GWh to more than 100m$^3$/GWh, depending on local conditions. At the national scale this amounts to 0.1% to 4% of total water resources, although in some cases, particularly in warm, flat areas it can be up to 25%.

In thermoelectric plants, cooling – in open and closed cycles – is generally done with river water, but in Mexico marine water cools important power plants located in coastal areas. Geothermal plants along the western mountainous areas of LA are in arid regions and use closed cycle cooling fed with groundwater or air cooling. These cooling needs water consumption may be a significant fraction of local surface and groundwater resources, which in arid areas can compete against other water demands for a large share. Thus, water security may become an important consideration for the plant operation, for the downstream local population and for the environment.

The production of biofuels may introduce an important water demand where irrigation is needed, which may in turn have a great impact on local and downstream local water security. This would be especially true in semi-arid and arid areas and furthermore in the areas from where the water resources are to be taken. It seems that some projects on the Pacific side of South America may create important local water imbalances or require expensive water conveyance systems and energy-consuming water imports from further afield areas for the sake of income from biofuel exportation.

Water security considerations for industry are as varied as the involved activities. In many cases they are connected to urban water supply and share their water security circumstances, as explained in Chapter 8. This includes part of the production of bottled water and refreshments that are common in LA, Mexico being a world leader in per capita production and consumption. Large industrial establishments, which include thermoelectricity production, have their own water supply. Other important water-independent industries are those related to refineries, large chemical plants, smelters for iron, aluminium and other metals, textiles, leather and large sugar plants, amongst others. Comments made above for energy water security also apply here. Additionally water security for populations and the environment has to consider the pollution generated by these plants – something which is highly dependent on the types of activity and technology – and also on the existence and enforcement of legislation and civil society action. Circumstances vary largely in LA. Large industrial concentrations are found in several places in Mexico, Brazil and

Argentina, and large sugar plants ('ingenios') in Colombia. The impact of water security on the population also depends on the location of these industrial plants. Many of them are close to the coast – large lakes do not exist – and have less downstream water security impact, but others are far inland and are often at high altitude (São Paulo, Bogotá, Mexico City) and thus have a higher impact on downstream water security.

Mining is an important activity and a great source of income in many LA countries such as Mexico, Colombia, Venezuela, Brazil, Peru, Chile, Argentina and Bolivia. Some mines are in areas with plenty of water – where the problem is how to get rid of it – but others are in semi-arid areas with water supply problems (e.g. central Mexico, northern Colombia, northeastern Brazil) and in arid and hyper-arid areas (northern Chile, northwestern Argentina, eastern Bolivia, southern Peru) where water resources are very scarce and groundwater with very slow renovation (up to several thousand years) is used and partly mined. Water security for mining is an important concern, so in some cases seawater desalination at the coast has been introduced. For example in northern Chile costly desalinated seawater is pumped to the highlands where the copper mines are located. In the case of mining, water security can be solved when mining can support the involved cost of procuring and producing water given the current high prices of metals.

From the point of view of human water needs, mining may become an important threat in arid and semi-arid areas, but may also generate large benefits. Mining may seriously interfere with water security of locals by reducing river and spring flow, even exhausting them, or in other cases damage wetlands. This is a complex situation as changes in the groundwater resources are slow and delayed, which may pass unnoticed for years. Detailed hydrogeological studies are therefore needed to measure this impact over time. Thus, it is important to know the pace of recovery after a mine closes; it may be that this rate is too slow to be significant. It is relatively common that open pit mines are not refilled as they may be conceivably re-opened in the future or is not considered in their mining permit; thus this can leave a large and deep lake capable of evaporating large water flows if groundwater seepage is enough or if surface water gets in when barriers fail. This may reduce local and downstream water resources and even exhaust springs and small streams. There is little information on this issue, especially due to poor monitoring since many large mining activities are relatively young and the evaluation is complex owing to weather and climate variability.

From the water quality point of view, mining may affect the water security of inhabitants and of the environment, both local and downstream. This is due to the disposal of water with high salinity, acid and/or containing diverse unwanted and noxious solutes derived from minerals – diverse heavy metals – or from concentration and processing, such as flotation compounds, and quicksilver (mercury) and cyanide in the case of the many gold mines in LA, especially the small and artisanal ones. This is a common situation in Colombia – where the supply and even agricultural use of water from many rivers is jeopardized – and the Amazonian side of Peru. The situation is less acute in the case of well-operated modern mining, where wastewater disposal is relatively small and controlled.

Industry, energy production and mining together consume 8 to 15% of water resources in the seven considered LA countries. Water consumption is respectively 4 to 9% for industry, 2 to 5% for energy production (hydroelectric energy consumption not included) and up to 6% for mining. Water economic productivity for these uses may range from 3 to 10US$/m$^3$. It is a high value when considering direct costs and benefits but if externalities are considered the economic picture may change, depending on the social discount rate that is applied.

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