WEO-2016 water-energy nexus methodology

Water for energy. Energy for water. These linkages have enormous significance for economic growth, life and wellbeing. Recognising the importance of this nexus, the *World Energy Outlook* in 2012 examined the water requirements of the energy sector and the issue has been taken up in subsequent reports, most recently in *WEO-2015* with a study of the impact of water scarcity on the choice of cooling technology in coal-fired power plants in India and China. The analysis presented in *WEO-2016* updates and expands upon the previous analysis. In addition to new projections for future freshwater requirements for energy production, *WEO-2016*, for the first time assesses the energy used for a range of different processes in the water industry, such as wastewater treatment distribution and desalination. What follows is the description of how these projections were derived.

Water for Energy

Water is a critical input to energy production in each scenario in the *World Energy Outlook*. Energy can impact water availability and water availability can pose acute risk to energy projects that require larges volumes for operation or those built in a water basin that faces scarcity concerns. Water quality can also be degraded physically or chemically by use, even when the volume used is minimal, and may pose environmental hazards when discharged.

Being able to assess these risks is aided by improved understanding of present and future water requirements for energy production. As such, in the second iteration of the IEA's analysis of the water-energy nexus, *WEO-2016* includes projections of the water requirements for energy production, expressed as withdrawal and consumption, by scenario, region and energy source over the period 2014-2040.

We project two distinct types of water use: withdrawal (volume of water removed from a source) and consumption (volume of water withdrawn that is not returned to the source). Water withdrawal is by definition, always greater than or equal to consumption. For this analysis, 'water' refers to accessible freshwater (see Box 1.1 for list of definitions used in the report). While we recognize that non-freshwater sources are already being used, either to replace or complement freshwater, in many places the use of alternative sources is at a nascent stage or is not yet economic, relative to freshwater, and is not quantified in this analysis.

Primary energy production

In order to quantify the water requirements for primary energy production, we conducted a comprehensive review of published water withdrawal and consumption factors for relevant stages of oil, gas, coal and biofuels production. Water factors were taken from the most recent sources available, and as much as possible from operational rather than theoretical estimates. These were then compiled into source-to-carrier ranges for each fuel, disaggregated by production chain, and applied across the *WEO-*

2016 energy supply projections at an equivalent level of disaggregation by scenario and model region. The water factors applied are generally global, with the exception of biofuels, where factors range widely depending on where feedstock is grown.

The production chains were disaggregated as follows:

- Oil- conventional oil (primary and secondary recovery), arctic, NGLS, extra heavy oil bitumen, kerogen, tight, coal-to-liquids, gas-to-liquids, enhanced oil recovery (by various methods);
- Natural gas- conventional gas, shale, tight, coal-to-gas, coalbed methane, and;
- Biofuels- sugarcane ethanol, corn ethanol, lignocellulosic ethanol, soybean biodiesel, rapeseed biodiesel and palm oil biodiesel.

Power generation

In order to quantify the water requirements for power generation, we conducted a comprehensive review of published water withdrawal and consumption factors for electricity generation technologies by cooling system type. Water factors were taken from the most recent sources available, and as much as possible from operational rather than theoretical estimates. Water factors compiled did not account for water used to produce the input fuel, as this may be supplied outside of the country where power is generated. These average water factors were applied to the *WEO-2016* projections for power generation in each scenario, region and generating technology, disaggregated by cooling system, by fresh and non-fresh water type, using present shares based on information from Platts. Technologies were further broken down into existing and new capacity. In most cases shares of cooling technologies were held constant, with several exceptions where known policies and plans were accommodated (including the United States, China and India). The cooling systems included were once-through, wet cooling tower, wet cooling pond, dry and hybrid.

The water factors for primary energy production and power generation were sent to a group of peer-reviewers for further review.

Energy for Water

The dependence of water services on the availability of energy will impact the ability to provide clean drinking water and sanitation services. Energy is needed for all parts of the water sector, including supply and transport and treatment. The amount of energy required varies. It is influenced by a range of factors, such as topography, distance, water loss and inefficiencies, and the level of treatment necessary. So far, there has been no systematic attempt to quantify the amount of energy consumed in the global water sector, or to examine how this might evolve in coming decades.

For this analysis, we referred to the embedded energy use in the water use cycle from its natural source (lakes, reservoirs, aquifers, and sea) to the end-users (agricultural, municipal, and industrial), as well as re-used water flows and water losses combined in

the system. Only energy consumption for processes whose main purpose is to treat/process or move water from or to the end-user has been included.

We used the best available data and the results were calibrated against the available country studies; but significant data challenges remain, because of a lack of recorded, precise measurement of many of the processes involved. We used the water projections (and their underlying assumptions) of the leading institutions in the field: projections for groundwater and surface water extraction, as well as water withdrawal and consumption for agriculture and by municipal sources and industry come from the World Resources Institute (Luck, Landis and Gassert, 2015), the University of Utrecht (Bijl, et al., 2016), the University of Kassel and the International Institute for Applied Systems Analysis (Wada, et al., 2016). For future levels of water withdrawals and consumption for power generation and primary energy production, we have used our own projections. In addition we have collected information on water losses, wastewater collection rates and treatment levels from various sources, including the OECD (2016), Eurostat (2016), GWI (2016) and the World Bank (2016). For projections on desalination, we have relied on current capacity data from GWI (2016) and, for re-use, on FAO (2016). Current policies have been taken into account and the assumption made, that countries in the Middle East and Africa will gradually reduce withdrawals form non-renewable sources towards the end of the projection period. In order to assess the energy-savings potential, we have carried out a review of relevant technology for all steps in water treatment and distribution and wastewater facilities (including energy recovery). In our 450 Scenario, we assume that the economically viable energy efficiency potential is fully exploited.

In order to quantify the energy requirements for the water system, we conducted a comprehensive review of published energy intensities factors for various operational processes. Energy requirements were taken from the most recent sources available, within a specific country/region context, and as much as possible from operational rather than theoretical estimates. These average energy intensities were applied to the relevant water processes (groundwater/surface water extraction, water transfer, water treatment, water distribution, wastewater treatment, desalination and water re-use) in order to obtain estimates for overall energy use and further contribute in identifying possible energy efficiency opportunities in water management. The energy intensities are region specific since numbers differ depending on the geological conditions and technologies employed. The energy intensities for the water sector were sent to a group of peer-reviewers for further review.

Box 1.1 ▷ Glossary of energy and water terms

Surface water: Natural water in lakes, rivers, streams or reservoirs.

Groundwater: Water that is below the land surface in pores or crevices of soil, sand and rock, contained in an aquifer.

***Aquifer*:** Large body of permeable or porous material situated below the water table that contains or transmits groundwater.

Freshwater: Water with less than 1 000-2 000 parts per million (ppm) of dissolved salts.

***Non-freshwater resources*:** Includes brackish or saltwater; urban or industrial wastewater (with or without treatment); and agricultural drainage water. Also referred to as alternative or non-conventional water resources.

***Renewable water resources*:** Total amount of surface and groundwater resources generated via the hydrological cycle.

***Non-renewable water resources*:** Deep aquifers that have minimal rate of recharge during an average human life-time.

Water stress: Defined as when renewable annual freshwater water supplies fall below 1 700 cubic metres (m^3) per person; *water scarcity* is below 1 000 m^3 per person; and *absolute scarcity* below 500 m^3 per person.

***Water withdrawal*:** The volume of water removed from a source; by definition withdrawals are always greater than or equal to consumption.

***Water consumption*:** The volume withdrawn that is not returned to the source (i.e. it is evaporated or transported to another location) and by definition is no longer available for other uses.

***Water sector*:** Includes all processes whose main purpose is to treat/process or move water to or from the end-use: groundwater and surface water extraction, long-distance water transport, water treatment, desalination, water distribution, wastewater collection, wastewater treatment and water re-use.

***Water treatment*:** Process of removing contaminants from water or wastewater in order to bring it up to water quality standards and for storage in freshwater reservoirs.

Desalination: Reducing the contents of total dissolved solids or salt and minerals in sea or brackish water.

***Water distribution*:** Delivery of treated water to the customers via distribution networks (pumping, pressurising, storing and distributing).

Wastewater treatment: Involves collection (pumping, transporting sewage), treatment (primary, secondary, tertiary) and discharge.

***Re-used water treatment*:** Processes related to re-using or recycling the not discharged, treated wastewater effluent (conventional tertiary treatment, membrane treatment).

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