CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

INTERNATIONAL SOLAR ALLIANCE

International Solar Alliance Expert Training Course

In partnership with the Clean Energy Solutions Center (CESC)

Dr. David Jacobs

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INTERNATIONAL SOLAR ALLIANCE

Session 33: Water-energy nexus - Solar PV in a water-constrained world

In partnership with the Clean Energy Solutions Center (CESC)

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Supporters of this Expert Training Series

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CLEAN ENERGY SOLUTIONS CENTER

ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

IET – International Energy Transition GmbH

Dr. David Jacobs

- Founder and director of IET
- Focus on sustainable energy policy and market design
- 14+ years experience in renewable energy policies
- 60+ publications on energy and climate
- 40+ countries work experience (consulting and presentations)

Training Course Material

International Energy Transition

This Training is part of Module 6, and focuses on socio-economics of PV

<u>Related training units are:</u>

- ✓ 37. Thinking in Eco-Systems: People, Money, Technology and Policy

Eight Modules

Expert Content and Analysis

Up-to-date Market Insights

1. Policies for Distributed PV
2. Policies for Large-Scale PV
3. The Future of Solar Policy
4. Technical Integration of Solar
5. Market Integration
6. Socio-Economic Aspects
7. Off-grid Solar
8. Solar Heating & Cooling

Overview of the Training Session

1. Introduction: Learning Objective

2. Understanding Water Consumption of PV and other Power Generation Technologies

3. Outlook to the Water-Energy-Food Nexus

4. Further Reading

5. Knowledge Check: Multiple-Choice Questions

Introduction:

Learning Objective

Learning Objective

- Understand the implication the climate crisis on water scarcity
- Understand the water consumption of different power generation technologies in comparison
- Understand water consumption of solar PV, including module cleaning options
- Implications of lower water consumption for electricity systems (case studies)

Introduction:

Climate Crisis and Water Scarcity

The Impact of the Climate Crisis on Water Scarcity

- Only 2.5% of the water on planet earth is fresh water
- Agriculture is consuming about 70% of fresh water
- By 2025 people scarcity 1.8 billion people will be living in countries or regions with absolute water scarcity
- 66% of all people will living under water stress conditions

Source: FAO 2016

Increasing Dryland World-Wide

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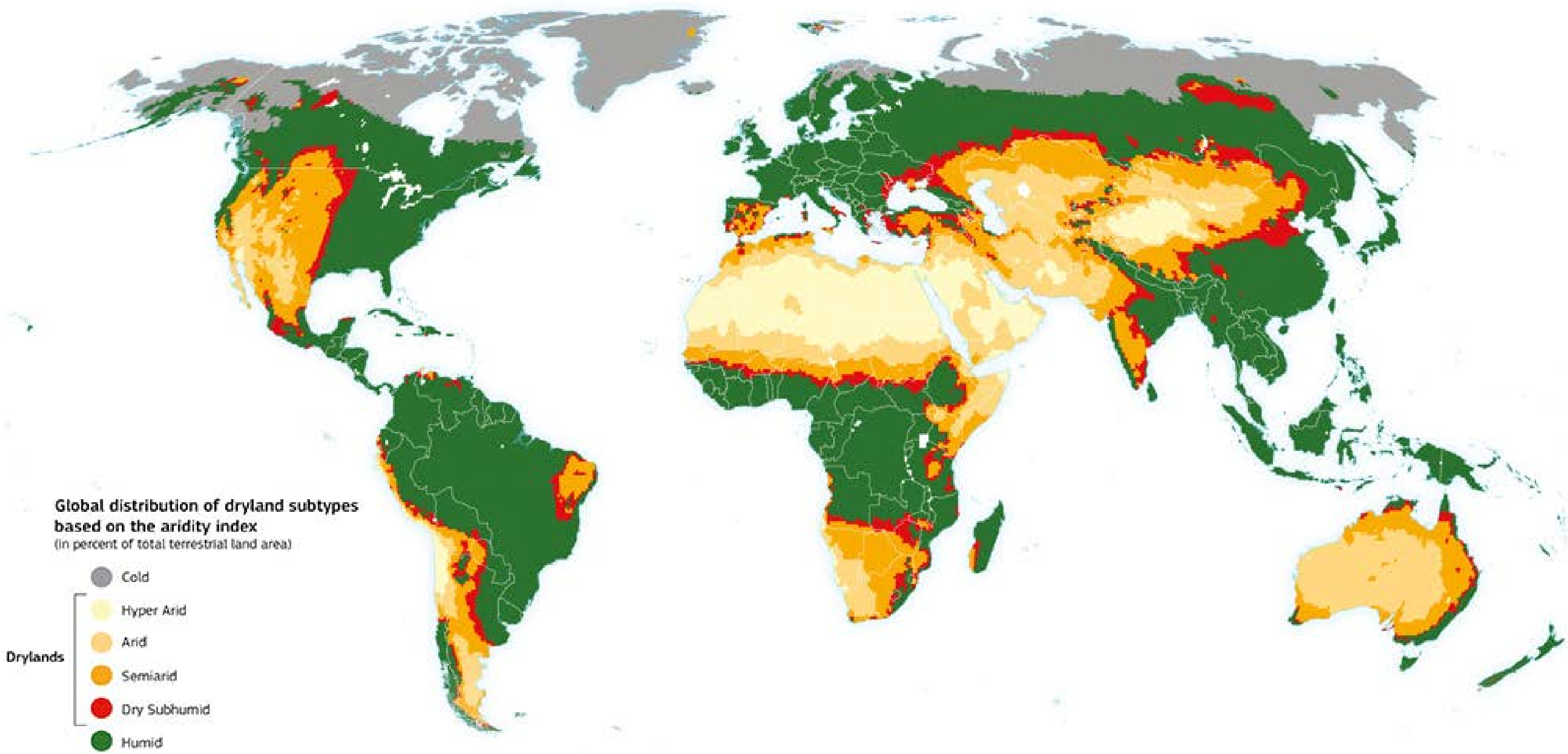
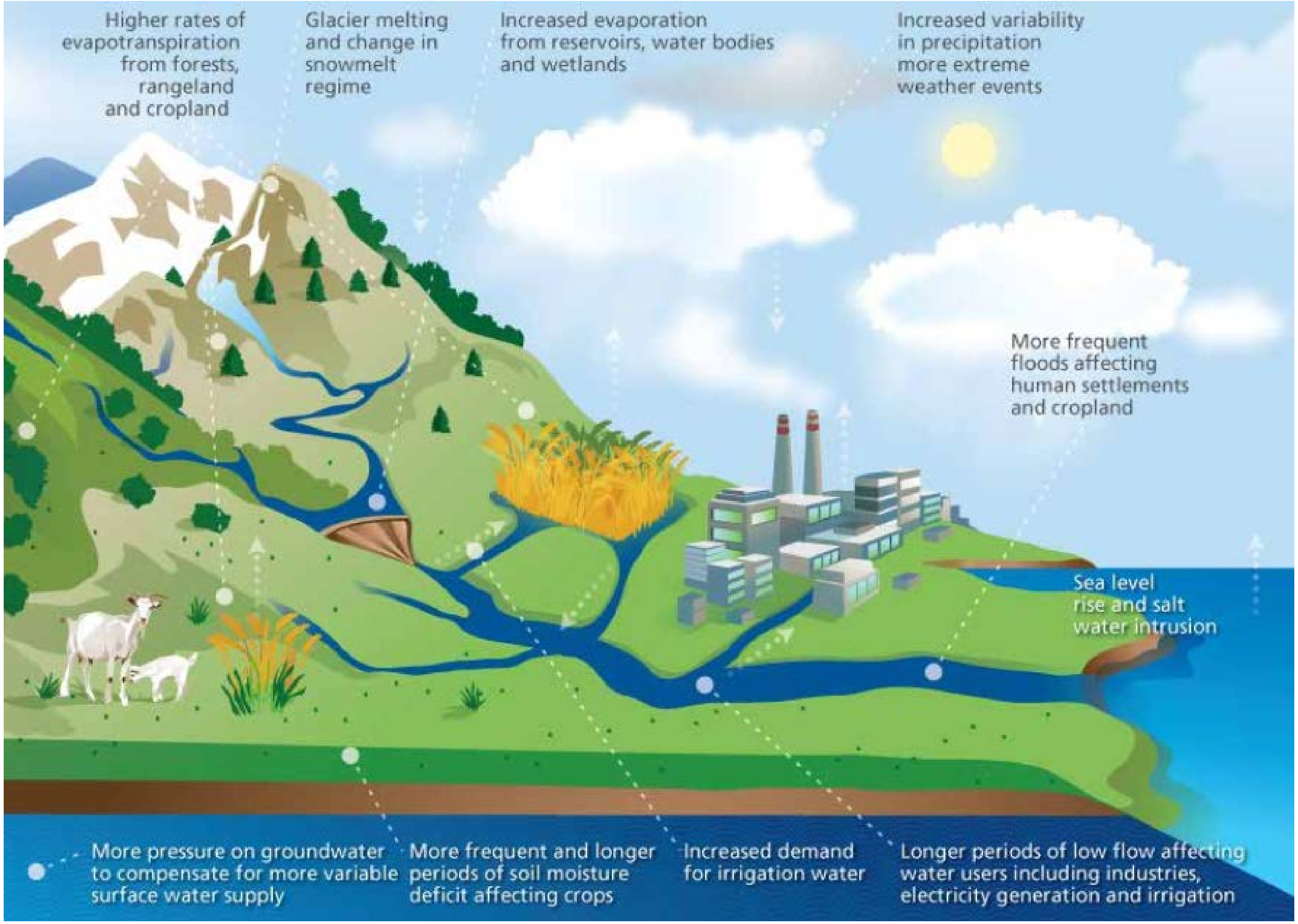


Source: https://www.carbonbrief.org/explainer-desertification-and-the-role-of-climate-change

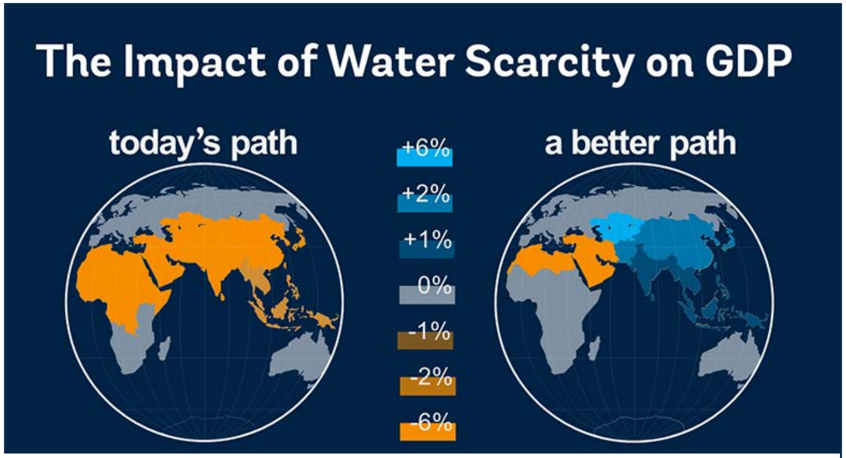
Water Scarcity will Intensify



Source: FAO 2016

The Impact of Climate Change on Water Scarcity

- Water scarcity, exacerbated by the climate crisis, could cost some regions up to 6% of their GDP, spur migration, and spark conflict.
- The combined effects of growing populations, rising incomes, and expanding cities will see demand for water rising exponentially, while supply becomes more erratic and uncertain



MAP ES.1 The Estimated Effects of Water Scarcity on GDP in Year 2050, under Two Policy Regimes

Source: World Bank 2016

Source: World Bank

The Impact of Climate Change on Water Temperature

- The largest increases in water temperature by 2050 globally are expected in eastern North America, Europe, Asia, and Southern Africa (1.3ºF–2.2ºF).
- Decrease in annual stream flows in many parts of the world
- River temperatures are already increasing due to urbanization and higher air temperatures.
- As water flows in some regions decline, higher air temperatures will impact water temperatures more than they have in the past

Source: Van Vliet et al. (2016)

Water for Energy:

Water consumption in the Power Sector

Energy Related Water Consumption: Terminology

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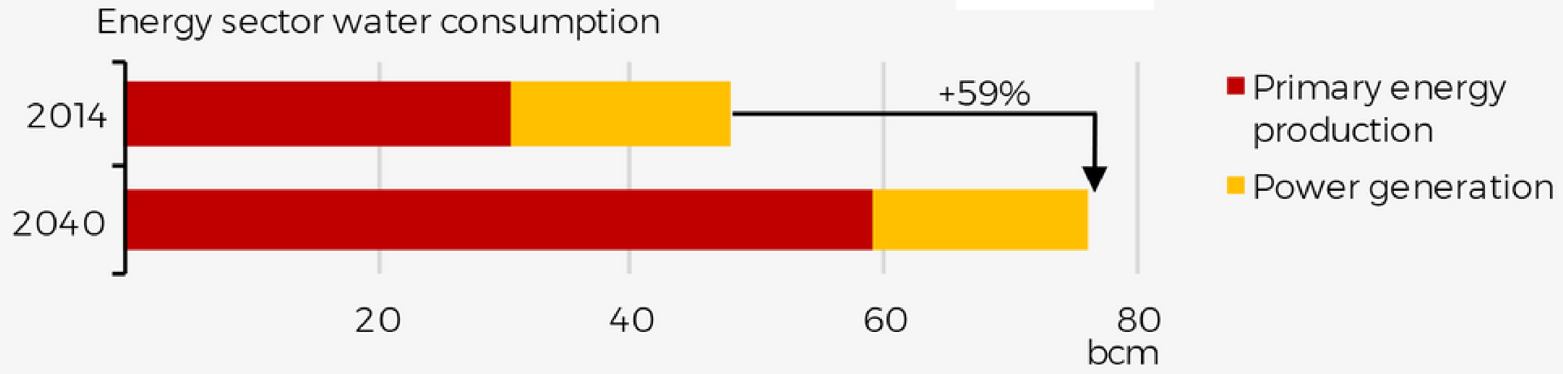
- Water Withdrawal:
  - Freshwater withdrawal or abstraction for an economic activity. Also referred to as gross water abstraction or withdrawal.

- Water Consumption:
  - The portion of WW that is not returned to the original water source after being withdrawn. WC occurs when water flows to the atmosphere through evaporation or is incorporated into a product or plant.

Source: JRC 2019

Energy Related Water Consumption: The Global Picture

- Global energy-related water withdrawal ranges between 398 and 583 billion m3 per year.
- Around 10% of the total water abstraction is related to energy sector activities.



Source: IEA WEO 2018

Water Consumption of Primary Fuels

Figure: Water withdrawal and consumption for primary fuel extraction, processing and transportation

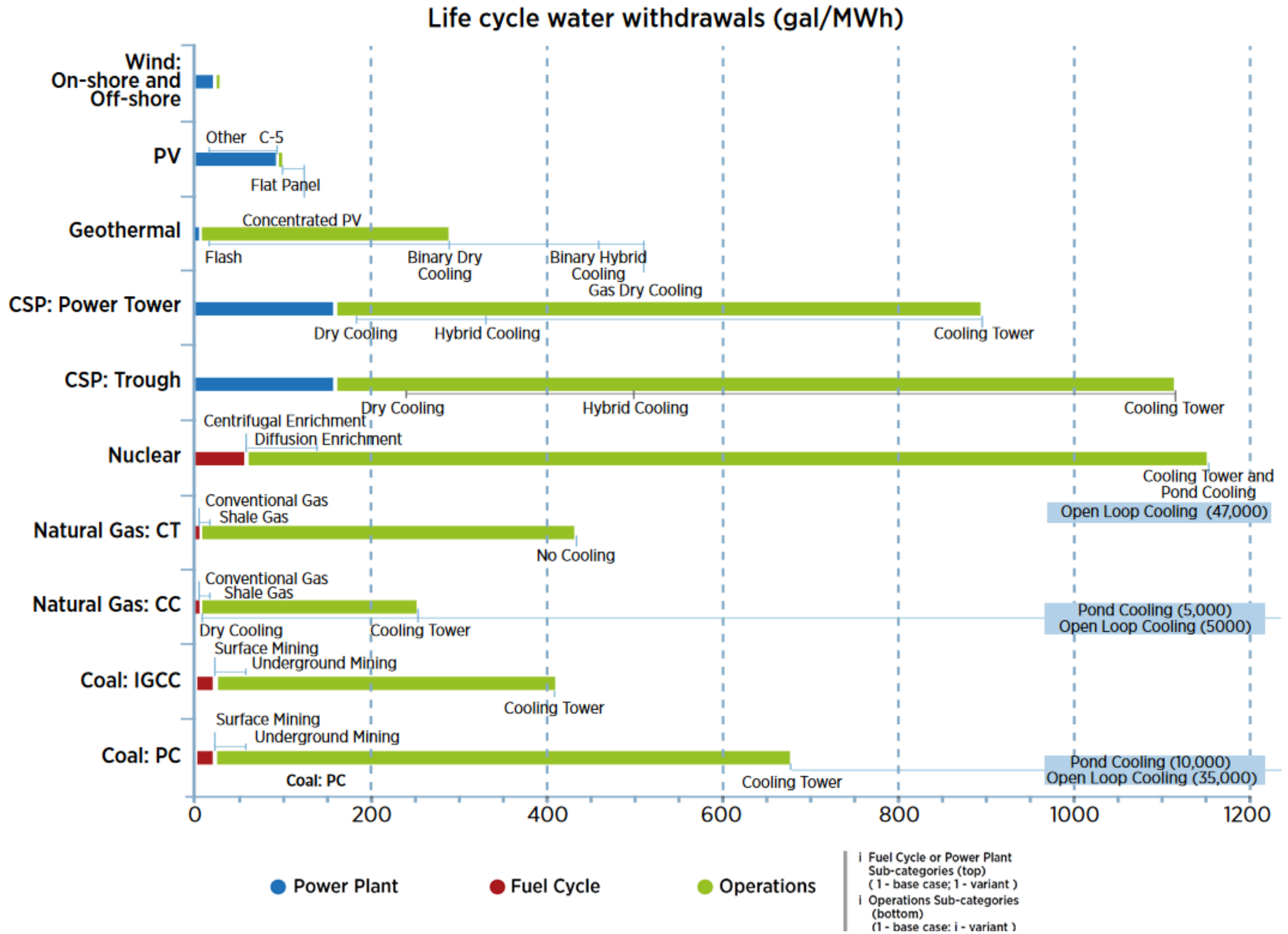
Source: IEA (2012)

Water Cooling Technologies

Once-Through (Open-Loop) Cooling	Closed-Loop (Wet) Cooling	Dry (Air) Cooling
• Water runs through the system's heat exchanger to condense the low-pressure steam at the exhaust of the turbines. • Water consumption low. • However, availability of water is critical to plant operation. • Risk of droughts, high-temperature events and competition for water resources.	• Cooling water circulates between the condenser and a cooling tower. • These cooling systems have much lower water requirements but consume much more of the withdrawn water.	• Dry cooling systems are very similar to closed-loop systems, but air replaces water to cool the circulating cooling fluid, thus eliminating water withdrawal and consumption. • This greatly reduces the plant efficiency. • Capital cost of such a system is about 10 times more than that of an open-loop system.

Source: Thopil et al. 2016

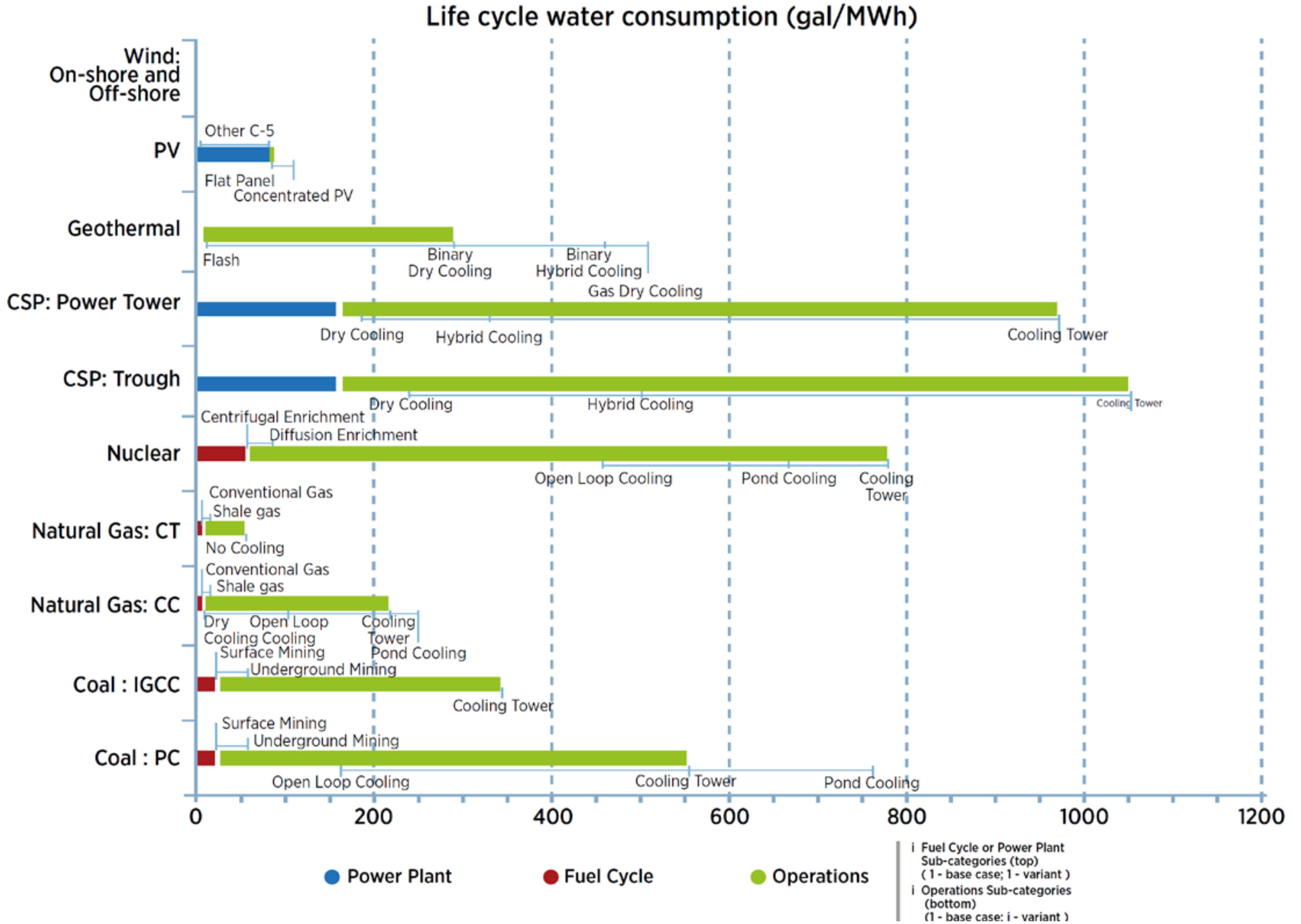
Life-cycle Water Consumption from Power Generation Technologies



Source: IRENA (2015), Renewable Energy in the Water, Energy & Food Nexus

Life-cycle Water Consumption from Power Generation Technologies

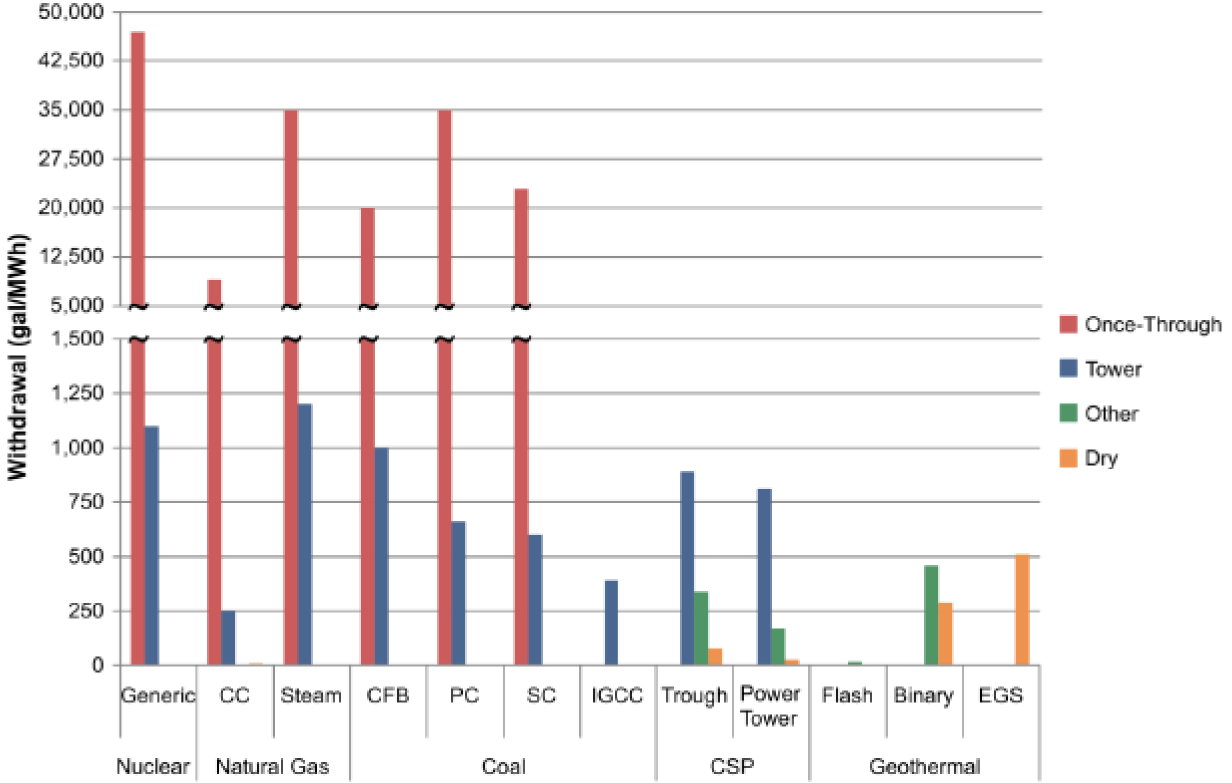
International Energy Transition



Source: IRENA (2015), Renewable Energy in the Water, Energy & Food Nexus

Life-cycle Water Consumption from Power Generation Technologies

- Once-through cooling technologies withdraw up to 100 times more water than alternative cooling technologies



Source: NREL (2017)

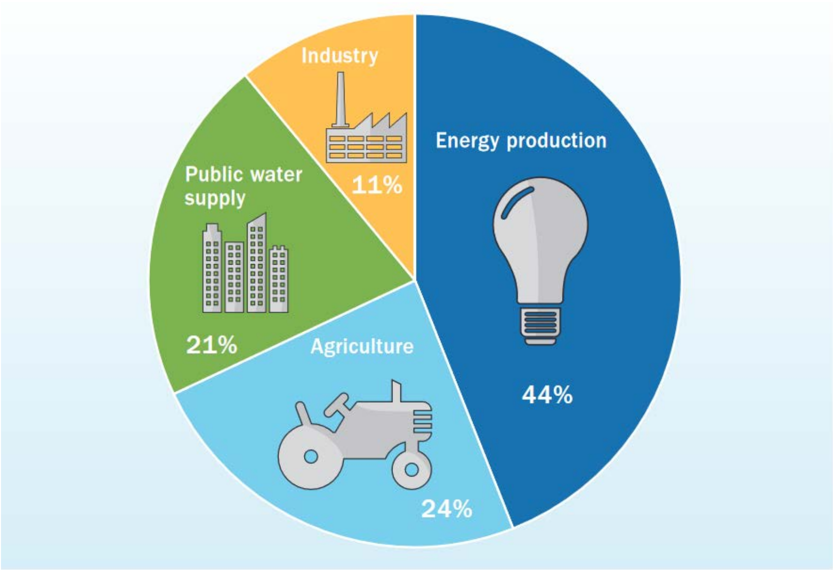
Water for Energy:

Case Studies (Fossil Fuels)

Water Consumption in Energy: Case Study Europe

- Energy production (primarily cooling water) uses the highest amount of water withdrawal in the EU (44%).

- The water used by thermal electricity generation and nuclear is equivalent to the average annual household water use of 82 million EU citizens or the population of Germany



Source: EEA, 2009

Source: EWEA 2014

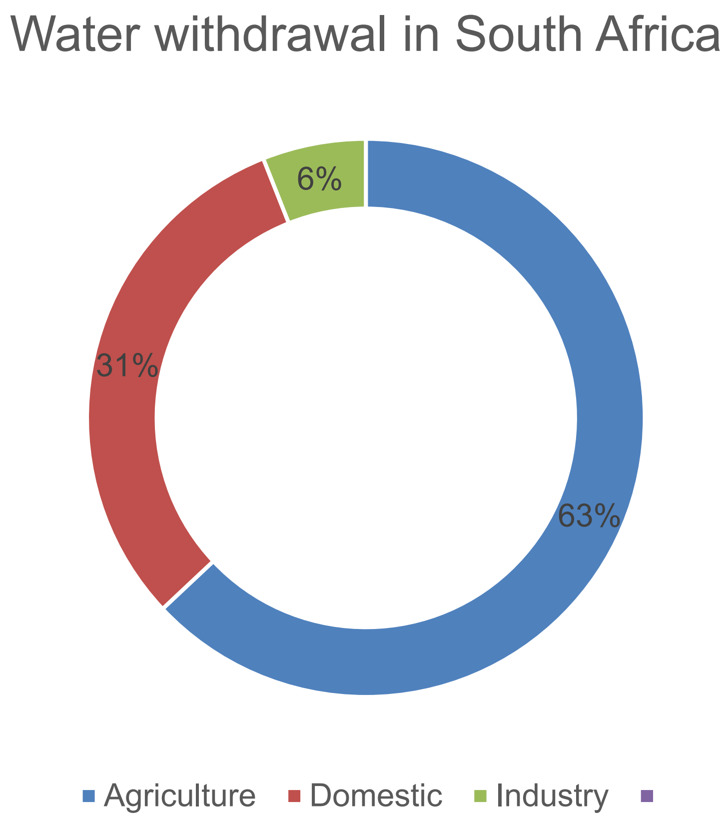
Water Use and Energy Security: Case Study US and EU

- Lack of water/drought can impact operation of power plants:
  - Europe: Curtailment of nuclear in warm summers due to water temerature of rivers (Once-Trough Technologies)
    - During the 2006 heat wave in Europe, when many thermal generators were forced to curtail or shutdown, spot electricity prices were 11% higher than average electricity prices
  - US: From 2000 to 2015, 43 incidents of water-related curtailment. Of these incidents, 18 involved coal-fired power plants and 25 involved nuclear plants.
    - Four categories: intake water too warm, discharge water too warm, both intake and discharge water too warm, and lack of intake water.
  - Average available capacities of thermal plants in the U.S. and Europe would decrease by 4.4%–16.0% in summer months

Source: Own, NREL 2017, Van Vliet et al. 2012

Water Consumption in Electricity: Case Study South Africa

- Water consumption of the power sector in South Africa is relatively small (about 6% of total water demand).
- Almost 63% of water is used by the agricular sector
- However, the power sector has priority access to water (in case of scarcity)



Source: Thopi et al. 2016

Water Consumption in Electricity: Case Study South Africa

- South Africa's coal fired power plants are built based on wet recirculating technologies
- Newer power plants are equipped with dry cooling technologies

Figure: Cooling Technologies Used in South Africa's Coal Plants

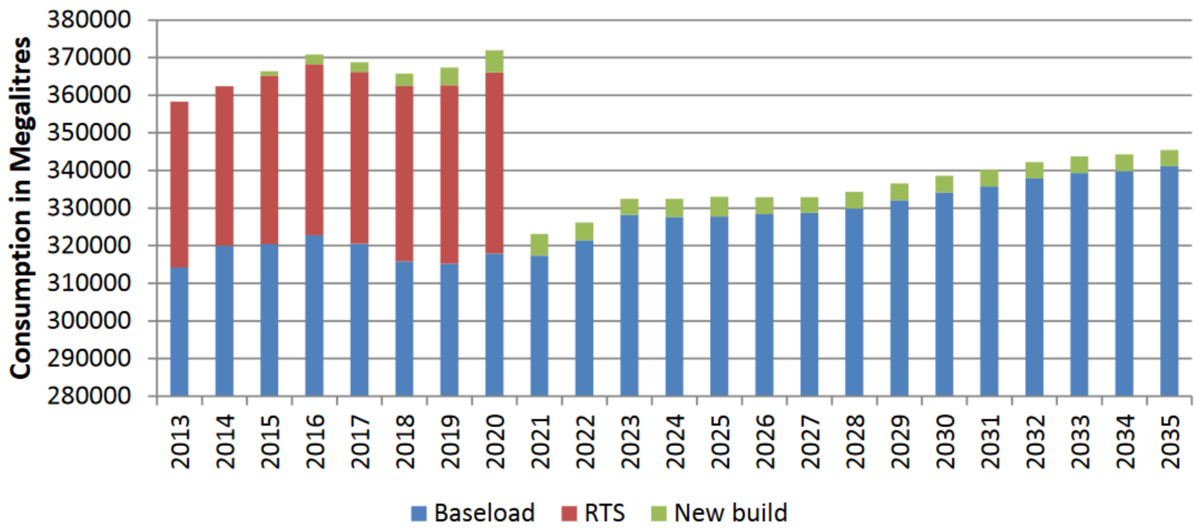
Power station	Cooling technique	Year completed	Location	Generation capacity	Water usage (m^3)		
				MW	2015	2016	2017
Arnot	Wet recirculating	1975	MP	2,352	21,377	24,633	22,172
Hendrina	Wet recirculating	1970	MP	2,000	22,922	22,655	20,652
Duvha	Wet recirculating	1984	MP	3,600	34,368	36,948	34,015
Kriel	Wet recirculating	1979	MP	3,000	36,493	35,009	27,348
Kendal	Indirect dry	1993	MP	4,116	4,143	3,970	3,325
Matla	Wet recirculating	1983	MP	3,600	44,551	44,264	38,163
Tutuka	Wet recirculating	1990	MP	3,654	42,857	36,140	35,649
Lethabo	Wet recirculating	1991	LP	3,708	42,167	42,763	37,900
Matimba	Direct dry	1991	MP	3,990	3,295	3,290	3,203
Majuba	Wet recirculating & dry	2000	MP	4,110	19,380	22,803	22,377
Camden	Wet recirculating	1967	MP	1,510	19,234	18,089	16,021
Grootvlei	Wet recirculating & dry	1973	MP	1,200	9,822	9,974	7,035
Komati	Wet recirculating	1966	MP	940	10,657	11,237	6,647
Medupi	Direct dry	ongoing	LP	4,788	1,041	736	1,463
Kusile	Direct dry	ongoing	MP	4,800	500	1,864	2,013
				47,368			

Source: Thopi et al. 2016

Water Consumption in Electricity: Case Study South Africa

- Older return to service (RTS) power plants which have been brought back to operation due to electricity shortages are water intensive and are located in water constrained areas.
- Should be phased out gradually and replaced by higher efficiency dry cooled power plants

Figure Projected water consumption in the South African power sector



Source: Thopi et al. 2016

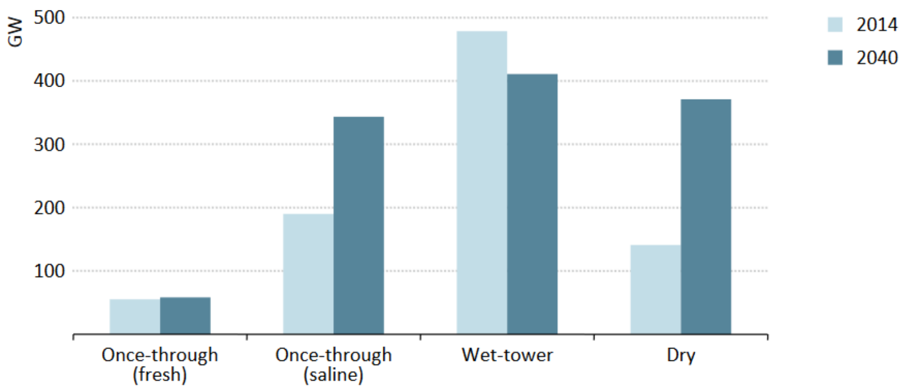
Power System Planning and Water Scarcity: Case Study China

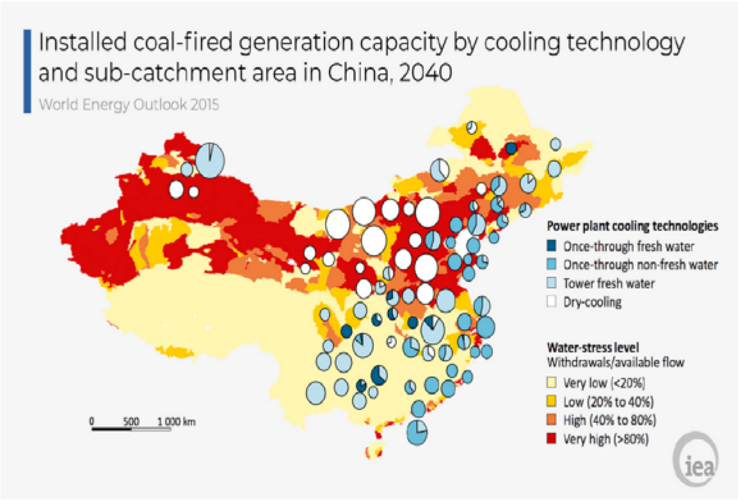
- 79% of water withdrawals in China for all purposes occur in water-stressed regions
- Coal-fired power plants are responsible for around 90% of total water withdrawals related to the power sector
- The large-scale adoption of CCS (as projected in our 450Scenario) could increase overall water requirements significantly, due to the additional cooling for carbon capture

Source: IEA WEO 2015

Power System Planning and Water Scarcity: Case Study China

- In the northern and eastern regions, more than 100GW of coal power plants are equipped with more expensive dry cooling
- About 175GW of installed coal-fired capacity, mainly plants with wet-tower systems in northern China, need to be retrofitted with dry cooling

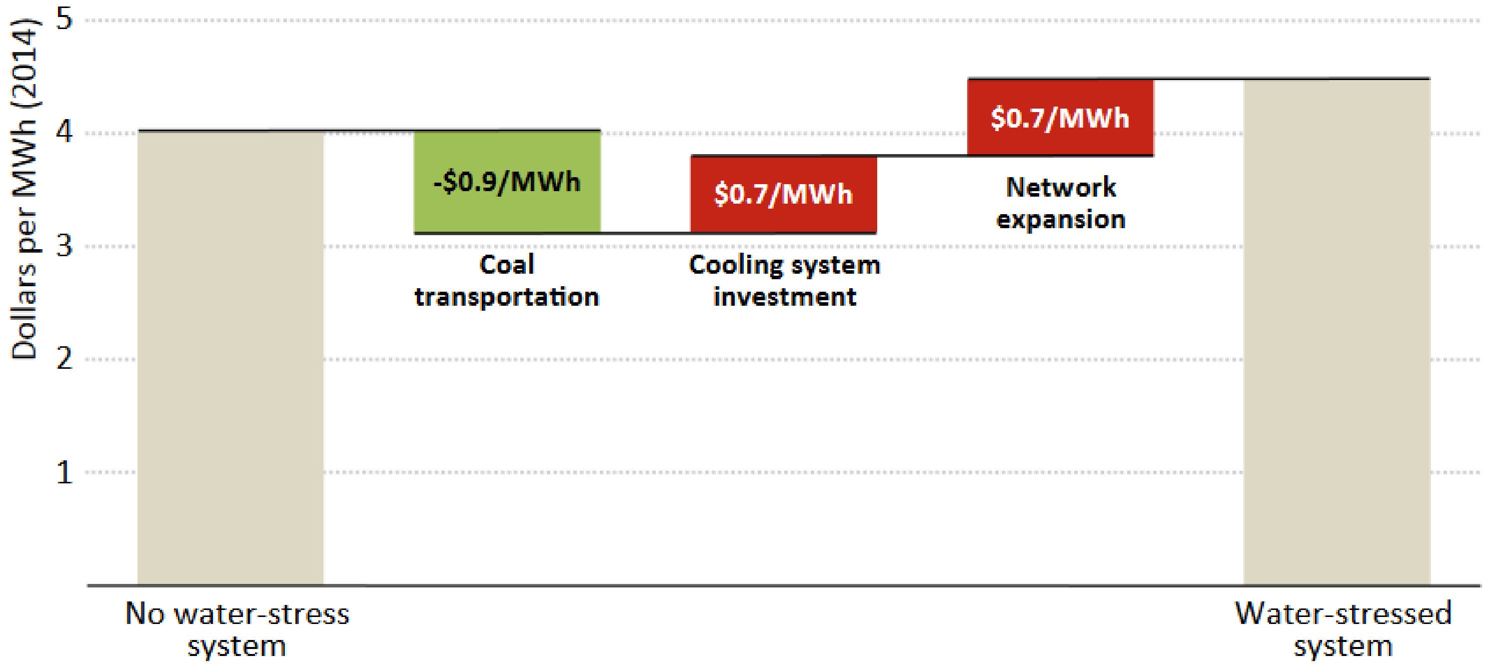




Source: IEA WEO 2015

Power System Planning and Water Scarcity: Case Study China

- Retrofitting with dry cooling technologies will increase the cost of coal



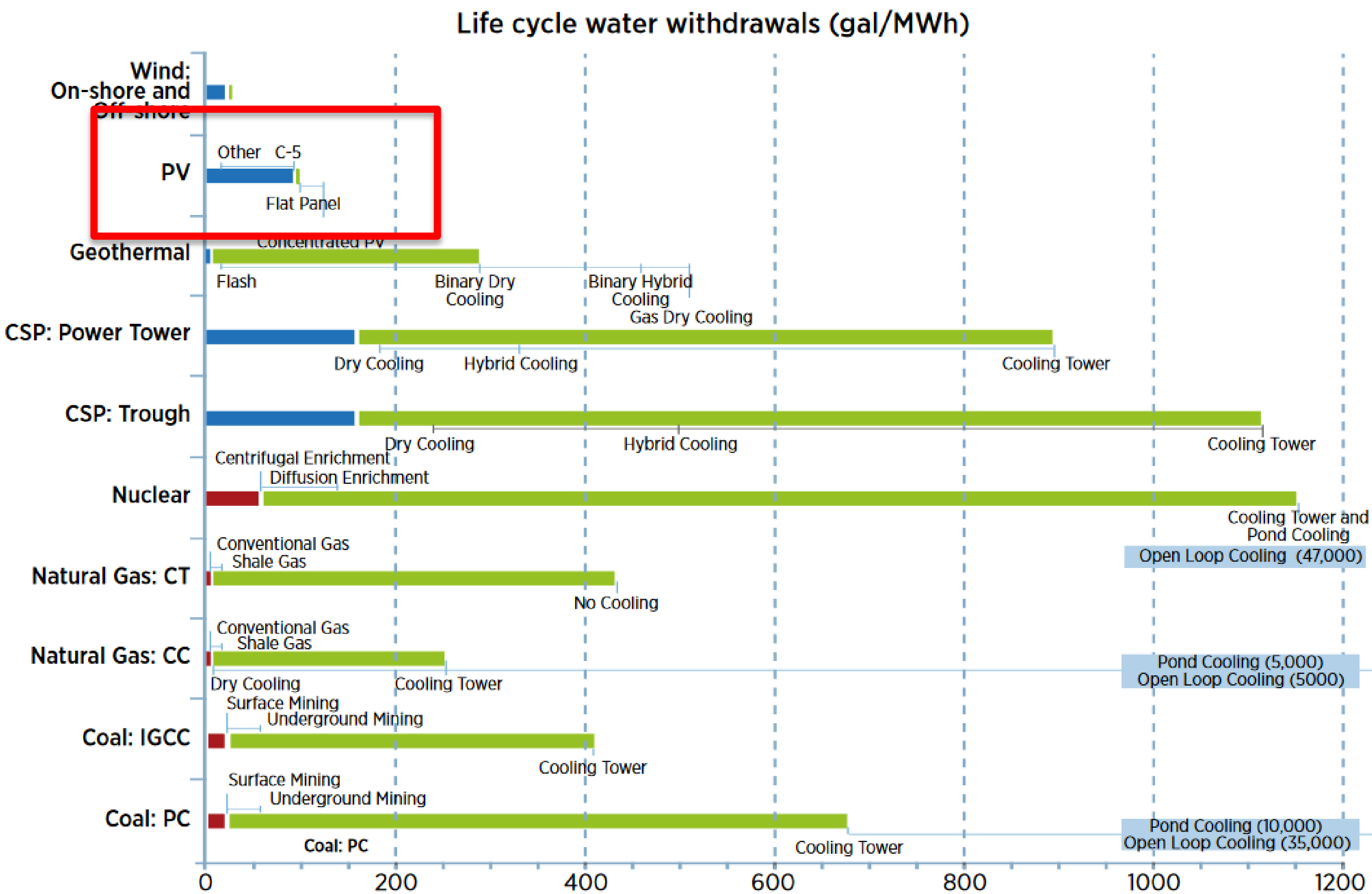
Note: The graph only refers to the generation cost component that can be attributed to the location of a plant.

Source: IEA WEO 2015

Water for Energy:

Water Consumption Related to Solar PV

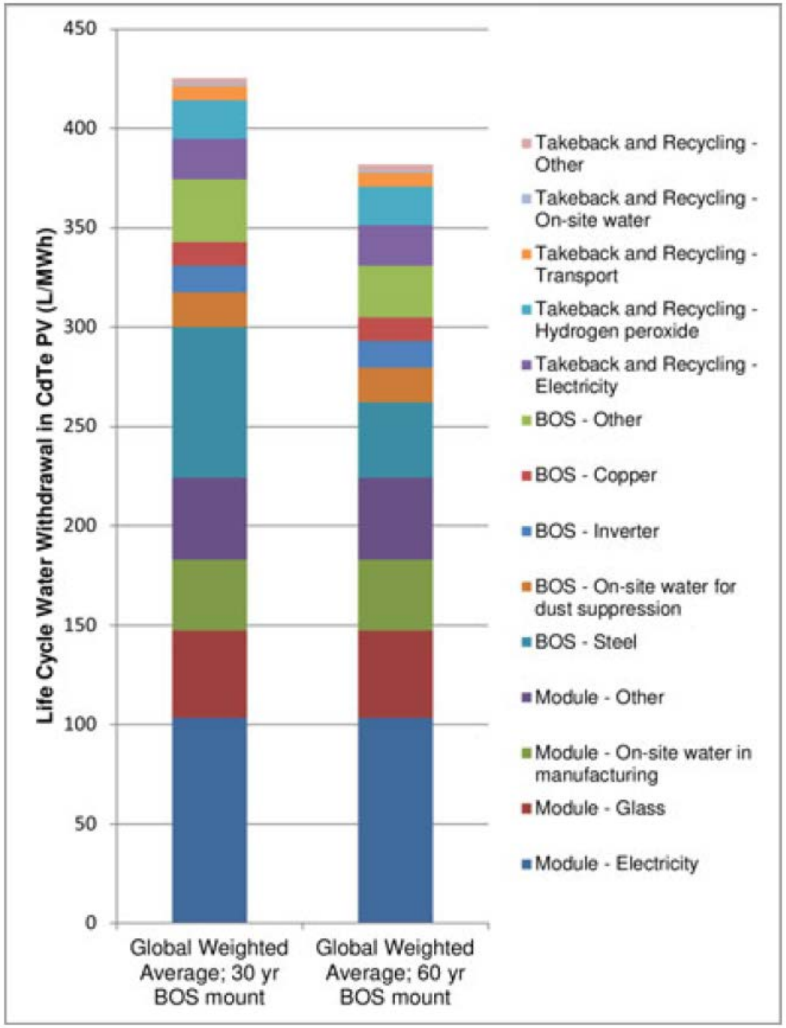
Life-cycle Water Consumption from Power Generation Technologies



Source: IRENA (2015), Renewable Energy in the Water, Energy & Food Nexus

Water Consumption of PV – Module Manufacturing

- Life cycle water withdrawal from solar PV (CdTe)
  - 50% for module manufacturing
  - 33% for balance of system (BOS)
  - Only 12% for onsite use (e.g. cleaning)



Source: Sinha et al. (2012)

Water Consumption of PV – Panel Cleaning

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- Water required for PV module cleaning depends on the selected cleaning method

Source Pic: IBC Solar / PV Magazine India

Water Consumption of PV – Panel Cleaning

- Solar PV Module Cleaning Options:
  - Wet cleaning
  - Dry cleaning
  - Manual cleaning
  - Truck mounted
  - Semi-automated cleaning
  - Fully-automated cleaning
  - Future: Portable robots/drones

Source Pic: BP Metalmeccanica s.r.l.

Source Pic: Geva-Bot

Source Pic: Ecoppia

Source: PI Institute (2017)

Water Consumption of PV – Panel Cleaning

- Solar PV Module Dry Cleaning Options:
  - Mechanical:
    - Mechanical brush
    - Mechanical brush & vacuum cleaner
    - Microfiber-based cloth wiper
    - Microfiber & vacuum cleaner
  - Chemical Self-Cleaning
    - Nanofilms

Source Pic: First Solar

Water Consumption of PV – Panel Cleaning

- Selection of cleaning option depends on:
  - Water availability/scarcity in the region
  - Expected soiling levels
  - Frequency of cleaning
  - Type of PV plant
  - Proximity to labor sources

Source: PI Institute (2017)

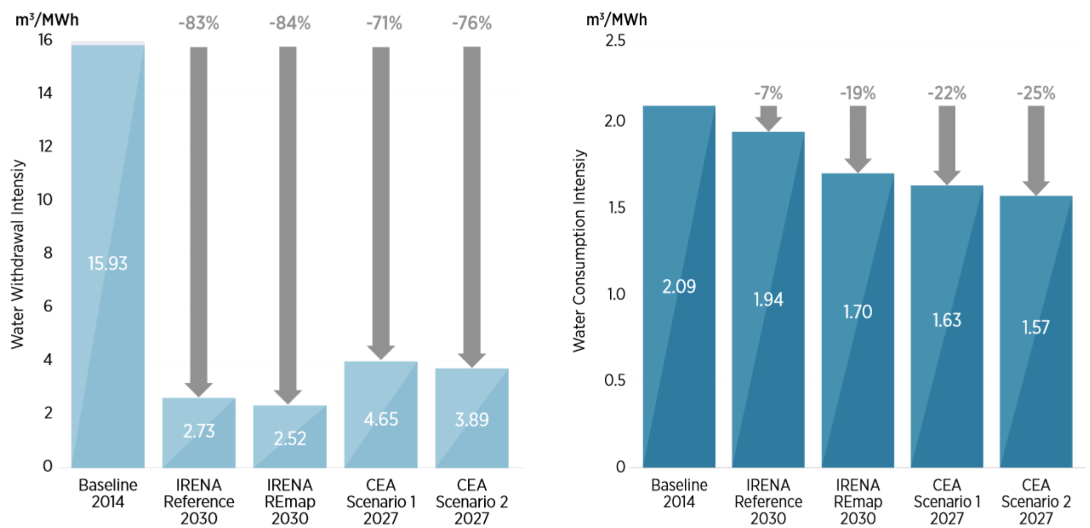
Water for Energy:

Case Studies (RE and Solar PV)

Reducing water use via PV: Case study India

- The combination of improved cooling technologies and RE deployment (wind and PV) could reduce the use of fresh water considerably.
- By 2030, the water withdrawal intensity could be reduced by up to 84%

Figure 3. Change in water withdrawal (left) and consumption (right) intensity of thermal and non-hydropower renewable generation, by scenario (relative to 2014)

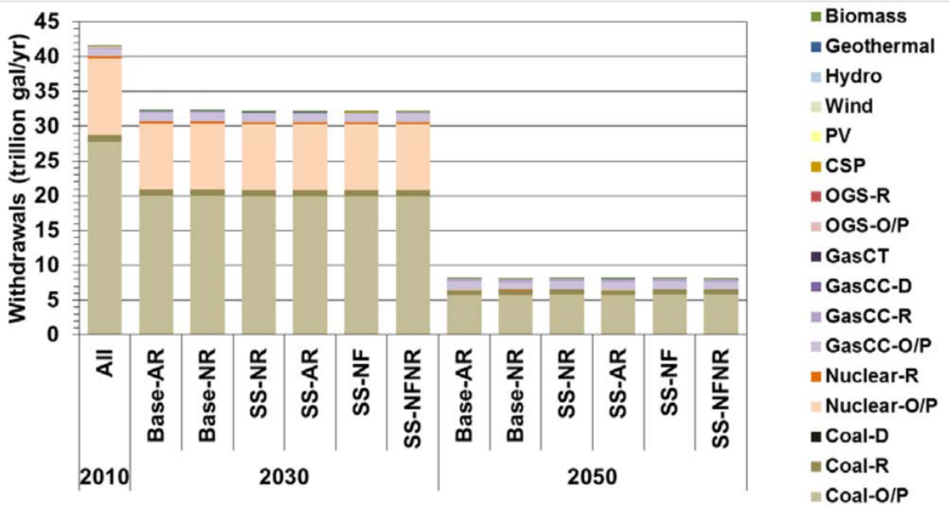


Source: IRENA (2018)

Reducing water use via PV: Case study USA

- water withdrawals being heavily dominated by once-through cooling demands of coal, nuclear, and natural gas facilities
- Water withdrawals decline from around 42 trillion gallons per year to 8 trillion gallons per year in 2050

Figure: US water withdrawal by fuel and cooling system

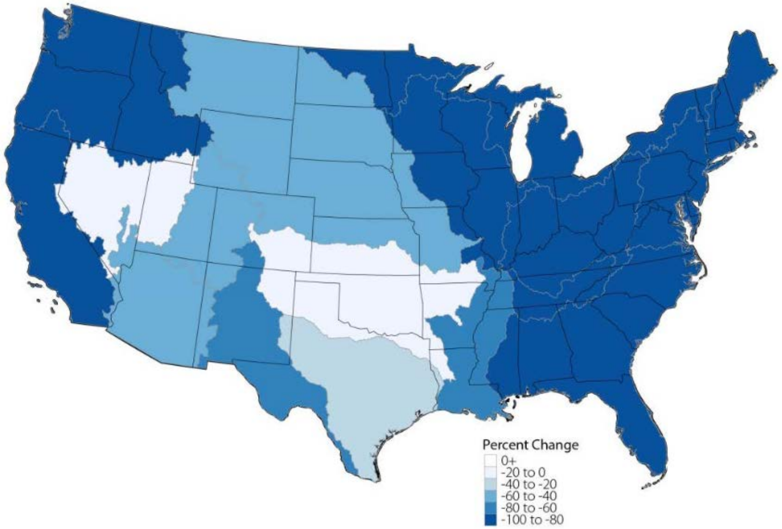


Source: NREL (2018)

Reducing water use via PV: Case study USA

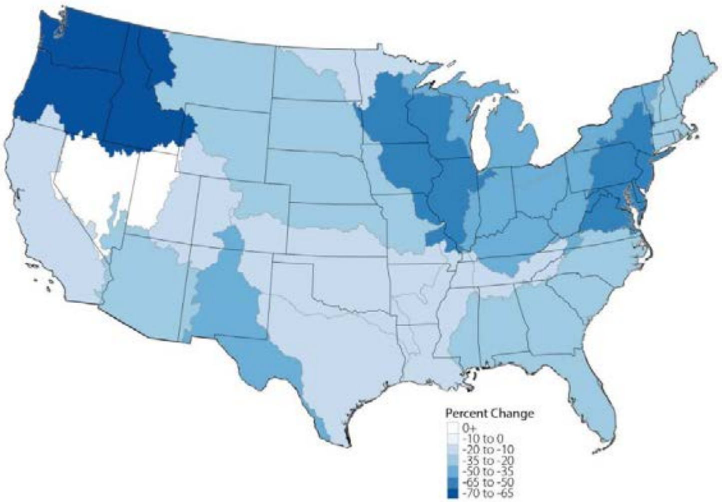
- Water withdrawal: Four regions having reductions greater than 90%
- Water consumption declines are less dramatic than water withdrawal declines

Figure: US water withdrawal (2010 vs 2050)



Source: NREL (2018)

Figure: US water consumption (2010 vs 2050)

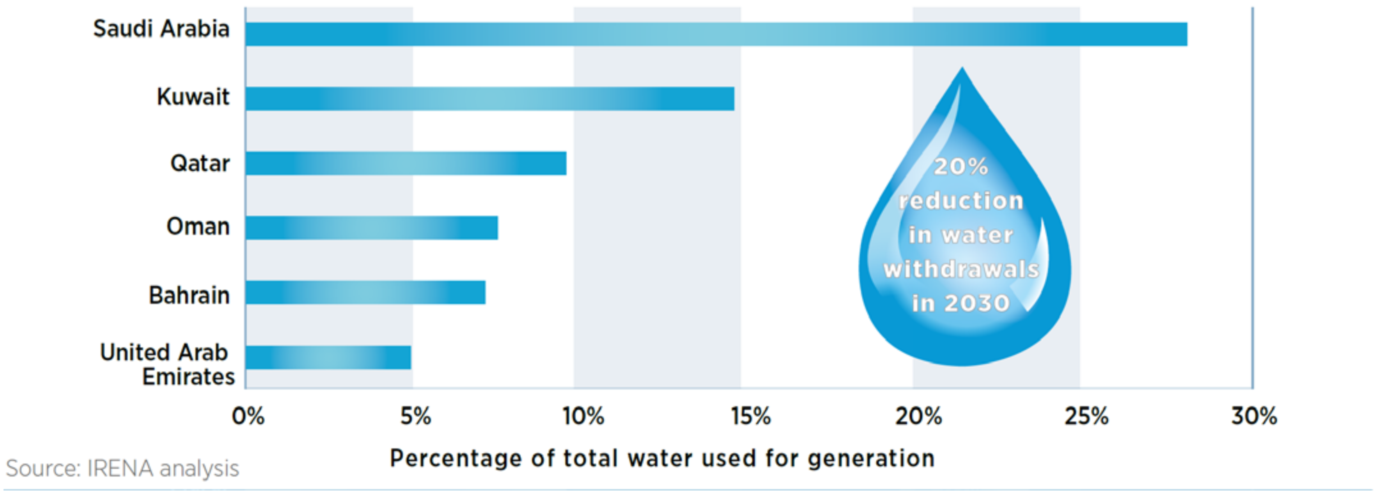


Source: NREL (2018)

Reducing water use via PV: Case study GCC Region

- Each country has announced a RE plan:
  - Bahrain (5%, by 2020), Kuwait (10% by 2030), Oman (10% by 2020), Qatar (2% by 2020), Saudi Arabia (54GW by 2032), United Arab Emirates (7% by 2020 in Abu Dhabi and 5% by 2030 in Dubai),

Figure: Potential for reduction in water withdrawals for power generation in GCC region by 2030



Source: NREL (2018)

Source: NREL (2018)

Summary

Summary of Key Findings

- The climate crisis will increase water scarcity: By 2025 people scarcity 1.8 billion people will be living in countries or regions with absolute water scarcity; 66% of all people will living under water stress conditions.

- The energy sector is responsible for 10% of water use globally.

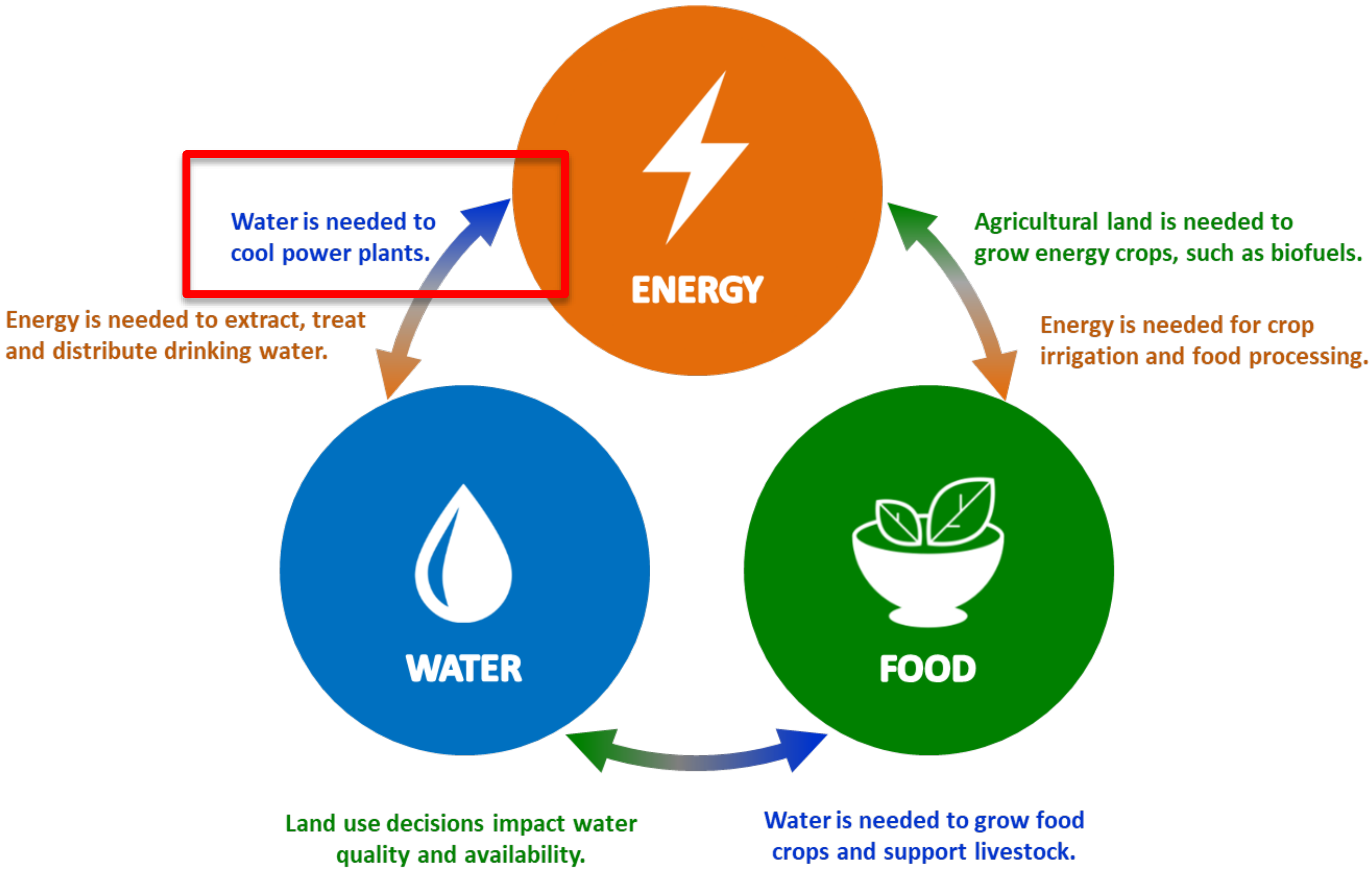
- In the electricity sector, coal plays a crucial role in water consumption and different cooling technologies are available.

- Water use in the electricity sector can be significantly reduce by moving to RE technologies such as solar PV and wind energy.

Outlook:

Water-Energy-Food Nexus

Energy-Water-Food Nexus



Source: CESC https://cleanenergysolutions.org/resources/energy-water-food-nexus/integrated-approaches

Further Reading/List of References

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Thank you for your time!

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Factor
Ideas for change

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6. Knowledge Checkpoint: Multiple Choice Questions