SUSANA C. (RUGE) TRICARICO
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Energy-Water Nexus and Climate

Introduction

Water, Energy and Food are requirements to sustain life. Supplying them to all people around the globe, guaranteeing there will be enough resources for the future is one of the biggest challenges for Sustainability.

Water, agriculture and energy use have deep impacts in ecosystems. They are intricately interconnected and scientists are barely starting to understand most of those linkages. In those relationships with ecosystems a new actor has come into scene: climate change. This will affect the availability of water, energy and food, and those three elements in turn have impacts on climate change.

Energy is required for treatment of raw water, desalination, distribution/transportation, wastewater treatment and irrigation. Water is required to produce electricity, transportation of fuels, food production and growing some crops used as fuel. Both, energy and food production have a marked impact on water quality.

Although this paper focuses only on the water-energy nexus and its relationship with climate change, food production nexus is a recurrent subject that cannot be neglected, specially with the increasing use crops in biofuel. An integral approach is central for creating adaptive capacity to climate change effects because water, energy, agriculture and climate are all pieces of the same system and are connected.

Hoff (2011) schematizes in Figure 1 the nexus showing the factors affecting it as urbanization, population growth and climate change. He indicates that changes are also required in economy, society and environment management, pointing out that actions in finance, technology and policy are required for achieving sustainable growth, water-energy-food security and resiliency.

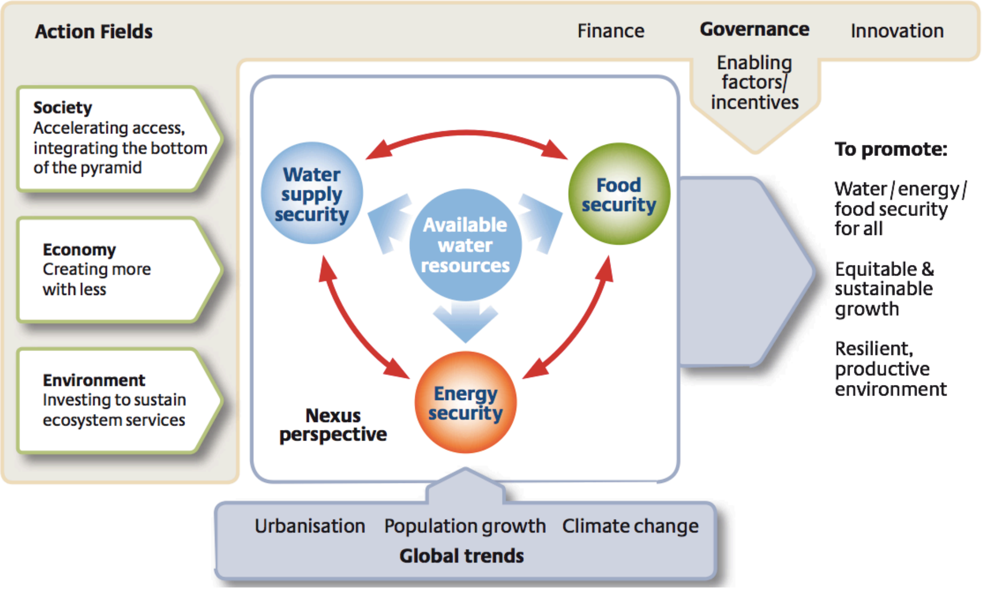

Figure 1 The water, energy and food security nexus[1]

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[1] (Hoff, 2011, p. 16)

Water and Energy mutual uses and their relationship with climate

Energy use in water

Energy is required for extracting, treating, purifying, distributing, and the heating/cooling of water. Water is required to produce electricity, extract fossil fuels and store potential energy in dams, boilers and turbines, as well as for growing biomass crops.[2] Energy inputs required in a typical water-use cycle have five basic stages as shown in Figure 2.

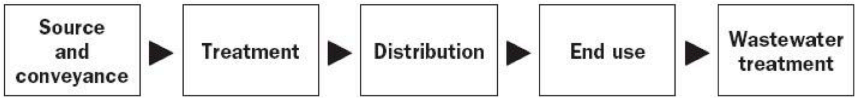
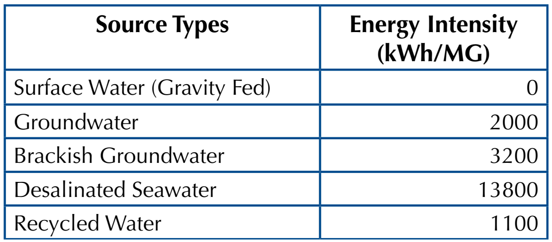


Figure 2 Uses of electricity in the water-use cycle (From Wolff et al., 2)[3]

Energy consumption (energy intensity) depends also on the water supply source. Figure 3 shows the energy intensity by source. Usually reclaimed water is highly energy-intensive and may vary per m^3 from 0.37KWh for surface water, 0.66-0.87KWh for reclaimed wastewater and 2.6-4.36KWh for desalinated water. Groundwater pumping for irrigation may imply up to 40% of the total energy use in some countries because pumping in greater depth may increase energy demand by a factor of 80 as the water table falls (from a depth of 35 to 120m).[4]



Source Types	Energy Intensity (kWh/MG)
Surface Water (Gravity Fed)	0
Groundwater	2000
Brackish Groundwater	3200
Desalinated Seawater	13800
Recycled Water	1100

Figure 3 Generic intensity of water supply types[5]

Climate Change and Water Consumption

Greenhouse gas (GHG) emissions are associated to the water use. Figure 4 shows the energy consumption by sector and associated Carbon emissions. Note the greatest numbers in energy and emissions are given by wastewater treatment (public and private), irrigation and water supply.

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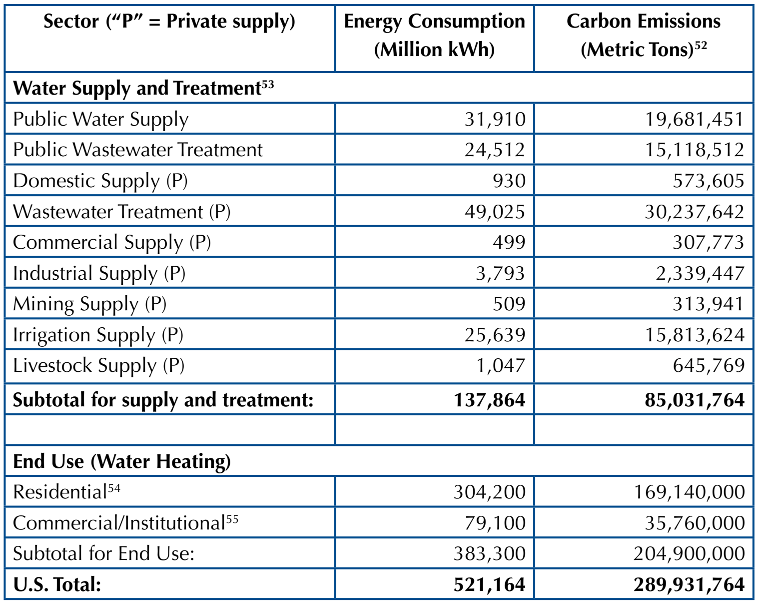
[2] (Platonova & Leone, 2012, p. 6)

[3] (Griffiths-Sattenspiel & Wilson, 2009, p. 11)

[4] (Hoff, 2011, p. 22)

[5] (Griffiths-Sattenspiel & Wilson, 2009, p. 13)



Sector ("P" = Private supply)	Energy Consumption (Million kWh)	Carbon Emissions (Metric Tons)[52]
Water Supply and Treatment[53]		
Public Water Supply	31,910	19,681,451
Public Wastewater Treatment	24,512	15,118,512
Domestic Supply (P)	930	573,605
Wastewater Treatment (P)	49,025	30,237,642
Commercial Supply (P)	499	307,773
Industrial Supply (P)	3,793	2,339,447
Mining Supply (P)	509	313,941
Irrigation Supply (P)	25,639	15,813,624
Livestock Supply (P)	1,047	645,769
Subtotal for supply and treatment:	**137,864**	**85,031,764**
End Use (Water Heating)		
Residential[54]	304,200	169,140,000
Commercial/Institutional[55]	79,100	35,760,000
Subtotal for End Use:	383,300	204,900,000
U.S. Total:	**521,164**	**289,931,764**

Figure 4 U.S. Annual Water-Related Energy Use and Carbon Emissions, 2005[6]

Electricity will also be demanded for water pumping and desalination in areas that will see shortages in water supply; competition for water resources in some water-scarce areas will demand policy intervention. Climate change is expected to affect significantly hydropower, generating competing uses between water and energy supply.

Water use in electricity

Right now, there are many water-stressed regions on Earth. Many people lack of water supply and sanitation. Stress will be increased by climate change because overall projected temperature increase and decline of rainfall. Anthropogenic factors such as competing land use, pollution, dilution of chemicals and minerals and growing population are added to climate factors causing more pressure on the system.

Power plants impact the quality and quantity of local water resources. The power sector withdraws more freshwater annually than any other sector in the US (41% in 2005 for thermoelectric cooling needs primarily)[7] and once used and cooled, water temperature is increased and may impact aquatic ecosystems.[8] Another important fact to notice is that in the United States, on average, the water footprint of electricity use compared to the water use in a household is about 5.4 times greater (39,829 gallons/month vs. 7,336 gallons/month) as shown in Figure 5. This evidences the necessity of a nexus approach in order to protect water resources.

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[6] (Griffiths-Sattenspiel & Wilson, 2009, p. 22)

[7] (Macknick, Sattler, Averyt, Clemmer, & Rogers, 2012, p. 1)

[8] (Macknick et al., 2012, p. 2)

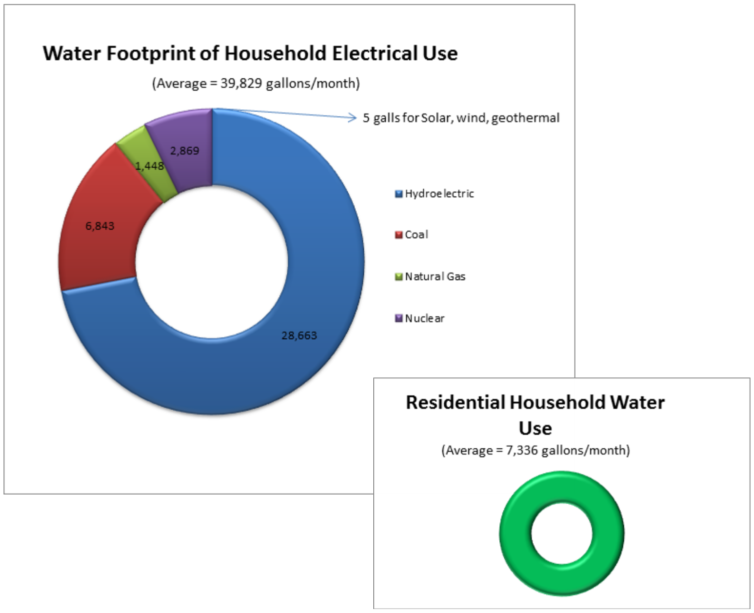

Figure 5 Water Footprint of Household Electrical Use versus Direct Household Water Use[9]

Figure 6 shows a schematic of the relationship between generators, boilers, and cooling structures in power plants. Although new technologies allow recirculating water with cooling purposes, a fresh source of water is always needed.

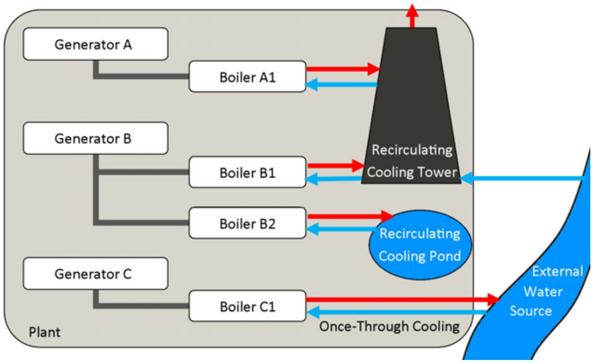

Figure 6 Relationship between electricity plants, generators, boilers and cooling structures[10]

Water in electricity generation is accounted as both consumption and withdrawal. Water has different life cycle stages: Fuel cycle, power plant and operations (see Figure 7). Figure 8 shows the consumption in gal/MWh and Figure 9 shows the withdrawal in gal/MWh. It is clear that high water consumption and high water withdrawals are not always related. Notwithstanding the cooling processes are always the highest users in both withdrawals and consumption. Renewable technologies as photovoltaic solar and wind power have only consumptions in the power plant construction and maintenance and have low impacts. Geothermal shows also as an option with some water consumption and withdrawal in the operation phase.

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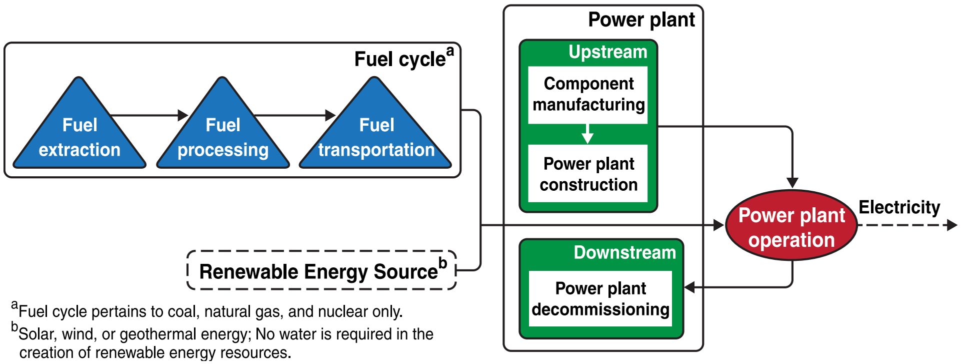
[9] (Wilson, Leipzig, & Griffiths-Sattenspie, 2012, p. 12. Chart 3)
[10] (Averyt et al., 2013, p. 3. Figure 1)



[a] Fuel cycle pertains to coal, natural gas, and nuclear only.
[b] Solar, wind, or geothermal energy; No water is required in the creation of renewable energy resources.

Figure 7 Water life cycle stages in electricity generation[11]

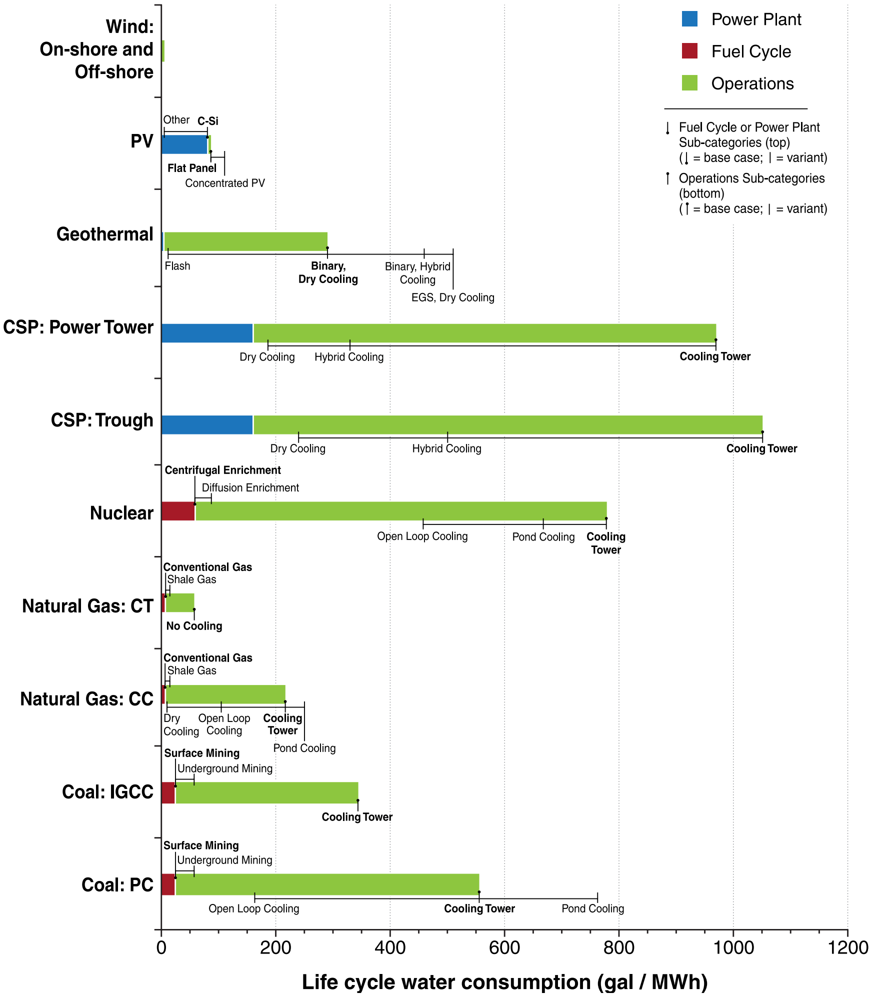


Figure 8 Estimated life cycle water consumption factors. Note: PV = photovoltaics; C-Si = crystalline silicone; EGS = enhanced geothermal system; CSP = concentrating solar power; CT = combustion turbine; CC = combined cycle; IGCC = integrated gasification combined cycle; and PC = pulverized coal, sub-critical.[12]

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[11] (Meldrum, Nettles-Anderson, Heath, & Macknick, 2013, p. 3. Figure 2)
[12] (Meldrum et al., 2013, p. 13. Figure 4)

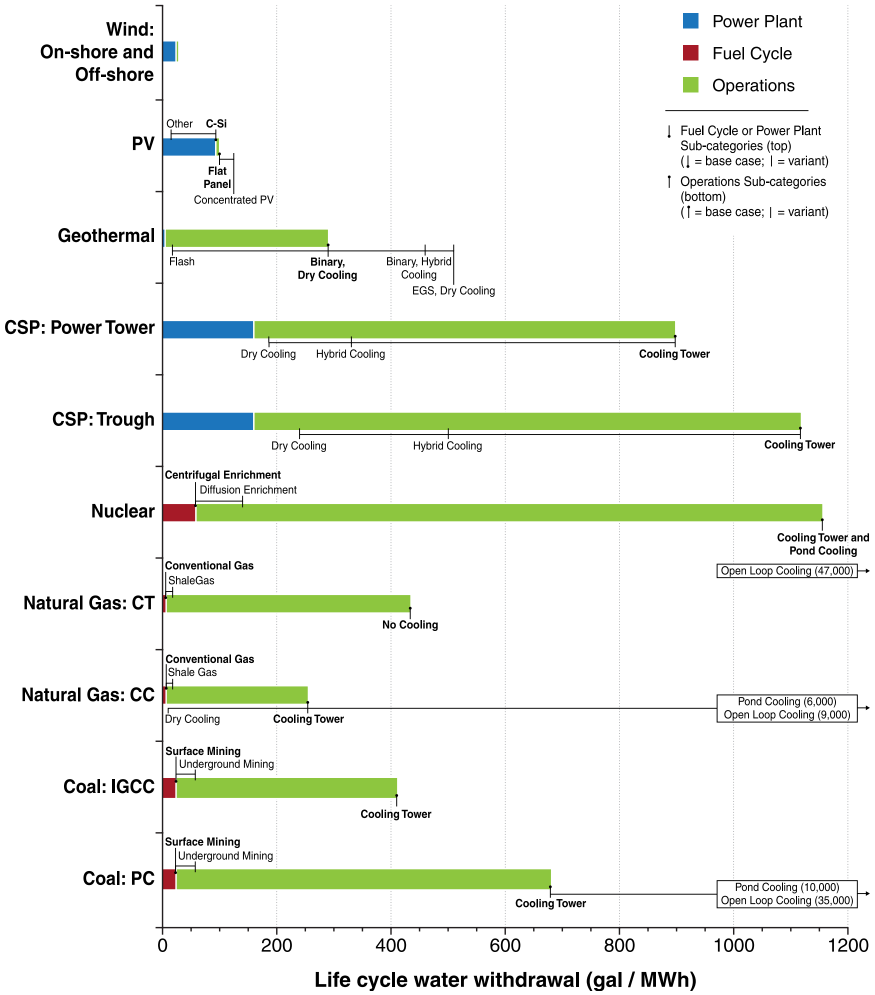

Figure 9 Estimated life cycle water withdrawal factors. Note: PV = photovoltaics; C-Si = crystalline silicone; EGS = enhanced geothermal system; CSP = concentrating solar power; CT = combustion turbine; CC = combined cycle; IGCC = integrated gasification combined cycle; and PC = pulverized coal, sub-critical.[13]

Macknick et al. (2012) also analyze water use in the electricity sector in four scenarios. One is a reference from the EIA's Annual Outlook 2011 and three carbon-constrained scenarios with different technologies and generation as shown in Figure 10.

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[13] (Meldrum et al., 2013, p. 14. Figure 5)

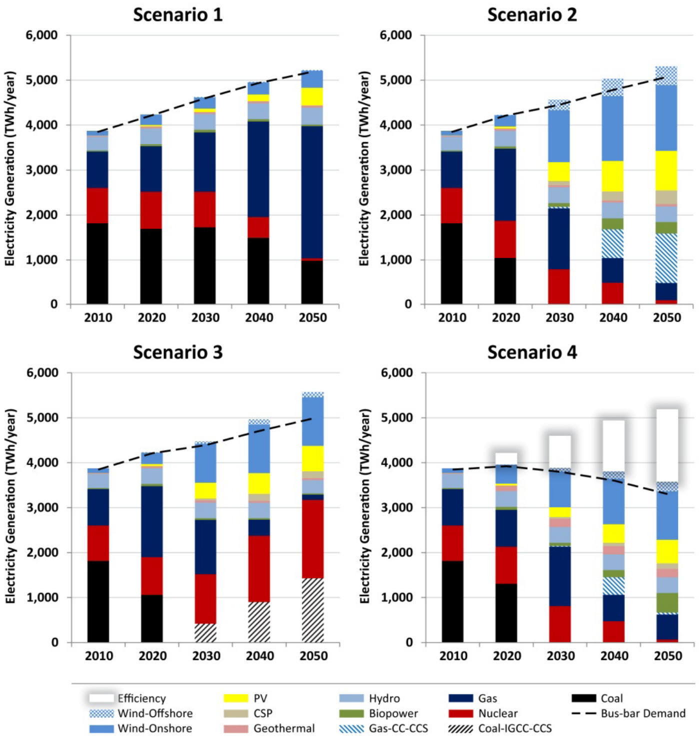

Figure 10 National electricity generation by scenario. Results from the ReEDS model indicate a variety in total electricity generation values and deployed electricity generation technologies in 2030 and 2050. Scenario 1, reference case; scenario 2, carbon budget, no technology targets; scenario 3, carbon budget with coal with CCS and nuclear targets; scenario 4, carbon budget with efficiency and renewable energy targets.[14]

Figure 11 shows the results of water withdrawal for each scenario. Macknick points out that the reduction is mainly due to recirculating cooling technologies in coal plants in scenario 1, the replacement of coal powered plants by natural gas combined cycle in scenario 2, cooling recirculation in nuclear and new coal plants in scenario 3 and a reduction of demand and related water requirements in scenario 4.

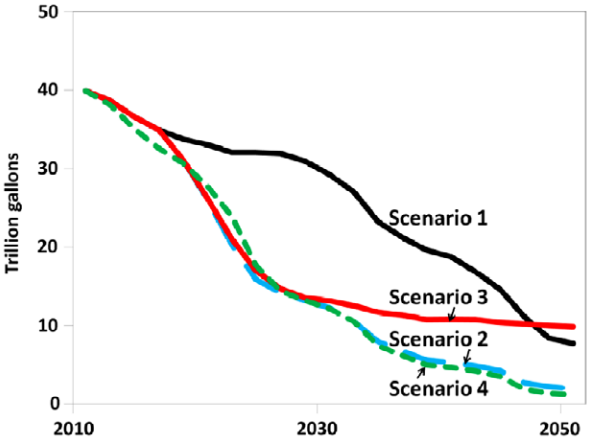

Figure 11 National-level water withdrawal results for four electricity scenarios. Scenario 1, reference case; scenario 2, carbon budget, no technology targets; scenario 3, carbon budget with coal with CCS and nuclear targets; scenario 4, carbon budget with efficiency and renewable energy targets.[15]

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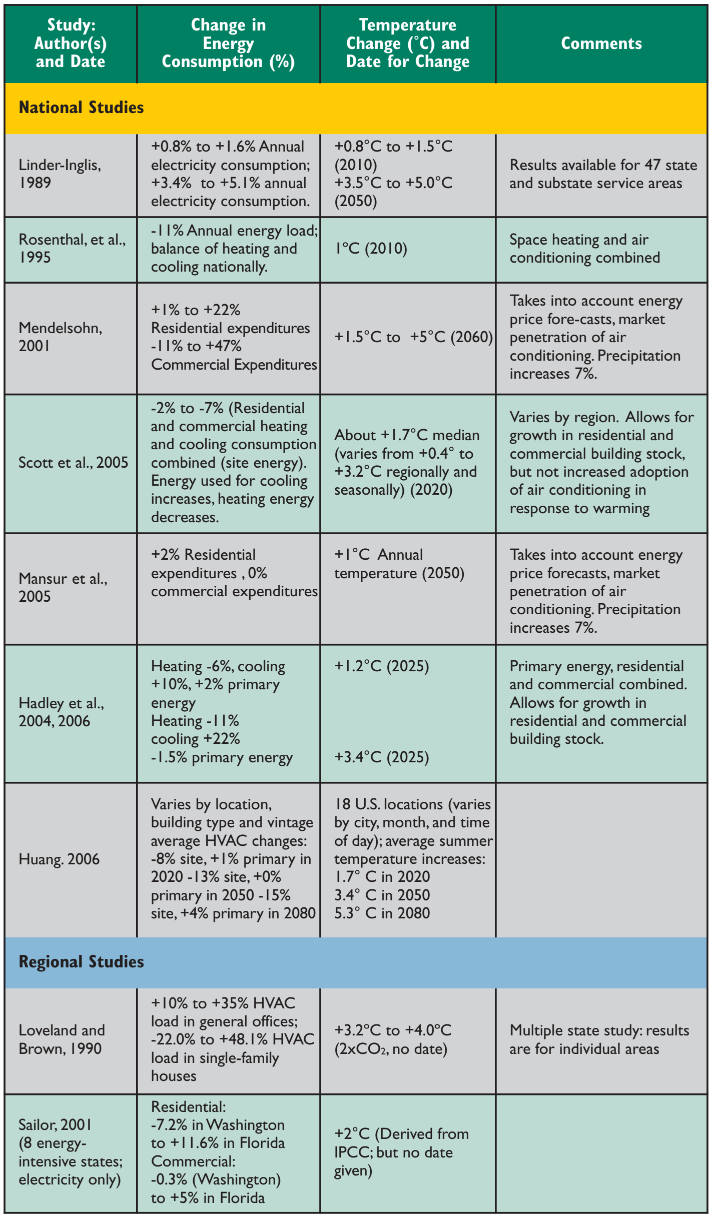
[14] (Macknick et al., 2012, p. 4. Figure 2)

[15] (Macknick et al., 2012, p. 5. Figure 3)

Climate Change and Electricity generation

Studies conclude that climate warming will mean a reduction in heating requirements and an increase in cooling requirements, varying by season and region, and in consequence increasing the energy requirements and its costs. They do not agree on the amount of energy consumption reduction in heating times and increment in cooling times. It varies per sector (residential and commercial), location, region and estimation of temperature increase (See Figure 12). Research is less conclusive in how electricity demand will be affected in case of extreme events, where reduction in water supply availability for thermal and hydropower generation will be affected. The effects will most likely be regional in the case of water shortages. It is expected that both the global trade market and energy market will change because of impacts in other countries.[16]



Study: Author(s) and Date	Change in Energy Consumption (%)	Temperature Change (˚C) and Date for Change	Comments
National Studies			
Linder-Inglis, 1989	+0.8% to +1.6% Annual electricity consumption; +3.4% to +5.1% annual electricity consumption.	+0.8°C to +1.5°C (2010) +3.5°C to +5.0°C (2050)	Results available for 47 state and substate service areas
Rosenthal, et al., 1995	-11% Annual energy load; balance of heating and cooling nationally.	1°C (2010)	Space heating and air conditioning combined
Mendelsohn, 2001	+1% to +22% Residential expenditures -11% to +47% Commercial Expenditures	+1.5°C to +5°C (2060)	Takes into account energy price fore-casts, market penetration of air conditioning. Precipitation increases 7%.
Scott et al., 2005	-2% to -7% (Residential and commercial heating and cooling consumption combined (site energy). Energy used for cooling increases, heating energy decreases.	About +1.7°C median (varies from +0.4° to +3.2°C regionally and seasonally) (2020)	Varies by region. Allows for growth in residential and commercial building stock, but not increased adoption of air conditioning in response to warming
Mansur et al., 2005	+2% Residential expenditures , 0% commercial expenditures	+1°C Annual temperature (2050)	Takes into account energy price forecasts, market penetration of air conditioning. Precipitation increases 7%.
Hadley et al., 2004, 2006	Heating -6%, cooling +10%, +2% primary energy Heating -11% cooling +22% -1.5% primary energy	+1.2°C (2025) +3.4°C (2025)	Primary energy, residential and commercial combined. Allows for growth in residential and commercial building stock.
Huang. 2006	Varies by location, building type and vintage average HVAC changes: -8% site, +1% primary in 2020 -13% site, +0% primary in 2050 -15% site, +4% primary in 2080	18 U.S. locations (varies by city, month, and time of day); average summer temperature increases: 1.7° C in 2020 3.4° C in 2050 5.3° C in 2080	
Regional Studies			
Loveland and Brown, 1990	+10% to +35% HVAC load in general offices; -22.0% to +48.1% HVAC load in single-family houses	+3.2°C to +4.0°C ($2xCO_2$, no date)	Multiple state study: results are for individual areas
Sailor, 2001 (8 energy-intensive states; electricity only)	Residential: -7.2% in Washington to +11.6% in Florida Commercial: -0.3% (Washington) to +5% in Florida	+2°C (Derived from IPCC; but no date given)	

Figure 12 Climate Change Effects in Combined Residential- Commercial Studies and Combined Results from Sector Studies[17]

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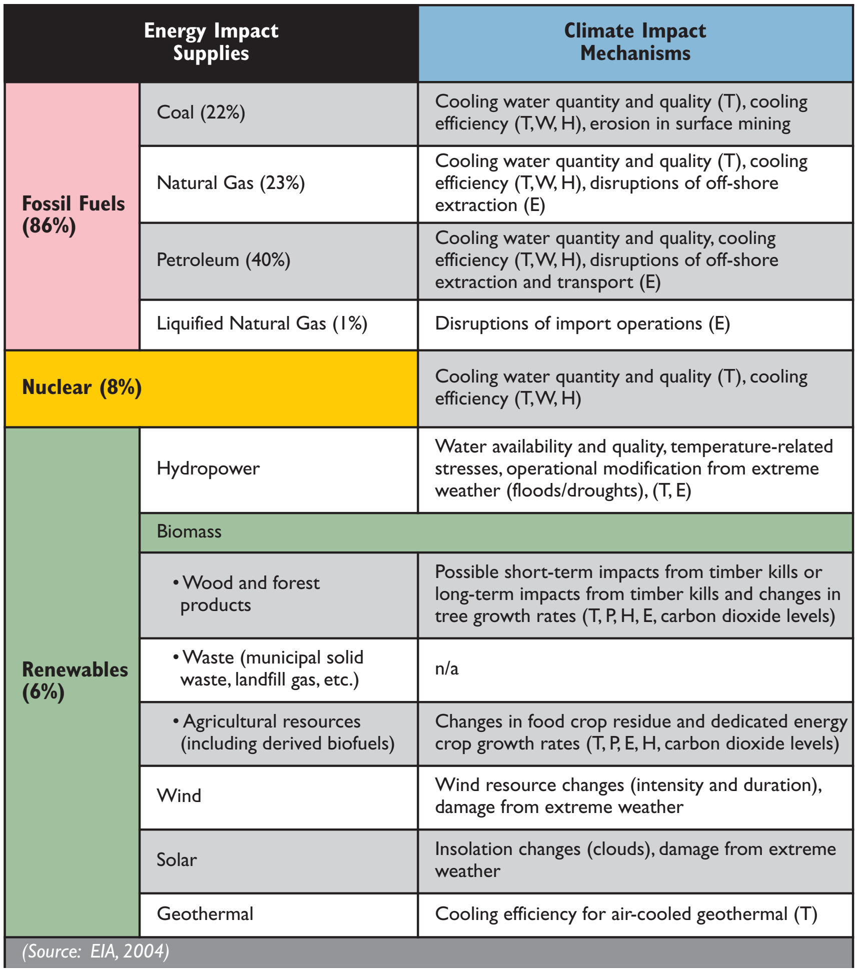
[16] (Wilbanks et al., 2008)
[17] (Wilbanks et al., 2008, p. 19)

Increased temperatures will have effects in evapotranspiration and water requirements for hydroelectric generation, large-scale agriculture and livestock activities (mainly for irrigation purposes). Regions dependent on rainfed agriculture may see their water security impacted. There will be other effects of climate change on energy that need to be addressed, as Wilbanks et al. (2008) states in in Figure 13, in the United States according to the EIA.



Energy Impact Supplies		**Climate Impact Mechanisms**
Fossil Fuels (86%)	Coal (22%)	Cooling water quantity and quality (T), cooling efficiency (T,W, H), erosion in surface mining
	Natural Gas (23%)	Cooling water quantity and quality (T), cooling efficiency (T,W, H), disruptions of off-shore extraction (E)
	Petroleum (40%)	Cooling water quantity and quality, cooling efficiency (T,W, H), disruptions of off-shore extraction and transport (E)
	Liquified Natural Gas (1%)	Disruptions of import operations (E)
Nuclear (8%)		Cooling water quantity and quality (T), cooling efficiency (T,W, H)
Renewables (6%)	Hydropower	Water availability and quality, temperature-related stresses, operational modification from extreme weather (floods/droughts), (T, E)
	Biomass	
	• Wood and forest products	Possible short-term impacts from timber kills or long-term impacts from timber kills and changes in tree growth rates (T, P, H, E, carbon dioxide levels)
	• Waste (municipal solid waste, landfill gas, etc.)	n/a
	• Agricultural resources (including derived biofuels)	Changes in food crop residue and dedicated energy crop growth rates (T, P, E, H, carbon dioxide levels)
	Wind	Wind resource changes (intensity and duration), damage from extreme weather
	Solar	Insolation changes (clouds), damage from extreme weather
	Geothermal	Cooling efficiency for air-cooled geothermal (T)

(Source: EIA, 2004)

Figure 13 Mechanisms Of Climate Impacts On Various Energy Supplies In The U.S. Percentages Shown Are Of Total Domestic Consumption; (T = water/air temperature, W = wind, H = humidity, P = precipitation, and E = extreme weather events)[18]

Other climate change studies indicate that hurricanes, increased lighting and, sea level rise will also impact power generation plants by fuel availability, mostly delivered by barge or locate close to the coast such as nuclear plants, affecting plant facilities and transmission infrastructure. Temperatures will be associated with peak demands of electricity and will decrease the overall thermoelectric generation efficiency.

Analysis on security signaled that climate change is likely to produce instability in developing nations. This will affect the institutions, turning them into less functional and therefore a less effective way for providing electricity or evaluating how to balance the competitive electricity usage. Some of these nations are strategic for the United States as fuel and mineral sources that will be affected by a local economic output. The impacts on the local economies are given by desertification, infrastructure impacts and reduced

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[18] (Wilbanks et al., 2008)

hydropower capacity. As King and Gulledge (2013) indicated "Policies designed to increase energy security may have the perverse effect of accelerating greenhouse gas emissions"[19].

All these effects combined may lead to an increase in energy prices, instigated by reduction in subsidies and natural market price increments in fossil fuels and policy changes leading to reduce Greenhouse Gas emissions.

Most of the studies used as source in this paper are not accounting for population increase, urbanization, and rural agricultural increased demands for the projections. This will intensify the effects of climate, water and energy use.

Case studies

California

The California is a carefully studied case of the impacts of climate change in the energy production because the state has invested a lot of resources trying to combat it. They estimate a demand increase due to temperature increases. The snowpack of the Sierra will also be affected being reduced in 70-90%. Population and urbanization increases will also increase the energy and water demand. California is considered highly sensitive to climate change in terms of water resources, vegetation distribution and coastal effects. California is vulnerable to shortfalls in peak electricity, as demonstrated in 2001 shortage and in the heat wave in 2006. Miller et al., (2006) (cited in Wilbanks et al. (2008)) demonstrated that Los Angeles extreme heat days may increase from 12 to 96 days per year (almost the entire summer). The water sector accounts for 19% of California's electricity consumption in transport, treatment, pumping and agriculture uses.[20] Power plants in California mostly use water for cooling. Figure 14 shows the Greenhouse gas increment in 40 millions of tons of CO2e with an increased demand from 300TWh to 500TWh in 2048.

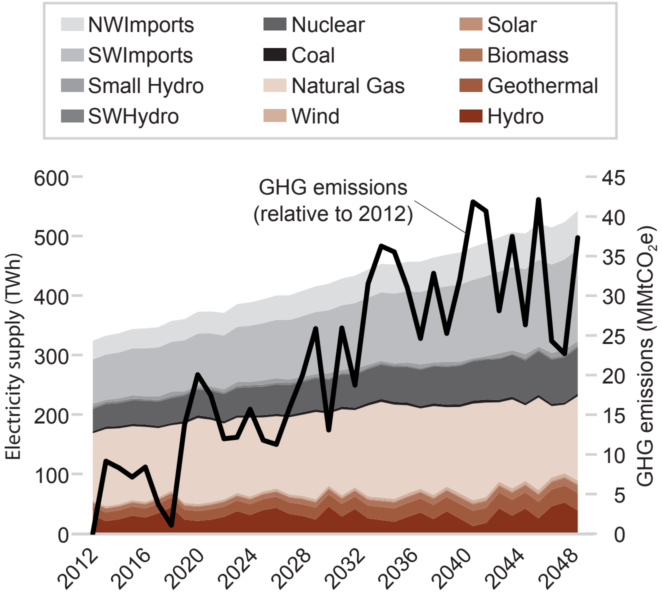

Figure 14 California electricity supply and related GHG emissions in Business As Usual (BAU) Scenario[21]

The desalination scenario implications are shown in Figure 15, where there would be an increase in electricity demand, CO2e emissions, but a reduction in water imports. Experts in the Stockholm

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[19] (King & Gulledge, 2013, p. 36)

[20] (Mehta & Purkey, 2012, p. 2)

[21] (Mehta & Purkey, 2012, p. 3)

Environment Institute (SEI) indicate that a careful policy evaluation is required for weighting the pros and cons of a desalination policy.[22]

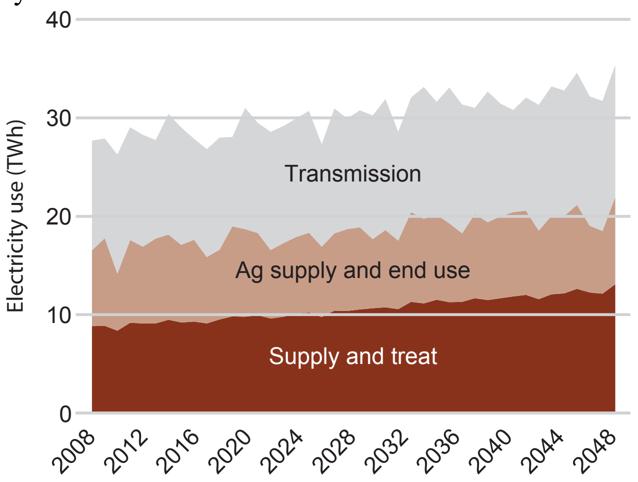
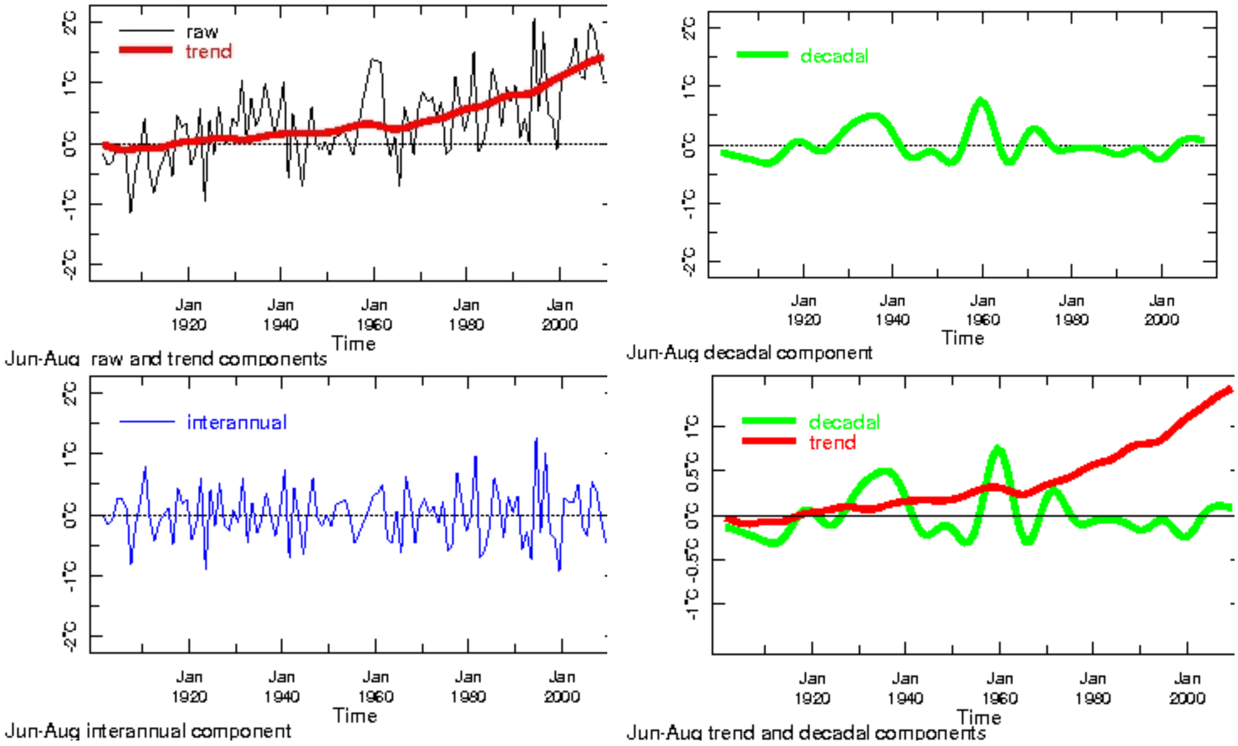


Figure 15 Electricity use by the water sector not including commercial and residential use[23]

Using the IRI maproom[24] on the California region for temperature in the summer period (June to August), there is a clear increasing trend on temperature but when the matter of study is precipitation things are not so clear. In the temperature mapping the trend is 39%, decadal trend is 14% and inter-annual is 43% in precipitation, things are not so clear and there is not a certain trend where trend is 4%, decadal variation 16% and interannual 81% leading to no conclusion.



Jun-Aug raw and trend components

Jun-Aug decadal component

Jun-Aug interannual component

Jun-Aug trend and decadal components

Figure 16 Temperature Analysis in the IRI system for California

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[22] (Mehta & Purkey, 2012)

[23] (Mehta & Purkey, 2012, p. 3)

[24] http://iridl.ldeo.columbia.edu/maproom/Global/Time_Scales/

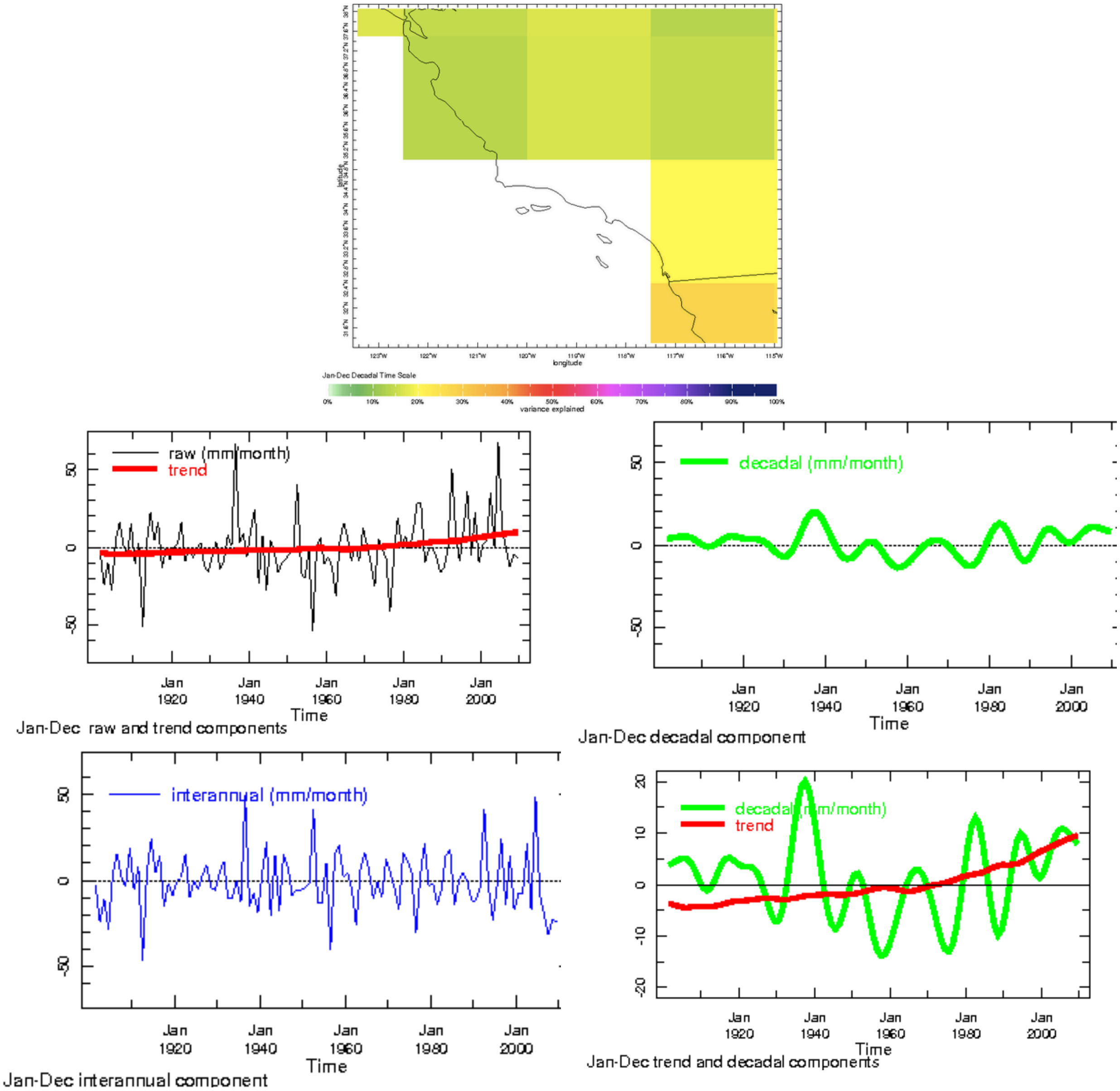

Figure 17 Precipitation Analysis in the IRI system for California

MENA Region

Some organizations state that only a ‘nexus’ approach will help in mitigation and adaptation in the MENA region (Middle East and North Africa) because of the increasing pressure on water that has been caused by population growth leading to urbanization and environmental degradation. There is under investment in social safety, infrastructure and public services. This has led to instability. Historically water and energy have been managed as separate issues. For example, desalination technologies are considered highly CO2-intensive.[25] That is why a combined effort is important. Jordan’s food relies on imports (80%), water supply depends on pumping groundwater and 25% of its water supply goes to satisfy energy demand. Jordan depends on nuclear power. Desalination in the MENA region may account about 22 million cubic meters of water per day with a projected growth of 500% for 2030.[26]

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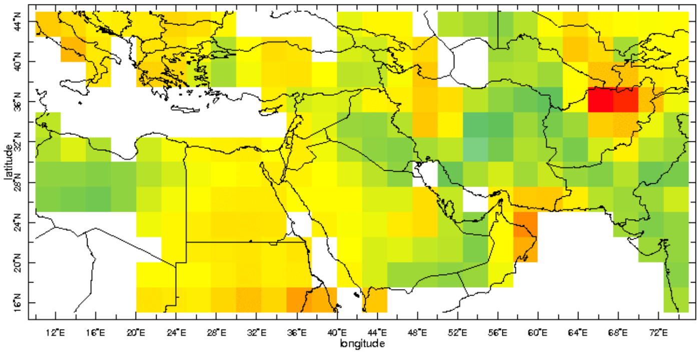
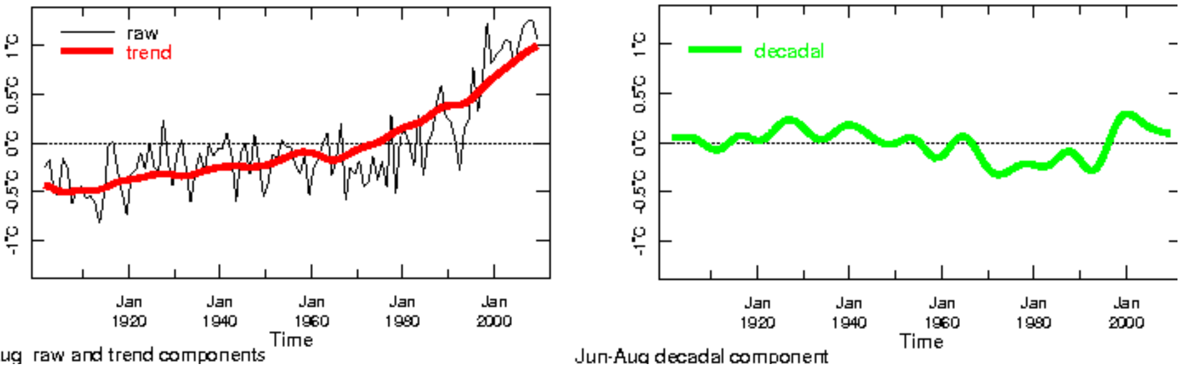
[25] (Benzie, Davis, & Hoff, 2012)

[26] (Hoff, 2011)

As in California Case, MENA has a clear increasing temperature trend with 71%, Decadal 11%, inter-annual 17% in the IRI maproom. In precipitation there are not conclusive trends (Trend 3%, Decadal 20%, inter-annual 77%).

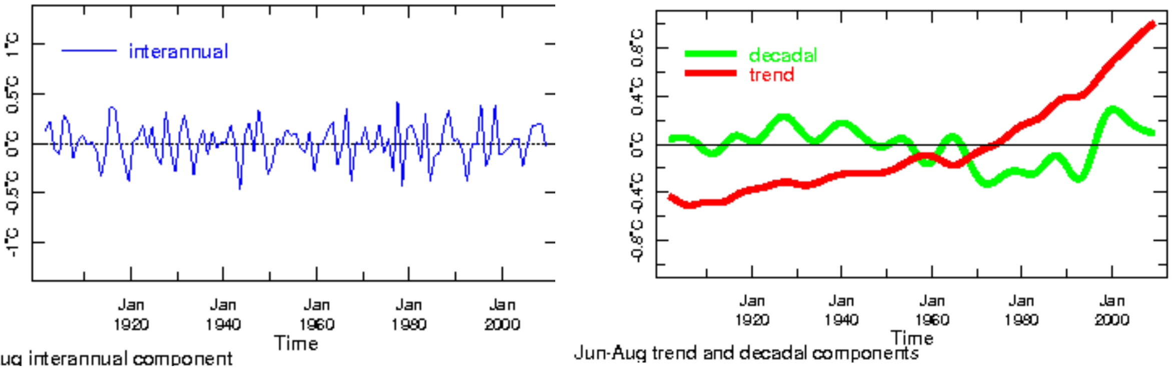


Jun-Aug Decadal Time Scale



Jun-Aug raw and trend components

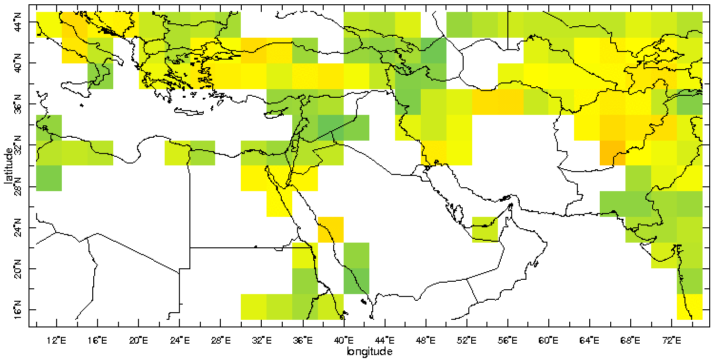
Jun-Aug decadal component



Jun-Aug interannual component

Jun-Aug trend and decadal components

Figure 18 Temperature Analysis in the IRI system for MENA Region



Jan-Dec Decadal Time Scale

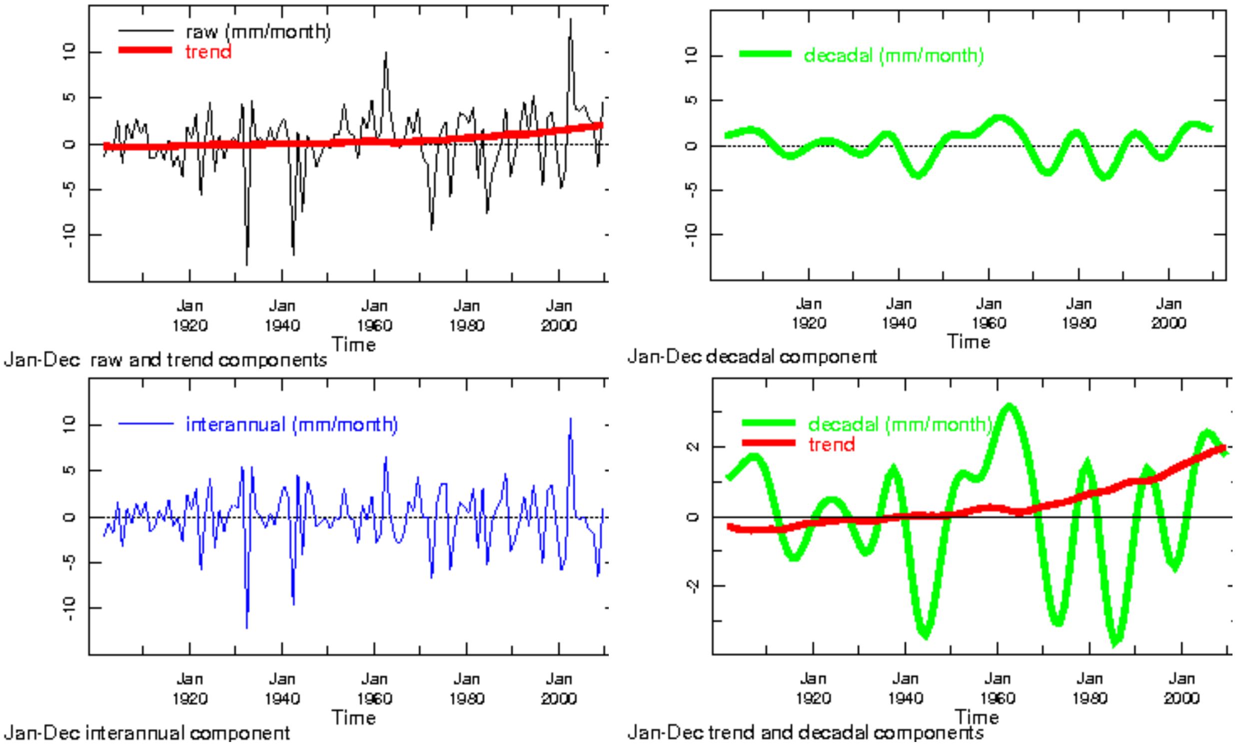
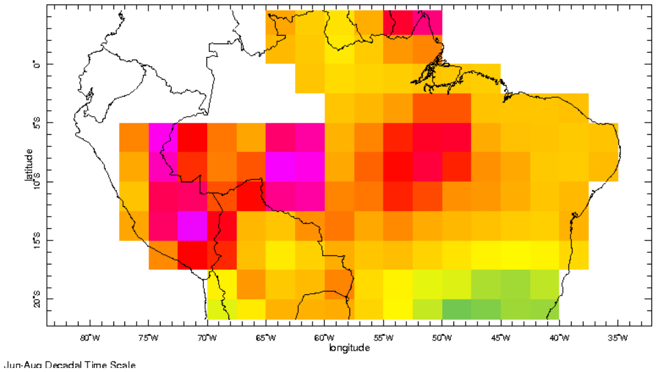


Figure 19 Precipitation Analysis in the IRI system for California

Amazonian Dams

Dams are built by flooding vast regions, usually a forest. Dead trees cause high amounts of Methane emissions. Methane is a greenhouse gas with a potential 21 times greater than CO_2. The amount of gases is usually poorly accounted for, and this is the case or several dams in Brazil where electrical authorities have made a number of mistakes in mathematical calculations when compared to real emissions, they were up to 346% greater than estimations. These dams have been promoted as an option for mitigation in the Clean Development Mechanism (CDM) of Kyoto Protocol, but studies state that they were expected to have greater cumulative effects than fossil fuels and in greater time-scales.[27]

The same case of California and MENA is repeated in the Amazon tropical zone where temperature increasing trend as 16%, Decadal 31%, inter-annual 48% in the IRI maproom and with a not conclusive precipitation trends as shown in Figure 20 and Figure 21 (Trend 0%, Decadal 17%, inter-annual 81%).



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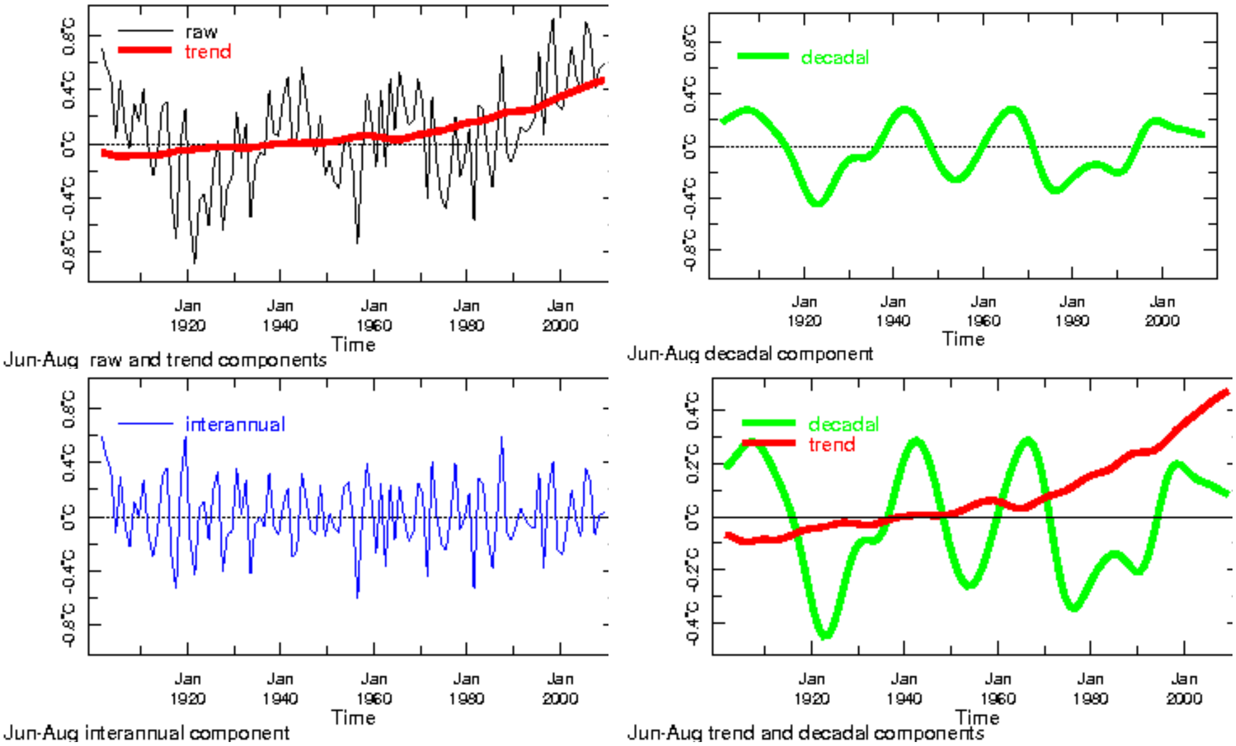
[27] (Fearnside & Pueyo, 2012, p. 383)



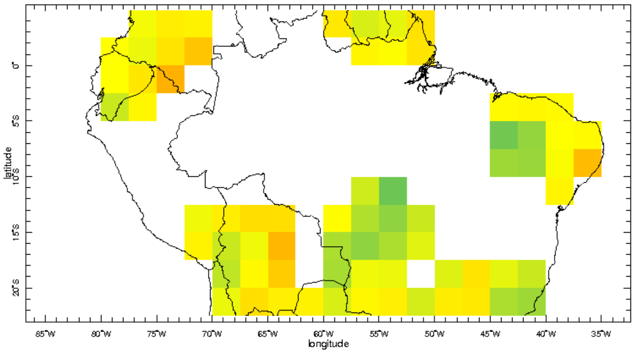
Jun-Aug raw and trend components

Jun-Aug decadal component

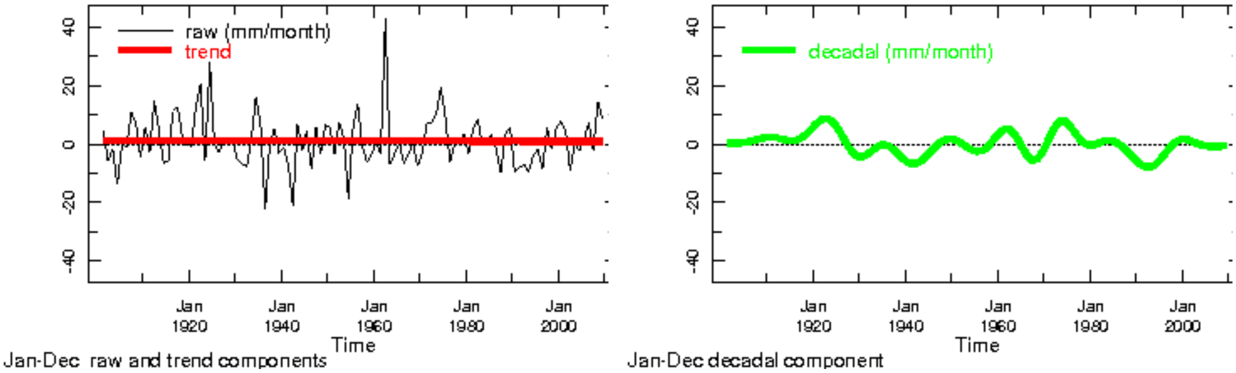
Jun-Aug interannual component

Jun-Aug trend and decadal components

Figure 20 Temperature Analysis in the IRI system for the Amazon Region



Jan-Dec Decadal Time Scale



Jan-Dec raw and trend components

Jan-Dec decadal component

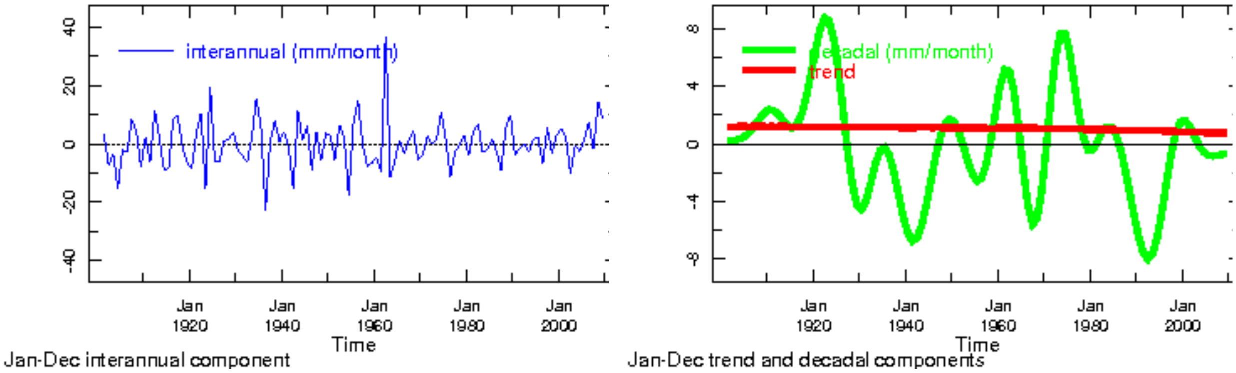


Figure 21 Precipitation Analysis in the IRI system for the Amazon Region

Potential solutions

Many of the support papers suggest that there is not enough information and that an analytical framework is necessary for evaluating a trans boundary context. However, as temperature curves suggest, there is not enough time for standing still while research gives a conclusive analysis. Strength of water impact analysis, improve data collection and monitoring, developing an “Energy-Return-on-Water-Invested” (EROWI) support tools will help improve the information system. Integration of fragmented geological, geophysical, and hydrological information constitutes one of the key factors. But climate change is happening and some measures need to be taken. The most important consideration should be reducing vulnerability, creating resilience and improving robustness.

One suggestions is the adoption of a flexible approach to use Integrated Water Resource Management (IWRM), taking into account all stakeholders users as suggested United Nations for Development Program in the Low Emissions and Carbon Resiliency Development Strategies (LECRDS) where the sectors, stakeholders and levels are accounted for in modeling and planning as shown in Figure 22.

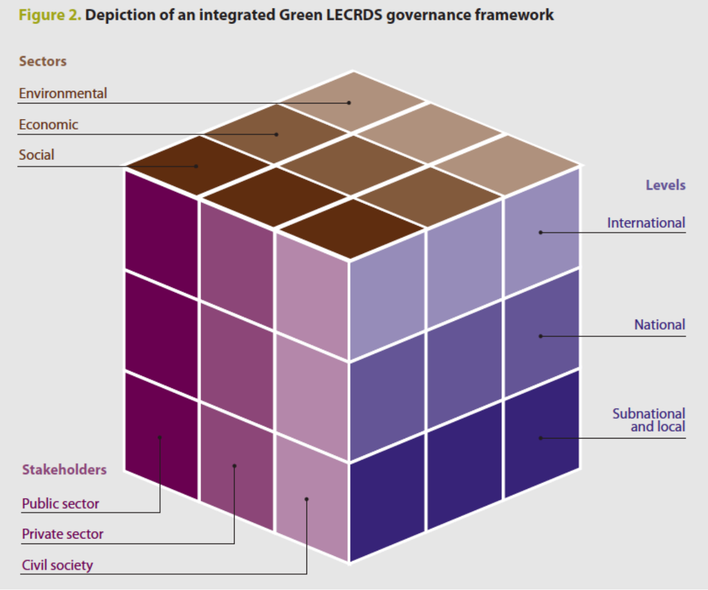


Figure 22 Integrated Green Low Carbon Development Strategy[28]

For small private sector users, affordability and micro-loans should be taken into account. Maintenance, service capacity, and uptake of technologies are also an adoption factor. Physical factors as

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[28] (Programme, 2012, p. 3)

energy limitations for pumping systems and variable demands have to be taken into account too.[29] Switching to clean technologies, controlling pollution, and carbon sequestration technologies may be game changers.

Off-grid power systems may constitute a solution. However, they cannot be adopted as a panacea, and regional considerations must be evaluated. Other key factors that involve social and cultural issues will lead to adoption or rejection of new policies. Retrofits will also play an important role as they reduce consumption and improve efficiency. Increasing resource productivity (water or energy) and using waste products as a resource in multiple systems, stimulating development through economic incentives may increase efficiency as well.[30]. It will be necessary to increase the capacity factor of power plants, which means the percent of operative time versus the design time of operation.[31]

Water must be included in Climate Action Planning, including affected communities and reassuring their participation in restoration and sustainability programs.

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[29] (Platonova & Leone, 2012, p. 9)

[30] (Hoff, 2011)

[31] (Sattler et al., 2012)

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