Assessing Water and Carbon Footprints for Green Water Resource Management

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Water & Energy in Changing Climates

Pittsburgh, PA
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Five WRAP tool boxes in development: Urban-engineering centric

- **Tool Box #1** – Hydroclimatic data and climate change impacts
- **Tool Box #2** – Water availability forecasting platform
- **Tool Box #3** – Water reuse and water storage / ASR
- **Tool Box #4** – Advanced water conservation
- **Tool Box #5** – Water adaptation engineering for the future
Key Points

- Water footprint and carbon footprint are two criteria evaluating the greenness in urban development.
- Carbon footprint and water footprint need to be compared to constraints in local and regional resources.
- Setting system boundary important to quantitative calculation of water footprint and carbon footprint.
- Two cases are examined and presented: 1) water footprints in energy productions; 2) carbon footprints in water systems.
Constraints in Sustainable Development: Carbon and Water Footprints

Green Development in Resource Constrained Environment

Energy & water supply - Economy

Climate Change Water Availability

Carbon Footprint

Water Footprint

Ecological footprint - Environment
Carbon and Water Footprints in Green Development

Constraints in Sustainable Development: Carbon and Water Footprints

From Energy to Adequate, Safe and Clean Water

- Municipal water supply and irrigation are two energy-intensive sectors
- Both will increase by 2050, particularly in regions other than coasts and Mountains
- Municipal water and wastewater consumes ~4% U.S. electric production

### A Case of California
(California Energy Commission, 2005)

<table>
<thead>
<tr>
<th>Water Supply and Treatment</th>
<th>Electric (GWh)</th>
<th>Natural Gas (Million Therms)</th>
<th>Diesel (Million Gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>7,954</td>
<td>19</td>
<td>77</td>
</tr>
<tr>
<td>Agricultural</td>
<td>3,188</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>End Uses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural</td>
<td>7,372</td>
<td>18</td>
<td>88</td>
</tr>
<tr>
<td>Residential</td>
<td>27,887</td>
<td>4,220</td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Supply and Treatment</td>
<td>2,012</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Total Water Related Energy Use</td>
<td>48,012</td>
<td>4,284</td>
<td>88</td>
</tr>
<tr>
<td>Total California Energy Use</td>
<td>250,984</td>
<td>13,571</td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td>19%</td>
<td>22%</td>
<td></td>
</tr>
</tbody>
</table>

### Range of Energy Intensity kWh/MG

<table>
<thead>
<tr>
<th>Water-Use Cycle Segments</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Supply and Conveyance</td>
<td>0</td>
<td>14,000</td>
</tr>
<tr>
<td>Water Treatment</td>
<td>100</td>
<td>16,000</td>
</tr>
<tr>
<td>Water Distribution</td>
<td>700</td>
<td>1,200</td>
</tr>
<tr>
<td>Wastewater Collection and Treatment</td>
<td>1,100</td>
<td>4,000</td>
</tr>
<tr>
<td>Wastewater Discharge</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>Recycled Water Treatment and Distribution</td>
<td>400</td>
<td>1,200</td>
</tr>
</tbody>
</table>

Total U.S. Energy for Water Demand: 123 Million MWh/yr
Constraints in Sustainable Development: Carbon and Water Footprints

From Water to Energy Production

- Hydropower generation – reservoir management under climate change
- Coal-fired electric power plants – next generation in oxy-coal and IGCC processes, and gas power plants
- Nuclear plants  
  (water consumption in cooling)

- Biofuel (sugar/starch-to-ethanol; cellulosic ethanol; biodiesel) – water use in biomass and fuel production
- Wind and solar – water use in cleaning and maintenance

(Power generation close to source to avoid energy penalty in power transmission)
**Likely green development criteria:**
- Reduce footprints in energy and water supply
- Approach energy and carbon neutral
- Use power of lower carbon and water footprints

**Adaptation:**
- Engineering scenario analysis in planning
- Optimization in design and operations

Water and Carbon Footprints: End Scenarios

- (1) – Water pumping & distribution
- (2) – Water loss (leakage, evaporation…)
- (3) – RO treatment
- (4) – Biological treatment
- (5) – Evaporation w/ water recovery
- (6) – Water reuse
- (A) – Hydropower (only usage)
- (B) – Coal-fired power plant
- (C) – Biofuels
- (D) – Nuclear power plant
Water and Carbon Footprints: Evaluation and Management

**System Optimization**

- Consumption (ΔE/unit)
- CO₂ footprint (ΔCO₂/ΔE)
- Water footprint (ΔQ/unit)

**Paradigm shifting**

- Consumption (ΔE/unit)
- CO₂ footprint (ΔCO₂/ΔE)
- Water footprint (ΔQ/unit)
Water and Carbon Footprints: Quantification

System boundary

Co-dependence between two footprints

LCA vs analysis time frame

Example #1: Water footprint in energy productions

Example #2: Carbon footprint in water resource planning

Example #3: Carbon footprint in alternative water supplies scenarios
Example #1: Water Footprint in Energy Production

Life-cycle CO2 and water footprint analysis for ethanol production (Liang et al., 2009)

CO2 and water footprint analysis for ethanol production process

Define Analysis Boundary in carbon and water footprint calculations
- Likely a range for CO2 in energy productions
- Likely dependant on energy production mode
- Likely a function of locations and electric grids

Carbon and water footprints, and combined index for urban water resource programs

\[
C_{sys} = \sum_{i=1}^{n} f_i C_i E_i \quad \text{and} \quad W_{sys} = \frac{\sum_{i=1}^{n} \gamma_i W_i}{W_{av}}
\]

\(W_{av}\) - Water availability at a location (Chang et al., 2010)
Example #1: Water Footprint in Energy Production

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Water Footprint (gal/kWhr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional electric power plants:</td>
<td></td>
</tr>
<tr>
<td>Coal-fired power plants</td>
<td></td>
</tr>
<tr>
<td>IGCC</td>
<td></td>
</tr>
<tr>
<td>Oxy-coal</td>
<td></td>
</tr>
<tr>
<td>Corn-to-ethanol: crop + fermentation</td>
<td></td>
</tr>
<tr>
<td>Cellulosic ethanol: crop + production</td>
<td></td>
</tr>
</tbody>
</table>

- Conventional electric power plants:
  - Coal-fired power plants
  - IGCC
  - Oxy-coal
- Corn-to-ethanol: crop + fermentation
- Cellulosic ethanol: crop + production
Example #2: Water and Carbon Footprints in Water Supply in Arizona

Large population increase coupled with climate change led to worsening water scarcity and the long-distance water diversion from Colorado river - the Central Arizona Project (CAP)

Housing, by Year Built
- New homes
- Existing homes

Population, Pima County

Percentage change in March-April-May precipitation for 2080-2099 compared to 1961-1979 for a lower emissions scenario (left) and a higher emissions scenario (right). Confidence in the projected changes is highest in the hatched areas.

Courtesy of Kenneth Seasholes
Arizona Department of Water Resources
Example #2: Water and Carbon Footprints in Water Supply in Arizona

- CAP only for Phoenix and Pinal AMAs, not for Prescott and Tucson of further distance
- For Prescott and Tucson, water reuse is taken as a priority
- Decreasing agricultural usage, but increasing municipal water consumption
Example #3: Water and Carbon Footprints in Water Supply Planning in Manatee Co., FL

- 20 sets of long-term water supply options (2009-2030) were identified by Manatee County Utility Operations Department to meet municipal, agricultural and ecological water demands
  
  Groundwater: 4 options; Surface water: 5 options; Water rights transfer: 3; Regional water management: 5; Others (e.g., desalination): 3

- Each option involves infrastructure built-up constructed in any of the 5-year master plan periods, and operation after online for operation

- Options are studied and simulated to quantify cost and sustainability impact factor (e.g., carbon and water footprint, and landuse demand).

- Optimized for cost and sustainability using multi-objective and multi-stage mixed integral simulation:

  Objective 1: Minimize $Z_1 = \text{total sustainable impact factor} = \min \sum_{t=1}^{4} \sum_{i=1}^{20} Y_{it} SII_i$

  Objective 2: Minimize $Z_2 = \text{total cost} = \min \sum_{t=1}^{4} \sum_{i=1}^{20} 1000 A_t C_i + Y_{it} F_i$
Full analysis is ongoing

Each management option has unique characteristics in cost and sustainability impact factor

Phased implementation or bring-online for 1) best case – slowed water demand growth; 2) worst case – dwindling supply and increased demand

Quantitative analysis for management options to reduce cost and sustainability impact (i.e., footprints)
Water and Carbon Footprints: Paradigm change for sustainable development

- Avoid or reduce transportation – decentralized systems
- Select options for least water footprint compared to available water resources
- Reduce carbon prints by avoiding energy penalties
- Increase water and energy efficiencies
- Calculate the footprints with defined physical boundaries
Thank You!