Embedded Resource Accounting: An Analysis of Water and Energy Resources in the Western U.S.

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Introduction

An analysis of the causal relationships between climate and economic changes and the energy-water nexus is needed for the purpose of informing National water and energy policy for the 21st century. Climate change is expected to cause increasing temperatures and evaporation, decreased rainfall, and more intense droughts in the Southwestern U.S. As population and industry in urban areas continue to grow, resource demands increase and become more spatially concentrated - especially demands for electrical energy. Energy production accounts for the largest percentage of gross water withdrawals in the U.S., placing water resources at the focal point of the energy-water nexus as an important and climate-sensitive constraint on electrical energy production. Reallocation of water supplies in addition to redistribution of the production of electrical energy and other resources will be necessary to adapt reduced supplies to meet increasing and spatially concentrated resource demands.

The *re-location* of existing "old" water resources and *access* to low-quality "new" water resources often involves prohibitive infrastructure costs, energy costs, and legal barriers. However, there is a significant amount of water embedded in electrical energy production. Therefore, the remote production and *virtual* transmission of this and other resources provides a powerful management solution for an efficient reallocation of water resources. Embedded, or virtual, water accounting combined with economic analysis provides a method for the evaluation of proposed electrical energy production adaptations.

This study evaluates the water intensity of power generation plants in the eleven Western states included within the Western Electricity Coordinating Council region (Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming), then combines this information with retail electricity sales to estimate the economic value per gallon of water embedded in electrical energy production and trade. The results of this embedded resource analysis are presented as a network of production and trade in electrical energy and associated embedded water volumes throughout the Western United States.

Conclusions

This analysis does not establish a price for water, but rather uses the intensity of water embedded in trades of electricity for currency as a proxy for the relative value of water in different States- and, in future analyses, between water embedded in different types of goods and services. This is an alternative paradigm to inform the value and efficient use of water resources.

Our preliminary results show that the currency intensity of water embedded in electricity (on the order of $1/gal) is significantly greater than the price usually paid for potable water in the region (on the order $0.01/gal) (Figure 3, and Brown, 2006). Additionally, importing states pay less for imported embedded water than locally consumed embedded water and exporting states realize higher values for exported embedded water than locally consumed embedded water. Everybody wins from this embedded water trade!

The volume-weighted average margin between the average price paid and received per gallon of embedded water is $0.28 (Figure 3). This represents an 88% increase in value of water realized by the system as a whole, on average, when water is traded by embedding it in electricity. This increase in value suggests a rational market where value is added through trade, and demonstrates that such a market has already implicitly emerged by substituting trade in electricity (on the power grid) for trade in water (for which efficient regional transportation networks generally do not exist).

High volume importers, California in particular, have higher retail electricity prices (Table 1 and Figure 2), and high volume exporters (Wyoming, Utah, Arizona) generally have higher water consumption intensities (Table 1 and Figure 2).

Import and consumption of embedded water and electricity traded on the Western Power Grid is dominated by California (roughly 80% of total trade is consumed by CA, Figure 1), which has the highest retail electricity prices, but also very low water-use intensities for local electricity production (Figure 2). California is using its water relatively efficiently for power production (which implies higher local water costs), and is outsourcing its additional needs for water to states with higher water-use intensities (which implies that these other states have lower local water costs). Everybody wins in this arrangement.

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Table 1 presents the data used in this analysis: the average water consumption intensity of all the power generation facilities within each state (electrical production), the average retail price paid by electricity consumers within each state (electrical consumption), and the adjusted net interstate trade of electrical energy entering or leaving each state via the Western Power Grid. The net importers of electrical energy are California, Idaho, and Colorado, and these states tend to have relatively high retail electrical prices.

State	Water Consumption Intensity (gal/MWh)	Average Retail price (US$/MWh)	Adjusted Net Interstate Trade (MWh)
Arizona	183.81	$ 86.23	31,685,245
California	129.69	$ 125.26	(84,137,000)
Colorado	352.66	$ 100.26	(4,815,000)
Idaho	83.31	$ 62.91	(12,333,000)
Montana	297.32	$ 81.57	5,775,543
New Mexico	437.25	$ 103.56	15,700,958
Nevada	349.23	$ 80.10	1,655,392
Oregon	82.04	$ 67.65	5,079,110
Utah	411.77	$ 81.35	12,389,184
Washington	52.52	$ 61.65	2,117,039
Wyoming	384.17	$ 85.57	26,882,529

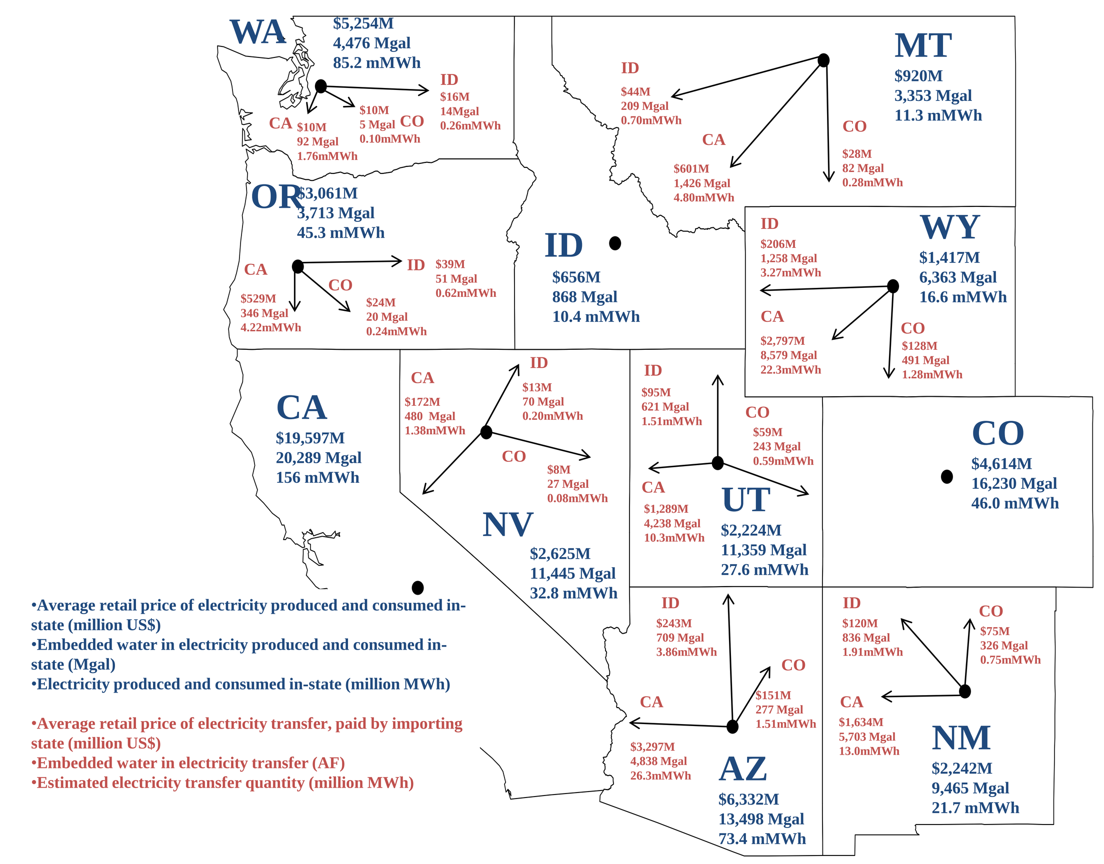

Figure 1 illustrates the electrical energy production and trade network in the Western U.S. California, Idaho and Colorado are net importers; all other states are net exporters. California consumes roughly 80% of the traded electricity and embedded water.

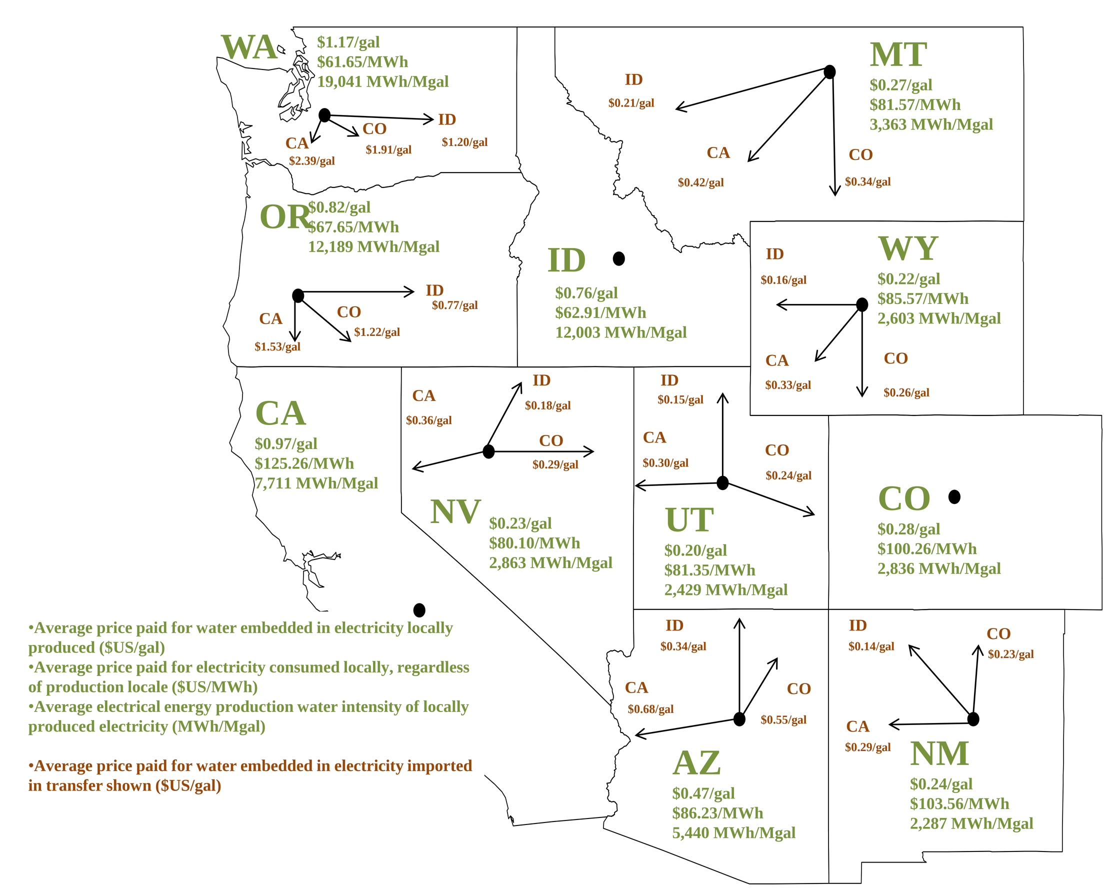

Figure 2 gives the embedded resource intensities for the network. Net exporters generally realize a higher currency price per embedded water gallon for their embedded water exports than they realize for local embedded water consumption; the opposite is true for net importers, which generally pay a lower price per embedded water gallon for their imports than they pay for locally produced embedded water.

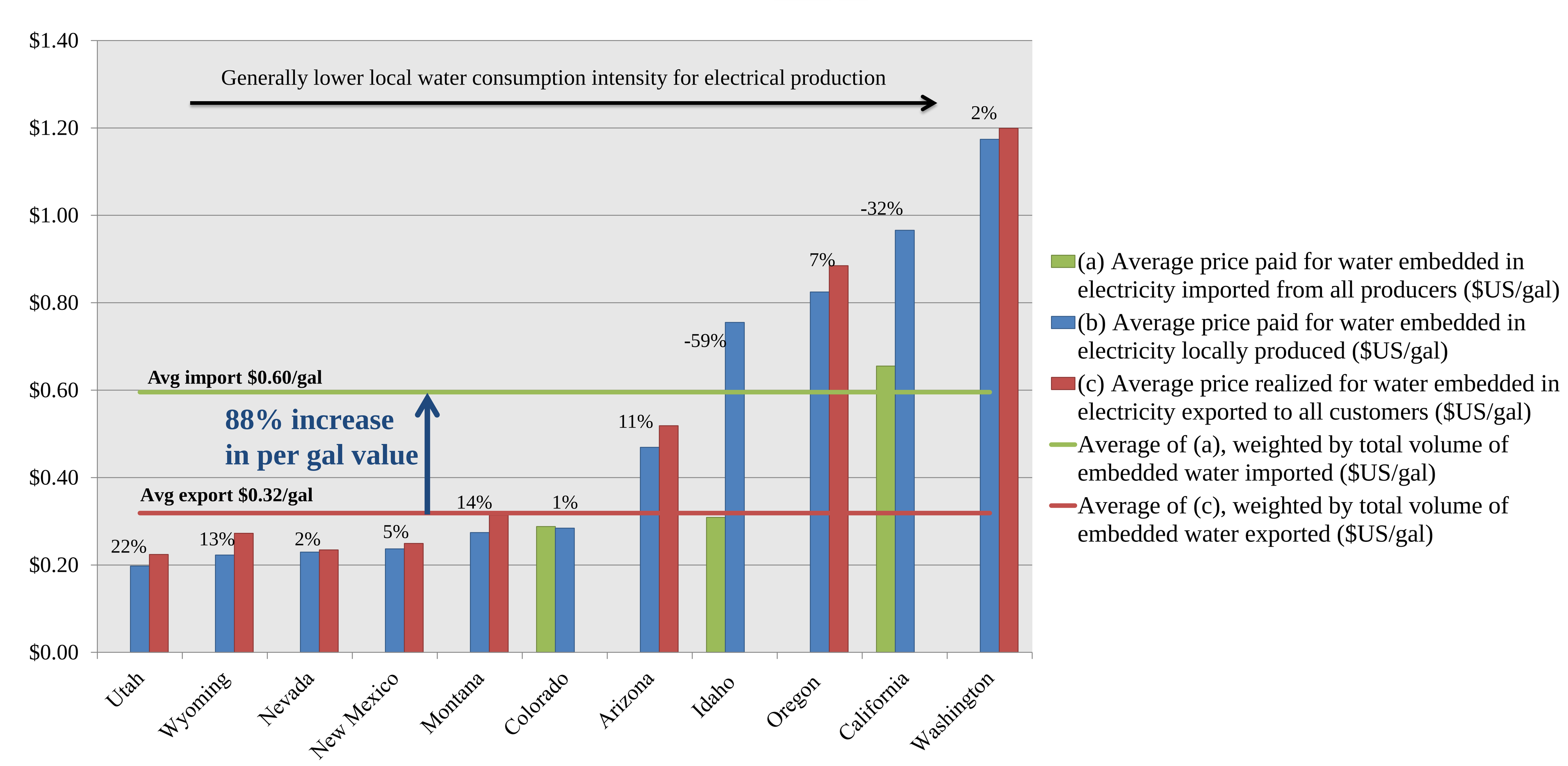

Figure 3 presents the intensity of currency per unit of water embedded in locally consumed and traded electricity. Higher currency intensities (i.e. embedded per-gallon prices) are generally associated with States that have lower local water use intensities per MWh (i.e. less water used per MWh, or more water-efficient generation). Exporters generally realize a higher embedded water price for exports versus domestically consumed water embedded in electricity; importers generally pay a lower embedded water price for imports versus domestically produced water embedded in electricity. When this difference is averaged and weighted by the volumes of embedded water, the value of embedded water in the system as a whole increases an average of 88% due to trade.

Methodology

The electricity generation and distribution network in the Western United States is comprised of power plants, electric utilities, electrical transformers, transmission and distribution infrastructure, etc. We conceptualize the system as a transportation network with resources (electricity, economic currency, and water embedded within electricity) flowing between nodes (states). For this analysis we simplify the trade network to a system in which retail consumers exchange economic currency for electricity and power plants exchange embedded water and electricity for economic currency.

The electricity generation and distribution network can be represented as a network of 11 nodes (Strogatz 2001). Connectivity of all nodes within the network is assumed.

The energy intensity of water, in units of kWh per gallon of water, is used to describe the amount of electricity required to convey, pump, treat, deliver, collect, and / or reclaim water for a given area (Scott and Pasqualetti, 2010).

This analysis evaluates value of water by measuring the intensities of trade in water, electricity, and currency, by analyzing the water and currency exchanges that are "embedded" in, i.e. associated with, interstate electricity trade on the western power grid. Consumers of electricity are effectively paying the producers to use water so the consumers can avoid using water.

A comparison of the resources R (equation 1) embedded in the production and transport of electricity allows us to establish a unique measure of the embedded value of water. The analysis is performed using the Embedded Resource Accounting (ERA) methodology. The governing equation is:

$$R[i,x](t) = U[i,x](t) + V[i,x](t) \qquad (1)$$

Where R is the consumption of the resource stock x caused by process i at time t, U is the net direct physical consumption of the resource stock x by process i at time t, and V is the net indirect or "virtual" consumption of the resource stock x at time t resulting from the consumption of stock x by processes that provide inputs to process i or which consume the outputs of process i. For this analysis we neglect V.

The data utilized in the study is:

- MWh of electricity produced annually at each power plant within each state for 11 western U.S. states (EPA 2010),
- Estimated total water consumption per day for each of the plants (Sandia National Lab Energy/Water Nexus Group Calculations 2011, following EIA 2005, Kenny et al. 2009, Macknick et al. 2011, and Solley et al. 1995)
- Average utility retail price of electricity for each utility within each state for 11 western U.S. states (EIA, 2011a).

Import and export data for each state is on record in the EIA online database state electricity profiles (EIA, 2011b). Data from 2009 was used for this analysis. Each state has either a surplus or a deficit of available electricity. Three nodes have reported net electrical energy deficits, these are defined as importers; the remaining eight nodes are net exporters (Table 1). Consumption of electrical energy must equal production for the system as a whole. The EIA production and consumption data for 2009 for the 11 states under analysis results in an excess of electrical energy of less than 1% of the total production. To balance the system for this analysis the exporting states' productions were reduced by this amount (Table 1); the excess electricity is presumed to leave the grid for other neighboring grids. We furthermore assume that all locally produced electricity within a State

References

Brown, T.C. (2006). Trends in water market activity and price in the western United States. Water Resources Research, Vol 42, W09402, doi: 10.1029/2005WR004180.

EIA (U.S. Energy Information Administration), 2011a. Online. Sales data tables. *Electricity*. Accessed October 2011. http://www.eia.gov/electricity/data.cfm#sales.

EIA (U.S. Energy Information Administration), 2011b. Online. State energy profiles. *U.S. States*. Accessed October 2011. http://www.eia.gov/state/.

EIA (U.S. Energy Information Administration), 2005. Steam-Electric Plant Operation and Design Report (EIA-767).

EPA (U.S. Environmental Protection Agency), 2010. Emissions & Generation Resource Integrated Database (eGRID), version 1.0.

Kenny, J., Barber, N., Hutson, S, Linsey, K., Lovelace, J., & Maupin, M. (2009). Estimated use of water in the United States in 2005. *U.S. Geological Survey Circular 1344*.

Macknick, J., Newmark, R., Heath, G., & Hallett, K.C. (2011). A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies, NREL/TP-6A20-50900, National Renewable Energy Laboratory, Golden, CO, pp. 29.

Sandia National Lab Energy/Water Nexus Group (2011): Estimates of water withdrawal and consumption at existing plants were developed from a variety of sources.

Scott, C., & Pasqualetti, M. (Fall 2010). Energy and water resources scarcity: Critical infrastructure for growth and economic development in Arizona and Sonora. *Natural Resources Journal, 50*, 645-682.

Solley, W., Pierce, R., & Perlman, H. (1995). Estimated Use of Water in the United States in 1995, *U.S. Geological Survey Circular 1200*.

Strogatz, S. (2001). Exploring complex networks. *Nature,* 410, 268-276.