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. The 21st-century energy change includes a focus on sustainable water-energy nexus, and a source of decreasing water availability, increased temperatures, and evaporation, decreased rainfall, and more intense droughts in the Southwestern U.S. As a result, energy demand is increasing and becoming 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 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 political, infrastructure, energy, 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 water and other resources provides a method for assessing and accounting for embedded water. Embedded, or virtual, water accounting combined with economic analysis provides a method for evaluating 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 (Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming). This combines this information with the 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 traded energy for currency as a proxy for the relative value of water in different States and, in future analysis, 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!

Figure 1 illustrates the electrical energy production and trade network in the Western U.S. California and Colorado are net importers; all other states are net exporters, which gives roughly 30% of the traded electricity and embedded water.

Methodology

The electricity generation and distribution network in the Western United States is comprised of power plants, electric utilities, transformers, transmission and distribution lines, and other components. We conceptualize the system as a transportation network with resources (electricity, economic currency, and water embedded within electricity) flowing through the network and consumed at various points. To simplify the analysis, we simplify the trade network system in which retail consumers exchange economic currency for electricity and power plants exchange embedded water and economic currency 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.

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

$$ R(x) = \frac{P \cdot R \cdot C \cdot V}{x} $$

Where $R$ is the consumption of the resource stock $x$, $P$ is the retail physical consumption of the resource stock $x$ by process $i$ at time $t$, and $C$ is the net direct physical 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 consumes the output process. For this analysis we neglect $C$.

The data utilized in the study is:

- MW h of electricity produced annually at each power plant within each state for 11 western U.S. states (EIA 2010).
- 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 electric power production (2009). Data from 2009 was used for this analysis. Each states 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 defined as exporters of electrical energy.

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

References


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