Assessing water use in energy systems: towards enhancing the quantification of a water equivalent footprint (H_2O_f)

Sara Goto & David B. Layzell

Department of Biological Sciences, Canadian Energy Systems Analysis Research (CESAR) Initiative

UNIVERSITY OF CALGARY

CESAR CANADIAN ENERGY SYSTEMS ANALYSIS RESEARCH

Introduction

Efforts to transform energy systems have focused on reducing greenhouse gas (GHG) emissions, yet the choice of technologies may also have a major impact on water resources. Technologies that are able to address GHG emissions (a global issue) may exacerbate water or land use issues (a regional issue).

A simple metric has been developed to calculate water footprint, but we argue that it needs to be enhanced to aide decision making. The existing water footprint measures the volume of direct or indirect freshwater consumption as well as water contamination. Water withdrawn and returned has an effective 'weight' of zero whereas water consumption has three classifications;

- Blue (surface/ground water with a weighting of 1.0),
- Green (soil water with a weighting of 1.0) &
- Gray (contaminated water with a weighting proportional to the dilution needs to meet standards for release to the environment).

We propose a weighting system that gives withdrawn water a value > 0 and provides more nuance to uses of blue & green water by recognizing:

- Regional differences in the availability and impact of water use and
- Other positive or negative impacts on the overall environmental costs or benefits of water use.

This work provides a method to compare the environmental footprint of energy systems choices in terms of H_2O equivalent footprints (H_2O_f) for different regional scenarios that will complement measures of CO_2 equivalents (CO_2e).

Approach

1. Use published life cycle assessments (LCAs) to quantify and characterize the water and carbon footprints associated with various pathways for energy production and use
   - For biomass growth, we developed calculation of evapotranspiration
2. Develop a classification system (Table 1) and weighting system for water use and employ it in an equation for H_2O_f to compare the water footprints associated with energy systems pathways
   - $H_2O_f = \sum V(C) * IF(C)$
   - Where V(C) is the volume of water in classification (C) per GJe and IF(C) is the impact factor associated with the classification
3. Use values for CO_2e and H_2O_f footprints to compare pathways for power generation

Results

Water withdrawn was divided into classifications (C) (Table 1) and each feedstock was evaluated under three different regional scenarios with respect to water availability (Table. 2).

Table 1. Water classification system

	C	Description	Examples	IF(C)
Water withdrawal	C1	Blue water that returns to blue water after use	Majority of hydro and nuclear power generation	Possibly pos. or neg. impact
Water consumption	C2	Green water that is converted to water vapor	Crop plant evapo-transpiration minus irrigation	Possibly pos. or neg. impact
	C3	Blue water converted to green water	Crop irrigation	Possibly pos. or neg. impact
	C4	Blue water that is released as water vapor	Thermal power generation, evaporation from hydro reservoir	Possibly pos. or neg. impact
	C5	Blue water that has been polluted to gray water	Power plant construction, coal mining	Negative impact only

Table 2. Scenarios of various regions

Scenario	Details
1	**Water Constrained** • Region lacks sufficient water to meet demand • The use of available water has a high cost due to the low supply
2	**Water Sufficient** • Water resources exceed the regions demand • There is little concern over water use
3	**Excessive Water** • Region with excessive water and frequent flooding • May benefit from the removal of water from the system

Figure 1. Life cycle GHG emissions (kg CO_2e/GJe) and water hierarchy of feedstocks

	CO_2e (kg CO_2e / GJe)	Water scenarios (H_2O_f / GJe): 1	2	3
Best Option	1. Wind (3.2)	1. Wind	1. Residual Biomass	1. Hydro
	2. Residual Biomass (6.1)	2. Solar	2. Dedicated Biomass (non-irrigated)	2. Dedicated Biomass (irrigated)
	3. Hydro (6.3)	3. Residual Biomass*	3. Dedicated Biomass (irrigated)	3. Dedicated Biomass (non-irrigated)
	4. Solar (10.6)	4. Hydro*	4. Hydro	4. Uranium
	5. Uranium (18.4)	5. Dedicated Biomass (non-irrigated)*	5. Wind	5. Residual Biomass
	6. Dedicated Biomass (non-irrigated) (26)	6. Shale Natural Gas	6. Solar	6. Solar
	7. Dedicated Biomass (irrigated) (26)	7. Conventional Natural Gas	7. Conventional Natural Gas	7. Wind
	8. Coal – CCS (50.2)	8. Coal	8. Coal	8. Coal - CCS
	9. Conventional Natural Gas (112)	9. Coal - CCS	9. Coal - CCS	9. Coal
	10. Shale Natural Gas (135)	10. Uranium	10. Shale Natural Gas	10. Conventional Natural Gas
Worst option	11. Coal (275.6)	11. Dedicated Biomass (irrigated)	11. Uranium	11. Shale Natural Gas

* These feedstocks may not be accessible in the region

Discussion

Decisions regarding energy system choices should consider the costs, benefits and tradeoffs of each pathway. As shown in figure 1, regional differences in water availability or other environmental impacts could change the relative cost or benefit of the water footprint of an energy pathway. For example,

1. Scenario 1 represents a region with higher demand than the available water supply (Table 2). Therefore, all water use has a cost and the IF(C) weighting applied was higher than that of scenarios 2 & 3. Consequently, wind and solar are among the highest ranked and irrigated biomass was the lowest (Figure 1).
2. In scenario 2 the water resources exceeded demand resulting in a lower water IF(C) than scenario 1. As water was not limiting, the water pollution impact was more prominent. Therefore those technologies that produce the least amount of polluted water become the best options to consider.
3. Scenario 3 is subject to frequent flooding due to excessive water resources and soil saturation. In this case, water use from soil or management through reservoirs could be beneficial to prevent flooding. This resulted in hydro ranking the highest along with irrigated biomass energy. Also, the magnitude of water contamination becomes important as they become difficult to contain.

Per GJ of electricity generated (GJe), the life cycle GHG emissions varied by 86 fold among energy pathways (Figure 1). From a GHG position the best options for energy pathways available are represented by low GHG feedstocks.

This study provides an initial framework for creating a metric that recognizes both regional and technological differences in energy pathways. In addition to water use and GHG emissions, energy system choices consider economic and reliability issues. Decisions should not be made on any one of these characteristics, but all are important and should feed into the decision making process.

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Literature Cited

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