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ABSTRACT

It is well established that population and economic growth will present major challenges for meeting the world's growing water and energy needs over the coming decades. Water scarcity is rapidly affecting every continent and countries are exploring new sources of water to meet the increased demand for fresh water. This paper seeks to make progress in this area by providing new insights for making tradeoffs between transferring water and other water supply options. The paper reviews cost estimates of transferring water and establishes a method for analyzing the Energy for Water Transfer (EN4WT), a method which could be helpful in determining future strategies for water supply. The design of this study provides a detailed characterization of energy requirements, specifically developing a new database of energy for water at the national level for several countries and a method for the comparison of country-level energy use for water transfer. Conclusions from this paper suggest the following: (1) Energy for water transfer is a function of several factors including climatic and geographical factors over which countries have no control, in addition to other factors related to the type of technology used, Gross Domestic Product (GDP), and the volumes of water required to be transferred (2) Normalization of energy intensity of water supply transfer using slope (change in elevation divided by horizontal distance) resulted with an average 62% decrease in energy intensity, while normalization using precipitation resulted with 12% reduction in average energy intensity.

Keywords
water transfer; energy intensity; desalination, benchmarking tool; model

1. Introduction

The global availability of fresh water has decreased by 30% in 20 years, from 12,900 m3/capita to less than 7,000 m3 in 2000. By 2030, given the average global economic growth, global water requirement would grow from 4,500 billion m3 as in 2009 to 6,900 billion m3. This is a 40% increase and above the current accessible and reliable water sources including recycling and the portion should be preserved for environmental requirements. (UNEP, 2008; Addams et al.,2009).

Many societies are moving towards more energy-intensive options to meet water demand from sources that are more difficult to obtain, that are farther away and are of lower quality (UNESCO, 2013). The U.S. is moving towards large-scale investment in mega water transfer projects such as in the southwest desert of California, where water is transferred from areas of surplus to areas in critically short supply (Sanders and Webber, 2013). In Texas, developers proposed to transfer water from the Ogallala aquifer hundreds of kilometers across the state to Dallas-Fort Worth Metroplex (Berfield, 2008). Similarly, China's South–North Water Transfer project aims to transfer 44.8 billion m3 of fresh water through pipelines of 500, 1,200 and 1,300 km in length (Aaron Jaffe and Keith Schneider, 2014).

Other countries such as Saudi Arabia, Kuwait, Bahrain, Oman, Singapore, and India have committed to expand current desalination facilities (and establish new ones) to provide supplemental volumes of drinking water. Jordan, Egypt, South Africa, Lesotho, Brazil, Greece, Peru and Australia are also planning and constructing large water supply projects to meet the demand of their growing communities (Siddiqi and Anadon, 2011). This has led to complex pipeline connections to transfer desalinated water and supplemental water from new sources to end users.

While governments have legitimate reasons for moving water over long distances, a headlong rush into water transfer projects could bring its own challenges. Unless planned properly, water transfer projects are likely to increase competition for energy resources and push up the costs of water supply systems.

Just as water is essential in almost all forms of energy production, energy is also required for the extraction, treatment, and transfer of water. Distributing and transferring water using high service pumps to end users can be extremely costly and energy intensive. For instance, distributing surface water in California consumes 12 times more energy than treating that same amount of water (CEC, 2005; Bennett et al., 2010). Typically, average energy use for a surface drinking water system is 0.026 kWh/m3 for extraction, 0.066 kWh/m3 for treatment and 0.303 kWh/ m3 for storage and transfer (EPA, 2013).

The bulk of the literature has focused on the energy requirements to treat and extract water, but less attention has been paid to the energy requirements to distribute and transfer water (EN4WT). As water demand increases and sources become more challenging to secure, this topic is of growing importance to policymakers. However, gathering a robust evidence base to inform policymakers presents formidable challenges due to a complex set of variables and no established methodology.

Energy Assessment of Water Supply Chain

Supplying water in most countries is a key element of human development; starting with identifying a source, extracting the water, transferring the water to a purification/treatment plant, distributing the water to end users, collecting wastewater, transferring it back to wastewater treatment plants and finally discharging the treated water either to water bodies or end users based on local regulations and standards (Figure 1).

Figure 1 defines the life cycle of every stage of supplying water. Clearly, water transfer lines are dominant at each stage of the life-cycle chain, which adds up to the energy consumption, sometimes water is pressurized at high-pressure rates during the distribution and other times distributed utilizing gravity if the topography allows.

Every stage of the water lifecycle chain requires different amounts of energy; extracting and distributing water to end users is estimated at about 2% of global primary energy, while 6% of global electricity use goes to treat and release used water (Williams, 2013).

Energy intensity also differs by the source of supply. Extracting a unit of volume of groundwater (m^3) from a 46 m well depth requires 0.3 kWh/m^3 (Figure 2). The deeper the groundwater well, the more energy required to extract the water. Thus, as aquifers are depleted and the water table level falls, the energy required for its extraction significantly increases as well.

On the other hand, pumping and transferring a unit of water from a surface source varies based on total distance, friction loss, pressure requirements, and elevation. For example, extracting and moving water over a 745 km distance in Spain would consume 4.07 kWh/m^3, while it requires 1.6 kWh/m^3 to extract and transfer water over 389 km in Los Angeles in the U.S. Though energy intensity varies among countries, it also varies within the same country which is made apparent in Australia. Extracting and transferring water over 450 km and 502 km from different sources in Perth would consume 3.3 kwh/m^3 and 2.07 kwh/m^3 respectively (Burt and Soto, 2008).

The last stage of the water supply chain is wastewater treatment which also can be energy intensive. On average, and based on World Health Organization (WHO) and European Union (EU) standards, water turbidity must drop to less than five Nephelometric Turbidity Units for each 100 ml of water before it is discharged from a facility. For a typical treatment plant in Europe, this would require between 0.2 and 0.8 kWh/m^3 to comply with these standards (Water in the West, 2013). While in the U.S and based on the technology utilized, wastewater plants would consume between 0.066 kWh/m^3 and 1.03 kWh/m^3 (EPA, 2013).

At present, there is no systematic information or well-structured database on the EN4WT. What is available has focused on the energy intensity of small-scale projects and is generally focused on water extraction and treatment rather than transportation. The literature which discussed energy intensity for water transfer is very little and tended to combine energy for water transfer with extraction.

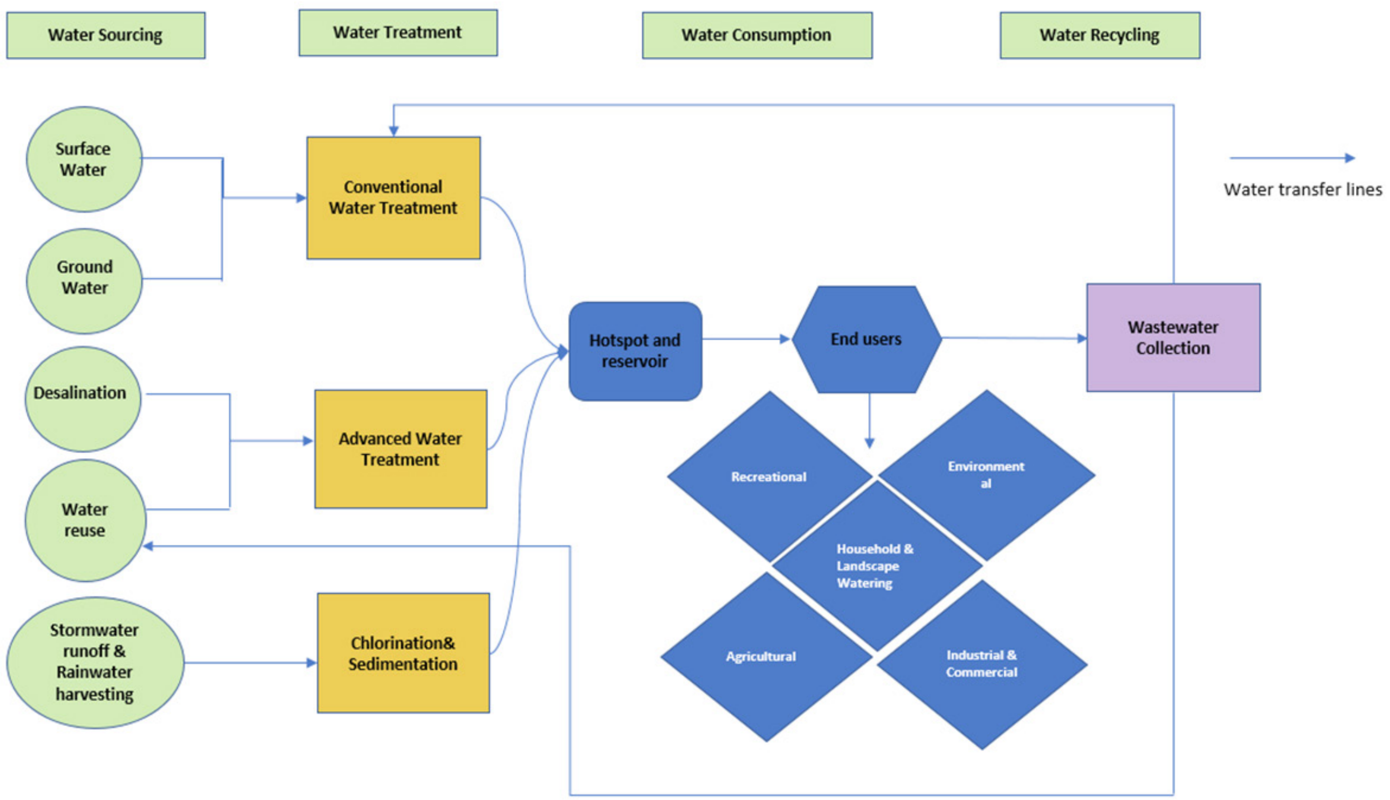

Figure 1. Water life cycle chain starting from source through treatment, consumption and ending in recycling.

The primary challenge of estimating EN4WT is the need to trace energy inputs from a point of origin right after extraction through to a point of use and ending in disposal or re-use. Previous studies relied on aggregated water distribution and energy use data or aggregated energy intensity estimates for the inventory of all technologies deployed across the water system (Wilkinson, 2000; Wolff, Cohen, and Nelson 2004; CEC, 2005; Cooley and Wilkinson, 2012). In this paper, the data utilized is as detailed as possible to identify the factors affecting energy intensity as well as estimates of energy requirements. The paper also combines data for water imported from outside the basin and from local water sources.

Given the significant energy consumed in water transfer, it is surprising that policies for improving water transfer are seldom discussed in the literature. Where it has been discussed, a typical recommendation is that one way to save on energy used for water transfer is to simply transfer less water and make up the deficit with more local, non-conventional sources such as recycling and rainwater harvesting (Wolff et al., 2004). Other policies require operators to conform to supplying water to the irrigable agricultural area or to local customers in order to discourage waste and promote reasonable use. Additional policies suggest investigating the viability of desalination to replace long-distance water transfer in the hope that the energy intensity and capital costs of desalination will drop in the coming decade (Stokes and Horvath, 2009).

Since a national/international methodology has not yet been adopted to estimate EN4WT, there are no benchmarking tools to help policymakers accurately and consistently account for the social, environmental and economic impacts of water transfer operations. This paper responds to this need by proposing a tool that can be used to assess the EN4WT over distances, compare case studies, develop method for analysis and thereby offer a more solid evidence base for policy formulation and action in this area.

Dataset Construction and Analysis

This paper presents a new method of analysis and a tool to analyze energy for water at the national level to provide a more detailed characterization of energy intensity variance and investigate potential correlations between factors impacting energy use. Case studies and benchmark factors were established to help policy makers assess water transfer options. Energy Intensity

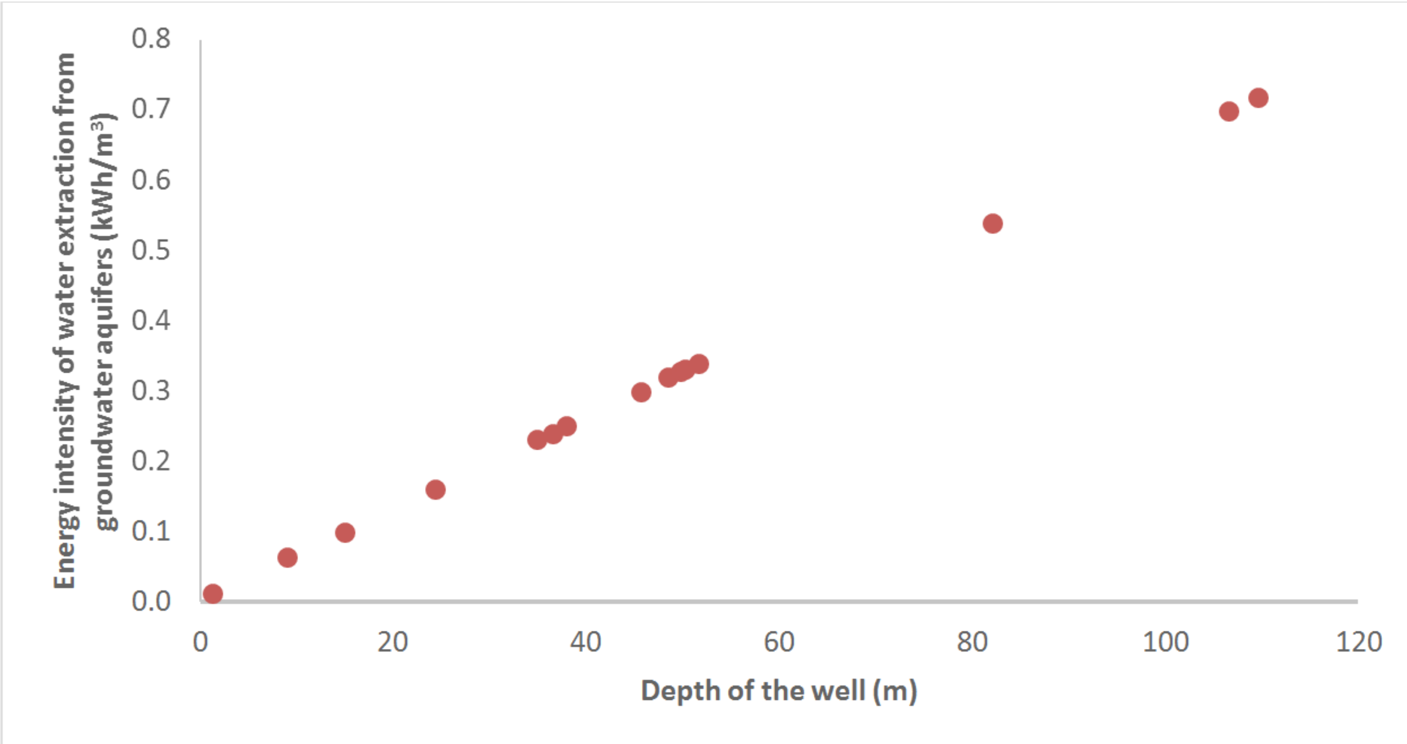

Figure 2. Average energy intensity of extracting water from groundwater aquifers at different depths
Source: Burt and Soto, 2008

as defined here is the amount of energy (kWh) needed to transfer a unit of water (m^3) over distance (km).

The energy requirements of transferring water can be estimated from the early-stage design of the water supply network. Engineers are capable of sizing pipelines, defining the capacity and type of pump stations that result in minimum design and operating cost for a given water demand and, accordingly, estimating the operating hours of each pump station and energy consumed. This is a common practice in each micro-scale water project. However, to understand the energy requirements for water transfer on a national level and to conduct comparisons among countries would require enormous amounts of input data that even most developed countries currently lack.

Water operators and agencies might know how much energy is being used, but it is more complex to break the energy data into finer levels of detail, such as the amount of energy needed at each stage of the water supply process, including transfer and distribution. Furthermore, such data typically comprises regional or national figures and there is almost no data that captures local variability in energy intensity for water utilities.

Data

This paper uses data compiled from detailed studies to explain the variation in the energy requirements to transfer water within different countries. Our analysis is based on a review of 52 water utility databases and several journal articles. The paper extracted the data related to energy for water transfer and compiled it in a local database that can be found in Energy for Water Transfer Database (EWTD). The two specific elements of energy inputs examined in this study are EN4WT from treatment plants to hotspots/reservoirs, and EN4WT from hotspots/reservoir to end users.

Several studies on energy for water have included multiple models and estimations where they combined water transfer and water extraction (Wilkinson, 2000; Lienhard, 2010). They concluded that energy requirements for water distribution (extraction and transfer) are highly dependent on topography, the size of the municipality, and the distances that water must travel. Additionally, they suggested the design of power tariff to reduce groundwater withdrawals based on the actual cost of generation and distribution of power.

Our review includes only studies that provide an estimate of the energy requirements to transfer a unit of water over distance. The data reviewed from water utility databases and journal articles yielded 71 estimates of the EN4WT in Saudi Arabia, the United States, Jordan, Spain, and India.

The volumes of water being pumped (m^3) and energy use (kWh) to transfer water over distances were collected from available databases and several journal articles . Distance and elevation (lift) between the source of extraction and hotspots of distribution were analyzed by creating elevation profiles using Google Earth.

Empirical Model

To assess the relative importance of a range of factors responsible for the energy used in the transportation of water, in this section we conduct an OLS regression analysis for a range of physical and socio-economic variables. Developing the quantitative relationship between non-controllable factors such as precipitation and slope and controllable factors such as total amounts of water being pumped and prices is highly desired for energy management.

The formula below (Equation 1) shows the energy requirements of pumping water (water horse power; WHP) as defined in the literature as the total equivalent height (H) that a fluid is to be pumped, the pump discharge rate (Q) and the specific weight of the fluid (W) (Peirce and Vesilind, 2003):

$$WHP = \frac{Q \times H}{3960} \qquad \text{(Equation 1)}$$

Most of the available literature that attempts to study EN4WT has been generated from a variety of physical parameters related to fluid properties, pump efficiency, pump type and friction losses (Cherchi et al., 2015). These studies suggested the use of a combination of variable and fixed-speed pumps that best-minimized costs of pumping water. They also suggested designing hydraulic efficiency indicators for the management and decision making of water supply systems. These indicators would allow for comparison between different pump designs based on energy and hydraulic terms. These studies considered the theoretical pump characteristic curves, which implies only considering the pump and motor efficiencies of the pumping station. With these methods, energy saving was mainly obtained by means of the improvement of the sequence of activation of the pumps (Moreno et al., 2007). It is worth noting that the engineering details of such calculations are beyond the scope of the present paper.

The previous studies provided several measures and parameters to evaluate EN4WT, and these measures can be useful for designing purposes and for micro-scale assessment. At the broader societal level, in order to assess EN4WT a number of socio-economic indicators are also likely to be relevant. Multiple regression models were introduced to fulfill this purpose and to investigate if the dependent variable (EN4WT) was significantly related to independent parameters: (1) the volumes of water required to be transferred; (2) travel distance or length of the pipeline, which has a major influence on the efficiency of the system due to friction; (3) elevation head (lift) caused by changes in topography; (4) investment in water and sanitation with private capital participation; (5) Gross Domestic Product (GDP) ; (6) industrial electricity tariff(s); (7) precipitation.

Input data were transformed using logarithm transformation to meet the assumption of a statistical inference procedure (Equation 2). Statistical analyses including sensitivity analyses and testing the robustness of the variables were conducted to identify which variables can cause significant uncertainty in estimating energy intensity. Data for five countries was pooled together in a cross-section econometric analysis to estimate the following log transform model:

$$Log\ (EN4WT) = \beta_1 Log(Slope) + \beta_2 PVP + \beta_3 Log(PCP) + \beta_4 Log(GDP) + \beta_5 Log(Elec.Price) + c$$

(Equation 2)

where,

EN4WT:	Energy requirements to transfer a unit of water over distance (kWh/m^3/km)
Slope:	Elevation head (lift) divided by horizontal distance
PS:	Investment in water and sanitation with private capital participation, dummy variable; 1: accounts for the inclusion of private sector in water contract, and 0 where there is no participation by the private sector
PCP:	Average annual precipitation (mm)
GDP:	Gross Domestic Product
Elec.Price:	Industrial electricity tariff ($/kWh)
β :	Coefficient for each predictor variable
c :	Intercept

Correlation coefficients for variables measured are highly significant at 95 % confidence interval (Table 1). The data was averaged for each country and used to analyze the EN4WT (kWh/m^3/km). Four conclusions can be drawn from the analysis.

First, it is comparatively less energy intensive to move water over horizontal distance than if the water has to be lifted. For example, on average, Jordan, India, and Saudi Arabia have to move water over the same horizontal distances. However, Jordan has to lift its water higher than the other two countries, which increases the energy intensity of this process by at least four orders. In general, a 1.2% increase in energy intensity would result for each percent increase in slope (Table 1).

Second, investment in water by the private sector (PS), which was defined as a dummy variable has had an impact on reducing total energy consumption for water transfer. The United States is an example of the inclusion of the private sector in water contracts, and this has resulted in the U.S. having the least energy intensity among sample countries. This can be explained as follows: private operators are capable of achieving higher efficiency performance measures by improving water delivery, reducing wastage, rehabilitating poor water infrastructure and continuing institutional and financial capacity building. The average growth of energy intensity is expected to drop by almost 7% for each inclusion of the private sector in water projects (Table 1).

Third, the increase in electricity rates reflects significance reductions in EN4WT. This is not surprising, as higher the electricity prices the less consumption, and the higher the opportunity to invest in high energy-efficient pump systems.

Fourth, GDP and level of precipitation (PCP) were other factors that had an impact on energy intensity for water transfer. The higher the levels of precipitation, the higher the availability of water sources, the higher the consumption, and thus the higher energy is needed. A 0.47% increase in energy intensity will likely happen for each percentage increase in annual precipitation. Lastly, countries with a lower GDP are expected to have low energy-efficient pumping systems and high loss rates in the network. Generally, for each 1% increase in total GDP, energy intensity is expected to decrease by 0.14%.

Benchmarking Tool

In this section, and after estimating energy intensity of water transfer, we seek to answer the question: how do the energy requirements for transferring a unit of water compare among different countries? The main objective here is to help public policymakers evaluate

Variable	Model Expression (β)	Std. Error	t-Statistic	Prob.
Investment (PS), dummy variable	-1.99	0.4435	-4.49	0.00
LOG(Elec.Price)	-0.54	0.1308	-4.19	0.0001
LOG(PCP)	0.47	0.1348	3.51	0.0008
LOG(GDP)	-0.149	0.1035	-2.44	0.015
LOG(Slope)	1.20	0.0742	16.17	0.0000
C	-5.052	2.0256	-2.49	0.015
R-squared	0.88			
Adjusted R-squared	0.87			
Standard error of the regression	0.61			
Residual sum of squares	23.33			
Log likelihood	-60.12			
F-statistic	90.96			
Prob.(F-statistic)	0.000			

Table 1. Model coefficient estimates and statistical analysis.

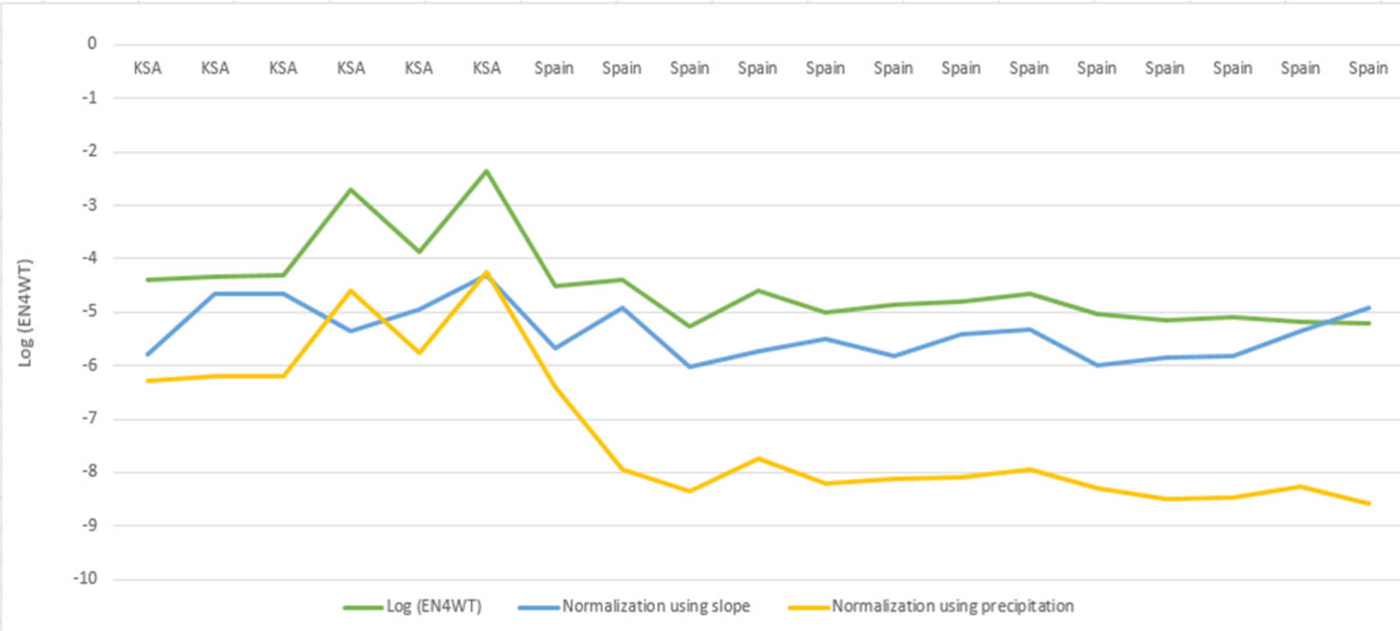

Figure 3. A comparison between normalization of EN4WT using precipitation and slope

their energy requirements for water transfer, inform them where they stand with respect to others, and improving sustainability in the water industry. There is currently no systematic approach used by the water industry to select appropriate water sources taking into consideration the cost of energy, which is one of the biggest expenses to the water industry. There are several environmental benchmarking tools that are widely used in some industries, but their adoption by the water industry has been slow (O'Neill and Rudden, 2013).

The empirical model developed in the previous section estimates average energy intensity by considering a set of potential variables that might affect energy intensity. The estimated EN4WT data was normalized to separate the potential impacts of non-controllable factors include slope and precipitation. The slope is the most significant independent variable of EN4WT as the regression analysis shows and since it is a non-controllable factor, additional normalizing for this factor allows comparison of EN4WT data across countries and enables policymakers to make unbiased and comparable evaluations.

Figure 4 shows a comparison between normalization of EN4WT using slope and precipitation. Results show varying percentages in reductions, on average the normalization using slope resulted with 62% reduction in EN4WT and by using precipitation the average reduction was 12%.

Figure 3 provides a tool for assessing energy use performance in water transfer by providing estimates for each energy use after eliminating the potential impact of slope and precipitation. The primary differences in energy use among countries are twofold. Firstly, while some countries such as the United States had very efficient water transfer projects within the same watersheds, moving water by interbasin transfer increased total energy intensities by an order of magnitude. Colorado River Aqueduct and California State Water Project are examples of water transfer projects with low energy efficiency where water is moved through open channels with high loss rates. Secondly, although a water pumping system may be characterized by low operational efficiency (40-50%), in some developing countries such as India, the EN4WT was low. This can be explained by the relatively low per capita water withdrawals in India at 52 m^3/year (AQUASTAT, 2015).

While some projects continued to reflect high energy intensity after normalization using slope, the introduction of precipitation was sufficient in relocating these projects under low energy-intensive projects (Figures: 4, 5).

A normal distribution curve was plotted to help policymakers assessing energy intensity after eliminating the potential impact of slope (Figure 6). On average, the energy intensity of transferring water across countries and after eliminat-

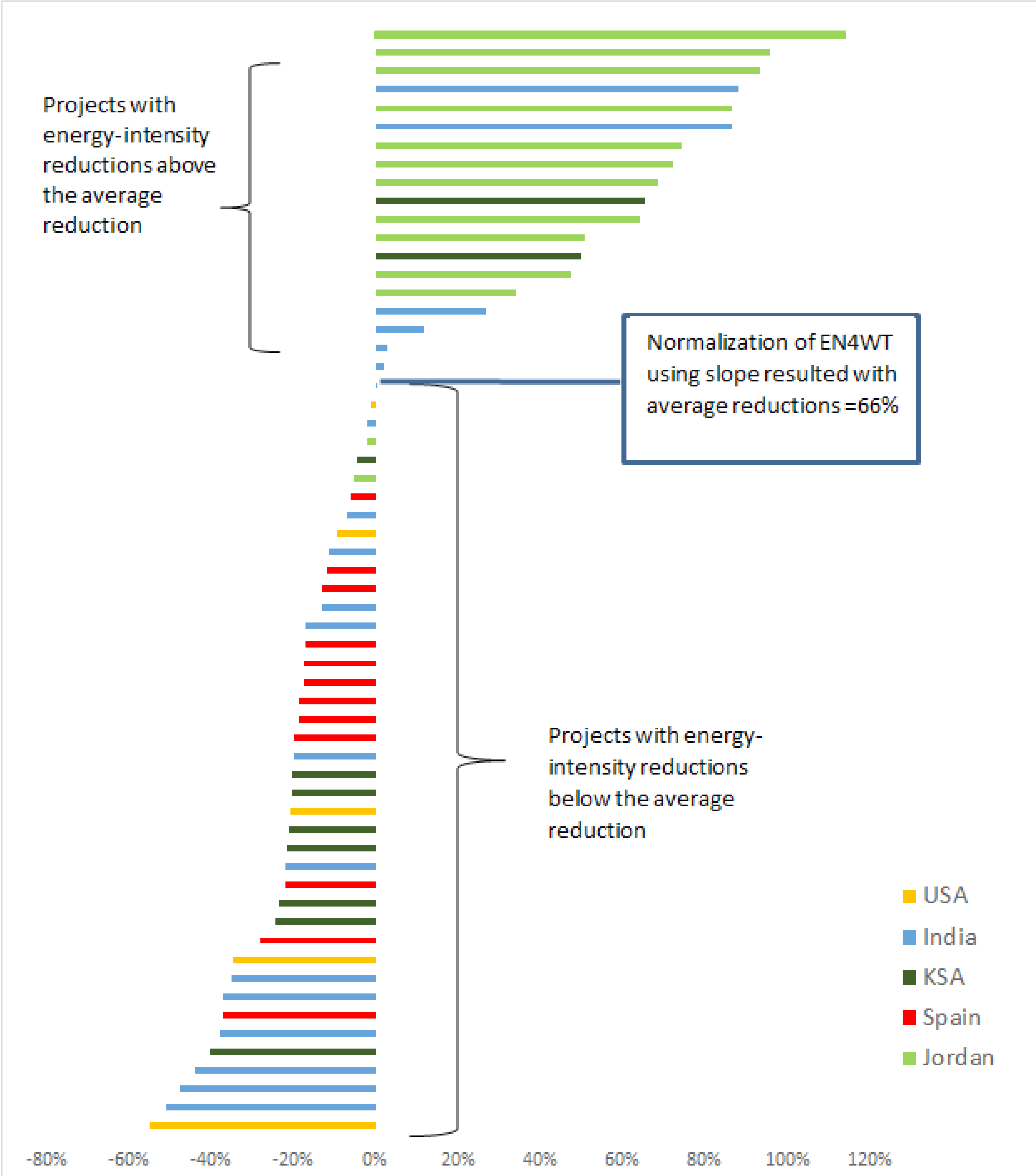

Figure 4. Normalization of energy intensity for water transfer by using slope.

ing the potential impact of slope equates to 0.0058 kWh/m^3/km with a standard deviation of 0.021.

Economic Cost

The price of water is a thousand times less than the price of crude oil, though it costs roughly the same to move the same unit. In water-scarce countries, water is often subsidized; and even in water-abundant countries, the price of water is too low (OECD, 1999). These low prices lead to inefficient water use and often create pressure on other resources needed to supply water. Governments are forced to divert returns from other sources of revenue and reduce budgets for water infrastructure in order to make up

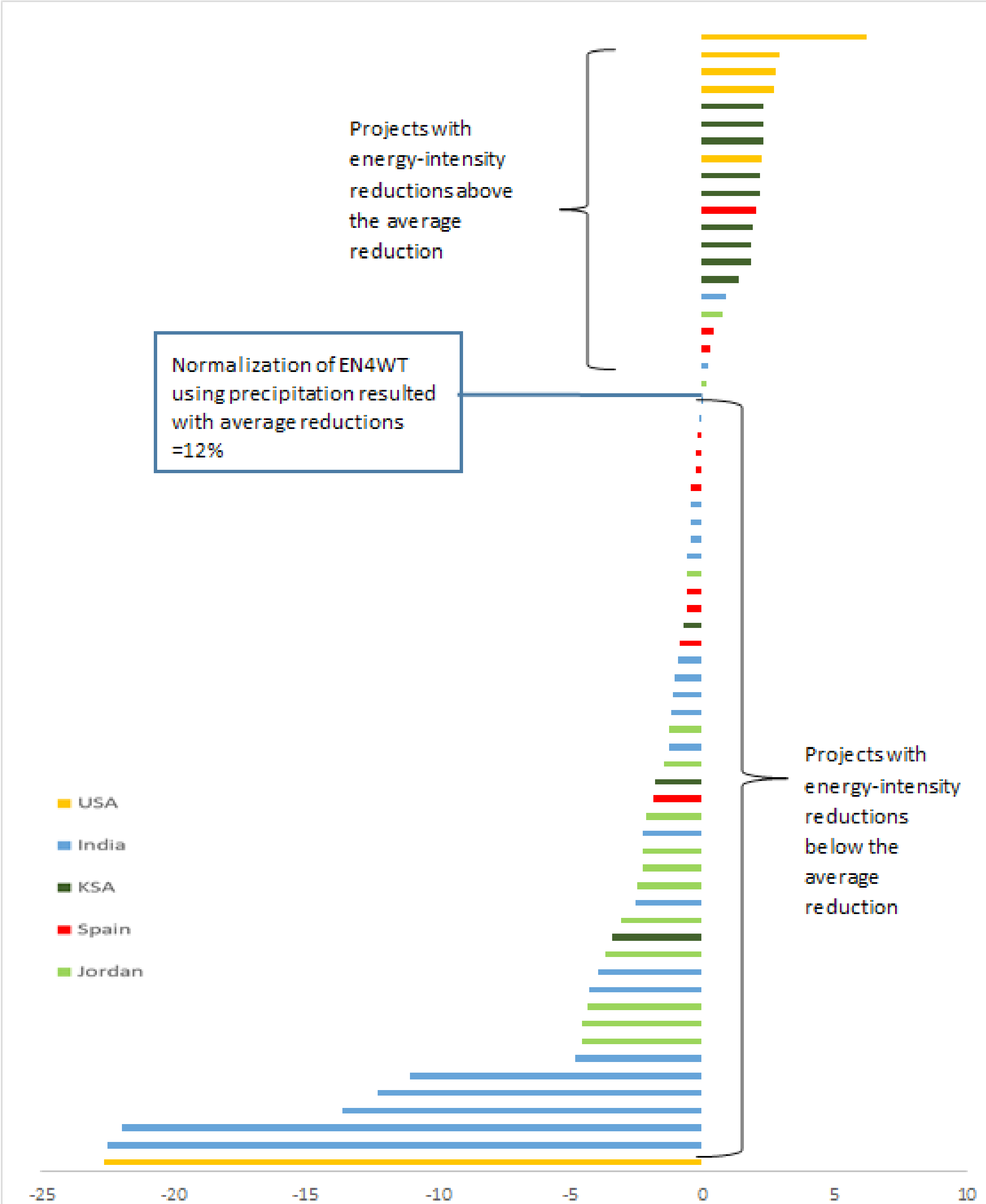

Figure 5. Normalization of energy intensity for water transfer by using precipitation.

for the low returns they receive from tariffs that generally do not cover the full cost of supplying water.

This paper evaluates the total cost of potential water transfer projects from sources which in this case (a desalination plant) at the nearest point of distribution for several coastal countries that currently face serious water scarcity problems. The cost was estimated only from the coast to the storage tank and not to end users. The cost of delivering water to end users varies significantly based on the distribution system, operating pressure, blending and purification.

The cost of transferring water is assessed based on the pipeline costs of oil transport, which is a much more developed area. Costing a new water transfer system

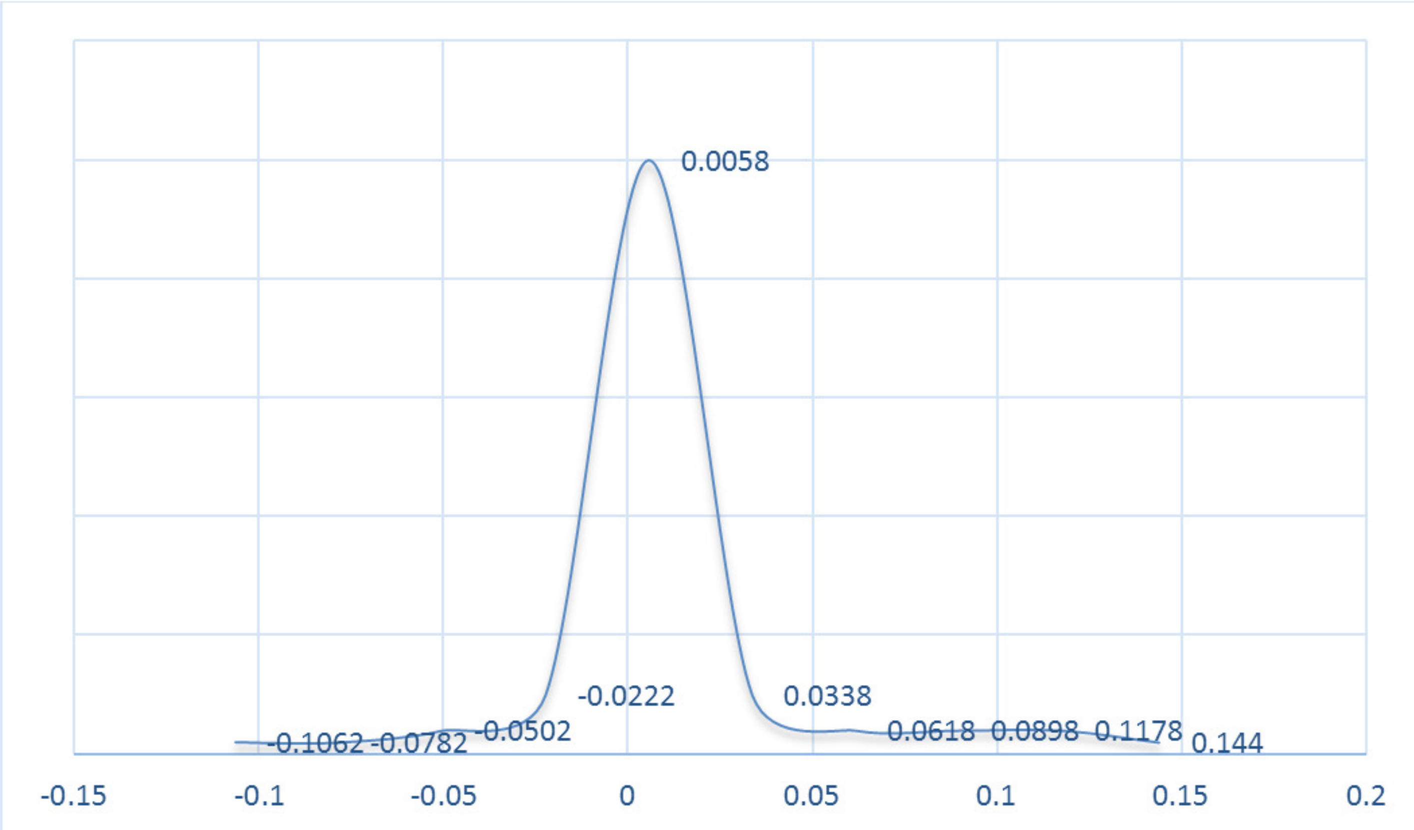

Figure 6. Distribution of energy intensity (kWh/m3/km) to transfer water across countries after normalizing for slope

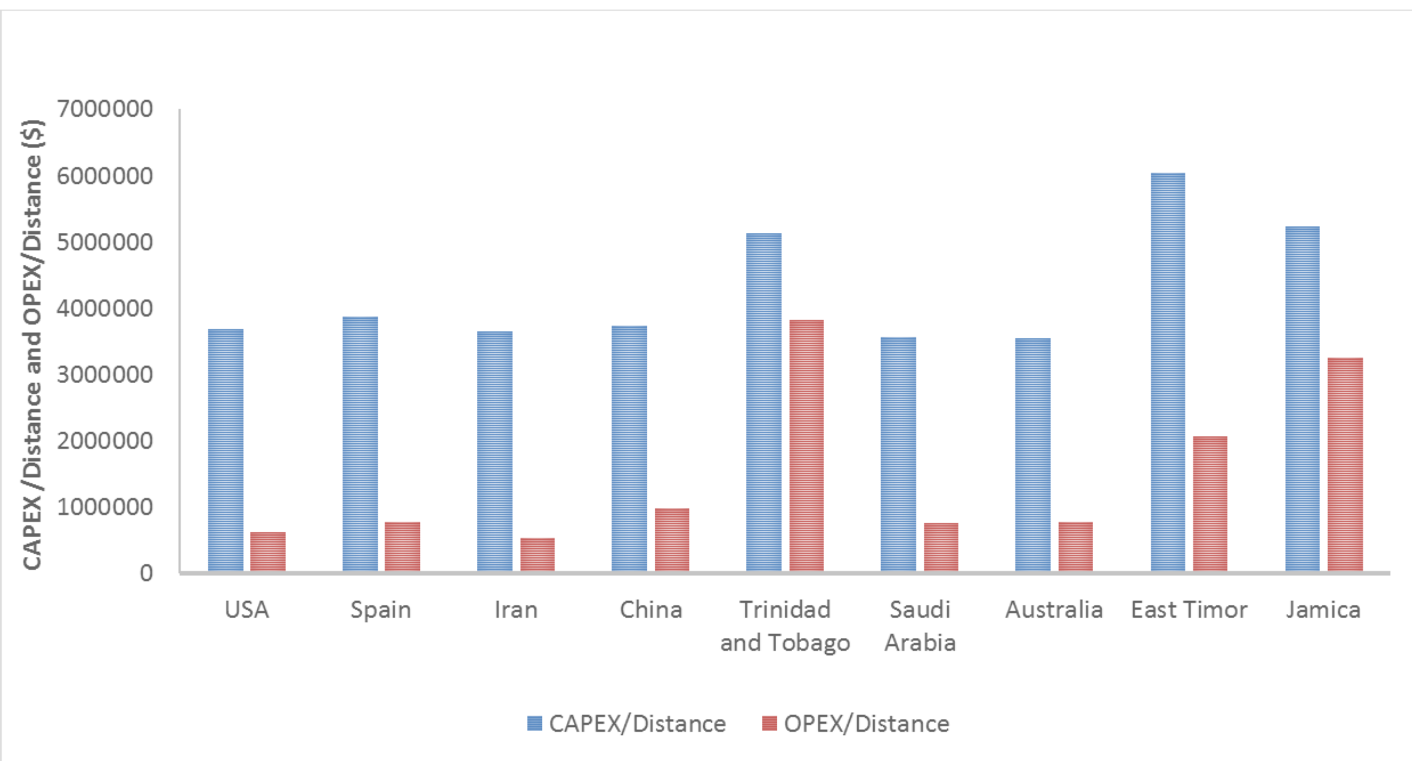

Figure 7. Total estimated operating and capital costs/distance of transferring 100 million m3/ year of water across several countries

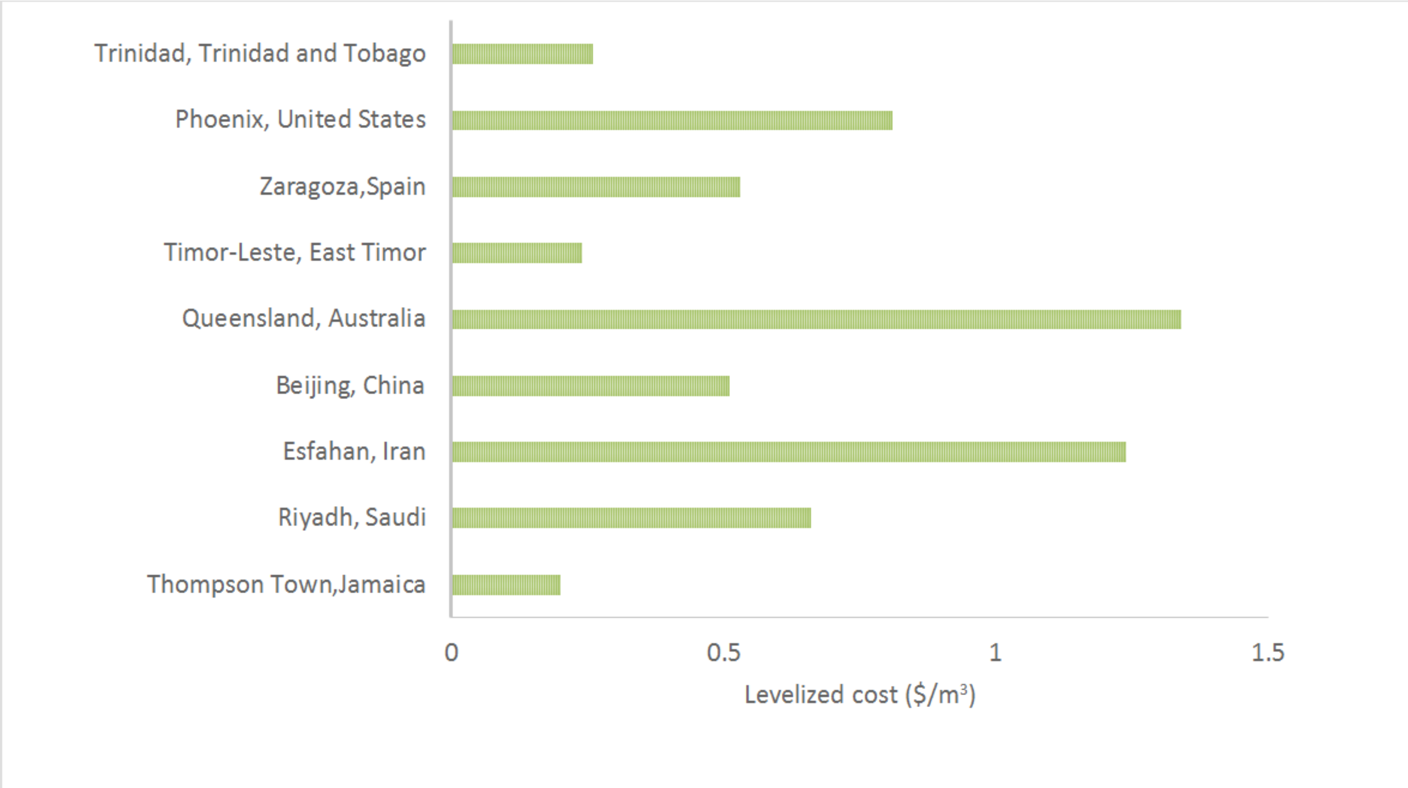

Figure 8. The Levelized costs of delivering desalinated water in selected water stress cities.

for a location where there is currently no such system is likely to be complicated because there is no comprehensive database for estimating the cost of water supply projects (Hutton and Bartram, 2008). QUE$TOR® software developed by IHS (IHS, 2018), which provides concept screening, optimization and detailed oil and gas capital expenditure (CAPEX) and operational expenditure (OPEX) cost estimates, was used to estimate the cost of constructing potential water pipelines. The capital and operating costs were estimated to reflect a typical water transfer project and discounted over the anticipated 50-year lifetime of the project (Figures: 6 and 7). The assumed pipeline material in question is carbon steel with a minimum 30 psia outlet pressure, 1,520 mm nominal diameter, 9.52 mm wall thickness, 3 mm corrosion allowance and one booster station. The duration of the construction phase for each project was assumed to be six days for each kilometer.

This paper assumes a transfer of 100 million m^3/ year using pipeline systems based on the Hazen-Williams equation. The elevation and distance were calculated using the Google Earth application. China was proposed as the supplier of materials for the projects.

A Levelized cost at which water must be transferred to break even over the anticipated 50-year lifetime of the project was estimated at a discount rate of 5% by applying the following modified equation (IEA, 2005):

$$LCOE = \frac{I_t + \sum_{t=1}^{n} \frac{Mt}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Vt}{(1+r)^t}}$$

where:
LCOE = Levelized cost of energy used in water transfer projects
It = investment expenditures in the year t
Mt = Operations and maintenance expenditures in the year t
Vt = Quantity of water transferred in the year t
r = Discount rate
n = Life of the system

The cost of a given water transfer project will depend a great deal on the size of the project, the cost of the pipeline, the energy costs to pump the water and various additional factors. Most these factors are directly affected by total elevation (lift) and distance changes from the coastline to the storage tank. This becomes clearer by reviewing the estimated Levelized cost for potential water transfer projects (Figure 8). Australia, Iran, the U.S. and Saudi Arabia had the highest cost of water transfer as they have to move the water over 450, 445, 380 and 350 km horizontal distances respectively, and over 200, 1,300, 783, and 122 m elevations (lift) respectively. Jamaica had the lowest potential water transfer cost due to the short distance the water has to travel: over 30 km at 80 m elevation.

This economic analysis should provide policymakers with insights which might allow them to make tradeoffs by determining the Levelized cost and accordingly the net value of water use. These economic tools could reduce water use and result in water and energy savings. In other words, the use of these tools should determine whether the total benefits outweigh the total costs (taking into consideration initial and ongoing costs, such as personnel) relative to alternative policy tools.

Conclusions and Policy Implications

This paper evaluates the energy intensity in water transfer and distribution. A new method was developed to help decision makers compare water supply options by integrating the energy component with the goal of improving sustainability in water-scarce areas.

This work helped to fill the gap in the literature by creating a basic method for evaluating energy use in water transfer and distribution, which is missing from most water-energy benchmarking studies. It offers a chance for crucial parameters to be applied effectively to existing and new water projects in order to quickly identify and eliminate highly energy-intensive options.

Transferring water may cause a variety of negative social, economic and environmental impacts depending on factors such as the total volume of water to be moved, the pipeline path, topography and the conveyance system.

Economic considerations specifically include upgrade and construction costs of existing and new infrastructure, the energy costs of water transfer, and the comparison between water transfer and other water supply alternatives. Social considerations include the cost of releasing significant greenhouse gas (GHG) emissions due to pumping the water and the associated negative impacts on communities' health and the environment in general. They also include the current value of water for local communities and the value of employment opportunities that such schemes may create. Environmental considerations may vary based on the location of water sources and delivery locations. Water transfer over long distances may give rise to changes in river flows, the alteration of the composition and population of aquatic ecosystems, implications on sediment movements, channel stability and alterations in water quality.

Desalination may be a solution for some water-scarce regions, but not for areas far from the coast, deep in the continental interior or at high elevation. The total cost of desalination remains higher than for other alternatives in most regions of the world. It also has some negative impacts on the environment such as the production of concentrated brine and carbon dioxide emissions. Desalination may become competitive with water transfer depending upon the water transport method, energy prices, water transfer distance and geographical location.

The future development and possible changes in policies related to energy and water strategies should be based on the performance of alternative sources in delivering water and their potential contribution to making water and energy savings. Policymakers on both water and energy should give higher priority to water conservation practices. Policies targeting the end users of water would have much larger energy implications than policies targeting the water supply chain. The implications of water conservation practices go beyond water and energy savings and may comprise environmental benefits such as the planet's resilience to the effects of climate change.

Installing a desalination plant and delivering water to nearby communities might be more promising and cost effective than transporting water over long distances. Therefore, improving the productivity with which energy is used to supply water provides an important opportunity to increase related energy efficiency. Significant economic and environmental benefits can be achieved in the energy sector through efficiency improvement of water supply and conservation.

Policymakers should look for synergies between water-energy and other policy objectives. For instance, water transfer and energy savings can go hand in hand. In Amman, Jordan, a Red Sea-Dead Sea canal water transfer project allowed for the supply of potable water to Jordan, Palestine, and Israel, stabilizing the Dead Sea water level, and also generating the electricity needed to support the project.

Introducing the parameters of social costs and carbon emissions reduction in water transfer projects is a vital question and needs to be considered by policymakers before they set the framework for subsequent investment. Water utilities rarely track the GHG emissions that occur within their direct scope of operations through the consumption of electricity and natural gas to extract, purify, and deliver the water. GHG emissions tracking and control should become a common practice. In this respect, financial incentives to implement energy savings and emissions reduction programs have become very necessary.

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Reference

Aaron Jaffe and Keith Schneider. 2014. A Dry and Anxious North Awaits China's Giant, Unproven Water Transport Scheme. http://www.circleofblue.org/waternews/2011/world/a-dry-and-anxious-north-awaits-china%E2%80%99s-giant-unproven-water-transport-scheme/

Addams, L., G Boccaletti, M Kerlin, M Stuchtey - McKinsey & Company, New York, 2009. Charting our water future: economic frameworks to inform decision-making. The Barilla Group, The Coca-Cola Company, The International Finance Corporation, McKinsey & Company, Nestlé S.A., New Holland Agriculture, SABMiller plc, Standard Chartered Bank, and Syngenta AG.

Cooley and Wilkinson, 2012. Implications of future water supply sources for energy demands, and computer models with WESim User manual . Pacific Institute and Bren School, University f California Santa Barbara.

Berfield,S. 2008. There Will Be Water. Bloomberg. June 12, 2008

Bennett, B., L. Park and R. Wilkinson, "Embedded Energy in Water Studies: Statewide and Regional Water-Energy Relationship." California Public Utilities Commission, 2010. Available at: http://www.waterenergyinnovations.com/publication/view/cpuc-embedded-energy-in-water-studies-1-statewide-and-regional-water-energy-relationship/

Burt, C.M. and M. Soto. 2008. Conversion to Groundwater Pumping with Drip/Micro Irrigation Irrigation Training & Research Center. California Polytechnic State University, San Luis Obispo, California, USA. ITRC Report No. R 08-001. 28 pp.

CEC (2005) "California's Water Energy Relationship". Final Staff Report. Prepared in Support of the 2005 IEPR Proceeding. California Energy Commission (CEC). CEC-700-2005-011-SF

Cherchi, C., Badruzzaman, M., Oppenheimer, J., Bros, C. M., & Jacangelo, J. G. (2015). Energy and water quality management systems for water utility's operations: A review. Journal of environmental management, 153, 108-120.

EPA .2013. Strategies for saving energy at public water systems. Office of Water (4606M). EPA 816-F-13-004. July 2013

Greene, D. (Austin Water), Spelman, J. (Austin Energy) and Kjelsson, J. (University of Texas, Austin). 2013. Water and Energy in Austin, Texas. (Unpublished)

Gupta, J. and Zaag, P. 2008. Interbasin water transfers and integrated water resources management: Where engineering, science and politics interlock. Physics and Chemistry of the Earth 33 (2008) 28–40

Hayek, B. 2014. GIZ/WAJ IEE study. German-Jordanian Programme "Management of Water Resources" Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ) GmbH. Amman, Jordan

Helix. 2013. Helix Water District Capacity Fees Effective April 15, 2013. http://www.hwd.com/pubs/capacityfee.pdf

Hutton, G., Bartram, J. 2000. Regional and Global Costs of Attaining the Water Supply and Sanitation Target (Target 10) of the Millennium Development Goals. Public Health and the Environment World Health Organization Geneva 2008

IEA. 2005. Nuclear Energy Agency/International Energy Agency/ Organization for Economic Cooperation and Development Projected Costs of Generating Electricity

IHS. 2018. QUE$TOR. https://ihsmarkit.com/products/quest-or-oil-gas-project-cost-estimation-software.html

JCBU. 2014. Electricity Consumption Analysis. Jeddah City Business Unit. Jeddah, Saudi Arabia

Lienhard V JH. Barriers to adoption of energy efficient water supply technologies. In: London: Lecture at Imperial College.; 2010.

Marcuello, J., Capilla, A., Murillo, J., Barcones, J., Meyer, A., 2003. The allegation of the authorized water transfer project in the law of the national water plan and the study of the environmental impact. Document to Trabajo 03/2003. http://citarea.cita-aragon.es/citarea/bitstream/10532/160/1/10532-80_136.pdf

Moreno, M. A., Carrion, P. A., Planells, P., Ortega, J. F., & Tarjuelo, J. M. (2007). Measurement and improvement of the energy efficiency at pumping stations. Biosystems Engineering, 98(4), 479-486.

OECD. (1999). The Price of Water Trends in OECD Countries: Trends in OECD Countries. OECD Publishing, Aug 16, 1999 - Business & Economics - 176 pages

O'Neill, K., Rudden, P.J. 2013. Environmental best practice and benchmarking report. European Green Capital , RPS Group, Ireland

Peirce,J., Vesilind, A. 2003. Environmental engineering. Fourth Edition. Amsterdam Boston London

Sanders, K.T, Webber, M.E. 2013. The energy-water nexus: Managing water in an energy-constrained world. Earth- The sciences Behind the Headline. June 30, 2013

Stokes, J., Horvath, A. 2009. Energy and Air Emission Effects of Water Supply. Environ. Sci. Technol., 2009, 43 (8), pp 2680–2687

Scott, C., Pasqualetti,M., Hoover,J., Garfin, G., Varady,R., and Guhathakurta, S. 2009. Water and Energy Sustainability with Rapid Growth and Climate Change in the Arizona-Sonora Border Region. A Report to the Arizona Water Institute June 2009

Siddiqi, A, and Anadon, L.D. 2011. The water–energy nexus in Middle East and North Africa. Energy Policy39(2011)4529–4540

SWCC. 2015. Saline Water Conversion Corporation has started the second phase of moving water from Ras Alkair to Riyadh city. http://www.swcc.gov.sa/modules/SwccNews/Detail.asp?ID=2061

TERI. 2005. Technical, policy and economic assessment on energy conservation. Tata Energy Research Institute. TERI Report No. 2005IB33

UNESCO. 2013. Managing Water Report under Uncertainty and Risk. The United Nations World Water Development Report 4 Volume 1

UNEP. 2008. An Overview of the State of the World's Fresh and Marine Waters. Vital water graphics. United Nations Environment Programme. UNEP/GRID-ARENDAL

Westland. 2012. Water Management Plan 2012. Westlands Water District

Williams, E. 2013. Impact of Increasing Energy Demands on Natural Resources. The energy Sustainability Challenge. MIT-CSIS

Wilkinson RC. Methodology or Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits through Integrated Water Energy Efficiency Measures, Retrieved from /http://www.rivernetwork.org/resource-library/methodology-analysis-energy-intensity-california%E2%80%99s-water-systems-and-assessment-muS. A River Network Report 2000 (2000).

Wolff G., R. Cohen and, B. Nelson, (2004), Energy down the drain-the hidden costs of California's water supply, Natural resources defense council. Oakland, California