Energy Implications of Water Transfer:
Understanding Tradeoffs and Identifying Options

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Abstract

Water and energy are inextricably linked. Water is essential in almost all forms of energy production, while energy is required to extract, treat, distribute, and transfer water. The bulk of the literature discusses energy requirements to treat and extract water. But less attention has been paid to the energy requirements to distribute and transfer water. Indeed, such energy requirements represent a controversial topic, and one most often incorrectly assessed due to the lack of clear methodology and to the complexity of variables involved.

Distributing and transferring water using high service pumps to end users can be extremely intensive in terms of energy and economy. For instance, distributing surface water in California, USA consumes 12 times more energy than treating the same amount of water (CEC, 2005; Bennett et al., 2010). In China, the energy requirements by pumps to transfer surface water is 99%, while 1% only goes for water treatment (Wang, 2008). Moving water often includes pumping the water over hills and mountains or into water storage facilities, a process that can require large amounts of energy.

As weather and rainfall patterns become more difficult to predict and the world's population continues to grow, water transfer projects could play a significant role in increasing overall resilience to water supply uncertainty and achieving water security. Plans to meet future water demands in arid regions by desalinating sea water and building pipelines to transfer water from rich regions to scarce regions will also raise the energy requirements and cost of water supply.

Governments have good reasons for moving water over long distances. Yet, a headlong rush into water transfer projects could bring its own challenges. Unless planned properly, water transfer projects are likely to increase competition for both water and energy, especially where it is already scarce.

This paper seeks to provide policymakers with new insights for making tradeoffs between transferring water and other water supply options. The paper also seeks to establish a method for analyzing the energy intensity of water transfer, a method which could be essential in determining future strategies of water supply.

Keywords: Energy, Water, water transfer, Benchmarking Tool, Efficiency, kWh/m^3

Introduction

Water transfer is the transmission of water over distance using pipes, canals, aqueducts, rivers, tunnels, and other structure, from a source of extraction to treatment plants and end users. The transfer may be entirely within a country where water originates within the watershed or is imported into the watershed from another basin. There are two main forms of water transfer projects based on the time frame of the project: short term transfer and long-term transfer. Short term transfer usually takes place between local water agencies during wet periods – when reservoirs are replenished and supply is inessential – to manage water distribution in an existing network. Long term water transfer projects aim to resolve long standing water shortage problems and would include individual and multi-year transfers. Interbasin water transfer is an example of long term water transfer projects. The purpose of this transfer is to alleviate water shortages in the receiving areas where water is less available by mass transfer of water from a different basin.

Countries with limited local water supply are left with few options to meet the water demand of their communities. One of the options is water transfers and interconnection system, an option that often is heralded as a highly energy intensive solution, especially if the water has to be moved over long distances and up a significant elevation gain.

Water transfer projects are attracting a lot of interest, but policymakers need to recognize that such projects will have a major impact on energy resources, environment, and employment. Understanding energy intensity for these projects should be carefully considered before any investment in these projects is made. However, assessing energy intensity in water transfer is an extremely challenging task. Factors that determine energy requirements include those that are fixed for a given location and those that operators can influence. Factors that operators can influence include: hours of operation; how often the system is being run; whether to operate during peak hours or not; application efficiency; and the pressure required to meet water demand. The process of water distribution and transfer is unlike water treatment and water extraction in terms of the total energy requirements. Water transfer and distribution requires maintaining constant pressure within the network, and demand can be determined only by the user, which would determine when the system bears the most load. The fixed factors include: topography, conveyance system, climate, and distance as well as the physical and chemical characteristics of the water.

There are two main systems employed to convey water from source to end user, including open and closed systems. Typically, closed systems such as pipes are more efficient and less energy intensive than open systems – such as canals, aqueducts and rivers – due to the low total losses that occur from evaporation and leakage. The capital cost for closed systems is much higher than that for open systems, which is the main reason why most developing countries still invest in open systems. Further complexity to the calculations occurs when losses and leakages in open systems have to be estimated, particularly to better determine energy requirements and maintain minimum pressure to deliver the water.

Many studies have been conducted to help policymakers develop polices for water resources, energy, and environment (Wilkinson 2000; Wolff, Cohen, and Nelson 2004; CEC 2005; CPUC 2010a; CPUC 2010b; Cooley and Wilkinson 2012). However, these studies have not considered what kinds of impacts water transfer projects might have. By contrast, this paper offers a framework for evaluating the energy requirements to transfer a unit of water over distance in several countries. This paper aims to correlate water utilities energy use in transferring and distributing water and to normalize the influence of factors impacting energy use that are outside the control of water utilities such as water source, topography, distance, population served, so that a meaningful comparison can be made among countries.

Why estimate energy intensity for water transfer?

Supplying water for the domestic and industrial needs of a growing population is one of the biggest challenges facing current water governance. The global trend of increase in demand for drinking water and the dearth of this resource has given rise to the various interbasin transfer projects. The availability of water in has decreased by 30% in 20 years, from 12900 m^3/capita in 1970 to 9000 m^3/capita in 1900, and to less than 7,000 m^3 in 2000, while for the future, it is expected to reach 602 m^3/capita by the year 2025 (Clarke, 1991; Jackson et al, 2001; Shiklomanov, 1999).

Water transfer projects help to meet the demand of drinking water, irrigation, industry, and similar uses. This transfer played a significant role in the sustainable development in the areas surrounding the receiving basins. Megacities in the United States – such as San Diego and Los Angeles – were established and maintained their economic growth due to water transfers (Keshari, 2004).

The U.S. is moving toward large investment in mega water transfer projects which are done in the Southwest desert of California, where they transfer water from areas of surplus to areas in critically short supply. China's South–North Water Transfer project, scheduled for completion in 2050, aims to transfer 44.8 billion cubic meter of fresh water through pipelines of 500, 1,200 and 1,300 kilometers in length (Aaron Jaffe and Keith Schneider, 2014). Israel has signed a water transfer treaty to import 1 billion m^3 of water, or 50Mm^3 /year, at \$0.75/m^3 from Turkey over a period of 20 years at an expected total cost of \$800 million to \$1 billion (Global Water Intelligence, 2002). Other countries, such as Kuwait, Singapore, and India, have committed to establish and expand current desalination facilities to provide supplemental amounts 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). Complex pipeline connections will be required to transfer desalinated water and supplemental water from new sources to end users. Table 1 shows the contribution of water transfer projects for water provision in different regions in the world.

Table 1. Contribution of interbasin water transfers (IBTs) to all water withdrawals of the world (Gupta and Zaag, 2008)

Region	Water withdrawals (10^9 m^3)		
	Total	Through IBTs	
South America	182	3	2%
North America	705	300	43%
Asia	2357	146	6%
Europe	463	79	17%
Africa	235	11	5%
Australia and Oceania	32	1	3%
World total	3974	540	14%

Though all these projects are essential to cope with the demands of an increasingly urbanized population and correct the spatial mismatch in water availability distribution, they would require high energy consumption which would produce a large quantity of greenhouse gases, and burden the economy of countries with limited energy resources. It's already difficult to meet existing energy demand in several parts of the world. Allocating big shares of energy to transfer water in such cases would result in even more friction.

Since a national/international methodology has not yet been adopted to estimate energy intensity in water transfer and distribution, there are no benchmarking tools to help policymakers accurately and consistently account for the social, environmental and economic impacts of water transfer operations. The first step in understanding what causes these market failures in the water-energy sector is to evaluate the energy requirements in water transfer and distribution projects. The few studies that have looked at the energy requirements in the water sector tend to focus on the energy needed to extract water from a source or energy requirements to treat and purify water. The primary challenge to estimate energy in water transfer is a need to trace energy inputs from a point of origin right after extraction through a point of use and ending in disposal or reuse. 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, these data are typically regional or national values and there are almost no data that capture the local variability in energy intensity for water utilities.

Water Transfer And The Environment

The water supply sector already faces conflicts between meeting water demand and environmental objectives. Water transfer projects are most likely to add to these. In Canada, there are more than 60 large water transfer projects that have been constructed to help in meeting growing water demand (Table 2).

Table 2. Interbasin water transfer projects in Canada

Jurisdiction	Project	Contributing Basin(s)	Receiving Basin	Average Annual Diversion(m^3/s)
British Columbia	Kemano	Nechako (Fraser)	Kemano	115
British Columbia		Bridge	Sector Lake	92
British Columbia		Cheakamus	Squamish	37
British Columbia		Coquitlam Lake	Buntzen Lake	28
Saskatchewan		Tazin Lake	Charlot (L Athabasca)	25
Manitoba	Churchill Diversion	Churchill (southern Indian Lake)	Rat-Burntwood (Nelson)	775
Ontario		Lake St Joseph (Albany)	Root (Winnipeg)	86
Ontario		Ogoki (Albany)	Lake Nipigon (Superior)	113
Ontario		Long Lake (Albany)	Lake Superior	42
Ontario		Little Abitibi	Abitibi (Moose)	40
	Welland Canal	Lake Erie	Lake Ontario	250
Quebec	James Bay	Eastmain-Opinaca	La Grande	845
Quebec	James Bay	Fregate	La Grande	31
Quebec	James Bay	Caniapiscau	La Grande	790
Newfoundland	Churchill Falls	Julian_Unknown	Churchill	196
Newfoundland	Churchill Falls	Naskaupi	Churchil	200
Newfoundland	Churchill Falls	Kanairktok	Churchil	130
Newfoundland	Bay D'Espoir	Victoria, White Bear Greay and Salmon	Northwest Book (Bay d'Espoir)	185

Source: Adapted: Day and Quinn (1992)

Yet, major conflicts are emerging between the transfer of water to meet demand and environmental needs. For example, transferring large volumes of water and the diversion and alteration of flow regimes could have implications on movements of sediments, channel stability, seepage losses, water temperature at different depths, and alterations of water quality. It could also imbalance the aquatic life and impact the communities that depend on water and its associated benefits. Water transfer projects involve high energy and fuel requirements that would release significant greenhouse gas emissions into the atmosphere (Environment Canada, 2001, Quinn and Edstrom, 2000, Das, 2006).

Apart from environmental consequences, there are immense social, political and legal obstacles involving water transfers. Water transfer includes the displacement of people, an increase in water-borne, an effect on the microclimate of the region, increase value of employment that such schemes may create for the recipient communities, loss of income and natural asset, and deprive many of the donors' livelihoods (homes, field, grazing land, etc.).

Potential benefits of water transfer projects can be restricted by environmental regulations. The issue of how to resolve these challenges with acceptable tradeoffs is going to be a major concern for policymakers. It is important to involve public and other sectors in the process and to take their views into account, while deciding on big investment such as these projects in order to reduce the associated environmental and socio-economic impacts.

Water transfer Cost

Water transfer cost can vary significantly based on several factors: type of conveyance, length, changes in elevation, labor cost, costs for operation and maintenance, pumping stations, dams, and storage tanks, as well as the prices of water and energy. Gruen (2000) estimated the unit cost of transporting water from Turkey to Turkish Cyprus over a 78km pipeline with a capacity of 75 mln m^3 by 25-34 ¢/m^3. Similarly, Kally (1993) evaluated the cost of transporting 100 million cubic meter over 200km in Egypt and the total cost was 21.4 ¢/m^3. Transporting water using canals with total length of 900km with a capacity of 1000 mln m^3 from Ebro to Barcelona and Southern Spain revealed a total cost of 36 ¢/m^3 (Uche et al., 2003). In contrast, transporting 32 bln m^3/yr using 1150km-long canal from Yangtze to China's north with 65 m elevation head would cost 10-16 ¢/m^3 (Liu and Zheng, 2002). According to Zhou (2004) a 100m vertical water transfer lift is about as costly as a 100km horizontal transport at $0.05 –$0.06/m^3. Similarly, transporting desalinated water over distance showed high variations in unit cost due to variations in distance and elevations. Zhou and Tol (2005) had two main conclusions: that water transport cost is a function of both travel distance as well as elevation head, and that elevation head is more significant in defining the total cost.

In sum, transporting water over a horizontal distance is comparatively cheap whereas the main cost is for lifting it up. Zhou and Tol (2005) identified that delivering desalinated water to coastal cities has more economic incentive than pumping water to cities far from the sea with high elevation. They concluded that transporting desalinated water to Bangkok would cost 1.1 $/$m^3$, Phoenix for 1.3 $/$m^3$, and to Zaragoza for 1.4 $/$m^3$. While the cases of New Delhi, Harare, and

Mexico City – which are far from the city with higher elevation head – had a total unit cost of 1.9 $/m^3$, 2.0 $/m^3$ respectively.

Potential Alternatives To Water Transfer

Desalination is the second available option to meet water demand in areas limited with surface water and deteriorated groundwater aquifers. Desalination's total cost dropped to $0.6/m^3 and – based on the method (thermal or reverse osmosis) and water type (brackish or sweater) – the average cost is between $0.6/m^3 and $1/m^3 (Zhou, 2004). This downward trend in total cost is associated with technology development, such as the improvements of membrane performance, and with the ability to recover energy from the process (Busch and Mickols, 2004).

It is worth noting that most of the desalination costs documented in the available literature are for producing water and do not include the transmission and distribution network system. At this point, desalination might become competitive to water transfer upon the water transport method, energy prices, travel distance to transport the water, and geographical location, with some suggesting it can be cheaper and others suggesting it can be more expensive (Walton, 2010 and Mayrand, 2008).

Regions that are water scarce and far from the coastal area, have to consider improving water use efficiency in distribution networks, reducing leakage, updating irrigation network, encouraging reduced water consumption, enhancing aquifer recharge, increasing the use of recycled water, helping communities to install rainwater harvesting tanks, and higher water pricing.

Methodology

How to estimate energy intensity in water transfer

One of the objectives of this paper is to establish a basic method for analyzing the energy requirements of water transfer in a given location. Traditionally, energy requirements to transfer water can be estimated in early- stage design of the water supply network. Engineers are capable to size the pipelines, define the capacity and type of pump stations that result in minimum design and operating cost for a given water demand and accordingly estimate operating hours of each pump station and energy consumed. This methodology is kind of standards in each water project on a micro-scale. In order to understand the energy requirements for water transfer on a national level that would require enormous amounts of input data that most often countries lack for.

Additionally, since each country has a unique terrain, and has different hydrological conditions, no two counties or even no two water utilities are identical. Therefore, the energy requirements of water transfer throughout much of its service area are analyzed in this paper, taking into account factors that utilities can control and those it cannot control. This paper uses data that are as detailed as possible to identify the factors affecting energy intensity and to estimate energy requirements. It also incorporated data for water imported from outside the basin and from local water sources. Figure 1 shows a flowchart for the process to estimate energy requirements in water transfer projects. The first step is to define the factors that could affect energy requirements to transfer water. These factors can be divided into two groups based on the capability of the country/water utility to control and have data for those factors. Factors that utilities might not control – such as water source, topography, distance, and total population served – are normalized to better compare cases among different countries. Factors that countries have control over – such as volume of water and operating hours of the pumps – are correlated and integrated in a model to estimate energy intensity.

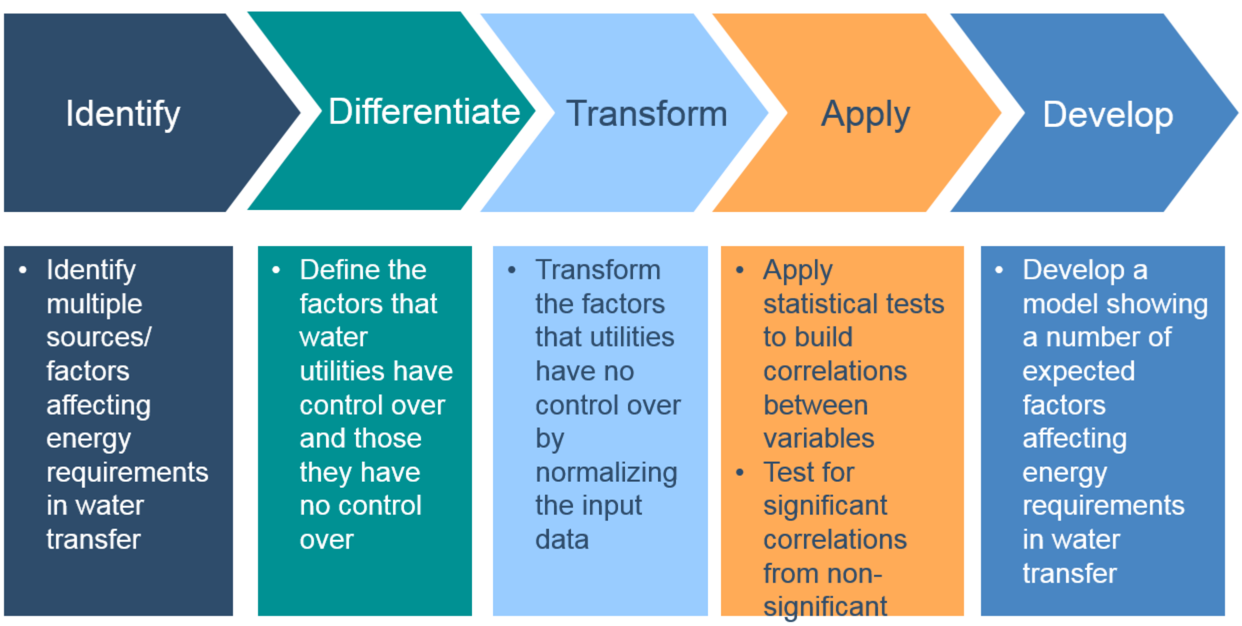

Figure 1. Flowchart of a process to develop a mathematical model to determine the energy requirements in water transfer and the associated factors.

The next step was to transform the input data to meet the assumption of a statistical inference procedure and apply statistical tests to build correlations between input data. Statistical analysis including sensitivity analysis and testing the robustness of the variables were carried out to identify which variables can cause significant uncertainty in estimating energy intensity. Lastly, a mathematical model was developed showing the relationships between input data and energy requirements.

Model Development and Validation

A multiple-regression analysis was developed to estimate energy requirements to transfer water based on volume of water to be transferred, travel distance, total population, and elevation head (lift). Though total water demand should be driven by total population, number of population was added as a variable to investigate amounts of water being supplied in different countries per capita and how it differs.

The next step was to validate the model using observed data for real scenarios. Three water transfer projects were selected to ensure the validity of the developed model. The first project was conducted in California, a water-scarce state in which demand exceeds supply. Most of the water supply is met by groundwater resources that are nonrenewable and have been mostly depleted at unsustainable rates. An interbasin water transfer project was established to alleviate local water supply shortages in the state. The Colorado River Aqueduct was constructed to transfer water to Los Angeles with two reservoirs and five pumping stations. The project provided job opportunities for more than 30,000 people over an eight-year period (Zetland, 2009).

The energy intensity involved in transferring water from Tracy Pump station to Westland Water district was evaluated using the developed model. The input data include: the total length of the project of 206 km, total volumes of water supply coming from this transfer project is 141850.4 cubic meter, total population expected to benefit from the project is 1512, and total elevation head is 110 m (Cohen et al., 2004).

The second project was the Colorado River in Austin, Texas that aims to transfer water from Colorado River in southern Austin to the north through pipeline systems. The route is almost 2 km long with total elevation of 230 m, and volume of water transfers in the whole route is 488318 cubic meter. The expected average population benefiting from this project is 945000 (City of Austin, 2014).

The third water transfer project proposed was a potential water pipeline in Australia, between Kimberley and Perth. The northern part of the country often witnesses flooding and very intense rainfall, while water is very scarce in the south. A direct route from a storage dam near the Willare

Barrage on the Fitzroy River to Westdale, Perth using a 1900km pipeline was proposed to serve 1.696 million people. The water has to be lifted up to 700 m and total volumes to be delivered is 200 million m^3/year.

Water Transfer Cost

The paper evaluated the total cost of potential transporting of desalinated water to 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 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.

QUE$TOR® software developed by IHS which provides concept screening, optimization and detailed oil and gas CAPEX/OPEX cost estimates was utilized to estimate the cost of constructing potential water pipelines. This paper assumed a transport of 100 million m^3/ year using 42 inches pipeline systems based on Hazen & William equation. The elevation and distance were calculated using Google Earth. Projects' supplies of materials were proposed to come from China. A levelized cost at which water must be produced to break even over the anticipated 50-year lifetime of the project was estimated and discounted by 5%.

The Capital and operating costs were estimated and discounted over the anticipated 50-year lifetime of the project. Pipeline material is Carbon Steel with minimum 30 psia outlet pressure, 1520 mm nominal diameter, 9.52 mm wall thickness, 3 mm corrosion allowance, and one booster station. The duration of construction phase for each project was assumed to be 6 days for each Km length. The production was anticipated to start right after the construction phase is done.

Development of Benchmarking Tool

In this section, and after estimating the energy intensity of water transport, we seek to answer the question how does energy use compare against peers? The modeled energy use results were compared to overall energy use mean. A correction factor was introduced to adjust energy use for the different water utilities across 13 countries through dividing the modeled energy use by the mean energy use observed. The next step was to correct the modeled energy use values through dividing it by the correction factor. The corrected energy use values were plotted against a percentile scale which would represent the score of each water utility's energy use.

Results

Energy intensity for water transfer

A total of 79 observations were collected and analyzed to evaluate energy intensity. Figure 2 shows a summary of energy intensity to transfer water per volumes of water supply (kWh/m^3) and over distances (kWh/m^{3}km) across countries. This analysis revealed small variability in the energy requirements for water transfer among 13 countries. India and USA had higher variability in energy intensity over distance than the other countries. This can be explained because India's water pumping system is characterized by low operation efficiency (40-50%), while USA especially the case of California, water is transferred in open channel with high losses rates. The energy intensity had a median of 0.61 kWh/ m^3 and an average value of 0.76 kWh/m^3. The energy intensity over distance had a median of 0.01 kWh/m^{3}km and an average value of 0.03 kWh/m^{3}km.

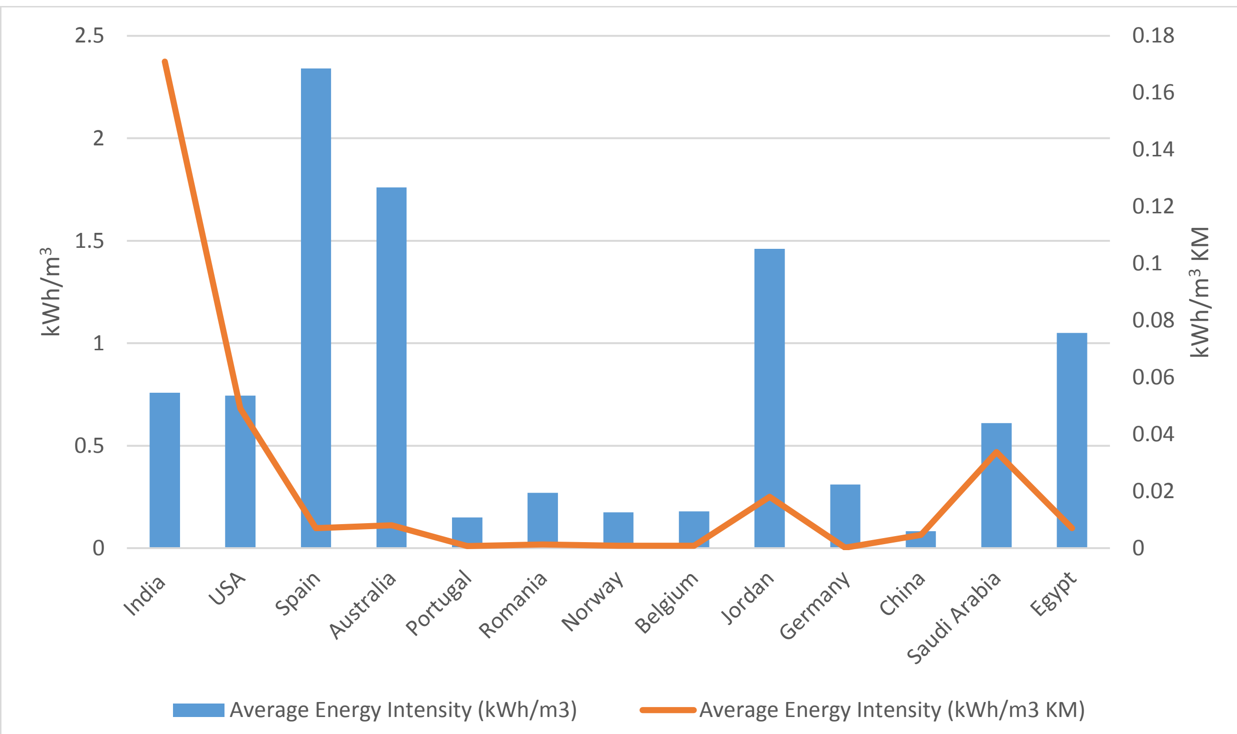

Figure 2. Average energy intensity to transfer water per volumes of water supply and over distances across countries.

The second level of assessment was carried out by evaluating the energy intensity of water transfer per capita. The average energy intensity for the selected countries was 2.28 kWh/capita with a median equal to 0.5 kWh/capita.

Model Development and Validation

The developed model to assess energy requirement for water transfer can be expressed as follows:

$$Y = 0.744\,X1 - 0.0256\,X2 - 0.104\,X3 + 0.853\,X4 - 0.2003 \qquad \text{(Equation 1)}$$

where, Y : LN* (energy requirements- kWh/m^3)

X1: LN (total water supplied- m^3)

X2 : LN (Travel distance-km)

X3: LN (Total population served)

X4: LN (Total elevation head (lift) –m)

* LN : is the natural logarithm

These parameters explained 87% of the energy requirements variability as noted by the R^2 correlation statistics (Table 3) and the model residuals were randomly distributed (Figure 3). All the parameters were tested individually through a t-test and they all showed a significant relationship with energy use.

Table 3. Statistical analysis

Multiple R	0.9300	S.D. dependent var	2.394772
Adjusted R-squared	0.843307	Akaike info criterion	2.786305
S.E. of regression	0.92131	Schwarz criterion	3.015326
Sum squared residu	21.2203	Hannan-Quinn criter.	2.862219
F-statistic	40.018837	Durbin-Watson stat	2.427396
Prob (F-statistic)	1.602E-10		

R Square 0.864919881

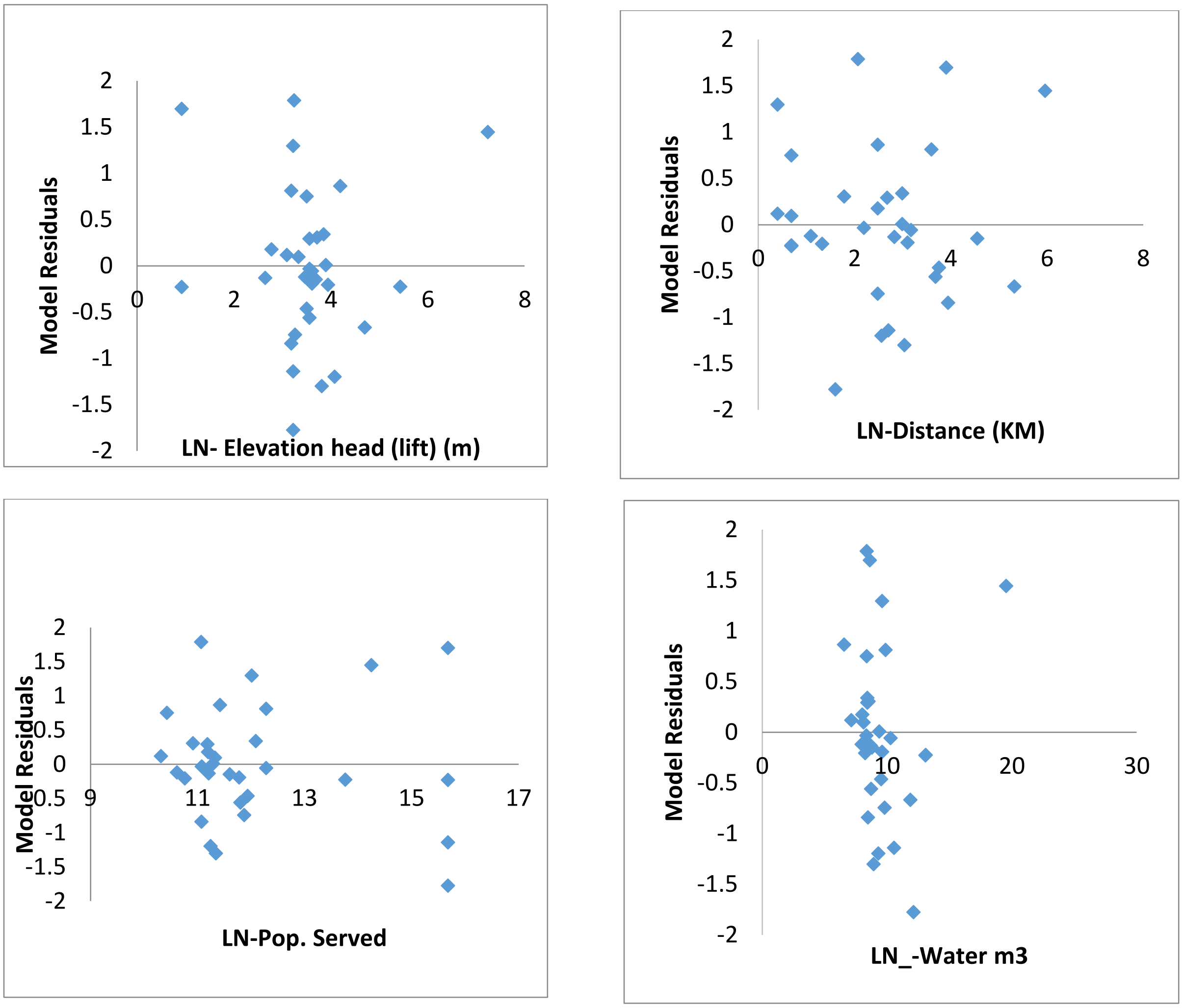

Figure 3. Water transfer energy use model residuals relationship to parameters

Modeled energy use results consistently show a good agreement with observed data (Figure 4). It is worth noting that Australia case study did not have the exact match as the other case studied had and this is because of two things; total number of population benefiting from the project are roughly estimated as a percentage of total population and based on total water supply the project is contributing, and this project was a potential project that never constructed and the reported data for energy and water supply are estimated figures based on design solely.

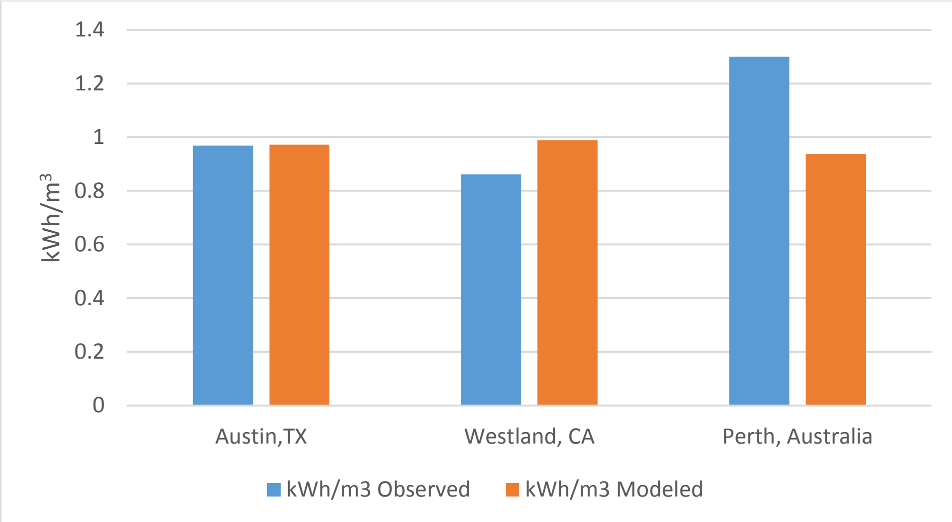

Figure 4. Validating energy use consumption per amount of water supply using Equation 1

Based on both graphical and statistical tests, the developed model was confirmed to be both validated, and provides a sound basis for estimating energy use for water transport.

Transfer Cost

Table 4 contains sample calculations for the input data and costs of delivering desalinated water in selected water stress cities.

Table 4. Input parameters for estimating total costs of water pipeline projects

City	**Country**	**Length, km**	**Elevation, m**	**Levelized Cost ($/m^3)***
Thompson Town	Jamaica	30	85	0.20
Riyadh,	Saudi	350	122	0.66
Esfahan	Iran	445	1459	1.24
Beijing,	China	154	47	0.51
Queensland	Australia	444	198	1.34
Timor-Leste	East Timor	40	1355	0.24
Zaragoza,	Spain	165	457	0.53
Phoenix,	United States	280	783	0.81
Trinidad	Trinidad and Tobago	34	112	0.26

*Levelized cost discounted at 5%

The Capital and operating costs were also estimated and discounted over the lifetime of the project (Figure 5).

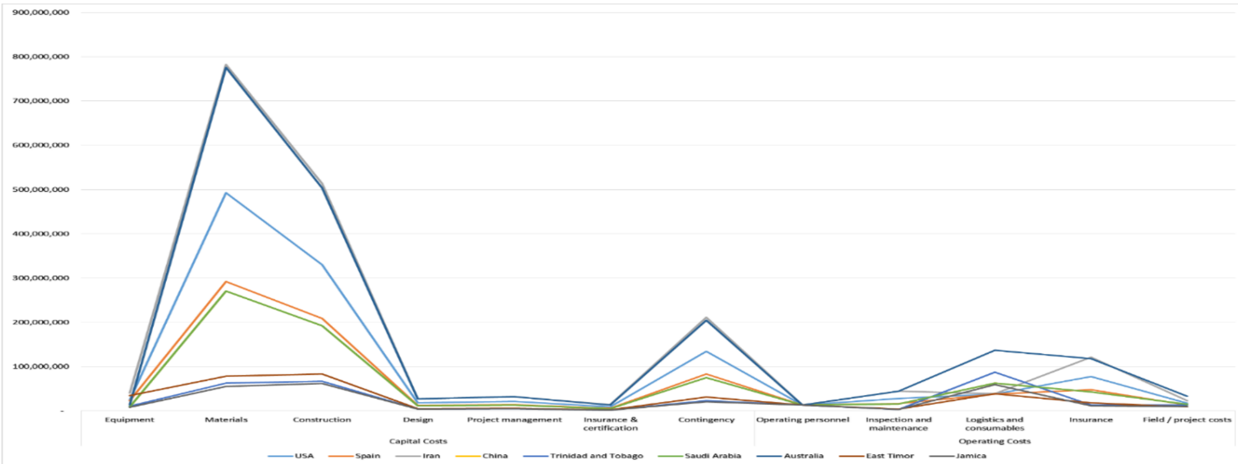

Figure 5. CAPEX and OPEX of water pipeline projects for selected countries

Some of the key factors determining the economic viability of any water project are the discount rate to estimate the present value of net benefits, and the rate of growth in the public's ability and, more importantly, willingness- to- pay for the water. This paper analyzed the total Net Present Value (NPV) for several discount rates as shown in Figure 6. Under the assumptions made to construct this analysis, these results suggest that all the projects would have a net positive public benefit except for Australia at 15% discount rate, Iran at both 15% and 25% discount rates, and USA at 25 % discount rate.

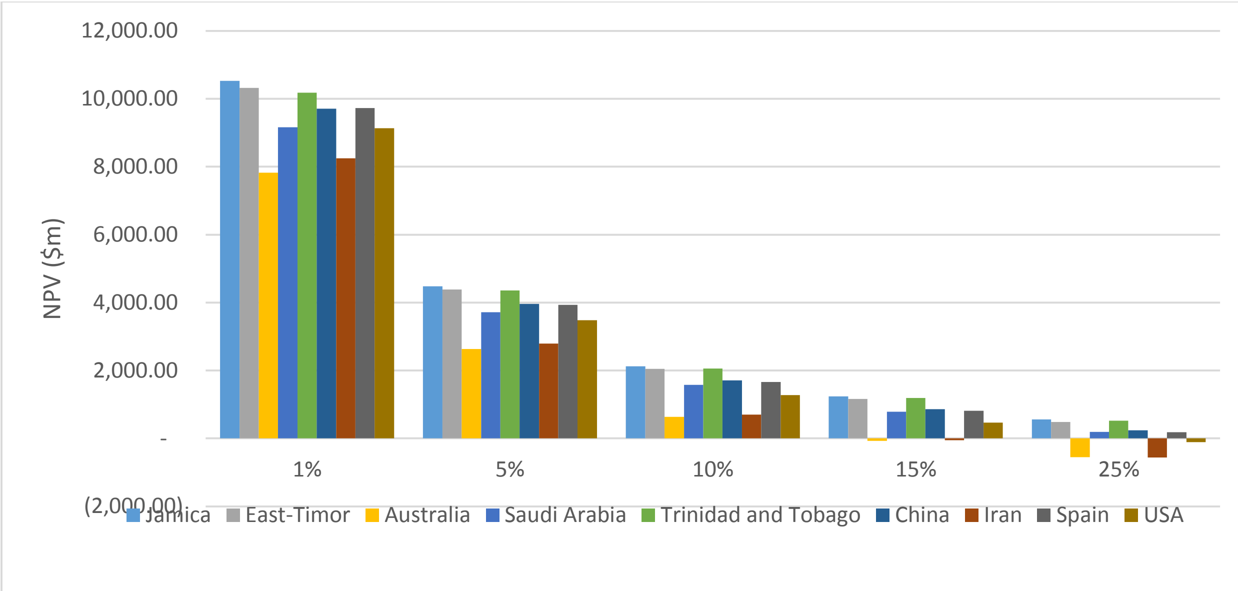

Figure 6. Total NPV values over the project lifetime

The willingness to pay assumed to be constant among the different countries for the sake of comparison as 3$/m^3 to cover at least the transportation fees. Cumulative cash surplus remaining over the lifetime of the project was estimated to provide policymakers with some insights when water transfer projects start to have positive surplus and what is a potential cash surplus (Figure 7).

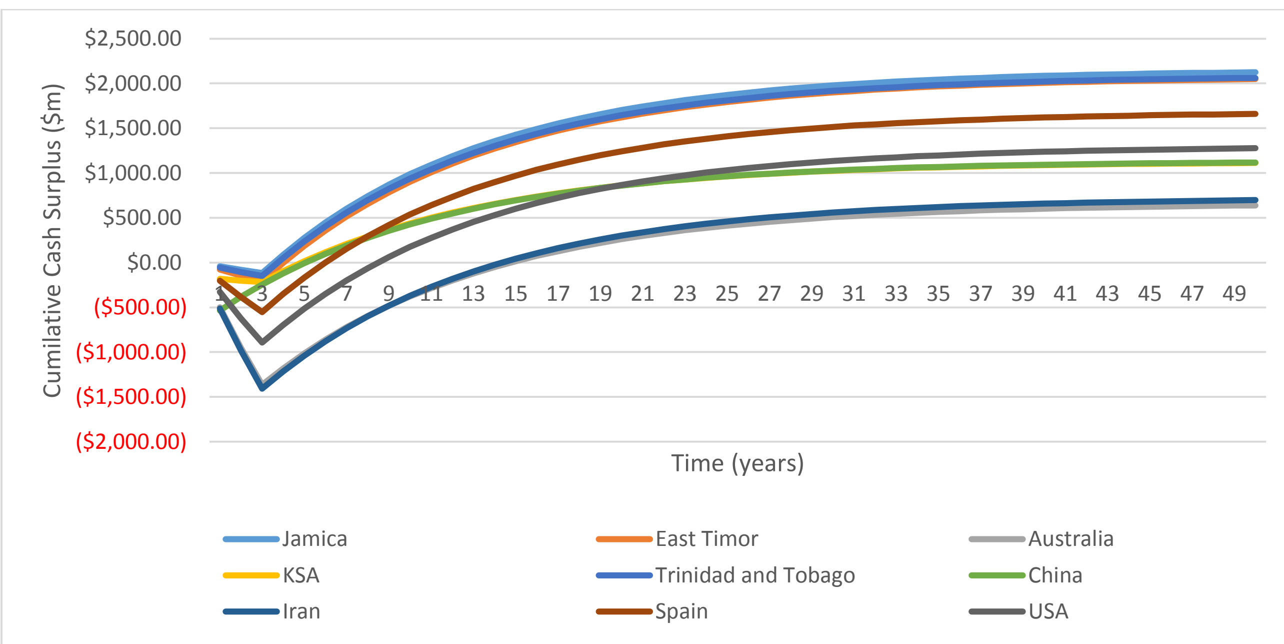

Figure 7. Cumulative cash surplus for water transfer project across countries

Development of benchmarking tool

Figure 8 provides a tool to assess energy use performance in water transport. Figure 8 also identifies where the water utility/operator stands against other peers. Clearly, the 100 percentile reflects the least use of energy and no action needs to be taken at this point. But 0 to 10 percentile represents the greatest consumption of energy use and energy efficiency procedures therefore have to be considered at this level.

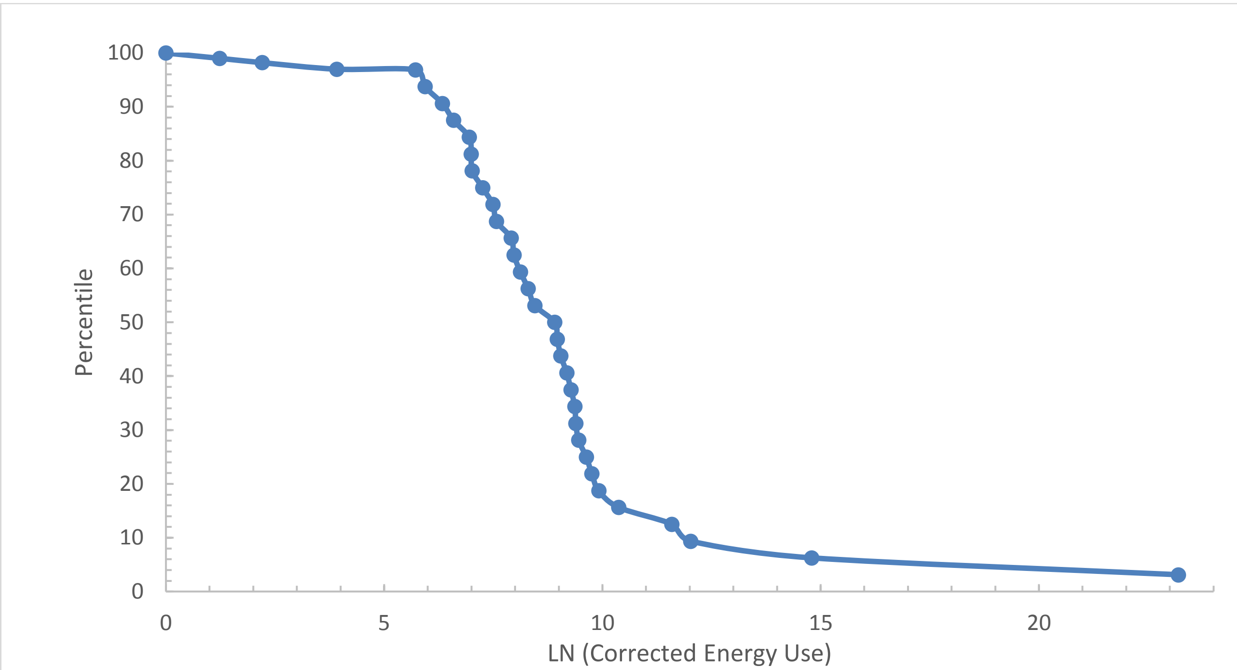

Figure 8. Benchmarking of energy use in water transport

In addition, Figure 8 can be used as a judgment tool in evaluating different energy efficiency plans in order to improve current practice and move towards the use of best practices. This benchmarking tool also lays the groundwork for a more detailed and sophisticated understanding of energy use in water transfer, and it also can be applied to the whole water supply chain, starting from extraction and ending in reuse.

Conclusions

This paper evaluated the energy intensity in water transfer and distribution. This paper offered a new opportunity to select the most appropriate water supply option based on a strong sustainability approach that uses the environment and the economy as the most significant dimension of sustainability. A benchmarking framework was developed to help decision makers compare water supply options by integrating the energy component with a goal of improving sustainability in water scarce areas.

This work helped to bridge the gap in the literature by creating a basic methodology to evaluate 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 effectively applied to new and existing water projects in order to quickly assess and eliminate high energy intensive options.

Transferring water may cause a variety of negative social, economic, and environmental impacts depending on a number of factors such as the total volume of water to be moved, the pipeline path, topography, and the conveyance system. Economic consideration includes the upgrade and new construction costs of required infrastructure, the energy costs to transport water, and the comparison between water transfer and other water supply alternatives.

Social consideration includes the cost of releasing huge amounts of greenhouse gas emissions due to pumping the water and the negative impacts associated with communities' health and environment in general. It also includes the current value of water for local communities and the value of employment opportunities that such schemes may create.

Environmental consideration may vary based on the location of water sources and delivery location. Water transfer over long distances includes changes in river flows, alteration of the composition and population of the ecosystem and aquatic life, implications on sediments movements, channel stability, and alterations of water quality.

Though water trade and export between countries contributes to improve relationships, as well as build networks and alliances, there are no international regulations that manage water pipelines crossing international borders. Water pipelines in the international trade system do not enjoy a specific status such as that of oil and gas pipelines. While there are sets of norms and regulations that manage the oil and gas pipelines – such as the 1994 Energy Charter Treaty – there is no such status for water pipelines. Therefore, policymakers have to create a legal framework specifically for the transport of water in the international system.

Desalination may be a solution for some water-scarce regions, but not for areas far from the coast, deep in the interior of a continent, or at high elevation. The total cost of desalination remains higher than other alternatives for most regions of the world. It also has some negative impacts on the environment such as production of concentrated brine and carbon dioxide emissions. It might become competitive to water transfer upon the water transport method, energy prices, travel distance to transport the water, 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 to deliver water and their potential contribution to save water and energy. Both water and energy policymakers have to give higher priority to water conservation practices. Policies targeting the end uses of water would have much larger energy implications than policies targeting water supply chain. The implications of water conservation practices goes beyond the water and energy savings to environmental benefits and increases the resilience to uncertainty over climate change.
Another example, 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 opportunities for synergies between water-energy and other goals. 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 to supply potable water to Jordan, Palestine, and Israel, stabilize the Dead Sea water level, and generate electricity needed to support the project (World Bank, 2011).

Introducing the social cost in water transfer projects and reduction in emission is a vital aspect and needs to be considered by policymakers before they take decisions to invest in such projects. Water utilities rarely track the greenhouse gas emissions that occur within their direct scope of operations through the consumption of electricity and natural gas to extract, purify, and deliver the water. Greenhouse gas emission tracking and control should become a common practice. Financial incentives to implement energy saving and emission reductions programs are highly required. And other programs – such as national and regional programs to audit and monitor energy consumption in the water sector into finer levels of detail – may combine the data needed to enable better understanding of energy consumption in the water sector.

Acknowledgements

I would like to thank Akil Zaimi, Shahid Hasan, Chris Napoli, and Berenice Garcia-Tellez for their helpful comments.

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