Joint Measurement of Economic and Environmental Performance of Water Industries

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Abstract

Water industries are currently facing the challenge of simultaneously improving economic and environmental performance while continuing to provide high quality services at low cost. The study provides an overview of the conceptual frameworks that underpin the approaches towards this seemingly irreconcilable challenge. A brief literature review on efficiency measurement in the water industry is provided. The study illustrates the theoretical framework of tradeoffs between economic and environmental outcomes particularly for water industries. Recently developed methods for environmentally adjusted productivity measurement that are able to jointly measure economic and environmental efficiency of water industries are briefly discussed and critically analysed. Models suited for this environmentally adjusted productivity measurement are discussed and implications of these new analytical developments for water policy are identified.

Key words: Water Industries, Performance Measurement, Environmentally Adjusted Efficiency

JEL codes: D24, Q25, Q28, Q50

1. Introduction

There is a growing demand for services that are provided by water industries. Increased demand for food due to increasing population and standards of living requires increased food production, which in turn implies increased water use in irrigated agriculture. Growing population and its urbanisation also lead to growing need for municipal water supply and wastewater treatment (Figure 1). Consequently, there is a growing trend in total water withdrawal across the globe (Figure 2). The annual water use across sectors varies among individual countries (Figure 3). Whereas water industries need to grow and provide services to an ever growing number of users, the current economic environment does not offer favourable conditions for such growth. In the post GFC (Global Financial Crisis) world, there are tight budgetary conditions for all key economic players: governments, businesses, and individual consumers. Economic agents at all levels are becoming very conscious about spending. The situation is also very difficult on the investment front: water industries are forced to compete for investment funds on the open capital markets, in contrast to a time gone-by when governments – whether local, regional or national – where willing and able to fund water infrastructure project. Given the fiscal position of many governments around the world, this source of investment funding is not going to be very generous in foreseeable future. As a result, the overall subdued status of the economies in the developed world, characterised with high unemployment, government austerity measures, and low returns on capital, makes users very sensitive to pricing of all utility services, including water. The water industry is going to find it increasingly harder to ask, and to receive, higher prices for the services it provides. The economic situation in the developing world is relatively better, but their consumers are climbing the social-economic scales from a very low base, and are therefore still very sensitive to prices of key utilities. Overall, the water industries are in a situation where they will have to do 'more with less', implying that they will be required to continuously improve their economic efficiency, and to deliver high quality services at affordable prices.

In parallel to the demands for improved economic efficiency, the concerns about the state of water resources and environmental health in general are mounting. In many parts of the world water resources are extracted close to the brink of the physical limits, and many more are nearing such physical resource scarcity (CAWMA, 2007). There are increasing calls for the irrigation sector to minimise the damage it is causing to water dependent ecosystems by excessive extraction of irrigation water (McCartney et al., 2007). Perhaps a best example of this can be found in Australia, where water resources have been substantially overallocated, leaving almost nothing for the rivers, lakes and ecosystems that they support (Quiggin, 2001; Randall, 1981; Lee and Ancev, 2009). As a result, Australian government has initiated buying back of water entitlements from irrigators, and is now holding significant quantity of entitlements for environmental purposes (Ancev, 2014).

Municipal and wastewater industries are also subject to significant environmental concerns. Building new dams and reservoirs for drinking water is almost out of question in many countries due to environmental concerns (MEA, 2005). Quality requirements for bulk water supplied to drinking water treatment plants is ever increasing, implying that superior environmental management of catchment areas is required. Wastewater treatment plants are also facing increasingly stringent standards on effluent quality, mostly on environmental grounds (Rodriguez-Garcia et al., 2011).

In the era of carbon pricing, the requirements for improved energy efficiency and reduction of Green House Gas (GHG) emissions are very relevant for the water industries. They are expected to deliver the services that they provide and at the same time to use energy efficiently and to reduce their emissions of GHGs (Rothausen and Conway, 2011). All this imposes requirements on water industries to improve environmental performance, and to reduce their environmental 'footprint', and at the same time to improve its economic performance in a challenging economic environment. These seem to be two almost irreconcilable demands. A key question that this paper addresses is whether economic and environmental performance of water industries can be jointly improved. This question will be pursued by proposing the use of methods for environmentally adjusted productivity measurement to jointly measure environmental and economic efficiency in water industries. Measuring efficiency allows identifying practices, technologies, and locations where we observe the highest economic and environmental efficiency. This can then serve for benchmarking purposes within the water industries, and for formulating policies to promote superior economic and environmental performance.

The literature on productivity and efficiency measurement provides us with key theoretical and methodological approaches for jointly measuring environmental and economic efficiency. The main concepts of incorporating environmental performance measurements in standard productivity analysis were postulated by Pitman (1983), Fare et al. (1989), and Chung et al. (1997). Fare and Grosskopf (2004) firmly put environmental effects in the theory and practice of productivity and efficiency analysis. More recent studies have utilized these methods in applications to variety of industries (e.g. Zaim, 2004; Kuosmanen and Kortelainen, 2005) including irrigation (Azad and Ancev, 2010; Azad and Ancev 2013). The present paper adds to the existing literature by synthesizing the existing knowledge in this research area, and by proposing how to use this knowledge to jointly evaluate economic and environmental performance of a broad range of production activities undertaken by the water industries. This has important implications for designing contemporary water policy that encompasses social concerns about environment, resource use, accessibility to water and its affordability.

2. Tradeoffs between the Economic and Environmental Performance

The use of methods for environmentally adjusted productivity and efficiency analysis allow researchers to jointly investigate the economic and environmental performance of individual production units, and to evaluate the tradeoffs between them. In the context of water industries, those tradeoffs can be represented by Figure 4. The figure conveys that water resources can be either withdrawn from the environment for some type of economic use (i.e. irrigation or municipal water uses) or left to serve the purpose of supporting the ecological and environmental needs of water-dependent systems. Both economic and environmental uses are beneficial to society through the production of man-made goods and services (desirable outputs) and the provision of ecosystem services. However, the production of man-made goods and services often creates negative effects on the environment and natural resources. This is exemplified by the 'undesirable outputs' in Figure 4. These apparent tradeoffs between withdrawing water or leaving it for the environment suggest that a rational approach to allocating water is to compare the values created in economic and environmental uses, but also to account for the 'undesirable outputs' generated from economic use. Withdrawing water will be justified as long as the value of that water to society, net of the negative environmental effects associated with the production process to which water is an input, is greater than the value of that water in environmental use. Environmentally adjusted efficiency measurements allow us to evaluate these trade-offs, and identify productive activities that create high economic value and have relatively small environmental impacts, as well as productive activities that create large environmental impact, but only create modest economic value.

Being able to identify individual enterprises of the latter type within the water industries, whether municipal water treatment plants, wastewater treatment plants, or irrigation operations, will allow regulators and policy makers to better target policies towards them. In particular, the key characteristics (size, location, technology) of enterprises that create relatively large environmental impact per unit of economic benefit they are providing to society will be identified and will be used to inform decision making. Likewise, the characteristics of enterprises that have relatively small environmental impact per unit of economic benefit they create can be used to create benchmarks to which the industry can aspire. Ultimately we would like to see a decreasing number of enterprises that have large environmental effects but relatively modest economic value added, and commensurate increase in enterprises that are able to deliver significant economic benefits at minimal environmental costs.

3. Conceptual Framework

The following section first describes the fundamental notions of measuring productivity and efficiency in any industry including water industry, and then it describes the main ideas behind environmentally adjusted productivity and efficiency measurement. In-depth expositions on productivity and efficiency measurement and their environmental adjustment are described in Fare and Grosskopf (2004). Efficiency of individual enterprises within an industry, such as the water industry, can be conceptualised in a fairly straightforward way. This involves collecting data on key inputs and outputs from a number of individual enterprises that constitute the industry. Further, consider plotting these data on a scatter plot, as presented in Figure 5a.

The next step is to fit an outer envelope through these data. The fitting of such an envelope (a curve, or a frontier) can be done using two main groups of methods: 1) parametric methods, where the envelope is estimated using statistical/econometric methods, with the most widely used approach being the stochastic production frontier estimation (Aigner et al., 1977; Green,1980; Battese and Coelli, 1995); and 2) non-parametric methods, where the envelope is estimated using methods of mathematical optimisation (maximise output for a given quantity of input, or minimise input for a given output), with the most widely used approach being the data envelopment analysis (DEA) (Färe et al., 1985; Charnes et al.,1995; Lovell, 1994; Thanassoulis, 2001). Whichever method of estimation is used, those observations that are on the frontier are deemed to be efficient: they produce the maximum output, given the level of input they are using, or vice versa they use minimum input for the level of output that they are producing (Figure 6).

For example, the observation on production unit B in Figure 6 indicates that this unit is efficient, whereas the observation on unit A is considered as inefficient, since it uses the same amount of input as unit B, but produces substantially less output. The inefficiency of unit A can be measured by calculating the Euclidean distance between the observation for it and the frontier. This distance can be measured by a distance function, as introduced by Farrell (1957). The distance can also be measured in any direction towards the frontier (to be discussed in detail below). Efficiency is then expressed as a proportion of the measured distance. It is a score between zero and unity, with a score of unity indicating that the production unit operates on the frontier.

The general approach described above has been extensively used in many studies and under many methodological variations (Emrouznejad et al., 2008). However, this approach focuses exclusively on the economic efficiency (i.e. transformation of production inputs into outputs). It does not take into account, in its canonical form, any environmental and natural resource use implications from a productive activity.

As environmental concerns have grown throughout the world, the need for measuring environmental performance led to adjustments of the methods for efficiency analysis described above so to take into account the environmental performance of individual production units. This is approached by noting that many production processes use environmentally sensitive inputs (e.g. water, energy) and produce ‘undesirable’ or ‘bad’ outputs, e.g. emission of pollutants, together with the typical ‘good’ or ‘desirable’ output (Färe et al., 1989; Chung et. al.,1997). If these ‘environmental’ inputs and outputs and their effects can be quantified, the standard efficiency measurements can be adjusted to reflect not only economic, but also environmental efficiency (Färe et al., 1989). This is presented in Figure 7. It is assumed in the figure that the levels of inputs are unchanged from those presented in Figures 5 and 6. In addition, rather than representing inputs on the horizontal axis, the quantity of undesirable output is presented. In this case, production unit A is inefficient because it creates the same amount of environmental effects (undesirable output) as the unit B, but produces considerably less of the usual, ‘desirable’ output. This means that unit A damages the environment without providing a commensurate economic benefit. From society’s point of view, it will is beneficial for unit A to improve its performance, and either increase its desirable output to the level of unit B, or indeed and perhaps more preferable, increase its desirable output, and simultaneously decrease its undesirable output by moving to the point C on the frontier. In this way, the economic performance will be improved (even though not to the maximum possible extent), and at the same time, environmental performance will be considerably improved by reducing environmental effects. The move is in a specific direction, and in this case efficiency can be measured using slightly different type of function, called directional distance function (Chambers et al, 1996). This function allows the investigator to choose a direction in which to evaluate the efficiency of a production unit: it can be in a straight vertical direction (towards point B in Figure 7), which will be a measure of pure economic inefficiency; in a radial direction (towards point C in Figure 7), measuring both economic and environmental inefficiency; and in straight horizontal direction (unmarked in Figure 7), measuring only environmental inefficiency.

A key requirement for this environmentally adjusted efficiency measurement is to have data on the quantity of environmental effects caused by individual production units. This can sometime be obtained in a fairly direct way. For instance, data are often available for such environmental effects as GHG emissions, or energy use in municipal and wastewater treatment plants, use of water in irrigation, or the quantity of remaining pollutants in the treated wastewater. Other times gathering data can be very difficult, especially when the aim is to quantify the effects of environmental impacts from productive activities on ecological assets. For instance, withdrawing water from rivers and streams can have very different environmental impacts dependent on the location and the associated climate, as well as the type of ecosystem that is affected.

4. Methods for Environmentally Adjusted Efficiency Measurement

Based on the principles outlined above, there are several specific methods that can be used for environmentally adjusted measurement of efficiency in water industries. Perhaps the simplest one is the environmental performance index (*EPI*), which is based on estimating distance functions for the desirable and undesirable outputs and then forming indexes based on the estimated functions, and taking ratios of those indexes. An *EPI* (denoted by *E*) can be represented by:

$$E^{k,l}(x^o, d^o, u^o, d^k, d^l, u^k, u^l) = \frac{Q_d(x^o, u^o, d^k, d^l)}{Q_u(x^o, d^o, u^k, u^l)} \qquad (1)$$

where Q_d and Q_u are quantity indexes of desirable and undesirable outputs, respectively, given by:

$$Q_d(x^o, u^o, d^k, d^l) = \frac{D_d(x^o, d^k, u^o)}{D_d(x^o, d^l, u^o)} \quad (2)$$

$$Q_u(x^o, d^o, u^k, u^l) = \frac{D_u(x^o, d^o, u^k)}{D_u(x^o, d^o, u^l)} \quad (3)$$

Where the distance functions D_u and D_d are defined as follows:

$$D_d(x, d, u) = \inf\{\theta : (x, \frac{d}{\theta}, u) \in T\} \quad (4)$$

$$D_u(x, d, u) = \sup\{\gamma : (x, d, \frac{u}{\gamma}) \in T\} \quad (5)$$

Symbol x stands for input, d for desirable output and u for undesirable output. Superscript o stands for fixed quantities (i.e. indicates that those quantities are not varied within the evaluation), superscript k stands for the quantity that is being observed and evaluated, and superscript l stands for the quantity observed for a designated reference unit.[1] The operator 'inf' in Eq. (4) denotes an *infimum*, and the operator 'sup' in Eq. (5) denotes a *supremum*. γ and θ are scaling parameters.

The *EPI* index effectively measures how much undesirable output is produced per unit of desirable output produced and ranks productive units according to this measure. Units with high *EPI* score have good environmentally adjusted performance, whereas those with low scores have poor environmentally adjusted performance. A recent example of using the *EPI* in the water sector is provided by Azad and Ancev (2010).

Another way to measure efficiency is by using the method of non-radial DEA. This method allows for differential scaling of multiple inputs used in a production process, and consequently makes them particularly suitable for conducting efficiency analyses of production activities where environmentally sensitive inputs (e.g. water, energy) are

[1] The reference unit can be designated in variety of ways. One popular way is to construct a hypothetical reference unit from that data, based on the minimum-maximum criterion, which effectively creates a worst possible performing unit (lowest desirable output, highest undesirable output, highest input), and compares the performance of all the other units to it.

prominent. Using non-radial DEA, the researcher is able to measure the relative efficiency with which the environmentally sensitive input is used. The objective function of the optimisation problem that leads to the computation of efficiency scores is given by the following equation:

$$NRD(y,x) = \min\left\{\sum_{n=1}^{N}\lambda_n / N : (\lambda_1 x_1, \lambda_2 x_2, ..., \lambda_N x_N) \in L(y), 0 \leq \lambda_n \leq 1\right\} \quad (6)$$

where λ stands for the weight given to an input *x*, *L(y)* is the production possibility set, *y* denotes output, and *NRD* stands for non-radial DEA. A recent example of using a non-radial DEA to measure efficiency is provided by Hernandez-Sancho et al. (2011) and Azad et al. (2013).

While the previous two measures of efficiency are based on distance functions, there are other approaches that make use of directional distance functions. One such approach is the environmentally adjusted Luenberger productivity index, which is suitable to measure efficiency, as well as changes in environmentally adjusted productivity over time. The index can be written as:

$$L_t^{t+1} = \frac{1}{2}[(\vec{D}^{t+1}(x^t, y^t, u^t; g_y, g_u) - (\vec{D}^{t+1}(x^{t+1}, y^{t+1}, u^{t+1}; g_y, g_u) + (\vec{D}^t(x^t, y^t, u^t; g_y, g_u) - (\vec{D}^t(x^{t+1}, y^{t+1}, u^{t+1}; g_y, g_u)] \quad (7)$$

Where the directional distance function for period *t*, $\vec{D}^t$ represents the reference technology constructed from data for period *t*, to which the performance for period *t+1*, as measured by the directional distance function $\vec{D}^{t+1}$, is compared. The indicator can be used to measure efficiencies in periods *t* and *t+1*, as well as environmentally adjusted productivity and efficiency change between *t* and *t+1*.

5. Current State of Environmentally Adjusted Efficiency Measurements in Water Industries

The importance of jointly measuring economic and environmental performance of water industries has been evident in the literature in recent years. While environmentally adjusted productivity and efficiency measurements have been applied to many production sectors over the last 10-15 years, their application to the water industries has been very recent. Applications of standard economic efficiency measurements to water industries have been widespread, with dominance of studies focusing on municipal water supply and wastewater treatment, and comparably smaller number of studies on efficiency in irrigated agricultural sector. While these studies are important in their own right, they do not address the environmental performance of studied production units, and can therefore not be used to characterise environmental-economic trade-offs in considered water industries. Several studies that appeared recently have started applying environmentally adjusted efficiency measurements to production units in water industries, and there is significant amount of current research work that is likely to be published in near future.

In an empirical application to the irrigation industry, Azad and Ancev (2010) proposed joint evaluation of economic and environmental efficiency by constructing indexes that capture the effects of water withdrawal for irrigation on environmental conditions of the affected rivers and streams. When it comes to wastewater treatment plants, Sala-Garrido et al. (2012) recently estimated economic efficiency of plants in the Valencia region, Spain. One of the key inputs considered was energy use, which was implicitly identified as an environmentally sensitive input.

Other, unrelated techniques that have recently been widely used produce results that can be used as valuable inputs into environmentally adjusted productivity measurement. An example is the large body of research on Life-Cycle Analysis (LCA), including studies on wastewater treatment plants (Rodriguez-Garcia et al., 2011; Larsen et al., 2010; Fagan et al., 2010; Lin, 2009; Munoz et al., 2008; Gallego et al., 2008; Nogueira et al., 2007; Gallego et al., 2008). The findings from LCA studies are a source of particularly useful inputs that could be used in environmentally adjusted efficiency analyses. In a recent study Rodriguez-Garcia et al. (2011) evaluated the performance of wastewater treatment plants by identifying environmental indicators (eutrophication and global warming potential) and economic indicators (operation costs). While this study falls short of performing a fully-fledged environmentally adjusted efficiency analysis, it really opens up opportunities to think about integrating LCA into the frameworks for environmentally adjusted efficiency and productivity analysis described above.

A summary of previously published work by water sector and by type of efficiency analysis is provided in Table 1. The table does not provide exhaustive list of the literature that reports research on economic efficiency. The study by Abbott and Cohen (2009) provides such exhaustive list of studies reporting on economic efficiency for both municipal water supply and wastewater treatment sectors.

6. Implications for policy

Water policy in the 21st century is faced with serious challenges and needs to be able to strike a balance between unprecedented varieties of social demands. A key aim for water policy is to ensure sustainable and safe access to municipal water and to wastewater treatment services by an ever growing human population that is increasingly urbanised. This involves carefully utilising existing water resources to ensure viability of their use for a long time into the future. As mobilising new water resources is increasingly difficult and expensive, given that most easily accessible resources have already been tapped into, managing existing resources in a sustainable way is a policy priority. The competing demands for these existing resources are coming from three main sources: irrigation, the environment, and municipal and industrial water, and are creating a very complex policy landscape that needs to be navigated. Understanding and being able to measure the relationships between some of these competing demands, in particular between extractive water uses and the associated environmental and natural resource effects brings a distinct advantage to modern water policy.

The methods described above are well suited to inform policy about tradeoffs that stem from these relationships. In particular, the use of environmentally adjusted productivity and efficiency measurement can help identifying those activities within the water industries that create relatively modest benefits to society, but generate significant environmental and natural resource pressure. These activities should consequently be targeted by policies that will discourage wasteful and environmentally damaging use of water resources. Examples of such policies are instituting adequate water pricing mechanisms in areas where prices have been distorted by government involvement, or have been influenced by political pressures; removing direct or indirect subsidies that allow inefficient operators to be viable; promotion of technologies that have low environmental impact; and granting rights to water on behalf of the environment.

In addition, the methods described above also allow policymakers to identify best-practice activities within the water industries: irrigation enterprises that deliver greatest benefit per unit of environmental / natural resource damage caused; wastewater treatment plants that use less energy and emit less GHGs per unit of contaminant removed; and municipal drinking water suppliers that serve most customers per unit of water resource impounded from its natural state. These best-practice activities can serve as goals towards which water policy should aim, and the water industries can aspire.

7. Conclusion

Water industries – irrigation, municipal water supply, and wastewater treatment – will have to find ways to improve both their economic and environmental performance. This is dictated by the mounting pressures to deliver better and more reliable services to users without increasing the cost of provision, and to do so in an environmentally prudent way. Managing this required improvement in economic and environmental efficiency of water industry operations relies on the ability to quantify and measure efficiency, and to elucidate and evaluate the trade-offs between economic and environmental performance. In recent years there have been significant developments in the methods of productivity and efficiency analysis, which are now at a level of sophistication that allows joint evaluation of economic and environmental efficiency. Several very recent studies have applied these methods to cases of irrigation and wastewater treatment. Several others have come very close to jointly evaluating economic and environmental performance. The amount of research work that is currently in progress is very significant, pointing to an impending widespread application of these methods to the water industry.

The use of methods for economic and environmental efficiency measurement is going to enable identification of technologies, practices and temporal and spatial attributes that can deliver superior economic outcomes at least cost to the environment. This will result in more economically and environmentally efficient water industry for the future. From a standpoint of current economic and environmental climate, this seems to be the only way forward for the industry.

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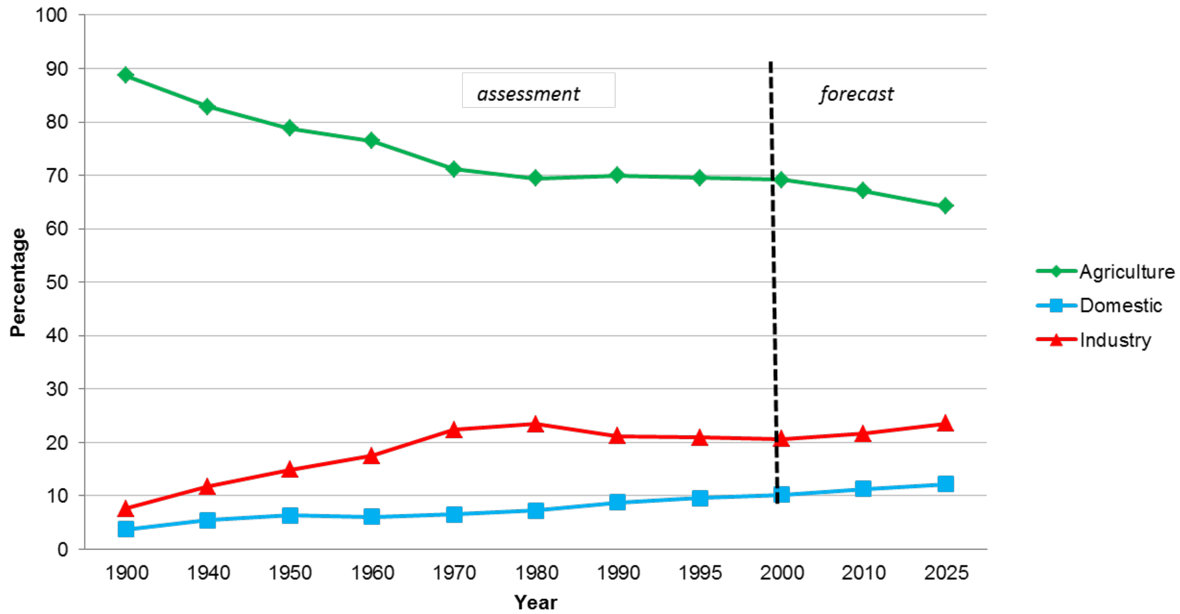
Table 1. Previously published work on efficiency measurement in the water industry.

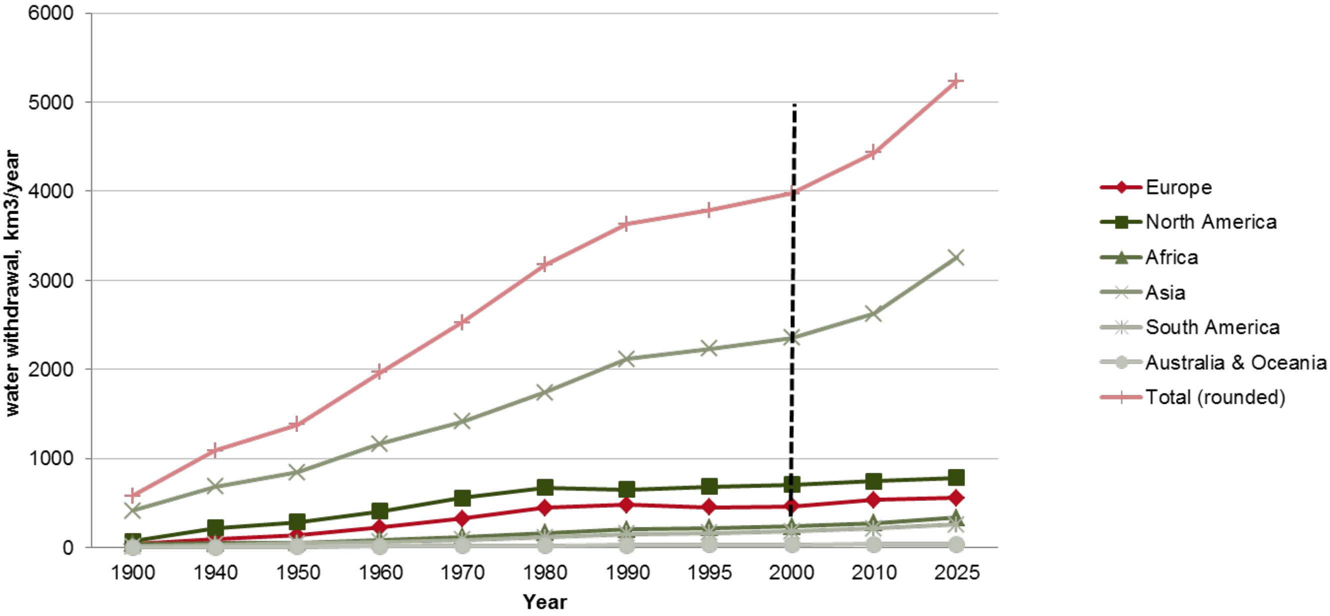
Water sector	Economic efficiency only	Combined Economic and Environmental Efficiency	Life cycle analysis as input in Economic and Environmental Efficiency analysis
Irrigation	Speelman et al., 2008; Lilienfeld and Asmild, 2007; Karagiannis et al., 2003 Fraser and Cordina, 1999.	Azad and Ancev, 2013. Azad and Ancev, 2010; Azad et al., 2013	
Municipal water supply	Byrnes et al., 2010; Fagan et al., 2010; Abbott and Cohen, 2009; Munisamy, 2009; Garcia-Sanchez, 2006.	Picazo-Tadeo et al.2009 Renzetti and Dupont, 2009;	Bauman and Tillman, 2004; Finnveden et al., 2009.
Wastewater treatment	Hernández-Sancho et al., 2011; Rodriguez-Garcia et al., 2011; Hernández-Sancho and Sala-Garrido, 2009; Gallego et al., 2008; Molinos-Senante et al., 2010; Molinos-Senante et al., 2003;	Sala-Garrido et al.(2012)	Rodriguez-Garcia et al., 2011

Figure 1. Water withdrawal trend by sector (in percentage)



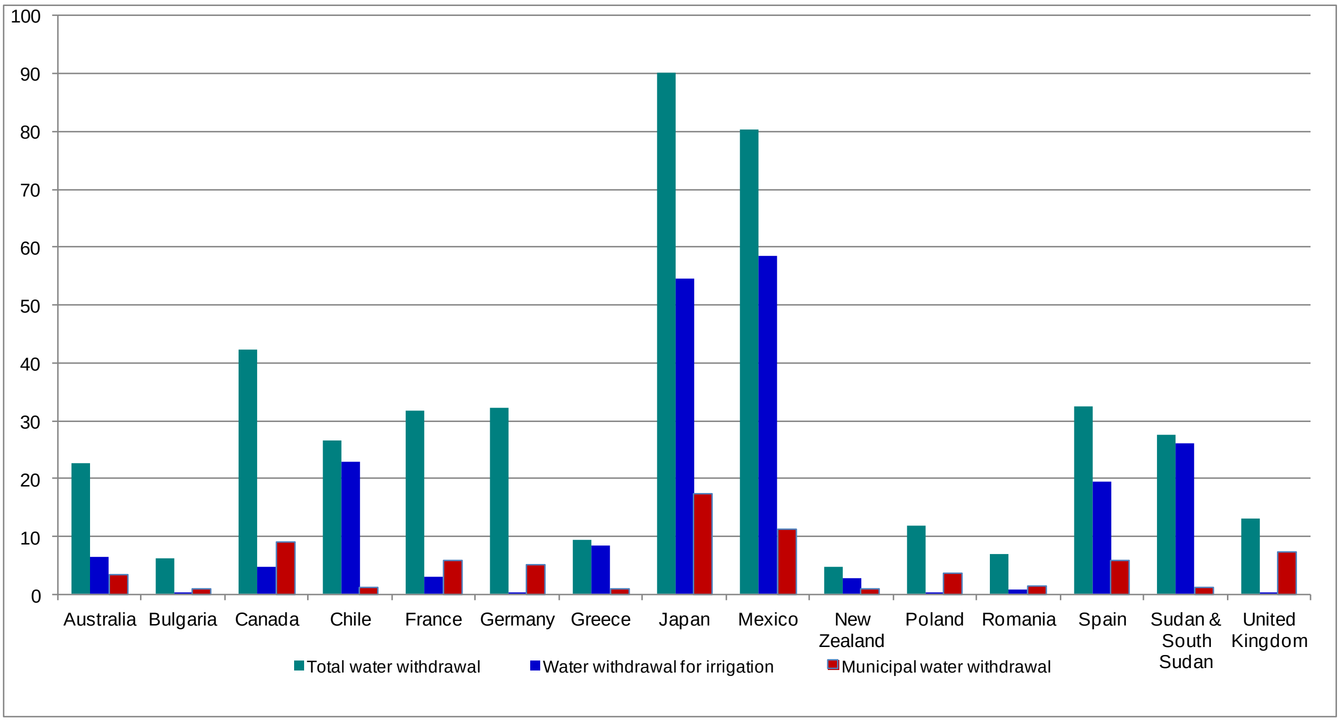
Source: UNESCO, 2013

Figure 2. Total water withdrawal trend (km3/year) by region.



Source: UNESCO, 2013

Figure 3. Annual Water withdrawal (10^9m3) by industry for some selected countries



Note: Graph based on latest available 4 years average data.

Source: FAO (Aquastat) database.

Figure 4. Tradeoffs between economic and environmental water use.

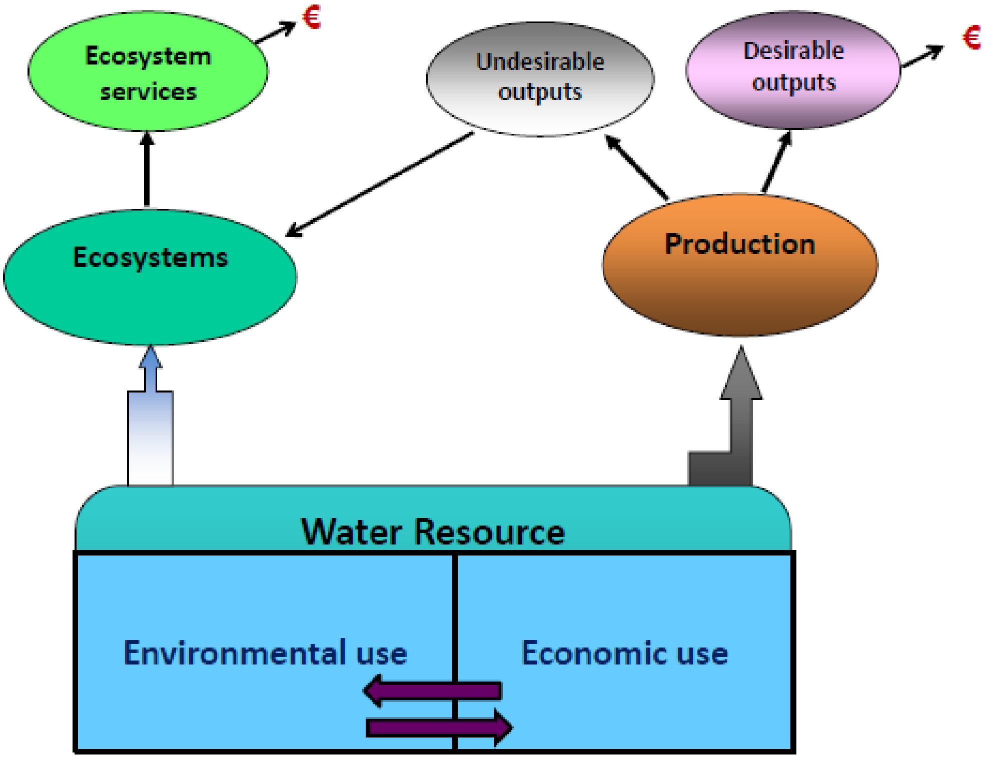
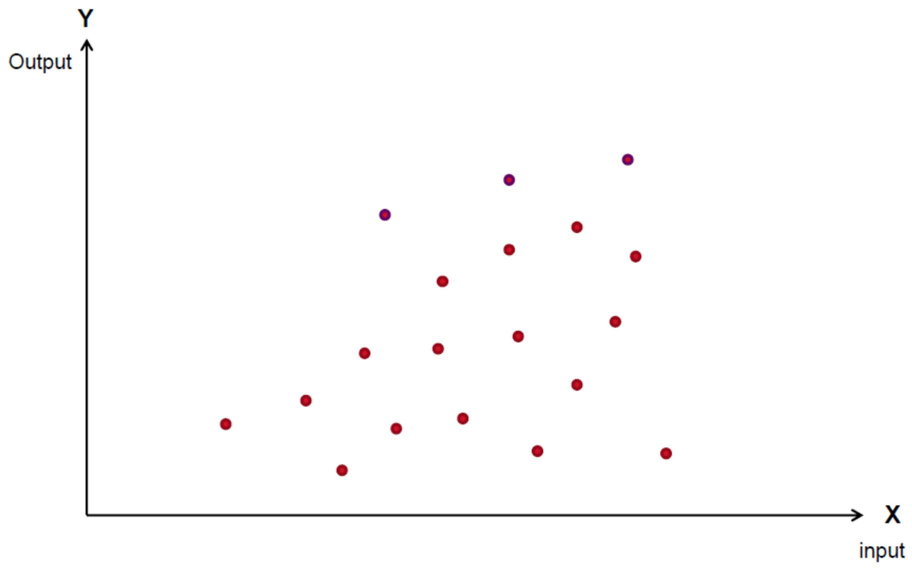


Figure 5a. Scatter plot of observations on inputs and outputs;



5b. A fitted outer envelope

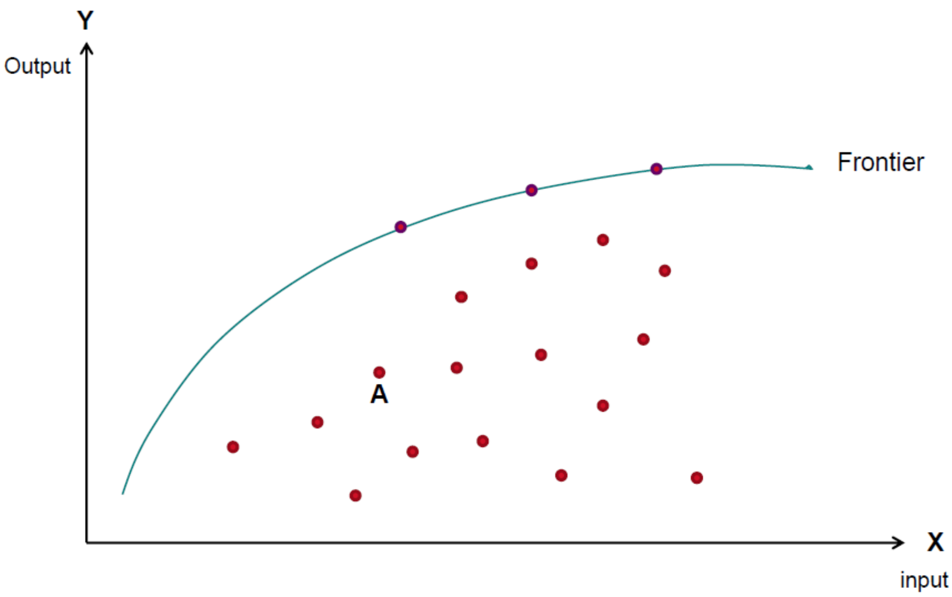


Figure 6. Production frontier and efficiency.

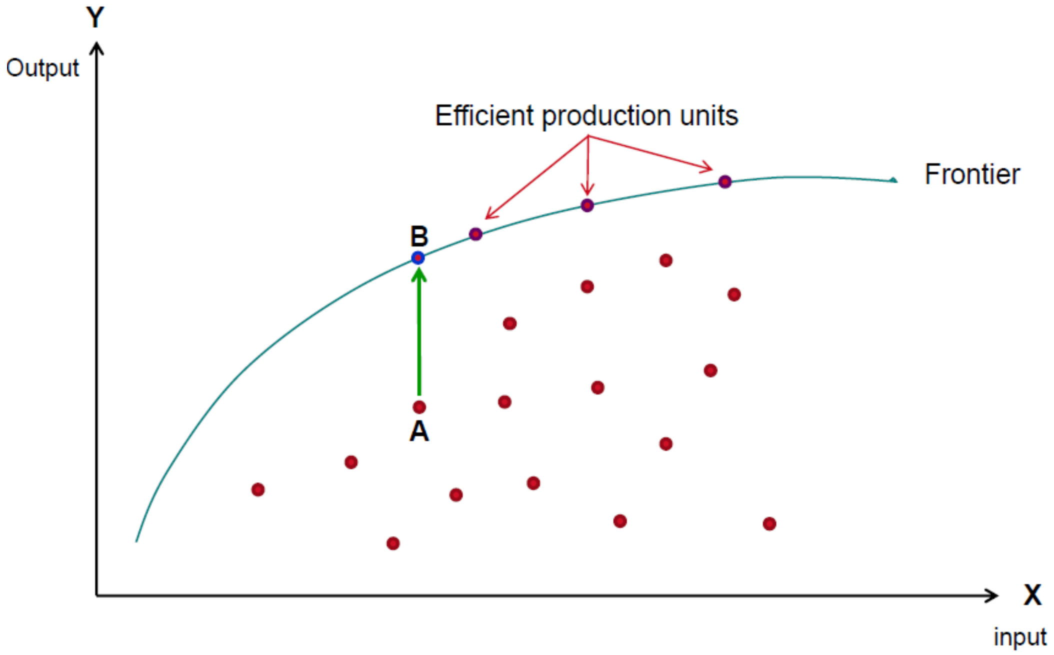


Figure 7. Environmentally adjusted efficiency measurements.