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Cost-benefit analysis of irrigation modernization in Guadalquivir River Basin

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ABSTRACT

In water scarce areas, policy makers frequently opt for water conservation and saving technologies (WCSTs) as a measure to ensure resource use sustainability, although this policy is subject to scientific and political debate. This paper presents an application of an integrated methodological approach for analysing the costs and benefits of using WCSTs to achieve water policy objectives. The focus is on the measures aimed at reducing irrigation water abstraction under the 1st and 2nd cycle of Water Framework Directive implementation in the Guadalquivir River Basin (Southern Spain). The method is a combination of a multicriteria assessment of the main effects of water-saving investments at basin level, estimated using a selected group of indicators. In a second stage, a cost-benefit analysis is conducted. The study finds a benefit-to-cost ratio of 4.1/1 for the Guadalquivir River Basin, thus concluding that irrigation modernization in this case study has been a good social investment. The method can be extended to other hydrological systems (aquifer basins) to draw general conclusions.

1. Introduction

The world's population is expected to grow to almost 10 billion by 2050, boosting agricultural demand leading to more intense competition for natural resources, especially water that appears as one of the most limiting factors to deliver sustainable food and agricultural production. While world population has rapidly increased the use of freshwater for human consumption, agriculture, industry, and other uses has increased six fold, with agriculture representing 70% of total water withdrawal and accounts for 86% of consumption (FAO, 2017). Nowadays water scarcity is considered one of the greatest risks facing the planet (World Economic Forum, 2016).

"Water use" describes the total water withdrawn by the farmer from its source, when the seasonal crop irrigation requires 10,000 m^3, even if the farm returns 30 percent of the withdrawn water to the watershed, the farm still needs all 10,000 m^3 to operate. "Water consumption" is the portion of water use that is "consumed" by crop transpiration and evaporation and is not returned to the hydrological system. Increasing irrigation efficiency has been suggested as a solution to water scarcity but its potential rebound effect (increased ex-post water consumption) is receiving growing attention. Although improved irrigation efficiency may reduce water use, some authors argue that, paradoxically, it may also increase water consumption (Perry et al., 2017), unless strict governance measures are introduced to control increased consumption (Huang et al., 2017; Berbel and Mateos, 2014; Berbel et al., 2018a, b).

On the other hand, modern irrigation technologies are considered a measure for climate change adaptation (projected higher temperatures, lower rainfall, more frequent droughts) and improving guaranteed water supply and water quality in a context of growing scarcity. Modern irrigation technologies may result in reduced water use but they frequently increase energy consumption (due to pressurized networks) and consequently, greenhouse gas (GHG) emissions (Fernández-García et al., 2014; Mushtaq et al., 2013) unless improved application efficiency reduces pumping costs (Sanchis-Ibor et al., 2016). Both negative effects (higher GHG emissions and likely rebound effects) have been suggested as potential conflicts that may arise from increasing irrigation efficiency subsidies.

Mushtaq et al. (2013) analyse the climate change impact of irrigation modernization in Australia, although the analysis was limited to a) financial effects and b) emissions of CO_{2eq} due to the change from previous open channels to pressurized networks. Our approach takes into consideration additional effects of technological change. A wider review of published literature analysing the effects of investment in irrigation water saving measures can be found in (Berbel et al., 2015; Perry et al., 2017).

European Union water policy is largely based on the Water Framework Directive (WFD), which sets out ambitious objectives for the quality and protection of all waters bodies (ecological status,

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quantitative status, chemical status and protected area objectives). The River Basin Management Plans (RBMPs) are a key element of the WFD, providing the overall context for water management in the River Basin District. The RBMPs in Spain have been developed in line with the WFD agenda and include investment in irrigation water saving as part of the programme of measures.

The WFD Art. 11 proposes the use of Cost-Effectiveness Analysis (CEA) as a general method for water policy decision-making (Berbel et al., 2011), while Cost-Benefit Analysis (CBA) is recommended as a tool for dealing with possible derogation from environmental objectives provided for in WFD Art. 4. CEA is a decision method that ranks intervention alternatives comparing relative costs (in monetary terms) and the relevant outcome under consideration measured in physical terms (e.g. reduction in water withdrawal, reduction of Nitrogen load). CBA assigns a monetary value both to the cost and the effects. Nevertheless, CBA has rarely been applied in WFD implementation (Feuillette et al., 2016; European Commission, 2015). This paper aims to contribute to the scarce literature on the use of CBA in the specific context of the WFD and water saving investment and presents an application of CBA to investment in irrigation water saving measures.

2. Case study

After a severe drought during the 90 s, the Spanish Ministry of Agriculture approved an Irrigation Plan (MAPA, 2001), in which the main measure was the transformation of old open-channel distribution systems into pressurized pipe networks. The goal of the plan was to save 3000 Mm^3 annually (Fernández García et al., 2014). The second phase of irrigation modernization was linked to the development and approval of 1 st and 2nd cycle RBMPs, both under the WFD implementation. Berbel et al. (2012) analyse the Guadalquivir RBMP and the role of WCSTs, also called modernization. The implementation of WCSTs resulted in estimated water savings of 259.5 hm^3 (Berbel et al., 2011).

The Guadalquivir river basin (GRB) contains 25% of Spain's irrigated land and the longest of the southern rivers (657 km); it can thus be considered one of the most important basins in Spain. It covers an area of 57,679 km^2 and has a population of 4.3 million. The basin has a Mediterranean climate with a heterogeneous precipitation distribution. The annual average temperature is 16.8 °C, and the annual average precipitation is 573 mm, with a range between 260 mm and 983 mm (standard deviation of 161 mm). The average renewable resources, that means the quantity of water that go into the basin each year, amount to a median value of 5.1 km^3/year (Berbel et al., 2012). Reservoirs storage capacity is through a complex and interconnected system of 65 dams have a global storage capacity of 8.5 km^3. The main land uses in the basin are forestry (49.1%), agriculture (47.2%), urban areas (1.9%) and wetlands (1.8%) (Confederación Hidrográfica del Guadalquivir, 2015) (Fig. 1).

Economic activities in the GRB generated around €69.8 billion in 2015, equivalent to 7% of the value of Spanish GDP. Over 71% of GVA in the GRB is concentrated in the service sector. Industrial activities amount to ≈16% of GVA, energy production ≈8% and agricultural production ≈5%. Global water abstractions in the GRB are estimated at 3.8 km^3/year (Confederación Hidrográfica del Guadalquivir, 2015). Local and seasonal droughts cause aquifer salinization and environmental stress. Moreover, water quality is a significant problem throughout the river basin. The main sources of pollution include urban and industrial wastewater discharge, erosion, and nutrient and pesticide runoff from agricultural land (Confederación Hidrográfica del Guadalquivir, 2015).

Basin Water Agency was created in 1927 and today has a mixed success in water governance. According Hydrological Plan 2015, 39% of surface water bodies and 37% of groundwater bodies have an environmental status 'less than good' due to quantitative or qualitative pressures, (Confederación Hidrográfica del Guadalquivir, 2015). This figure is over EU average (50%) but still unsatisfactory. The best results in GRB have been achieved in regulated surface water (80% of water supply) where a minimum guaranteed environmental flow is defined (and strictly respected) as part of river protection. Water use overexploitation emerges in groundwater resources (19% of water supply) where some aquifers are severely damaged such as the 'iconic' Doñana Natural Park area under pressure for high value berries (Scheffer et al., 2015) and conflict is still unsettled while other aquifers in the basin have reached a sustainable governance management (Berbel et al., 2018a, b).

3. Methodology

CBA assigns values to non-monetary flows (e.g. reduced diffuse pollution) with the aims to evaluate positive and negative consequences (benefits and costs) of economic activities by estimating the monetary flow associated with policy-induced changes. It can thus be used to assess policy-making (Choy, 2018). CBA is an analytical tool for evaluating the economic advantages or disadvantages of an investment decision to assess the welfare change attributable to it. This tool has been used in hydro-economic decision-making contexts, such as watershed conservation measures (Burnett et al., 2017) or aquifer recharge (Birol et al., 2010).

Our approach to CBA will be divided into three phases. Fig. 2 illustrates phase 1, which is sub-divided into the following steps: i) the identification and characterization of water saving investment measures, ii) the identification of the different responses, iii) the identification of the direct and indirect outcomes.

Secondly, once both direct and indirect outcomes have been identified, a set of indicators is defined and evaluated to estimate these effects in economic terms. Finally, a CBA is carried out to predict whether the multiple benefits of irrigation modernization policy (both monetary and non-monetary outcomes) outweigh its multiple costs (including non-monetary cost). Water policies are often still evaluated primarily according to their financial costs since such costs tend to be relatively easy to calculate. The calculation of all costs and benefits, including (second-order) indirect effects on sectors and non-priced environmental effects is a more difficult task (Brouwer and Sheremet, 2017).

The CBA will be carried out to evaluate and compare the various advantages and disadvantages of the investments in water saving measures in a structured and systematic way. The benefits are compared with the associated costs within a common analytical framework with clearly-defined spatial and temporal boundaries. Since these costs and benefits relate to a wide range of impacts measured in widely differing units, a monetary value is assigned as the common denominator to enable a meaningful comparison that includes discounting future cost and benefits. The results of this analysis can be interpreted as a B/C ratio that is, total benefits divided by total costs; a ratio greater than one indicates that the policy measure is beneficial from a social point of view and hence yields a welfare improvement.

3.1. Cost estimation

3.1.1. Financial cost

The identification and characterization of WCST measures have been taken from the Guadalquivir RBMP 2016–2021. The Annual Equivalent Cost (AEC) is used as an indicator of financial cost. The time horizon for this type of infrastructure is typically 25 years and a discount rate of 4% is used. Operating cost items of water investments generally include energy, materials, services, technical and administrative personnel, maintenance, and sludge management costs. The Annual Equivalent Cost (AEC) is defined as:

$$AEC = \frac{r\cdot(1+r)^n}{(1+r)^n-1}\cdot I + OMC \tag{1}$$