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Measuring the CO_2 shadow price for wastewater treatment: A directional distance function approach

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HIGHLIGHTS

- The shadow price of CO_2 informs about the marginal abatement cost of this pollutant.
- It is estimated the shadow price of CO_2 for wastewater treatment plants.
- The shadow prices depend on the setting of the directional vectors of the distance function.
- Sewage sludge treatment technology affects the CO_2 shadow price.

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ABSTRACT

The estimation of the value of carbon emissions has become a major research and policy topic since the establishment of the Kyoto Protocol. The shadow price of CO_2 provides information about the marginal abatement cost of this pollutant. It is an essential element in guiding environmental policy issues, since the CO_2 shadow price can be used when fixing carbon tax rates, in environmental cost-benefit analysis and in ascertaining an initial market price for a trading system. The water industry could play an important role in the reduction of greenhouse gas (GHG) emissions. This paper estimates the shadow price of CO_2 for a sample of wastewater treatment plants (WWTPs), using a parametric quadratic directional distance function. Following this, in a sensitivity analysis, the paper evaluates the impact of different settings of directional vectors on the shadow prices. Applying the Mann–Whitney and Kruskal–Wallis non-parametric tests, factors affecting CO_2 prices are investigated. The variation of CO_2 shadow prices across the WWTPs evaluated argues in favour of a market-based approach to CO_2 mitigation as opposed to command-and-control regulation. The paper argues that the estimation of the shadow price of CO_2 for non-power enterprises can provide incentives for reducing GHG emissions.

1. Introduction

One of the biggest global challenges related to environmental pollution is the climate change induced mainly by anthropogenic emissions of CO_2, methane and other greenhouse gases (GHG) [1]. The construction and operation of water utilities, while it is not the main source of GHG emissions, contributes to climate change [2]. In particular, the energy consumed and, consequently, the indirect GHG emitted by wastewater treatment plants (WWTPs) has grown considerably in the recent past as a result of increases in the volume of wastes treated and because of the implementation of new processes aimed at achieving higher effluent quality [3].

It is certainly true that some governments have already realised the important role that the wastewater treatment industry might play in the reduction of GHG emissions. For example, it is likely that the water industry in Canada will become subject to a carbon levy (a carbon tax is already in place in Quebec and British Columbia). Because the reduction of the carbon footprint of WWTPs is not just an environmental issue but also an economic one, a carbon cost levied on electricity derived from fossil fuels will create an

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incentive for WWTP operators to implement systems that aim to balance several sustainability objectives including minimising carbon emissions and minimising operational costs [2].

Infrastructure investments in sanitation and wastewater treatment are almost always the responsibility of governments. To facilitate an efficient use of resources, any investment should be preceded by a cost-benefit analysis (CBA) [4]. A CBA considers all the benefits and costs derived from a project, including those without a market value. According to the Water Framework Directive (EU Directive 60/2000/EU), CBA is the approach to be followed for assessing the economic feasibility of projects related to water management. In this context, previous studies have identified and quantified the positive environmental externalities of wastewater treatment, using different methodologies [5–8]. However, WWTPs also involve negative environmental externalities, such as the GHG emissions associated with electricity consumption. The economic value of these emissions must be integrated into the CBA or there will be an over-estimation of the benefits of wastewater treatment. This necessarily involves the quantification of the value of CO_2.

The estimation of CO_2 values has become a major research topic since the United Nations Framework Convention on Climate Change (UNFCC) established the Kyoto Protocol in 1997 [9]. Two main approaches have been used to derive a carbon emissions value: a direct approach, which is based on the establishment of the costs of the social damage of emitting an extra tonne of carbon, and an indirect approach, where the value is derived from an estimation of the shadow price of the carbon, in the form of the marginal abatement costs of cutting CO_2.

The social cost of carbon (SCC) is the marginal present value of the future costs caused by additional GHG emissions [10]. In other words, the SCC compares the damage done by one more tonne of CO_2 emissions with a baseline context in which those emissions do not increase [11]. In recent years, many studies have attempted to estimate the SCC using a range of approaches [12]. The approach that estimates the shadow price of CO_2 assumes that policies already implemented create a cost per unit of emission for regulated agents [4]. Economic theory suggests that the equilibrium permit price in a well-functioning carbon market should be equivalent to the marginal abatement cost [13].

After a systematic review of the direct and indirect approaches to estimating CO_2 values, Mandell [4] concluded that, although both approaches are necessary, the indirect approach (i.e., shadow price estimation) should be the primary tool for the CBA of infrastructure projects. Hence, our study is focused on the estimation of the CO_2 shadow price for the wastewater treatment industry.

In an ideal world, emission trading could be designed in such a way that allows the achievement of the desirable reduction of emissions [14]. However, there is a range of factors, such as transaction costs and asymmetric information, that complicate the operation of emission trading. These difficulties are relevant for the water industry, for which the CO_2 emissions are relatively low compared with other sectors such as transport or energy production. Hence, other measures to reduce energy consumption and consequently GHG emissions are needed. In this context, information on CO_2 marginal abatement costs across sources is critical for both policy makers and water utility managers. To overcome this limitation, and within the framework of studies into production efficiency, Färe et al. [15] developed a methodology to derive the shadow prices of both desirable and undesirable outputs (emissions), based on the concept of a distance function. The shadow price that is derived reflects the trade-off between the desirable and the undesirable outputs, and can be interpreted as the marginal abatement cost arising from regulations that prevent the free disposal of pollutants.

Several applications have used this approach to estimate the shadow price of different pollutants, such as the sulphur dioxide emissions resulting from the manufacture of electrical appliances [16,17], the waste generated by the ceramics industry [18], water pollutants from several industries [19] and the CO_2 emitted by electrical power plants in Korea [20]. Following the same methodological approach, other studies have utilised a directional distance function (instead of a distance function) to estimate the shadow price of pollutants [21,22,13]. A summary of the existing studies in this field is provided by Zhou et al. [23]. While the distance function assumes a proportional adjustment for all outputs (desirable and undesirable) [24], the directional distance function allows a simultaneous expansion of desirable outputs and contraction of undesirable outputs [25]. Therefore, in the presence of undesirable outputs under regulation, the directional distance function is more suitable for measuring performance [26,27]. The main weakness of this approach is that the shadow prices of undesirable outputs vary crucially with the choice of the directional vectors [28].

With regard to water utilities, some recent studies have utilised both the distance function and the directional distance function to estimate the shadow prices of the main contaminants removed in WWTPs [6]. In this context, a shadow price for the undesirable outputs was considered to be equivalent to the environmental damage that would have been caused by the discharge of such water pollutants into water bodies. Following the same approach, the shadow price of CO_2 can be interpreted as the value of the negative externalities associated with the use of energy for treating wastewater.

Most previous studies estimating the shadow price of CO_2 in this way have focused on coal, fossil fuel and thermal power plants in Korea [29,20], Japan [30], the US [31,32], India [33] and China [13,34]. However, because of the increasing importance of CO_2 emissions, the shadow price of this pollutant has been estimated not just for the energy production industry but also for other sectors such as dairy firms [9], agriculture [35,36] and transport [37].

This paper is the first to estimate the CO_2 shadow price associated with energy consumption in WWTPs. The directional distance function in quadratic form is used to quantify this CO_2 shadow price for a sample of 25 Spanish WWTPs. Subsequently, as a sensitivity analysis, we evaluate the impact of different directional vector settings on the shadow prices. We conclude with an analysis of the factors affecting CO_2 shadow prices.

From a policy perspective, the results of our research are expected to be of great interest and use to decision makers as a decision support tool, since they provide the first CO_2 shadow price estimates in the framework of WWTPs. Being able to assess the marginal abatement costs is an important first step in environmental policy issues, since these costs can be used when fixing carbon tax rates and ascertaining an initial market price for a trading system [15,13]. In other words, information about marginal abatement costs helps in choosing the most efficient burden-sharing rule and abatement mechanism. One of the marked advantages of the approach followed in this study is that it shows the variability of CO_2 shadow prices across facilities. According to Wei et al. [13], "the mean marginal abatement cost could be used to predict an initial permit price, and the variance could be observed by decision makers to determine whether emission trading is worthwhile".

2. Methodology

The estimation of the shadow price of CO_2 was carried out following the methodological approach of Färe et al. [38], which is based on the directional distance function. Hence, we first introduce the directional distance function and then derive the shadow prices.