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On the economic analysis of wastewater treatment and reuse for designing strategies for water sustainability: Lessons from the Mexico Valley Basin

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ABSTRACT

As the global economy continues to grow and water challenges become more complex and urgent, there is an increasing need for assessing the contributing role of wastewater treatment and reuse to designing strategies for water sustainability. For economic analysis, this need calls for modeling frameworks capable of representing the particularities of the relationship between economic systems and water resources in terms of appropriation from natural sources, utilization by production processes, and generation, treatment, reuse, and discharge of wastewater. We explore an integration of these particularities into an input-output model of the economy designed for technological choice featuring resource endowments as production constraints. We apply the model for studying the intentional reuse of treated wastewater in the regional economy of the Mexico Valley Basin, whose highly intervened hydrology is compromised by unsustainable exploitation of natural sources and minimal treatment of wastewater flows. We design scenarios for testing the response of the economic system to the constraining of groundwater extraction by aquifer recharge and to the reduction of leaks in domestic networks. Our findings indicate that avoiding aquifer overexploitation requires treatment processes to generate up to 1.4 $\text{km}^3\text{yr}^{-1}$ of high quality water for intentional reuse, while the control of domestic leaks can reduce regional water intake by 13% and, therefore, reduce the required treatment effort to 0.9 $\text{km}^3\text{yr}^{-1}$. The extent to which these results can support the design of a strategy for water sustainability with empirical relevance for this region ultimately depends on accurate representations of treatment technologies and conveyance infrastructure in economic models. We suggest that detailed representations of technologies for water distribution and wastewater treatment into economy-wide analysis constitute an important field of collaboration for industrial ecologists and input-output economists for the near future.

1. Introduction

Water plays a major contributing role in the ecological sustainability of socio-economic systems at all scales (Sivapalan et al., 2014). Not only is water essential for the maintenance of healthy ecosystems and biodiversity: human activities of all sorts rely on water appropriation from different sources and on engineered deliveries in qualities and quantities proper to uses ranging from production of energy or food to human consumption for elemental survival. Water, therefore, is by own merit a human right, a competitive factor of production, and a necessity for viable ecosystems. Research on water scarcity at global and regional scales has documented in recent decades a critical situation in several regions of the world (Pande and Sivapalan, 2017). Increasing economic demand has been met with engineered solutions frequently yielding a highly intervened hydrology characterized by overexploited aquifers and extensive modifications of surface flow regimes, the ecological consequences of which are by no means negligible. Challenges for promoting water sustainability for the global economy, complex and substantial in the present already, are to become more demanding as population and affluence continue to grow in the rest of the 21st century.

The tasks of understanding the relationships between water resources and socio-economic systems require analytical frameworks able to deal with the particularities of water as a natural resource and its ubiquitous essentiality for production and consumption activities. Input-output economics is well suited for this task as its economy-wide scale allows for studying the different ways in which it is utilized by different economic activities, including for household consumption.

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Furthermore, recent developments in input-output economics are instrumental for studying the prospects for water sustainability for at least two reasons. First, they can explicitly relate economic demand for water to its natural availability in surface or underground sources to study alternative technological configurations of the economy as a response to water scarcity (Duchin, 2005; Duchin and Levine, 2011,2012; López-Morales and Duchin, 2015; Cazcarro et al., 2016a,b). Second, they allow for the analysis of wastewater in its relation to economic activities and treatment technologies (Nakamura and Kondo, 2002, Lin, 2009,2011).

In this paper we integrate these developments as a means to better represent in economic models the particularities of water appropriation and to bring forward the analysis of wastewater production, treatment, and reuse in its role for designing strategies for water sustainability. In particular, we extend the approach to include wastewater generation, treatment, and reuse in an input-output economic model first explored by Cazcarro et al. (2016b) by working with the Rectangular Choice of Technology model (RCOT, Duchin and Levine, 2011) to incorporate concepts and features first developed in the Waste Input-Output model (WIO, Nakamura and Kondo, 2002) and implemented for wastewater-analysis by Lin (2009,2011). To implement the RCOT model for the analysis of water use and wastewater production, we take on the example of a particular regional economy characterized by an unsustainable and highly intervened hydrology: the Mexico Valley Basin, containing the metropolitan area of Mexico City with over 21 million people and representing about a quarter of Mexico's economy.

Water demand in this region is currently satisfied with extraction from overexploited aquifers and with inter-basin transfers of surface water from neighboring states. While less than 10% of wastewater produced in the region receives primary treatment, reuse of treated water is minimal and restricted to a handful of activities, mainly irrigation of peri-urban agriculture and of urban landscapes. The bulk of the wastewater produced is discharged untreated to neighboring basins. We represent the economy of the Mexico Valley Basin and its dependence on water sources through an 80-sector input-output table previously built for water analysis distinguishing activities for water distribution and treatment and representing economic activities as of 2008. We perform a scenario analysis to study the potential role of water treatment and reuse in a strategy for water sustainability in which aquifer extraction is constrained by recharge levels and in which leaks occurring within households are substantially reduced. This implementation succeeds at showing differences between the RCOT and the WIO models for wastewater analysis (namely the endogenous allocation between wastewater types and treatment processes associated to the choice of treatment technologies), but the empirical relevance of its findings to support the design of plausible strategies for water sustainability depends on accurate representations of treatment technologies in input-output databases.

While staple models in input-output economics are usually based on aggregate descriptions of production technologies, the RCOT model allows for the representation of individual technologies, the description of which requires information external to standard input-output tables. For this particular study, we reviewed the literature performing life-cycle analyses for wastewater treatment processes and found dominance of process-based methods, therefore lacking detailed accounts for their relation with the wider economic system. We suggest that the relationships between particular treatment processes and the rest of the economy need to be described with more precision, finding the middle ground between economy-wide descriptions of average treatment sectors in input-output tables and the high detail of *in-situ* process-based descriptions. We believe this task constitutes fruitful grounds for further collaboration between input-output economists and industrial ecologists.

The present article is organized as follows. Section 2 situates our exercise relative to the existing literature. Relevant studies on the importance of reuse of wastewater for sustainability purposes are identified. The economic approach for water and wastewater analysis utilizing the RCOT model is compared to other economic studies in input-output economics, but also to those based in frequently used modeling strategies, such as computable general equilibrium models. A brief on water management in the Mexico Valley Basin provides for context and empirical motivation for our case study. Section 3 presents the modeling strategy, describes the database over which the model is implemented, and presents the design of scenarios. Section 4 summarizes and discusses results from the scenario analysis and Section 5 presents concluding remarks.

2. A review of the literature for empirical motivation, economic methods, and the case of the Mexico Valley Basin

2.1. Water appropriation, treatment, and reuse for sustainability

Water appropriation requires manufactured systems for withdrawal, storage, and conveyance between source and use sites, sometimes including for purification processes, and for collection and discharge of wastewater to waterways or other sinks, sometimes including for treatment processes. While the characteristics of these systems are site-specific and can be very different between rural and urban areas, and between developed and developing regions, the continuous process of urbanization worldwide entails challenges for their adequacy to ensure access and sanitation to a growing, more affluent population in a sustainable way (McDonald et al., 2014; Yang et al., 2016; Pacheco-Vega, 2015). Generally speaking, water sustainability requires appropriation to be within renewable volumes while promoting the maintenance of healthy ecosystems (Postel et al., 1996). The sustainability role of adequate treatment of wastewater flows is being increasingly recognized for a variety of reasons, including human health concerns, the prevention of ecosystem degradation from pollution, or for increasing the prospects for intentional reuse, especially in regions with growing scarcity (Angelakis and Snyder, 2015; Jiménez-Cisneros, 2014a,b; Leverenz et al., 2011).

According to the United Nations 660 million people currently lack access to drinking water, 1.8 billion depends on a contaminated water source, and 2.4 billion lacks access to sanitation (United Nations, 2017). Goal 6 of the UN's Sustainable Development Goals (SDGs) calls for "ensuring clean water and sanitation by 2030″ through increasing the global capacity of wastewater treatment and reuse while conserving water ecosystems. The following particular targets of Goal 6 are highly relevant (UN, 2017):

1 Universal and equitable access to safe and affordable drinking water to all
2 Achieve access to adequate and equitable sanitation and hygiene for all
3 Improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
4 Substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity
5 Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
6 Expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
7 Support and strengthen the participation of local communities in improving water and sanitation management.

The global economy of today withdraws about 4000 $km^3 yr^{-1}$ from natural sources for economic purposes, 45% of which is released back