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Added-value from linking the value chains of wastewater treatment, crop production and bioenergy production: A case study on reusing wastewater and sludge in crop production in Braunschweig (Germany)

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ABSTRACT

The limited availability of natural water resources and dependency on mineral fertilizer challenge agricultural value chains in arid and nutrient-poor areas. Reusing wastewater in agriculture may help and could reduce costs and lead to increased added-value. The objective of this analysis is to assess the economic impact of linking the value chains of wastewater treatment, crop production and the generation of bioenergy by reusing treated municipal wastewater and sludge. The assessment was based on the cost/benefits and the added-value from the reused wastewater by the Braunschweig Wastewater Association (Germany). Benefits were assessed by comparing the costs of wastewater irrigation and sludge application with conventional disposal options, as well as comparing the costs of irrigation and fertilization with treated wastewater to groundwater irrigation and mineral fertilization. The added-value was calculated by ascertaining the remunerations received by the stakeholders in the various value chains. The results indicate that the reuse of wastewater and sludge results in: (a) the development of linked regional value chains; (b) lower costs of wastewater treatment and sludge disposal; (c) higher profitability and added-value in crop production; and (d) a high share (77%) of regional added-value. However, the results also show that the reuse of wastewater and sludge within linked value-chains can restrict actors and lead to crowding out effects on the added-value. Agricultural reuse schemes should provide additional opportunities that enable farmers to increase their scope of possibilities and compensate for missed economic potential.

1. Introduction

The primary task of conventional wastewater treatment is the purification and disposal of wastewater, and the elimination of nutrients and hazardous substances, in order to minimize hazards to humans and the environment. Doubtlessly, conventional systems of wastewater treatment have enhanced the living conditions in urban areas and relieved environmental burdens (Dockhorn, 2006). However, due to the possibility of recycling wastewater and the nutrients contained in it, additional goals of improving sustainable resource management in wastewater treatment have gained importance (Gude, 2015).

Indications of this paradigm shift are an increase in research on nutrient recovery in wastewater treatment (Cordell et al., 2011; Mehta et al., 2015; Satorius et al., 2011) or the European Union's Urban Wastewater Treatment Directive which says that "treated wastewater should be reused whenever appropriate" (EU, 1991: 4). At the same time, dependency on limited natural fresh water resources and mineral fertilizer pose a challenge for the future of agricultural value chains in arid and nutrient-poor areas. Currently, about 70% of global water withdrawals are used for agricultural irrigation (World Bank, 2015; WWAP, 2014). Estimates indicated

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that with current efficiencies, agricultural water consumption will increase by about 20% globally by 2050 (WWAP, 2012). These concerns have created a growing interest in seeking for alternative water resources and treatment options that can recirculate nutrients. One solution for addressing both concerns is the reuse of treated wastewater via irrigation.

The FAO (2010) promotes the recycling of urban wastewater as an essential component of integrated water resource management, which can simultaneously benefit farmers, cities and nature. It can contribute to meeting increasing water demands, saving potable water and reducing the disposal of wastewater to surface water bodies (Aiello et al., 2007). Furthermore, it can reduce purification levels and treatment costs, as soils and crops act as bio-filters (Haruvy, 1997; Rosenqvist and Dawson, 2005). Wastewater can also supply macronutrients and, therefore, contribute to securing and/or increasing the yields of crop production (Aiello et al., 2007; Bedbabis et al., 2015; Dimitriou and Rosenqvist, 2011; Singh et al., 2012; Zema et al., 2012), and saving finite mineral fertilizers (Paranychianakis et al., 2006).

Reusing wastewater in agriculture is not new; it has been a common practice in many developing countries (Norton-Brandão et al., 2013) and is now increasingly being explored in regions with water scarcity, growing urban populations and areas that demand irrigation water (FAO, 2010). Some of the concerns regarding the reuse of wastewater in agriculture include potential health hazards for farm workers and food consumers (Pedrero et al., 2010), soil salinization (Muyen et al., 2011) and the buildup of heavy metals and anthropogenic trace contaminants in soils and food crops (Fatta-Kassinos et al., 2011; Khan et al., 2008; Mapanda et al., 2005; Pedersen et al., 2005; Toze, 2006). When reusing wastewater for irrigation in agriculture, precise management strategies, including the application of proper purification levels, periodic monitoring of soil and plant properties, as well as suitable irrigation, cultivation and harvesting practices, are imperative to minimize hazards to humans and the environment (Aiello et al., 2007; Muyen et al., 2011; Qadir et al., 2010; Rusan et al., 2007).

The reuse of wastewater and sludge in agriculture causes linkages between the water and agriculture sectors, due to shared resources (e.g., land), input-output relations (e.g., nutrients), and interdependence of actions (e.g., interdependence of crop cultivation practices and wastewater treatment practices). The linkages may extend further to the energy domain through the irrigation of dedicated crops for bioenergy production. These linkages do not only connect the use of resources across sectors, but may also lead to the development of linked regional value chains comprising various economic activities, as well as actors and organizations (Maaß et al., 2014). Taking advantage of the synergies within such linked value chains may contribute to meeting increasing demands for water, food, biomass and energy as well as to convert from linear to circular production and consumption patterns. Several authors mention the benefits of integrating value chains, due to synergy effects resulting from collaboration and joint resource use, optimization of production processes and higher cost efficiency (Bausch and Glaum, 2003; Cao and Zhang, 2011; Möller, 2006; Van der Vaart and van Donk, 2008). This is supported by empirical studies showing that value chains integrated within local economic cycles can contribute to an increase of added-value for local economies (Bentzen et al., 1997; Hoffmann, 2009; Kimmich and Grundmann, 2008; Kosfeld and Gückelhorn, 2012; Marcouiller et al., 1996). However, the existing studies say little about the economic effects of specific linkages of value chains from different sectors, including those affecting the distribution of the generated added-value.

Present studies on the reuse of wastewater in agriculture have mainly focused on the suitability of wastewater for irrigation, evaluating its impact on soil and crop properties as well as the ability of particular techniques to meet specific parameters of the irrigation water quality (Norton-Brandão et al., 2013). Assessment studies have so far evaluated monetary and environmental costs and benefits from exemplary schemes only for farmers and operators of wastewater treatment facilities (Garcia and Pargament, 2015; Haruvy, 1997; Molinos-Senante et al., 2011; Rosenqvist and Dawson, 2005). The research has thus far neglected the added-value resulting for utilities and stakeholders as well as the impact of wastewater reuse on the local economic development. As operators of wastewater treatment facilities realize that the support and acceptance from the local communities and public bodies is indispensable for the future development of wastewater reuse schemes, there is high interest in assessing the impacts at the local level (BIO by Deloitte, 2015; TYPSA, 2012).

This paper will undertake an economic assessment of interconnected natural-resources-based value chains for providing water, crops and bioenergy. It will investigate the theoretical assumption that the reuse of treated municipal wastewater and sludge in agriculture is conducive to the development of linked regional value chains which bring about cost reductions and higher added-value generation. In this context, we will present a methodological approach for comparing alternative systems of wastewater treatment and crop production with conventional ones from a regional economic perspective. In particular, the study will address the following specific research questions:

[1] What monetary costs and benefits are associated with reusing wastewater and sludge in agriculture?
[2] What additional added-value can be generated from the agricultural reuse of wastewater and sludge in the value chains of crop production?
[3] What is the added-value from the linkage of the value chains of treated water provisioning, food and energy crop production and bioenergy generation?
[4] How is the added-value from the nexus of natural resources distributed among linked value chains and stakeholders?
[5] What impact does the linkage of natural-resource-based value chains have on the added-value of local economies?

2. Conceptual foundations

This research is mainly guided by the concept of the circular economy, an adaptation of the "Water–Food–Energy Nexus" and the added-value concept. "A circular economy is an industrial system that is restorative or regenerative by intention and design" (EMF, 2012: 7). As a theoretical concept it is primarily concerned with the transition of the linear production and consumption model of 'take-make-dispose' towards restoration and reusing, repairing, refurbishing and recycling existing materials and products (EU, 2014). Based on the core principles of "reducing, reusing and recycling" (Su et al., 2013), the concept of circular economy aims to achieve "optimum production by minimizing natural resource utilization and pollution emission simultaneously, and minimum wastage by reusing the wastes from production and minimum pollution by recycling and restoring the technically useless wastes" (Wu et al., 2014: 164). Several authors have shown that the transition to a circular economy can be important for mitigating environmental impacts and reducing waste and resource consumption (Geng et al., 2009; Hu et al., 2011; Li et al., 2010; Ma et al., 2014). Furthermore, it can contribute to keeping the added-value in products for as long as possible (Smol et al., 2015) and to ensuring higher regional and domestic competitiveness by increasing the effectiveness of resource allocation, resource utilization and productivity (Su et al., 2013).

Circular economies involving natural-resources-based sectors and activities, like agriculture, are characterized by the