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Circular economy and the opportunity cost of not ‘closing the loop’ of water industry: the case of Jordan

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ABSTRACT

The water industry is moving from an end-of-pipe approach consistent with the linear economic model to a circular approach consistent with the circular economy model. The economic dimension of wastewater circularity has not received the attention that other dimensions have; this study attempts to fill this research gap by studying the economic dimension, in order to estimate the net opportunity cost of a non-circular water industry The financial and environmental benefits of treating wastewater, along with the associated operating and capital costs, are calculated to arrive at the opportunity cost and the ‘closing the loop charge’. The analytical results reveal an estimated net opportunity cost of 643 million Jordanian dinar (JOD) (907 million US$) if the option not to go circular is chosen, with JOD 212 million (US$ 299 million) of this amount currently squandered. Furthermore, this indicates an average ‘closing the loop charge’ of JOD0.70/m^3 (\$1.0/m^3), which represents the average shadow price of the associated environmental externalities. Having thus shown a strong economic case for the circular model in the water industry, movements in all economic sectors to adhere to this model appear to be highly desirable.

1. Introduction

Depletion of the earth's resources has pushed governments to run resource-efficient economies, where resource productivity is enhanced and the environment is better protected (European Commission, 2014a). Along these lines, many European governments (SITA UK, n.d.) and China (Li and Ma, 2015) have been adopting policies that aim to achieve resource-efficient economies. The assumptions of infinite resources and the cheap disposal of waste that underlie the current economic linear model have become indefensible in the face of increasing global demand (COM, 2014). The ‘circular economy’ is an alternative model that relies on increasing resource efficiency and decoupling economic growth from resource use (COM, 2014). Indeed, the circular economy is a development strategy that is based on restorative thinking, which aims to maximize resource efficiency and minimize waste production within the framework of economic and social sustainability (Hislop and Hill, 2011). The building blocks of a circular economy are product design, new business models, reverse-cycle networks, and conducive conditions (WEF, 2014). In a circular economy mode, companies are involved not only in designing and producing the product but also in its use and disposal (Accenture, 2014). Also product design should be rethought in order to increase product recyclability and hence its compatibility with a circular model (The U.S. Chamber of Commerce Foundation, 2015). Furthermore, adopting business models that are built on, for example, longevity, capacity sharing, renewability, and dematerialization, enable achieving a circular economy that decouples growth from resource use (Accenture, 2014).

To stimulate the taking of the circular economy approach, water, phosphorous, and various metals have been identified, among others, as critical input resources to the world economy that have been under pressure because of the current linear economy and hence circular uses of these resources should be promoted (Hislop and Hill, 2011). In addition, the private sector has been called upon to play a major role in achieving this circularity (Ellen MacArthur Foundation, 2013). Private business partners can be attracted through innovative funding mechanisms such as crowdfunding

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(Innovfin Advisory and European Investment Bank Advisory Services, 2015) and Public-Private Partnership (United States Government Accountability Office, 2010). Interestingly, the water industry has been revolutionary in its movement towards the circular economy model. In fact, water pollution and shortage problems naturally push this sector toward restorative and regenerative thinking, both of which are at the core of the circular economy. What's more, water is considered essential to the circular economy, and water communities need to work on 'closing the loop' for water, given its importance not only with respect to human life but also because of the energy and materials it contains (Veolia, 2014).

The application of restorative thinking to the water industry demands that the 'end-of-pipe' approach of the traditional linear economic model be replaced with the 'circular' approach of the circular economy model. In such thinking, wastewater is viewed not as waste but rather as a valuable non-conventional resource (Lettinga et al., 2001; Werner et al., 2003) that should be circulated to sustain scarce life-essential resources. In fact, wastewater is a valuable non-conventional resource not only for water, but also for nitrogen, phosphorous and organic matter, where the latter is measured by the chemical oxygen demand (COD). The benefits of circulating wastewater components are both economic and environmental; e.g. to avoid the eutrophication problem. Other non-conventional sources of water that could also be used to achieve a sustainable water industry (Hamdy and Ragab, 2003) include water harvesting and seawater desalination (Jaber and Mohsen, 2001). The use of regenerative thinking thus leads to new models in the water industry—including the decentralized sanitation and reuse (DeSaR) model and the ecological sanitation (EcoSan) model (Otterpohl et al., 1999; Zeeman and Lettinga, 1999)—that look to frame the process of wastewater circulation. These models recognize wastewater as a resource that is an integral part of a system containing very interrelated dimensions, including technical, social, institutional, economic, and environmental ones (Abu-Ghunmi, 2009). While technical and environmental dimensions have been studied extensively at both the research and practical levels, related social, institutional, and economic dimensions have not drawn such attention. However, the European Commission (2008) has stressed that financial and economic analyses are essential to assessing the financial sustainability of water projects. In the process of moving water industry toward a circular economy, the social and intuitional aspects are essential players for the successfulness of this movement. In fact, a circular water industry could, like other sectors in the economy, be successfully implemented only in a social and institutional context that promotes innovations and pushing toward the required regulations and standards (Heshmati, 2015). Therefore, assessing the level of circularity, through looking at the economic and environmental losses to society as a result of not going circular, is followed by analysing institutional setups and social barriers (Ellen MacArthur Foundation, 2015). The circular economy (i.e. 'closed loop' economy) can serve the water industry even more, by addressing an overlooked dimension that can help achieve circularity—namely, water pricing policy (Hislop and Hill, 2011; Greyson, 2007). The water market price or value should reflect not only internal costs, but also external costs (externalities), including those of an economic, social, or environmental nature (Hislop and Hill, 2011; Greyson, 2007). Circular economy instruments, according to Hislop and Hill (2011), promote resource efficiency and the reuse and recycling of products, and so their use would move the water sector to become more circular. A suggested economic instrument is 'pre-cycling insurance'; this has been developed based on the concept within the European WEEE directive of 'cycling insurance', where the price of the insurance is added to the purchase price of the product (Greyson, 2007).

In this context, a number of governments, including the Jordanian government, have realized the importance of wastewater as a non-conventional resource (Lienhoop et al., 2014). Treating wastewater is about recycling used water and its components, in order to 'close the loop' and therefore ameliorate the water supply shortages that many government face. In fact, treated wastewater is an inevitable component of Jordan's water budget, and it is currently used for irrigation (MWI, 2013a). Similarly, according to Haruvy (1998), by 2040 it will be a key component of the total irrigation water used in Israel and Palestine; this is further evidence of how the water industry has been moving toward a circular economy.

Furthermore, what makes a strong economic case for adopting the circular economy model in the water industry is the fact that there are associated environmental benefits that can be monetized and measured by using various approaches, including the contingent valuation method (Lienhoop et al., 2014) and shadow price (Hernández-Sancho et al., 2010; Molinos-Senante et al., 2010, 2012). These environmental benefits include the avoidance, by virtue of undertaking the treatment process, of costs associated with restoring the environment, such as from the eutrophication impact. However, these are not the only benefits associated with wastewater. Choosing *not* to go circular also results in the loss of other benefits that would otherwise have stemmed from treating the wastewater and recovering its valuable contents. The other resources that could be recovered from wastewater include, the treated wastewater that can be directed to different uses; sludge, which can be utilized as fertilizers or a source of energy; and biogas, which can be used for energy production (Hanjra et al., 2015).

Accordingly, this study aims to estimate the net opportunity cost of not embracing a circular economy in the water industry, as a way to assess the current level of circularity in this vital sector. Estimating the net loss to society of not treating wastewater and conducting an effective market valuation of water are important tasks that should not be overlooked. Therefore, this paper also proposes a method by which to estimate the market value of water, as accurate valuation will push the water economy toward a more circular paradigm. Both objectives require a comprehensive analysis of the costs and benefits that account for environmental externalities and relevant types of costs; capital and operating. Therefore, the economic analysis "cost–benefit analysis (CBA)" is the approach applied to carry out the economic analysis of wastewater circularity within the framework of a circular economy—and, in the process, to estimate the net economic losses inherent in not going circular and to derive an accurate market value for water. For these purposes, this study takes up the case of the centralized wastewater treatment industry 'plants' that have been operating in Jordan for more than three decades.

The remainder of this paper is organized as follows. Section (2) overviews the concept of the circular economy and how it relates to the water industry, and Section (3) describes the data and the methodology used herein. Section (4) reports and discusses the findings of this study. Section (5) discusses the importance of 'closing the loop' in the water industry, and finally Section (6) provides concluding remarks.

2. Circular economy and the water industry

In the face of increasing amounts of waste being produced and not returned to the economy, Greyson (2007) challenges the workability of the incremental improvement approach, which takes the form of waste reduction, and proposes a waste prevention approach. In his attempt to propose a better approach, Greyson (2007) resorts to Boulding's (1966) concept of the circular economy. In a circular economy, the loop is closed and waste becomes a resource (COM, 2014). Therefore, the realization of the objectives of a circular economy makes it necessary to extend the useful life of products as much as possible (e.g. through reuse and repair) and to eliminate waste (e.g. through recycling and resource and energy recovery) (Smol et al., 2015). Therefore, switching to a circular economy necessitates changes throughout the value chain: it requires changes in product design, the business model, waste handling, financing methods, consumer behaviour, technologies, and policies (COM, 2014; Smol et al., 2015). Within policy and economic contexts, Greyson (2007) recommends constructing new economic instruments; he further proposes using 'pre-cycling', as a term that refers to the actions required to transform current resources into future resources. Interestingly, the application of a circular economy to the waste management sector could help resolve some of the global economy's most challenging issues, including growth, employment, and the use of green energy (SITA UK, n.d.).

On the resource front, one of the major resources on which pressure needs to be relieved is water; fortunately, such relief can be achieved by applying the principles inherent in a circular economy (Veolia, 2014). Studies that apply the circular economy concept to the management of water resources have garnered far less attention than those that touch on the management of the flow of materials (European Commission, 2014b). Despite the fact that in the water industry the reuse of wastewater has the benefit of enhancing abstracted water productivity in agriculture and turning waste into materials and energy—and hence returning them back to the economy, which would save fresh resources (Veolia, 2014)—there is indeed a dearth of research in this area. Therefore, the treatment of wastewater is part of 'closing the loop', where waste becomes a resource—namely, functionally cycled water and sludge.

There is considerable supporting evidence in the literature. In Denmark, an industrial symbiosis project has managed to save ground water by diversifying its water sources, one of which is wastewater (European Commission, 2014b). In Jordan, 6% of the water budget pertains to reclaimed wastewater (MWI, 2013a). Furthermore, in moving the water industry towards greater circularity, there is a 'snowballing' effect: ash derived from the incineration of sewage sludge can be used in the construction industry, for example, in brick, cement, and ceramic production, as well as in road construction (Smol et al., 2015). Ash is a toxic material that imposes an environmental problem, however, its use in the construction industry reduces the volume of toxic constituents that leak into the environment and also reduces the cost of sludge treatment (Smol et al., 2015). Thus, considerable attention has been paid to the importance of water in a circular economy, especially by the European Commission (COM, 2014). In crafting resource-efficient measures as economies shift to a more circular model, the Commission has emphasized that in the process of achieving resource-efficiency targets, there is a need to create and adhere to measures that address water use and its environmental impact, among other resources (COM, 2014).

Moving to a circular economy, however, is not an obstacle-free process; it involves barriers such as (1) resources not being correctly priced (i.e. the price does not account for both the price of the resource itself and cost recovery) and hence do not induce resource efficiency and pollution reduction, and (2) there are no enough incentives to internalize the externalities inherent in the policy-making process and in creating effective measures (European Commission, 2014b). At the same time, countries are called upon to encourage the private sector to invest in resource efficiency and encourage the disclosure of environmental information, the latter of which allows investors to make informed decisions regarding the benefits and risks involved (COM, 2014). Therefore, the economic value of the environmental externalities of the product (i.e. recycling cost and landfill and carbon emission costs) should be included in its market price, where the resulting increase in resource and raw material prices will encourage movement toward a circular economy (European Commission, 2014b). This problem also applies to the water sector: in England and Wales, for example, water is priced very cheaply to induce sustainable use in the long run (European Commission, 2014b). As a way of achieving resource efficiency and economic growth in moving toward a circular economy, Europe is calling for more reuse and recycling (COM, 2014); however, in the absence of supportive policies and as long as prices do not reflect the true economic costs of products, barriers to implementing a circular economy will persist (COM, 2014). In fact, having emphasized the importance of the investment by the private sector, wastewater treatment sector needs to adopt a full-cost recovery model that charges, users of the reclaimed water, a price that covers the full cost incurred in wastewater treatment (CCME, 2006). This is an important consideration for all economic sectors—and in particular, the water sector, as evidenced by the resource efficiency scoreboard constructed by the European Union. This scoreboard sets a resource-efficiency measure that comprises three tiers of indicators—namely, (1) a lead indicator for resource productivity, (2) dashboard indicators for materials, land, water, and carbon, and (3) thematic indicators that relate to transformation in the economy, nature and ecosystems, and key areas (European Commission, 2014a).

3. Data and methodology

3.1. Data collection

There are 27 wastewater treatment plants (WWTPs) distributed geographically across Jordan. These plants employ biological treatments that form the core of their treatment processes. Data for 27 WWTPs were obtained from the Ministry of Water and Irrigation (MWI) for 2012; however, based on data availability and plant homogeneity regarding treatment type and influent volume, only 14 WWTPs are included in this study. The average annual treated effluent discharged from the 14 plants is 1,691,246 m^3/year (MWI, 2013a). All 14 plants apply three main treatment stages; primary treatment based on physical operations; secondary treatment based on aerobic mechanical biological processes and finally, in the third stage, the effluent is disinfected with chlorine. The As-Samra WWTP, which is responsible for around 73% of the treated wastewater influent in Jordan (Seder and Abdel-Jabbar, 2011), is excluded on account of the unavailability of detailed cost data and that major reconstruction is occurring there (MWI, 2013a). Nevertheless, as As-Samra WWTP uses the same treatment technologies of the study sample, as well as receives influents with characteristics similar to the other plants in the study (MIGA, 2013), the analytical results from this study are also likely to approximate those of this plant.

Data were collected on a number of technical and economical parameters, as follows.

The **technical parameters** of the characteristics of raw and treated wastewater include monthly influent wastewater volume (in m^3); COD concentration (in mg/L), broken into 'in' (amount contained in the influent) and 'out' (amount in the effluent); total suspended solid (TSS) concentration (in mg/L), likewise broken into 'in' and 'out'; phosphorous (P) concentration (in mg/L), which is strictly an 'out' parameter; and nitrogen (N) concentration (in mg/L), which is also an 'out' parameter. The average technical parameters of the study sample are as follow; the average removed COD is 1.155 kg/m^3, the average removed TSS is 0.562 kg/m^3, the average removed P is 0.032 kg/m^3 and the average removed N is 0.067 kg/m^3.

The **economic parameters** for each WWTP include capital costs; the annual operating cost, which comprises energy, staff, reagents, and other costs. Additionally, the selling price of reclaimed wastewater earmarked for irrigation purposes is obtained from the Jordan Valley Authority. All values are in Jordanian dinar (JOD).

3.2. Methodology

This study adopts the cost–benefit analysis (CBA) in order to achieve its objectives because this approach takes into account the environmental externalities. Although another economic approach, called cost-effective analysis (CEA) applied by Yuan et al. (2010) to study the feasibility of industrial WWTPs, accounts for environmental benefits, it uses only operating costs, while the CBA approach uses both operating and capital costs (Olivieri et al., 2005) in addition to accounting for environmental benefits (Hussain et al., 2001; Molinos-Senante et al., 2012, 2013). Accordingly, CBA is the relevant approach to the task at hand, which is carrying an economic analysis of wastewater industry in the context of a circular economy to estimate the net economic losses to society of not going circular in wastewater industry and arriving at an accurate market value for water.

When resources do not have market value, then their economic value could be derived through a number of economic valuation methods such as, hedonic property pricing, travel cost, contingent valuation, choice modelling, and transfer method (Johns and Ozdemiroglu, 2007; NAP, 1997) and shadow price (Hernández-Sancho et al., 2010). However, shadow price, which is based on the distance function of Färe et al. (1993), has the advantages of providing understanding of the benefits associated with implementing a particular environmental program and its calculations are less costly compared with other methods such as contingent valuation methods which require surveying processes (Hernández-Sancho et al., 2010). These advantages make using shadow price to estimate the environmental benefits of wastewater treatments; i.e. avoided costs appealing in the context of a circular economy model.

3.2.1. Removal of phosphorus, nitrogen, chemical oxygen demand, and total suspended solid

The main constituents of domestic wastewater, which are P, N, COD, and TSS are serious threat to the environment (Metcalf and Eddy, 2013b). P and N are the macronutrients of the plants that are required for their growth, therefore the uncontrollable discharge of N and P to the environment causes severe damage through, for example, eutrophication and ground water contamination. The biodegradable fraction of the COD and TSS severely depletes the oxygen in the soil and water environment and thus threatens their ecosystems. Therefore recycling wastewater by using different treatment technologies results in a number of benefits including; removing these constituents as well as generating water for different use options (Lettinga et al., 2001). The removed amounts of P, N, COD, and TSS were calculated as the difference between the 'in' and 'out' amounts. For P and N, we assumed that the 'in' amounts were 50 and 85, respectively (Uleimat, 2012); from these amounts, the 'out' amounts were subtracted in order to derive the removed amounts.

3.2.2. Shadow price approach

To estimate the net opportunity cost of the water industry not going circular and the 'closing the loop charge'[1]—the shadow price approach is applied. The shadow price is used to estimate the avoided cost associated with discharging undesirable products into the environment (i.e. environmental benefits), and it is calculated by following Hernández-Sancho et al. (2010) [2] and using the distance function of Färe et al. (1993), as in Eq. (1).

$$
\begin{aligned}
LnD_0(Input^p, Output^p) &= \partial_0 + \sum_{i=1}^{I} \lambda_i {*} \ln\left(Input_i^p\right) \\
&+ \sum_{o=1}^{O} \nu_o {*} \ln\left(Output_o^p\right) \sum_{i=1}^{I} \sum_{i'=1}^{I} \lambda_{ii'} {*} \ln\left(Input_i^p\right) {*} \ln\left(Input_{i'}^p\right) \\
&+ \frac{1}{2} \sum_{o=1}^{O} \sum_{o'=1}^{O} \nu_{oo'} {*} \ln\left(Output_o^p\right) {*} \ln\left(Output_{o'}^p\right) \\
&+ \frac{1}{2} \sum_{i=1}^{I} \sum_{o'=1}^{O} \omega_{io} {*} \ln\left(Input_i^p\right) {*} \ln\left(Output_o^p\right),
\end{aligned}
\tag{1}
$$

where $Input_i^p$ is an operating cost i (staff, energy, reagents, and other operating costs), and $Output_o^p$ is an output i of the wastewater treatment process (reclaimed wastewater [functionally cycled water], removed P, removed N, removed COD, or removed TSS). The coefficients of the trans-log distance function (Eq. (1)) is solved by optimizing the objective function in Eq. (2) and using linear programming subject to constraints, as per Hernández-Sancho et al. (2010):

$$
Max \sum_{p=1}^{P} \left[LnD_0(Input^p, Output^p) - \ln(1)\right], \tag{2}
$$

Subject to.

(i) $LnD_0(Input^p, Output^p) \leq 0$

(ii) $\frac{\Delta\, LnD_0(Input^p, Output^p)}{\Delta\, \ln(Input_i^p)} \geq 0,\ p;$ desirable output

(iii) $\frac{\Delta\, LnD_0(Input^p, Output^p)}{\Delta\, \ln(Output_o^p)} \leq 0, p;$ undesirable outputs

(iv) $\sum_{0=1}^{O} \nu_O = 1,\ \sum_{0'=1}^{O} \nu_{OO'} = \sum_{0=1}^{O} \omega_{io} = 0$

(v) $\nu_{oo'} = \nu_{o'o}, \quad \lambda_{ii'} = \lambda_{i'i}$

3.2.3. Opportunity cost calculations

To account for the full opportunity cost associated with the water industry not going circular (i.e. the potential increase in Jordan's aggregate wealth due to wastewater being treated), Eq. (3) is applied.

$$
\begin{aligned}
&\boldsymbol{Net\ Opportunity\ Cost\ of\ Not\ Going\ Circular}\left(\frac{\boldsymbol{JD}}{\boldsymbol{Year}}\right) = \\
&\boldsymbol{PV\ of\ Financial\ Benefits}\left(\sum (TWWV{*}S)\right) \\
&+ \boldsymbol{PV\ of\ Enviromental\ Benefits}\left(\sum ((M_{COD}{*}SP_{COD}) \right. \\
&+ (M_{TSS}{*}SP_{TSS}) + (M_P{*}SP_P) + (MN{*}SPN) \\
&\left. - \boldsymbol{PV\ of\ OperatingCosts} - \boldsymbol{Capital\ cost}\right),,
\end{aligned}
\tag{3}
$$

where $TWWV$ is the annual effluent volume (in m^3); S is the reclaimed wastewater selling price (in JOD/m^3) for irrigation; $M_{COD}, M_{TSS}, M_P and M_N$ are the annual amounts of COD, TSS, P, and N removed (in kg), respectively; and $SP_{COD}, SP_{TSS}, SP_P\ and\ SP_N$ are

[1] For more details, see Section 6.

[2] The shadow price is calculated as per Hernández-Sancho et al. (2010). See also Färe et al.'s (1993) Eq. (15).

Table 1
Shadow prices and environmental opportunity costs of wastewater treatment.

Items	Shadow price	Total average annual removal	Average annual environmental benefits
COD	−0.0590	27,141,992	1,602,631
TSS	−0.0648	14,033,204	909,334
P	−2.7557	815,109	2,246,173
N	−0.3343	1,531,227	511,846
Total average annual environmental benefits			5,269,983
Average annual benefits/flow (m^3) (14 plants studied)			0.223
Average annual benefits from all plants			27,660,360
Annual operating cost (annual)			7,018,745

Shadow prices are calculated using Eq. (2) and are based on data for 14 WWTPs that are classified as mechanical treatment plants. COD, TSS, P, and N are chemical oxygen demand, total suspended solids, phosphorous, and nitrogen, respectively.

their respective shadow prices (in JOD/kg). All terms should be discounted using the appropriate discount rate to arrive at their present values (PV) and hence the net opportunity costs (NPV).[3]

4. Discussion of results

In line with the technology currently employed and the quality of the effluent discharged from the Jordanian WWTPs under investigation, the outputs of wastewater treatment can be classified in terms of a circular economy model (Ellen MacArthur Foundation, 2013)—namely, as functionally cycled water (i.e. treated wastewater) and functionally cycled material (i.e. sludge). The produced sludge is a mixture of N, P, organics, and organisms (Metcalf and Eddy, 2003a). In this study, the monetary value of the functionally cycled water and sludge represents the financial benefits, and hence an opportunity cost of not going circular. This is because these outputs could be sold for use in many applications, including those in agriculture and industry. Furthermore, the shadow prices of the N, P, and organics represent the environmental benefits (i.e. avoided costs of keeping undesirable products out of the environment) (Hernández-Sancho et al., 2010) and therefore another opportunity cost of not going circular.

The shadow price is calculated for each of the functionally cycled sludge components (i.e. N, P, COD, and TSS) (Table 1). The highest level of environmental benefit per kilogramme is that of P, followed by those of N, TSS, and COD. A similar benefit pattern is reported by Hernández-Sancho et al. (2010) for the case of Valencia. However, the cost of treating environmental pollution caused by P and N in Jordan is less than that in Valencia, as the shadow prices of P and N in Jordan are lower than their counterparts in Valencia. This differential can be attributed to wastewater concentration, as in Jordan, wastewater is more concentrated (Abu-Ghunmi et al., 2008; MWI, 2013a) than in Valencia (Molinos-Senante et al., 2011). The detailed comparison of the results of Jordan to those of Hernández-Sancho et al. (2010) concerning Valencia, it is found that the removed amounts of P in Jordan are 40 times larger than those removed at the WWTPs in Valencia. In addition, it is found that the removed amounts of N in Jordan are 15 times larger than those reported in Valencia. Furthermore, the average amount of wastewater effluent in Jordan is 1,691,246 m^3/year, which is close to half the amount reported by Hernández-Sancho et al. (2010) for Valencia. This indicates that a greater level of environmental benefits is associated with heavily polluted wastewater and therefore a greater opportunity cost associated with not going circular. This argument is further enforced by knowing that the market price of functionally cycled water for agriculture in Jordan, which is JOD0.023/m^3,[4] is much lower than the market prices of functionally cycled water that Hernández-Sancho et al. (2010) use for the case of Valencia, which are EUR0.1, 0.7, 0.9, and 1.5/m^3 (i.e. JOD0.086, 0.604, 0.777, and 1.295/m^3).

In Jordan, the cost of treating environmental pollution caused by TSS and COD is higher than that in Valencia (i.e. the shadow prices of TSS and COD are higher in Jordan)—despite the fact that the amounts of TSS and COD removed at WWTPs in Jordan are 12 and 23 times higher, respectively, than those in Valencia. This differential can be attributed to higher energy and staff costs, and other costs, in Jordan per cubic metre of functionally cycled water, compared to those reported by Molinos-Senante et al. (2011) for Valencia. These figures may imply that the wastewater treatment sector in Jordan is relatively inefficient and should therefore be improved.

The environmental opportunity costs (environmental benefits) of functionally cycled water are calculated using Eq. (3); these are reported in Table 1 for the 14 WWTPs under study. The results show that the average annual environmental opportunity costs are JOD5.3 million, and the average for influent is JOD0.223/m^3. If this rate were to be applied to the influent of all 27 WWTPs operating in Jordan, the average annual environmental opportunity cost would amount to JOD27.7 million—a figure almost four times the corresponding annual operating costs.

Table 2 estimates the full opportunity cost of not going circular, calculated as in Eq. (3) using environmental and financial benefits and while accounting for operating and capital costs. The calculations are based on a 3.5% discount rate (Molinos-Senante et al., 2011) and 20 years of depreciable life (Lienhoop et al., 2014; Molinos-Senante et al., 2011); they are for only nine WWTPs, due to data being unavailable for the others. The results show that only one WWTP is actually associated with positive NPV (i.e. opportunity cost), while the others show losses: in those WWTPs, the operating and capital costs of treating wastewater exceed the associated financial and environmental benefits. This can be attributed to the very low average price of functionally cycled water (JOD0.023/m^3) and also to operational inefficiencies, as mentioned. If the price were to be increased to just JOD0.075[5]/m^3 for functionally cycled water, the net opportunity cost (NPV) turns out to be around JOD 68.9 million, as shown in Table 3; this is even after controlling for the inflation effect. The WWTPs were constructed in different years, and span the 1985–1999 period; therefore, the capital costs should be adjusted for inflation, as done in Table 3.

The total annual influent volume of the nine WWTPs in Table 3 amounts to approximately 18 million m^3. This represents only 16% of the total annual influent of the 27 WWTPs in Jordan (MWI, 2013a). Knowing that, and using the average NPV of JOD3.79/m^3, the total opportunity cost of the 27 WWTPs is therefore around JOD431 million. Furthermore, as only 67% of Jordan's wastewater flows to WWTPs, this implies that there is an existing (and currently squandered) annually opportunity cost of around JOD212 million; this cost is directly associated with not functionally recycling 33% of the wastewater. These numbers do not even take into account the opportunity cost associated with the functionally

[3] Molinos-Senante et al. (2013) use NPV in their study of the economic feasibility of wastewater treatment.

[4] JOD = 1.41 US dollar.

[5] We made incremental increases in the price and recalculated the NPV to arrive at price that was just high enough to turn the project into positive NPV.

Table 2
Net opportunity costs of not going circular.

WWTP	Financial benefits	Environmental benefits	Operating cost	Capital costs	Net opportunity cost
WWTP1	44,158	605,209	330,461	5,581,000[a]	−1,048,579
WWTP2	98,331	1,024,753	424,995	7,640,000	2,281,520
WWTP3	34,000	380,572	262,290	8,200,000	−6,035,706
WWTP4	89,667	924,819	566,424	18,657,763	−12,289,724
WWTP5	34,023	251,558	139,172	4,638,000[a]	−2,557,178
WWTP6	54,897	465,902	337,658	4,638,000	−2,035,137
WWTP7	13,225	96,218	100,425	871,304	−743,121
WWTP8	22,143	151,516	146,982	888,517	−509,380
WWTP9	27,981	240,860	87,859	3,360,000	−787,809
Total	418,424	4,141,407	2,396,265	54,474,584	−23,725,114

[a] These values are approximated, based on values associated with similar projects.

Table 3
Opportunity cost assuming JOD0.075/m^3 price for functionally cycled water.

Plant	Total annual benefits − Operating costs	Capital costs	Net opportunity cost
WWTP1	1,787,039	10,957,461	14,440,662
WWTP2	3,237,234	20,083,242	25,925,640
WWTP3	1,089,575	21,555,312	−6,069,836
WWTP4	2,741,683	22,488,264	16,477,639
WWTP5	792,071	5,796,896	5,460,330
WWTP6	1,360,597	14,125,888	5,211,466
WWTP7	256,457	2,148,715	1,496,162
WWTP8	419,296	1,744,471	4,214,733
WWTP9	788,796	9,427,169	1,783,520
Total	12,472,749	108,327,418	68,940,315

Shadow prices are recalculated assuming that the price of 1 m^3 of treated wastewater is JOD0.075, and that capital expenditures are adjusted for inflation; consumer price index information used for this purpose was drawn from the Central Bank of Jordan website (www.cbj.gov.jo).

Table 4
Sensitivity analysis of opportunity costs.

Plant	Net opportunity cost (5%)	Net opportunity cost (30 years)
WWTP1	11,312,999	21,909,847
WWTP2	20,259,855	39,456,122
WWTP3	−7,976,802	−1,515,803
WWTP4	11,679,165	27,936,892
WWTP5	4,074,054	8,770,901
WWTP6	2,830,158	10,898,274
WWTP7	1,047,312	2,568,062
WWTP8	3,480,884	5,967,241
WWTP9	402,975	5,080,405
Total	**47,110,599**	**121,071,940**

cycled sludge produced by the treatment process; this factor still needs to be quantified, if we are to arrive at the full opportunity cost of not going circular in the water industry.

To reduce uncertainty surrounding the discount rate and useful life of the WWTPs, in line with Molinos-Senante et al. (2013), we undertook sensitivity analysis. Column (2) in Table 4 reports new opportunity costs while assuming a 5% discount rate, rather than one of 3.5%. Meanwhile, column (3) shows the opportunity cost while assuming a useful life of 30 years, rather than one of 20 years (Molinos-Senante et al., 2013; Yuan et al., 2010). These results show the robustness of the benefits of going circular: even with a higher discount rate, the net opportunity cost is two-thirds the previously calculated figure.

Therefore, based on the above results, it is recommended that the average price of 1 m^3 of functionally cycled wastewater be increased to JOD0.075/m^3 [6]; this will help ensure the benefits of going circular, even while not accounting for the opportunity costs associated with functionally cycled material (i.e. sludge). Consequently, the economic analysis conducted in this study provides further evidence of the urgent need to accelerate movement toward a circular economy model—a movement in line with the recommendation of the WEF's (2014) report.

5. 'Closing the loop' in the water industry

There has been a global call to increase the private sector's participation in moving toward a circular economy. The average consumption of water in Jordan, during 2000–2013, is close to 869 million m^3 (MWI, 2013b). The average percentage of water consumption for irrigation purposes is 61%, while 4% is used by the industrial sector and 35% is used by the municipalities (MWI, 2013b). According to MWI (2009), treated wastewater makes 11% of the water supply, where 10% used by agriculture and 1% by industry. In fact, the market for treated wastewater is expected to have a larger contribution to water supply in 2022, where 15% of Jordan's water need is expected to be supplied by treated wastewater; 13% for irrigation and 2% for industry (MWI, 2009). This shows the importance of the treated wastewater market that might attract the interest of private sector. Furthermore, the results reported herein indicate that in Jordan, the wastewater industry is a net creator of value; this should encourage private sector investment in this sector. However, in order to achieve such investment, the monetary value of environmental externalities (i.e. shadow prices) should be included in the total benefits of wastewater treatment. This amount of money should be forwarded to the WWTPs, so that their benefits may exceed their costs. In fact, this consideration of environmental externalities meets the requirements inherent in the European Commission's (2014b) recommendation that the market value of the product reflects environmental externalities and also is consistent with the full-cost recovery funding model (CCME, 2006). Accordingly, we introduce the term 'closing the loop charge', which is defined as the avoided cost of closing the water industry's loop; and we propose the shadow price as the tool by which to determine the monetary value of this charge. To the best of the authors' knowledge, this is the first time the shadow price is used in pricing water resources.

In the case of Jordan and based on the results of this study (Table 5), the average 'closing the loop charge' is about JOD0.70/m^3 of water. Taking into account the importance of the private sector in achieving circularity (Hislop and Hill, 2011), this 'closing the loop charge' should be paid to the WWTPs. This would ensure that investors in this sector are making profits, which would in turn encourage them to compete in treating wastewater, and thus

[6] The proposed price of JOD0.075/m^3 is still low, compared to the price of 1 m^3 of domestic-use water—a price that ranges from JOD0.19 to JOD1.60, based on consumption.

Table 5
Waste pricing: Circular economy charge (JOD/m[3]).

Plant	Extra charge
WWTP1	1.028
WWTP2	0.782
WWTP3	0.840
WWTP4	0.774
WWTP5	0.555
WWTP6	0.637
WWTP7	0.546
WWTP8	0.513
WWTP9	0.646
Average	**0.700**

improve wastewater treatment efficiency. The 'closing the loop charge' is similar to the pre-cycling insurance concept of Greyson (2007): this pre-cycling insurance is charged to the manufacturer to cover any reuse, repairing, recycling, remanufacturing, redesigning, and/or other actions required to generate resources and energy from waste and to accelerate movement toward a circular economy. However, in the case of water, WWTPs protect the environment by 'closing the loop' of the water sector, by treating wastewater and hence not letting undesirable products infiltrate the environment. This 'closing the loop charge' could be paid by the government to the WWTPs, in the form of subsides or direct payment, or by the WWTPs adopting a full-cost recovery approach for pricing the reclaimed water (functionally cycled water). Furthermore, excessive consumption of water by households, farmers, and industries should be penalized by levying a corresponding amount in the form of extra tax. Ultimately, who should pay the 'closing the loop charge' is an issue that should be discussed at the national level, with the involvement of all stakeholders.

Furthermore, there is a number of other funding mechanisms that can be tapped to attract the private sector to invest in the wastewater treatment industry including: issuing bonds in the financial markets; securing loans from banks and other financial institutions (CCME, 2006; U.S Department of Energy, 2015); using Public-Private Partnership (PPP) arrangements (CCME, 2006) and/or using crowdfunding (U.S Department of Energy, 2015). The latter two funding mechanisms could be of particular interest to the wastewater treatment sector. Crowdfunding, which is a new internet-based financing method, seeks to raise small amount of investments from a large number of investors and then aggregate these contributions into a loan or an equity type of investment (U.S Department of Energy, 2015). Interestingly, the use of crowdfunding to finance new business models, which is one of the tools of circular economy, is seen as a good response by the financial sector to such needs (Innovfin Advisory and European Investment Bank Advisory Services, 2015). PPP engages the private sector, in the wastewater treatment industry, in a way that most likely enhances the operational and cost efficiency of this industry and enables its access to alternative sources of fund (United States Government Accountability Office, 2010). Under the PPP, the private partner participates not only in financing the project but also participates in the planning; design; construction; operation and maintenance processes (United States Government Accountability Office, 2010). The extent of the private sector involvement depends on the PPP arrangements (United States Government Accountability Office, 2010). This clearly supports the transition to a circular economy where efficiency is an important issue.

6. Conclusion

This study estimated the full opportunity cost inherent in not replacing Jordan's water industry's current linear economic model with a circular model; it also investigated a method by which to calculate the 'closing the loop charge'. Using the current average price of functionally cycled water for irrigation (JOD0.023/m^3), the results indicate that the costs outweigh the financial and environmental benefits inherent in a circular model. However, when the price is raised to JOD0.075/m^3—which is still far below the average price of 1 m^3 of drinking water—the NPV reaches nearly JOD68.9 million, even after adjusting for inflation. What is more, in extending analysis to the total wastewater influent generated in Jordan, the NPV reaches JOD643 million, leaving JOD212 million of an already-missed opportunity cost associated with untreated wastewater.

Attracting the private sector to the wastewater treatment industry is a must, if Jordan is to 'close the loop' of its water resources. We calculated the 'closing the loop charge' in the water industry for 1 m^3 of water, based on the shadow price; we found it to be JOD0.70. This amount should be paid to the WWTPs, to ensure profitability among investors in this sector and thus attract foreign and domestic investment—investment that is essential to making improvements to Jordan's wastewater treatment industry, within the framework of the regenerative thinking found within a circular economy.

This study's findings show that Jordan's adoption of a circular economy model within the water sector is justified on economic grounds. Therefore, accelerating the water industry's process of going circular is inevitable, if Jordan is to increase its water-use efficiency and conserve its scarce water resources.

The findings of this paper have profound theoretical and practical implications for circular economy model, full-cost recovery approach, and water pricing policy. It provides evidence that a circular economy model is not only appealing from a theoretical perceptive, where closing the loop in an industry is the way forward to save and sustain resources, but it also confirms this empirically. It shows, based on Jordan's water industry experience, how much benefits have already been achieved from going circular and how much benefits still to be gained by going fully circular. This paper also supports the full cost recovery approach of pricing resources and provides further evidence to policy makers that going circular along with adopting the right water pricing policy is a must to sustain water industry. The full cost recovery approach that captures both the financial and the environmental costs associated with water industry provides the baseline for pricing its products in order to be able to make profits and hence appeals to the private sector.

However, challenges lie ahead. There should be a national debate involving all stakeholders, about cost allocation of wastewater treatment externalities, so that scarce water resources are used efficiently and justly. In addition, as one of the major challenges to carrying out studies in circular economy is data limitations, water industry along with other industries, should work on developing a comprehensive detailed database, which is needed to fully measure the circularity of any industry. Furthermore, laws and regulations should be directed to facilitate the movement to a circular economy, such as; setting appropriate environmental standards for the use of recycled products; specifying health regulations related to the reuse and recycling of products; and encouraging investment and innovation in reuse and recycle industry. Municipalities, local governments and environmental activists should increase the awareness of society and local communities to the importance of going circular and therefore, increasing their acceptance to the reuse and recycle of products.

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