An Economic Index for Measuring Firm's Circularity: The case of Water Industry

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Abstract

Transition towards circular-economy model is a must to sustain the planet resources. Under circular economy model wastewater is transformed from a waste into a resource. Therefore, a comprehensive circular economy index; the Circonomics Index, is proposed to measure circularity of wastewater industry. The component indicators of the index are linked directly to the three Rs; reduce, reuse and recycle, of circular economy. The novelty of the proposed Index is that it uses objectively constructed weights that reflect the environmental benefits of the treatment process, and the index captures the reuse and recycling efficiency of an WWTP, which reflect the specific nature of wastewater. The findings show that treatment technology is a major factor in determining the production efficiency, reuse rate and recycling performance of a WWTP. The results of using the Circonomics Index have profound implication for policy makers to speed up the process of moving to a circular economy.

Keywords: Reduce; Reuse; Recycle; Circonomics Index; Wastewater

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1. Introduction

The linear economy model, which has shaped how economies are functioning for decades, is no longer sustainable and should be replaced by circular economy model which is considered as a 'value creation opportunity' Ellen-MacArthur-Foundation [2015]. The underlying philosophy of a circular economy is a 'win-win' philosophy that keeps both the economy and the environment healthy (Geng and Doberstein [2008]; Geng et al. [2012]). A number of countries; such as China and Germany, have pioneered in pushing their economies to move toward a circular economy model (Geng et al. [2012];

Heshmati [2017]). Believing in its importance, Lieder and Rashid [2016] emphasised that a circular economy is the solution to the current global economy's challenges of environmental degradation, resource scarcity, price volatility and economic growth. This is because a circular economy decouples growth from resource consumption, which could be shown by realising resource use intensity rates that exceed economic growth rates (Geng et al. [2012] and Heshmati [2017]). Decoupling growth from resource consumption is achieved by maximizing the value created from each unit of resources, that not only boosts the productivity of materials but also save virgin resources and reduce price volatility (Ellen-MacArthur-Foundation and Granta-Design [2015]; Heshmati [2017]). The tools of implementing a circular economy model include; new business models, product design, system conditions and reverse logistics (Ellen-MacArthur-Foundation and Granta-Design [2015]). However, in order to achieve an effective implementation of circular economy, there is a need for set of indicators that serves as a measure of development and as evaluation criteria of the effectiveness of this implementation (Zhijun and Nailing [2007]; Su et al. [2013]), however, measuring company's transition to circular economy has not been established until recently. In response to this, Ellen-MacArthur-Foundation and Granta-Design [2015] has developed two indicators; a main indicator; material circularity indicator that addresses restorative aspect of CE and a complementary set of indicators that address other impacts of CE.

As in any system, key performance indicators are required for evaluation, in this paper we develop an indicator that is in accordance with the principles of a circular economy. This enables policy makers to understand of how far an economy is progressing toward a circular model in order to achieve the required outcomes (Pintér [2006]; Geng et al. [2012]). It is also a necessary tool for individual businesses to enhance their circularity performance through drawing a comparison of their performance with others within the same industry (Ma et al. [2014]). Circular economy is expected to have a positive impact on the growth of the economy, job creation, carbon footprint, and consumption of virgin resources and profitability (Ellen-MacArthur-Foundation [2015]).

Water issues are one of the main challenges facing the global economy today, and these challenges not only concerned with the increase in water demand and water pollution (Abu-Ghunmi et al. [2016]), but also with the necessity to improve the environmental and financial performance of water sector while maintaining low cost and high quality service. Interestingly, the call for water industries to 'do more with less' is in absolute coherence with the underlying philosophy of circular economy, that is decoupling economic growth from resource consumption. Furthermore, the water recycling industry is considered as a necessary infrastructure in a circular economy's holistic strategy that motivates material circulation, cleaner production and energy efficient use (Zhijun and Nailing [2007]). This indicates that the solution to water sector lies in moving to a circular economy (Lieder and Rashid [2016]).

Zhijun and Nailing [2007] in promoting circular economy on the ground, suggested a circular economy index that includes an economic development index, a human development index and a green development index. The green indicator includes reduction indicators such as waste discharge per output value; reuse indicators, such as reuse ratio of water for a particular purpose and urban sewage treatment ratio, and resource indices such as utilization ratios of waste industrial gases and domestic wastes (Zhijun and Nailing [2007]). Furthermore, among the proposed indicators of circular economy are: resource productivity, which is the ratio of GDP to domestic material consumption; circular activities, such as recycling rate; waste generation, such as amount of municipal waste per capita and amount of waste per GDP output; and energy and green gas emissions, such as share of renewable energy (Ellen-MacArthur-Foundation [2015]). These cover key areas of circular economy (Ellen-MacArthur-Foundation [2015]).

Two European Union indicators; the EU Resource Efficiency Scoreboard and Raw Material Consumption are Europe circular economy initiatives to measure progress towards more resource efficiency (Ellen-MacArthur-Foundation [2015]). Resource efficiency brings not only environmental benefits but also it allows the transformation of the current linear economy into a circular economy, where materials are reused and recycled and hence closes the loop of a product and creates new technologies and jobs opportunities (EU 2015).

Not all wastes in the economy are recycled due to missed opportunities for recycling and/or because of entropy (i.e. the second law in thermodynamics) (Andersen [2007]). Unfortunately, according to Georgescu-Roegen [1971] the degree of entropy is a positive function of the extracted energy and material (Andersen [2007]).

Nevertheless, until recently, there has been no defined comprehensive measure of circularity (Heshmati [2017]; Ellen-MacArthur-Foundation [2015]). In fact, lack of indicators has been seen as one of the barriers to moving to a circular economy, along with the need for setting regulations that back such a model to reduce uncertainty and encourage businesses to adopt it (EA-SAC 2015). Therefore, the objective of this paper is to develop a composite circularity indicator that measures and evaluates the circularity of a vital sector, which is wastewater treatment sector, according to principles of circular economy. The contribution of this paper to circular economy and water industry is not only in term of combining relevant indicators that capture circularity of wastewater sector but also in its novelty of using shadow prices as a weighting scheme in constructing the Circonomics Index.

The rest of the paper is organized as follows; Section (2) reviews relevant literature on development of circular economy indicators, Section (3) explains the methodology of building the circular economy index; Circonomics Index, and data requirement, Section (4) presents the results and discusses them and Section (5) concludes.

2. Developing Circular Economy Indicators

Circular Economy is a strategy 'towards regenerative sustainable industrial development with a closed loop' (Heshmati [2017]) that is achieved by simulating the natural ecological system (Foundation) [2013]), which has the thermodynamic law on 'mass conservation' as one of the fundamentals of this concept (Pintér [2006]). The pillars of a circular economy model are reducing, reusing and recycling (Geng et al. [2012]) of materials that are rooted in the production and consumption processes (Heshmati [2017]). Therefore, flows of material and energy are the core of circular economy and hence circular economy indicators should be able to capture these dimensions (Pintér [2006] and

Ellen-MacArthur-Foundation [2015]). Moving toward a circular economy should be of interest to all participants in the economy even those who are driven by profit-maximization because circular economy aim to maximizing products' and services' added-value throughout the entire value chain; minimizing waste and extending the length of use period of resources (EA-SAC 2015).

Effective implementation of a CE strategy requires enacting economic policies that accelerate the application and movement towards circular economy (Pintér [2006]). Then the process relies on two steps; implementation and then evaluation of the implementation. The implementation consists of action plans for the different tools such as business model, product design, system conditions and reverse logistics (Ellen-MacArthur-Foundation [2015]). Evaluation requires developing indicators that assess the circularity performance and informs policy makers towards an appropriate regulatory response. (Pintér [2006]; Geng et al. [2012]; Heshmati [2017]). This requires a set of comprehensive indicators that measure the economic, environmental and social benefits (Geng et al. [2012]) that should also be able to objectively measure what they are set for in order to inform the decision making process (Pintér [2006]). Because firms, industries and regions are heterogeneous, it is necessary to develop different sets of indicators that are able to accommodate the different characteristics and operating environments (Heshmati [2017]).

Unlike the expectations of some, circular economy indicators are not to be invented or to be developed from scratch. Pintér [2006], for example, relies on material flow analysis to develop what is called Material Flow Analysis MFA-based indicators. Material flow should be tracked based on, not only, weight but also on quality along with ecosystem sensitivity (Pintér [2006]; Geng et al. [2012]). The material flow analysis and the other sustainability aspects have been the target of Ellen-MacArthur-Foundation [2015] that developed two types of indicators; 'Material Circularity Indicator' (MCI) to capture the restorative aspect of material flow, and other 'complementary indicators' to capture the urgent need and benefits of going circular. Ellen-MacArthur-Foundation [2015] pointed out that 'provides an indication of how much a product's materials circulate, it neither takes into account what these materials are, nor does it provide information on other impacts of the product', therefore they also suggested combining MCI with complementary indicators. The MCI does not directly address one important aspect of CE which is Reduction.

In 2007, China has become the first country in the world to develop national CE indicators (Geng et al. [2012]). Two sets of CE indicators; macro and meso (inter-firm) but not micro, were developed based on the 3Rs principles and each set is comprised of four categories: resource outputs; resource consumption; integrated resource utilization; and waste disposal, which capture respectively, material efficiency; impact on ecosystem; material recycling (i.e. less virgin resources consumption) and circular economy performance efficiency (Geng et al. [2012]). Ma et al. [2014] constructed a comprehensive circular economy efficiency composite index that is composed of four indicators; level of equipment used (coal injection and iron resource efficiency); utilization level of materials; pollutant emission level; and resource consumption level of fresh water, with indicators' weights constructed from an expert questionnaire. Ma et al. [2014] circular economy composite index is directed specifically to iron and steel industry performance in moving toward circular economy and have not explicitly shown the relation of different indexes to the "Three Rs". Furthermore, they use weights which are subjective compared.

Other proposed indicators of decoupling economic growth and resource requirements at the macro-level are; relative decoupling of economic growth measured as the ratio of gross domestic product (GDP) to total material requirement; and resource productivity estimated as the ratio of GDP to direct material inputs (Moll et al. [2005]; Pintér [2006]). Other measures of how much progress are made toward circular economy include; resource efficiency scoreboard, eco-innovation index; recycling rates; and waste per GDP, though not without limitations (Bourguignon [2016]). Even though resource efficiency enhancement is essential for sustainable development it is believed that a prompt attention is required for recycling to reduce waste disposal and recycling rate needs to be constructed in a way that effectively pushes forward the recycling industry (Di Maio and Rem [2015]). Di Maio and Rem [2015] argue that the current way of constructing the recycling rate which looks at how much material enters recycling process or facility is misleading and hence propose a market value based Circular Economy Index which is calculated as the ratio of material value recycled from an end of life product divided by the value of material needed to reproduce an end of life product. This measure addresses strategic as well as environmental and economic aspects of the recycling process and requires a detailed account of all materials, parts and components of an end-of-life product that go through recycling and how much of these are used in the recycled raw materials, but nevertheless it is superior to life cycle analysis due to its simplicity and data availability (Di Maio and Rem [2015]). On the other hand, Zhijun and Nailing [2007] identified reduction as the leading principle of circular economy and stressed that environment protection is an urgent need as well.

Despite the many attempts to construct circular economy indicators, these are not without controversies. Some of these indicators are applicable to macro levels not to micro (Moll et al. [2005]) or to macro and meso levels but again not to micro level such as of China's national set of indicators (Geng et al. [2012]). This is despite that implementation of circular economy starts at the micro level; i.e. firm level and then moves up to the macro level and the entire country (Zhijun and Nailing [2007]). Also material flow analysis suffers from a number of shortcomings; it is applicable to macro level but not to meso or micro levels unless other indicators such as substance flow and life-cycle analysis are considered; there is limitation on data availability to conduct a comprehensive material flow analysis especially for developing countries; some focus on weights and not on quality (Pintér [2006]; Geng et al. [2012] and Ma et al. [2014]). There are also limitations on resource productivity measures that use material consumption; they do not pay attention to how much valuable the materials are; ignore water and land and other important resources; and merely focus on quantities rather than efficient use (Bourguignon [2016]). In addition, particular attention should be given to the weighting scheme used to aggregate circular economy indicators into a composite index. Weights assigned to individual indicators to build a composite index should echo the underlying phenomenon being captured by Molinos-Senante et al. [2014]. In fact, aggregation has been objected to due to the possible arbitrary choice of weighting method (Sharpe [2004]; OECD. [2008]). A number of weighting methods are available to aggregate individual indicators including among others; principle component analysis (PCA)/ factor analysis; correlation analysis, budget allocation process; analytic hierarchy process (AHP); and conjoint analysis, where the last three solicit opinions of experts, politicians and others (OECD. [2008]; Molinos-Senante et al. [2014]). Although PCA and correlation analysis, which are considered as direct methods, produce objective weights but the weights are considered less stable compared with the those produced by the indirect methods such as AHP which are, nevertheless more subjective (Molinos-Senante et al. [2014]). Ma et al. [2014] estimated indicators weights through a questionnaire survey of experts. Others have used different weighting methods to construct composite indicators along with sensitivity analysis to check the robustness of their measures, such as the environmental sustainability index (Esty et al. [2005]) and the composite indicator of sustainable wastewater treatment technologies (Molinos-Senante et al. [2014]).

3. Data and Methodology

3.1. Data

In order to construct the Wastewater Circonomics Index, for each of the 10 WWTPs with available data, the following variables were collected:

1. Monetary variables; capital costs; annual operating costs which include: energy, staff, reagents and other costs obtained from the Ministry of Water and Irrigation (MWI) for 2012; and the selling price of functionally- cycled water used for irrigation, obtained from Jordan Valley Authority. All values are in Jordanian Dinar.
2. Wastewater treatment parameters: average monthly wastewater influent volume (m3); amounts of chemical oxygen demand (COD) concentration (mg/L); total suspended solid (TSS) concentration (mg/L); nitrogen (N) concentration (mg/L) and phosphorous (P) concentration (mg/L) in the influent. In addition, the amounts of COD concentration (mg/L) and (TSS) concentration (mg/L) in the effluent. All variables were obtained from the MWI. For of the COD and TSS, the removed amounts were calculated as the difference between the amount in the influent and the amount in the effluent. For N and P, the removed amounts were calculated as the difference between the assumed amounts in the influents; 85 (for N) and 50 (for P), respectively (Uleimat [2012]) and the amount in the effluent.
3. Consumer price index obtained from the Central Bank of Jordan (www.cbj.gov.jo), in order to adjust capital costs for inflation, as these costs were incurred in different years
4. Reclaimed water price is JOD0.075/m^3 (Abu-Ghunmi et al. [2016])

Each selected WWTPs employs one of the following treatment technologies; Activated sludge; Extended aeration; Oxidation ditch; and Trickling filter.

3.2. Methodology

The objective of a CE is an efficient production that optimizes/maximizes resources productivity; material; energy; labour and money, and minimizes/eliminates waste disposal. Maximizing productivity and eliminating waste are interrelated, which, had it been accomplished, would maintain an environmentally and socially viable economy. In order to assess the circularity performance of a wastewater treatment plant (WWTP), required is a comprehensive composite indicator that is capable of tracking the 3R principles of circular economy; Reduction; Reuse; and Recycle, which also addresses the economic, environmental and social performance of a WWTP. This provides a theoretical background for constructing a composite indicator for circular economy, which we call a Circonomics Index. Establishing the theory behind an index is the first step toward developing an index that fits for purpose, which is followed by selection and analysis of relevant data, aggregation, weighting scheme selection and uncertainty analysis (OECD. [2008])[1].

Therefore, the next step is selecting, based on data availability, individual indicators that capture the "Three Rs" (see green development index of Zhijun and Nailing [2007]);

R1; Reduction, which refers to production efficiency; using minimum amount of energy and materials to produce a product with the lowest waste discharge and negative impact on the environment. Resources' reduction is described as the leading principle of a CE (Zhijun and Nailing [2007]; Su et al. [2013]). For wastewater industry, the current study proposes calculating the following efficiency indicator for each WWTP (p):

$$WPEI_p = \frac{(AVRW * SellingPrice) + (AMRP * AverageSellingPrice)}{AOC + ACC} \tag{1}$$

where WPEI represents Waste Production Efficiency Indicator, AVRW represents Annual Volume of Reclaimed Water, AMRP represents the Annual Mass of the Removed Pollutants, AOC is the Annual Operating Cost and ACC is the Annualised Capital Cost. This indicator measures the monetary value of the two major components of wastewater treatment process[2]; the annual treated wastewater effluent flow (measured in volume unit; cubic meter (m^3)) and the removed pollutants (nutrients; undesirable outputs) (measured in mass unit; kg) to the total annual costs. Operating and capital costs represent the value of input resources, i.e. material, energy and other production factors that are used to produce the output. The two main outputs of wastewater treatment industry are the reclaimed water, which is referred to in the context of circular economy as 'functionally-cycled' water (Abu-Ghunmi et al. [2016]) and the removed pollutants; such as nitrogen, phosphorous, etc. This firm's level measure is consistent with Ellen-MacArthur-Foundation [2015] proposed circular economy indicator for resource productivity, at macro level, calculated as the ratio of GDP to domestic material consumption, and Geng et al. [2012] measure of GDP to mineral resources. It should be noted here that capital costs were adjusted for inflation and converted, using time value of money concept, into their equivalent annualized capital cost assuming 5% cost of capital and 25-year useful life for WWTP.

R2; Re-use, which refers to the reuse of a product at the end of its consumption life in other processes, industries, facilities, etc. (Zhijun and Nailing [2007]; Su et al. [2013]). The Re-use

[1]See p.21 for the other three steps of back to data, links to other indicators and visualization
[2]Assuming efficiency is 100%; no loss of water volume.

indicator for each undesirable output (removed pollutant) of a WWTP is calculated as follows:

R3; Where O; represents COD, TSS, N or P (in Kg). Re-use indicator measures the annual removed COD, TSS, N or P (Kg) - which are undesirable outputs in the case of WWTP - as a percentage of their corresponding annual amounts in the influent, assuming these outputs are removed from wastewater and then reused in economic activities such as in agriculture. If not all removed nutrients and sediments re-enter the economy; i.e. disposed of in the environment, then the Re-use indicator is calculated as follows:

$$WastewaterReuseInd._Q = \frac{AnnualReusedPollutant * AveSellingPrice}{AnnualRemovedPollutant * AveSellingPrice} \tag{2}$$

Eq. (2) is consistent with the Ellen-MacArthur-Foundation [2015] measure of 'the fraction of the mass of the product going into component reuse' in their calculation of the Material Circularity Indicator.

The next step is combining Wastewater Re-use indicators into a Composite Re-use Indicator. Aggregation of indicators better captures what is intended to be measured and summarizes the information in a meaningful and easy way to understand, however, choosing the appropriate weighting process is a challenge (OECD. [2008]). The Composite Wastewater Re-use Indicator is calculated as follows:

$$CompW.ReuseIndic_p = \frac{\sum_{Q=1}^{M} WastewaterReuseIndicator_Q * ShadowPrice_Q}{\sum_{Q=1}^{M} ShadowPrice_Q} \tag{3}$$

The novelty in this paper is the use of shadow price as the weighting scheme in constructing the Composite Re-use Indicator. It is a value-weighted Indicator, where the weights are the corresponding shadow prices of removed pollutants. The rationale is that as shadow prices reflect avoided costs and hence environmental benefits of treating wastewater, then the removed percentage of each pollutant should be weighted by its shadow price to reflect its relative environmental benefits. This meets the requirement of a composite indicator to capture the economic and environmental aspects of circular economy in order to drive effective polices, as using market value instead of mass relates the index better to economic and environmental policies (Ma et al. [2014]). Furthermore, this weighting scheme is consistent with the theory behind circular economy, which makes it consistent with the requirement of OECD. [2008] in choosing the weighting scheme to build a composite indicator. Using shadow price as weighting scheme is also a response to the argument of Ellen-MacArthur-Foundation [2015] which criticizes their resource productivity measure of not reflecting environmental cost in the weights used to construct the material consumption component of the measure.

Shadow price was calculated following Hernández-Sancho et al. [2010][3] using the distance function of Färe et al. [1993] that compares the true production output with the more efficient production process. Also Färe et al. [1993] has applied this method to calculate shadow prices for undesirable

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

outputs of wastewater treatment plants.

Re-cycle, which refers to the use of primary products or material many times rather than only one time. Establishing the right recycling rate is imperative to set policies that move an economy into a circular model as the ineffectiveness of the current measures of recycling performance has resulted in policy makers not doing enough to enhance recycling industry (Di Maio and Rem [2015]). Wastewater Recycle Indicator for an $WWTP_p$ is calculated as follows:

$$W.CirconomicsIndexWWTP_p = \frac{TotalUsedReclaimedWater * Price}{AnnualReclaimedWater * Price} \quad (4)$$

It represents the percentage of functionally cycled water (reclaimed wastewater) that is produced by a WWTP and used by economic activities; i.e. functionally-cycled wastewater that has stayed in the economy and not discharged into watersheds and therefore has reduced pressure on virgin fresh water. In the ideal scenario when all recycled water has been returned to the economy, then the value of eq. 4 equal 1. Eq. 4 measures 'the fraction of feedstock derived from recycled sources', which is part of their Material Circularity Indicator calculation and Geng et al. [2012] macro level measure of wastewater recycling rate.

Careful attention should be paid to how indicators are aggregated, what weights are used, source of data and uncertainties involved (Di Maio and Rem [2015]). This paper overcomes problem of aggregation and hence weighting scheme for the overall index by calculating the overall Wastewater Circonomics Index for a WWTP as follows;

$$\begin{aligned} W.CirconomicsIndexWWTP_p = & WastewaterProductionEfficiencyIndicator_p \\ & * CompositeWastewaterReuseIndicator_p \\ & * WasterwaterRecyclingindicator_p \end{aligned} \quad (5)$$

The Wastewater Circonomics Index measures production efficient as well as recycling and reuse efficiencies of each WWTP.

4. Results and Discussion

In order to reduce the risks that businesses could be exposed to due to price volatility and the potential disruption to supply chain and to open the door to innovation in business models and technologies, policy makers should set proper legislation to stimulate movement to a circular economy model (and recycling) and hence comes the urgent need for an appropriate circular economy index (Di Maio and Rem [2015]). As long as enhancing wastewater industry efficiency and protecting water resources are on the priority list of government agenda, then our index; Wastewater Circonomics Index, and indicators components of circular economy; Production Efficiency Indicator, Composite Reuse Indicator and Recycled Indicator, are the right measures. This is important as certain criteria should be considered when developing and selecting circular economy indicators and indices including integrating the indicators into the current system such as the current accounting system;

and they should be linked to some specific policy objectives in order to be used for performance evaluation (Pintér [2006])

The "Three Rs" of circular economy are; reduction, which indicates improving production efficiency through using less inputs of materials and energy to produce the same amount of outputs; reuse, which means extending life of the product as well as using wastes and by-products of firms and/or industries as inputs to other firms and/or industries, and recycling, refers to converting recyclable products into new materials and products to ease the stress on virgin materials (Su et al. [2013]). Figure 1 attempts to measure each of these dimensions (Rs) for each WWTP in the study in order to gauge how far each of these plants have moved toward circular economy and to shed light on which technology best supports this transition. Using shadow prices of undesirable outputs of each WWTP, as weighting scheme, the results show that plant (TF1) has the highest value of the Wastewater Circonomics Index. In calculating Circonomics Index for this study, the Recycled Wastewater Indicator is assumed to equal one for all WWTPs, due to data unavailability. TF1 has the highest CE performance and it employs trickling filter technology. Interestingly this WWTP has the second highest production efficiency indicator and the fourth highest composite reuse indicator. While, the plant with the highest production efficiency (TF3) also employs trickling filter technology, the WWTP (AS2) that scores the highest value for the re-use indicator employs activated sludge technology. On the other hand, this latter plant has the lowest production efficiency, which is clearly the reason why it has a low value of Circonomics Index. In other words, even activated sludge technology has the highest value for removing sludge and nutrients from wastewater and hence provides the highest re-use rate (it was assumed that the removed sludge is re-used). Its overall low CE performance results from it low efficiency. AS2 has the highest construction cost but the average daily flow is much less than the capacity of the plant, which clearly shows that it operates way under its capacity that may explain the high cost per unit of flow. This has two implications; the high cost is partially due to operating below capacity and secondly due to the inherent high cost of activated sludge, evidenced by findings that the other two WWTPs with activated sludge technology; AS3 & AS1, have the third and fourth lowest production efficiency, respectively.

Figure 1 shows ten Wastewater Treatment Plants (WWTP) performances toward circular economy that are measured in terms of Wastewater Production Efficiency Indicator (WPEI) (square), Single Wastewater Re-use Indicator (SWRI) (circle) and Wastewater Circonomics Index (triangle). WWTP are represented by their applied treatment technology: Trickling Filter (TF), Activated sludge (AS), Oxidation Ditch (OD) and Extended Aeration (EA). Calculation is based on using each WWTP Shadow prices. In calculating Wastewater Re-use Indicators, it was assumed that the total amount recovered is reused.

Insert Figure 1 about here

The high re-use performance of activated sludge technology comes from either high shadow prices or high removal percentages or from both. For example, the highest shadow prices of COD and N were achieved by AS2, and the same activated sludge plant (AS2) has the second highest shadow price of TSS. AS1 has the highest removal percentage of P while the highest removal percentage of TSS achieved by AS2 followed by AS3 and then by AS1. As long as these nutrients are used by other industries, such as using sludge in agriculture as fertilizers, which is assumed in this study, then this measures the of re-use rate. Sludge is a waste according to the linear economy model, so if this waste is reused as inputs to other industries it will be kept longer in the use -cycle which is consistent with the re-use concept of circular economy.

As mentioned earlier, the performance of any WWTP on the composite re-use indicator is derived from the weight; shadow prices, and the removal percentages of the undesirable outputs. To eliminate the impact of the differences in shadow prices between WWTPs and to focus the attention on the removal performance of each technology and hence the reuse rate of each WWTP, Figure 2 uses average shadow prices of all WWTPs as weights for undesirable outputs; COD, TSS, P and N to calculate the Composite Water Reuse Indicator. Therefore it neutralizes the effect of shadow prices and leaves the effect to sludge and nutrients removal efficiency. In fact, average cost in a competitive market should converge. The results in Figure 2 confirms our earlier findings that TF1, which employs trickling filter technology, still has the highest Circonomics Index, while AS2, which uses activated sludge, has the lowest CE performance. The results also provide a robustness check to the methodology used to construct the Circonomics Index and its components.

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Insert Figure 2 about here

The overall results show that trickling filter is consistent with circular economy. It has high production efficiency and performs moderately on the reuse dimension. Therefore, adopting this technology might accelerate moving wastewater industry toward circular economy, especially if WWTPs that use this technology enhances the removal and hence the reuse possibility of the undesirable outputs; COD, TSS, N, & P. Furthermore, CO_2 emission is best for trickling filter and worst for activated sludge, which supports our findings of the superiority of the CE performance of trickling filter technology. On the other hand, although, the findings of this paper show activated sludge technology suffers from huge production inefficiency that renders it with a low overall performance on the CE measure, this technology has great reuse potentials. Therefore, attention should be directed to improving the production efficiency of this technology.

Wastewater treatment plants are destined to circular economy model by its very nature. The major output of wastewater industry is the functionally-cycled water, which would ease the stress on virgin water sources that are in danger of drying up, particularly in countries that are already enduring water shortage. Our measure of recycle; Recycled wastewater indicator, which is the ratio of the used reclaimed (functionally cycled) water to total reclaimed water is consistent with Di Maio and Rem [2015] proposed measure of Circular Economy Index. They defined their measure as the percentage of material (measured in market value) required to reproduce an end-of-life product that comes from the recycled material of the end-of-life product. However, our measure, due to the specific nature of waster sector, relates the market value of used recycled water to the market value of the total reclaimed water. The higher is the percentage of the Recycled wastewater indicator the greater is the circularity. This percentage increases as the total volume of wastewater reclaimed and used back in the economy in each WWTP increases.

Our measure of circular economy; the Circonomics Index and its three components; Production Efficiency Indicator, Re-use Indicator and Recycle Indicator are important tools for governments in countries that adopt the circular economy strategy. The relative performance of the Circonomics Index and its component indicators would enable policy makers to track whether the firm is moving over time closer to a circular economy business model as well as relative to other companies. Furthermore, the Circonomics Index sheds light on the best performers in the industry which would help policy makers to take decisions regarding what technologies to adopt to accelerate movement to circular economy. In addition, by decomposing the performance based on the three components; production efficiency; reuse; and recycle, decision makers would be able to pinpoint the strengths and weakness of each industry in moving to circular economy business model and hence capitalize on its strengths and overcome its weaknesses.

5. Conclusions

The unsustainable demands placed upon natural resources and the wider ecology by economies linked to the "linear economy model", merits a move towards a more sustainable model as outlined in the idea of the circular economy. Every single industry should adopt a circular economy model and the water industry, especially in countries with water shortages, should be a pioneer. This study addresses how to measure the circular economy performance of the water industry, investigating the wastewater treatment sector.

We propose a Wastewater Circonomics Index, which is composed of three indicators; wastewater production efficiency indicator; composite wastewater re-use indicator; and wastewater recycling indicator, to capture the reduction, reuse and recycle concepts that made circular economy. The novelty of this study is using an objective weighting scheme for the composite reuse indicator, which is constructed using shadow prices of undesirable outputs of wastewater treatment. Shadow prices represent the avoided costs or the environmental benefits of treating wastewater.

Another contribution that this paper provides stems from relating each indicator to one of the "Three Rs" of the circular economy; reduction, reuse and recycle. This enables measuring the performance of wastewater industry on each of circular economy concepts separately and hence addressing where efforts need to be concentrated to advance wastewater sector to a circular economy model. The proposed Wastewater Circonomics Index, due to the selected components indicators, reflects the reuse and recycling rates of treated wastewater. The application of this measure of circular economy to Jordan wastewater sector, shows trickling filter technology has the best circular economy performance. The high performance comes primarily from the high production efficiency of this technology, while it scores a moderate performance on the re-use indicator. Interestingly, activated sludge technology has the highest performance on the reuse indicator, even though its overall circular economy performance as measured by Wastewater Circonomics Index resulting from its production inefficiencies. The results have important policy implications. In order to speed up the process of moving water industry to circular economy, trickling filter technology seems to be the best candidate. Furthermore, its circular economy performance could be improved by looking to ways to increase its removal and hence reuse rate. On the hand, despite the poor performance of activated sludge technology on the circular economy index, this is due to its low production inefficiencies. This suggest that there is a need to look to how to improve the production efficiency of this technology, where the potentials could be high.

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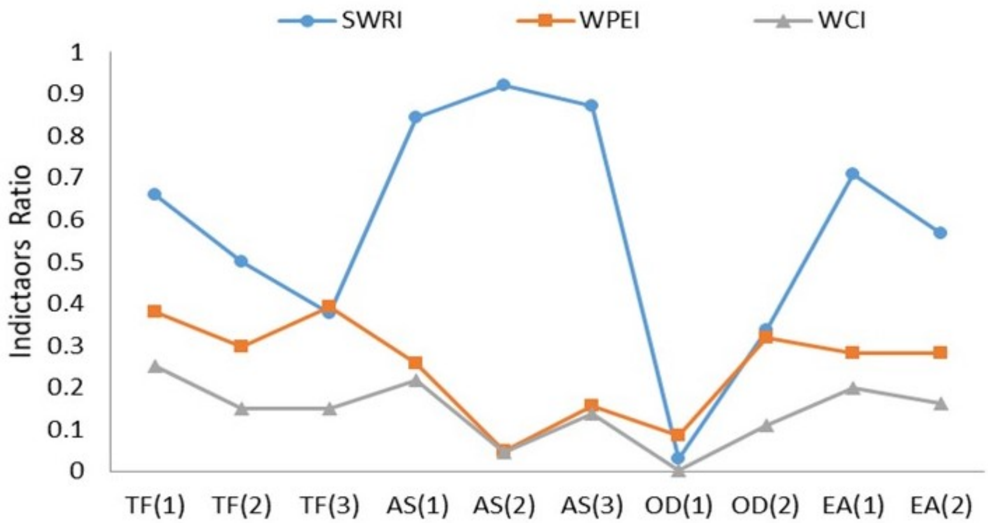
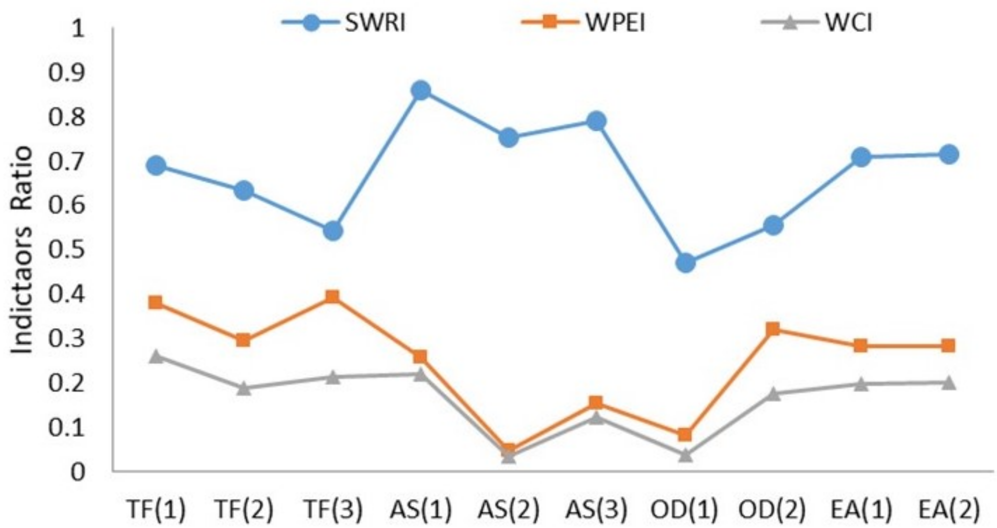
Figure 1: Ten Wastewater Treatment Plants (WWTP) performances toward circular economy



Note: The above figure shows ten Wastewater Treatment Plants (WWTP) performances toward circular economy that are measured in terms of Wastewater Production Efficiency Indicator (WPEI) (square), Single Wastewater Re-use Indicator (SWRI) (circle) and Wastewater Circonmics Index (triangle). WWTP are represented by their applied treatment technology: Trickling Filter (TF), Activated sludge (AS), Oxidation Ditch (OD) and Extended Aeration (EA). Calculation is based on using each WWTP Shadow prices. In calculating Wastewater Re-use Indicators, it was assumed that the total amount recovered is reused.

Figure 2: Ten Wastewater Treatment Plants (WWTP) performances toward circular economy



Note: The above figure shows ten Wastewater Treatment Plants (WWTP) performances toward circular economy that are measured in terms of Wastewater Production Efficiency Indicator (WPEI) (square), Single Wastewater Re-use Indicator (SWRI) (circle) and Wastewater Circonmics Index (triangle). WWTP are represented by their applied treatment technology: Trickling Filter (TF), Activated sludge (AS), Oxidation Ditch (OD) and Extended Aeration (EA). Calculation is based on using Average Shadow prices of all WWTPs. In calculating Wastewater Re-use Indicators, it was assumed that the total amount recovered is reused.