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Review

Economic assessment of nature-based solutions as enablers of circularity in water systems

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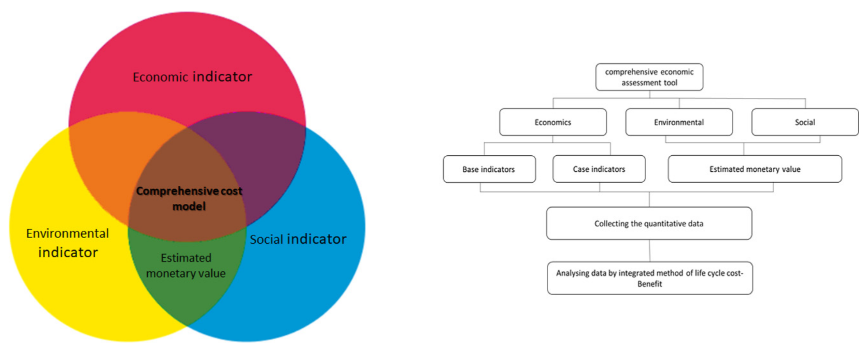
HIGHLIGHTS

- There is a gap in body of knowledge for a systemic method for assessing the economic impact of circular models in Water System.
- There is no inclusive economic impact analysis of NBS for managing water.
- Environmental and societal impact of Circular Economy need to be included in cost-benefit analysis of NBS in Water Systems.
- Water Circularity assessment is multifacetted Socio-Economic problem.
- This work combines the monetary value of environmental and social gains verses technology investment costs.

GRAPHICAL ABSTRACT



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ABSTRACT

The transition from the current linear model of abstraction, use and discharge of water into recycle-reuse under the circular economy (CE) principles is momentous. An analysis of recent literature about the economic impact of *linear to circular* (*L2C*) transition is made. The review investigates the economic implications (i.e. cost-benefit) of deployment of enabling technologies, tools and methodologies within the circular water systems. The study is enhanced by presenting the results of our investigation into the policy impact (push-barriers) of L2C transition. As the vehicle for the L2C transition, nature-based solutions (NBS) and its economic and policy implications is discussed. A framework is proposed for the monetary assessment of the costs of investment in NBS technologies, infrastructure and education against the environmental and socio-economic benefits within the policy frameworks. This framework may build the early foundation for bridging the gap that exists for a systematic and objective economic impact (cost-benefit) analysis of L2C transition in the Water sector. This framework will lead to a generic multi-parametric cost model of NBS for Circularity Water Systems.

Contents

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1. Introduction

Economic development is driving population growth, changes in land use, agricultural and urban expansion leading to the overexploitation of water resources (Zhang et al., 2017). It is estimated that by 2030 there will be a 40% deficiency of drinking water worldwide, conferring to the 2015 United Nations report on the development of global water (WWAP, 2015). The existing resources in a short time will be stretched to breaking point, due to the severe water resource exploitation in Europe, especially freshwater (EEA, 2015; European Commission, 2012; UNEP, 2017). Better water demand management can minimize the damage to the environment and regenerate the natural ecosystems (WWAP, 2018). The linear pattern of "take-make-consume and dispose" is not a sustainable model for the water industry, since water is successively qualitatively degraded after use in human-managed systems that follow a linear model and becoming unfit for further use by both humans and ecosystems. (Stuchtey, 2015). Therefore, adoption of the circular economy (CE) model is proposed in response to the linear pattern that decouples economic growth and development from the consumption of finite sources (Murray et al., 2017; Babbitt et al., 2018; Hofmann, 2019). The circular economy approach emphases on closing water material and energy loops and thereby on decreasing environmental influences and boost the economic performance by retaining the value of materials in circulation. CE offers a way to close resource loops and increase the lifespan of resources, leading to the more sensible use of natural resources and recycling and reusing nutrients to gain their full value at the minimum cost (Ellen MacArthur Foundation, 2017; Naustdalslid, 2014; Scheepens et al., 2016; Zink and Geyer, 2017; Busch and Ferretti-Gallon, 2017). The water can be seen as a media of resources which should be considered for changing to circular pattern came from its importance concerning energy and materials it holds (Veolia, 2014).

To make a successful transition from a linear economy to a CE, the development of a new business model that has extra added value combined with lower eco-burden (less resource consumption as well as less environmental pollution) is needed (Scheepens et al., 2016). Due to the importance of water and wastewater for having energy and nutrients such as phosphorus (8.01% P_2O_5), calcium (5.11% CaO) and magnesium (2.75% MgO), the water management is one of the main tasks that gets attention in studying CE concepts (Smol et al., 2020).

Different types of uses must be defined in the business to properly evaluate circularity of water systems. In business sectors, the major distinction in economics evaluation of circularity pattern in water system is made between its direct and indirect use. Water as an economic good may be called an intermediate or consumption good. For end products (e.g., agriculture, industry, clean potable water) intermediate goods are used, whereas consumption goods provide direct human satisfaction (e.g., water used by households). In the case of intermediate goods, the conceptual valuation structure is given by the economic theory of a profit-maximizing producer, whereas the utility-maximizing market theory is used in the case of consumer goods (Young and Loomis, 2014; Spellman, 2015). To assess the sustainability of CE, two set indicators including the Material Circularity Indicator, a key indicator that tests how the material flows of a commodity or enterprise are restorative and Complementary indicators that help to consider additional impacts and risks, have been developed by EMF (Ellen MacArthur Foundation) and WEF (World Economic Forum) (2017) and EMF (Ellen MacArthur Foundation) and Granta Design (2015). Different aspects of the circular economy have been covered by these indicators.

Some economic indicators that work in evaluating the circular economy have been chosen from literature (Table 1).

According to the definition of Global Cost in the Standard EN 15459:2007, the Global cost is the foundation for the Life Cycle Costing approach (European Committee for Standardization CEN, 2007). Two methods have been introduced to calculate the Global cost in the economic standard including (i) the global cost method, and (ii) the annuity method. The global cost method applies to make a comparison between the different scenarios in terms of economic feasibility by studying the energy need for different scenarios and calculating the economic performance as a whole versus calculating depreciation on an asset by calculating its rate of return on the annuity method (Fregonara, 2017). Several economic indicators are used to determine the global cost method including Net present Value (NPV), Net Savings (NS), Simple or Discounted Pay Back Period (PP), Savings to Investment Ratio (SIR), and Adjusted Internal Rate of Revenue (AIRR).

Table 1
Economic indicators to measure the circularity of water system.

Dimension	Indicators	Study
Indicators on CE influenced by harmonized economic	Production indicators (land-product ratio). Reuse indicators (water reuse) Resource index (emission of industrial gases or solid waste)	Zhijun and Nailing (2007)
Economic development (evaluation indicator)	Gross domestic product per capita, the proportion of tertiary industry (%) The weight of high technology in GDP (%) Social welfare (household disposable income in monetary units, level of urbanised development (%) The net annual income of rural households	Chen et al. (2015)
Economic performance (level of sustainability)	The overall effectiveness of the equipment, Remanufacturing process flow, Adequacy of remanufacturing process planning, Availability of machines and tools, Level of service and level of stocks consumed.	Golinska et al. (2015)
Economic development indicators (performance measures in eco-industrial parks)	Industrial value-added per capita The growth rate of industry (%)	Geng et al. (2009)

Transition to NBS has been suggested by many researchers to work compatibly with ecosystems to mitigate and adapt climate change effects, conserving biodiversity and enhancing human health and wellbeing (Cohen-Shacham et al., 2016). Copying nature or biomimicry has gained growing attention across EU over the past decade. Adaptation to climate change (EC, 2009, EC, 2013), biodiversity protection (EC, 2011a), integrated water resource management (EC, 2012, EC, 2014), and disaster risk reduction (EC, 2011b), all come under Ecosystem-based creativities category.

The European Commission expressed NBS as “solutions inspired and supported by nature, designed to address societal challenges which are cost-effective, simultaneously provide environmental, social and economic benefits, and help build resilience” (European Commission, 2016; Raymond et al., 2017a). NBS can be applied in resolving either a specific problem like climate change or multiple problems (Cohen-Shacham et al. (2016).

Different frameworks have been proposed to analyse and assess the effectiveness of NBS from environmental and economic perspective. Liquete et al. (2016); Raymond et al. (2017b); and Zölch et al. (2017) have focused on assessing NBS in European urban or peri-urban environments, whereas Reguero et al. (2018) and Narayan et al. (2017) have focused NBS concerning avoided losses of coastal hazards in the United States. Due to ongoing environmental changes that may affect the capacity of NBS to deliver the expected outcomes, it is important to design ‘dynamic’ assessment frameworks which account not only for that impact climate change has on the frequency of the hazards of interest but also on the way the effectiveness of the proposed solution will be affected. Pearlmutter et al. (2020) mentioned that NBS in the built environment, can contribute to CE and through the establishment of ecosystem services, reduce the negative impacts of urbanization. For each natural or man-made product, the concept of CE is to create a closed-loop by converting the linear resource flow into a circular flow. The scale of thinking for the urban environment must be more global to solve urban metabolism as a whole and establish not only unique CE systems, but also an overarching framework of resource management for the urban biosphere. Therefore, since such systems can be modified and run decentralised where the highest demand exists, NBS proves to be a sufficient way to fix significant problems at the local level. In addition to their initial technological goals, the main advantages of NBS are the effect on urban micro-climate and resident leisure purposes (Langergraber et al., 2020). Although the CE aims to minimize the environmental burden of socio-economic activities, it has the potential to boost the environmental and ecological status of NBS and to tackle the human demand for natural resources. By altering the fluxes of water, sediments, nutrients, and pollutants, NBS will restore the critical natural processes that drive the water cycle and thus return the circularity to the water systems. The transition to circular water systems includes the renovation of the water infrastructure, the application of recent developments in knowledge and the combination of nature-based ecosystems to the grey infrastructure (O'Hogain and McCarton, 2018). NBS promote the transition from open to closed loop by restoring water supplies, such as nutrients that fit into natural water and nutrient cycles (Cohen-Shacham et al., 2016; Raymond et al., 2017a, b; O'Hogain and McCarton, 2018; Langergraber et al., 2020). consequently, NBS is an imperative stimulus for developing a circular economy and can be counted as an enabler of circular water systems since there are interactions adopted between the two concepts of NBS and CE. With this in mind, analysing NBS can be a pattern to assess the moves toward circular economy. This research links the economics of implementing circular water systems through NBS as enablers of water circularity. An effort is made here to provide a method to evaluate the economic efficacy of NBS based circular water systems. The objective is to provide an interpretation of the circumstances where NBS could mitigate against risks of grey infrastructure, whilst making good economic sense. The proposed systematic and breakdown of the key attributes of NBS in circular water systems would allow practitioners and researchers to better assess the cost-benefit of investing in such solutions.

The primary aim of this review is to summarize and evaluate the literature considering the economic impact of CE transition models in the water sector. Moreover, it analyses and discusses the applied economic models and related indicators to assess the economic performance aspects of the circular economy. As a final point, this study discusses the methods that can be applied to comprehensively assess the economic sustainability of a circular water system. Since the NBS and applying CE in water system are relatively new subjects, the findings of this study are limited due to lack of long-term and continuous empirical studies available in the literature. Most literature are relatively recent and starts from late 2000s. A combination of the existing literature and five case studies being implemented in an EU-H2020 research programme are the basis of the presented work.

The presented research work intends to provide an encompassing economic perspective to the implementation of NBS as an enabler of circular water system. To the best knowledge of the authors a combination of classical direct economic analysis and external impact analysis using live case studies has not been attempted before. This study for the first time combines advanced economic assessment tools to propose a more realistic assessment of economic, environmental and social characteristics of NBS solutions in Circular Water Systems. The result of this work is an attempt to fill the gap in the body of knowledge and contribute to the transition to CE of the Water Sector.

This study is structured in 5 sections. Section 2 discusses the tools and methods assessing economic impacts of the circular economy in water management systems. Section 3 focuses on the methodology for systematic analysis considering the economic impact assessment of NBS as an enabler of a circular water system, and the applied methods, tools, and indicators are analysed. The main results and gaps that have arisen from literature and a proposal of a method that can be used to assess the economic sustainability and circularity of a water system is the main objective of Section 4. Section 5 provides the main conclusions of the current study.

2. Most widely applied tools for economic assessment of circular water management system

Water scarcity and the issues in supplying freshwater (Arnell and Delaney, 2006; Cromwell et al., 2007; Dworak et al., 2007; EEA, 2007; Mukheibir, 2008), has led the water managers to seek a way for water management system (Smith and Rodrigues, 2015). Three recent white papers by Stuchtey (2015), IWA (2016) and Arup et al. (2018) emphasize on building various water functionalities that may create harmony between water withdrawals and return streams. Arup et al. (2018), categorized the three principles of circular water system of “Design out waste externalities”, “Keep resources in use” and “Regenerate natural capital”. To the best knowledge of the authors, the proposed method is yet to be implemented in practice and has yet to prove whether it would provide a comprehensive framework for assessing circular water systems.

The fragmented management and execution of such models would struggle to achieve the intended results. Therefore, the development of a comprehensive economic assessment framework would be a timely to support circular water management approach. The authors suggest an assessment model that takes into account the economics of water, energy and material as well as environmental and social impacts to create an integrated water management analysis.

Cost assessment is one of the most important and crucial aspects of the feasibility and sustainability assessment of water recovery projects in the water sector (Sipala et al., 2003). Cost prediction for the water system is not an easy procedure and, a detailed cost function comprising environment, social and economic parameters is required to make comprehensive cost predictions of various scenarios. Water management interventions within water supply management system, water demand management system, and wastewater system go through a systematic appraisal that has technical, economic, environmental, and social dimensions (Herrington, 2003). Any intervention as part of a decision-making process in the water management system requires an understanding of its feasibility and impact from environmental, social, and economic perspectives (Arena et al., 2018).

The cost of wastewater treatment is dependent on the size, population served, type of wastewater, and a used treatment. For example, if the size of plants increases the cost will be decreased (De Martino et al., 1969). D'Antonio et al. (1970) illustrated the relationship between the costs and the physical parameters such as tank volume, transverse area, installed electrical power, etc. Pinheiro et al. (2018) proposed a cost function for five types of wastewater treatment plants (WWTP) based on their hydraulic and physical characteristics, using a simple linear regression model. The results allowed one to assess the capital costs of a new WWTP and the current value of existing assets at strategical and tactical planning levels without having data on the specific components of the facilities. This method can be used in wastewater reuse project within the concept of circular economy. However, the results allow the estimation of the capital costs of new wastewater systems at strategic planning levels of the current value of existing assets without awareness of the particular components of the facilities. Additionally, for applying this method to analyse circular water systems, the operation, maintenance and disposal cost functions should be evaluated as well. Abu-Ghunmi et al. (2016) focused on the economic dimension of transition to wastewater circularity in non-domestic scale, and by applying CBA, the net opportunity cost of the non-circular water industry calculated the ‘closing the loop charge’. The estimation of the net present value (NPV) of opportunity cost at various water prices, which are far below the average price of drinking water, revealed that the costs were compensated by the financial and environmental benefits associated with a circular model. Therefore, going circular in the water industry is economically feasible and beneficial. This study lacks a systematic economic framework to determine not only the wastewater management system itself but the circularity of the entire system. Also, there is no single database for cost allocation of wastewater treatment externalities to use it in economic analysis of circular economy. Acampa et al. (2019) provided a tool to estimate the construction cost of a conventional urban wastewater treatment plant with medium-low capacity (<50,000 pe). This tool is useful for the project funded by public administration capacity building, which defines how to invest the available public financial resources is a crucial phase. In addition to water-saving steps, the treatment and reuse of wastewater provide a safe water source solution as part of an integrated approach to water management. The results helped the generation of a new rule including the concept of an ‘action plan on the circular economy’, with the dual aim to ensure the reduction of waste and protection of European water resources. This study examined the 28 tenders awarded between 2001 and 2011 for the adjustment and new construction of wastewater treatment plants in the Sicily Region. Construction costs were calculated according to two different procedures: a synthetic estimate of the costs for civil works, using parametric costs; and a multiple linear regression for the cost of the electromechanical equipment. These functions enable the establishment of relationships between construction costs and the Population Equivalent (PE). Excluding the operating costs (staff, energy, reagents, etc.) from this study is the main drawback of this research.

In order to capture the reduction, reuse and recycle principles of circular economy, Kayal et al. (2019), proposed a Wastewater Circonomics Index consisting of three indicators; wastewater output efficiency indicator; composite wastewater reuse indicator; and wastewater recycling indicator. The innovation of this analysis was the use of a composite reuse indicator objective weighting system, which is built using shadow prices of undesirable wastewater treatment outputs. Each indicator connects to the circular economy's ‘Three Rs’, reduction, reuse and recycling. This makes it possible to independently assess the output of the wastewater system on each of the principles of the circular economy and thus discuss where efforts need to be focused to advance the wastewater sector to a circular economy model. In order to have a comprehensive circular economy index, main parameters of the water industry should be considered depending on the scope of the study. Maaß and Grundmann (2016), performed an economic assessment based on the added-value from the reused wastewater and the cost-benefit analysis. The connection of crop production, value chain of wastewater treatment, and production of bioenergy through the reuse of treated municipal wastewater and sludge was assessed economically. The benefits were measured by comparing the cost of the application of sludge with conventional disposal options and wastewater irrigation, as well as by comparing between the cost of irrigation and fertilisation of treated wastewater and the groundwater irrigation and fertilisation with minerals. By assessing the remuneration obtained by stakeholders in the different value chains the value added was determined. The results demonstrated that the mentioned linkage via the agricultural reuse of wastewater and sludge can add to regional economic growth. The tenacity of the proposed reuse scheme in this study is associated to the institutional regulation of the agricultural sludge use. Therefor applying this scheme in other area is not promising. Hadjikakou et al. (2019), proposed an integrated method to evaluate the water supply option. The approach of hybrid multi-regional input-output-based life cycle assessment (MRIO-LCA) is a combination of multi-criteria decision analysis (MCDA), and social impact analysis. Due to its capacity to integrate different indicators, this approach presented a verified computational engine for performing sustainability assessment by measuring a selection of the triple bottom line indicators associated with key water supply option's processes. Although the data availability is limited at the early stage of project, the proposed model presents the result within the range of process-based LCAs. There are some limitations for this study as in any quantitative assessment including the selection of the criteria; a number of additional factors could be incorporated into the framework. Also, the product resolution of the proposed model is far less than the process-based LCA approaches. Liquete et al. (2016) applied a multi-criteria analysis as a basis for an integrated valuation to evaluate the sustainability of green infrastructure (a series of constructed wetlands surrounded by a park) in a peri-urban area. The authors addressed a specific strategy required at territorial level in the application of the EU Water Framework Directive. The proposed economic assessment model was based on cost-benefit analysis considered; a set of case-based crucial criteria (indicators). The indicators of the value of wood production, reduce public costs including total construction costs, and total maintenance costs were assessed through a multi-criteria analysis. The exclusion of public cost scores due to lack of quantified values is the limitation of this study.

Vásquez-Lavín et al. (2020) applied the production function method to estimate the marginal productivity of water which relates to its economic value. A trans-log specification studying capital, labour, energy, and material, have been used for cost function estimation and production function estimation. They concluded that the water in the non-domestic sector has an elastic demand. Policymakers can establish water policies that promote the management of water demand by having knowledge about the economic value of water. Although this approach helps to design public policies based on water used efficiency and effectiveness of the industrial sector, its results cannot be counted for the effect of water-saving amount and firm characteristics that are essential for policy purposes due to aggregation considered and lack of enough data. Severis et al. (2019), performed the economic, risk and sensitivity analysis to assess the feasibility of three rainwater harvesting (RWH) systems planned to supply for single-family residences. The systems were assessed based on water demand, distribution arrangement and degree of treatment. The net present value, return of investment and benefit-cost ratio were calculated as the economic indicators. The sensitivity analysis was performed and revealed that the system's economic viability is sensitive to demand, water price, initial investment cost and discount rates. The drawback of this study is that the cost of

Table 2
Economic assessment tools for the circular water systems.

Study	Methodological approach	Tools	Description	Scale	Components	Application
Abu-Ghunmi et al. (2016)	Opportunity cost and shadow price	Cost-benefit (CBA)	Estimating the net opportunity cost of a non-circular water industry, the economic 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'.	Municipalities & industrial	Annual effluent volume reclaimed wastewater selling price for irrigation, annual amounts of COD, TSS, P, and N removed, shadow prices of COD, TSS, P, and N	Jordan Valley Authority
Acampa et al. (2019)	Estimation of costs for civil works and multiple linear regression for the cost of the electromechanical equipment	Cost model	Estimate the construction cost of conventional urban wastewater treatment plants with medium-low capacity (<50,000 pe)	Urban areas	Technical construction cost, the operating cost of the yard, entrepreneur's profit, general costs of the company	Sicily region, Italy
Pinheiro et al. (2018)	Construction cost estimation	A cost function based on regression techniques	The cost function for five types of WWTPs based on their hydraulic and physical characteristics, using a simple linear regression model.	Urban areas	Cost of construction, cost of civil works, equipment cost	Portugal
Maaß and Grundmann (2016)	Economic sustainability assessment	Cost-benefit analysis and added-value from the reused wastewater	Assessing the economic impact of crop production, wastewater treatment value chain, and production of bioenergy through the reuse of treated municipal wastewater and sludge.	Municipal	Crop production, value chain of wastewater treatment, and production of bioenergy	Federal State of Lower Saxony, Germany
Vásquez-Lavín et al. (2020)	Production function	Trans-log specification	Production function method to estimate the marginal productivity of water which relates to its economic value. A trans-log specification studying capital, labour, energy, and material, have been used for production function.	Non-domestic (industry section	Capital including the fixed assets (machinery, buildings, and vehicles), labour, energy, intermediate materials, and revenue	Chilean regions of Valparaíso, Chile
Kayal et al. (2019)	Circular wastewater industry assessment	Circonomics Index	Using a composite reuse indicator objective weighting system, which is built using shadow prices of undesirable wastewater treatment outputs to assess wastewater output.	Municipal	Wastewater output efficiency indicator; composite wastewater reuse indicator; and wastewater recycling indicator	Jordan Valley Authority

treatment and reduction of water intake were not considered in the analyses. Table 2 summarises the most prominent methods reported to date about the economic assessment of the circular water management systems.

3. Material and method

This research followed the steps outlined in Fig.1 to comply with the criteria for systematic reviews and Meta-Analysis. The aim was to examine the current state of studies on the economic assessment of NBS, as a facilitator of CE implementation in the water sector (Tools and Methods). This paper presents a systematic analysis of literature on the subject of CE and NBS in order to avoid the limitations of narrative reviews (Tranfield et al., 2003).

The work of Denyer and Tranfield (2009) provided an analysis of the CE's economic impacts assessment strategies, tools and methods in water sector; the latter was the basis of the current study.

The review provided an overview of the methodologies used by different studies along with their focus and findings. The publication of scientific journals was reviewed using the databases of Science Direct and Scopus. The keywords that were searched in various combination include: "nature-based solutions", Rainwater harvesting, constructed wetlands, Green infrastructure (GI), "Economic assessment", "cost estimation", "cost model", "water", "water system", "circular economy", "circularity". The database lists all papers that were found except a few in which no monetary values were stated, and it contains 306 papers. And out of those only 112 papers were in the relevant area of this study. Fig. 2. Shows the results of the systematic review.

A two-phase approach was chosen to conduct a review of the relevant literature. In phase 1 a database of the literature pertinent to the economic and cost assessment of NBS complemented with descriptors of the qualitative data was created. In the second phase, the database of phase 1 was classified based on a quantitative analysis, which was carried out as a meta-analysis appraisal.

Concerning the economic models that have been used in literature to assess the sustainability of water systems from an economic

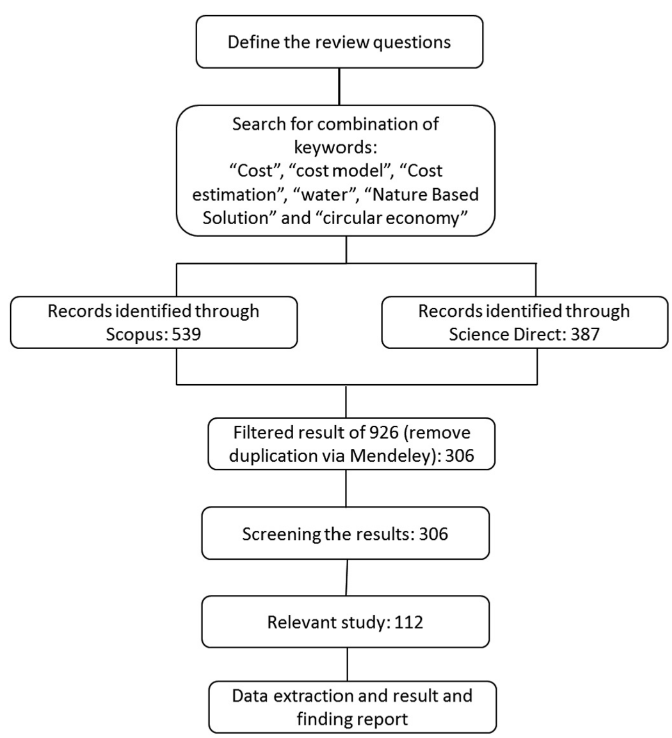

Fig. 1. The flow chart of a systematic review.

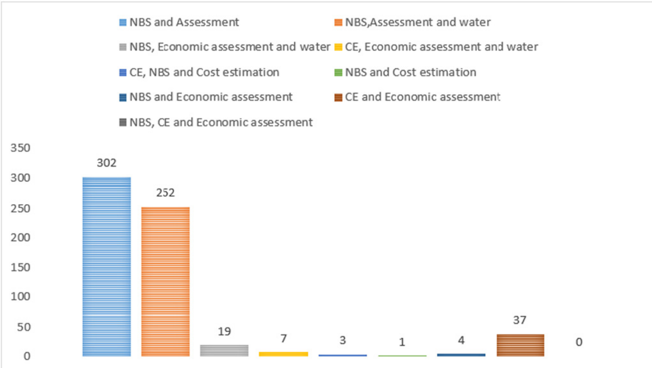

Fig. 2. Results of systematic literature review on the subject of NBS.

perspective, the results of Fig. 3 show that Life cycle costing (26.87%) stands in the first place, while cost-benefit analysis (23%), eco-efficiency (19%), cost-effectiveness, input-output analysis, have been widely used in literature.

3.1. Life cycle costing (LCC)

Life cycle costing (LCC) is the most widely applied model with a share of 26.9%. LCC is defined in the International Organization for Standardization standard, Service-life Planning, Buildings, and Constructed Assets, Part 5: Life-cycle Costing (ISO 15686-5) as an "economic assessment considering all agreed projected significant and relevant cost flows throughout analysis expressed in monetary value. The projected costs are those needed to achieve defined levels of performance, including reliability, safety, and availability." LCC analysis is based on monetary value of all the costs associated with purchasing, delivery, installation, commissioning, and insurance, operating and maintenance costs, and end-of-life costs, such as removal, recycling, or refurbishment and decommissioning (Maisham et al., 2019). It mainly covers the operational and capital expenditures (OPEX and CAPEX) of the resources and infrastructure. The economic indicators and measures including the annual life cycle costing, net present value (NPV), benefit-cost ratio (BCR), payback period (PP) help to express the results of LCC. Alim et al. (2020), Leong et al. (2019), Amos et al. (2018), and Roebuck et al. (2011) applied LCC for assessing the economic impact of rainwater harvesting. Alim et al. (2020) considered parameters, such as roof and tank size, daily filtration rate and water demand to assess the performance of the rainwater harvesting system in small-scale of rural/isolated communities. They concluded that at a reasonable cost, consistent with "United Nation's Sustainable Development Goal 6: Clean Water and Sanitation", the production of drinking water from rainwater harvesting for rural areas is feasible. The proposed model works in the specific climatic conditions and the model should be changed for different areas.

Leong et al. (2019) used LCC for evaluating commercial and domestic rainwater harvesting, greywater reusing, and hybrid rain-grey water and they concluded that the commercial hybrid rain-grey water and domestic rainwater harvesting system are economically optimal systems. The sensitivity analyses revealed that LCC is sensitive to the number of parameters as increasing the discount rate and water tariffs enhance the financial viability, while increasing electricity tariffs, and installation factor, reduce the financial viability.

Roebuck et al. (2011), evaluated a total of 3840 domestic device configurations taking into account different stakeholder viewpoints and future cost scenarios of a combination of four discount rates, four discount intervals, three water use combinations and five occupancy rates in the financial evaluation, yielding a total of 240 simulation scenarios. They concluded that a domestic RWH within the UK has reduced return of investment (ROI) with payback periods exceeding the RWH lifecycle and despite the assumptions made at the time, domestic RWH systems in the UK were improbable to offer any rational payback period. The financial loss of the RWH system is equal to its capital cost. The importance of taking full account of all related maintenance costs associated with modern RWH systems is highlighted. The scale of this study was one of the limitations since if RWH systems were to be installed on a greater scale, a further investigation is needed to explore the broader costs and benefits. For instance, if many RWH systems have been implemented in a catchment area, then benefits in terms of reduced peak flows and volumes in sewers and watercourses can be seen. Amos et al., 2018) developed an economic analysis tool, called ERain, based on life cycle cost analysis to evaluate economic effects of RWH in developed countries. As economic measures, the relationship between the benefit-cost ratio, reliability, and quality (the percentage of available water used) and differences between the benefit-cost ratio (BCR) and the net present value (NPV) are addressed. Results showed that in order to increase rainwater harvesting systems economic feasibility, a reduction in capital and operational and maintenance costs rather than increasing the price of water is required. By using LCC the majority of the research studies on RWH system have found that their feasibility mostly depends on scale (Kumar, 2004; Roebuck et al., 2011; Rahman et al., 2012).

Ziogou et al. (2018) and Wong et al. (2010) applied LCC for the economic evaluation of green infrastructures. Ziogou et al. (2018) performed LCC to evaluate two alternative rooftop retrofit options for two

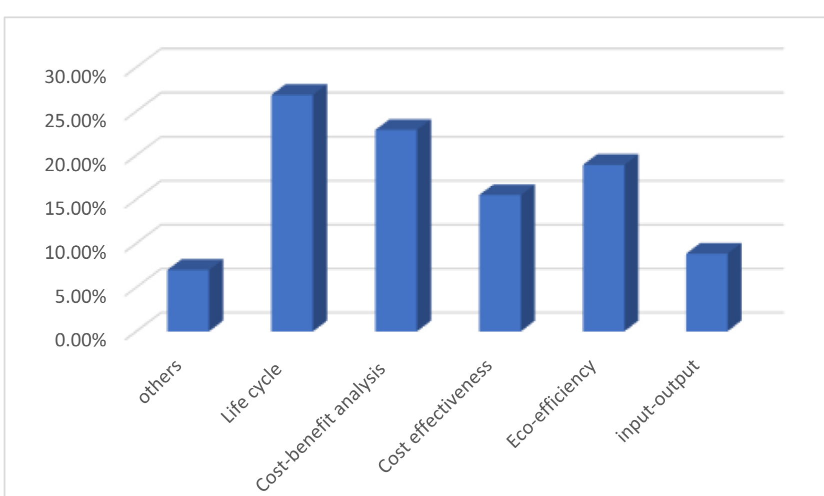

Fig. 3. Models used for the economic impact assessment of water systems.

dominant styles of residential buildings in Cyprus in terms of environment, energy and economics. Regarding the economic aspects, in most cases, such investment in the residential sector is not cost-effective due to high installation costs. However, sensitivity analysis, has shown that green roofs are economically feasible with only modest reductions (ranging from 6% to 35%) in their construction costs, which are possible due to their increased implementation in the medium term due to technical development or learning-by-doing. The authors did not consider the added associated environmental benefits, as those were hard to quantify financially. Resende et al. (2019) performed LCC and LCA to assesses the economic and environmental performance (eco-efficiency) of two small-scale, decentralised wastewater treatment systems linked to developed wetlands. System 1 contains a wetland of vertical and horizontal flow (S1). System 2 contains a wetland with artificial aeration of vertical subsurface flow (S2). The current study established the phases of the life cycle (construction, operation or end-of-life) and inflows or outflows which are the most critical triggers for impacts. Results from the LCC show that S2 is the least costly option, even though land costs and energy costs are taken into account. Finally, the efficiency of S2 (aerated system) nutrient removal is superior to the efficiency of S1 nutrient removal. Also, electricity cost are in charge for only 4.6% of the total cost or 14% of the O&M costs of the system. Yerri and Piratla (2019) used the LCC model to perform a comparative analysis of added life cycle costs and expected monetary benefit of greywater reuse systems. Precisely, the satellite and onsite greywater reuse systems were assessed in comparison with the traditional centralized systems. Some parameters including the value of decreased freshwater withdrawal, cost of treatment technology, have been evaluated to find leading factors that affect the feasibility of implementation of greywater reuse. The results of this study introduced control of water utilities to plan future water supply alternatives. This study's limitation was an absence of considering the diverse household water usage trends.

Although LCC is one of the most used tools to assess the economic impacts it normally does not involve benefits (Jeswani et al., 2010), and if the benefits were included, the expected environmental or social benefits (e.g., reduction in urban flooding, biodiversity increase, increased property value due to aesthetic improvement, etc.) cannot be included as these impacts do not have monetary value. The translation of these impacts to monetary values is not a straightforward process. Thus, this is one of the main LCC drawbacks that makes is results less precise to be used by decision-makers (Amos et al., 2018b; Ziogou et al., 2018).

3.2. The cost-benefit analysis (CBA) method

By calculating the total cost and capturing the external financial gains Hansson (2007) provides a more complete picture of the economic trade-off analysis. To perform a meaningful CBA, we need to define the boundaries of the system, estimate cost and benefits and their internal correlations through a comprehensive data collection. It includes the development of a clear mechanism for continuous monitoring and performance evaluation of the NBS–CE Water system, and the development of a CBA model to estimate NPV, IRR. A hypothesis testing would be the final stage to validate and verify the solutions. The CBA method is one of "the most widely applied tools for economic analysis" (Balanay and Halog, 2019). In terms of NBS, CBA has been used in assessing nature-based solutions; for example, Feng and Hewage (2018) applied CBA based on life cycle costs, individual and public benefits to assess the payback period of green roofs in different markets. Calculation of Payback period and net present value revealed that there are individual and social advantages to green roofs. And the life cycle cost of the green roof can be recovered in markets of most of the world. The Payback period with average initial costs is shorter than green roofs' lifespans. The authors concluded that at a bigger implementation scale, the social advantages of green rooftops will be expanded immensely. Notwithstanding, the advantages of the green rooftop will increment significantly whenever implemented at a bigger scope. Arborea et al. (2017) performed an extensive economic evaluation of the related cost and benefit gained from wastewater treatment to get a sustainable system. A methodological framework was based on cost-benefit analysis. The method tested two different scenarios of using treated water for irrigation: 1); and 2) as an alternative to the current conventional method. The results presented that improved urban wastewater treatment would increase the local availability of irrigation water by about 10%. The benefits of wastewater reuse are quite stable, treatment costs are highly dependent on the incoming effluent quality and plant size. However, this assessment only measures the cost of treatment at the plant gate, excluding the costs needed to supply and transportation of the recovered water. Furthermore, the other significant long-term environmental benefits were not included in the economic assessment, such as the projected improvement in the quality of coastal seawater. Ali et al. (2020) proposed a hydro-economic model to investigate water saving, stormwater capture efficiency and financial viability of rainwater harvesting systems under five climatic regions. The financial feasibility assessment of RWH was performed by applying the benefit-cost ratio. The tank size of RWH was examined by using the highest value of the benefit-cost ratio. The results showed that in warm areas, the benefit-cost ratio is lower than 1, so the installation of a rainwater harvesting system is not financially viable. The benefit-cost ratio is sensitive to catchment area size, as the larger catchment area produces more rainwater, and thus, more benefits. Uncertainty is the main limit of the hydrological models and three major causes of the uncertainty of model structure, input data, and model parameters can affect the modelling results. Reddy et al. (2015) proposed a hydro-economic model to assess the water shortage risk of alternative scenarios including NBS by studying public and private costs and benefits in a CBA model at a basin scale. In the assessment the direct use values or indirect use values, such as environmental values, and amenity were not considered.

Although CBA can be used in a single language of monetary values to weigh the social and environmental costs and benefits of various alternatives; however translating the expected benefit into the monetary value is not a straightforward process (Jeswani et al., 2010).

3.3. Cost-effectiveness analysis (CEA)

The focus of CEA is to find a low-cost alternative with reaching an anticipated result (Boerema et al., 2018). CEA can overcome the limitation of CBA by monetizing environmental impacts. According to Yates (2015), in order to determine project feasibility, CBA measures a project 's costs and benefits in monetary terms over the life span of the project. However, when benefits do not have a monetary value, a CEA can be applied. CEA is an economic assessment method that looks at 'cost per result' of at least two intercessions, where the outcomes are estimated by "natural" units (adverse impact prevented, saved years of life). CEA is a method for comparing the costs of various choices that produce the same results.

Some studies evaluate the cost-effectiveness of NBS including Helm and Hepburn (2012). The study offers a method to measure economic trade-offs by putting a monetary value on the effectiveness of biodiversity conservation. Similarly, Machiwal et al. (2018) assessed the cost-effectiveness of a small reservoir (rainwater harvesting) used for supplying water to wheat and mustard crops. The results offer valuable information to decision-makers for planning appropriate strategies, showing that the most critical variable influencing the cost-effectiveness of the reservoir system is grain yield, which needs to be closely monitored and improved to further increase the efficiency of the reservoir in arid regions. Gachango et al. (2015) performed a cost-effectiveness analysis to assess the financial viability of implementing surface flow constructed wetlands (SFCW). The result demonstrated that in drainage catchments with higher nutrient loads, SFCW may be a better optimal nutrient mitigation measure. Each measure has

Table 3
Nature-based solution water system economic assessment tools.

Study	Indicator	Description	Methodology	Component			Application
				Direct economic	Externalities (environmental/social)	Natural capital	
Alim et al. (2020)	Cost of the produced drinking water	Water price	LCC	✓	✓		Werrington, New South Wales, Australia
	Payback time	The time required to recover an investment or loan		✓			
	Capital cost	Fixed cost		✓			
Leong et al. (2019)	Net present value (NPV)	The sum of the annual net cash flows (i.e., the difference between cash outflow and inflow reduced by an appropriate discount rate) over the project's lifetime		✓			Klang Valley, Malaysia
	Payback period (PP)	The time required to recover an investment or loan		✓			
Amos et al. (2018)	Net present value (NPV)	The sum of the annual net cash flows (i.e., the difference between cash outflow and inflow reduced by an appropriate discount rate) over the project's lifetime		✓	✓		Australia and Kenya
	Benefit-cost ratio (BCR)	The sum of discounted costs divided by the sum of discounted benefits (e.g., water savings) as they occur over the project's lifetime		✓	✓		
Roebuck et al. (2011)	Capital expenditure (CAPEX)	Money spent to acquire, upgrade, and maintain physical assets		✓			UK
	Operating expenses (OPEX)	Ongoing costs for running a product, business, or system		✓			
	Return of investment (ROI)	Measure the amount of return on a particular investment, relative to the investment's cost.		✓			
Ziogou et al. (2018)	Life cycle cost (LCC)	Changes in economic welfare due to the avoided environmental deterioration, i.e. consideration of construction and operational costs and environmental costs of the emissions		✓	✓		Mediterranean island of Cyprus
Resende et al. (2019)	Life cycle cost (LCC)	Use of the present value method, including infrastructure, operation, and maintenance		✓			São Paulo, Brazil
Yerri and Piratla (2019)	Added benefits	(i) Savings in drinking water treatment and pumping costs, (ii) savings in freshwater withdrawal, (iii) savings in wastewater collection and treatment costs		✓			U.S.
	Added costs	Capital cost: treatment unit, storage tank, plumbing adjustments, pumps, dual piping, treatment facility set up Operational cost: consumables, energy cost, maintenance, repair, land use		✓			
Feng and Hewage (2018)	Net present value (NPV)	The values were converted into a net present value (NPV) by the means of discounting.	CBA	✓			British Colombia, Canada
	Payback period (PP)	The time required to recover an investment based on the benefits and costs		✓			
Arborea et al. (2017)	Economic value	The value of an asset calculated according to its ability to produce benefit or cost in the future		✓			Puglia, Southern Italy
Ali et al. (2020)	Payback period (PP)	The time needed to regain a scheme cost		✓			Pakistan
	Daily water balance model	The time needed to regain a scheme cost		✓	✓		
	Stormwater capture efficiency	The portion of stormwater generated from a catchment area, and then collected by the system and used to fulfil the water requirements.		✓	✓		
	Water-saving efficiency	The ratio of the total amount of water yield to the total amount of water requirements.		✓			
	Time reliability	It can be considered as the fraction of time when an RHS fulfils water demands (Zhang et al., 2019)			✓		
	Benefit-cost ratio (BCR)	Relationship between the benefits and investments		✓			
Reddy et al. (2015)	Environmental flows	Monetary estimates in 2012 US$, present value (PV)				✓	Brazos River, Texas
	Farm operations savings			✓			
	Soil conservation					✓	
	Avoided costs from reduced pesticide use and nutrient runoff			✓			
	Lower utility costs			✓			
	Decreased operating costs for treatment plants			✓			
	Lower water treatment costs			✓			
	Direct payments			✓			
Machiwal et al. (2018)	Benefit-cost ratio (BCR)	Relationship between the benefits and investments	CEA	✓			Gujarat, India
	Net present value (NPV)	The sum of the annual net cash flows (i.e. the difference between cash outflow and inflow reduced by an appropriate discount rate) over the project's lifetime		✓			

Table 3 (*continued*)

Study	Indicator	Description	Methodology	Component			Application
				Direct economic	Externalities (environmental/social)	Natural capital	
	Internal rate of return (IRR)	Percentage rate earned on each unit invested for each period that it is invested					
Gachango et al. (2015)	The establishment costs	Consultancy fees, Wetland excavation cost, Infrastructure (pipes and pump), vegetation establishment		✓			North Jutland in Denmark
	Annual and periodic operational and maintenance costs	Site supervision annual, pump running annual, pump maintenance		✓			
	The relevant opportunity costs.	Land rent			✓		
Faragò et al. (2019)	Total economic value added (TVA)	Salary has been excluded from the value loss, implying that salary is considered a value to society.	EEA	✓	✓		Aarhus, Denmark
Lam et al. (2017)	Total life-cycle cost (TLCC)	Price of the component used for each scenario multiplying the quantity of the component used for each scenario		✓			New Territories, Hong Kong

different units in CEA; thus, all the measures are treated separately, therefore the integration of assessing each measure for an overall assessment is not always feasible.

3.4. The eco-efficiency (EE) measurement method

After the adoption by the World Business Council for Sustainable Development (1999) in 1999, the concept of eco-efficiency (EE) has become common. An eco-efficiency indicator expresses the ratio between a financial and an environmental variable (Jeswani et al., 2010). The economic system value was measured in terms of total value added (TVA), while potential environmental influences were calculated using life cycle assessment (LCA). The LCA and TVA were assessed across the entire water chain, including end-user consequences and an estimate of each stakeholder's single economic added value. Eco-efficiency evaluation was made using a combination of LCA and TVA (Faragò et al., 2019). The principle of eco-efficiency has recently been improved by the creation of an eco-efficiency evaluation standard (ISO 14045, 2012). According to this standard, eco-efficiency quantification requires the linking of LCA-evaluated performance to the product system value, based on an objective and scope specification.

Faragò et al. (2019) assessed the possibility of increasing economic benefit at the same time as decreasing the environmental impacts of implementing a non-potable rainwater use system in urban growth. Considering the management of stormwater to control flood is a key point of their study. A combination of LCA for the environmental and total value added for economic assessment provides a way to measure the eco-efficiency of the rainwater system. The results of the research work endorsed the introduction of non-potable alternative water supply in the urban area. Lam et al. (2017) developed an eco-efficiency analysis (EEA) framework with the integration of economic analysis and life-cycle assessment (LCA) to evaluate the different greywater reuse system. The outcome of the research revealed that the EEA framework is a useful management tool to be used with a planner to have a sustainable greywater recycling system. Although EE and its indicator(s) can be employed for comparing different scenarios, there is a variation of methods used depending on the scope of the study.

Table 3 summaries individual and integrated methods, as well as the associated indicators, applied for the economic assessment of NBS. The selection of the suitable economic indicators is case-specific; for example, Lee et al. (2020) consider the revenue from products in their approach, whilst Ziogou et al. (2018) consider the environmental cost of emissions for their LCC analysis. Therefore, a system-based approach can perform a better evaluation of economic impacts compares to developing indicators.

4. Discussion

The quantitative analysis of the bibliometric analysis between 2000 and 2020, shows that the LCC is by far the most used methodology in the economic assessment of nature-based solutions. CBA stands in second place; however, these methods have difficulties in monetizing external (environmental, social) impacts. The use of EEA models, even though limited, is increasing recently. This demonstrates a growing interest for a more integrated (economics and environmental) approach. Other types of approaches including probabilistic analysis, hedonic price method, empirical monitoring data, multiple linear regression models, inexact two-stage stochastic programming, and travel cost are less frequently used than those discussed earlier.

The results of the analysis of the economic impact assessment tools reveal that there is a wide range of methodologies and tools which are currently suggested to evaluate the impact of NBS in the water sector. Table 4 summarises the most widely applied economic indicators of impact assessment of NBS on water systems, which were discussed in this study. It is worth noting that indicators such as NPV or BCR can be considered as universal and common indicators shared in many studies and could be considered as *Base* parameters in a *Systems Approach*. Whilst indicators like the value of wood production, construction, and maintenance cost in the economic assessment of green infrastructure (Liquete et al., 2016) are considered as case-based parameters.

The study reveals that despite the existence of a wide range of methods and tools for economic impact evaluation of NBS and Water Management Systems, there is still scope for a Systems Approach in establishing standards and protocols for a global economic impact assessment for modern Sustainability and Circularity initiatives. The use of haphazard case-based indicators alone may not necessarily convince policymakers and investors to shift from existing solutions.

The LCC and CBA are the most applied approaches for the economic evaluation of NBS. Although the results of this study revealed that both the LCC and a CBA can be used within a sustainability assessment framework, there are some key parameters, that should be taken into account. The dissimilarity between LCC, and CBA is the first point. While LCC can be classified as product-related evaluation, CBA focuses more on programmes or policies (Ness et al., 2007; Rorarius, 2007). The timespan is a second dissimilarity factor. LCC concentrates on the economic life cycles of the target products, while CBA first focuses on the lifetime of a specific project and then the lifetime of the target products will be considered (Hoogmartens et al., 2014). The third dissimilarity of LCC and CBA is about their usage for comparison purposes. LCC is a comparative assessment method that evaluate goods, while CBA is usually used for an independent evaluation of projects. For example, the estimation of the NPV give a clear result for CBA analysis of the system

Table 4
List of economic indicators for sustainability assessment in water systems.

Indicators	Definition/measurement	Criterion	Positive or negative	Currently achievable (CA)/aspirational (A)	Qualitative (L) or quantitative (T)/model (M) or user (U) provided	Study
Benefit-cost ratio (BCR)	The sum of discounted costs divided by the sum of discounted benefits (e.g. water savings) as they occur over the project's lifetime	Sum of discounted costs divided by the sum of discounted benefits as they occur at a time, over the lifetime of the project	Positive	CA	T/U	Amos et al. (2018))
Net present value (NPV)	The sum of the annual net cash flows (i.e. the difference between cash outflow and inflow reduced by an appropriate discount rate) over the project's lifetime	The sum of present values (PVs) over the project life defines the NPV	Positive		T	
Benefit-cost ratio (BCR)	Sum of discounted costs (C) divided by the sum of discounted benefits (B) as they occur at a time (t) over the lifetime of the project N	Sum of discounted costs divided by the sum of discounted benefits as they occur at a time, over the lifetime of the project	Positive	CA	(Ql)	Severis et al. (2019)
Internal rate of return (IRR)	The internal rate of return (IRR) is the discount rate that makes the net present value (NPV) of a project zero.	Should be greater than the minimum required rate of return, typically the cost of capital, then the project or investment should be pursued	Positive		(Ql)	
Net present value (NPV)	The sum of present values (PVs) over the project life defines the NPV	The sum of present values (PVs) over the project life defines the NPV	Positive		Qn	
Lifecycle cost	The present value of costs over the useful life of WSO divided by water produced. Cost includes capital, O&M.	The lifecycle cost of water supply option to utility per unit of water produced	Negative	CA	T/M	Hadjikakou et al. (2019)
Income generation	Income includes wages, salaries, proprietor income, profit/represents contribution of WSO to national income	Impact of water supply option's construction and operation on U.S. resident income per unit of water produced	Positive		T/M	
Outside capital cost	Measures extent to which cost is shared with others thus reducing the financial impact to customers	Fraction of capital cost to be paid by outside entities	Positive		T/U	
Variable cost	% of annualized capital and O&M cost that is variable over 1 to 3 years (chemicals, energy, and labour). Captures the financial flexibility of WSO.	The variable cost percentage of the total cost	Positive		T/MU	
Cost of import	The annualized cost of imported capital, operation, and maintenance goods as a percent of total capital, operation, and maintenance cost	Cost of imported capital and O&M as a percent of the total cost	Negative		T/M	
Value of wood production	Produce market goods	Produce market goods	Positive	CA	T	Liquete et al. (2016)
Total construction costs	The costs of the grey infrastructure were estimated from other existing infrastructures by the construction company.	Economic benefit/reduce public costs	Positive		T	
Total maintenance costs	The actual construction and maintenance costs (for a 20-year lifespan) of the green infrastructure were reported by the funders (reduce public cost)	Reduce public costs	Positive		T	

without requiring a comparison with other alternative systems. Therefore, the integrated application of LCC and CBA is important for a sustainability assessment study. The paper contributes to the understanding of contradictory assessment outcomes and the harmonisation of assessment methodologies by clarifying the main aspects and the relationships between the various methods and tools.

Additionally, in order to estimate the economic impact of a water system in a circularity and sustainability assessment, environmental and social costs and benefits should be taken into account along with economic cost and benefit in the quantification of externalities principles. The environmental (actual impacts, e.g., increase or loss of biodiversity, and potential impacts, e.g., global warming potential) and social (health, job creation) aspects should be translated to a monetary value in order to be considered in an evaluation. Fig. 4 presents the data and indicators required to obtain a comprehensive economic impact evaluation of moving toward a circular water system following a systemic approach. This latter considers the economic, environmental, and social costs and benefits at the same time. The estimation of the monetary value of environmental and social impacts should be obtained through some pricing methods including shadow pricing and hedonic pricing. An integrated method of life cycle cost-benefit analysis (LCCB) can be employed to analyse the collected data and present the results to investors and decision-makers.

5. Conclusions

NBS play a key role in re-connecting nature with human-managed water resources to would help in tackling societal challenges. The presented research work is an attempt to provide an economic perspective for NBS.

A review of the current economic assessment methodologies for measuring the cost-benefit of NBS do not seem to be cover a number of important aspects. The majority of existing body of knowledge regarding NBS in water management is concentrated on the technological performance with some elements of cost-benefit analysis. The economic impact analysis normally deals with the monetary values of investment on the physical infrastructure, whilst ignoring the monetary benefits of environmental and social gains. Although, LCC and CBA tend to address some aspects sustainability factors, but they lack of quantitative metrics.

An attempt was made to identify the gaps in the literature about the economic impact of *linear to circular* (*L2C*) transition. The review covered the economic implications of NBS enabling technologies, tools and methodologies within the circular water context. Finally, based on the identified gap, a framework was proposed for the monetary assessment of the costs of investment in NBS technologies, infrastructure and education against the environmental and socio-economic benefits within the policy frameworks. This framework would be an early building block for a systematic and multi-parametric economic impact

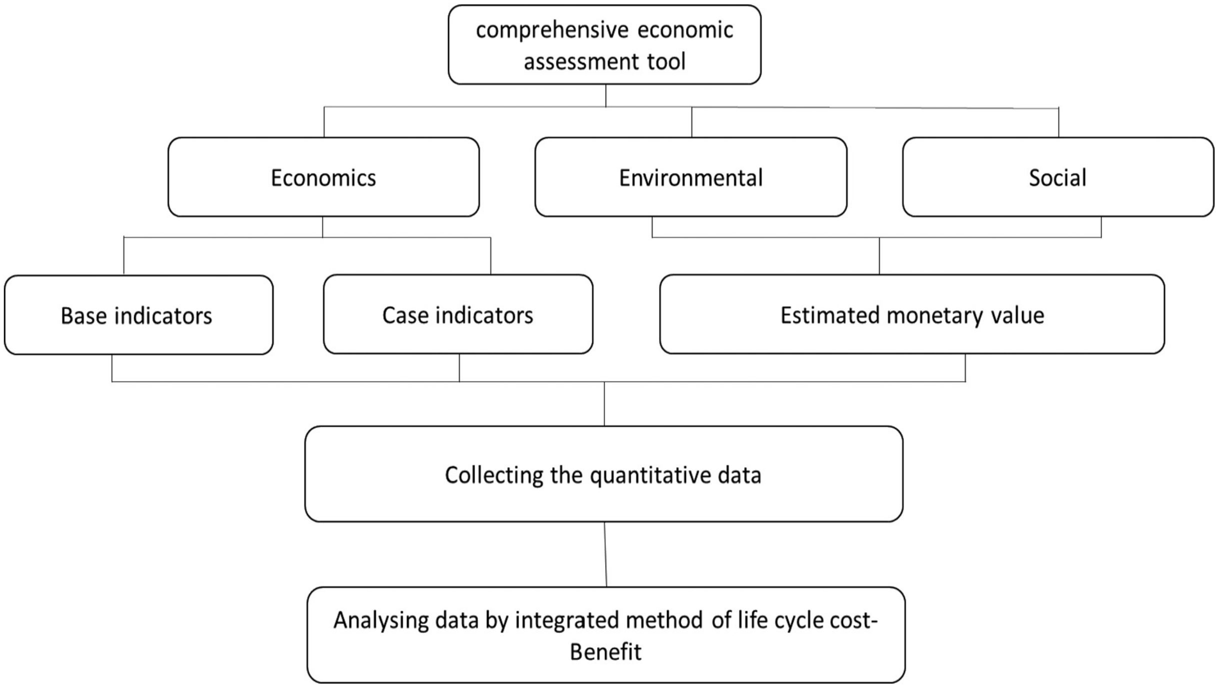

Fig. 4. Steps of formulating an economic assessment tool following a systems approach.

analysis of L2C transition in the Water sector, by creating monetary values for environmental, social gains alongside the costs of investment in the physical NBS.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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