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Review

Assessment of Sustainability of Urban Water Supply and Demand Management Options: A Comprehensive Approach

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Abstract: A comprehensive evaluation framework that can assess a wide range of water supply and demand management policy options in terms of economic, social, environmental, risk-based, and functional performance is crucial to ascertain their level of sustainability. However, such a detailed, generic, and holistic policy evaluation framework is not found in the literature. This paper reviews studies to evaluate water supply and/or demand management options conducted during 2000–2016. Primarily, the paper reviews the evaluation criteria used by different studies for decision making given their significant difference and the importance of a comprehensive set of criteria to complete a rigorous evaluation. In addition, a comprehensive set of water supply and demand management options are not considered together for a comparative assessment to prioritise best options for a certain area and time. Further, performance of these options needs to be evaluated for a range of uncertainties arising from changes of spatial and temporal variables of the system. While this paper highlights the important aspects that need to be included in a comprehensive policy evaluation framework, available studies collectively present a rich set of information to support it.

Keywords: sustainability; evaluation criteria; urban water system; water supply; water demand

1. Introduction

1.1. Background

Population growth, increased food production, and industrial growth in conjunction with improved living standards lead to increased water demand, while climate change and environmental pollution affects the availability of water resources to meet this growing demand [1–3]. Scarcity of traditional water sources, such as surface and groundwater, coupled with low water use efficiency are increasingly threatening the security of urban, agricultural, and environmental water needs. Becker [3] explains the problem of ground water depletion and overdraft of river water, giving examples from different continents. Sustainable use of these water resources is increasingly important as their mismanagement leads to severe financial, environmental, and social issues. This context highlights the need for introducing alternative water sources and demand management, and importantly to consider the sustainability of all these water sources.

With the advancements in technology and increased need of alternative water supplies, a range of water sources such as desalinated water, reclaimed water, stormwater, rainwater, and grey water have been introduced and are used in many parts of the world. Depending on the purpose, water is treated using an appropriate technology and supplied to meet different water needs such as drinking, other residential end-uses, farming, industry, commercial, institutional, and recreational. Sustainability of water sources in meeting these diverse water demands must be studied and understood in detail.

The term "sustainability" originated around 1980s as an approach to growing the economies without destroying the environment or sacrificing the well-being of future generations [4]. Another definition for sustainability is a desire to create a society that is safe, stable, prosperous, and ecologically minded [5]. Nearly all definitions for sustainability in recent years emphasise the notion that human society and economy are intimately connected to the natural environment [5]. Following this concept, environmental, economic, and social sustainability have become integral parts of development projects where numerous evaluation criteria are used to assess them.

The path towards achieving sustainability differs between countries and jurisdiction. Rygaard et al. [6] discuss how water infrastructure decisions have been influenced historically around the world. They use examples from the Middle East, India and Europe which have been influenced by needs such as agriculture and hygiene.

In Australia, the development and management of the urban water sector has undergone four phases: protecting public health, securing urban water supplies, microeconomic reform, and every drop counts [7]. These decisions can attract heavy criticism due to their political nature and lack of scientific evidence and evaluation [8–11]. For instance, sustainability and choice and scale of water supply augmentation projects adopted during the Millennium Drought (e.g., Wonthaggi desalination plant, North-South pipeline) which had serious infrastructure and economic impacts on urban water supplies in Australia remain a question mark in terms of the sustainability performance. Approaches to assess sustainability, however, vary widely across the water sector which highlights the need to rely on an objective framework to evaluate water supply policy initiatives using criteria that includes: health and hygiene, supply reliability, sustainability of governing institutions, efficiency of supply, and environmental sustainability. Further, speedy decisions made during the Millennium Drought and their accelerated delivery time played a key role in leaving other important criteria overlooked [12]. To date, the two major water supply augmentation projects in Victoria, Australia, implemented during drought are not in use due to the abundance of water and political reasons [8]. Had there been a comprehensive policy support framework with already available information to support those policy decisions, outcomes could be more sustainable and politically less vulnerable.

Rygaard et al. [13] also highlights that the decisions on urban water infrastructure are often influenced by political aspects and physical constraints, although these decisions affect future inhabitants, economic and environmental systems, and other social aspects such as public acceptance. These examples emphasise the need for a comprehensive water policy assessment framework for long-term planning which is also a proactive approach compared to a reactive emergency type response [14]. This paper aims to review current studies evaluating urban water supply and demand management options to support the development of a comprehensive policy assessment framework to evaluate both water supply and demand management options.

1.2. Studies Evaluating Water Supply and Demand Management Options

A significant number of studies were conducted during last 15 years to support decision making on urban water planning around the world. These studies are primarily decision support frameworks which often include simulation and modelling of parts or the entirety of the urban water system. The trend is accompanied by the increased complexity of urban water systems and the dynamic interactions which increase the uncertainty of water management decisions. Often these evaluations are supported by methods such as multi-criteria analysis [13,15–18], cost-benefit analysis [18,19], life cycle assessment [20–24], and optimisation techniques [17,24–26]. While few studies compare water supply options using available data [27], the majority of studies model the entirety of the urban water cycle to estimate impacts of different water supply options on other components of the system [14,25,28,29].

Although these studies are significantly different in many aspects, they have three common components. These are: water supply and/or demand management options, scenarios considered for these options, and evaluation criteria used to assess their sustainability (Figure 1). Typically, a set of criteria is used to assess sustainability performance of selected water supply and demand management options and to prioritise them. Scenario paths are introduced to assess this performance upon a range of uncertainties arising from changes of the spatial and temporal variables of the system. Among these components, evaluation criteria play a key role in ascertaining the level of sustainability of different water planning options.

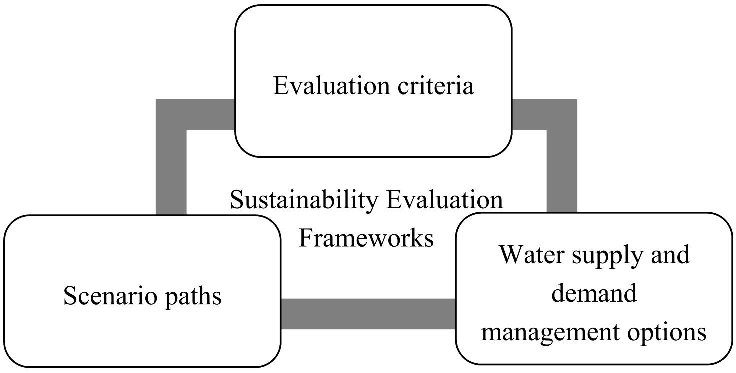

Figure 1. Components common in studies evaluating water supply and demand management options.

From these studies, this paper reviews studies carried out from year 2000 to 2016 with a view to evaluating urban water supply and/or demand management options encompassing a range of sustainability aspects. The collection of papers is restricted to those studies that evaluate at least three water supply options and use a number of sustainability criteria. We propose to include in the evaluation of sustainability a range of criteria that include those used in the individual studies, and review the studies with reference to these criteria. At this point, it is important to point out that there is a significant number of studies discussing one or two evaluation criteria or water supply options in detail [30–33]. These studies, however, are not included in this review due to their narrow scope.

Based on this broad set of evaluation criteria presented in Section 2, Section 3 presents the review of studies evaluating water supply and demand management options. Section 4 discusses differences in scenario paths such as climate change, economic development, population and urban growth among others, and various water supply and demand management options considered by the available studies, followed by the conclusions in Section 5.

2. Evaluation Criteria to Assess Water Supply and Demand Management Options

Among many definitions of sustainability of water resources, Mays [34] presents sustainability of water resources in detail as seven requirements. Those include a guaranteed basic water requirement to all humans to maintain human health; a guaranteed basic water requirement to restore and maintain the health of ecosystems; water quality to meet certain minimum standards; the requirement that no human actions impair the long-term renewability of freshwater stocks and flows; the requirement that data on water resources availability, use, and quality is collected and accessible to all parties; institutional mechanisms to prevent and resolve conflicts over water; and the requirement that water planning and decision making is democratic, thereby ensuring representation of all affected parties and fostering direct participation of affected interests. These requirements show various aspects of sustainability while they can be categorised into groups for simple presentation.

As such, the Triple Bottom Line (TBL) assessment has introduced three pillars of sustainability named social, economic, and environmental [35]. This is introduced to account for the full cost of a project including profit and loss, and also benefits of a business or a company giving broader definition for bottom-line assessment. Likewise, concepts such as four-capital, five-capital, and six-capital methods are also derived from economics, whereby capital stocks provide a flow of goods and services [36]. For example, the six-capitals method proposes financial, manufactured, intellectual, human, social, and natural capitals to account for all the flows of benefits, some of which are quantified with a monetary value and others are not [36].

Based on these concepts, frameworks to report sustainability of organisations have emerged such as Global Reporting Initiative (GRI), Principles for Responsible Investment, and International Integrated Reporting Council [37]. Among them, GRI is a popular and a comprehensive sustainability framework used by organisations around the world [37]. However, these guidelines are seldom used by water planners to support their sustainability assessments due to their less applicability and lack of availability of data.

Based on available studies on water planning, economic, environmental, and social are the three most common categories used to account for cost and benefits of water planning decisions. The economic category illustrates the flow of capital and the main economic impacts associated with the water supply and demand management options while the environmental category covers the impacts related to inputs (such as energy and water) and outputs (such as emissions, effluents, and waste). The social category includes the impacts on humans and society such as health impacts, and community and political acceptance. These factors determine the social acceptance of a water supply option and their long-term use governs by social aspects. For example, ability to provide clean water is a major determinant in selecting water supply options, while maintaining those sanitary needs is an essential requirement for its long-term use. In addition to these three main categories, technical and functional is another category considered by few studies [19,25,28]. Hellström et al. [19] consider robustness, performance, and flexibility as technical and functional criteria, whereas Makropoulos et al. [38] consider performance, reliability, durability, and flexibility as technical criteria. All other studies that are reviewed in this paper do not consider a technical and/or functional category in their studies, although the majority have used criterion/criteria to assess risk of water supply, which is discussed in Section 3.4 in more detail. Therefore, we propose a separate category to consider these risk-based performance criteria while all other criteria which are not included under these four categories are introduced as functional criteria in Table 1 due to their association with the function of water supply options. The functional criteria include the factors related to the durability, performance, and flexibility of the selected water supply option from construction to operation. Table 1 summarises the criteria utilised by available studies and projects to assess the sustainability of different water supply and demand management options under these five main categories. It is intended to be a set of guidelines for the evaluation of sustainability, recognising that each specific case may not require the application of the entire set of criteria. The generic nature of this set of criteria facilitates its application in a wide range of contexts and water supply and demand management options.

Table 1. Evaluation criteria utilised in literature to assess sustainability of water supply and demand management options [1].

Objectives		Evaluation Criteria
Environmental criteria	River and waterbody health	Quality of waste water produced and their impacts (contribution to acidification and eutrophication, effects on flora and fauna) [13–15,17–23,28,29,39] Quantity of wastewater produced [15,22,25,29,40] Stormwater runoff [15,25,29]
	Maintain river, local creaks, and wetlands	Effect on environmental flow and surface water [14,18,25,40] Freshwater/portable water saved [13,15,17,24] Effects on groundwater level and pattern (ground water infiltration, recharge, and depletion) [14,19,24,39,41]
	Protect land ecosystem	Effects on fauna and flora/biodiversity [39–41] Effects on habitats and protected natural habitat area [14,39,40] Land cover change effects (e.g., habitats affected) [21,39,41] Solid waste quantity and quality (e.g., sludge) [14,21,22,28,39,41]
	Protect atmospheric ecosystem	Greenhouse gas and other emissions [13,14,18–21,23,26,28,29,33,39,41] Photochemical oxidant formation [13,21,23] Other pollutants (e.g., dust, noise) [41]
	Efficient resource use	Energy use and recovery [14,19–26,28,33,38,39] Ability to use renewable energy source(s) [17] Fresh water use [19,20,22,28,29,38,39] Land use [14,19,20,29,38,39] Materials for construction [19,23,28,39] Chemical use [19,21–23,28,38] Reuse and recycling of resources [13,19,22,28,39]

Table 1. *Cont.*

Objectives		Evaluation Criteria
Social criteria	Ability to meet user acceptance	User acceptance in terms of water quality [13,25] Willingness to accept demand management options [18] Acceptance of increase/decrease in water bill [18,38] User awareness and involvement [13,17,19,38–40]
	Ability to meet community acceptance	Recreational values (visual amenity) [18,39–41] Impacts on urban heat island effect [40] Provision of educational opportunities [40] Small scale flood mitigation benefits [14,18,40] Odour/pests—any other negative impacts on the local community [40] Number of jobs it creates [40]
	Health and hygiene	Safety (number of incidents/accidents) [19,39] Risk of infections (number of outbreaks/people affected) [13,14,19,39] Risk of other health hazards (presence of carcinogenic compounds in influent water) [13,14,19,23,24,38] Exposure to toxic components (Cd, Hg, Pb) in operation [14,19]
	Political approval	Project duration (e.g., design and construction phase) [26,40,41] Management/institutional effectiveness and efficiency [39] Uncertainty of volume, timing, cost, approval, and delivery [12] State of readiness (availability of institution, documents, policy) [12,39] Ability to meet environmental or other regulations [18,41]
Economic criteria	Total direct cost	Capital cost [12–14,17,19,20,24,25,29,38,39,42,43] Maintenance cost [17,19,24,29,42] Operational cost including energy and other costs [13,14,17,19,20,24,25,28,29,38,42] Disposal cost [24] Cost of water distribution-construction, maintenance, and operation [14] Cost of water storage—construction, maintenance, and operation [14]
	Total indirect cost	Value of hydropower/energy and other byproducts, such as fertiliser
Risk-based criteria	Reliability	Probability of supply shortfalls (chance of not meeting the expected production) [13–15,17,25,26,29,38,39,42,43]
	Vulnerability	Magnitude of failure [19,28,38,42]
	Resilience	Failure duration or how quickly system returns to its satisfactory state after a failure [42]
	Robustness	Ability to perform satisfactorily under a range of system changes (e.g., climate) [13,14,18,26,28,39,42]
Functional criteria	Flexibility of the option	End-uses it can fit [14] Flexibility in scaling [13]
		Capacity/Yield [14,18,26,39] Potential for growth [26,39]
	Construction flexibility	Challenges with management of site (presence of contaminated soil and underground services) [40] Ability to blend with available supplies/infrastructure [12]
	Operational and maintenance flexibility	Ease of maintenance including monitoring frequency based on water quality and quantity [40] Technical knowledge needed in handling the system [40]
	Durability	Life span of the water supply infrastructure/option [38,43]
	Interactions between the system components	Effects on sewer distribution network such as sewer blockage, odour, and corrosion [15] Effects on drainage distribution network [15] Effects on water supply network (e.g., size of pipe) [15]

Notes: [1] Not all studies referring these criteria are cited in this table due to the scope, broad categorisation, and differences in definitions.

3. Review of Studies Evaluating Water Supply and Demand Management Options (2000–2016)

Table 2 summarises studies published after the year 2000 that evaluate urban water supply and demand management options for various domains of sustainability. All these studies consider at least three different water supply and/or demand management options. The majority of these studies evaluate the sustainability of these water supply and demand management options by embedding them in the whole of the urban water system. All the publications summarised in Table 2 are peer reviewed except a few studies (i.e., [18,25,29]) published as technical reports are also included in this review.

Table 2. Summary of studies assessing the sustainability of various water supply and/or demand management options.

Study Title	Approach	Evaluation Criteria				
		Environmental Criteria	**Economic Criteria**	**Social Criteria Including Health and Hygiene**	**Risk-Based Criteria**	**Functional Criteria**
1. Integrated framework for assessing urban water supply security of systems with non-traditional sources under climate change [42]	Systems analysis		Capital and ongoing costs (labour, chemical, power, upgrades)		Reliability, Maximum duration of failure, Maximum robustness, Vulnerability of water supply	
2. Understanding the role of alternative water supply in an urban water security strategy: an analytical framework for decision-making [14]	Melbourne's Alternative Water Atlas: A spatial analytical model with rapid assessment methodology	Environmental flow requirements, Land area used, Solid waste generated, Energy used (greenhouse gas emissions), Extent to which the option protects and enhances existing water and land ecosystems, Ability to control impacts of urbanisation of catchments on natural flow regimes and ground water patterns, Pollution loads from runoff water quality affecting inflow	Capital, operational storage, and distribution cost	Human health (probability of water quality failures and magnitude), Flood mitigation benefits	Reliability, Ability to cope with change over time	Yield, End-uses the source can fit
3. Using system dynamics for sustainable water resources management in Singapore [43]	System dynamics model		Capital cost in building water infrastructure		Self-sufficiency and adequacy	Lifespan
4. Dynamic performance metrics to assess sustainability and cost effectiveness of integrated urban water systems [28]	System dynamics model	Water, energy, and material consumption, Dissolved constituents, Dynamic environmental impacts and greenhouse gas emissions arising from water, wastewater, stormwater, dissolved constituents, reagents, infrastructure materials, sludge processing, recycling of materials, direct greenhouse gas emissions, and energy.	Capital and operational cost		Climate dependency	Changes in flow rate (leakage)
5. Urban water infrastructure optimization to reduce environmental impacts and costs [24]	Mathematical optimisation model with life cycle assessment	Water and energy conservation, Effect(s) on ground water level	Life cycle cost (capital, operational, maintenance, and disposal cost)	Human health and hygiene		
6. Accountability in planning for sustainable water supplies in South East Queensland [39]	Global Reporting Initiative (GRI) sustainability framework	Material and energy use, Land and water use, Recycling and reuse, Greenhouse gas emissions, Waste generated, Ecosystems/habitats affected, Biodiversity impacts, Impermeable surface/effects on infiltration, Protected areas/species restoration	Direct cost, Indirect economic impacts (visual and recreational impacts, improved water quality of stream flows, loss of prime agricultural land)	Administrative efficiency and effectiveness of government service, Process for managing impact (community engagement), Health and safety risks, Public agency disclosures on policy and implementation	Reliability, Vulnerability to climate change	Potential for growth, Yield

Table 2. *Cont.*

Study Title	Approach	Evaluation Criteria				
		Environmental Criteria	**Economic Criteria**	**Social Criteria Including Health and Hygiene**	**Risk-Based Criteria**	**Functional Criteria**
7. Holistic assessment of a secondary water supply for a new development in Copenhagen, Denmark [13]	Multi-criteria assessment	Greenhouse gas emissions, Terrestrial acidification, Photochemical oxidant formation, Eutrophication, Eco and human toxicity, Metal depletion, Freshwater saving	Capital and operational cost	Risk of infection, Public acceptance (trust in water quality, User knowledge and involvement	Resilience toward natural changes, Water self-sufficiency	Integration with resource management (e.g., nutrient recovery), Flexibility in scaling
8. Balancing the Triple Bottom Line in Water Supply Planning for Utilities [17]	Goal programming (Optimisation technique) with multi-criteria analysis and triple bottom line analysis	Water quality environmental issues, Renewable energy use, Water reuse	Capital, operational, and maintenance cost	Ease of permitting and institutional issues (e.g., Public involvement, user acceptance)	Supply reliability	
9. A systems framework of big data driving policy making—Melbourne's water future [29]	Integrated systems approach	Freshwater use, Wastewater discharge, Stormwater runoff, Nutrient loads to water ways, Land requirement for stormwater management, Greenhouse gas emissions	Construction, operational, and maintenance costs		Supply reliability	
10. A decision support framework for identifying optimal water supply portfolios [25]	Systems analysis approach (combined simulation optimisation approach)	Embodied and operational energy, Environmental flow, Stormwater and wastewater discharge to the Gulf	Capital and operational cost of water supply sources	User acceptance	Volumetric reliability of non-portable water demand, Time based reliability for portable supply	
11. A Streamlined sustainability assessment tool for improved decision-making in the urban water industry [20]	Life cycle assessment, Life cycle costing and multi-criteria analysis	Primary energy use, Greenhouse gas emissions, Water use, Eutrophication potential, Physical footprint (land use)	Capital and operational cost			
12. Towards sustainability in urban water: a life cycle analysis of the urban water system of Alexandria City, Egypt [21]	Life cycle assessment	Effluent quality (presence of heavy metals and nutrients), Greenhouse gas and other emissions including organic and inorganic pollutants, Sludge quality and quantity, Chemical use (affecting minerals depletion and ozone layer), Fossil fuel use, Land cover changes				
13. Life-cycle and freshwater withdrawal impact assessment of water supply technologies [23]	Life-cycle assessment	Global warming, Acidification, Nutrient enrichment, Photochemical ozone formation, Eco-toxicity in water, Resource consumption		Human toxicity via water and soil		
14. Decision support for sustainable option selection in integrated urban water management [38]	Urban Water Optioneering Tool based on a water balance model	Water usage and loss, Energy use, Chemical use, Land use, Service provision, Environmental impact	Life cycle costs, Willingness to pay, Affordability, Financial risk exposure, Capital cost, Operational cost	Risks to human health, Acceptability, Participation/responsibility, Public awareness, Social inclusion	Reliability	Technical performance, Durability, Flexibility/adaptability

Table 2. *Cont.*

Study Title	Approach	Evaluation Criteria				
		Environmental Criteria	**Economic Criteria**	**Social Criteria Including Health and Hygiene**	**Risk-Based Criteria**	**Functional Criteria**
15. A Water Supply and Demand Investment Options Assessment Framework [18]	Various methods (e.g., multi-criteria assessment, cost-benefit analysis)	Impacts on air, water, and land (waterway health, water quality, environmental flow, greenhouse gas emissions)	Cost to society, Externalities (recreational uses, and social and cultural values)	User affordability, Ability to meet the environmental regulations, Acceptance of water restrictions (frequency, duration, and level), Flood risk reduction	Resilience	Yield
16. An Integrated Framework for Assessment of Hybrid Water Supply Systems [15]	Water balance modelling, contaminant balance modelling, and multi-criteria decision analysis	Reduction in potable water demand, Reduction in wastewater discharges, Reduction in contaminant loads of wastewater flow, Reduction in stormwater flows, Reduction in contaminant loads from stormwater to receiving water			Improvement of supply reliability	
17. A framework for systems analysis of sustainable urban water management [19]	Cost-benefit analysis, functional risk analysis, microbial risk analysis, life-cycle assessment, sensitivity analysis, material-flow analysis, and behaviour/attitude investigations	Groundwater preservation, Contribution to Eutrophication and acidification, Contribution to global warming, Spreading of toxic compounds to water and soil, Use of natural resources (land, energy, chemical, material, water, potential recycling of phosphorus)	Capital, operational, and maintenance cost	Easy to understand, Social acceptance, Risk of infection, Exposure to toxic compounds, Number of accidents in working environment		Performance (leakage), Functional robustness (e.g., overflow), and flexibility
18. Development of a modelling framework for optimal sequencing of water supply options at the regional scale incorporating sustainability and uncertainty [26]	Multi-objective optimization approach	Environmental factors such as greenhouse gas emissions and energy use	System cost	Social factors (not elaborated), Design life of water supply infrastructure	Robustness, Reliability	Capacity, potential for growth

Thirteen studies out of eighteen consider at least three categories of environmental, economic, social, and other sustainability criteria while some of them have limited scope to consider one or two of these areas [21,23,24,42]. Sixteen studies out of eighteen assess environmental sustainability and majority of these studies consider this aspect in detail, highlighting its significance in urban water planning (Table 2). Fifteen studies out of eighteen assess economic sustainability, while only eleven studies consider social criteria in their assessments (Table 2). In addition, thirteen studies consider criterion or criteria to assess the risk of water supply, such as reliability and resilience [13,14,29,38,39,42]. There are studies which consider the majority of these important considerations together (i.e., [14,39]). However, those studies fail to consider a number of functional criteria listed in Table 1.

The summary in Table 2 presents that there is paucity of studies considering all the criteria listed in Table 1. It also shows that some criteria are defined and evaluated similarly across the majority of studies, and some are not. These differences among studies and the limitations in scope can be due to issues such as data unavailability and the complexity. This is evident by some studies showing high levels of detail only in some aspects [21]. Further review identifying criteria that are given a significant consideration in the literature and areas that need to be improved in sustainability assessment are given below.

3.1. Economic Criteria

According to Table 2, cost is a key consideration for the majority of studies that are reviewed in this paper. Not all studies consider the cost of capital, maintenance, and operational of water supply options, including water distribution and storage (Table 2). In addition to these costs, Lim et al. [24] included disposal costs of water supply options by calculating the life cycle cost.

Low et al. [44] highlight the lack of a comprehensive study on cost including externalities of distributed and centralised water management approaches. While externalities are not commonly considered in the literature, Baldwin and Uhlmann [39] consider a number of indirect economic impacts, including visual and recreational impacts, improved water quality of stream flows, and loss of prime agricultural land close to city. While externalities such as recreational value can also be considered under social criteria, value of by-products associated with different water supply options, such as energy and fertiliser, can be accounted under economic considerations.

3.2. Environmental Criteria

Compared to economic and social criteria, the highest number of criteria is included under this category, showing the strong focus of the available studies on environmental sustainability (Table 2). These criteria are commonly related to inputs (e.g., energy and material use), outputs (waste produced), and associated environmental impacts. Among these environmental impacts, greenhouse gas emissions and pollutants to waterways are common considerations for many studies [14,20,28,29,39]. Few studies address a broader set of criteria including resources use and reuse, effects on groundwater pattern and level, and many other effects on ecosystems [14,19,21,39]. These impacts on ecosystems can be on water ecosystem, land ecosystem, or atmospheric ecosystem. For examples, acidification, eutrophication, and effect on environmental flow are common impacts on water ecosystems considered in the literature [13,14,17,28,29]. While solid waste generation and effects on flora and fauna are some impacts on land ecosystem, impacts of greenhouse gas emissions and photochemical oxidant formation affect the atmospheric ecosystem. Although the studies, when considered together, provide a rich set of criteria in this category, this will be benefitted by detailed studies on environmental impacts caused by different water supply options.

3.3. Social Criteria

Social sustainability is the category that received the least attention in the literature out of the three main categories. Among the criteria evaluating social sustainability, human health and hygiene is the most frequently considered criterion in the literature (Table 2). In addition, studies collectively introduce criteria such as user acceptance, flood mitigation benefits, public awareness, factors related to governing institutions, and exposure to toxic compounds (Table 2). However, there are numerous social factors that need to be considered in evaluating water supply or demand management options which are not considered in policy evaluation frameworks available in the literature. Factors such as aesthetic values, ability to provide education, negative impacts on the community, such as odour or pests, are some examples considered by the stormwater harvesting projects launched in Melbourne [40].

Further, the criteria considered by the Victorian government in 2007 when introducing large scale water supply augmentation projects (i.e., how soon water can be delivered to avoid severe restrictions, its link to other sources, uncertainty of volume, timing, approval and delivery, and state of readiness) highlight the importance of some other criteria as decision factors [12].

Readiness includes availability of institution, documentation, and policy such as environmental laws to introduce and manage novel water supply augmentation projects. This plays a key role in selecting water supply options, and decides the project duration which can cost additional payments. For example, Royal Park stormwater harvesting project (1984) is one of the first stormwater harvesting projects planned for the city of Melbourne and expended 22 years from initiation to completion, whereas such projects implemented recently required about 3–5 years for this process [40]. However, only a few of these criteria are considered in the literature. For example, Baldwin and Uhlmann [39] include administrative efficiency, effectiveness, and process for managing impacts such as community engagement in their study, while Liner et al. [17] consider permitting and institutional issues under social goal considering similar aspects.

3.4. Risk-Based Criteria

Bichai et al. [14] introduced a criterion named "Resilience" to evaluate the ability of water supply sources to withstand climate change induced trends, such as long droughts and higher number of peak runoff days and short term climate perturbations, such as bush fires. The authors consider probability of failure and its magnitude under the same criterion. In contrast, Paton et al. [42] describe reliability (probability of supply shortfalls), maximum failure duration (how quickly a system returns to a satisfactory state after a failure), maximum vulnerability (magnitude of supply shortfalls), and robustness (the degree to which the system performs at an acceptable level under a range of possible scenarios) as risk-based performance criteria to assess urban water supply systems providing more depth to these aspects. Many studies use scenario analysis to evaluate these risk-based performances, which are critical in assessing the sustainability of these water supply options [13,26,38,42].

3.5. Functional Criteria

Maheepala et al. [25] use technical feasibility as a criterion to assess water supply augmentation projects to ensure their long-term functionality. In addition, an ability to use already available water infrastructure, end-uses that water supply options can fit, flexibility in scale and capacity are some of the functional criteria considered by available studies [14,26]. Performance in terms of leakage is another criterion used by the literature [19,38]. Moreover, challenges with management of site and monitoring frequency (e.g., sediment traps) are some of the other important criteria related to the construction and operational flexibility of the system [40]. Another set of criteria which are not widely considered by the literature are the interactions between system components, such as effect on water distribution networks and sewer networks, some of which are considered by Sapkota et al. [15].

4. Discussion

All studies that are reviewed in this paper present important findings, although significant differences in terms of sustainability criteria, the categories that they have considered, and the level of detail in assessment, even within the same study area, are evident. This is a common feature for all studies summarised in Table 2. Therefore, there is the need to combine a broad and diverse set of knowledge and skills to conduct a comprehensive study. Baldwin and Uhlmann [39] acknowledge the challenges of undertaking a thorough and rigorous sustainability review of water supply options due to both the diverse skill sets needed and the limited data availability. Studies around the world provide a rich set of information necessary to build a policy support framework for assessing water supply and demand management options. Therefore, this review shows the importance of combining the considerations introduced by the different studies discussed in this paper and the need for a holistic, detailed, and generic framework to assess water supply and demand management options.

The majority of studies evaluate both centralised and decentralised water supply options due to the increased application of integrated urban water management principles to urban water management. However, many of them compare only a selected set of water supply options for an area. Further, few studies compare demand management options together with water supply options [18,25,29]. As a result, studies which compare or evaluate a comprehensive list of water supply options (e.g., surface water, ground water, desalinated water, recycled water, rainwater, stormwater, greywater) conjunctively with demand management options which are essential for long-term planning and to avoid the evaluation of incomplete systems could not be found.

Different scenarios were considered by different studies to assess water policy initiatives as a method of considering the uncertainty of the system due to its variable nature. Coombes et al. [45] defined scenarios based on climate change, population/urban growth (i.e., Greenfield development), and economic change. Hellström et al. [19] defined scenarios based on water or energy shortage, behavioural changes, and availability of economic resources. Mukheibir and Mitchell [18] characterise uncertainties in three broad categories. They are: trends; the gradual changes of the system (water demand), shocks, step changes of the system (bush fire, increase in energy price), and extreme variability of the system such as drought and flood. As such, different studies consider different sets of drivers from the system and the consideration of all these drivers in a single policy evaluation framework is essential. Further research is needed to include all drivers representing spatial and temporal factors affecting the water demand, supply, and other system components.

While these improvements are needed for a comprehensive policy evaluation framework for water supply and demand management options, collecting relevant information, data monitoring, and findings that are already available in the literature is recommended to support and inform this generic policy support framework. The areas suggested for further studies include identification of indicators and their plausible range of values, variability, and sources of uncertainty.

5. Conclusions

Increase in water demand, depletion of available water sources, and supply variability induced by climate change necessitate the augmentation of water sources and the introduction of new policies into the present water management system. These measures must be evaluated for their economic, social, environmental, risk-based, and functional sustainability to select the most sustainable options for a particular condition.

Environmental sustainability is the main focus of the studies reviewed in this paper, and the list of evaluation criteria used for this category is wide-ranging. Economic sustainability is another key consideration, although external costs as well as disposal costs are not widely considered in the majority of the studies. Social sustainability is the category that received the least attention in the literature out of the three main categories. Criteria commonly used to assess social sustainability of water supply and demand management options are largely confined to health and hygiene, while a significant number of criteria related to community acceptance and political approval are introduced in this paper. Some studies comprehensively consider risk-based criteria, while there is a paucity of studies that consider functional criteria in detail.

There are a number of case-specific frameworks that cannot be used for a comprehensive sustainability evaluation of long-term sustainable water planning. The majority of the reviewed studies fall short of one or more of the evaluation criteria proposed in this study. This study proposes a comprehensive-generic set of sustainability criteria collected from available studies. This is applicable to a wide range of contexts and water supply and management options. A subset of the evaluation criteria can be applied to any specific context and selection of water supply and demand management options.

In addition, no reviewed framework is sufficiently comprehensive to include the most common scenario settings, and supply and demand management options for a holistic, detailed, and generic framework to assess water supply and demand management options. While these improvements are needed for a comprehensive policy evaluation framework for water supply and demand management options, collecting relevant information, data monitoring, and findings that are already available in the literature is recommended to support and inform this generic policy support framework.

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