Nuno Ferreira da Cruz and Rui Cunha Marques

A multi-criteria model to determine the sustainability level of water services

Article (Accepted version) (Refereed)

Original citation:
da Cruz, Nuno Ferreira and Marques, Rui Cunha (2013) *A multi-criteria model to determine the sustainability level of water services.* Water Asset Management International, 9 (3). pp. 16-20. ISSN 1814-5434

A Multi-Criteria Model to Determine the Sustainability Level of Water Services

Nuno Ferreira da Cruz and Rui Cunha Marques
CEG-IST, ULisboa, Portugal

Abstract

Sustainability is frequently associated with the triple bottom line (TBL) approach (social, environmental and economic concerns). We argue that the TBL framework is not sufficient to describe urban water cycle services (UWCS) sustainability since technical and governance aspects are also quite relevant. Therefore, several dimensions, objectives and criteria that represent the sustainability level of UWCS are suggested. A multi-criteria decision analysis model is used to aggregate the numerous aspects that are relevant for UWCS sustainability. To illustrate the usefulness of this model, the weights of each criterion of the "Economic" dimension were obtained through an iterative process involving a decision-maker with extensive experience in UWCS management. We demonstrate that it is possible to assess the global sustainability level of UWCS and also the performance in each particular dimension taking into account the values and judgments of the legitimate stakeholders.

Introduction

There is no unique pathway for the adoption of sustainable practices for utilities, cities, or any other organization involved in urban water cycle services (UWCS). Therefore, there is currently no consensus on how to assess the sustainability of UWCS, although some recent proposals have been made (e.g. van der Steen, 2011, and van Leeuwen et al., 2011). It is obvious, nevertheless, that the complexity of the sustainable urban water cycle is high and the challenges towards achieving it are huge.

This study proposes a framework to measure UWCS sustainability. It was carried out within the TRansitions to the Urban Water Services of Tomorrow (TRUST) research project and follows the major literature in this scope (Marques, 2012). First, both the dimensions and objectives of UWCS sustainability and their corresponding assessment criteria were defined. Second, a set of performance indicators or other metrics were identified for each criterion of the "Economic" dimension. Third, a multi-criteria decision analysis (MCDA) model was developed.

The MCDA technique is particularly useful to assess UWCS sustainability. It allows for taking into account the priorities and preferences of a specific set of actors (that should represent the local, regional and/or national characteristics). For example, in a given jurisdiction some environment criteria can damage economic sustainability (e.g. demanding a high level of wastewater treatment) and the priorities of UWCS in water resources scarcity regions are naturally different from the areas where these resources are abundant. In addition, sustainability (of UWCS) is a highly contested concept and very prone to different interpretations.

Water Services Sustainability

Regarding UWCS the sustainability concept was firstly defined as "(…) being those water resource systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity" (ASCE and UNESCO, 1998). The emphasis of this definition is mostly on the environmental dimension of UWCS, although the "objectives of society" embrace also the economic and social dimensions. Urban water services have evolved significantly over time. Not long ago, water quantity, drinking quality and adequate pressure were, *per se*, conditions of an appropriate drinking water service. Today, they are not enough. Customers and society demand more. Water utilities should be efficient, effective and customer-responsive. The multiple actors and stakeholders comprising several areas with multiple objectives and interests make governance issues (e.g. participation and transparency) in this scope very important as well.

Furthermore, due to the increasing cost of water (and wastewater) services and to the high investments required and the need to reflect them into the polluter and user-pays principles, economic and social dimensions are more and more fundamental issues. Urban water services are quite important for the social and economic cohesion of society. The population wishes to have sound drinking water services at affordable prices. Indeed, customers need to feel the value for money spent.

The sustainability concept is frequently associated with the triple bottom line (TBL) approach, comprised by social, environmental and economic dimensions or principles. These dimensions can be regarded as a set of objectives relative to a particular sector that should be pursued. Some authors call criteria to these dimensions which correspond to the 'set of factors that may be used to assess which of a range of options offers the greatest contribution to achieving sustainability objectives' (Ashley et al., 2004). Nomenclature issues aside, the question is if the TBL approach is the most appropriate to deal with UWCS sustainability. We, like others, disagree (at least partially). The social dimension of UWCS sustainability should include aspects related to the access to urban water services, the satisfaction of the users' needs and expectations, the public acceptance and the relevant role in the community of these services. The UWCS environmental dimension concerns the impact of UWCS on living and non-living natural systems and encompasses the optimization of the use of water, energy and materials and the minimization of the downstream negative impacts. Other issues, such as biodiversity, could also be included. Finally, the UWCS sustainability economic dimension would include all the objectives related to economic and financial issues, such as the full cost recovery.

However, it seems that the TBL approach is not enough to characterize UWCS sustainability since technical (assets or infrastructure issues) and governance aspects are also quite relevant. Even if they are not ends in themselves, they are instrumental and essential for the social, environmental and economic dimensions and the objectives of sustainability (see the definition of sustainability of the TRUST project, Brattebø et al., 2012). The "Assets" dimension is associated with asset management and the system of physical infrastructure and might encompass aspects concerning the system performance, its durability, reliability, flexibility and adaptability. Governance is related to the "rules of the game", the respect for those rules by the stakeholders, the transparency, their participation in the decision making process, particularly the customers, the effectiveness and efficiency of the measures taken and the quality of the

accountability and adjustment mechanisms. The existence and alignment of city planning with the UWCS is also a relevant governance issue.

Methodological Framework

The suitability of the five dimensions (TBL plus Governance and Assets) was discussed in the previous section. Associated with these dimensions or principles of UWCS sustainability the specific objectives were defined. The objectives, in opposition to the dimensions that have a more transversal scope, depend on the field where sustainability is being assessed. Therefore, we set out specific and elaborated objectives for the UWCS which can change in intensity according to water utilities patterns and their stakeholders. Most of them are not found in other sectors but all of them embrace the TBL approach together with the Assets and Governance dimensions. Based on the relevant literature and on the discussions of a panel of experts, 14 objectives were defined for sustainable UWCS (Brattebø et al., 2012).

Certain criteria are associated with each objective of UWCS sustainability. Those objectives are achieved if the corresponding criteria are fulfilled (Marques and Leeuwen, 2012). For instance, to achieve the objective of ensuring 'access to urban water services' the satisfaction of the criteria a1) Physical service accessibility and a2) Economic service accessibility is required. Table 1 presents the criteria for the objectives defined for UWCS sustainability (Brattebø et al., 2012).

Each criterion will require the proper performance descriptors (not only indicators but other metrics, such as best practices check lists or other qualitative scoring systems) which will allow for its operationalization and measurement. A performance descriptor is an indicator or an ordered set of plausible impact levels for a criterion that allows us to measure the degree to which the objectives are being accomplished (Bana e Costa et al., 2003). The metrics displayed in Table 1 are rough indications for each criterion (relative to each objective of UWCS sustainability); they were proposed by the authors and discussed by a group of experts from the TRUST project (Brattebø et al., 2012).

. The following section provides detailed metrics for the Economic dimension.

[Insert Table 1 here]

Using a multicriteria methodology for the evaluation of UWCS sustainability entails several advantages. For instance, such a framework (1) allows for the inclusion of all types of criteria (either qualitative or quantitative); (2) the objectives, criteria, scores and weights are explicit and transparent, allowing for open discussion; (3) the decision-making process is participatory and can be documented, facilitating communication, auditing and reviewing; (4) the measurement of each particular aspect (criterion) can be carried out by external experts; (5) it is possible to compute partial and global scores which can be very informative for policy-making; (6) methodologies for assigning scores and weights conforms to sound theoretical principles; and (7) the whole process can be supported by computer-based tools, which speeds up the decision-making. The agenda for the MCDA framework can be easily described:

Given a set 'U' of 'm' UWCS, U = u1, u2, …, um and a set 'C' of 'n' criteria reflecting the strategic objectives, C = c1, c2, …, cn, evaluate the UWCS considering all criteria.

However, determining and calibrating each one of these parameters is not straightforward. For instance, who will validate the set of criteria (and their respective descriptors) and provide input for weight elicitation? Moreover, to perform a global evaluation with an additive aggregation model one has to accept the 'compensatory' assumption (it must be admissible that a 'good' score in one criterion may compensate a 'bad' score in another criterion). Taking these issues into account and after the designation of the legitimate decision-maker (or group or decision-makers), a simple additive aggregation model can be used to compute the global sustainability score of each UWCS (see equation 1).

$$S(u_i) = \sum_{j=1}^{n} c_j \times S_j(u_i) \qquad \text{with} \qquad \sum_j c_j = 1 \tag{1}$$

Where,

$S(u_i)$ is the global sustainability score of UWCS u_i;

c_j is the weighting coefficient of criterion j;

$S_j(u_i)$ is the local score of UWCS u_i considering criterion j.

In MCDA frameworks there are two main evaluation stages: a) the partial (or local) evaluation of UWCS sustainability according to each criterion, and b) the global evaluation of UWCS sustainability (the aggregation of the partial evaluations). During the partial evaluation stage a scoring function for each criterion will have to be assumed or determined. Scoring functions associate a score (value in a predefined scale) to each level of performance or impact. Descriptors allow for the measurement of 'real-world' impacts and these impacts need to be converted into scores respecting a scale that should remain the same for every criterion. In the current study we assume a linear relationship between performance impacts and scores.

Weighting coefficient are 'scaling constants' that convert partial scores (in each criterion) into global scores. Note that the weight of a given criterion does not represent the 'importance' of that criterion; it represents the increase in the global score associated with a swing in that criterion between a 'lower bound' performance level (for instance with a local score equal to zero) and an 'upper bound' performance level (for instance with a local score equal to 100). These reference levels are useful to operationalize the notion of 'trade-off' and should be established by the decision-maker.

There are several methods available to determine scoring functions and perform weight elicitation (Cruz and Marques, 2013). For instance, to build scoring functions one can use the 'direct-rating', the 'bisection method', the MACBETH approach, among others. To determine weights one can use the 'swing weights method', the 'trade-off' method, the MACBETH approach, the AHP, etc. Here we use the MACBETH approach to construct the model. Weight elicitation using the MACBETH approach involves a process of pairwise comparisons: specifically, the decision-maker evaluates the swings between the reference levels of two criteria using seven qualitative categories for his/her judgments, namely: "no difference", "very

weak", "weak", "moderate", "strong", "very strong" or "extreme" difference in preference. By solving a linear programming problem it is possible to suggest weights that are consistent with the qualitative judgments of the decision-maker (e.g. the M-MACBETH software provides this automatically, see Figure 1). The next section explains in more detail the procedure to compute weights through this approach (for more on this technique see, for example, Bana e Costa et al., 2003).

In real-world applications, modeling should be developed with the input of the legitimate decision-maker. For instance, for the illustration presented in the next section, an experienced decision-maker validated the objectives and the structure of the value tree (criteria set of the Economic dimension), approved the performance descriptors (metrics), and provided judgments regarding the relative importance of swings between two reference levels in each criterion.

Case-study: The Economic Dimension

After identifying the fundamental criteria, which is the cornerstone of a global additive evaluation model, the definition of the scales of attractiveness or scoring functions for each criterion is required. Scoring functions convert impacts (performance levels) into scores. Here we have a model that uses quantitative and qualitative criteria.

To illustrate the application of the MCDA model, we discussed the criteria and the descriptors of the Economic dimension with a real decision-maker with extensive experience in UWCS management. After this, we asked him to define the upper ('Good') and lower ('Neutral') references in terms of performance for each criterion. This operationalizes the idea of a good performance and a neutral performance (that is, neither attractive nor repulsive). The following descriptors and reference levels were set in a decision conference with the decision maker:

Investment

Level I. Both indicators in Table 2 are at (or above) the "Good performance" level.

Level II. One of the indicators is at (or above) the "Good performance" level. The other indicator is not below the "Acceptable performance" level. - **Good level**

Level III. Both indicators are at (or above) the "Acceptable performance" level. None is at the (or above the) "Good performance" level. - **Neutral level**

Level IV. One of the indicators is below the "Acceptable performance" level.

Level V. Both indicators are below the "Acceptable performance" level.

[Insert Table 2 here]

Efficiency

Level I. Both indicators in Table 3 are at (or above) the "Good performance" level.

Level II. One of the indicators is at (or above) the "Good performance" level. The other indicator is not below the "Acceptable performance" level. - **Good level.**

Level III. Both indicators are at (or above) the "Acceptable performance" level. None is at the (or above the) "Good performance" level. - **Neutral level.**

Level IV. One of the indicators is below the "Acceptable performance" level.
Level V. Both indicators are below the "Acceptable performance" level.

[Insert Table 3 here]

Leverage

- Debt equity ratio (-) – **Neutral level** is 4,0 and **Good level** is 2,5.

Liquidity

- Current ratio (-) – **Neutral level** is 0,5 and **Good level** is 1,0.

An explicit statement regarding good and neutral levels of reference makes it possible to represent the notion of intrinsic 'value of sustainability' of each UWCS, assigning it to one of the following categories:

- Highly sustainable UWCS, when it is at least as good as a fictitious good UWCS (a UWCS that has a performance equal to the upper reference level in all criteria);
- Sustainable UWCS, if it is at least as good as a fictitious neutral UWCS, but less attractive than a fictitious good UWCS;
- Unsustainable UWCS, if it is not as good as a fictitious neutral UWCS (a UWCS that has a performance equal to the lower reference level in all criteria).

As mentioned above, weights reflect the relevance that the decision-maker gives to the swings in each criterion. Hence, as substitution rates, weights must be determined with reference to criteria impact scales. To compute the weights for the Economic dimension we adopted the following procedure: (1) ask the decision-maker to consider a 'virtual UWCS' that is Neutral 'all over'; (2) ask which criterion would the decision-maker select to swing from the Neutral to the Good performance level; (3) continue to ask the same question until the 'virtual UWCS' is at the Good performance level in all criteria. Considering the order chosen by the decision-maker it is possible to rank the importance of the swings in each criterion (between Neutral and Good), from the most attractive to the least attractive, according to his preferences.

After this ordinal ranking of the criteria, the decision-maker is asked to provide a judgment regarding the differences of attractiveness of the swings Neutral-to-Good between the several criteria. It is not necessary to make all possible pairwise comparisons. As shown in Figure 1, it is possible to compare just successive criteria (for instance). The weights corresponding to the matrix of judgments depicted above are also shown in Figure 1 (under 'current scale'). Having the local scores and the weights, one can compute the global score of the UWCS using equation 1.

[Insert Figure 1]

Conclusion

This paper presents a proposal for measuring UWCS sustainability based on a MCDA model. After discussing the concept of UWCS sustainability and its dimensions we propose a UWCS sustainability scorecard based on the objectives of UWCS sustainability, their criteria and performance metrics. We set

out five different dimensions for UWCS sustainability which are the following: social, governance, environmental, economic and infrastructural. UWCS sustainability encompasses 14 objectives which are achieved if the criteria for each one are fulfilled. Each criterion has at least one performance metric associated with it. To assess UWCS sustainability, weights are required for the defined scorecard, which depends on the decision makers (who should be the stakeholders in the case of UWCS). Indeed, the assessment of UWCS sustainability should be validated in the real world. Therefore, the MCDA approach should be applied and tested with the decision makers who are the stakeholders of UWCS under assessment and, particularly, water utilities managers.

References

ASCE and UNESCO. 1998. Sustainability Criteria for Water Resource Systems. ASCE Task Committee on Sustainability Criteria and the Working Group of UNESCO/IHP IV Project M-4.3, Reston, Virginia, USA.

Ashley R., Blackwood D., Butler D. and Jowitt P. 2004. Sustainable Water Services: a Procedural Guide. IWA Publishing, London.

Bana e Costa C., De Corte J. and Vansnick J. 2003. MACBETH. Working Paper LSEOR, no. 56, London School of Economics and Political Science, London.

Brattebø H., Alegre H., Cabrera E., Marques, R., Hein, A. and Cruz, C. (2012). A master framework for UWCS sustainability. TRUST Project.

Cruz N.F. and Marques R. 2013. New development: The challenges of designing municipal governance indicators. Public Money and Management, 33(3), 209-212.

Marques, R, 2012. MCDA approach for the UWCS sustainability scorecards. TRUST Internal Report.

Marques, R., van Leeuwen K. 2012. Current State of Sustainability of Urban Water Cycle Services. TRUST project.

van der Steen, P. 2011. Application of Sustainability Indicators within the Framework of Strategic Planning for Integrated Urban Water Management. A training manual for Process Facilitators of Urban Strategic Planning Processes. SWITCH, UNESCO-IHE Institute for Water Education.

van Leeuwen K., Frijns J. and Wezel A. 2011. Indicators for the Sustainability of the Urban Water Cycle. Watercycle Research Institute, the Netherlands.

Table 1. Dimensions, objectives and criteria of UWCS sustainability (adapted from Brattebø et al., 2012)

Dimension	Objectives	Criteria	Metrics (illustrative examples)
Social	a) Access to urban water services	a1) Physical service accessibility	Water coverage; wastewater coverage
		a2) Economic service accessibility	Price of the average household consumption (e.g. 12 m3); average bill
	b) Effectively satisfy the current users' needs and expectations	b1) Quality of service	Interruptions; flooding of properties; billing
		b2) Drinking water quality	Drinking water quality
	c) Acceptance and awareness of UWCS	c1) Willingness to pay	Inquiry on willingness to pay
		c2) Complaining	Complaints; suggestions
		c3) Acceptance of new sources of water	Acceptance of reclaimed water
	d) Relevant role in community	d1) Social responsibility	Investment on community
		d2) Work conditions	Training; absenteeism; work accidents, employee satisfaction
Environment	e) Optimize the use of water, energy and materials	e1) Efficient use of water	Leakage (real losses); leakage best practices; reclaimed water; use of grey water; rainwater harvesting; checklist of best practices
		e2) Energy use	Energy efficiency; energy generation; checklist of best practices
		e3) Material use	Checklist of best practices (materials, chemicals and construction)
		e4) Final uses of efficiency	Checklist of best practices (water, wastewater, rain water)
	f) Minimize downstream negative impacts	f1) Pollution prevention	Wastewater treatment coverage; quality issues (wastewater, sludge, nutrients, treatment failures, …); overflow discharges; greenhouse gas emissions
		f2) Pollution control	
Economic	g) Ensure economic sustainability of the UWCS	g1) Investment	Innovation; maintenance and replacement of assets
		g2) Efficiency	Coverage of total costs; staff productivity
		g3) Leverage	Debt equity ratio
		g4) Liquidity	Current ratio
Governance	h) Public participation	h1) Participation initiatives	Check list of best practices
	i) Transparency	i1) Availability of information and documents	Check list of best practices
		i2) Accessible information and written documents	Check list of best practices
		i3) Public disclosure	Check list of best practices
	j) Accountability	j1) Individual mechanisms of accountability	Check list of best practices
		j2) Collective mechanisms of accountability	Check list of best practices
	k) Clearness, steadiness and measurability of the UWCS policies	k1) Clearness of policies defined ex-ante	Check list of best practices
		k2) Change of policies	Check list of best practices
		k3) Implementation of policies	Check list of best practices
	l) Existence and alignment of city planning	l1) Corporate planning	Existence of plans (strategic, tactical, …)
		l2) City planning	Check list of best practices
		l3) Water resources planning	Investment on community
Assets	m) Performance	m1) Failures	Main failures; sewer blockages
	n) Robustness	n1) Flexibility	Checklist of best practices
		n2) Adaptability	Checklist of best practices
		n3) Reliability	Replacement/rehabilitation; treatment utilization; storage capacity

Table 2. Investment indicators.

Indicator	Good performance	Acceptable performance
R&D (% of turnover)	1%	0,2%
Maintenance and replacement of assets (% of network)	3%	1,5%

Table 3. Efficiency indicators.

Indicator	Good performance	Acceptable performance
Total cost coverage ratio (%)	100%	90%
Staff productivity (No./1000 connections)	2,0 to 5,0 employees per 1000 connections	1,5 to 2,0 or 5,0 to 5,5 employees per 1000 connections

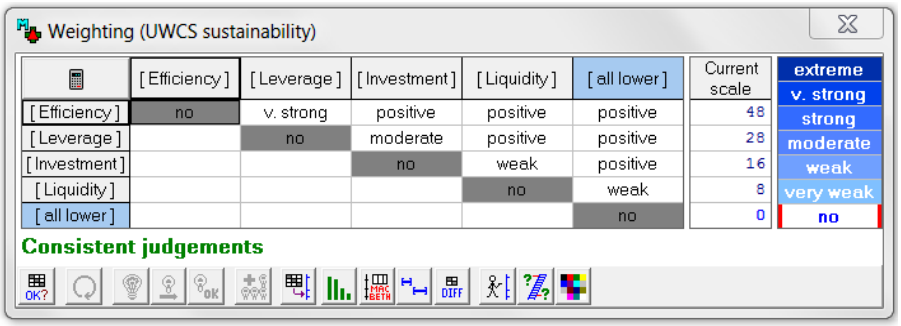

Figure 1. Judgments of the decision-maker (M-MACBETH software).