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HOW TO ASSESS SUSTAINABILITY OF URBAN WATER CYCLE SYSTEMS (UWCS). DEVELOPMENT OF A METERING METHODOLOGY

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Abstract: This paper incorporates an extended definition of sustainable development of urban water cycle services combined with a system to measure the progress towards sustainability. Two dimensions of sustainability, namely the values of assets and the practice of governance are added to the three conventional dimensions, social, economic and environmental impact. The metering system further comprises objectives, criteria and metrics. The method implies a definition of risk factors that may compromise a sustainable development and the impact of interventions to compensate this. The concept of metabolism or other LCA (Life Cycle Assessment) methods may be used to analyze the impact of these interventions on the environment as well as the social and economic impact and the effect on the assets and governance. The impact of climate change is considered to become a main aspect in future urban water cycle services and is addressed in particular.

Keywords: Urban water services; Sustainability assessment; TRUST

1. Introduction

During the European collaborative R&D project TRUST (https://www.trust-i.net), the need to reach a common understanding on the term "sustainability" soon became apparent. In classical definitions it is referred to the social, economic and environmental dimension of asset management. However there are no established standards on measurement of the achievements of sustainability for urban water cycle systems. Since TRUST is dealing with "Transition to Sustainable Systems for Tomorrow" it has been necessary to define a link between the ultimate objectives as the above mentioned dimensions and traditional systems for performance assessment and benchmarking.

Furthermore there was a need to develop an assessment system to support analysis of alternatives to obtain sustainable urban water cycle services. For this, the concept of metabolism was applied, and two complementary tools were developed for distributed modelling (WaterMet2, Behzadian et al 2014) and lumped system models (DMM, Venkatesh et al 2014). The models have been tested in pilot cities. An integrate approach for infrastructure asset management based on the TRUST sustainability framework has also been adopted and improved, giving place to a series of best practice manuals (Alegre ed. 2015), a software platform and an e-learning course, all publicly available from the TRUST website. This paper does not focus on the TRUST IAM approach, described in e.g. in Alegre et al. (2015).

Impact of climate change is expected to become one of the most important drivers for change of urban water cycle systems. This factor is handled in particular in a number of international projects, for example the finished project PREPARED, and the ongoing EU collaborative R&D projects BINGO (https://www.projectbingo.eu) and the 7FP project PEARL (https//www.pearl-fp7.eu). Some preliminary results are available and are addressed in this paper.

2. Definition of sustainability

The framework of sustainability of TRUST consists of the dimensions, objectives, criteria and metrics (Brattebø et al 2013). Additional to the classical "triple bottom line" TRUST proposes two more dimensions, governance and infrastructural (assets) as the main instruments to achieve required services with regard to security of people (social), the economy and the environment. Thus the TRUST general definition is: *"Sustainability in urban water cycle services (UWCS) is met when the quality of assets and governance of the systems is sufficient to actively secure the water sector's needed contributions to social, environmental and economic sustainability in the urban system as a whole".*

Sustainability assessment of urban water cycle services in TRUST includes the dimensions of social, environmental, economic, assets and governance sustainability. The assessment should in particular provide insights in how to improve the management and development of assets and governance, as part of a strategic transition process towards 2040, as these dimensions represent the opportunities where interventions may directly be made by the water utility in order to positively influence the end dimensions of social, environmental and economic sustainability (Figure 1).

Objectives comprise the second level of the UWCS scorecard. TRUST set out specific and elaborated objectives for the UWCS which can change in intensity according to water utilities patterns and their stakeholders. For each objective that is shown on the outer circle in Figure 1 there is a set of criteria defined and for each criterion there must be corresponding performance metrics as shown in an example for the assets dimension in Table 1.

The assessment is made operational by critically and carefully examining a chosen set of performance metrics/indicators and how they comply with a predefined set of sustainability objectives and criteria.

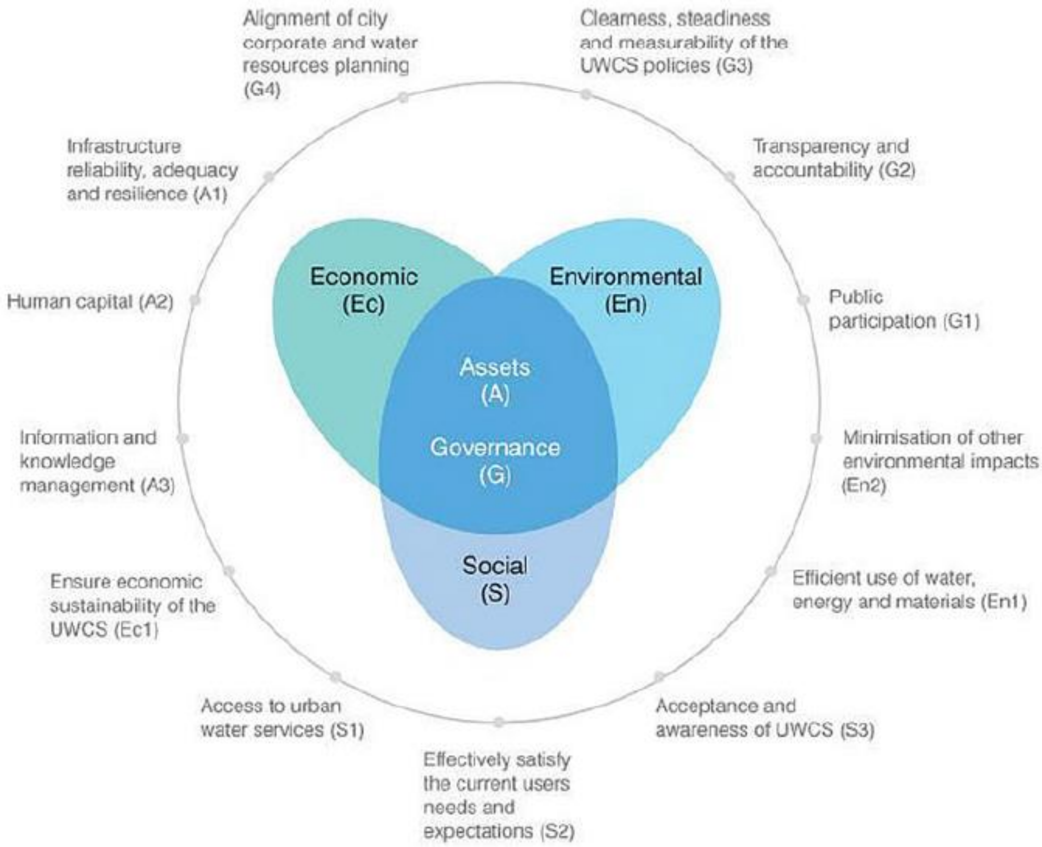

Figure 1: Dimensions and objectives in urban water cycle sustainability (Brattebø, 2012; Venkatesh et al, 2015b)

Table 1: Dimensions, objectives and criteria of the UWCS sustainability (example, Brattebø, 2012)

Dimension	Objectives for 2040	Assessment criteria
Assets	**A1**) Infrastructure reliability, adequacy and resilience	**A11**) Adequacy of the rehabilitation rate **A12**) Reliability and failures **A13)** Adequate infrastructural capacity **A14)** Adaptability to changes (e.g. climate change adaptation)
	A2) Human capital	**A21**) Adequacy of training, capacity building and knowledge transfer
	A3) Information and knowledge management	**A31**) Quality of the information and of the knowledge management system

The performance metrics/indicators may be quantitative and/or qualitative, and are specifically chosen in order to account for the particular context and challenges of a given urban water cycle system, in a medium- and long-term transition context. The UWCS sustainability assessment method must be transparent, valid and holistic, and should make use of metabolism (system flows of resources and emissions) accounting and life-cycle assessment perspectives when this is needed. The assessment method should be inclusive and flexible with respect to stakeholder involvement and decisions regarding target setting and trade-off as part of a multi-criteria decision analysis process.

3. Metabolism risk-controlled model

An overarching methodology was developed for evaluating risks related to sustainability of existing urban water systems and possible intervention options, hence improving the understanding on how decisions can contribute to meeting sustainability targets in the set time horizon.

The methodology proposed essentially follows the standard steps of a risk management process as defined by ISO 31 000: 2009, but adjusted to be used at strategic (macro) level using an integrated approach. At strategic level the usual approach of using a detailed analysis based on representative risk events (accidents or incidents) is not considered appropriate. Herein, the events should correspond to changes in circumstances (for a period of time, e.g. a year), which need to be based in plausible scenarios of change for conditions such as climate change, water and energy scarcity, rising energy costs, population growth. These conditions can affect the performance of water services, eventually increasing their vulnerability and the level of risk or decreasing reliability and resilience. Achievement of sustainability targets for water systems can be jeopardised by these changes in circumstances.

The methodology (Ugarelli et al, 2014c) builds on (and it is aligned to) the TRUST sustainability definition. Assuming a list of established sustainability objectives, defined for a specific system, risk can be identified in the context of the occurrence of certain circumstances causing undesired and uncertain deviations from the objectives. Hence, in the risk approach proposed, "events" are related to the occurrence of a particular set of circumstances (ISO Guide 73:2009) evaluated in a given period.

From the methodological point of view, a definition of objectives needs to be incorporated in the risk management process for each specific application and each objective has to be expressed by an appropriate set of criteria, supported by a set of metrics and corresponding targets. The proposal is to analyze risk using scenarios that allow for the characterization of the circumstances influencing the sustainability objectives. The urban water system is modelled by "metabolism models" which are deterministic and quantitative model developed in TRUST, allowing quantification of the main water flows and other relevant fluxes in the urban water system. Risk assessment uses results from the metabolism models to analyze risk in the urban water system (Ugarelli et al, 2014c).

The concept of metabolism for UWCS is shown in Figure 2.

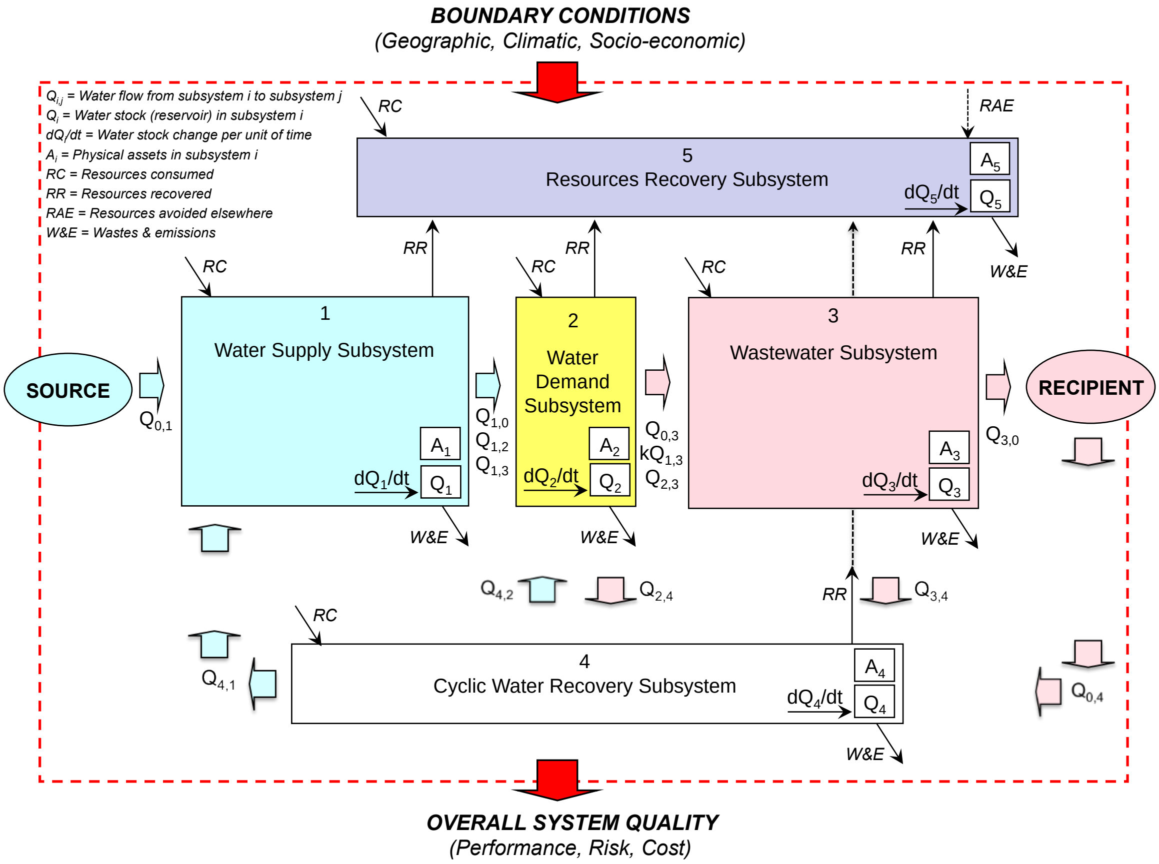

Figure 2: Concept of metabolism for urban water cycle systems (Venkatesh et al. 2015b)

The metabolism model operates with boundaries as geographic, climate and socio-economic conditions and calculates the overall system quality in terms of performance, (e.g. effluents to receiving air and water), costs and risks related to sustainable development. The UWCS is typically divided into main elements of source water supply, water demand (driver), wastewater and resources recovery subsystem.

In TRUST, two supplementary approaches to urban water metabolism have been developed, aligned and tested with the risk methodology: the WaterMet2, developed at Exeter university (Behzadian K et al 2013) (Ugarelli et al., 2014a), UK and the Dynamic Metabolism Model (DMM), developed at NTNU (Venkatesh G et al 2015), (Ugarelli et al., 2014b),. The testing, which have taken place a.o. in Oslo, Norway and Reggio Emilia, Italy, has shown a high potential to support assessment of sustainability in today's solutions and with regard to directions towards the future .

The models allow to take into account the changes brought by different possible scenarios and utilize selected metrics/indicators to provide an understanding of the efficiency of alternative interventions to meet, under the different scenarios, selected objectives towards a time horizon that in the TRUST case has been set as 2040. The specific scenarios addressed are population growth, impact of climate change, degradation of infrastructure and increased requirement of service level.

A corresponding list of possible interventions to address the scenarios has been developed.

Table 2: Typical interventions to compensate sustainability risks (Venkatesh 2015, Beheshti 2015)

Water supply	**Wastewater**
Harnessing new raw water sources	Extension of wastewater network
Expansion of or new water treatment plants	Reduction of I/I. Rehabilitation
Leakage control, rehabilitation of pipelines	Energy management
Consumer awareness, creation of water metering	
Increase in water prizing	

The assessment of metabolism connected with the scenarios and intervention options form a basis for choices/selections which utilities would like to make depending on their priorities, targets and benchmarks they would set for themselves. There are differences in WM2 and DMM, which make them useful in different contexts – situational, circumstantial etc. WM2 offers different spatial and temporal resolutions, and is thereby useful in contexts where utilities would like to focus on sub-catchments within the city to understand and solve specific problems. DMM is based on conventional resource-flow analysis and presents annually-aggregated values for the entire urban water system, though it is possible to derive corresponding indicators for the individual sub-systems as well.

As an example of the metabolism analysis (DMM) figure 3 and 4 below shows the long-term effect of rehabilitation on the water demand per capita and the capital expenditure per cubic meter water demand, in the water distribution system. It should be noted here that this test narrows down the scope and focuses on the effect of different rehabilitation rates on indicators pertaining to only the water distribution system.

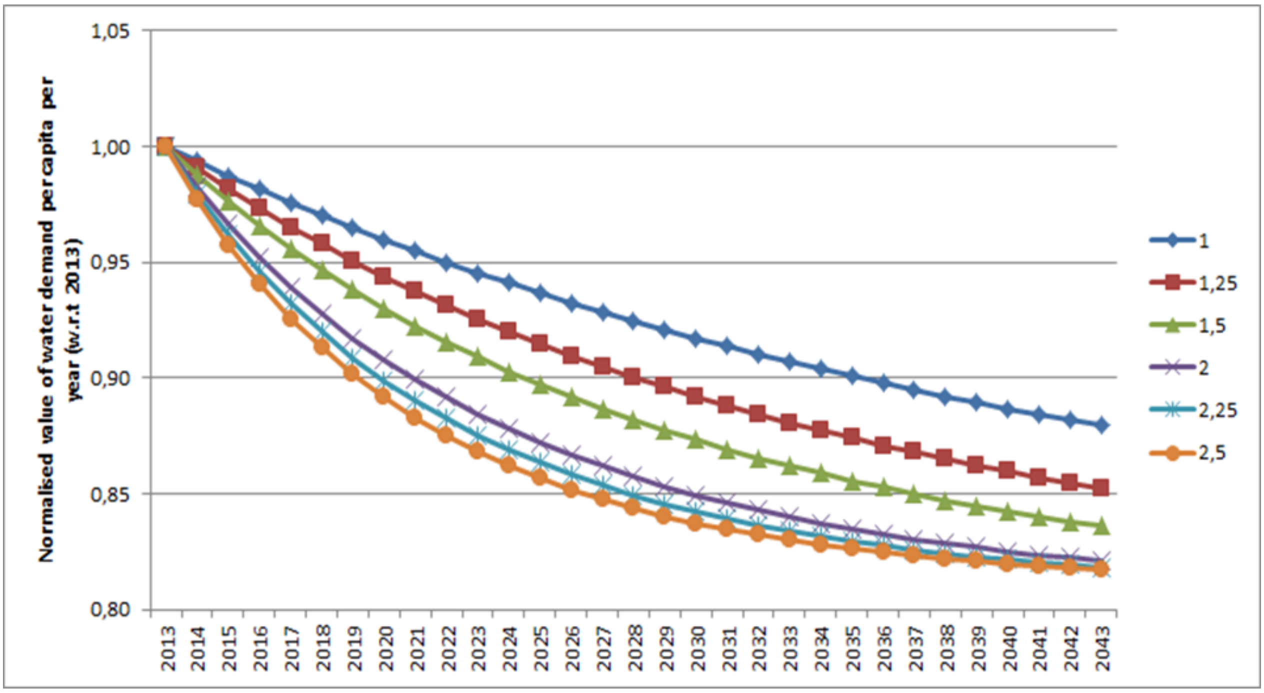

Figure 3: Effect of degrees of rehabilitation on the water demand per capita per year, in the water distribution system (Each line represents one particular annual rehabilitation percentage). (Venkatesh et al 2015a)

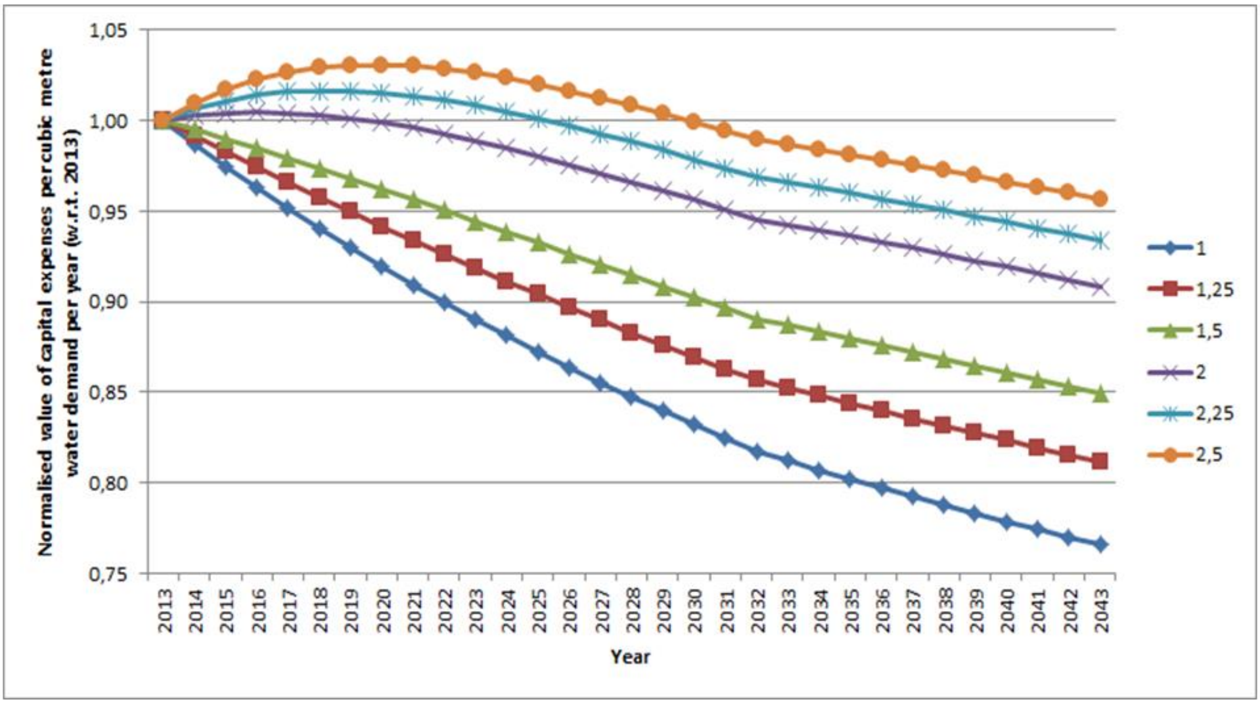

Figure 4: Effect of degrees of rehabilitation on the annual capital expenditure per cubic meter water demand in the water distribution system (Each line represents one particular annual rehabilitation percentage), (Venkatesh et al, 2015a)

Beheshti (2015) calculated the impact of various intervention combinations to compensate for population growth and degradation of networks in city of Trondheim, Norway. The interventions are a) reduction of infiltration/inflow to wastewater system, b) reduction of rehabilitation rate, c) extension of current network and d) energy management. This work may act as an example from a metabolism analysis of wastewater systems. It shows how active use of sets of interventions such as rehabilitation of pipelines and energy saving measures may cause a significant improvement of GHG gas emission to the atmosphere from operations on wastewater systems. The reduction is mainly due to reduced energy requirements for pumping and treatment of wastewater.

4. Impact of climate change

Impact of climate change as lack of resources for water supply as well as flash floods from local rainstorms in urban areas is one of the most prominent risk factors for a sustainable development. A precondition for the selection of efficient interventions to meet this risk is the actual design values for each geographical area. The prognosis from the UN climate panel forms the basis for downscaling to local conditions. The principle for downscaling to a large degree depends on the local climate and topography. This is a subject for several research initiatives. The European collaboration R&D project BINGO (https://www.projectbingo.eu) demonstrates the impact of downscaling as available water resources in the long range and design criteria for stormwater runoff. A pre-study of BINGO for the city of Bergen, Norway, using the downscaling principles together with extended analysis of hydrological data from the catchments for water supply concluded that for the city growth prognoses towards 2100, the water resources were sufficient if the leakage from the network is kept under control (less than 20 % leakage, Kristvik & Riisnes, 2015).

5. Conclusion

The paper presents a comprehensive definition of urban water sustainability by incorporating the asset management and governance into the classic definition of economic, environmental and social sustainability.

Metabolistic models may be a very powerful tool to assess sustainability of urban water systems. It provides the opportunity to balance between several dimensions (economy, environment, social, assets and governance) and corresponding criteria for sustainability. An example from city of Trondheim demonstrates the importance of maintaining existing infrastructure in the context for city development.

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