Contemporary Engineering Sciences, Vol. 14, 2021, no. 1, 23 - 34
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2021.91637

Sustainability in the Urban Water Cycle in Sustainable Cities

Roberto Alonso González Lezcano

Escuela Politécnica Superior, Universidad CEU San Pablo
Montepríncipe Campus, 28668, Boadilla Del Monte, Madrid, Spain

Eduardo José López Fernández

Escuela Politécnica Superior, Universidad CEU San Pablo
Montepríncipe Campus, 28668, Boadilla Del Monte, Madrid, Spain

David Baeza Moyano

Facultad de Farmacia, Universidad CEU San Pablo
Montepríncipe Campus, 28668, Boadilla Del Monte, Madrid, Spain

Gastón Sanglier Contreras

Escuela Politécnica Superior, Universidad CEU San Pablo
Montepríncipe Campus, 28668, Boadilla Del Monte, Madrid, Spain

Abstract

Improving water management in the coming years is an unavoidable challenge, given the dramatic situation posed by climate change, which forces all actors involved in the processes of the urban water cycle to rise to the occasion. In the article, the authors undertake a detailed review of the methodologies for measuring sustainability through indicators, both in general and in particular in the urban water cycle. The work compiles the theories that establish the consideration of intelligent water management systems and the conditions that intelligent meters must meet in order to be considered as such. The indissoluble relationship between water and energy in all the processes of the urban water cycle is also dealt with, as well as the relevance of the different resources coming from waste water. After the authors' objective analysis, the lines of study and research that offer the greatest potential for improving sustainability and energy efficiency in all phases of the urban water cycle are highlighted.

Keywords: sustainability; urban water cycle; energy efficiency; smart meter; water management; life cycle assessment (LCA); energy consumption.

1 Introduction

Changes in demographics, including an ageing population, socio-economic factors, climate, change, biodiversity, energy use, water supply and consumption, and ageing infrastructure for water supply, distribution and treatment [1-3] require a thorough understanding of the various options available for moving towards sustainable cities.

A sustainable society is one that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs, where each individual human being has the opportunity to develop freely in a well-balanced society in harmony with his or her environment" (UN 1987) [4] . From an anthropocentric point of view, sustainability has been summarized as "improving the quality of life of human beings while living within the carrying capacity of supporting ecosystems" [5-7].

In search of an appropriate set of indicators to measure a country's level of sustainability, Van de Kerk and Manuel [5] developed a Sustainable Society Index (SSI). The SSI integrates the most important aspects of sustainability and quality of life of a national society in a simple and transparent way. It consists of only 22 indicators, grouped into five categories. The indicators were carefully chosen, meeting the following criteria [8-10]:

-the indicator must be relevant to a topic according to the definition used;
-the indicator must be measurable;
-the indicators must be independent of each other and must not overlap;
-indicator data must be publicly available from scientific or institutional sources;
-data must be available for all countries

In order to improve water supply in cities, they must first be assessed with respect to different aspects of sustainability; i.e. efficient use of water, energy and non-renewable resources, climate change, security, biodiversity, green space, recreation, human and environmental health, public participation, compliance with current and future legislation, transparency, accountability and costs [11]. Despite the global challenges of water security and urbanisation, which predominantly affect cities [12], a specific set of indicators for the IUWM is currently lacking.

Van Leeuwen et al [2] based on the following criteria proposed 24 indicators to assess the sustainability of the Urban Water Cycle

- The city plans should include: water security, water quality, drinking water, sanitation, infrastructure, climate robustness, biodiversity and attractiveness, as well as governance
- A quantitative approach is the preferred option in which expert panel scores can also be included
- City plan indicators should be scored on a scale from 0 (serious concern) to 10 (no concern).

- Calculations and scoring of indicator values should be relatively easy.
- Data should be readily available from public sources
- The results should be relatively easy to interpret and communicate, not only to experts but also to politicians and the public, preferably in a graphic image such as a web spider, without the need for in-depth knowledge of the methodology applied.

Urbanisation is a multidimensional process that is accompanied by increasing uncertainty due to climate change, human migration, and changes in the capacity to sustain ecosystem services. Hurlimann and Wilson [13] believe that the development of a regulatory framework to guide the assessment and implementation of sustainability of adaptation decision options in the urban water supply sector would be beneficial, in which spatial planning could play a key facilitating role. Incorporating the development of this regulatory framework in multiple case study sites will help advance the achievement of the necessary adaptation to climate change.

2. Smart water management system

The dramatic change in climate and the increase in population meant that water was insufficient compared to demand. As water consumption is increasing, water management becomes a major challenge for both the government and the water companies. The challenge also includes providing quality water at minimal cost and using energy. Water management has a role in many aspects of human life such as water consumption, agriculture, food production, the environment, etc. [14].

Current water network structures are based on large, centralized systems where management options are limited. The main limitations of these systems are: low operational efficiency due to the imbalance between freshwater supply and demand, loss and/or contamination of water supply, high energy requirements for production and transportation of supply water, water treatment, cost and/or low efficiency of water supply and wastewater treatment due to fixed treatment processes, and lack of integration of alternative water sources. To overcome these limitations, a new real-time water management scheme is required [15].

Future water shortages require immediate measures for resource development, demand reduction and increased efficiency in treatment and transportation. Management of future flood risks requires immediate action in risk assessment, defence and relief systems, forecasting and warning systems, and institutional and governance measures [16].

Technology has been revolutionised in recent years and is entering an application phase that focuses on several areas, including the environment. A relevant example is that of the European Union, which has defined a high priority for the next 20 years on 'ICT for sustainable growth' with the ambition of leading innovation on a global scale. The current situation in the field of water is characterised by a low level of maturity with regard to the standardisation of ICT business solutions and processes. The massive and rapid diffusion of communication devices within Society and their application to industrial sectors is not coordinated. According to Gourbesville 2016 [17] the only relevant angle for the development of these technologies (M2M), within the water domain, has to be based on the identification of the added value provided in each commercial process by the introduction of the new solutions.

Gourbesville 2011 [18] stated that in order to develop specific information systems (IS) for water cycle management, a methodology is needed to identify priorities and strategic investments to be made in the field of ICT. The requested approach needs to investigate all and provide a map of the various processes that take place in the different domains of the water use cycle. Gourbesville [18] states that the uses in the urban environment, carried out by water companies, can be defined with a limited number of business processes - 29 in total - summarised in Table 1 and covering drinking water, wastewater, water from various forms of precipitation and water management. From this list of BP, the ICT solutions that provide real added value can be identified. This diagnosis has to be shared by professionals and operators to ensure a coherent deployment.

Table 1. Business processes for urban uses

Asset management	Crisis management	Field intervention management
Field works	Use of GIS	Maintenance of GIS
Management of plant maintenance	Electro mechanical maintenance	Laboratory activity and quality control
Automation and Sensors	Real time network management	Planning and design of new assets and plants
Water resources management	Environment management	Drinking water treatment plant management
Water primary network management and water balance	Water secondary network management	Leak detection
Meter reading (AMR and MMR)	AMR and MMR management	Public service contract management
Waste water network management	Storm water network management	Waste water treatment plant management
Sewer inspection and sewer cleaning	Billing	Customer care and communications
Innovation and pilots	Supports	

Efficiency in urban water cycle management is strongly influenced by a scenario that is unique to each city. These general trends and pressures can hardly be influenced by urban water management. Anna Strzeleckaa et al [19] developed a separate Trends and Pressures (TPF) framework to provide a context. The TPF consists of 12 descriptive indicators that are equally distributed [20]. Through the TPF, awareness is raised about the most relevant issues that are hindering or, conversely, revealing opportunities for the Integrated Water Resources Management (IWRM) [21].

3. Smart meter

Brophy-Haney et al., 2009 [22] and Darby, 2010 [23] indicate that there is no single definition or consensus on what it means for a meter or metering system to be classified as "advanced" or "smart" regardless of utility (gas, water or electricity). Darby [23] comments that the realities of smart metering are simple; smart is a meter that stores and transmits measurements at frequent intervals. Several authors [24-27] claim that smart meters can also replicate the collection of water consumption data for end use including leak detection in existing homes. Ferreira et al [28] note that advanced water metering and communications technologies allow data to be transferred from end-use water consumption data; analysis of this high-resolution data points to unusual patterns caused by water waste. The importance of managing customer data at this high level should not be underestimated [29].

Kowalsky and Marshallsay [30] define residential water consumption, in a number of micro components. Metering of these components; toilets, taps, showers, etc. provide information on how water is used in and around the home. There are two approaches to monitoring residential water end-use: 1) typical end-use and 2) advanced end-use water metering depending on the type of water meter and data capture technology [31]. Typical end-use studies measure water use using an intelligent meter that uses high-resolution data in combination with household audits to check household appliance stocks and residents' self-compiled water use logs [25,26,31]. The smart metering technology used today can measure water consumption with resolutions from 0.014L [25] to 5L [32] and in time intervals of 1 to 5 s [33], 10 s [25,34] and 1 h [32]. The meter and recorder determine the richness of the data [25] and the level of investment correlates with the complexity of the technology and the potential for behavioural change [33]. Software packages such as Trace Wizard® study the consistency of flow plotting of water use patterns; leaks are identified and quantified from their continuous monitoring data [35].

4. Energy consumption in the urban water cycle

Energy and water are of great importance in human life and are two fundamental resources that play a vital role in various aspects of socio-economic systems [36]. In most man-made systems, water and energy are interrelated, and this relationship is called the water-energy nexus [37]. Gleick [38] first introduced the nexus in 1994, but recently it has received much attention because of the interdependence between water and energy sustainability.

Schnoor [37] states that the Water-Energy Nexus will become increasingly important in the coming years. The world desperately needs both. Communities with severe water stress alleviate their situation in one of three ways: (1) by importing water from upstream sources or through inter-basin transfers; (2) by unsustainable pumping of groundwater; or (3) by reusing wastewater or saline water. Only the last solution is sustainable in the long term. For countries with energy stress, try to increase the production of domestic energy resources and avoid oil imports by manufacturing biofuels. All these solutions have a substantial environmental impact.

Water is used in the energy life cycle and energy is used in different stages of the urban water cycle; therefore the water-energy nexus exists in all urban ecosystems [39-43]. Energy is consumed at all stages of the urban water cycle (UWC), which begins with the acquisition of groundwater and surface water, followed by raw water treatment, local distribution, end-use, and wastewater collection and treatment [44].

Wakeel and Chen (2016) [45] investigated energy consumption at each stage of the water cycle in the city of Lahore, Pakistan. Following the study, the authors recommend that renewable energy options such as solar water heaters be installed to reduce energy consumption at the household level. Similarly, they observed that the city of Lahore had no large-scale political wastewater, nor did it have any recycling and reuse management; therefore, they considered that wastewater should be recycled to avoid energy consumption during the extraction stage.

The energy sector is one of the main users of freshwater resources in China. Zhang and Anadon (2013) [46] investigated the life cycle of water withdrawals, water use and wastewater disposal in China's energy sectors and their water-related environmental impacts, using a multi-regional input-output mixed model (MRIO) and a life cycle impact assessment (LCIA) method based on the Eco-Indicator 99 framework. The authors concluded that the most important feature of the energy-water nexus in China is the significantly unequal spatial distribution of water consumption and corresponding environmental impacts caused by the geological discrepancy between fossil fuel resources, freshwater resources and energy demand.

Life cycle assessment (LCA) is useful as an information tool for the examination of alternative future scenarios for strategic planning. Developing a life cycle assessment for a large water and wastewater system involves making methodological decisions on the level of detail to be maintained throughout the different stages of the process. Lundie et al. (2004) [47-48] examine a methodology tailored to strategic planning needs that maintains a high degree of model segmentation to improve the modelling of a large and complex system. This is illustrated by a case study of Sydney Water, Australia's largest water service provider. The authors conducted a life cycle assessment to examine the potential environmental effects of Sydney Water's total operations in 2021. This was the first study to create an LCA model of an integrated water and wastewater system with this degree of complexity. The authors constructed a system model to represent current operating assets as augmented and improved through 2021. The results of the base case provided a basis for the comparison of alternative future scenarios and for the conclusions to be drawn regarding possible environmental improvements.

5. Wastewater resources for sustainable cities

Actual wastewater treatment is based primarily on conventional activated sludge (CAS), which achieves a sufficiently low level of carbon, nitrogen and phosphorus effluent; but it is not cost-effective, barely achieves recovery, requires electricity equivalent to a fossil fuel consumption of 85 kWh per inhabitant equivalent (IE) per year and has an operational CO2 footprint of 80 kg CO2 IE x year-1.

Scarcity and the need to reduce greenhouse gas emissions force us to rethink the treatment of wastewater for sustainable cities of the future; as well as, the use and reuse of all types of resources that are currently not taken into account in cities, but will undoubtedly be in the future (Figure 1). Verstraete, and Vlaeminck (2011) [49] offered a short-cycle approach to water (ZeroWasteWater), energy and valuable materials, while properly disposing of pathogens, heavy metals and organic waste. A less diluted solution of waste will result from improvements in sewerage, more rational use of drinking water and the addition of kitchen waste, complemented by an advanced concentration pass system at the entrance to the wastewater treatment plant. The main challenges of the approach have been to incorporate the water chain into holistic urban planning and to make a cradle-to-cradle approach that society will find acceptable.

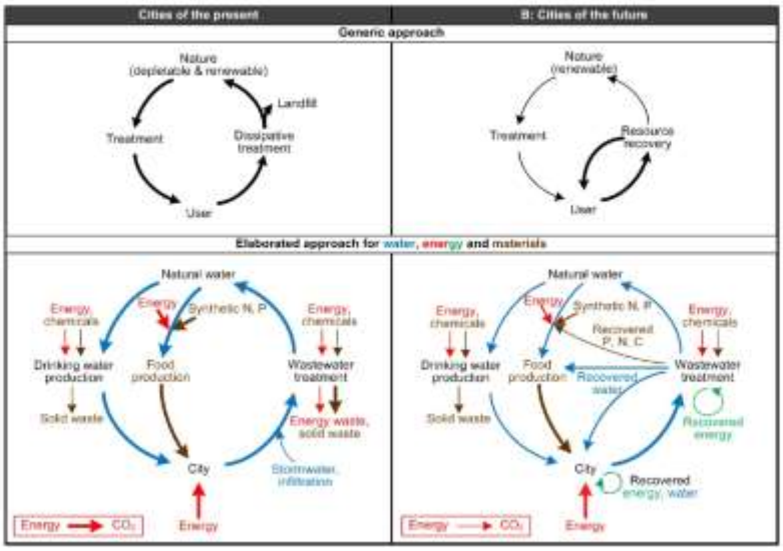

Figure 1. Major pathways in the cities of the present (A), wasting a lot of depletable resources, and in the cities of the future (B), rationally and sustainably recovering resources [49]

6. Conclusions

The following are the conclusions and proposals for study and implementation, which the authors present within the great possibilities that the urban water cycle offers:

As a result of the review presented by the authors in this work, they wish to highlight the large number of initiatives and solutions presented in recent times in everything related to water management within the urban cycle and the enormous possibilities that are opening up in the field of optimising all the processes that complete the urban water cycle.

In the authors' opinion, the water sector is perfectly prepared to face each and every one of the challenges of climate change, which must contribute to giving definitive shape to the concept of Smart City, without forgetting the great challenge of solving the scarcity of the resource in a large part of the world. However, it is precisely the efforts directed towards sustainability and optimisation of the use of the resource that will undoubtedly lead to real solutions to these problems.

It is necessary to promote all energy efficiency strategies that help to improve all the processes of the urban water cycle.

It is advisable to intensify and improve the processes of generating by-products (sludge, sand, fat, nitrogen and phosphorus) in the treatment of waste water, in order to convert them into clearly recoverable products.

Extraordinary energy efficiency and saving measures should be considered, which will contribute to reducing the greatest possible amount of greenhouse gases and the carbon footprint resulting mainly from the consumption of electricity in the urban water cycle.

In the treatment of waste water, processes depend on multiple factors that could undoubtedly be improved with models based on Artificial Intelligence (AI) that will contribute to reducing the high energy consumption of some phases of the cycle.

To conclude, the authors wish to place particular emphasis on the need, in coalition with the Sustainable Development Goals 2030 (ODS 2030) proposed by the UN, to multiply the installation of systems powered by renewable energies in all phases of the urban water cycle.

References

[1] Ernstson, H., Leeuw, S. E. V. D., Redman, C. L., Meffert, D. J., Davis, G., Alfsen, C., & Elmqvist, T., Urban transitions: On urban resilience and human-dominated ecosystems, *Ambio*, **39** (8) (2010), 531–545. https://doi.org/10.1007/s13280-010-0081-9

[2] van Leeuwen, C. J., Frijns, J., van Wezel, A., & van de Ven, F. H. M., City Blueprints: 24 Indicadores para evaluar la sostenibilidad del ciclo del agua en las zonas urbanas, *Gestión de los recursos hídricos*, **26** (8) (2012), 2177-2197. https://doi.org/10.1007/s11269-012-0009-1

[3] Cohen, D., Earth audit. (cover story), *New Scientist*, **194** (2605) (2007), 34–41. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=rch&AN=27199200
[4] UN, Indicators of Sustainable Development: Guidelines and Methodologies – Third edition (Methodology sheets). Transport, 93 (2007). Retrieved from http://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets.pdf
[5] Van de Kerk, G., & Manuel, A. R., A comprehensive index for a sustainable society: The SSI - the Sustainable Society Index, *Ecological Economics*, **66** (2–3), (2008), 228–242. https://doi.org/10.1016/j.ecolecon.2008.01.029
[6] Caring for the Earth: A strategy for sustainable living, Caring for the Earth: A Strategy for Sustainable Living, Taylor and Francis, 2010, pp. 1–228. https://doi.org/10.4324/9781315066073
[7] Unep, Every Drop Counts: Environmentally Sound Technologies for Urban and Domestic Water Use Efficiency. Management, 2008, p. 193. Retrieved from http://books.google.co.uk/books?id=ejeR6v98N64C
[8] Bell, S., & Morse, S., Measuring sustainability: Learning by doing. Measuring Sustainability: Learning by Doing, Taylor and Francis, 2003, pp. 1–192. https://doi.org/10.4324/9781849771962
[9] Meadows, D., Atkisson, A., Bossel, H., de Vries, H., Revi, A., Peet, J., & Davis, J., Indicators and Information Systems for Sustainable Development. A Report to the Balaton Group, 1998.
[10] Guy, G. B., & Kibert, C. J., Developing indicators of sustainability: US experience, *Building Research and Information*, **26** (1), (1998), 39–45. https://doi.org/10.1080/096132198370092
[11] Verstraete, W., Van de Caveye, P., & Diamantis, V., Maximum use of resources present in domestic "used water", *Bioresource Technology* (2009). https://doi.org/10.1016/j.biortech.2009.05.047
[12] Engel, K., Jokiel, D., Kraljevic, A., Geiger, M., & Smith, K., Big Cities Big Water Challenges, WWF Germany, 2011, p. 80.
[13] Hurlimann, A., & Wilson, E., Sustainable urban water management under a changing climate: The role of spatial planning, *Water* (Switzerland), **10** (5) (2018). https://doi.org/10.3390/w10050546
[14] Fainstein, S. S., Cities and diversity: Should we want it? Can we plan for it? *Urban Affairs Review*, **41** (1) (2005), 3–19. https://doi.org/10.1177/1078087405278968
[15] Lee, S. W., Sarp, S., Jeon, D. J., & Kim, J. H., Smart water grid: the future water management platform, *Desalination and Water Treatment*, **55** (2) (2015), 339–346. https://doi.org/10.1080/19443994.2014.917887
[16] Fundamentals of Information Systems, Fundamentals of Information Systems. Springer US, 1999. https://doi.org/10.1007/978-1-4615-5137-9
[17] Gourbesville, P., Key Challenges for Smart Water, *Procedia Engineering* **154** (2016), 11–18. https://doi.org/10.1016/j.proeng.2016.07.412
[18] Gourbesville, P., ICT for Water Efficiency, Environmental Monitoring. InTech, 2011. https://doi.org/10.5772/27607

[19] Strzelecka, A., Ulanicki, B., Koop, S., Koetsier, L., Van Leeuwen, K., & Elelman, R., Integrating Water, Waste, Energy, Transport and ICT Aspects into the Smart City Concept, *Procedia Engineering*, **186** (2017), 609–616. Elsevier Ltd. https://doi.org/10.1016/j.proeng.2017.03.277

[20] Mori, K., & Yamashita, T., Methodological framework of sustainability assessment in City Sustainability Index (CSI): A concept of constraint and maximisation indicators, *Habitat International*, **45** (P1) (2015), 10–14. https://doi.org/10.1016/j.habitatint.2014.06.013

[21] Koop, S. H. A., & van Leeuwen, C. J., Application of the Improved City Blueprint Framework in 45 Municipalities and Regions, *Water Resources Management*, **29** (13) (2015), 4629–4647. https://doi.org/10.1007/s11269-015-1079-7

[22] Brophy Haney, a, Jamasb, T., & Pollitt, M. G., Smart Metering and Electricity Demand: Technology, Economics and International Experience, *Policy*, **44** (September) (2009), 1–72. https://doi.org/Han09

[23] Darby, S., Smart metering: What potential for householder engagement? Building Research and Information, **38** (5) (2010), 442–457. https://doi.org/10.1080/09613218.2010.492660

[24] Froehlich, J., Larson, E., Saba, E., Campbell, T., Atlas, L., Fogarty, J., & Patel, S., A longitudinal study of pressure sensing to infer real-world water usage events in the home, in: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), **6696** LNCS (2011), pp. 50–69. https://doi.org/10.1007/978-3-642-21726-5_4

[25] Willis, R., Stewart, R. A., Panuwatwanich, K., Capati, B., & Giurco, D., Gold coast domestic water end use study, *Water*, **36** (6) (2009), 84–90.

[26] Willis, R. M., Stewarta, R. A., Panuwatwanich, K., Jones, S., & Kyriakides, A., Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. *Resources, Conservation & Recycl.*, **54** (12) (2010), 1117-1127. https://doi.org/10.1016/j.resconrec.2010.03.004

[27] Stewart, R. A., Willis, R. M., Panuwatwanich, K., & Sahin, O., Showering behavioural response to alarming visual display monitors: Longitudinal mixed method study, *Behaviour and Information Technology*, **32** (7) (2013), 695–711. https://doi.org/10.1080/0144929X.2011.577195

[28] Ferreira, V., Alves, L., Fleming, P., Stuart, G., Patel, P., Webber, P., & Conway, S., "Low hanging fruits" or cost-effective energy and water savings using intelligent metering and monitoring systems?, *ECEEE 2007 Summer Study*, 2007, 739–742.

[29] Even, A., Shankaranarayanan, G., & Berger, P. D., Evaluating a model for cost-effective data quality management in a real-world CRM setting, *Decision Support Systems*, 50 (1) (2010), 152–163. https://doi.org/10.1016/j.dss.2010.07.011

[30] Kowalski, M., & Marshallsay, D., Using measured microcomponent data to model the impact of water conservation strategies on the diurnal consumption profile, *Water Science and Technology: Water Supply*, **5** (2005), 145–150. https://doi.org/10.2166/ws.2005.0094

[31] Beal, C. D., & Stewart, R. A., Identifying residential water end uses underpinning peak day and peak hour demand, *Journal of Water Resources Planning and Management*, **140** (7) (2014). https://doi.org/10.1061/(ASCE)WR.1943-5452.0000357

[32] Britton, T., Stewart, R. A., & Wiskar, D., Smart metering as a tool for revealing the characteristics of household leakage during a typical reading cycle, in Proc. IWA Efficient 2009 Conference, Sydney: Australian Water Association, 2009.

[33] Giurco, D. P., White, S. B., & Stewart, R. A., Smart metering and water end-use data: Conservation benefits and privacy risks, *Water* (Switzerland), **2** (3) (2010), 461–467. https://doi.org/10.3390/w2030461

[34] Heinrich, M., Water Use in Auckland Households. Auckland Water Use Study (AWUS) Final Report. EC1356 Report for Watercare Services. BRANZ Ltd, Judgeford, New Zealand, 2008.

[35] Mayer, P. W., Deoreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B., & Nelson, J. O., Residential End Uses of Water. Aquacraft, Inc. Water Engineering and Management, 1999, 310. https://doi.org/4309b

[36] Zhang, C., & Anadon, L. D., Life cycle water use of energy production and its environmental impacts in China, *Environmental Science and Technology*, **47** (24) (2013), 14459–14467. https://doi.org/10.1021/es402556x

[37] Schnoor, J. L., Water-energy nexus, *Environmental Science and Technology* (2011). https://doi.org/10.1021/es2016632

[38] Gleick, P. H., Water and Energy, *Annual Review of Energy and the Environment*, **19** (1) (1994), 267–299. https://doi.org/10.1146/annurev.eg.19.110194.001411

[39] Chen, S., & Chen, B., Urban energy–water nexus: A network perspective. *Applied Energy*, **184** (2016), 905–914. https://doi.org/10.1016/j.apenergy.2016.03.042

[40] Yang, J., & Chen, B., Energy-water nexus of wind power generation systems. *Applied Energy*, **169** (2016), 1–13. https://doi.org/10.1016/j.apenergy.2016.02.010

[41] Chen, B., Energy, ecology and environment: a nexus perspective. Energy, Ecology and Environment. Joint Center on Global Change and Earth System Science of the University of Maryland and Beijing Normal University, 2016. https://doi.org/10.1007/s40974-016-0017-8

[42] Lubega, W. N., & Farid, A. M., Quantitative engineering systems modeling and analysis of the energy-water nexus, *Applied Energy*, **135** (2014), 142–157. https://doi.org/10.1016/j.apenergy.2014.07.101

[43] Fang, D., & Chen, B., Linkage analysis for the water–energy nexus of city, *Applied Energy*, **189** (2017), 770–779. https://doi.org/10.1016/j.apenergy.2016.04.020

[44] Stokes, J., & Horvath, A., Life-Cycle Assessment of Urban Water Provision: Tool and Case Study in California, *Journal of Infrastructure Systems*, **17** (1) (2011), 15–24. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000036

[45] Wakeel, M., & Chen, B., Energy Consumption in Urban Water Cycle, *Energy Procedia*, **104** (2016), 123–128. https://doi.org/10.1016/j.egypro.2016.12.022

[46] Zhang, C., & Anadon, L. D., Life cycle water use of energy production and its environmental impacts in China, *Environmental Science and Technology*, **47** (24) (2013), 14459–14467. https://doi.org/10.1021/es402556x
[47] Lundie, S., Peters, G. M., & Beavis, P. C., Life cycle assessment for sustainable metropolitan water systems planning, *Environmental Science and Technology*, **38** (13) (2004), 3465–3473. https://doi.org/10.1021/es034206m
[48] López-Fernández, E. J., Alonso-Peralta, F., Sanglier-Contreras, G., & González-Lezcano, R. A., The Water Cycle in the Smart Cities Environment, (2020), 132–160. https://doi.org/10.4018/978-1-7998-3817-3.ch006
[49] Verstraete, W., & Vlaeminck, S. E., ZeroWasteWater: Short-cycling of wastewater resources for sustainable cities of the future, *International Journal of Sustainable Development and World Ecology*, **18** (3) (2011), 253–264. https://doi.org/10.1080/13504509.2011.570804

Received: January 11, 2021; Published: February 19, 2021