Using IoT Data-Driven Analysis of Water Consumption to support Design for Sustainable Behaviour during the COVID-19 Pandemic

Marco Zecchini
DIAG, Sapienza University of Rome
Rome, Italy
zecchini@diag.uniroma1.it

Alessandra Anna Griesi
DIAG, Sapienza University of Rome
Rome, Italy

Ioannis Chatzigiannakis
DIAG, Sapienza University of Rome
Rome, Italy
ichatz@diag.uniroma1.it
0000-0001-8955-9270

Irene Mavrommati
School of Applied Arts
Hellenic Open University
Patras, Greece
mavrommati@eap.gr
0000-0002-8870-746X

Dimitrios Amaxilatis
Spark Works Ltd
Galway, Ireland
d.amaxilatis@sparkworks.net
0000-0001-9938-6211

Orestis Akrivopoulos
Spark Works Ltd
Galway, Ireland
akribopo@sparkworks.net

***Abstract*—Aquatic environments are cornerstone for the existence of life, while water scarcity and unsafe water supply are major global issues affecting citizens [37]. Recently, the deployment of Internet of Things over water distribution networks has indicated ways to address some of these issues. Yet, policies for sustainable and efficient use of the aquatic resources depend largely on citizen's engagement.**

The use of data arriving from water metering and water quality sensors in educational environments as a mean to educate citizens and inspire environmental friendly behaviours has not been studied throughly in the past, mainly due to the lack of real-world data. Towards this end, real-world data collected by smart water meters can become a powerful tool to bridge digital and physical environments to support *design for sustainable behaviour*. A data-driven approach is adopted here that evaluates the effect of human actions related to the consumption of water within an educational setting. The data used in this study is collected from a pilot deployment of a 24 months period and is analyzed on weekly, daily and hourly basis to identify usage patterns. The examined period also includes the restrictions imposed by the local authorities as a response to the COVID-19 emergency taking place during the first quarter of 2020. The evaluation of water consumption before, during and after the lockdown period highlights the impact of human actions within the educational environment. The paper investigates how to design educational activities for sustainable behaviour based on the analysis of the data collected from the smart water grid.

***Index Terms*—Smart Water Grid, Smart Water Meters, IoT, COVID-19, Peak demand, Usage analysis**

I. Introduction

Ambitious policies that directly address the need for sustainable development and that can deeply affect the environment need to go beyond investments or technologies alone. It is evident that citizens, through their actions that harm the environment be it on land, air or sea, are those that need to change to protect the environment. Citizens, as individuals and within their communities, need to understand that their daily actions and lifestyles need to change to reflect a new healthy relationship with the environment. Citizens must become the real enabling agents of the envisioned change, taking on a leading role in climate actions and the efforts for sustainable development and environmental protection.

During the previous century, such attempts were primarily driven by the education community since it is the most relevant element of our society concerning increasing awareness and eventually achieving a change of perspective to the new members of the society. It is widely accepted that educating students and young people in sustainable development and helping them achieve environmentally beneficial behaviour changes and habits, can also affect their immediate environment. It is common for students to communicate their newly acquired knowledge to their parents, while recent studies document their ability to influence choices made by their families related to environmental issues [30] and that focusing on specific target groups is essential for designing a successful behavioural-change strategy [31].

The technological developments of the Internet of Things (IoT), the Smart Grid and the Smart Cities, have helped in bridging digital and physical environments to support *design for sustainable behaviour*. Design for sustainable behaviour applies principles of design research and co-design practice to understand and influence people's actions at multiple scales where there is an impact on climate or environment, from momentary choices around individual consumption decisions, through the energy or resource impacts of everyday practices

978-1-6654-2742-5/21/$31.00 ©2021 IEEE

at a family or group level, up to infrastructure-level change at a city or larger scale. Data arriving from IoT deployments can contribute not only simply to inform citizens on environmental conditions and consumption of resources but to experimentally educate them about the impact of daily activities and consumption behaviours on the environment. Such active involvement in the use of real-world data can help in giving long-term solutions to pressing environmental problems.

The starting point of this research is the availability of continuous measurements of water consumption based on the deployment of the Internet of Things (IoT). The analysis of the data can potentially connect water consumption with human actions and identify patterns of usage. Interactive visualizations can help citizens easily understand the impact of their actions on the environment and provide alternatives that have a smaller impact on the environment. The combination of different data-driven analysis approaches can support citizens effectively change their behaviours, e.g., by switching off the water while brushing teeth, or by preferring a shower rather than taking a bath.

Although the above points can support sustainable behaviours, up till now the utilization of data collected from IoT deployments has not been broadly used in education. At the same time, a variety of IoT solutions are already deployed, for example, to monitor the quality of aquatic resources in urban environments, or seawater pollution, however, such solutions are single-purpose. It is therefore important to reorganize existing deployments so that data can be integrated and allow applications that allow organizations and people to collaborate towards a more sustainable behaviour.

A data-driven education on sustainability and the scientific processes involved in experimentally evaluating the impact of human actions on the environment is attracting considerable attention in the educational sector. Initial attempts to raise awareness among young people started with the usage of electric energy and consecutively how to influence the habits of students and eventually influence the ways they use this utility. The focus on energy consumption is connected to the fact that Smart Grids for the distribution of electricity have seen tremendous developments during the past years [10], [12]. Drawing from human-computer interaction, psychology, sociology, several efforts have been made to achieve behaviour change concerning energy usage, through gamification, i.e., the introduction of game elements in everyday environmental behaviours [17]. In the aquatic enviroments, ealy attempts followed a crowdsourcing approach to collect data based on portable sensor devices developed within the Maker Movement approach [19], [33], [35].

During the past few years, Smart Water Grids are being deployed [2], [15], [27], [29]., providing access to water consumption and water quality data at large volumes. Today more than ever researchers and educators have new tools to develop new educational activities that enable the scientific understanding of aquatic resources. Confronting students with a data-driven detailed characterisation of their daily activities within their educational environment, including their unique patterns of usage, can help them understand the impact of their actions on the environment [23], [24].

The work presented here uses the data provided by a Smart Water Grid deployment in a University Campus over 23 buildings, for 24 months. The analysis presented here examines how a data-driven analysis of water consumption data can help to identify temporal patterns of consumption. The monitored period also includes two periods within 2020 and 2021 that correspond to the actions taken by the government to limit the effects of the first and second waves of the COVID-19 pandemic experienced. Looking into the consumption patterns during these periods provide valuable insights and helps us understand even further the effect of human actions on water consumption within the education buildings.

Regarding the impact of the actions taken by the governments to mitigate the effects of the COVID-19 pandemic on the water sector, the research predominantly looked into how to trace COVID-19 within wastewater and sewage waterways [3], [16]. At the same time, a limited number of results have appeared looking into the impact of the actions taken to counter COVID-19 on the consumption of water [11], [21], [25]. Interestingly, these results show indicated that water consumption in residential buildings initially increased during the COVID-19 lockdown periods, while for the case of non-residential buildings, consumption has slightly decreased. The work presented here is among the first to investigate the case of educational buildings.

The rest of the paper is organized as follows. In the next section, previous and relevant state-of-the-art is presented. The capabilities of the Smart Water Grid, the data collected and the processing pipeline are presented in Sec. III. The analysis of the effect of the human factor on water usage before the COVID-19 lockdown is presented in Sec. IV. The changes in water consumption during and after the 2020 COVID-19 1^{st} lockdown period are presented in Sec. V. The conclusions and directions for future work are presented in Sec. VI.

II. Related work

Smart water grids or intelligent water metering extend existing water distribution systems with information and telecommunication capabilities [20]. They continuously report on the operating status of the water distribution network through the use of smart metering devices and water flow equipment. Cloud-based solutions use the data provided by the smart water grids for real-time monitoring of the consumption and operating conditions of the water distribution network. Moreover, the analysis of the data can potentially improve risk-management for the infrastructure [20], build consumption profiles that can help understand water usage within a smart city [14]. The current status and trends towards the deployment of smart water grids are provided in [7].

The benefits of smart water grids and the new services provided in terms of monitoring system operation and managing more efficiently leakage control have been investigated through a series of pilot deployments realized during the past few years [2], [15], [27], [29]. These studies showcase how water supply infrastructure can integrate smart technologies along with real-time decision-support systems to better predict and encounter failures by significantly reducing the duration of disruption of repairs and maintenance, and in general optimize the overall operation of the distribution network.

The analysis of data arriving from IoT deployments can provide broader benefits not only to the management of the water distribution infrastructure but also towards raising environmental awareness. These broader benefits are presented by the International Water Association (IWA) [5]. Similarly, the ITU-T Focus Group on Smart Sustainable Cities outlines how smart water management within urban environments can help citizens better understand how to reduce the consumption of water and therefore reduce the cost of living [26]. Researchers have investigated how water consumption can be reduced by using data collected from IoT devices [9], [36]. Real-world data can be used in interactive visualization so that citizens are confronted with the impact of their actions and in this way try to identify alternative actions that could lead to a reduction in their daily water consumption. In this sense, citizens take an active role by changing their behaviour.

The current state of the art in applying design for sustainable behaviour includes the development of new ways to present and engage with data, including as part of IoT and Living Lab contexts, exploring the interaction of humans with 'smart' technologies in everyday practices for achieving a sustainability impact, e.g., [19], or the development of transition design in socio-technical contexts, e.g. [6], work on achieving energy resilience through a conjunction of technology innovation and design for new practices around repair and circular economies, e.g., [32], attempting to link mental models of phenomena perception with behaviour change.

Naturally, schools and universities are the centres of such acts, using the data provided by real-world smart grids and Internet of Things (IoT) devices [23]. Although data related to power consumption or air quality have been used within an educational environment, a limited number of results have appeared regarding water consumption. Some recent works provide educational scenarios targeting mainly young people on how freshwater resources are used in their daily habits [35]. The design and development of educational scenarios based on IoT data that work towards achieving more sustainable behaviours are presented in [33]. The benefits of providing immediate and direct feedback based on real-time data collected from smart sensing devices on confronting young students with the impact of their actions on the environment are presented in [34]. The use of IoT data on water consumption to develop a gaming platform whose goal is to engage users and help reduce water consumption within their home environment is proposed in [28]. The concept is to confront the users with missions implemented in the form of smart contracts where a blockchain infrastructure is used to record water consumption data in a privacy-friendly way while at the same time reducing the risks of counterfeiting consumption data. The use of blockchain technologies to promote and safeguard the engagement and active participation of citizens in such activities is examined in [8].

Recently several results have been published regarding water consumption data concerning the COVID-19 restrictions as a method to identify and quantify the impact of human actions on the use of water resources. These publications focus on the water consumption within households [11], [21], [25]. The first report that looks into water usage in educational institutes is [25] that examines the impacts of COVID-19 restrictions on water usage in California are examined based on water consumption daily data from a midsized city. The report looks into water consumption at schools, indicating initial reductions, then from June 2020, daily usage became stable and similar to 2018–2019 levels.

III. Material and methods

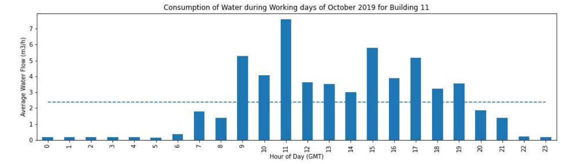
A. Smart Water Metering deployment

The smart water metering system used is based on two different types of IoT metering devices installed throughout the water distribution network that measures water consumption using the pulse method [7]: a *small* meter that records a pulse when 1L of water passes, and a *large* meter that records a pulse when 100L of water passes. These sensors achieve an accuracy of 0.25%–0.50% that depends on the temperature of the environment and of the water [18]. Additionally, a smart water pressure sensor using ultrasonic technology is positioned within the smart water distribution network. This sensor measures the average pressure within one hour with very high accuracy. The sensors are interconnected with the core network through an edge computing infrastructure that allows the execution of stream processing pipelines before the data are transmitted to the cloud for further processing. Finally, a set of cloud-level services are provided that enable the curation of data and the creation of datasets that enable data-driven analysis. A detailed presentation of the overall architecture, the services provided in terms of identity management, telemetry, asynchronous notifications and historic data storage, as well as the internal mechanisms introduced to efficiently aggregate data is presented in [2]. The use of long-range low-power wireless technologies to interconnect the smart devices is presented in [1] while improvements of the security of the wireless network are presented in [22].

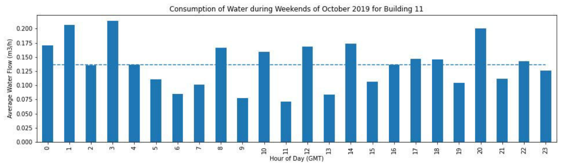
B. Data Source and Preprocessing

The data set used in this study is based on a period of 28 months, starting from January 2019 until April 2021. A total of 21,367,166 data points have been collected from the smart sensors that make up the smart water grid. In total 48 smart sensors are deployed throughout 26 buildings of a University Campus.

The deployment of smart water metering devices in underground environments results in low wireless signal quality. As a result, network connectivity experiences infrequent disruptions leading to the loss of some data packets. Moreover, due to the nature of the sensor technologies, depending on the ambient temperature and the temperature of the water, the data collected may be erroneous. As a result, data collected



(a) Average hourly consumption during Weekdays



(b) Average hourly consumption during Weekends

Fig. 1: Average hourly consumption for building 11 during Weekdays vs Weekends of October 2019

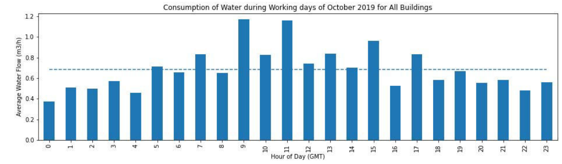


Fig. 2: Average hourly consumption during Weekdays of October 2019 for all buildings.

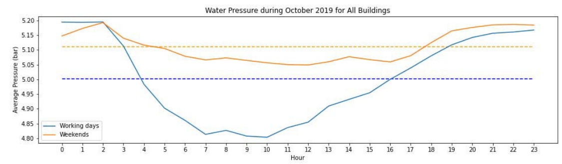


Fig. 3: Average hourly pressure during October 2019.

from the smart meters are processed using different statistical techniques for detecting and removing erroneous values and also filling in missing values. For a detailed presentation of different techniques for identifying erroneous values in IoT data see [13]. In addition, anonymization techniques were applied to disassociate any potential information that may be used to identify specific buildings and connect the data collected with people using the educational buildings during the aforementioned periods.

IV. Effect of Human factor on Water Usage

The analysis of the data collected from the smart grid started by examining the consumption of water during the periods the university buildings are used by students, researchers, faculty, administration, technical and support personnel as well as external visitors. The goal of this analysis is to identify potential patterns of usage between weekdays (from Monday to Friday) when classes take place and weekends (Saturday and Sunday) during which it is expected that the buildings are not used. To identify such patterns, water consumption was examined on an hourly basis.

As an example, Fig. 1(a) depicts the average hourly water consumption during weekdays for building number 11 of October 2019. In October 2019 the winter semester has started so it is assumed that students and professors were attending lectures regularly during the day, researchers were using their laboratories and in general, all personnel was present. The corresponding consumption for weekends is depicted in Fig. 1(b). The dotted lines represent the average consumption over all the hours of the day for the given period and building considered.

In this particular building and period, it is evident that the average hourly consumption of water during the weekdays is significantly higher. Hours are reported in GMT. It is observed that starting from 07:00 until 21:00 the average hourly consumption is at least 10 times higher than the average consumption observed during the weekends. In fact, between 09:00 until 19:00 when classes take place the consumption is even higher. It is also observed that during specific periods, for the example of building 11 during October 2019, at 09:00 when classes start, at 11:00 during the first break, at 15:00 after the lunch break, and at 17:00 before the last lecture period, water consumption is higher than the average consumption. This pattern of use is not specific to building 11 but it is observed for all the buildings of the university, as shown in Fig. 2.

The effect of water consumption during the weekdays and weekends for October 2019 is examined also from the point of view of the pressure on the water distribution network. Fig. 3 depicts the average hourly pressure measured at a specific point in the water distribution network for October 2019, during weekdays and weekends. Notice that even during weekends there is a fluctuation between day and night, however, these fluctuations are at a much smaller level in comparison with weekdays.

Apart from the identification of the effect of human actions on the consumption of water, it seems that there is a continuous flow of water even during the weekends or during the night period. The buildings of the pilot are not residential buildings, where one would expect that during night time the consumption would be zero. it is, therefore, reasonable to expect that certain functions within laboratories will require the use of water. Nevertheless, it is still possible that the water distribution network experiences water leaks that can be detected from the reported consumption.

V. Effect of COVID-19 Lockdown on Water Usage

Another way to evaluate the effect of human actions on water usage within the buildings is to examine the period during which the authorities has issued restrictions on all non-essential movement as a response to the COVID-19 pandemic. In more details, when the first wave of the pandemic hit the country in 2020, the authorities restricted movement outside the residence for specific reasons. For the case of universities, the authorities decided the closure of educational buildings and the continuation of all educational activities using online

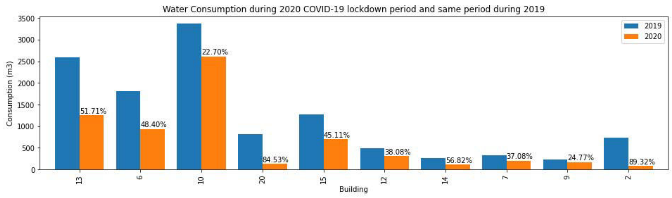


Fig. 4: Total consumption during 2020 COVID-19 lockdown period and same period during 2019 for Top-10 buildings with highest total reduction in water consumption.

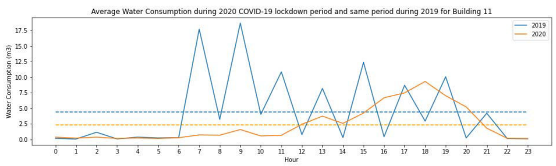


Fig. 5: Average hourly consumption for Building 11 during 2020 COVID-19 lockdown period and same period on 2019.

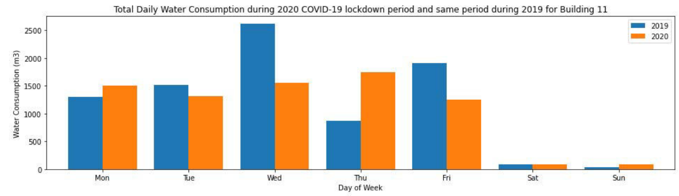


Fig. 6: Total daily consumption for Building 11 during 2020 COVID-19 lockdown period and same period on 2019.

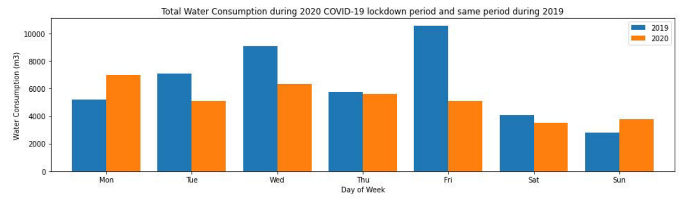


Fig. 7: Total daily consumption during 2020 COVID-19 lockdown period and same period on 2019.

methods and tools. As a result, the vast majority of the regular users (students, researchers, faculty, technicians and administrators) during the so-called period of lockdown we not using the university buildings.

The effect of the restrictions imposed as a response to the first wave of the COVID-19 pandemic is evaluated by measuring the total consumption of each building during the period. The total consumption of each building is compared to the total consumption for the same period of days during 2019. Fig. 4 reports the top-10 buildings with the highest total reduction in water consumption. In addition to the total consumption for the same period of 2020 and 2019, the figure also reports the percentage of reduction of consumption.

For almost all buildings the period of restrictions to movement and the continuation of education activities online had a significant effect on the consumption of water. However, the total consumption of water has not stopped completely. This is because, during the period of restrictions, movement to or from one's workplace during work hours was still permitted. Therefore some faculty, researchers, technicians and administration personnel continued to use the buildings. In addition, given the previous observation on potential leakages on the water distribution network, such kind of losses are also affecting the period of lockdown.

To provide further insights on the changes in the behaviour of water consumption, the average hourly consumption is examined. Specifically, for each building, the average consumption is examined on an hourly basis between the same period of 2020 and 2019. Fig. 5 includes the results for Building 11. The consumption patterns observed during weekdays for 2019 (see Sec. IV) are not present during the first period of restrictions in 2020. In particular, the average hourly consumption at the beginning of the day is lower - reaching zero - while COVID-19 measures are in effect and higher during the evening, reaching higher consumption than the one observed under normal situation (i.e., during 2019). Similar observations are reported also in [4].

The analysis continues by examining the consumption during a particular day of the week when considering the two periods. Once again it is evident that the usage patterns have changed. In Fig. 6 the results for Building 11 are reported. The consumption during the period of COVID-19 restrictions is almost the same for the weekdays while during the weekend it is significantly reduced. Interestingly, during the normal period, it seems that Thursdays has a much lower consumption when compared to the other weekdays. It is also observed that on Mondays the consumption during the period of COVID-19 restriction has increased. Remark that this pattern is not only related to Building 11. Fig 7 depicts the total daily consumption for all the buildings of the university. Again, Mondays and Thursdays indicate a reduced consumption in comparison to the other weekdays during normal situation (i.e., during 2019) and during COVID-19. A more in-depth analysis and more data are probably needed to understand why such a decrease is reported on Mondays and Thursdays.

Another way to observe the disruption of the consumption patterns is to consider the consumption over a weekly period. Weekly consumption is examined starting from 3 weeks before the beginning of the restrictions period and continuing up to 3 weeks after the end of the restrictions. In Fig. 8 the enlarged period of 12 weeks is presented, with the first week of the period of restrictions noted as week '0'. The previous observations are visible in this figure as well. During the period of restrictions, the total consumption of water is significantly reduced. It is observed that the first week after the end of the restrictions (i.e., week labelled '6'), the consumption of the normal period of 2019 is significantly reduced compared to the previous and next week. This reduction in consumption behaviour is not related to the COVID-19 emergency but rather to the spring break of 2019 that was on that week.

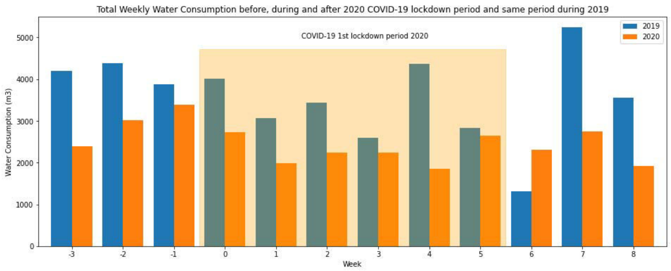


Fig. 8: Total weekly consumption before, during and after 2020 COVID-19 1^{st} lockdown period and same period on 2019.

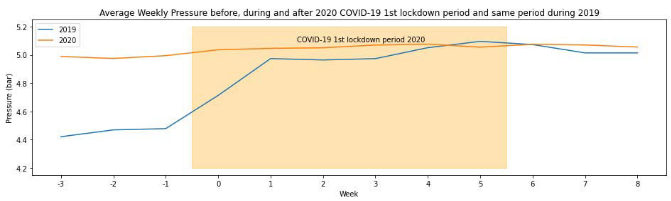


Fig. 9: Average weekly pressure before, during and after 2020 COVID-19 1^{st} lockdown period and same period on 2019.

The evaluation of the water distribution network over a weekly period is extended also concerning the pressure. Fig. 9 depicts the average weekly pressure over the enlarged period of 12 weeks. The values reported are in line with those presented above.

VI. Conclusions

The results presented here address the impact of human actions on the consumption of water and the performance of the water distribution network within the university campus. It is important to juxtaposition the consumption observed with diary events, such as winter breaks, but also with large scale emergency events, such as the CoVID19 lockdown. Throughout the university, only in three buildings, the water consumption increased during the first period of restrictions in 2020.

Such an increase could be the result of all actions connected to the hygiene of the building and people involved in activities. However, more in-depth analysis and probably more data are needed to understand why such an increase is reported in only one building of the university. Knowledge of such deviation patterns and studying them in-depth, can increase environmental awareness and help to establish sustainable human behaviour. New algorithmic approaches can be introduced for improving automation, based on these patterns and deviations, as well as specific techniques to enhance sustainable human attitudes.

The results presented here do not come as a surprise: it is expected to observe, via the proposed infrastructure, a general decreased water consumption in university buildings during the CoVID lockdown periods. Yet, this case study provides evidence for the verification of the data collection system itself. The system outlined in the Material and methods section is thus been validated, so that research can proceed in its next objectives: observe and explain abnormalities in the expected behaviour, and proceed to apply a similar approach to that of [24] aiming at increasing students awareness on the effect of human actions on natural resources.

Hands-on activities designed for young students, integrated into science classes where evidence is combined with theory, allow the investigation of the data and the design of effective water efficiency interventions. Such activities that utilize the scientific process can potentially help students understand how to mitigate consumption and identify sustainable behaviours. State-of-the-art approaches, although focusing on different areas of sustainable behaviour, share a recognition of the complexity of people's interactions with the technologies around them, and largely embody systems thinking models in which people are considered as socially and culturally situated, not solely as individuals acting in a vacuum. The use of participatory and co-design methods is central to this systemic approach. While advances in sensor technology and networked infrastructure, alongside the training of increasingly complex machine learning models, can enable more granular measurement of behaviours and their potential environmental impacts, it is engaging with the layers of human meaning that enables design for sustainable behaviour to move forward.

Acknowledgment

This work has been supported by the European Union's research project "Secure and Seamless Edge-to-Cloud Analytics" (ELEGANT) funded by the European Commission (EC) under the Horizon 2020 framework and contract number 957286.

References

[1] Dimitrios Amaxilatis and Ioannis Chatzigiannakis. Design and analysis of adaptive hierarchical low-power long-range networks. *J. Sens. Actuator Networks*, 7(4):51, 2018.

[2] Dimitrios Amaxilatis, Ioannis Chatzigiannakis, Christos Tselios, Nikolaos Tsironis, Nikos Niakas, and Simos Papadogeorgos. A smart water metering deployment based on the fog computing paradigm. *Applied Sciences*, 10(6), 2020.

[3] Sarpong Hammond Antwi, David Getty, Suzanne Linnane, and Alec Rolston. Covid-19 water sector responses in europe: A scoping review of preliminary governmental interventions. *Science of The Total Environment*, 762:143068, 2021.

[4] AquaTech. Case study: Data links covid-19 lockdowns to consumption change, April 2020. https://www.aquatechtrade.com/news/utilities/covid-19-lockdowns-impact-water-consumption/.

[5] International Water Association. Water statistics. http://waterstatistics.iwa-network.org/, 2019. [Online; accessed May-2019].

[6] J Boehnert, D Lockton, and I Mulder. Editorial: Designing for transitions. *Proceedings of DRS*, 3:892–895, 2018.

[7] Thomas Boyle, Damien Giurco, Pierre Mukheibir, Ariane Liu, Candice Moy, Stuart White, and Rodney Stewart. Intelligent metering for urban water: A review. *Water*, 5(3):1052–1081, 2013.

[8] Andrea Bracciali, Ioannis Chatzigiannakis, Andrea Vitaletti, and Marco Zecchini. Citizens vote to act: Smart contracts for the management of water resources in smart cities. In *2019 First International Conference on Societal Automation (SA)*, pages 1–8. IEEE, 2019.

[9] S. A. C. Tavares, R. J. B. V. M. Cavalcanti, D. R. C. Silva, M. B. Nogueira, and M. C. Rodrigues. Telemetry for domestic water consumption based on iot and open standards. In *2018 Workshop on Metrology for Industry 4.0 and IoT*, pages 1–6, April 2018.

[10] G Dileep. A survey on smart grid technologies and applications. *Renewable Energy*, 146:2589–2625, 2020.

[11] Luke Eastman; Erika Smull; Lauren Patterson; Martin Doyle. Covid-19 impacts on water utility consumption and revenues: Preliminary results. Technical report, Duke Nicholas School of the Environment, 2020.

[12] X. Fang, S. Misra, G. Xue, and D. Yang. Smart grid – the new and improved power grid: A survey. *IEEE Communications Surveys Tutorials*, 14(4):944–980, 2012.

[13] Anuroop Gaddam, Tim Wilkin, Maia Angelova, and Jyotheesh Gaddam. Detecting sensor faults, anomalies and outliers in the internet of things: A survey on the challenges and solutions. *Electronics*, 9(3), 2020.

[14] T.R. Gurung, R.A. Stewart, C.D. Beal, and A.K. Sharma. Smart meter enabled informatics for economically efficient diversified water supply infrastructure planning. *Journal of Cleaner Production*, 135:1023–1033, 2016. cited By 14.

[15] Jeffery S Horsburgh, Miguel E Leonardo, Adel M Abdallah, and David E Rosenberg. Measuring water use, conservation, and differences by gender using an inexpensive, high frequency metering system. *Environmental modelling & software*, 96:83–94, 2017.

[16] Bin Ji, Yaqian Zhao, Ting Wei, and Peiying Kang. Water science under the global epidemic of covid-19: Bibliometric tracking on covid-19 publication and further research needs. *Journal of Environmental Chemical Engineering*, 9(4):105357, 2021.

[17] Philip M Johnson, Yongwen Xu, Robert S Brewer, George E Lee, Michelle Katchuck, and Carleton A Moore. Beyond kwh: Myths and fixes for energy competition game design. *Proceedings of Meaningful Play*, pages 1–10, 2012.

[18] R Koech, D Pezzaniti, and B Myers. Effect of elevated temperature on water meter accuracy. *Water: Journal of the Australian Water Association*, 42(3):56–60, 2015.

[19] Lenneke Kuijer and Elisa Giaccardi. Co-performance: Conceptualizing the role of artificial agency in the design of everyday life. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–13, 2018.

[20] Seung Won Lee, Sarper Sarp, Dong Jin Jeon, and Joon Ha Kim. Smart water grid: the future water management platform. *Desalination and Water Treatment*, 55(2):339–346, 2015.

[21] Deike U. Lüdtke, Robert Luetkemeier, Michael Schneemann, and Stefan Liehr. Increase in daily household water demand during the first wave of the covid-19 pandemic in germany. *Water*, 13(3), 2021.

[22] Stefano Milani and Ioannis Chatzigiannakis. Design, analysis, and experimental evaluation of a new secure rejoin mechanism for lorawan using elliptic-curve cryptography. *J. Sens. Actuator Networks*, 10(2):36, 2021.

[23] Georgios Mylonas, Dimitrios Amaxilatis, Ioannis Chatzigiannakis, Aris Anagnostopoulos, and Federica Paganelli. Enabling sustainability and energy awareness in schools based on iot and real-world data. *IEEE Pervasive Computing*, 17(4):53–63, 2018.

[24] Georgios Mylonas, Federica Paganelli, Giovanni Cuffaro, Ilaria Nesi, and Dionysis Karantzis. Using gamification and iot-based educational tools towards energy savings-some experiences from two schools in italy and greece. *Journal of Ambient Intelligence and Humanized Computing*, pages 1–20.

[25] Mehdi Nemati. Covid-19 and urban water consumption. Technical report, Giannini Foundation of Agricultural Economics, University of California, 2020. ARE Update 24(1): 9–11.

[26] ITU-T Focus Group on Smart Sustainable Cities. Smart water management in cities. https://www.itu.int/en/ITU-T/focusgroups/ssc/Documents/website/web-fg-ssc-0122-r7-smart_water_management_in_cities.docx, 2014. [Online; accessed May-2019].

[27] Anthony Overmars and Sitalakshmi Venkatraman. Towards a secure and scalable iot infrastructure: A pilot deployment for a smart water monitoring system. *Technologies*, 8(4), 2020.

[28] C. Rottondi and G. Verticale. A privacy-friendly gaming framework in smart electricity and water grids. *IEEE Access*, 5:14221–14233, 2017.

[29] M Saravanan, Arindam Das, and Vishakh Iyer. Smart water grid management using lpwan iot technology. In *2017 Global Internet of Things Summit (GIoTS)*, pages 1–6. IEEE, 2017.

[30] Chelsea Schelly, Jennifer E. Cross, William S. Franzen, Pete Hall, and Stu Reeve. How to go green: Creating a conservation culture in a public high school through education, modeling, and communication. *Journal of Environmental Education*, 43(3):143–161, 2012.

[31] Jessica Stromback, Christophe Dromacque, and Mazin H. Yassin. The potential of smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison. Technical report, VaasaETT Global Energy Think Tank, 2013. Funded by European Smart Metering Industry Group (ESMIG).

[32] Nazli Terzioglu Özkan. Repair motivation and barriers model: Investigating user perspectives related to product repair towards a circular economy. *Journal of Cleaner Production*, 289.

[33] Chrysanthi Tziortzioti, Dimitrios Amaxilatis, Irene Mavrommati, and Ioannis Chatzigiannakis. Iot sensors in sea water environment: Ahoy! experiences from a short summer trial. *Electronic Notes in Theoretical Computer Science*, 343:117–130, 2019.

[34] Chrysanthi Tziortzioti, Giuseppe Andreetti, Lucia Rodinò, Irene Mavrommati, Andrea Vitaletti, and Ioannis Chatzigiannakis. Raising awareness for water polution based on game activities using internet of things. In *European Conference on Ambient Intelligence*, pages 171–187. Springer, 2018.

[35] Chrysanthi Tziortzioti, Irene Mavrommati, Georgios Mylonas, Andrea Vitaletti, and Ioannis Chatzigiannakis. Scenarios for educational and game activities using internet of things data. In *2018 IEEE Conference on Computational Intelligence and Games (CIG)*, pages 1–8. IEEE, 2018.

[36] S. Wadekar, V. Vakare, R. Prajapati, S. Yadav, and V. Yadav. Smart water management using iot. In *2016 5th International Conference on Wireless Networks and Embedded Systems (WECON)*, pages 1–4, Oct 2016.

[37] UN Water. Equitable access to water and sanitation is still a challenge for europe, 2020.